EMI shielding strategies for design and attachment options

Electromagnetic compatibility (EMC) is defined as the "ability of a device, equipment or system to function satisfactorily in its environment without introducing intolerable electromagnetic disturbances to anything in that environment (IEEE C63.12-1987)." For equipment designed for radio transmission as well as reception, EMC is maintained partially by the assignment and enforcement of discrete frequency bands. However, as has been shown through many anecdotal incidents, EMC has not always been achieved. For example, the interference between a notebook PC and testing equipment, printer and desktop PC, or a cellphone and medical devices is indicative of interference at higher frequencies. This problem is recognized as electromagnetic interference (EMI).

The operation of all electrical and electronic devices involves the changing of voltage or current levels either intermittently or continuously, sometimes at fast rates. This results in the development of electromagnetic energy at discrete frequencies and across a band of frequencies. The offending circuit radiates this energy into the surrounding environment.

EMI has two paths to follow when leaving or entering an electronic circuit: a radiated path and a conducted path. The radiated signal will leak out of gaps, slots, openings and other discontinuities that may be present in the housing structure. Conducted signals are coupled onto the power, signal and control lines leaving the housing where they are free to radiate in open space, causing interference.

Most EMI containment is accomplished by a combination of case shielding and aperture shielding. In most commercial application, a few simple rules can assist in EMI shielding: Reduce interference at the source, isolate offending circuits by shielding, filtering or grounding and increase the immunity of susceptible circuits.

Suppression, isolation and desensitization should be the goals of any circuit designer and should be implemented early in the design stage.

The use of shielding materials is an effective way for the design engineer to reduce EMI. Many types of housing or case shielding materials are used today, from metal cans, sheets and foil tapes to spray coatings and plating (such as conductive paint and zinc wire spray) to conductive fabrics and tapes.

Once the designer has selected a material for the electronic housing or case either metal or plastic with a conductive coating, the selection of gasketing can be addressed.

Shielding effectiveness of metal barriers

Shielding effectiveness (SE) is used to evaluate the suitability of a shield. Expressed in terms of decibels, the formula is:

$$SE_{dB} = A + R + B$$

Where:
A= Absorption loss (dB)
R= Reflection loss (dB)
B= Correction factor (dB) (for multiple reflections in thin shields)

For example, a basic shield might reduce the emergent field to one-tenth of the initial strength, i.e., an SE of 20dB. A demanding application might require a reduction to one-hundred-thousandth of the initial field strength, or an SE of 100dB.

Absorption loss is the amount of energy strength dissipated as the wave travels through the shield. The formula for absorption loss is stated as:

$$A_{dB} = 1.314(f * s * \mu)^{1/2} * t$$

Where:
f = frequency (MHz)
μ = permeability relative to copper
σ =conductivity relative to copper
t =shield thickness in centimeters

