

The Basic Principles of Shielding

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Abstract

Today's electrical and electronic devices are subject to mandatory EMC requirements throughout the world. Many devices operate at high frequencies and are very small. They are placed in nonconductive plastic cases providing no shielding. Essentially, all these devices cannot meet these mandatory requirements or they may cause interference to other devices or receive interference causing susceptibility problems without a proper program of EMI control. This program consists of identifying the "suspect" components and circuits that may cause or be susceptible to EMI. This is completed early on in the program to allow for an efficient design in keeping the cost of dealing with EMI as low as possible. A complete EMC program consists of proper filtering grounding and shielding. This article will discuss the latter, but the other factors cannot and will not be ignored or given insufficient priority.

The article will look into what EMI is and how to design to control it using shielding in conjunction with proper design. Various shielding materials and their uses will be discussed.

What is EMI?

EMI (Electromagnetic Interference) is a process by which disruptive electromagnetic energy is transmitted from one electronic device to another via radiated or conducted paths, or both. In electronic components, devices and systems, EMI can adversely affect their performance. The goal of all electronic designers is to achieve EMC (Electromagnetic Compatibility) in their designs. Not only to assure proper operation, but to meet the various mandatory EMC requirements imposed by legislation around the world.

EMI can simply be a nuisance such as static on a radio, or it can manifest itself as dangerous problems such as interference with aircraft control systems, automotive safety systems, or medical devices.

Remember, it is always more efficient and less expensive to deal with EMI at its source. The farther away you get from the source or the farther down the design chain you are, the more difficult and expensive it is to mitigate the problems.

The Problems

The trend in today's electronic devices is faster, smaller, and digital rather than analog. Most equipment of today contains digital circuits. Today's digital designer must create a circuit board that has the lowest possible EMI, combined with the highest possible operating and processing speeds; generally keeping it as small as possible. Design of the printed circuit board (PCB) is the most critical EMC influencing factor for any system, since virtually all active devices are located on the board. It is the changing current (accelerating electron movement) produced by the active devices that result in EMI.

The faster the digital speed, the greater the required circuit bandwidth, and the more difficult it is to control both radiated emissions and susceptibility. In this regard, it is useful to first consider the relationship between operating frequencies and radiated emissions. The fundamental frequency for each active device and its associated circuitry must be considered. But the harmonics of these devices can be 10 to 100 times greater in frequency than their fundamentals. The odd harmonics, 3, 5, 7, 9, etc. times the fundamental, are especially troublesome. As a result, increases in EMI with the evolution from analog to high speed digital circuits have been dramatic. RF energy levels at the higher frequency harmonics of analog devices are negligible. The harmonics of an ideal Gaussian wave shape, albeit more a mathematical concept than a practical reality, fall off very quickly at the higher frequencies.

A cosine-squared wave shape, approximately equivalent to that produced by a linear power supply or other analog continuous wave (CW) source having some harmonic distortion, exhibits high frequency harmonic amplitude falloff of 60 dB per decade of frequency. Moving from analog circuits to low speed digital circuits has no significant effect at the fundamentals level, but RF amplitudes increase at the higher harmonic frequencies because falloff occurs at 40 dB per decade rather than 60 dB. In moving from low speed to high speed digital operation, high frequency radio frequency (RF) levels increase even more as harmonics fall off at just 20 dB rather than 40 dB per decade. Given today's extremely fast rise times, one can see that the high frequency harmonics are much greater than in the past.

