INSIDE PQ

Observations on Supplemental Grounding and Bonding: Part 3

Single-point grounding is not nearly as straightforward as multipoint grounding — conceptual issues appear to be paradoxical

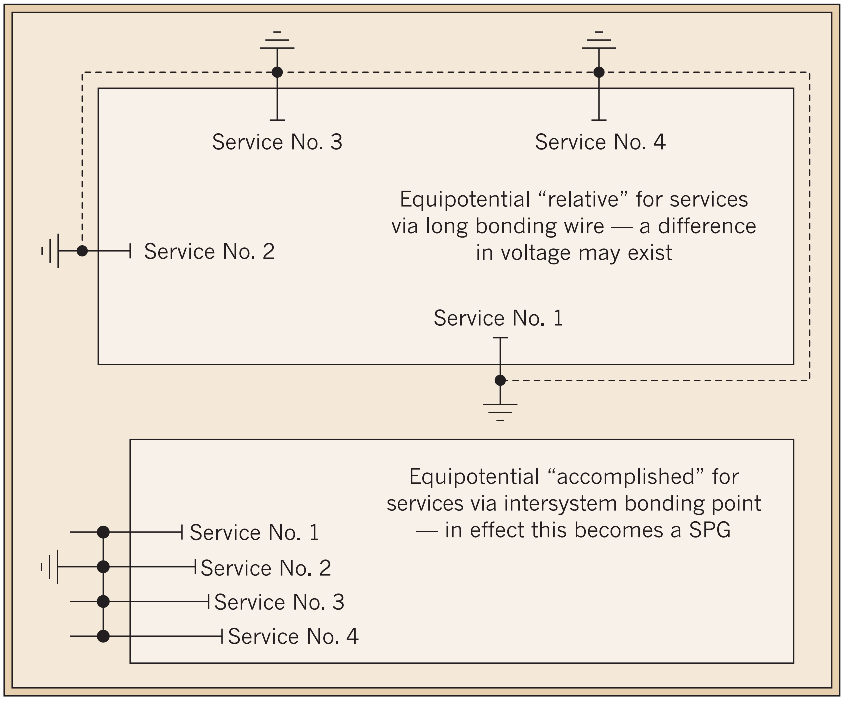
By William Bush, Panduit

In Part 2 of this article (August 2007), we described multipoint (or common-type) supplemental grounding and bonding between the T(M)GB [notation used here to indicate that the bar may be either the TMGB or TGB, depending on the location within the building] and the telecommunications and information technology equipment (ITE) systems. This installment will focus on the single-point (or insulated-type) supplemental grounding and bonding application and its relationship to equipotential.

The paradoxes of single-point grounding. Single-point grounding (SPG) is not nearly as straightforward as multipoint grounding, as conceptual issues arise that, at first pass, appear to be paradoxical.

Paradox 1: How can any piece of ITE be truly single-point grounded? At several megahertz, parasitic paths may emerge that act to bypass the intended low-resistance single grounding path. These parasitic paths are parallel (mainly capacitance) and serial (mainly inductive). These frequency-dependent parasitic paths are the bane of accomplishing true SPG at the ITE printed circuit board (PCB) level.

"System designers sometimes try to achieve a single point of connection between circuit ground on PCBs and the metal chassis of a system for a variety of reasons," says Douglas Smith, an engineering consultant on high-frequency measurements with D.C. Smith Consultants, Los Gatos, Calif. "Trying to isolate grounds in this way can cause significant immunity problems to stimuli like ESD and RF fields. Connecting circuit board grounds to the chassis at a single point is usually not necessary and can cause significant immunity problems. In my experience, I have found that securely connecting circuit boards to the chassis at many points generally reduces ESD and other noise problems, and restricting the circuit board to chassis at a single connection point often causes ESD and EMI problems."



Relative equipotential vs. accomplished equipotential (SPG) grounding system in a building. The service could be an AC power, CATV, telephone, or broadband coaxial cable.

From a systems (or functional block) perspective, as the length of the grounding wire increases, its self inductance also increases, and transient (higher frequency) events can impose a voltage offset between the ends of the grounding wire. The result is at some frequencies the grounding wire is acting as a nearly open conductor. The most pronounced effects occur when, at certain frequencies, either parallel or series electrical resonance occurs over the grounding wire path. See Figure 4-66 of IEEE Std 1100-2005, "The Emerald Book."

