Grounding and the Use of the Signal Reference Grid in Data Centers

White Paper 87

Revision 2

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> Executive summary

Signal reference grids are automatically specified and installed in data centers despite the fact that they are no longer needed by modern IT equipment. Even when installed, they are typically used incorrectly. This paper explains the origins of the signal reference grid, the operating principles and limitations, and why they no longer are needed.

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Introduction

The signal reference grid (SRG) is a network of copper wires typically installed below a raised floor in a data center as shown in **Figure 1**. An SRG can also be constructed of flat copper straps, aluminum wires, raised flooring substructure, or in extreme cases, a solid covering of sheet metal. The installation of signal reference grids has been common practice for over 30 years. Most data center designs call out for SRGs and their use and expense are not questioned.

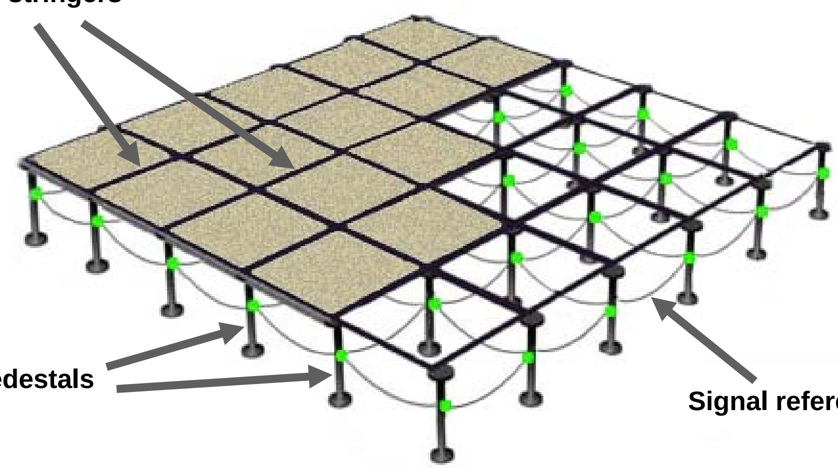

Figure 1

Example of a signal reference guide

Recently, more and more data centers are being constructed on existing hard-floor environments where SRGs cannot be installed under the floor. The evidence suggests that the lack of SRGs in such installations has given rise to no adverse effects on the operation of the IT equipment. Naturally this leads to the question of why systems can work reliably without an SRG and whether the SRG is ever a necessary or logical expense.

Background

The SRG became a standard part of data center design in 1983 as a result of US Federal Information Processing Standard FIPS PUB 94 “Guideline for Electrical Power for Automatic Data Processing Installations.” This landmark document first outlined the scientific principles of electrical interference with IT equipment and design strategies to eliminate interference. The SRG, in conjunction with other design strategies including isolation bushings and balun transformers, are explained and recommended in this document. At the time, electrical noise problems on data circuits were a very real problem plaguing many data centers, and the SRG was a key component of the solution to the problem. As a result, the SRG became part of standard data center specifications. Even though FIPS PUB 94 was withdrawn from publication in 1997, the standard is still commonly referenced today.

Today, various corporate and industry standards routinely specify or recommend a ground reference grid. One example is EIA / TIA 607 - Commercial Building Grounding and Bonding Requirements for Telecommunications. Most documents that recommend an SRG are not clear about when it should be applied, leaving users uncertain whether the SRG is suggested for smaller data centers, server rooms, or wiring closets. However, the general understanding in the user community is summarized by the following published recommendation:

“A signal reference structure (SRS) should be employed as the basic means of achieving a high-frequency common ground reference for all equipment within a contiguous area. A properly designed and installed SRS effectively equalizes ground potential over a broad range of frequencies from dc through the megahertz range.” [1]

Although the science of noise interference has not changed in the last 35 years since FIPS PUB 94, the nature of IT equipment has changed substantially. These changes in the design of IT equipment have totally changed the susceptibility of equipment to electrical noise. Equipment operates at much higher frequencies, with different types of power supplies, and most importantly, with different types of data cabling. For example, in 1983 the IBM System/36 operated at 20 MHz and used twinaxial cables to attach devices, while today, one of IBM’s BladeCenter HS20 blades operates at 3.6 GHz and uses Gigabit Ethernet.[2]

Function of the SRG

A survey of various documents and publications that describe the signal reference grid attribute the following functions to it:

- Equipment communication interference reduction
- Equipment damage prevention
- Noise discharge path
- Electrostatic discharge (ESD) protection
- Human safety

However, the widespread beliefs about these functions are mainly wrong, leading to a misunderstanding of the purpose of the SRG. For example, U.S. Air Force Engineering Technical Letter 90-6 states: “They are **used to control static charge** and provide an equipotential conducting plane to which high frequency signal circuits are referenced, thereby minimizing interference and noise.”[3] However, the purpose of the SRG is this: to reduce unwanted noise voltages on copper wire communication channels that are ground-referenced. Each of the above bulleted functions of the SRG will be examined and clarified in the next sections.