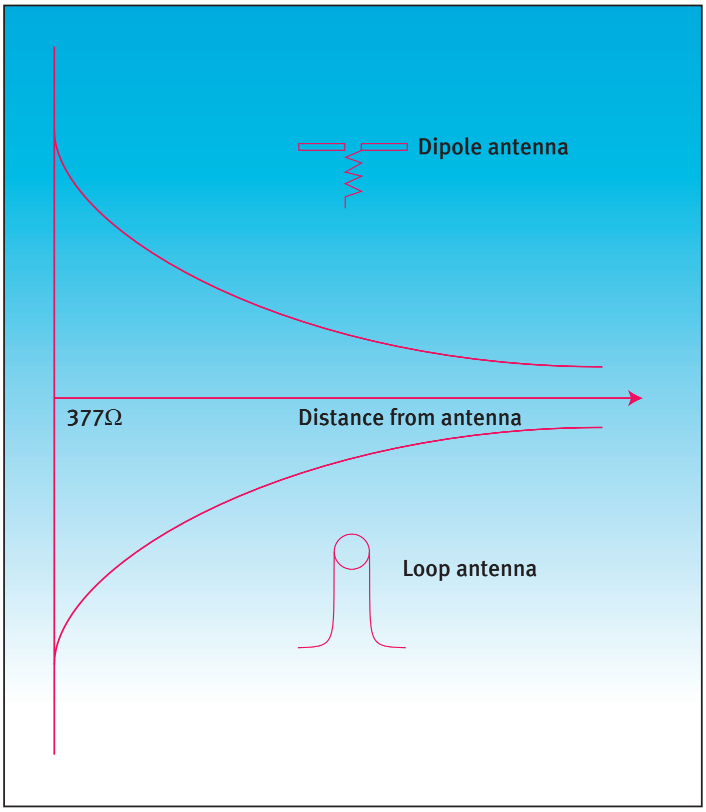

Figure: For rod or straight wire antenna, reflection loss depends on the nature of the source wave and the distance from the source.

Reflection loss (near field) depends on the nature of the source of the wave and the distance from that source. For a rod or straight wire antenna, the wave impedance is higher near the source and falls as distance from the source is increased, but levels out at the plane wave impedance (377).

In contrast, if the source is a small wire loop, the field is predominately magnetic, and the wave impedance is low near the source. The impedance increases with distance away from the source, but levels at 377 at distances beyond approximately one-sixth of a wavelength.

Reflection loss varies according to the ratio of wave to shield impedance, so that it will depend not only on the type of wave, but also on how far the shield is from the source. This is the situation for small, shielded equipment.

Reflection loss in the near field can be calculated as:

$$R\ (Electric)_{dB} = 321.8 - (20*\log r) - (30*\log f) - [10*\log(\mu/\sigma)]$$

$$R\ (Magnetic)_{dB} = 14.6 + (20*\log r) + (10*\log f) + [10*\log(\mu/\sigma)]$$

Where:
r = distance from source to shield
f = frequency (MHz)
μ = permeability relative to copper
σ = conductivity relative to copper

The final component of the SE equation is the calculation of the correction factor, B. The formula is:

$$B_{dB} = 20*\log_{10}[-\exp(-2t/\sigma)]$$

This normally is calculated only for magnetic near-field conditions and only if the absorption loss is less than 10dB. Re-reflection within the barrier, due to the absence of significant absorption, results in increased energy passing through the second face of the barrier. Thus the correction factor is a negative, indicating a reduced shielding effectiveness.

The requirement for high SE for very low frequencies can be met only by high-permeability products such as metal and iron. As frequency increases, the permeability of these materials decreases. Permeability can also be reduced if the initial magnetic field is strong, or by the mechanical process needed to fabricate the shield into the required shape. For all these reasons, the selection process of high-permeability materials for shielding is complex, and EMI shielding suppliers and consultants are often used as resources.

For higher-frequency electric fields, good SE can be achieved by the use of thin metal shielding as the case material or lining, but the assumption is that the shield is continuous and fully surrounds the sensitive items without gaps or apertures (a Faraday cage). In reality, it is rarely possible to construct a shield without some type of joint or aperture. The shielding may have to be fabricated in pieces, and therefore it may have seams that must be joined. Or it is usually necessary to penetrate the shield for providing access to cards or to mount components.

The difficulty in designing a case structure is that openings are unavoidable in manufacturing, yet they are needed for operation of the device. Seams needed for manufacturing, access panels and doors, ventilation openings, windows for outside monitoring and panel mounted components all penetrate the shielded housing, which effectively lowers the shielding performance of the case. Although slots and gaps are unavoidable, paying attention to the slot length as it relates to the wavelength of the operating frequency of the circuit can be beneficial in shielding design.

The wavelength for any frequency is:

Wavelength $(\lambda)_m$ = speed of light (C)/frequency (Hz)

At a gap length of $^1/_2$ the wavelength (the cut-off frequency), the RF wave starts to attenuate at a given rate of 20dB per decade (1/10 of the cut-off frequency) or 6dB per octave (1/2 of the cut-off frequency). The highest frequency of RF emission is usually the most critical because it has the smallest wavelength. When considering the highest frequency, it is important to take into account any harmonics that may be present. It is usually practical to consider only the first and second harmonics.