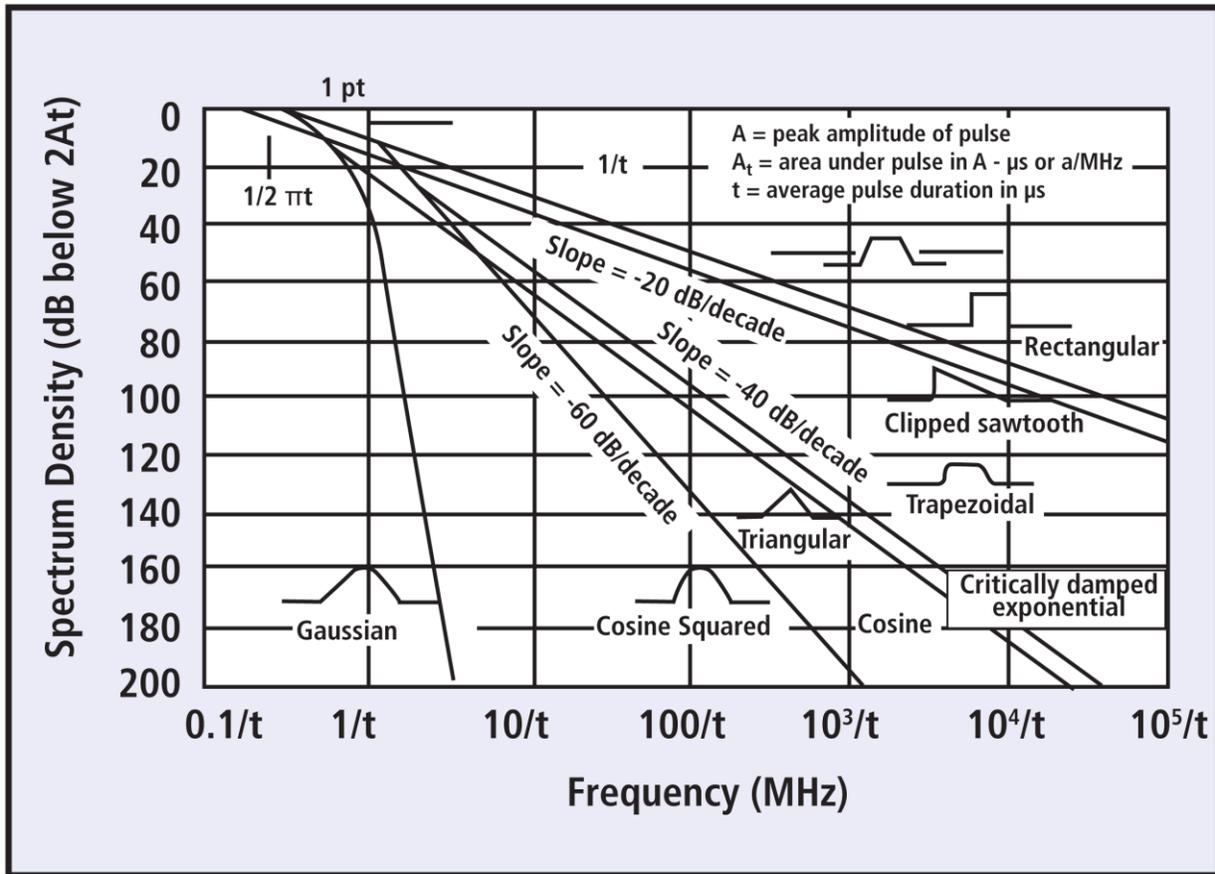


Figure 1. This chart compares the EMI characteristics of analog, low speed digital, and high speed digital logic.

Some Simplified Math

Radiation emitted by electronic devices results from both differential and common mode currents. In semiconductor devices, differential mode currents flowing synchronously through both signal and power distribution loops produce time variant electromagnetic fields which may be propagated along a conducting medium or by radiation through space. On simple one- or two-layer PCBs, loops are formed by the digital signals being transferred from one device to another that return by means of the power distribution traces. Loops are also created by PCB traces that supply power to these devices. Common mode radiation results from voltage drops in the system that create common mode potential with respect to ground. In addition, parasitic capacitive coupling, a hard-to-control phenomenon that occurs between all conductive materials, makes external cables act like antennas.