As noted in Part 2 of this article, the signal reference structure (usually a grid — SRG) was developed in FIPS Pub 94, "Guideline on Electrical Power for ADP Installations" (published September 1983 and later withdrawn July 29, 1997), since electronic equipment and power supplies of that era were recognized as susceptible to resonant effects over a single grounding wire. Where necessary to discourage resonance and promote a broadband frequency response, the length of the grounding wire or grid section is cited not to exceed anywhere from 1/8th to less than 1/20th of the highest frequency of interest — depending on what "authority" you cite. However, a "modern" system should be properly decoupled at its ports/links and exhibit immunity by withstanding surges/voltages across external connections to other systems.

Paradox 1 can be explained in terms of the application level and intention:

- The ITE PCB is designed as multipoint — even to becoming a solid copper ground plane. The MHz condition is inherently handled by designing the PCB for high-frequency signal integrity and electromagnetic compatibility (EMC).
- The ITE system is designed to be (or can become) multipoint; the MHz condition is handled by a common bonding network (CBN) design, as described in Part 2 of this article.
- The ITE system is designed to be (or can become) single-point; the MHz condition is handled sufficiently by controlling the length of the grounding conductor(s) and decoupling of the system ports/links.

Given the significant attention paid to multipoint grounding and megahertz conditions in Part 2 of this article, the megahertz conditions occurring in an SPG systems application deserves further explanation. (See **SPG and the Megahertz Condition** on following page.)

Paradox 2: How can you supplement an SPG when, by definition, there is only a single point of ground reference? Copper plates and bus bars are commonly used to accomplish an SPG for ITE. The physical size of these SPGs can allow for supplemental grounding paths to be attached. As long as the supplemental grounding wiring from the same SPG to the ITE does not form a substantial "loop area" with the primary grounding wiring, the SPG can be so supplemented. For example, envision two wires run in parallel and closely coupled; one designated primary and the other designated supplemental. The paradox of supplementing an SPG can be explained in terms of controlling (or minimizing) the loop area between the primary and any supplemental grounding paths. However, acknowledging that the SPG path can be supplemented does not readily translate into adopting the practice.

The following statements are useful in making a decision to supplement an SPG path:

- Where inductance of the existing wiring path is desired to be lowered, a supplemental path may be useful. Note: The added mutual inductance, due to the minimized loop area, may significantly counteract the reduction in self inductance.
- Where reliability of the existing wiring path is paramount, a supplemental path is useful.
- For general/typical AC branch circuits that are intentionally (IGR circuit) or unintentionally performing as an SPG path, a supplemental path is of little added value.
- Where an isolated (insulated) bonding network (IBN) configuration is used, supplemental paths within the IBN may be encouraged, especially for mesh variations. The IBN will be addressed in Part 4 of this article.

SPG application notes. The SPG approach is predominant in North America, as evidenced by the following list of power and telecommunications systems grounding practices:

- ANSI NFPA 70 (NEC) requirements for grounding the power system neutral once (only at the service or separately derived system).
- ANSI NFPA 70 (NEC) and ATIS T1.318-2000, "Electrical Protection Applied to Telecommunications Network Plant at Entrances to Customer Structures or Buildings" requirements for close-proximity intersystem bonding of grounding systems of all entering services.
- ANSI NFPA 70 (NEC) requirements for grounding the isolated grounding receptacle (IGR) circuit.

As noted in Paradox 1, the primary application of an SPG for ITE is predominantly targeted at interconnecting at the "systems level" and without undue concern for MHz conditions along the SPG wiring. Note that ANSI/NECA/BICSI 607 ballot draft 3.0, April 2007, "Telecommunications Bonding and Grounding Planning and Installation Methods for Commercial Buildings," addresses the grounding conductor from the T(M)GB to the telecommunications equipment lineup. The conductor is termed the telecommunications equipment bonding conductor (TEBC). Depending on installation arrangements, the TEBC could serve either as an intended or unintended SPG. An example of an intended application is an SPG for an IBN. SPG applications for telecommunications systems are also predominant in North America, as evidenced by recognized grounding practices that recognize the IBN:

- ATIS T1.333-2001 ("Grounding and Bonding of Telecommunications Equipment") requirements for telecommunications facilities; the vertical ground riser (VGR), floor ground bar (FGB) and equipment bonding networks (EBNs) — nested CBNs and IBNs.

