Shielded Rack and Cabinet Enclosures: An Introduction to EM Shielding for Part 15 Compliance

THOMAS J. SCHWANDA, Woodbine Industries Inc., Bensalem, PA
BRUCE D. SALATI, Technical Consultant, Palm Bay, FL

Integrating electronic equipment within a shielded enclosure can be the foundation on which an effective design for compliance with Part 15 technical standards is built.

INTRODUCTION

The design of electronic products containing digital devices must include provisions for achieving compliance with regulatory requirements for the control of electromagnetic interference. This article has been prepared to offer insight into U.S. regulatory requirements for the control of electromagnetic interference from digital devices, and to explain how radio frequency shielded enclosures can be part of an effective design for regulatory compliance.

CONDUCTED AND RADIATED EMISSIONS

The RF electromagnetic fields radiated directly into the environment by an electronic device are referred to as the device's radiated emissions. Sometimes a device can be responsible for EMI through an indirect path into the environment, most often by conducting RF currents into the device's power cord. Plugging a device's power cord into a wall outlet connects the device to the power wiring within a building. RF currents conducted into a building's power wiring can travel over numerous paths; the result may be disruption of radio reception throughout a building. RF currents present on interface and power conductors are referred to as the device's conducted emissions. Radiated and conducted emissions are both capable of causing EMI.

The radiation of RF electromagnetic fields or conduction of RF currents from an electronic device is an unintentional consequence of using digital electronic circuits that transition between logic states at high speeds. For this reason, some electronic devices containing digital electronic circuits are defined as "unintentional radiators" by regulatory agencies. Within the United States, the Federal Communications Commission has responsibility for maintaining and enforcing the technical standards limiting conducted and radiated emissions from unintentional radiators. The Federal Communications Commission's technical standards for unintentional radiators are published within the Commission's Part 15 rules.

WHAT IS PART 15?

Part 15 actually refers to Part 15 of Title 47 of the United States Code of Federal Regulations. The Code of Federal Regulations is divided into 50 titles which represent broad areas subject to Federal regulation. Title 47 contains general and permanent rules published in the Federal Register related to telecommunications. Part 15 of Title 47 contains the rules for radio frequency devices. Part 15 is divided into Subparts A through D, with Subpart B containing the rules for unintentional radiators. Designers who need to know about compliance to Part 15 EMI requirements for a product under development should be familiar with Title 47 of the Code of Federal Regulations (47 CFR). Copies are often available at Federal Depository Libraries. Copies of 47 CFR can also be purchased from the U.S. Government Printing Office. Part 15, as of 1 October 1995, is contained in the first volume (Parts 0 through 19) of Title 47.

Subparts A and B of Part 15 contain definitions and technical compliance standards that are important to anyone involved in the design and development of equipment containing digital devices. There is no substitute for complete familiarity with the contents of Subparts A and B, but there are a few topics that deserve immediate attention:

Subpart A, General

15.3 Includes definitions of Class A and Class B digital devices, digital devices, peripheral devices, and unintentional radiators.

15.31 Describes the measurement standard that will be used when testing your product for Part 15 compliance. Make note of Paragraph (a)(6) of Section 15.31; it describes how to obtain copies of American National Standards Institute (ANSI) C63.4-1992, "Methods of Measurement of Radio-Noise Emissions from Low Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz." This document details how a product will be tested for Part 15 compliance.

15.33 Defines the upper frequency limit that a product will be tested to during Part 15 compliance testing. Knowing the upper frequency limit will help you when selecting a shielded enclosure; most shielded enclosures are specified in terms of the shielding effectiveness they provide up to a specified frequency.

Subpart B,
Unintentional Radiators

15.101 Describes authorization requirements for equipment.

15.103 Defines exempted devices. This is very important; a product containing digital devices should not be designed and tested for Part 15 compliance if it is exempt from selected Part 15 technical standards. Examples of exempt (from Part 15.107 and 15.109 only) digital devices include equipment used exclusively in any transportation vehicle, digital devices used exclusively as industrial, commercial, or medical test equipment, and some specialized medical devices.

