Proper RF Shield Penetrations

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INTRODUCTION

In the field of RF shielded enclosures, stories abound concerning problems due to improper penetrations of shielded rooms. Typically, penetrations are made by an end user who does not fully understand or appreciate the ramifications of "simply drilling a hole through the shield." This article is intended to be a guideline for making penetrations into an RF shielded enclosure without degrading its shielding performance.

BACKGROUND

It has been said that the perfect RF shielded enclosure would be a solid metal box with no penetrations or openings anywhere on the surface. But since the Star Trek technology of "beaming up" people through barriers has not yet been perfected, this type of enclosure is not practical. At least one penetration, in the form of a door, is needed on every shielded enclosure.

Penetrations on shielded enclosures can also be in the form of windows, filters, waveguide-beyond-cutoff feedthroughs, HVAC vents, electronic/electric panel connectors, access panels, and fasteners for construction purposes. The shielding materials chosen for the design, construction and end-use of a penetration will affect its final performance. A shielded enclosure can have one, all, or any combination (and number) of the above penetrations. Any penetration made in the shielding surface of the enclosure can compromise its performance. All shielded room penetrations must be made correctly to minimize the possibility of reduced total system performance.

It is easy to see why the number of choices to be made about penetrations in a shielded enclosure can be daunting to someone not usually involved with shielded enclosures. Most shielded enclosure manufacturers, however, know which questions to ask in order to guide the end-user/buyer in selecting the correct components to meet the buyer's needs. This relieves the buyer from the burden of becoming a shielding expert.

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Nevertheless, buyers do need a basic understanding of the large number and types of penetrations that can be present in a shielded enclosure, an awareness of the problems associated with those penetrations, and information on proper installation. There are times when knowing about shielded room penetrations can be beneficial and necessary. The following information is presented to enable a prospective user to understand the requirements for the proper RF shield penetrations.

DOORS, WINDOWS, HATCHES, AND PANELS

The most important penetration of a shielded enclosure is the door. The door is typically the only active component on a shielded enclosure and is thereby subjected to the greatest amount of use and abuse in the enclosure. A door design compatible with the function of the enclosure and the expected daily use is crucial to the overall performance and long-term reliability of the entire enclosure.

Dozens of types and styles of RF shielded doors are currently available. The performance and complexity of doors varies greatly, as does the price. The factors affecting door performance are the shielding materials chosen for the door and jamb, the design of the RF seal between the door and the door jamb and between the jamb and the enclosure, the hardware used on the door (latches, hinges, handles, locks, closures, etc.), and the final installation of the jamb in the shielded enclosure.

The specifics of available door designs is a topic for a separate paper. The end user/buyer of RF shielded doors should look for a design that has been thoroughly tested and proven. The door supplied with the shielded enclosure should be properly matched to the enclosure performance. There are times when this is not the case because inadequate information is provided by the buyer. When more information is needed, the following questions should yield all the answers necessary to make an informed and intelligent decision.

- Is the door performance comparable to the performance of the shielded enclosure system? The door should have an inherent shielding effectiveness that is at least 10 dB higher than that specified for the shielded enclosure. Since the door is an active component of the enclosure, the performance of most doors can be expected to decline with use. The higher performance characteristics of the door will offset this occurrence. However, overkill on the door performance specification can lead to a correspondingly high price for the door.