Once the frequency at which an enclosure is radiating RF energy is known, and at what level, it is possible to calculate the maximum permitted gap, slot of hole in an enclosure. For example, if 26dB of attenuation is required, and the wavelength at 1GHz is 300mm, the gap or slot will start to attenuate at 150mm. A frequency of 1GHz will start to be attenuated by any gap smaller than 150mm. Therefore, at 1GHz, the gap should be no larger than: 15mm ($1/10^{th}$) for 20dB of attenuation, 7.5mm (1/2 above) for 26dB of attenuation, and 3.75mm (1/2 above) for 32dB of attenuation.

A suitable conductive gasket can be used to achieve this level of attenuation by limiting the gap to a required minimum size.

Frequency (f)	Wavelength (l)	Wavelength c/o (1/21)	-6dB slot	-20dB slot	-26dB slot
50MHz	6.00m	3.00m	1.5m	300mm	150mm
100MHz	3.00m	1.50m	0.75m	150mm	750mm
200MHz	1.50m	0.75m	37.5m	75mm	37mm
400MHz	0.75m	37cm	18.75cm	37mm	19mm
600MHz	0.50m	25cm	12.5cm	25mm	12.5mm
800MHz	37.5cm	19cm	9.5cm	19mm	9.5mm
1GHz	30.0cm	15cm	7.5cm	15mm	7.5mm
2GHz	15.0cm	7.5cm	3.75cm	7.5mm	3.7mm
3GHz	10.0cm	5.0cm	2.5cm	5.0cmm	2.5cmm

Table: Operating frequencies and the corresponding slot or gap sizes for 6dB, 20dB or 26dB attenuation.

Shielding design challenges

Any decrease in the conductivity of the shielded case, due to joints or apertures, will reduce its SE. Note that the attenuation for frequencies below the cut-off depends only on the ratio of length to diameter. For example, attenuation of 100dB can be obtained for a length-to-diameter ratio of 3. It is possible to use the waveguide properties of small holes in thick shields where penetration is necessary. An alternative method of achieving a good length-to-diameter ratio is to attach a small metallid add-on shield, such as a gasket with appropriate dimensions. This theory and its extension to multiple apertures forms the design basis for perforated shielded enclosures.

Multiple holes in thin barriers: An example of a multiple-hole application is the ventilation holes in a sheet metal part. This is an important consideration when the holes are spaced closely together. There is a formula that calculates SE for these cases:

$$SE = [20*\log_{10} (f_{C/O}/\sigma)] - 10*\log_{10} n$$

Where:
f = Frequency of interest
$f_{C/O}$ = Frequency of cut-off
n = number of holes

Note that the formula is applicable when the distance between holes is less than fi-hole diameter. This formula is also good for correlating the effectiveness of woven metal meshes.

Welding, brazing or soldering are the obvious choices for joints between sheets that are permanently secured. The metal faces to be joined must be clean to promote complete filling of the joint with conductive metal. Screws or rivets are less satisfactory methods to secure the joints, because permanent low-impedance contact along the joints between the fasteners is difficult to maintain.

The function of the conductive gasket is to reduce any slots, holes or gaps along seams and mating surfaces so that RF energy cannot be radiated. EMI gaskets are a conductive medium to fill apertures in the case and provide a continuous, low-impedance joint. Generally, EMI gaskets are designed to provide a flexible connection between two electrical conductors, enabling currents in each conductor to pass through to the other.

An EMI gasket to seal opening is selected by a number of performance criteria:

a. Shielding effectiveness over the specified frequency range
b. Mounting methods and closure forces
c. Galvanic compatibility with the housing structure and corrosion resistance to the outside environment
d. Operating temperature range
e. Cost

An important factor to consider is compression, which yields a high conductivity level between gasket and flanges. Poor conductivity between the opposing flanges through the gasket will result in lower shielding effectiveness. A total lack of contact along any part of the joint results in a thin gap capable of acting as a slot antenna. Such an antenna transmits energy at wavelengths shorter than about four times the gap length.