• ANSI J-STD-607-A ("Commercial Building Grounding [Earthing] and Bonding Requirements for Telecommunications") requirements for telecommunications in a commercial building; the telecommunications bonding backbone (TBB), telecommunications grounding bus bar (TGB) and the ITE grounding/bonding method of choice by the manufacturer or user; by reference, nested CBNs and IBNs.

• IEEE Standard 1100-2005 ("Emerald Book") recommendation to meet the requirements of ANSI J-Std-607-A and most of the requirements of ATIS T1.333.

Interestingly, length restrictions for SPG wiring for North American applications are not overly restrictive, considering the inductive voltage offset known to occur during transient events, especially lightning. For the IGR and equivalent insulated AC circuits, the NEC sizing tables are based on a 30.5-meter circuit and require adjustment to the equipment grounding conductor size for longer conduit/raceway lengths. For an IBN that is predominantly DC, the IEEE "Emerald Book" (Table 9-26) follows ATIS T1.333 and restricts the total horizontal SPG lead length from the serving ground to the IBN to 30.5 meters.

Recognized instances of SPG, as described in Part 2 of this article, plus other variations include the following:

• An IGR circuit;

• A multi-service, multi-port surge protection unit, which, in turn, is connected by its "single" power cord;

• Branch circuits made up with nonconductive (plastic) conduit or raceway;

• The metal conduit and green wire (standard receptacle circuit) that is otherwise insulated from other metal structures along its path;

• The wrapped, bare copper wire enclosed within non-metallic sheath cable typically used in residential and some light commercial locations; and

• ITE powered from the same power outlet unit (POU), which, in turn, is connected by its "single" power cord, such as in a furniture power distribution unit (FPDU – UL 962A), equipment rack or cabinet, or a work area.

Generally, SPG power circuits should be reduced to the shortest practical length for two reasons. First, ITE power line filters typically reference to the serving equipment grounding conductor and where these conductors are lengthy, wir-

SPG and the Megahertz Condition

Obviously, SPG cannot provide a broadband grounding system via a single wire, due to inductive voltage during transient conditions. Let's consider the lightning transient. IEEE C62.72-2007, "Guide for the Application of Surge Protective Devices for Low Voltage (1000 Volts or Less) AC Power Circuits", states, "For more effective lightning protection systems, consider grounding configurations that optimize the use of the first 30 meters surrounding the protection system."

This "30-meter rule" indicates that the lightning transient will impose full inductive voltage (based upon the value of lightning current) at the injection point if the path to remote earth reaches or exceeds 30 meters. We can therefore derive that lightning over a 30 meter section of the SPG wiring may allow full inductive voltage across the wiring path. Lightning, due to its frequency spectrum, will account for low values of megahertz. This fact is important as:

• SPG is recognized as a viable topology for those applications not exceeding a few megahertz. For example, a PCB (0V) SPG reference vs. chassis ground becomes progressively transparent as frequency increases [-20 db at 3 MHz (tolerable), but only -10 db at 7 Mhz (poor)].

• Being at a lower megahertz (meaning a longer wavelength), lightning current can sometimes "reach across" a circuit's (link) ends within a building and cause upset or damage. A decoupled circuit is more immune to these lightning currents. SPG is readily useful, such as for audio circuits, and greatly restricts "ground loops" that would otherwise carry common-mode currents along the grounding wiring. So now we can state how the SPG and megahertz condition can coexist as follows:

• Systems (inter)connected via an SPG topology should not require the external grounding/bonding system to maintain equipotential across its various ports and links. Or, stated another way: the ports/links must be effectively decoupled from foreign grounding systems.

Fiber optic links, transformers, etc. are useful to accomplish decoupling. The IEEE "Emerald Book" recommends this decoupling concept. Further, modern ITE design typically accounts for a minimum level of decoupling (inherently via EMC design), either by a regulatory compliance requirement or by being able to meet desired performance requirements (fast clocking electronics).

Therefore, even though megahertz conditions at some frequency(s) may actually exist on the SPG, ITE so connected can still be dispersed within the building. This is because modern power supplies are filtered, and interconnecting ITE links are typically decoupled and can withstand typical non-equipotential conditions.

ing inductance can impact the performance of the filter. Second, ITE interconnected via metallic links and powered from different circuits using SPG can become "exposed" to transients and electromagnetic fields contained in the large "loop area" developed between the power circuits.

