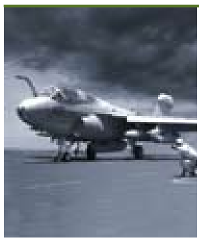

Design Considerations in Building Shielded Enclosures

Designing enclosures to protect against EMI requires following standards, making careful materials selection, and most importantly, backing up theoretical knowledge with first-hand experience.

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As electronic systems become more complex, the need to protect against unwanted electromagnetic interference (EMI) becomes more urgent. Components generating high amounts of electromagnetic radiation can interrupt the overall operation of a system or cause a potential security issue by revealing sensitive data.

Proper system enclosure design can prevent this problem. Unfortunately, such designs are not simple and require consideration of many variables to ensure proper shielding performance. Many times, engineers try to improve the shielding effectiveness of the enclosure by adding an expensive gasket or some other minor design change to solve an issue that appears long after the design process is under way.

Such last minute steps can be avoided by careful analysis and calculations during the initial design process. A robust process consists of following EMI standards, defining chassis goals and EMI parameters, choosing the proper materials and the judicial use of gaskets.

Meeting the Standards

Electromagnetic waves consist of two fields that are perpendicular to each other: electric and magnetic. A magnetic field is induced by a low impedance source. An electric field is induced by a high impedance source. At distances where the wave impedance is equal to that of free space (377 ohms) from the source, electromagnetic waves are called plane waves.

Shielded enclosures are normally designed for emission suppression or to limit susceptibility to electromagnetic

MIL-STD-285	Used for shielded rooms, but a modified version is available that is used for enclosures.
MIL-STD-220	Used for testing AC power lines.
NSA 65-6 NSA 94-106 NSA 73-2A IEEE 299	Standards for testing shielded rooms.
FCC Part 15	Mainly concerned with noise reduction and emissions.
CE Mark	European standard concerned with emissions up to 1 GHz.
SAE-ARP-1705	Used for measuring impedance of a gasket.
MIL-G-83528	Used to measure the shielding effectiveness of a gasket by direct radiation method.
MIL-STD-461	States the requirements for the control of EMI characteristics of sub-systems and equipment.

Table 1 Common EMI standards applied toward designing enclosures. (Based upon The Design of Shielded Enclosures by Louis T. Gnecco.)

radiations. Depending on the equipment that goes into the enclosure and the range of frequencies of the electromagnetic waves, the enclosure needs to meet some performance objectives. There are many possible design and performance objectives in different kinds of environments including shielding effectiveness, galvanic compatibility, longevity of gaskets, easy and less expensive maintenance, easy accessibility to the equipment inside the enclosure, and so on. Most of the time enclosure manufacturers are required to meet a specific standard. Table 1 shows some of the standards common in our industry.

Not all standards are performance standards. Some standards only describe the test procedures that need to be followed in order to measure the shielding effectiveness of the enclosure. Standards like FCC Part 15 actually spell out the cut-off point for electromagnetic radiation at particular frequencies. Following are some of the design steps, considerations and calculations that help in choosing the right type of materials for an enclosure.

Factors in Material Selection

Before getting involved in design and testing, write down the goals. From the list of goals, identify the parameters that need limits or values to be assigned. Parameters might include design for emission suppression, design for limiting susceptibility, the shielding standard to be met, the frequency range of the equipment inside the enclosure, the attenuation levels to be met, the type of environment where the enclosure will be used, or others. Following are some factors that need to be considered in selecting material for the enclosure.

One of the first consideration factors is cost, as most designs must carefully balance system requirements, performance, EMI protection and overall cost. Manufacturability and cost considerations are not the same for all the companies, but sometimes they are the driving factors in designing a shielded enclosure. For example, some companies don't have the right equipment to weld an aluminum enclosure, so material selection can only be done within the domain of that company's capabilities.