Equipment communication interference reduction

Related resource
White Paper 8
Inter-System Ground Noise: Causes and Effects

This function of the SRG is based on the ability of the SRG to reduce inter-system ground noise, which is the difference in chassis ground potential of interconnected IT equipment. This subject is described in more detail in White Paper 8, *Inter-System Ground Noise: Causes and Effects*. The difference in chassis ground reference voltage occurs for a number of different reasons, including fault currents, lightning, and noise currents injected into ground circuits. This is a very real problem which created documented communication problems in early data centers, particularly between remote terminals that communicated with the data center via dedicated home-run RS-232 connections.

A variety of unsupported claims regarding the susceptibility of IT equipment to inter-system ground noise have been made in the literature, including these examples:

1 IEEE Standard 1100-1999, IEEE Recommended Practice for Power and Grounding Sensitive Electronic Equipment, pg. 326

2 http://en.wikipedia.org/wiki/System_36 - accessed February 16, 2006

3 Engineering Technical Letter (ETL) 90-6: Electrical System Grounding, Static Grounding and Lightning Protection http://www.afcesa.af.mil/userdocuments/publications/ETL/ETL%2090-6.PDF - accessed February 16, 2006

The signal reference grid (SRG) maintains a common ground reference for all connected equipment in the data center. The physical form of the SRG – an expansive grid – makes it possible for high frequency noise to follow a low-impedance path to ground.

If acceptable to the ITE manufacturer, an SRG (signal reference grid) may be used to provide a nearly constant potential, low impedance, high frequency, signal reference grounding system. …Such a grid will effectively ground high frequency signals up to about 20Mhz. (ITIC guidelines for grounding IT Equipment)

The various claims and beliefs surrounding the susceptibility of IT equipment to inter-system ground noise are based on information and data from prior generations of IT equipment. Modern IT equipment uses methods for data communication which have substantially changed over time and now have dramatically reduced inter-system ground noise susceptibility. The different types of data communication interfaces are classified into susceptibility classes in **Table 1**.

Table 1

Ground noise susceptibility classes of different data cable types

Total immunity	High immunity	Partial immunity	Low immunity
•Fiber-optic •Wireless	•Ethernet	•Modbus •RS-485 •SCSI	•Parallel ports •RS-232 ports •Proprietary backplane •Video cables

"Low immunity" types of data interfaces use copper cabling that carry signals that are ground-referenced. Any shift in ground voltage between the interconnected equipment is superimposed on the data signal. Inter-system ground noise of 0.1 volt or even less can interfere with communication of these "low immunity" communication cables.

"Partial immunity" occurs in copper communication interfaces that have a balanced or differential signal transmission that is not ground referenced. These systems have a so-called "common mode range" of inter-system ground noise that they inherently reject, but succumb to interference with larger voltages. Inter-system ground noise of 10 volts or more can interfere with communication. "Partial immunity" data interfaces are a factor of 10 to 100 times more immune than "low immunity" interfaces.

"High immunity" occurs in copper communication interfaces that have a balanced or differential signal transmission using a transmission line cable system with full transformer isolation at both ends. The primary example of this type of interface is Ethernet, which has an interface breakdown voltage of over 1000 volts. This kind of interface is capable of withstanding much greater inter-system ground noise voltages than is the "partial immunity" type, and also capable of rejecting interference over a much greater frequency range. In addition, the communication protocols have built-in error correction.