15.107 Defines conducted emission technical standards. These are the power line conduction standards that equipment may be required to meet.

15.109 Defines radiated emission technical standards. These are the electromagnetic radiation standards that equipment may be required to meet.

EMI CONTROL TECHNIQUES

EMI control techniques are used to minimize the conducted and radiated emissions from an electronic device. All EMI control techniques are based on the concepts of minimizing the magnitude and spectral content of RF electromagnetic fields generated by the device's circuits, confining the generated RF electromagnetic fields within a controlled volume of space by shielding, or some combination of both concepts. EMI control techniques for electronic equipment include (but are not limited to): enclosure shielding, cable shielding, optical isolation, grounding, bonding, interface filtering, printed wiring board layout, logic rise time control, power decoupling and regulation, and power-line filtering.

Part 15 rules define the allowable levels of conducted and radiated emissions from equipment containing digital devices and the methods used for measuring the emissions. The various circuit level and enclosure level EMI control techniques needed to make a particular device compliant with Part 15 technical standards are the choice of the equipment manufacturer. There are no "FCC Approved" EMI control techniques or "Approved" parts such as shielded enclosures, EMI filters, or shielded cables that will guarantee Part 15 compliance when used in the general design and manufacture of a product.

The letters "FCC" are often used in advertising material for EMI control products. Most vendors are not trying to be misleading when using "FCC" in part number or product descriptions; the intent usually is to communicate that the product is suggested for use in equipment required to comply with Part 15 rules. It's helpful to be able to sort the products intended for Part 15 compliance applications from their more expensive counterparts intended for demanding military applications.

EQUIPMENT WITHIN A SHIELDED ENCLOSURE

Installing equipment within a shielded enclosure does not exempt the equipment from Part 15 compliance, but it can be part of an EMI design approach that may allow a manufacturer to shift the burden of Part 15 compliance from the equipment level to the "system" or "rack" level. If components of a product can be installed within a shielded enclosure, and if the product will be sold and used in that configuration, the product can be tested for Part 15 compliance at the rack or system level. This could be more cost-effective than designing and testing each hardware item for Part 15 compliance. The shielded enclosure approach has particular value for new devices and systems assembled from rack-mountable hardware (that may include devices that are not Part 15 compliant), or large backplane and card cage assemblies (that may not be Part 15 compliant) that can be adapted to rack mounting. Installation within shielded rack enclosures also offers cost-saving potential for custom systems, low volume production systems, and systems constructed from new equipment that may be tested for Part 15 compliance at a later date.

A shielded enclosure can be considered the foundation on which an effective EMI control approach is built. A shielded enclosure provides a means to confine radiated emissions to within a controlled volume of space, the interior of the shielded enclosure. Radiated emissions escaping from the shielded enclosure will be at levels much lower than they would be if the enclosure was not designed to provide RF shielding. This reduction in radiated emissions is what makes enclosure shielding such a desirable EMI control technique.

There is an important caveat when using a shielded enclosure: every mechanical and electrical interface between the interior and exterior surfaces of the shielded enclosure must be provided with EMI control measures to prevent degradation of the enclosure's shielding effectiveness. Equipment can be installed within the finest RF shielded enclosure available and still fail to meet the Part 15.109 radiated emission standards because the enclosure's interface hardware was not protected. The same can hold true for meeting the Part 15.107 conducted emission standards.

SHIELDED RACK ENCLOSURES

One of the more popular approaches to shielding equipment at the systems level involves installing system equipment within a shielded 19-inch rack enclosure. These shielded rack enclosures will accept equipment designed for installation within an Electronic Industries Association (EIA) Standard RS-310-C/D 19-inch rack mounting format. Some vendors of shielded rack enclosures can also offer custom enclosures for equipment that requires a non-standard mounting format.

Shielded rack enclosures differ from their non-shielded counterparts in the details of their construction. A shielded rack enclosure is constructed using materials and finishes that allow all of the enclosure seams to be electrically continuous, including the door seals, side panels, top and bottom covers, and removable access covers. Ventilation is usually through a mesh screen, perforated panel, or metal honeycomb vent. Windows, if used, are fitted with a fine conductive mesh or a transparent conductive coating.