The above situations are some of the reasons "The Emerald Book" does not recommend the IGR circuit.

SPG vs. equipotential. With equipotential as the objective, SPG seems to be inherently unacceptable as inductive voltage can be built-up across the SPG wiring during a transient event. But in reality, SPG and equipotential applications co-exist, actually complementing each other. Section 9.9.6 of "The Emerald Book" states, "It is important to understand that accomplished intersystem bonding originates the CBN as essentially an SPG entity. The better the intersystem bonding, the more the origination of the CBN resembles an SPG location." In effect, reaching equipotential among grounding systems of different services is best accomplished by equipotential bonding so dense as to act as an SPG at the common entry location. See the **Figure** on page 1 where four services are shown in "relative" vs. "accomplished" equipotential.

Equipotential is more often associated with multipoint bonding, whereby common-mode currents are anticipated and intended to divided across multiple connections. When there exists enough division (or mesh), every individual path is typically said to have a reduced amount of impressed current, resulting in a smaller voltage. When the voltage is small enough, then equipotential is said to be achieved. A better conception of equipotential is to recognize that there are limitations to the technology, and that equipotential can only be achieved "substantially."

During transient conditions, the grid or mesh will exhibit "high (voltage) spots" in certain areas and possibly even structural resonance that can amplify a high spot. Further, basic EMC theory requires electromagnetic fields associated with the voltages and currents of a circuit to follow the paths that store the least amount of field energy. Therefore, transients may actually traverse a grid or mesh and not use all the available paths — as some may require too much energy to be used. This phenomenon can be witnessed when lightning arcs downward across building steel to a lower section rather than force its way horizontally to another vertical column. But even with these recognized limitations, equipotential by some means (SPG, mesh, surge protective device) is a necessary practice.

For example, the equipotential concept is especially practiced in Europe, which uses EMC-based standards and practices that favor wholesale application of common-type bonding to accomplish equipotential. Even so, the SPG concept is evident in portions of the equipotential bonding requirements. An example document is EN 50310 "Application of Equipotential Bonding and Earthing in Buildings with Information Technology Equipment." Equipotential bonding requirements must be accounted for in new building design and installation and seriously considered for existing buildings. However, note that the realization of equipotentialization is not a given. Even some of the contributors (see Montandon and Rubenstein; IEEE Paper 00736210) to the reference standards cited in EN 50310 suggest that in some equipotential-based installations:

- A mesh may not perform any better than a single wire.
- Routing of power and signal cables to interconnect different equipment should be accomplished in more of an SPG-type mode with the accompanying decoupling of links.

Next month, we'll take a look at variations of IBNs, including star, mesh, and sparse-mesh types and their connection to the T(M)GB. **EC&M**

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Part 4

By William Bush, Panduit

In Part 3 of this article, we described how single-point grounding (SPG) is not nearly as straightforward as multipoint grounding systems. Using this improved understanding of SPG and equipotential systems, we can now take a look at variations of isolated (insulated) bonding networks (IBNs), including star, mesh, and sparse-mesh types — and discuss their connection to the T(M)GB.

Isolated (insulated) bonding network. SPG for an IBN must be derived from the common bonding network (CBN). IEEE Std 1100-2005, "The Emerald Book," points out that although the internationally derived term is 'isolated bonding network' (IBN), the BN is not isolated from the building's telecommunications grounding and bonding infrastructure (described in Part 1 of this article). An IBN is insulated so as to maintain a grounding connection only at a controlled physical location.

From Part 2 of this article, we noted from a reference "the purpose of a BN is to reduce the magnitude of the transfer function by controlling the design of how the BN is attached to the CBN." The IBN attachment method employed is blocking — isolated to effectively one galvanic connection. Note that this connection is at the "systems" level.

It's important to recognize that the IBN is harmonized with international and national standards. The **Table** at the top of page 7 provides identification and a brief description of four variations of IBNs. The distinction of these four variations allows all interested parties to readily identify the variation(s) of IBNs addressed at a given location.