If the goal is emission suppression, the enclosure material should have a maximum absorption loss of the emitted field. If the components in the enclosure are to be protected from outside fields, the enclosure material should have a

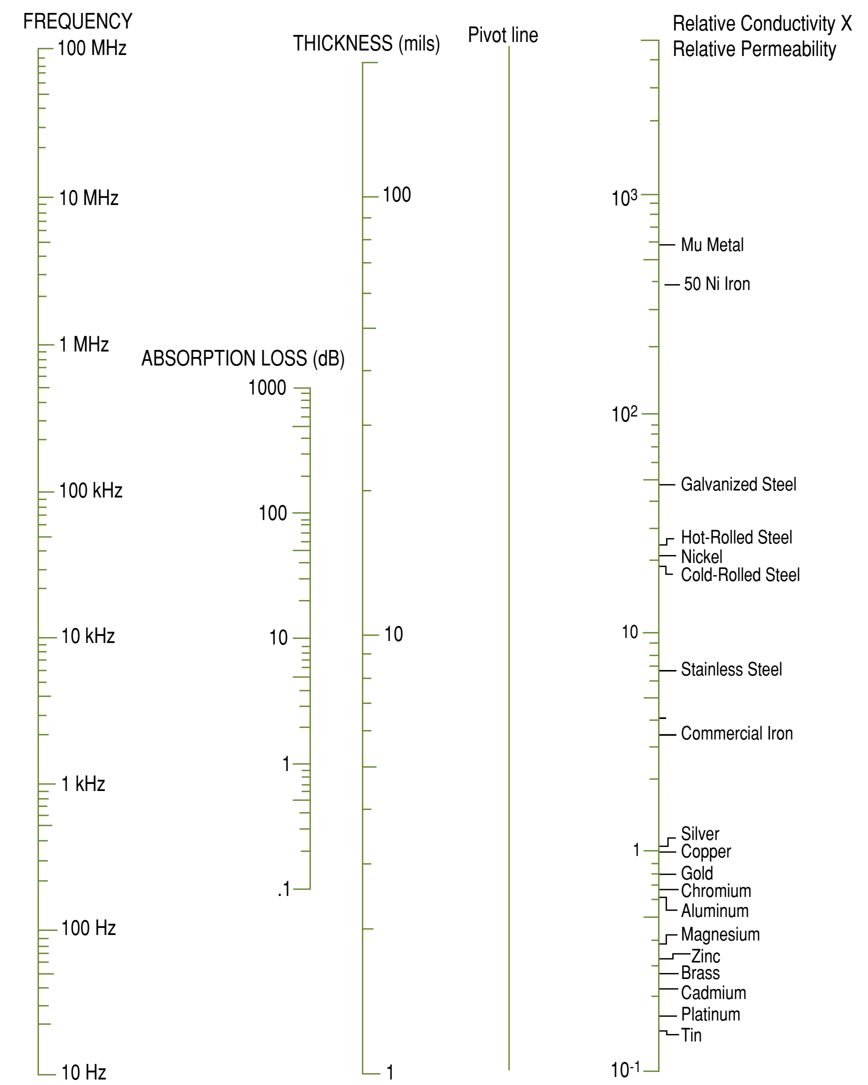

Figure 1

Nomograph to calculate the absorption loss in dB for Electric, Magnetic and Plane Waves for different materials at different frequencies. To determine the absorption loss, draw a straight line connecting the thickness of the material and the material itself. Draw another line connecting the intersection point of the first line and the pivot line to the frequency of the electromagnetic signal. The point where the second line crosses the absorption loss scale is the absorption loss in dB.

(Reference: EMI Shielding Theory by Chomerics, www.chomerics.com).