The radiated EMI levels created by the active circuit loops on the board are proportional to the square of the highest created frequencies. These frequencies are

determined by the data pulse rise time, and contain significant RF energy at typically 10 to 15 times the operating speed. The rise time also determines the circuit bandwidth. For small circuits whose dimensions are less than the dimensions at resonance, the plane wave emission levels generated by these loops may be calculated by the

following equation:

$$E = 1.3 AIF^2 / (DS)$$

Where:

- E = microvolts / meter
- A = radiating loop area in cm²
- I = current in amps
- F = frequency in MHz
- D = measurement distance in meters
- S = shielding effectiveness ratio

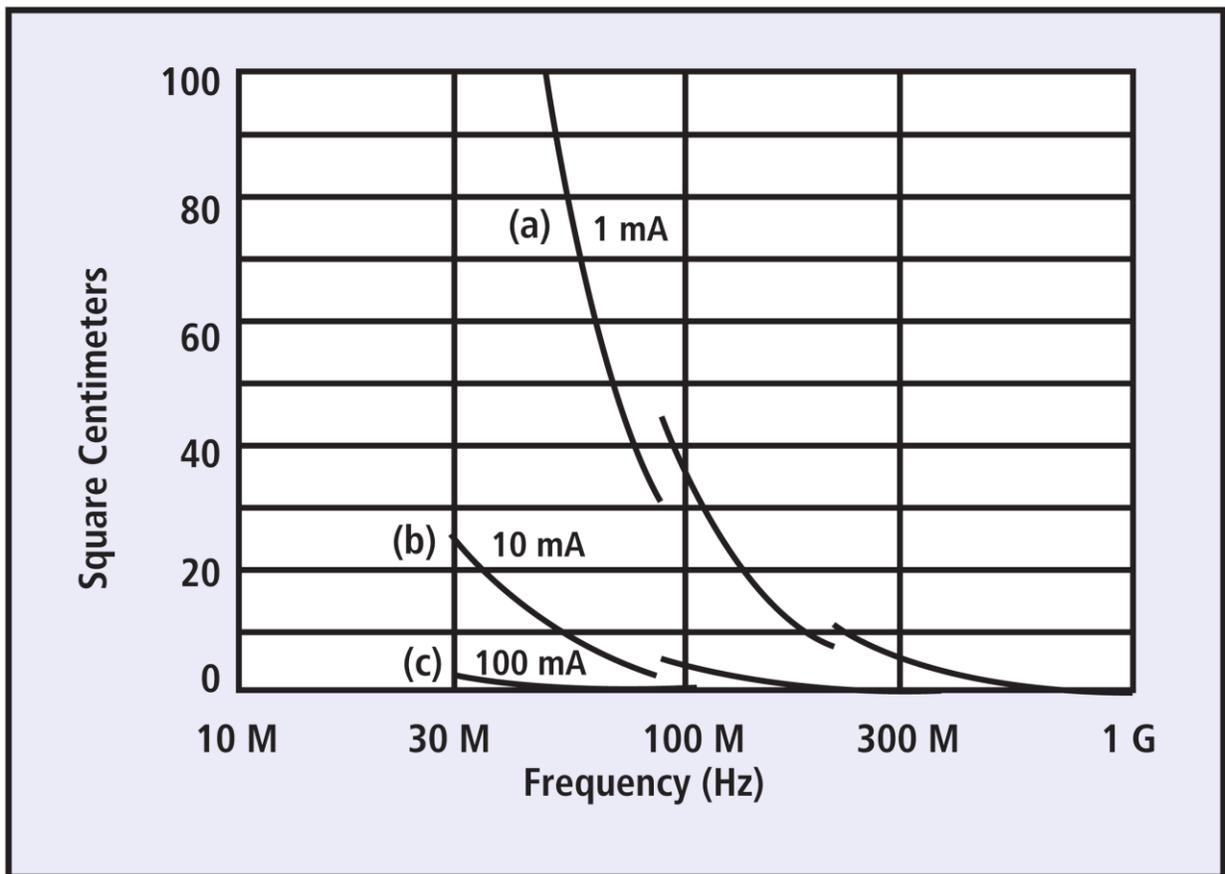


Figure 2. This chart correlates maximum loop area in square centimeters and the FCC Part 15B(B) limit for radiated RF at 1 mA (a), 10 mA (b), and 100 mA (c) of current. The measurement distance is 3 meters.