The first step toward ensuring conductivity is to make sure the flange faces are smooth, clean and treated as necessary to provide conductive surfaces. These surfaces must be masked prior to printing. It is essential that the shielding gasket material is continuously well-bonded to the appropriate flange. The compressibility of the conductive gasket is intended to compensate for any flange irregularity.

All gaskets have a minimum contact resistance needed to work effectively. The designer can lower the contact resistance of many gaskets by increasing the compression of the gasket. This, of course, increases the closure force and raises the chances of bowing in the case. Most gaskets work effectively with between 30 percent and 70 percent compression of their free-standing height. Thus, within the recommended minimum contact, pressure between the two facing low spots is nevertheless enough to ensure adequate conductivity between the gasket and flanges.

On the other hand, gasket compression should not have to be so high that it induces unnatural compression set, which can lead to gasket contact failure and possible electromagnetic leakage. Flange separation requirements are essential to control gasket compression to the range recommended by the gasket manufacturer. Included in that design is the need to make sure the flanges are sufficiently rigid so as not to bow significantly between flange fasteners. In some cases, additional fasteners may be needed to prevent bowing in the case structure.

Compression set is an important characteristic for joints that may be cycled, such as doors or access panels. If a gasket is prone to take a compression set, then the shielding performance will decrease with each cycle of the door panel. The gasket will require higher compression forces to achieve the shielding levels equivalent to a new gasket. In most applications, this is not possible, and a long-lasting EMI solution is needed.

If the case or flange is plastic with a conductive coating, the addition of an EMI gasket should not pose too many problems. However, the designer must consider the abrasion that many gaskets will impart on a conductive surface. Metal gaskets generally tend to be more abrasive on the coated surface. This will reduce the shielding effectiveness of the gasketed joint over time and could pose problems for the manufacturer down the road.

If the case or flange structure is metal, a gasket can be added by masking off flange surfaces before finishing materials are applied. The use of a conductive mask and peel tape works well. If the tape is used on both sides of a mating flange, the EMI gasket can be attached by mechanical fasteners, such as a "C-fold" gasket with integral plastic rivets, or pressure-sensitive adhesive (PSA). The gasket is mounted to one side of the flange, which completes the EMI shielded joint.

Gasket and attachment type

A wide array of shielding and gasket products is available. It includes beryllium-copper fingers, wire mesh with and without an elastomeric core, expanded metal and oriented wire embedded in an elastomer, conductive elastomers and metallized fabric-clad urethane foam gaskets. Most shielding manufacturers supply estimates of SE that can be achieved with the various gaskets. Be aware that SE is a relative function that depends on aperture, the size of gasket, compression of the gasket and material composition. Gaskets come in a variety of shapes to fit specific applications including wiping, sliding and hinged actions. Today, many gaskets are self-adhesive or use a fixing system that is integral to the gasket itself, such as press-in inserts, pin-in-place or barbs.

Of all the gasket types, fabric-clad-foam gaskets are the latest and some of the most versatile products in the market. These gaskets can be formed in a variety of shapes and thickness from 0.5mm on up and can be reduced to meet UL flame ratings as well as environmental sealing standards. A new type of gasket, an environmental/EMI hybrid gasket, can eliminate the need for separate single-purpose seals, reducing the cost and complexity of the designer's enclosure. These gaskets combine an outer UV-stabilized outer cladding that resists moisture, wind and cleaning agents with a metallized, highly conductive interior cladding. Another recent innovation, EMI gaskets with an integral plastic clip, is an attractive alternative to traditional stamped metal gaskets and provides savings in weight, assembly time and cost.

Shielding is always necessary in an enclosure because of the slots and gaps inherent in the structure. Some basic guidelines determine the amount of shielding necessary. There are, however, differences between theory and what actually happens. For example, in calculating the size and spacing of gaskets versus frequency, signal intensity must also be considered. This could be necessary in instances where multiple processors are used within the same enclosure. Surface preparation and flange design provide the keys to long-term shielding for EMC.

By Shane Hudak
EMI Product Manager
Schlegel Systems Inc.
E-mail: emiproducts@schlegel.com