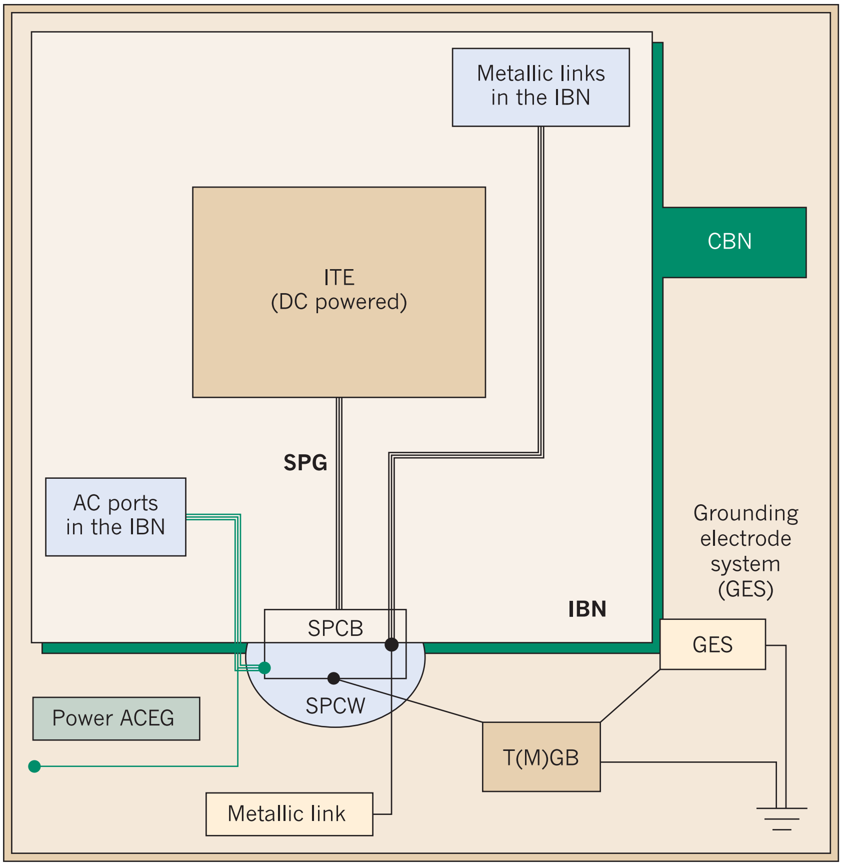

Fig. 1. Generic representation of the IBN concept (adapted from "The Emerald Book").

Variations of isolated (insulated) bonding networks (IBNs). The IBN generic concept is illustrated in **Fig. 1.** For simplicity, the DC power system is not shown. For details on IBN power and grounding, see "The Emerald Book," Chapter 9.

From Fig. 1, the following items should be understood:

• ITE and other metal structures declared as part of the IBN must be sufficiently insulated (for example, at 10kV) from the CBN so as to be grounded only by the grounding wiring to the single point connection bar (SPCB).

• The SPCB is shown with transparency to illustrate that it is connected to the CBN and T(M)GB (which is part of the CBN).

• IBNs are historically DC powered, but the concept remains intact even where the IBN is totally powered from AC.

• Grounding conductors (i.e., DC equipment grounding conductor (DCEG), AC equipment grounding conductor (ACEG), shields of metallic links such as coax, etc.) entering into the IBN must enter within the designated area of the single-point connection window

(SPCW), be referenced to the SPCB, and be insulated from the CBN from there forward. *Note*: The SPCW has historical reference to the "ground window," a term not recommended by "The Emerald Book."

• The SPCB must be of restricted size to control common impedance across the bar during transients.

An IBN is typically more explicit and visible in a restricted access area, especially for telecommunications service provider (TSP) DC-powered equipment, such as a dedicated equipment room. Compare this to a typical office area in a commercial building where the SPG may be undeclared, but still provided by the IGR circuit (Sparse CBN) or otherwise by AC circuits as previously described. The recent trend is for TSPs to deploy ITE into a CBN, citing the IBN as too maintenance-intensive for the grounding. In order to accomplish this, the TSPs typically require the ITE to meet stringent testing requirements specified in Telcordia document GR-1089-CORE-2004. However, there are still TSPs and other users holding on to the IBN concept because it is tried and true for blocking transient currents into the ITE.

> A great benefit of the IBN is the inherent ability to measure and monitor AC and DC currents on the SPG wiring.