Shielded rack enclosures are often specified by the shielding effectiveness (also called attenuation) the enclosure provides, expressed in decibels (dB), over a specified range of radio frequencies. Shielded rack enclosures with shielding effectiveness values of 20 dB to over 110 dB, with upper frequency limits extending above 10 GHz for some applications, are available. Buyers should keep in mind that enclosure cost and complexity increases with increasing shielding effectiveness and high upper frequency limits. At the same time, the technical standards of Part 15 are not very demanding. Shielded enclosures that offer moderate shielding effectiveness, good interface access flexibility, moderate cost, and a reasonable procurement lead time are available. Solid construction and attention to detail can help in the development of a product that meets the technical requirements of Part 15; spectacular shielding specifications will not.

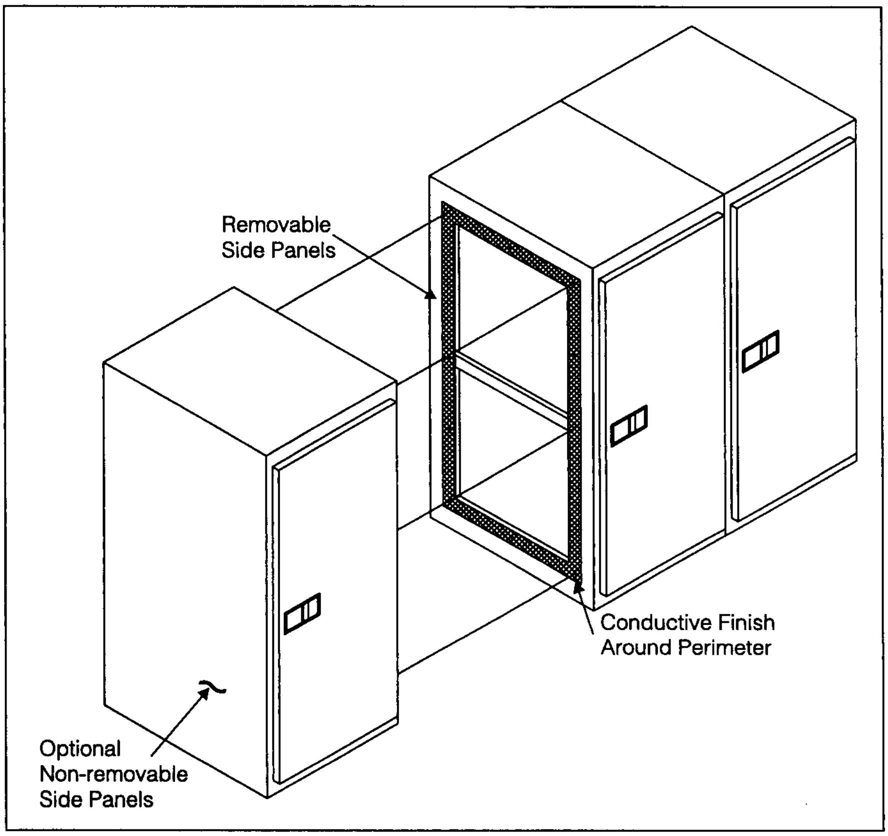

Figure 1. *Shielded enclosures can be joined to form a shielded multi-bay enclosure. This option allows direct connection of internal interface conductors between equipment in adjacent bays without the need for additional EMI control measures.*

INTERFACE ACCESS

Most electronic systems include external interfaces (interfaces that cross the boundary formed by the shielded enclosure's conductive surface) for signal input and output, power input, ventilation, alarms, and control. Protective measures must be incorporated into the design of external interfaces so that they can pass through the shielded surfaces of the enclosure without allowing the escape of excessive radiated or conducted emissions. Interface access can be through panels, doors and windows.