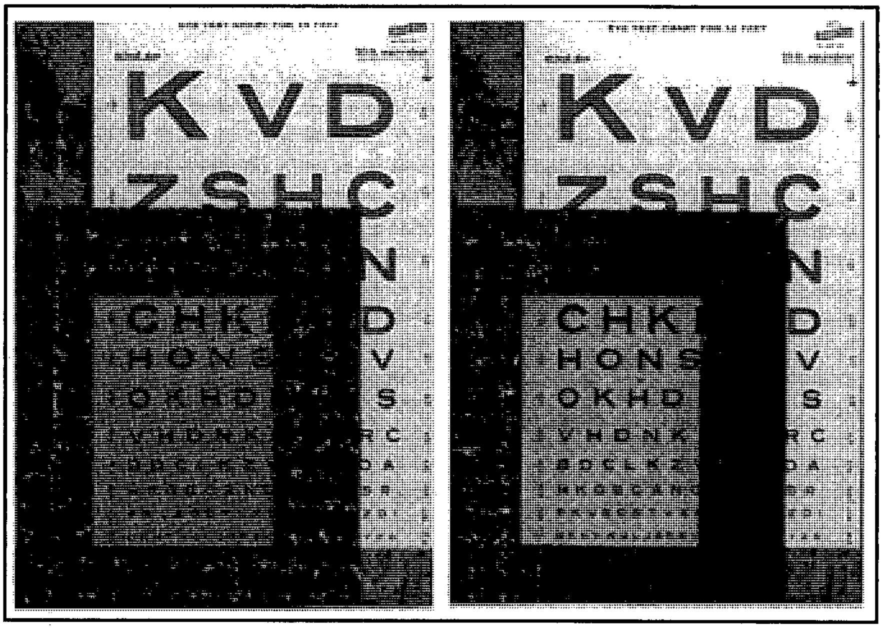

Figure 1. *Screen Mesh Selection Can Greatly Influence the Viewing and Shielding Characteristics of an RF Shielded Window. Mesh on left has higher performance, while mesh on right is optimized for viewing clarity and visibility.*

- Can the door be maintained easily? An easily maintained door will usually have a longer useful life and higher performance levels. Also, field maintenance and repair are generally less on a door that is easily maintained.

Windows are options in enclosures where the performance and/or frequency requirements are not extremely high. There are fewer RF shielded window options than there are door options, but the performance of the window must be considered when one is to be installed in an RF shielded enclosure. The material used to make the windows needs to be considered because it will affect both the visibility and clarity of the window, the shielding performance level at various frequencies, the size of the finished window, and ultimately the price of the window. Typically, if high performance (100 dB or greater) is needed above 1 GHz, a shielded window is not a feasible option for a shielded enclosure. Materials usually used to fabricate windows for shielded enclosures are screen mesh or metallized coating on a glass substrate. The following questions should be considered when an RF shielded window is an option.

- What RF shielding attenuation levels are required for the shielded enclosure system? Certain RF shielding materials for window construction work well at higher frequencies, while others work well at lower frequencies. Magnetic and electric near fields are typically low frequency fields. Electric fields are easy to attenuate; magnetic fields are difficult to attenuate. The attenuation of both fields depends heavily on the shielding material used to construct the window. Plane waves and microwaves are typically high frequency far fields that depend upon shielding materials *and* construction methods for window attenuation characteristics. Magnetic fields are difficult to attenuate with almost any RF shielded window, since most materials used for RF shielded window construction are either too thin and/or non-ferrous. However, it should be noted that near-field frequency strength decreases inversely with the cube of the distance from the generating source. This simply means that the field strength attenuation will increase rapidly within a very short distance from the shielded enclosure surface, thereby protecting equipment located sufficiently far (six to seven feet) from the shielded enclosure walls. Above 1 GHz, the attenuation of RF shielded windows typically begins to decline, and well above 1 GHz, this decline may be below acceptable attenuation levels for certain shielded enclosure applications.
- How important is visibility through the window? Materials used to construct an RF shielded window will greatly affect the visibility and clarity of the window. If screen mesh is used, the moiré pattern that can result from using two or more layers of mesh and the physical characteristics of the mesh can be very distracting and seriously degrade the visibility and clarity of the window (Figure 1). If a coated glass substrate is used, the lighting ratio between the interior and exterior of the shielded enclosure is crucial for visibility. Under certain lighting conditions, the high reflectivity of coated glass can simulate a mirror, limiting or totally eliminating the visibility through the window.

Access hatches and penetration panels are other potential problem areas on some RF shielded enclosures. They can create more problems than they solve if not properly designed and installed. The materials used to make the hatch or panel (usually copper, brass, aluminum, galvanized steel, or steel) must be compatible with the primary shield surface to avoid galvanic corrosion problems. Galvanic corrosion will most readily occur if two metals with substantial differences in galvanic compatibility are placed in contact with each other. (There are many sources available that list the galvanic compatibility characteristics of metals in a tabular form known as the galvanic series. An abbreviated table is shown in Table 1. Metals from one end of the table should not be placed in direct contact with metals at the opposite end). Galvanic corrosion should also be considered if a gasket material is to be used to achieve the RF seal. If a gasket material is to be used, the number of operating cycles to which it will be subjected (on and off, or open and close) and the RF frequencies and field types that need to be shielded must be considered before selecting the type of gasket material.

Penetration panels are used extensively where signal cables or lines must be brought into the shielded enclosure. These shield penetrations typically contain type N or BNC, D-subminiature, pneumatic, or other bulkhead connectors. Some shielding integrity can be lost around the panel connectors if they are not chosen or installed correctly. Access hatches are used extensively to reach certain areas of the shielded enclosure and may never be used again after the shielded enclosure is installed.