At the time the SRG was first created, the primary data interface systems were those in the "low immunity" group of **Table 1**. Over time, a migration has occurred where data interfaces are mainly of the "high immunity" or "total immunity" classes. Of the few "low immunity" types of cabling that remain, many are restricted to use with a single rack or adjacent racks where inter-system ground noise can be controlled within the enclosure (i.e. SCSI). **The result is that the susceptibility of interconnected IT equipment to inter-system ground noise has been reduced by orders of magnitude in the last decades.**

This improvement in data interconnection reliability has not been accidental. The interconnection of remote PCs and routers to data centers required that "high immunity" data interfaces be created, and the various Ethernet standards specifically addressed the noise problems by designing a transformer isolated interface used in all Ethernet devices. The switch to Ethernet and fiber into the data center means that the requirement for reduced susceptibility has been accomplished over time without the need for a supplemental SRG.

The SRG is particularly effective at reducing types of noise that no longer interfere with modern data interfaces.

Equipment damage prevention

Like the claims for interference reduction, this function of the SRG is again based on the ability of the SRG to reduce inter-system ground noise, which is the difference in chassis ground potential of interconnected IT equipment. In this case, large fault or lightning-induced currents flowing in the ground system can cause voltage differences between the chassis of IT equipment that are so large that the communication interfaces become damaged.

Note that the threat in this case is not due to surge or overvoltages on the AC power lines; the SRG does not affect or mitigate these voltages. The only voltages that the SRG helps to control are variations in the ground voltage between the various IT devices.

The susceptibility of IT equipment to inter-system ground voltage damage depends on the nature of the interfaces. Again, non-isolated interfaces based on ground referenced signals are the most susceptible, and the guidelines of **Table 1** apply. The susceptibility of equipment to become damaged is reduced dramatically when interfaces from the “high immunity” and “total immunity” categories are used.

When equipment is interconnected via “low immunity” methods, the SRG can be effective at reducing damage IF the equipment is supplied by separate branch circuits and not mechanically bonded together. However, if the equipment is powered by the same branch circuit or rack PDU, or is bonded together in a rack enclosure, then no inter-system ground noise exists and the SRG has no benefit.

Noise discharge path

This is based on the widely held belief that ground systems are a kind of “cesspool” into which unwanted electrical noises are safely disposed. A related concept is that noise may somehow “accumulate” if a big discharge path is not provided. This is a faulty concept that is not based on sound electrical principles. In fact, noise or any unwanted signal will always take the path of lowest impedance, a path which at high frequencies above 1 MHz is not the SRG but rather other nearby cables. **The concept of the SRG as a noise discharge path is based on a fundamental misunderstanding of grounding principles.**

Electrostatic discharge (ESD) protection

Electrostatic discharge should be of concern to any data center operator due to the risk of damage to equipment. The reason why data centers are commonly maintained at relatively high humidity such as 40% relative humidity is to deter the formation of static charges. Floors in data centers should have static discharge treatment which may include the use of special fixed or raised floor tiles. Some data centers restrict the allowable footwear to prevent personnel from being efficient static generators.

However, the SRG has no explicit role in preventing the creation of static charges, or protecting equipment from these charges. **The SRG cannot stop personnel from accumulating static charge. If an operator were to carry a static charge, the SRG cannot**

prevent this charge from being discharged into equipment (equipment is always grounded whether an SRG is present or not).

Human safety

Another commonly held belief is that the SRG provides safety benefits relating to grounding and the prevention of electric shock. It is true that proper grounding of electrical equipment is important to reduce the risk of electrical shock. It is also true that in the 1970-1980 time period some hard-wired IT equipment in data centers was deliberately wired without a safety ground, in order to reduce noise interference. However, today it is a violation of electrical codes to wire equipment without safety grounds, and all pluggable equipment uses a power cord that includes a safety ground. Therefore, the purposeful ungrounding of equipment in data centers is non-existent in today's data center.

In a properly grounded data center there is no problem with safety grounding that is solved by the SRG. The SRG does potentially provide a redundant safety ground, but this is not necessary or required. If a redundant grounding system is desired, it can be effectively achieved by bonding the racks in a row to each other and running a ground wire back from the rack cabinets to the local PDU ground. Rack grounding in this way is considered a "best practice" and effectively accomplishes the same incremental safety benefits that a SRG would provide.

The SRG, when properly deployed, is a redundant grounding system. Redundant grounding systems are not needed in the modern data center, but even if desired there are more effective and less expensive ways to achieve a redundant grounding system.