ENCLOSURE TOP AND BOTTOM PANELS

Shielded enclosure vendors can provide top and bottom panels designed for specific interface and access opening needs. Top and bottom panels should contain space for supply and return air ventilation panels, power and grounding entry, and all electrical interface hardware. It may be desirable to use removable interface panels that can be configured with bulkhead mounted connectors, filters, or filter pin connectors for each control and signal interface.

SIDE PANELS

Shielded enclosure vendors can provide side panel options allowing racks to be joined into a multi-bay enclosure. This option simplifies interface connections between equipment in adjacent racks as EMI control measures are generally not needed for internal interface hardware (interface hardware that does not need to cross the boundary formed by the shielded enclosure's conductive surface) (Figure 1).

Many shielded enclosures are available with removable side panels. Removable side panels may be useful for systems that require field expansion, but they require large gasketed seams that can be a source of RF emissions leakage. Investigation into enclosures with non-removable side panels is rec-

Continued on page 39

ommended. Side panels that are an integral part of the welded rack structure are less complex than removable side panels and do not require conductive gaskets and finishes that can degrade with time. The reduced mechanical complexity associated with integral side panels may often lead to reduced procurement costs.

DOORS

There are a variety of shielded enclosure door designs. The conductive sealing mechanism may include conductive polymer gaskets, woven conductive fabric bonded to a sponge rubber core, knitted wire mesh (with or without a sponge rubber core) or conductive metal spring fingers. The enclosure door should be easy to operate and have a reliable latch mechanism. The door's RF seal should be easily replaceable under field conditions; designs that require drilling out fasteners or scraping off old adhesive as part of the RF seal replacement procedure should be avoided (Figure 2).

WINDOWS

Some vendors can provide shielded windows for an enclosure door. They are costly, but there are some applications where it is essential to have a window through which front panel indicators can be viewed. Alternatives to door-mounted shielded windows do exist. There are situations where equipment can be installed within a shielded rack enclosure in such a way that a front door is not needed at all. An experienced designer working with a good test organization may be able to determine if this approach will work with your equipment.

EXTERNAL SIGNAL INTERFACE HARDWARE

Routing external interface conductors through a shielded enclosure surface requires EMI control techniques that allow the desired signal to pass through the interface while blocking undesired radiated and conducted emissions.

FIBER OPTIC SIGNAL INTERFACES

Fiber optic interfaces are very desirable in applications where EMI must be controlled. Optical fibers are made of nonconductive materials that block the flow of conducted emissions. The combined optical fibers and nonconductive jacket materials are usually bundled within a diameter small enough to prevent dielectric guiding of emissions. Small metal bushings can be used as a feedthrough device for optical cables. Large bundles of optical fibers may require a waveguide-below-cutoff access opening through an enclosure interface access panel. When selecting waveguide-below-cutoff access hardware, a cable connector diameter should be included with the estimate of cable bundle size. This will allow installation of fiber optic cables without having to remove or replace connectors.

Waveguide-below-cutoff openings only provide shielding when they contain nonconductive materials such as air, some fluids, and fiber optic cables. If conductive material is passed through a waveguide opening, the shielding effectiveness of the opening will drop to a very low level and emissions will increase. Conductive wires and cables routed through any opening into a shielded enclosure, regardless of the opening size, will usually allow emissions to escape from the shielded enclosure.

CONDUCTIVE SIGNAL INTERFACES

Most interface hardware, including coaxial cables, shielded twisted pairs, ribbon cables, and bundled cables, rely on the use of metallic conductors for the interface signal path. Unlike optical fibers, metallic conductors provide a direct electrical path for the flow of unintentional emissions. EMI control techniques can be applied to almost any interface cable to reduce emissions sufficiently to meet Part 15 technical standards. Interface conductors can be shielded to confine emissions, filtered to reduce the spectral content of emissions, or protected with some combination of both techniques.