Interestingly, the IBN concept is given significant attention at IET's 2007 tutorial workshop in London on Earthing & Bonding Techniques for Electrical Installations. Indeed, the IBN concept is still viable, even for regions entrenched to EN 50310 and Mesh-BNs. A great benefit of the IBN is the inherent ability to measure and monitor AC and DC currents on the SPG wiring. The measurement results readily lead to identifying wiring errors, insulation breakdown, and defective ITE. Compare this testing feature to the difficulty in trying to locate defective ITE in a CBN. Interestingly, the "intensive-maintenance" argument can also be brought to bear on the NEC requirement for SPG of the power system neutral. Inadvertent multi-grounding of the neutral downstream from the system grounding point is a commonly recognized finding during site grounding evaluations. However, don't expect the NFPA to soon forego that requirement due to maintenance issues.

Testing the IBN for integrity involves measuring the isolation (insulation) resistance. For detailed information on measuring the IBN, see "The Emerald Book" and Telcordia GR-295-CORE-2004. Continuous monitoring (with alarm function recommended) for leakage DC and stray AC at strategic SPG locations is recommended. The net effect is that if leakage current can flow on the grounding system, so can lightning and surge currents.

The IBN by itself does not ensure ITE will meet electromagnetic compatibility (EMC) requirements or objectives. ITE having a regulatory mark (such as CE) does not ensure its electromagnetic immunity when placed into the IBN. The ITE, IBN, and the CBN perform as a system, and you must coordinate the desired immunity margin to accomplish EMC. Supplemental grounding and bonding provided by the CBN and the IBN are key factors in achieving acceptable EMC.

Star isolated bonding network. An SIBN is equivalent to the IBN except the grounding conductors within the ITE block are specifically arranged into a star or radial pattern (**Fig. 2**). Advantages can include:

• An increased ability to monitor and measure the grounding conductor to a specific ITE unit.

• Reduction of magnetic energy induced into the ITE due to absence of ground loops within the block.

Mesh isolated bonding network. An MIBN is equivalent to the IBN except the grounding conductors within the ITE block are specifically arranged into a mesh pattern (**Fig. 3**). The density of the mesh is determined by the manufacturer, user, or both. The mesh is typically designed into the ITE block by means of metal racks, cable tray, raceway, metal sheets, etc. Although difficult and rarely performed, the MIBN can be arranged to include an insulated version of a mesh common bonding network (MCBN) installation under the raised floor, at the floor level (metal structure of the raised floor), or above the cabinet or rack (i.e., superstructure). The MCBN was described in Part 2 of this article. Effectively, the insulated version of the MCBN is incorporated into the MIBN and must follow IBN grounding rules. You can also describe such structures as insulated bonding mats. Advantages of an MIBN can include:

• Approximation to a reference plane whereby utilized single-ended circuits or low common-mode rejection ratio (CMRR) balanced circuits are made less susceptible to common-mode currents flowing between ITE units. Note that such circuits are atypical for modern data centers and telecommunications facilities.

• Increased electromagnetic shielding for the ITE block even though the block is IBN. This may become important where the ITE block is located near high power RF sources.

• The ability to bond the DC power circuit return conductor (which is system grounded) to the MIBN at multiple locations within the ITE block. Note that

Variation	Acronym	Description
Isolated (insulated) bonding network	IBN	An insulated declared entity with its grounding single-pointed to the CBN at an identified location.
Star isolated (insulated) bonding network	SIBN	An IBN with each unit typically bonded to a common bonding bar in a radial fashion.
Mesh isolated (insulated) bonding network	MIBN	An IBN with the units intentionally inter-bonded in a multiple fashion.
Sparse-mesh isolated (insulated) bonding network	S-MIBN	An IBN with the units intentionally inter-bonded in a minimum (sparse) fashion.

Four variations of isolated (insulated) bonding networks (IBNs) are outlined above.

this practice, although required by ETSI ETS 300 253 for European telecommunications facilities, is not recommended by "The Emerald Book."

Sparse mesh isolated bonding network. An S-MIBN is equivalent to the IBN except the grounding conductors within the ITE block are specifically arranged into a mesh pattern (**Fig. 4**). The density of the mesh is not a major concern and is determined by the manufacturer, user, or both. Advantages can include:

- Easy configuration of ITE units within the ITE block.
- Some limited ability to monitor and measure the grounding conductor to a specific ITE unit.