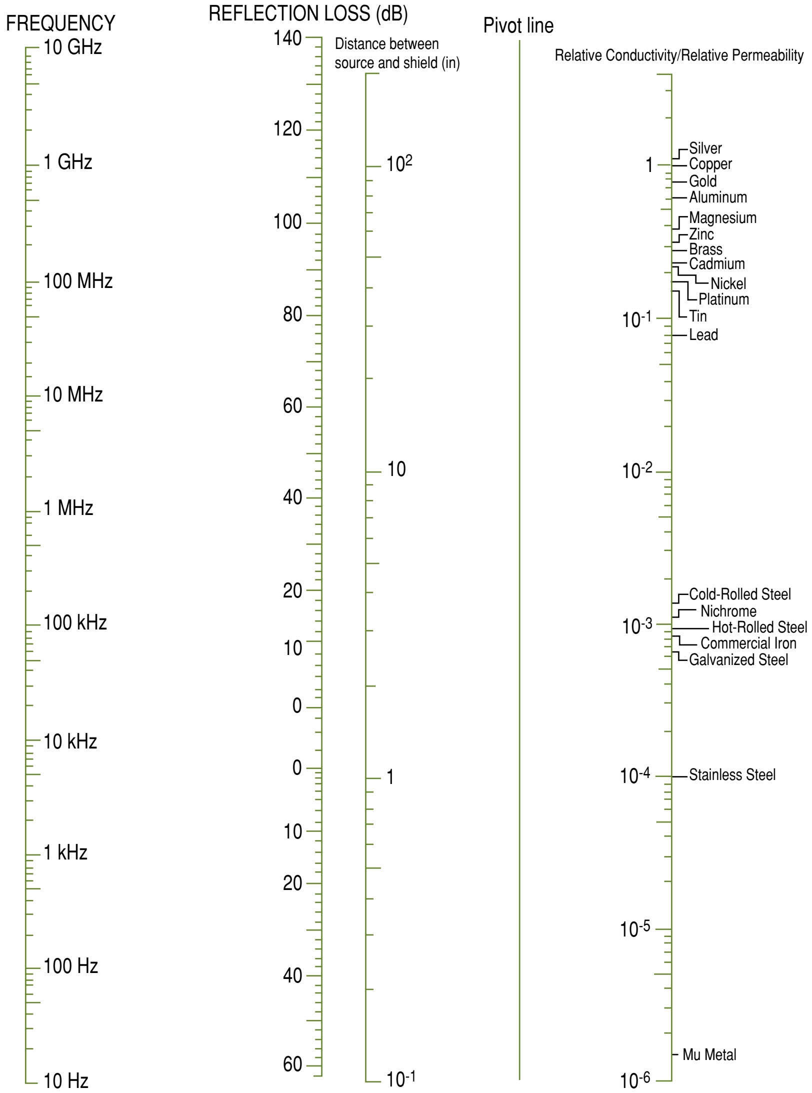

Figure 2

Nomograph to calculate the Reflection loss in dB for Magnetic Waves for different materials at different frequencies

(Reference: EMI Shielding Theory by Chromerics, www.chomerics.com).

maximum combination of absorption and reflection losses.

The absorption loss is the same for all electromagnetic waves. It depends upon the material thickness, relative permeability of material to free space, relative conductivity of the material with reference to copper and the frequency of the incident wave. Figure 1 shows a sample nomograph to determine the absorption loss.

To determine the absorption loss, draw a straight line connecting the thickness of the material and the material itself. Draw another line connecting the intersection point of the first line and the pivot line to the frequency of the electromagnetic signal. The point where the second line crosses the absorption loss scale is the absorption loss in dB.

On the other hand, the reflection loss is different for electric, magnetic and plane waves. It depends on the distance of the source to the material, relative conductivity of the material with reference to copper and the frequency of the incident wave. Figure 2 shows a sample nomograph to determine the magnetic reflection loss.

To determine magnetic field reflection loss, draw a straight line connecting the distance between source and shield to the material itself. Draw another line connecting the intersection point of the first line and the pivot line to the frequency of the electromagnetic signal. The point where the second line crosses the reflection loss scale is the magnetic field reflection loss in dB. Similar nomographs are available for determining the reflection losses for magnetic and plane waves.

The overall shielding effectiveness for emission suppression and susceptibility of the enclosure material can be closely determined by the following equations. Shielding effectiveness of the enclosure material used for emission suppression is approximately equal to the absorption loss. Shielding effectiveness of the enclosure material used for limiting susceptibility is approximately equal to the sum of absorption and the appropriate reflection loss depending on the type of incident wave.

$$(S.E_{dB})_{EmissionSuppression} \cong A$$

$$(S.E_{dB})_{Susceptibility} \cong A + R(appropriate)$$

Conductivity and Chassis Openings

Another important factor in selecting material for a shielded enclosure is the conductivity and continuity of the enclosure. A perfectly welded closed box would be ideal. However, the user needs to have easy access inside the enclosure to mount equipment. So it is common to have doors, side panels and I/O panel openings. Most of the time shielding effectiveness depends on how the electromagnetic waves are transmitted across the boundaries of these openings.