Costs

Costs for an SRG vary widely depending on the material used, the means of bonding employed, and the distance to the building steel bond, just to name a few. An idea of the costs involved for a particular scenario is presented below. A budgetary value for a typical copper wire type signal reference grid is on the order of \$6.50 / ft^2 (\$70 / m^2). This includes design, material, installation, and proper grounding and bonding of the grid to building metalwork. When this is combined with a typical space utilization of 28 ft^2 (2.6 m^2) per rack, a budgetary cost per rack for an SRG is \$182.

In addition to this cost, there is a maintenance cost. Various studies on the technical performance of SRG show that periodic inspection, testing and re-torquing of connections of an SRG are required to assure design performance. The eventual metal creep in the screw compression wire connections is known to degrade the impedance characteristics of the grid. If this work is performed every two years at a cost of \$2 / ft^2 (\$22 / m^2), then this translates to a maintenance cost of \$280 per rack over an expected 10 year data center life. Taken together, these TCO costs are approximately \$460 per rack, which is a material contributor to the cost of a data center and should only be incurred if needed.

Design guidance

A detailed analysis of the science and practice regarding grounding suggests the following best practices:

Use only Ethernet or fiber

Use Ethernet or fiber for data communication in a data center. Restrict all other forms of data communication, such as video, SCSI, RS-232, etc. to interconnections within a row of interconnected racks, or better yet within a single rack.

Interconnect racks with ground bonding wires

Connect racks in a row to each other with ground bonding wires. Ground interconnection kits are offered by most rack suppliers. Baying kits for racks do not typically provide a reliable bonding between racks because they do not break through the protective paint or plating surface on the rack metalwork.

Bond cable trays to equipment racks

When rows of racks are interconnected with power or data cable trays or cable ladders, the cable trays or ladders should be electrically connected to the racks at both ends using bonding wires. This guidance applies to these trays whether they are below the floor or suspended above the rack cabinets.

Protect the data cable entry points of the data center

Identify any points of data cabling entry into the data center. Any wires that are not fiber should go through a central location and not simply be dispersed around the data center. At this consolidated point of entry, treat the wires in the following way:

- Telephone wires: surge suppress, with a grounding strap from the surge protector to the primary power supply grounding point in the data center.
- RS-232: avoid use, but if used connect via an optical isolator, or surge suppress, with a grounding strap from the surge protector to the primary power supply grounding point in the data center.
- Ethernet: consolidate through a main router, with a grounding strap from the router to the primary power supply grounding point in the data center.
- Do not simply distribute wires of the above types into random locations in the data center without taking the above steps, since they all represent points of entry for noise or surges that can disrupt or damage equipment directly or indirectly by creating inter-system ground noise.
- The above guidance is appropriate whether or not an SRG is used. More details are provided in IEEE 1100-1999: "IEEE Recommended Practice for Powering and Grounding Electronic Equipment."

If the above guidance is followed, then the benefits of adding an SRG are greatly diminished making SRG installations typically unjustified.

Conclusion

The signal reference grid used in most modern data centers is no longer as important as it once was, due to changes in IT technology. The advent of Ethernet and fiber data interfaces have dramatically reduced the susceptibility of IT equipment to noise and transients, particularly when compared with the ground-referenced IT interface technologies of 20 years ago. The installation of an SRG is not harmful, other than the associated cost and delay. When data centers actually have an SRG installed, virtually no data centers actually use it as evidenced by their equipment and wiring installation practices. The SRG is no longer a required element in a data center design.

About the author

Neil Rasmussen is a Senior VP of Innovation for Schneider Electric. He establishes the technology direction for the world's largest R&D budget devoted to power, cooling, and rack infrastructure for data centers.

Neil holds 25 patents related to high-efficiency and high-density data center power and cooling infrastructure, and has published over 50 white papers related to power and cooling systems, many published in more than 10 languages, most recently with a focus on the improvement of energy efficiency. He is an internationally recognized keynote speaker on the subject of high-efficiency data centers. Neil is currently working to advance the science of high-efficiency, high-density, scalable data center infrastructure solutions and is a principal architect of the APC InfraStruXure system.

After founding APC in 1981, Neil served as Senior VP of Engineering and CTO for 26 years, assuming his current role after APC joined Schneider Electric in 2007. He received his bachelors and masters degrees from MIT in electrical engineering, where he did his thesis on the analysis of a 200MW power supply for a tokamak fusion reactor. From 1979 to 1981 he worked at the MIT Lincoln Laboratory on flywheel energy storage systems and solar electric power systems.

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