Supplemental grounding for SPG circuits. We previously raised the question regarding the value of supplementing an SPG path. The following statements are useful in making such a determination.

- Where inductance of the existing wiring path is desired to be lowered, a supplemental path is useful.
- Where reliability of the existing wiring path is paramount, a supplemental path is useful.
- Where an IBN configuration is utilized, supplemental paths within the ITE block may be encouraged, especially for mesh variations.
- For general/typical AC branch circuits that are intentionally (IGR circuit) or unintentionally performing as a SPG path, a supplemental path is of little added value.

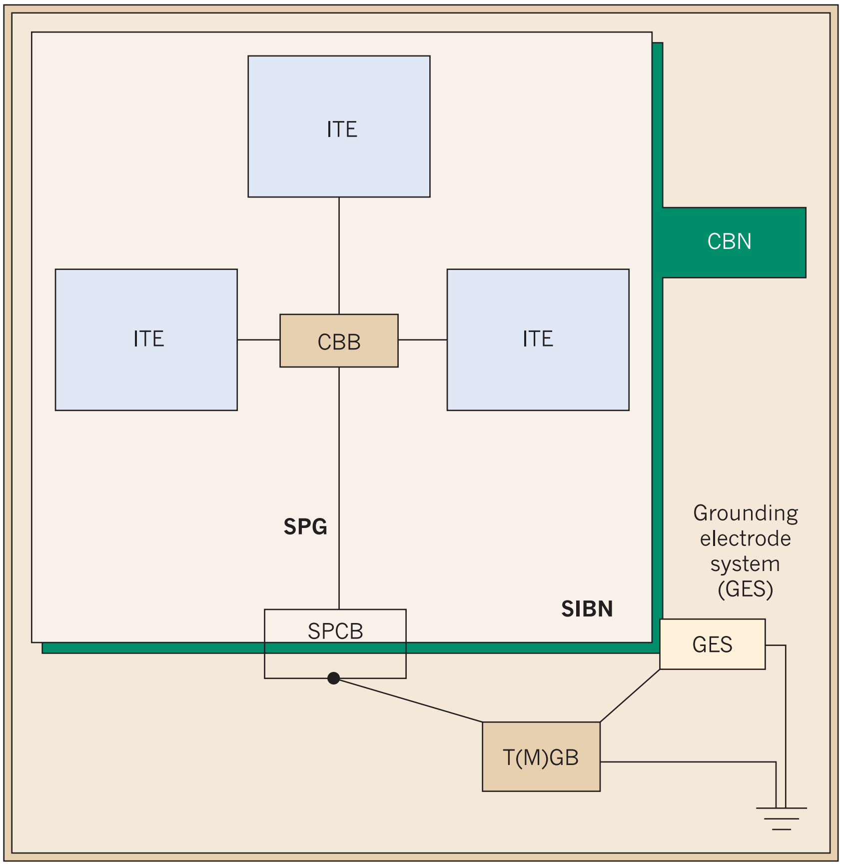

Fig. 2. Generic representation of the Star IBN concept (adapted from "The Emerald Book").

Supplemental grounding and bonding are more understandable when divided into segments addressing the telecommunications grounding and bonding infrastructure, ITE multipoint bonding networks, and ITE single-point bonding networks. It's important to be able to recognize the grounding and bonding topology actually applied to the ITE, whether AC or DC powered. By identifying against a standardized industry term, all parties involved can cogently analyze the grounding and bonding arrangement. In addition, there are recognized differences in North America and European approaches to supplemental grounding and bonding.

However, there is significant harmonization of both approaches to international standards. As a single source reference, "The Emerald Book" provides significant guidance on grounding and bonding electronic equipment and is a recommended practice. ITE should use supplemental grounding and bonding for improving performance and safety, especially for the more common multipoint grounding arrangements, such as a MCBN. In some instances, supplemental grounding and bonding for a single-point grounding arrangement is useful and can be accommodated. Complications arising from grounding of multi-powered ITE are beyond the scope of this article. **EC&M**

"The Emerald Book" provides significant guidance on grounding and bonding electronic equipment.