Radiated susceptibility, on the other hand, increases linearly with the offending frequency. For small circuits whose dimensions are less than the dimensions at

resonance, the maximum voltage induced into the circuit by a narrowband incident plane wave within its passband is given by:

$$V_i = 2\pi\epsilon AB_{pb}/\lambda S$$

Where:

- V_i = volts induced into the loop
- ϵ = field strength of incident wave in V/m
- A = circuit capture area in square meters
- B_{pb} = passband bandwidth response
- λ = wavelength in meters of incident wave
- S = shielding effectiveness ratio

Outside of the circuit passband, narrowband signal effects will be determined by the circuit attenuation response. Broadband signal effects will be determined by both the attenuation response and the circuit bandwidth. Of course, circuit attenuation can be increased with the installation of shielding.

By examining the two formulae, we can draw some conclusions. For emissions, the field strength is controlled by the specification that must be met or by the highest allowable emissions for the environment in which the device must operate. The distance is set either by the specification, such as three meters for the FCC part 15 requirements, or by the distance from the source to the receptor of the radiated energy. Generally, these factors are beyond the control of the device designer. Of course, 1.3 is a constant and cannot be changed. We now come to factors that the designer can control.

We see that frequency is squared; therefore, emissions increase exponentially as frequency increases. This explains why high frequency devices and circuits are the most troublesome. Emissions also increase linearly with current. Therefore, one must place high frequency and high current circuits at the top of the EMI suspect list. However, emissions also increase with loop area. By far, large uncontrolled and even unknown loop areas have proven to be the biggest reason for emission failures.

We see that the designer must control loop area once the frequency and current have been established. Especially for high frequency and high current circuits, the loop area must be kept to a minimum. This must be done at the beginning of the design. It is far too difficult and expensive to do this once the PCBs are designed, and even manufactured.

Once the frequency, current, and loop area have been set, and the circuit does not meet its emissions requirements, we now see that there is only one factor left in the equation that can bring the circuit into compliance: shielding!

For susceptibility, we see that the same good design practices as for emissions apply. In this case, the voltage induced into the circuit is a function of field strength which is controlled either by the specification or the circuit's environment. The bandpass

bandwidth response is controlled by the choice of components and other circuit design components such as the choice of the active components, and inactive components such as ferrite chip beads or filters. Again, we see that loop area is a factor. The larger the loop area, the more efficient the pickup of the circuit and generally, the more susceptible it will be. Finally, we see again that once the circuit design is finalized, if it is still susceptible, the only factor left in the formula is shielding!

Shielding

Shielding is a conductive barrier enveloping an electrical circuit to provide isolation. The “ideal” shield would be a continuous conductive box of sufficient thickness, with no openings. Shielding deals almost exclusively with radiated energies. Shielding Effectiveness (SE) is the ration of the RF energy on one side of the shield to the RF energy on the other side of the shield expressed in decibels (dB).