These openings cause a major prob-

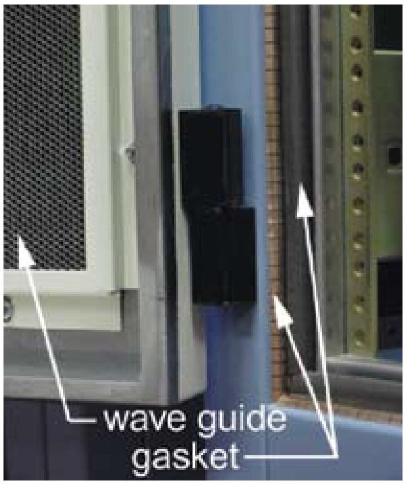

Figure 3

Equipto Electronics R5 series cabinet corner showing the double gasketed configuration and the wave-guide used to reduce EMI.

lem in the design of shielded enclosures because a commercial enclosure cannot be completely sealed. The most common openings in an enclosure are doors, side panels, I/O panels, ventilation ports and cables that ingress/egress. All openings in an enclosure will act as slot radiators of electromagnetic waves unless continuity is restored.

Any time two surfaces meet in a shielded enclosure the possibility of emissions exists. The doors and panels of an enclosure do not have perfectly flat surfaces, and gaps created by them will act as slot radiators. To eliminate this, mating surfaces should be extremely rigid so when compressed against each other they will not leave any gaps. The gaps can also be filled with conductive material to maintain continuity.

Using a highly conductive material for the enclosure and the gasket will help increase shielding effectiveness. Conductivity is normally expressed in (milliohm-in)$^{-1}$ and is the inverse of Resistivity. To deal with the imperfections inherent in commercial chassis design, gaskets are used to help maintain electrical continuity across enclosure openings.

Conductivity = 1/Resistivity

Maintaining Continuity: Gaskets

Gasketing is used to help maintain electrical continuity across enclosure openings. The gasket material should be galvanically compatible with the material of the enclosure. MIL-STD-889 states the rules for having dissimilar metals in contact with each other. When the gasket material is dissimilar from the enclosure metal, suitable protection against galvanic corrosion must be applied.

Care should be taken to protect the anodic member with proper electrical insulation of the joint or by excluding the electrolyte if it is feasible. Table 2 shows the standard potentials of common metals used for enclosures and gaskets. Although potentials difference in dissimilar metals is not the only reason for galvanic corrosion, it is better to select materials whose potentials are close to each other.

Most chassis applications involve two types of closure forces on the gasket: compression and shear. When gaskets are installed under a flat cover panel in a compression configuration, pressure is used to preserve the shielding effectiveness of the seam. The alternative is a shear application where a flange or a channel arrangement shears against a gasket before the enclosure is closed to accomplish shielding.

Gaskets are mounted to flanges in different ways. The most common method is to use adhesives or mechanical fasteners. There are two types of adhesives: conductive and non-conductive. Although non-conductive is the most common, conductive adhesives may give better shielding performance.

The purpose of the gasket is to improve conductivity in order to reduce emissions. But all gaskets are porous to some extent, and the porous spots in the gasket can act as slot radiators at high frequencies. It is important to calculate the shielding effectiveness of the gasket given its porosity. In addition, most

Metal	Electrode Potential
Mg^{2+}	-2.37
$A1^{3+}$	-1.67
Zn^{2+}	-0.76
Cr^{3+}	-0.74
Fe^{2+}	-0.44
Cd^{2+}	-0.40
Sn^{2+}	-0.14
Pb^{2+}	-0.13
H^{+}	0.00
Cu^{2+}	+0.34
Ag^{+}	+0.80
Hg^{2+}	+0.85
Pt^{2+}	+1.2
Au^{+}	+1.69

Table 2 Standard Electrode Potentials of commonly used metals.
(Reference: MIL-STD-889)

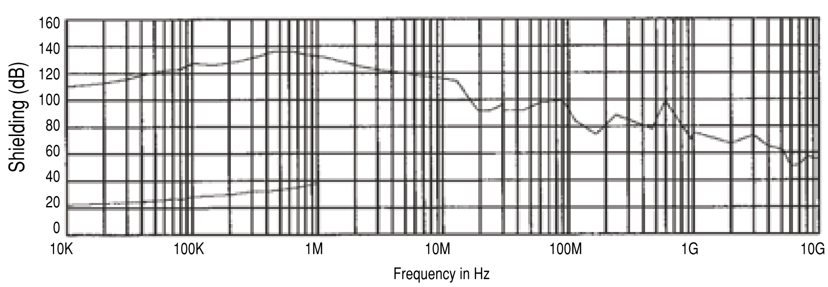

Figure 4

Shielding Effectiveness vs. Frequency graph for Equipto Electronics R5 Cabinet.