It should be obvious from this information that there is a large variety of penetration panels and access hatch designs. Hatches and panels are typically custom-fabricated to meet the specific needs of the end user. The following questions can be very useful in determining penetration panel and hatch requirements.

- What is the total shielding effectiveness required for the shielding system? Many connectors that are typically used in a penetration panel cannot meet the high performance shielding requirements of some users. Special panel designs are sometimes needed to meet high performance requirements. In many cases, the connectors will provide adequate shielding when they have no cables connected, or better yet, when they are capped with an appropriate conductive cover to form an RF seal. The end user needs to carefully consider the compromise to shielding integrity that cabling can cause. Upgrading the cable can often lead to improved shielding effectiveness of the entire system.
- Are there any special signal requirements to be passed through the shield? The type of signal to be passed through the shielded surface must be addressed prior to choosing the connector to be used in the penetration panel. It is important to let the shielding manufacturer know exactly what types of signals will be used in conjunction with the shielded room. In some cases, a filter may be the best choice for the application. In other cases, a fiber-optic line passed through a waveguide - beyond - cutoff feedthrough may be the best solution.
- What are the frequencies of concern and the shielding levels that are needed? This question will help answer what types of materials can be used to construct a hatch panel that will achieve the desired level of performance from a shielding materials perspective. If low frequency magnetic field shielding is required, some form of ferrous material will most likely be needed. If the performance requirements are not particularly high, an access hatch made of a screen mesh shielding material may suit the end user's needs at a lower cost. The shielding manufacturer should be able to direct the buyer towards the most effective solution for a given situation.
- Will the panel or hatch be removed after the initial installation, and if so, how often will it be removed? If the panel or hatch is expected to be removed frequently, the fastening method used to secure the panel/hatch to the shield room and therefore achieve the RF seal needs to be carefully considered. Fasteners that lose their ability to tighten securely over time may eventually create a path for RF leakage. In most cases, the best method of creating an RF seal with panels/ hatches is with metal-to-metal contact. If a gasket is to be used, the gasket material must be galvanically compatible with both the panel/hatch material and the RF shield material. If galvanic corrosion should occur, especially with the gasket material, RF shielding integrity may be lost rather quickly.

CORRODED END (Anodic)
Magnesium Magnesium Alloys
Zinc Galvanized Steel
Aluminum
Mild Steel Wrought Iron
13% Chromium Stainless Steel
50-50 Lead-Tin Solder
18-8 Stainless Steel (Active) Lead Tin
Nickel (Active)
Brass Bronze Copper
Nickel (Passive)
Monel
18-8 Stainless Steel (Passive)
PROTECTED END (Cathodic or Most Noble)

***Table 1.** Abbreviated Galvanic Series of Metals in Sea Water.*

FILTERS

Filters are used to pass signals, data or power through a shielded enclosure without degrading the performance of the enclosure. However, there are a great many systems for which the filter chosen must be carefully considered and selected. A thorough discussion on the use and selection of filters is a topic for a fully dedicated paper.[1] However, the following information is intended to get the user/buyer started in the right direction when specifying the required filters for an RF shielded enclosure.

Power filters are almost universally required on shielded enclosures. They are available in a variety of power handling capabilities. More importantly, they are available with a variety of attenuation characteristics. It is important to specify a filter which is compatible with the shielding performance of the enclosure system. It is extremely important to make sure that the filters and shielded enclosure are properly grounded prior to applying power to the filters to ensure safety and to meet the U.S. National Electrical Code. The design and operation of typical 2-line power-line filters will allow up to half the applied ac voltage to be present on the surface of the shield and filter. The presence of this ac voltage is a severe shock hazard if the enclosure and filters are not properly grounded. All shielding enclosure manufacturers should be able to answer any questions on proper safety grounding of shielded enclosures.

Signal and data line filters are used for a wide variety of applications, including smoke detectors, fire alarms, telephones, intercoms, test data transmission, test signal measurement, and equipment control. The important information needed by the filter supplier is line impedance (both line-to-line and line-to-ground), baud rate and rise time (for digital signals), maximum current and voltage, allowable system capacitance to ground, and number of lines that require filtering. This information should be available when first contacting a shielded enclosure manufacturer to discuss filter requirements, but if additional information is needed, the manufacturer should know the proper questions to ask and should help choose the correct filter for the application.

WAVEGUIDES-BEYOND-CUTOFF

Waveguides-beyond-cutoff are probably the simplest but most misunderstood components of shielded enclosure systems. Waveguides (as they are most often called) are open penetrations into the shielded enclosures that attenuate frequencies based on the conductivity and geometry of the waveguide. Waveguides are used to permit air, water, fiber optics, gas, or any other nonconducting material to pass into the shielded enclosure. (Water and certain nonmetallic tubes that contain carbon require special attention.) A waveguide should never be used to pass insulated wires or cables through a shielded surface since the wires or cables will act as antennas into the enclosure and defeat the whole purpose of a shielded enclosure.