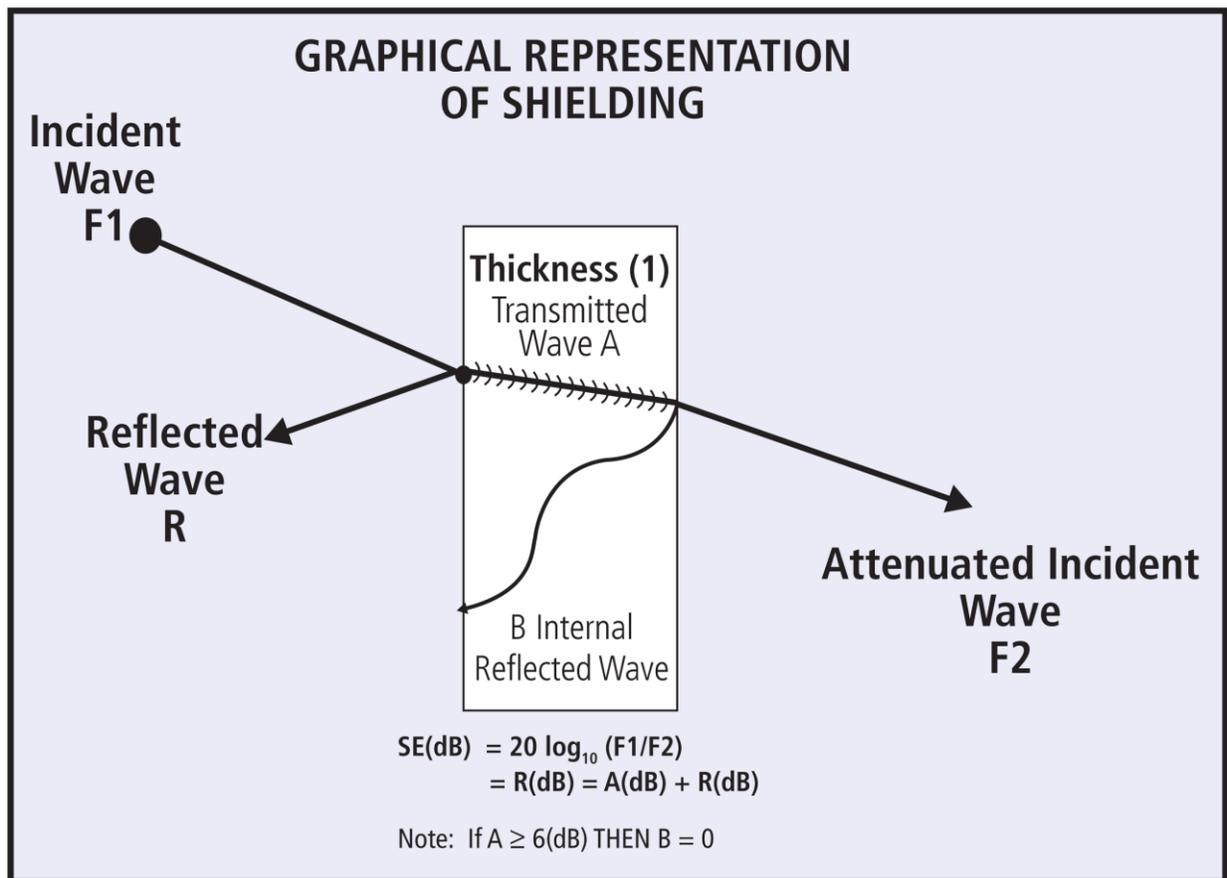


Figure 3

For sources outside of the shield, the absorption and reflection of the shielding material, in dB, are added to obtain the overall SE of the shield. For sources within the shield, roughly only the absorption of the shield can be considered.

The absorption of the shielding material at frequencies of concern is controlled by:

- Conductivity
- Permeability
- Thickness

The reflectivity of the material at the frequencies of concern is controlled by:

- Conductivity
- Permeability

However, this is only true for our “ideal” shield. Two other major factors are:

- “Apertures” - holes or slots in the enclosure.
- The mechanical characteristics and effectiveness of the gaskets used on the enclosure.