SHIELDED INTERFACE CABLES AND CONNECTORS

Shielding of cables is only effective when the shield is properly terminated (usually on both ends of the cable). Connectors for shielded cables should be fitted with conductive backshells that create a conductive shielded path from the cable shield to the connector mating surfaces. Connection to the shielded enclosure should be through a conductive bulkhead mounted connector. These bulkhead mounted connectors must be conductively bonded to the surface of the shielded enclosure. The enclosure vendor can design a removable interface access panel which is cut, drilled, and conductively finished to accept all of the bulkhead feedthrough connectors needed for your system. The buyer should remember that conductive wires, cables, and cable shields can not pass through an unprotected opening in a shielded enclosure, regardless of the opening size, without causing increased emissions (Figure 3).

Continued on page 258

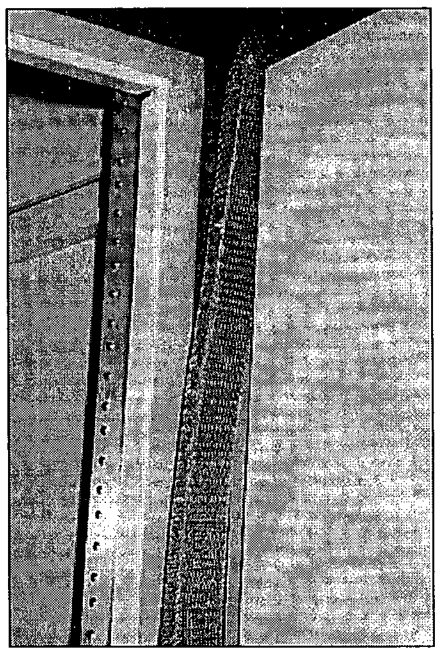

Figure 2. A knitted wire mesh over sponge rubber core gasket material is pressed into a conductive channel in this door seal design. The gasket can be easily replaced under field service conditions.

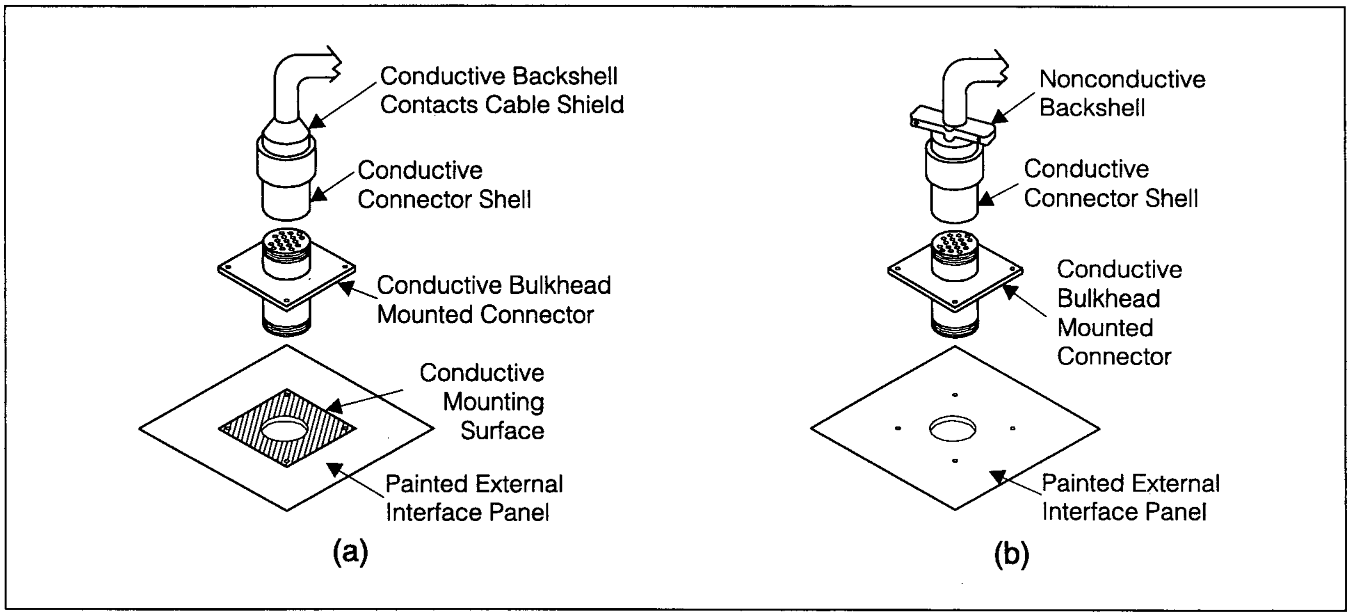

***Figure 3.** Correct Connector Backshell Configuration (**a**). Incorrect Connector Backshell Configuration (**b**).*[1]