The two most common waveguide shapes are round (pipes) and rectangular (tubes for light or HVAC use). A cutoff frequency can be calculated for any waveguide. Frequencies below the cutoff frequency are attenuated as they begin to pass through the waveguide, and frequencies above the cutoff frequency will pass through unimpeded. However, the attenuation within the waveguide begins to drop off rapidly for lower frequencies very close to the cutoff frequency. The calculations for determining the lowest possible cutoff frequency of a waveguide [2] are given below.

For rectangular waveguides:
$f_c = c/2a$
where:
f_c = cutoff frequency
c = speed of light, 1.181×10^{10} in/s
a = largest cross-section dimension of waveguide, in inches

For circular waveguides:
$f_c = c/3.412r$
where:
f_c = cutoff frequency
c = speed of light, 1.181×10^{10} in/s
r = radius of circular waveguide, in inches

For other uses:
$f_{c(MHz)} = 300/\lambda_{c(m)}$
or $\lambda_{c(m)} = 300/f_{c(MHz)}$
where:
$f_{c(MHz)}$ = cutoff frequency, in MHz
$\lambda_{c(m)}$ = cutoff wavelength, in meters

The length of the waveguide is also crucial to its performance. A general rule-of-thumb is to make sure the waveguide length is at least four times the diameter for circular waveguides, or four times the longest dimension (either height or width) for rectangular waveguides. People sometimes perform this length calculation and totally ignore the cutoff frequency of the waveguide. They think that the length is all that is important. A simple analogy may clarify the importance of cutoff frequency.

Visualize three different sized balls, each representing a different wavelength. The smallest ball is the smallest wavelength (highest frequency), the middle-sized ball represents the cutoff wavelength or frequency, and the largest ball represents the largest wavelength (lowest frequency). The middle-sized ball just fits through a circular waveguide, the largest ball does not fit in the waveguide and does not pass through, and the smallest ball rolls right through no matter how long the waveguide. This last point is important. Some people think that by increasing the length of the waveguide, the shielding performance will increase. While this is true for frequencies below the cutoff frequency, this will not work at frequencies above the cutoff frequency.

PROPER PENETRATION INSTALLATION

Once all the penetrations have been chosen for the shielded enclosure, it is very important that they are properly installed to ensure the shielding integrity of the enclosure.

Any penetration must be fastened tightly to the surface of the shielded enclosure. Ensuring that the penetrations are tight is important for maintaining electrical conductivity, for creating good RF seals, and for minimizing the possibility of corrosion between the metal surfaces (due to contaminates entering the joint area). If one can visualize a continuous path from the shield, through the contact area of the penetration and throughout the penetration itself, a good RF seal should exist. Loose connections can actually lead to poorer performance of the enclosure than leaving an empty hole in the shielded surface. This is because loose penetrations can act as antennas that re-radiate RF energy into the shielded enclosure. This concept applies to any penetration (nails, bolts, screws, staples, filters, waveguides,