Figure 5

Equipto Electronics FCC cabinet corner showing the metalized door and the gasket configuration.

gaskets have a limited lifetime, normally defined in cycles for a particular compression limit. Based on the usage of the particular opening, the longevity of the gasket can be determined and an appropriate maintenance or replacement schedule can be planned.

Other Chassis Considerations

Some enclosures have natural or forced convection cooling which require an inlet and an exhaust for air. In this kind of situation an arrangement needs to be made allowing air to come in and go out, but not the electromagnetic waves. The answer is a wave-guide. A wave-guide is nothing more than a tube made long enough such that it cuts off electromagnetic waves and acts like a brick wall. The rule of thumb regarding length of the wave-guide is that it should be at least five times its diameter. Figure 3 shows a wave-guide attached to the bottom of an enclosure door.

Sometimes cables and connectors are considered part of the enclosure and must also be shielded. The cables carrying power in and out of the enclosure radiate some electromagnetic waves. Proper insulating covers for the cables and their associated connectors should be used to eliminate any chance of cable-based EMI radiation.

Finally, after a prototype enclosure is built, one way to find any discontinuities prior to testing to a particular standard is by using the principle of skin effect. This requires using special equipment to determine the surface resistivity at different points (recall that resistivity is the inverse of conductivity; maintaining conductivity minimizes EMI). Afterwards, the enclosure should be taken to a laboratory to be tested according to the standard(s) specified by the design specifications. For some standards the customer's actual equipment needs to be present in the enclosure and operating at its maximum potential in order to determine the overall system-level pass/fail criteria.

Sample Designs

Equipto Electronics Corporation has over 15 years experience in designing shielded enclosures for a variety of applications, from military to commercial-based FCC shielding. All the aforementioned criteria are taken into account while designing the enclosures. Following are some sample designs and their shielding capabilities.

Referring back to Figure 3, it shows the R5 series where the enclosure material is stainless steel. The double gasketed design gives good shielding effectiveness at high-end frequencies (60 dB at 10 GHz as shown in Figure 4). Figure 5 shows a cabinet used for low-end shielding applications with the enclosure base material using 1010 cold rolled steel. The cabinet is metalized at places where the continuity needs to be maintained between the door and the gasket. Figure 6 shows the shielding effectiveness. ▮▮

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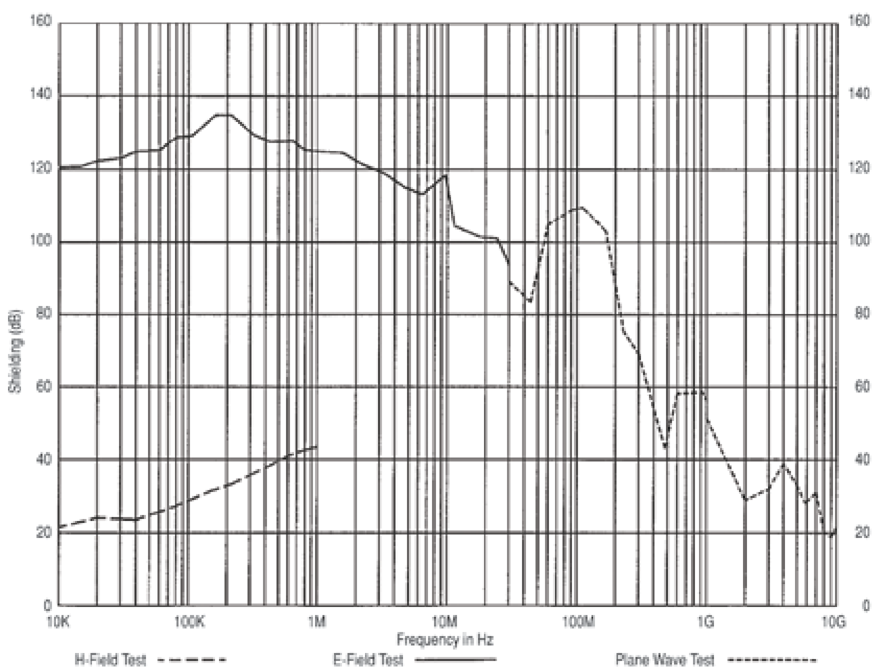

Figure 6

Shielding Effectiveness vs. Frequency graph for Equipto Electronics FCC cabinet.