INTERFACE FILTERS

Sometimes there is a need to remove RF emissions from signal interface conductors. Filters perform this function by attenuating RF currents while allowing the intended low frequency signals to pass without attenuation. Filters are typically constructed from reactive inductive and capacitive elements, or ferrites that have both reactive and absorptive properties. Reactive elements attenuate RF emissions by reflecting them back to their source. Absorptive elements attenuate RF emissions by converting the energy to heat.

A very popular method of filtering signal lines involves the use of filter pin connectors. These connectors contain internal filtering for multiple interface conductors and are available in several popular standard connector configurations used in telecommunications and computer applications.

Shielded enclosure vendors rarely provide signal line filters. There are so many types of electrical interfaces presently used in industry that it would be impossible to have readily available filters for every possible application. Selecting a filter requires knowledge of the interface's source and load impedance, data rate and rise time, interface spectral requirements, allowable delay and distortion, voltage, current, and transient conditions. Interface filters should be selected with care. The wrong choice of filter could result in unpredictable interface operation.[2]

A shielded enclosure vendor can support interface filtering needs by providing custom interface access panels with connector cutouts prepared to your specifications. Providing the details of how each filter will be mounted allows the selection of appropriate conductive finishes to provide for a conductive bond between the filter housing and the shielded enclosure surface. Many filters will not function unless they are conductively bonded to the shielded enclosure's surface (Figure 4).

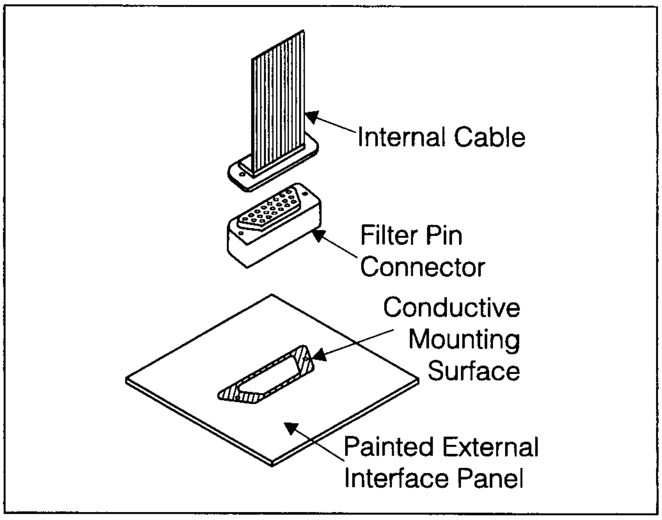

***Figure 4.** Filter pin connector cut-out must include provision for conductive bonding of the connector shell or to the enclosure's surface. Specify a conductive finish and mask paint (if used) at the mating surfaces.*

POWER INTERFACE HARDWARE

A shielded enclosure vendor may offer power-line filter options available from stock. Review the electrical characteristics of any power-line filter in detail; an understanding of how the filter can help or hinder the system is necessary. The leakage current of the filter must be in accordance with safety standards applicable to the equipment. The transient voltage withstand capability must be determined as well as the normal voltage and current handling capability.

The buyer must also determine whether the filter has sufficient attenuation to allow the equipment to meet the Part 15.107 conducted emission standards. This determination will most likely require some trial and error testing; it is very difficult to predict how a filter will perform under actual operating conditions. This difficulty arises because power filter attenuation ratings are based on insertion loss tests or calculations that assume a standardized 50-ohm measurement system, a condition that is not duplicated in real power systems.