“Mechanical characters” is pointed out because the biggest reason that RF gaskets do not perform as specified is because of improper installation, such as “putting a gasket where a gasket was never meant to go.” This is because many times, an RF gasket is used as a “fix” after the design has been set. As we saw in the formulas, shielding is necessary after all other factors in the circuit have been established. Sadly, it is also viewed that way. Rather than design in shielding and gasketing, it is used as a last desperate effort to get the device into compliance; adding the reason for so many failures in shielding and gasketing efforts.

Shielding, which is noninvasive and does not affect high-speed operation, works for both emissions and susceptibility. It can be a stand-alone solution, but is more cost-effective when combined with other suppression techniques such as filtering, grounding, and proper design to minimize the loop area. It is also important to note that shielding usually can be installed after the design is complete. However, it is much more cost-effective and generally more efficient to design shielding into the device from the beginning as part of the design process. It is important to keep in mind that the other suppression techniques generally cannot be added easily once the device has gone beyond the prototype stage.

The use of shielding can take many forms ranging from RF gaskets to board-level shields (BLS). An RF gasket provides a good EMI / EMP seal across the gasket-flange interface. The ideal gasketing surface is conductive, rigid, galvanically-compatible and recessed to completely house the gasket.

A device housed in a metal case is generally a good candidate for RF gasketing materials. When electrical and electronic circuits are in nonconductive enclosures, or when it is difficult or impossible to use RF gasketing, BLS provides the best option for

EMI suppression. A properly designed and installed BLS can actually eliminate the entire loop area because the offending or affected circuit will be contained within the shield.

Apertures

Apertures, or holes, have SE. The SE of an aperture and ultimately the entire electronic enclosure is determined by the size, shape and number of the apertures. The formula is:

$$SE_{dB} = k \log_{10} \left(\frac{\lambda}{2L} \right)$$

Where:

λ = Wavelength

k = 20 for a slit or 40 for a round hole

L = Longest dimension of the aperture

If there is more than one hole, we subtract from the original formula: $20 \log_{10}$ the total number of holes within half a wavelength.

Apertures are placed in electronic enclosures for many reasons. Apertures are required for viewing, controls, meters, wire entry, etc. One reason is simply the seam around the perimeter of the cover(s). To maintain the conductivity across the seam, we generally need to use RF gasketing. RF gasketing is also used around display panels, shielded connectors, and other apertures in the enclosure.

RF Gaskets

Although there are hundreds of gasket varieties based upon geometry and materials, there are four principle categories of shielding gaskets: beryllium copper and other metal spring fingers, knitted wire mesh, conductive particle filled elastomers and conductive fabric-over-foam. Each of these materials has distinct advantages and disadvantages, depending upon the application. Regardless of the gasket type, the important factors to be considered when choosing a gasket are RF impedance ($R + jX$, where R = resistance, jX = inductive reactance), shielding effectiveness, material compatibility corrosion control, compression forces, compressibility, compression range, compression set, and environmental sealing. However, many other factors may come into the selection decision. Below is a comprehensive list of selection factors.

- Operating frequency
- Materials compatibility
- Corrosive considerations

- Mandatory compliance
- Operating environment
 - Load / forces
 - Cost
- Attenuation performance
- Fastening / mounting methods
 - Storage environment
- Nuclear, biological, chemical (NBC)
 - Cycle life
- Shielding / grounding / other
 - Electrical requirements
 - Materials thickness / alloy
- Space / weight considerations
 - Product safety
 - Recyclability

Metal RF Gaskets (Fingerstock) and Spring Contacts:



Metal RF gaskets are made from various materials. They generally have the largest physical compression range and high shielding effectiveness holding steady of a wide frequency range. CuBe is the most conductive and has the best spring properties. They

can be easily plated for galvanic corrosion considerations.

Fingerstock and spring contact products are ideal for high cycling applications requiring frequent access, with hundreds of standard shapes available as well as cut-to-length and modified standards.