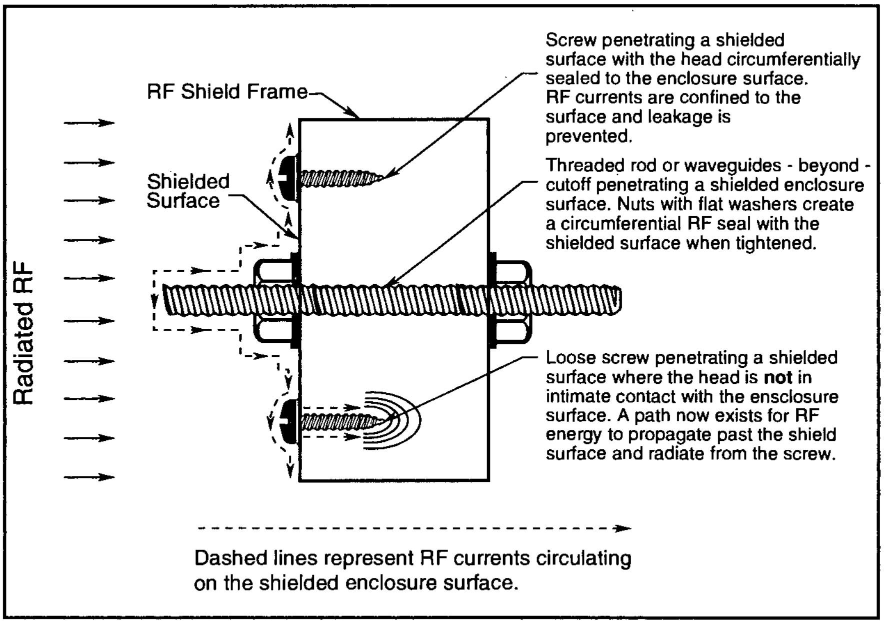

Figure 2. *Effect of Penetrations on the Attenuation of a Shielded Enclosure.*

etc.) on the shielded enclosure. Figure 2 shows how a continuous path can be visualized and how a loose penetration can lead to the degradation of an enclosure's shielding performance.

Metal compatibility between the shielding material and the penetration must also be considered. If poor galvanic compatibility or any other potentially corrosive condition exists, the possibility of galvanic corrosion increases and long-term reliability and performance of the enclosure is compromised. The selection of metals used to construct the shielded enclosure can also affect the initial and long-term performance of the enclosure itself. The seams present in any shielding system must also be considered potential penetration points into the shielded enclosure. These seams, and any gaps that may be present (but should not be), can be viewed as rectangular waveguides-beyond-cutoff. Gaps that result from fastening methods, corrosion or oxidation forming a dielectric break, metal deformation, or inadequate sealing by overlapping shielding material or using RF sealing tape may pose a threat to the integrity of the shielding system performance, especially at higher frequencies. Metal selection plays a key role since the conductivity (clamping pressure required to make a good seal is less with higher conductivity metals), workability (proper field repair in the event of damage) and oxidation (metal stability during shipment and storage) characteristics all combine to influence potential gap characteristics.

The most common penetration problems continue to be cables and wires being passed through a shielded enclosure without using proper filters or connectors. Shielded cable can be used with bulkhead connectors in a panel on the shielded enclosure. In these cases, the outer conductor or shield of the cable essentially becomes an extension of the shielded enclosure itself.

EXAMPLE

In preparation for a large city-wide festival, the city's law enforcement center was equipped with a new radio frequency shielded enclosure to enable the police department to communicate without disturbance from nearby radio towers. The entire system was installed and powered up, but wireless communication was impossible. The local radio stations were overpowering the transmission signals. Has the shielded enclosure failed? No, the source of the problem resides in the 30 improperly installed cable penetrations into the shielded enclosure.

In this example, the insulating jacket was stripped off the coaxial cable to expose the braided wire outer shield. The exposed braid was then bonded to the shielded enclosure surface using a temporary wire mesh RF gasket secured with shielding tape, thereby making the cable a part of the enclosure. This is not a permanent solution! These cables need to be cut, fitted with proper RF connectors and attached to the enclosure using true bulkhead mount feed-through connectors on the penetration panel.

The large number of bulkhead connectors and cable types result in a wide variety of possible combinations involving a broad range of performance capabilities. The price of a cable/bulkhead combination is directly related to the types of connectors and cable, as well as the attenuation required. Wherever possible, the user/buyer should specify to the manufacturer the exact type of connectors required and where the penetration panel should be located on the shielded enclosure. With RF shielded coaxial cables, it is not sufficient to tell the manufacturer that RG-XXX coax will be used; many different connector types are generally available for any given cable, so specificity is needed. Standard, unshielded wires or cables should never be passed through a shielded enclosure without using a filter. Passing unshielded, unfiltered wires or cables through the enclosure surface is a sure-fire way to destroy the integrity of the shielded enclosure. As a rule, a wire or cable with an insulated jacket should never be passed through a shielded enclosure.

If a problem does occur with a penetration, there are many instances where a simple redesign of the penetration method will correct the problem. There should be no problems with penetrations that are provided directly from the supplier, and a shielding supplier should be able to assist with any necessary redesign if the penetration was originally made on the construction site.

CONCLUSION

Proper shielded enclosure penetrations are perhaps the most crucial aspect of understanding shielding from the viewpoint of the end user. The shielding materials chosen, the assembly method used, and the construction of the various penetrations used in the enclosure should be the responsibility of the shielded enclosure supplier. Most problems with penetrations occur after the initial installation and testing of the shielded enclosure. With a basic understanding of penetrations by the end user or after consultation with the shielded enclosure supplier, many of these problems, and downtime, can be avoided.

ACKNOWLEDGMENT

The author wishes to acknowledge and thank Lindgren Enclosure's president, William Curran, Sr., and Lindgren colleagues Dale Svetanoff and Janet O'Neil for their contributions to this article.

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