Power conductors, including the green wire safety ground conductor, should enter the shielded enclosure without degrading the enclosure's shielding effectiveness (Figure 5). A good power-line filter will include a shielded termination compartment (sometimes referred to as a "dog house") with a feedthrough fitting for power cable entry. This feedthrough fitting, or the filter's conductive surface surrounding the feedthrough fitting, must be conductively bonded to the shielded enclosure's surface. Power-line filters are like most signal-line filters in that they will not function unless bonded to the shielded enclosure's surface.

The shielded termination compartment should also have a removable cover that allows access to the power terminals. This cover will prevent stray coupling of emissions to the power entry conductors and prevent stray fingers from contacting the power conductor terminations. Selection of a filter without a shielded termination compartment and feedthrough fitting may result in the need to run conduit, possibly shielded, from the point of power entry to the power filter.

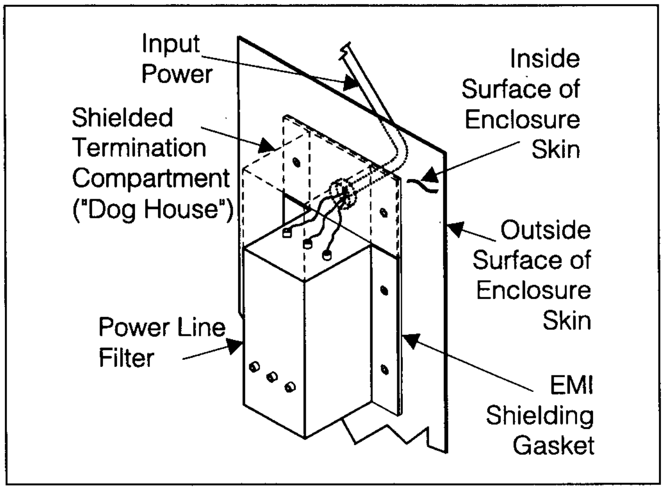

Figure 5. *Typical Shielded Enclosure Power Entry Design. Power entry is simplified by selecting power-line filters that have a shielded termination compartment.*

INTERNAL GROUNDING

Enclosure vendors can provide an internal copper ground bus for equipment ground connections within the shielded enclosure. Standard buses are drilled for mounting and tapped to provide electrical bonding points. The use of an internal ground bus is most often associated with electrical safety. Ground leads are routed from each equipment chassis ground stud to the internal ground bus such that, regardless of the type or condition of the equipment power cords, each chassis is securely bonded to the internal ground bus. The internal ground bus is usually bonded to the shielded enclosure by a jumpered connection to a threaded stud mounted at the base of the enclosure.

From an EMI control perspective, ground conductors routed from an equipment chassis to the internal ground bus are often not effective at radio frequencies. This is due to the high RF impedance created by long ground conductor length, particularly when the conductors are routed through cable retractors or used with chassis slide-mounted equipment. High frequency grounding is usually achieved inadvertently through the mounting hardware that secures the equipment to the rack. An advantage of using a shielded enclosure is that the enclosure structure forms an excellent high frequency ground plane; buyers should take advantage of this by verifying that equipment is installed within the rack using conductive hardware.

EXTERNAL GROUNDING

A shielded enclosure may need to be fitted with an external connection point to allow bonding to a safety ground grid or conductive raised computer floor grid within the system user's facility. The enclosure vendor can provide hardware options to allow connection of bonding jumpers to the shielded enclosure's exterior surface.

Connection to ground may also be made through the ground conductor of the cable supplying power to the enclosure. Most power-line filters are provided with a termination point for a ground conductor within the filter's shielded termination compartment.

A well-shielded system will usually function and meet all Part 15.109 technical standards regardless of the length or condition of the external ground connection. Emissions-related RF currents are confined to the shielded enclosure's interior surfaces by the conductive enclosure surfaces and protective control measures applied to each enclosure interface. This reduces the flow of emissions-related RF currents on the exterior surfaces of the shielded enclosure. A ground conductor connected to the exterior surface of a well-shielded enclosure will also have reduced emissions-related RF currents, minimizing radiation from the ground conductor.