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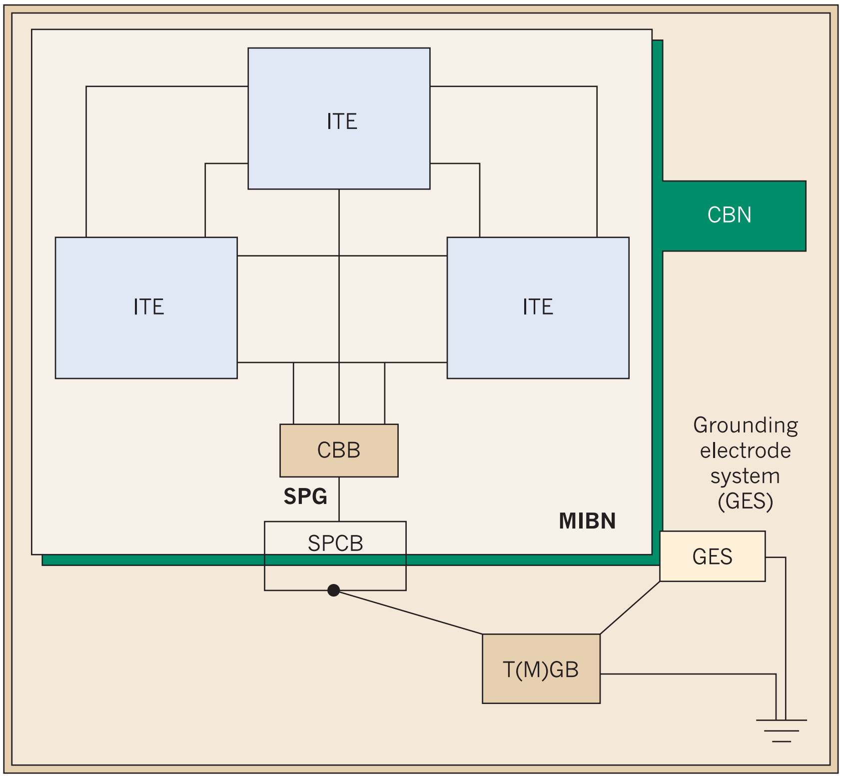

Fig. 3. Generic representation of the Mesh IBN concept (adapted from "The Emerald Book").

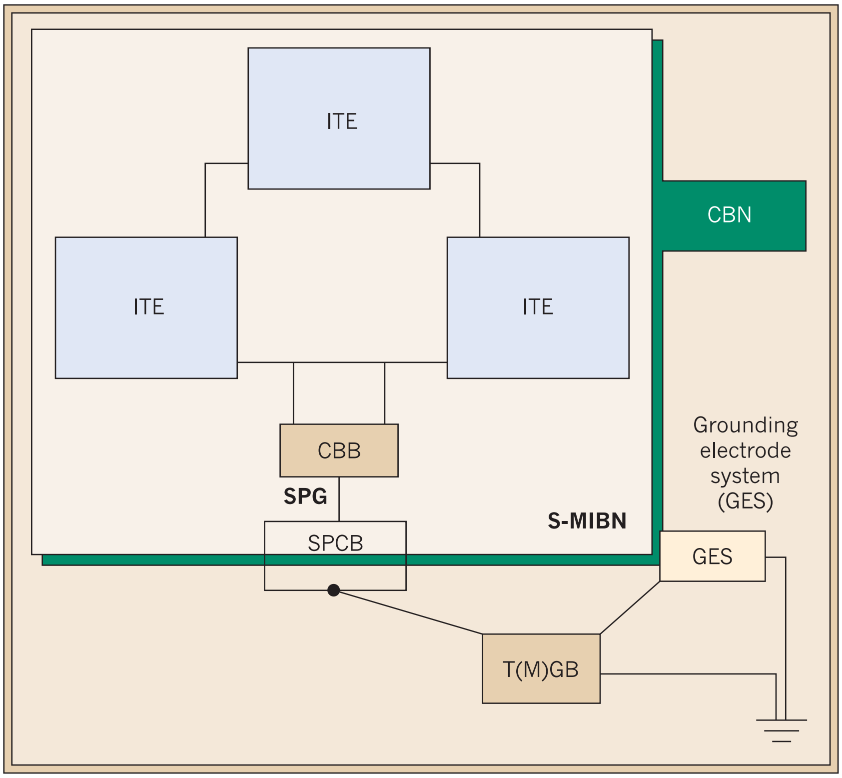

Fig. 4. Generic representation of the Sparse Mesh IBN concept (adapted from "The Emerald Book").