Wire Mesh and Knitted Gaskets:



Wire mesh gaskets can be made from a variety of metal wires, including monel, tin plated-copper clad-steel or aluminum. They are cost-effective for low cycling applications and offer high shielding effectiveness over a broad frequency range. They are available in a wide variety of sizes and shapes with the knit construction providing long lasting resiliency with versatile mounting options.

Conductive cloth knit offers close-knit stitch of the metalized nylon, providing a highly effective EMI shield, as well as a smooth, soft surface. Copper Beryllium (CuBe) Mesh offers superb resiliency for consistent, point-to-point contact requiring the lowest compression forces.

Elastomer Core Mesh combines excellent shielding performance with a high degree of elasticity.

Oriented Wire:



Oriented wire is a conductive elastomer in which individual conductive wires of either Monel or aluminum are impregnated into solid or sponge silicone. Oriented wire provides EMI protection and seals against moisture or rain on cast or machined surfaces.

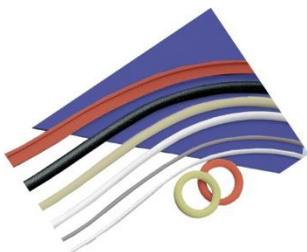
Fabric-Over-Foam (FOF):

FoF EMI gaskets offer high conductivity and shielding attenuation and are ideal for applications requiring low compression force. Typical FoF EMI gasket applications include shielding or grounding of automotive electronic equipment seams and apertures. There are a wide range of shapes and thickness to meet any design need.



Electrically Conductive Elastomers:

Conductive elastomers are ideal for applications requiring both environmental sealing and EMI shielding. They provide shielding effectiveness up to 120dB at 10GHz with a wide choice of profiles to fit a large range of applications. Conductive fillers include, but are not limited to:



Carbon (C)

Passivated aluminum (IA)

Silver-plated aluminum (Ag/Al)

Silver-plated copper (Ag/Cu)

Silver-plated glass (Ag/G)

Silver-plated nickel (Ag/Ni)

Nickel-coated carbon (Ni/C)

Silver (Ag)

Elastomer options include:

Silicone rubber

Fluorosilicone rubber

Ethylene propylene diene monomer (EPDM)

Fluorocarbon rubber, Viton, or Fluorel

Board-Level Shielding (BLS):

If done well, PCB level shielding can be the most cost-efficient means of resolving EMI issues. As a low cost, and most common shielding method, a variety of board-level metal can-type shields have been used to eliminate EMI radiation from entering or exiting sections of a PCB. This method has primarily employed solder-attached perforated metal cans being attached and soldered to the ground trace on a PCB directly over the electrical components that need to be shielded.



The can-type-shields are often installed in a fully automated fashion via a surface mount technology process at the same time the components themselves are installed onto the PCB using wave soldering, or solder paste and a reflow process. Such cans offer very high levels of shielding effectiveness, are typically very reliable, and are widely used in the industry.

Board-level shielding metal cans can consist of tin or zinc plated steel, stainless steel, tin-plated aluminum, brass, copper beryllium, nickel silver or other copper alloys.

Conclusion

Basic shielding theory is really not so basic. A comprehensive knowledge of EMI control, circuit design, mandatory specifications, environmental issues and other factors must be considered. Shielding requires a conductive enclosure around a circuit, device, apparatus, or even entire buildings to control EMI. The most cost effectiveness shielding is applied at the source of the problem. However, that is not always possible.

Once the design is established and there are EMI issues, many times, shielding is the only solution. Today there are a myriad of choices for shielding materials from BLS to metal and / or “conductive plastic” enclosures. In most cases, when shielded enclosures are required, RF gasketing is also necessary to provide a conductive interface across the enclosure’s apertures.

Simply trying to pick off-the-shelf shielding materials is not an option. There are many factors involved in the selection of RF shielding materials and RF gaskets. In fact, if one is not intimately familiar with the materials and mechanics of shielding, then it is best left to the experts in the shielding industry.

Please contact Shielding Source to support your Gasketing and Shielding needs.

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