Grounding of any conductive enclosure, shielded or not, is required for the safety of the user. Small values of power frequency leakage current will normally be present in the ground conductor, provided that care is taken in the selection of the power-line filter. The situation changes during power fault and external transient conditions. The ground conductor must be able to carry the full fault or transient current while holding the enclosure's surfaces at a voltage low enough to prevent injury to anyone contacting the enclosure (or it's associated shielded cables, peripherals, etc.). The subject of grounding for safety is not regulated by the technical standards of Part 15, but is worthy of the attention of persons installing and using electronic equipment. More can be learned about grounding of electronic equipment within facilities by reviewing the *National Electrical Code* (NFPA 70), and local electrical codes.

COOLING/VENTILATION

Electronic equipment dissipates energy as heat. Mounting electronic equipment within an enclosure restricts the flow of air that normally provides cooling. The result can be a dramatic increase in equipment temperature over what might be expected for the same equipment mounted outside of an enclosure.

The selection of ventilation hardware for a shielded enclosure requires knowledge of the amount of heat generated within the enclosure. A thermal analysis should be prepared that considers the inlet (supply air) temperature, the power dissipated within the enclosure, the maximum equipment operating temperature, and the air that must be removed from the enclosure to maintain the equipment at a safe operating temperature.

Honeycomb ventilation panels have often been used in high-level military shielding applications; they offer the highest shielding effectiveness available for a ventilation opening.

Once a thermal analysis has been performed, an enclosure vendor can work to select ventilation materials suitable for the shielded enclosure. Most enclosure vendors can provide ventilation hardware to support forced air cooling or convection cooling. Ventilation can be through perforated panels, ventilation screens, or honeycomb ventilation panels. Honeycomb ventilation panels have often been used in high-level military shielding applications; they offer the highest shielding effectiveness available for a ventilation opening. Honeycomb structures also offer the lowest restriction to air flow of any shielded ventilation technique, an important asset if the thermal analysis indicates the need to minimize restriction to airflow, so they may be an appropriate choice for a Part 15-compliant design. Screens and perforated panels may be more economical than honeycomb ventilation panels, but are more restrictive to air flow. The small air openings can become clogged with dust; select screens or honeycomb ventilation panels that can be cleaned or replaced in the field may be warranted.

CONCLUSION

Integrating electronic equipment within a shielded enclosure can be the foundation on which an effective design for compliance with Part 15 technical standards is built. There are also benefits to integrating equipment within a shielded enclosure that extend beyond the realm of Part 15 compliance. Each of the EMI control techniques described for the reduction of conducted and radiated emissions has applicability for controlling immunity to radiated and conducted emissions. This means that equipment will be less susceptible to disruption by external sources of EMI, adding considerable value for customers who will use the equipment near radio transmission, radar, and industrial equipment. There are no immunity standards presently contained within Part 15, but that may change in the near future as there is continuing pressure in the domestic regulatory community to address this aspect of EMI.

Each EMI control technique described in this article also has applicability to electronic equipment intended for export markets, particularly where there is a need for compliance with the European EMC Directive. The technical standards and measurement methods differ from those of Part 15, but the EMI control techniques needed to achieve regulatory compliance are similar.

NOTES

1. A list of shielded cable, connector, and connector backshell vendors is included in the Products and Services Index of this issue of ITEM. Check the listings under the following headings: *backshells; shielded assemblies; terminations; braid, cable and wire, shielded; and cable assemblies and harnesses, shielded.*

2. A list of signal line filter and filter pin connector vendors is included in the Products and Services Index of this issue of ITEM. Check the listings under the following headings: *capacitors; filters; connectors; filter pins; ferrite suppression components; filters, absorptive; filters, feed-through; and filters, signal line.*

THOMAS J. SCHWANDA *is the General Manager of Woodbine Industries Inc., specializing in the design and manufacture of shielded enclosures and consoles. (215) 638-7600.*

BRUCE D. SALATI *is a NARTE-certified EMC Engineer, active within the EMI/EMC/TEMPEST community since receiving his Bachelor of Science Degree in Electrical Engineering from Drexel University in 1980. He is presently a technical consultant specializing in the development of electronic equipment hardened for operation within a demanding electromagnetic environment. (407) 729-0136.*