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EMC Shielding Simplified

A basic discussion on shielding materials
and how to make shields work

by

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EMC SHIELDING SIMPLIFIED

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EMC shielding effectiveness analysis can take up whole books, but the basics can be covered easily, providing the reader with enough information to show where shields fail to perform as intended.

As will be discussed, almost any reasonable conductor will provide adequate shielding effectiveness for the overwhelming majority of shielding needs. The key issue is the openings in the shield and the wires piercing the shield.

This paper will start with a few concepts, using rules of thumb, to serve as the basis for the key issues in shielding effectiveness. This will be followed by a discussion of the shielding effectiveness of the material and the shielding failures and how to solve them.

1. BASIC PHYSICS

A few key concepts are needed to serve as the basis for shielding effectiveness. Theory will be kept to a minimum.

A. The key parameter in shielding is the maximum frequency of the offending interference source. The Fourier series gives us a method of determining the maximum expected frequency of a non-sinusoidal wave, such as a square wave or a transient event such as electrostatic discharge:

fmax = 300/tr, where tr is risetime in nanoseconds and fmax is in MHz.

If your source is a clock, and you don't know the risetime, assume fmax is 10 times the maximum clock frequency. Usually, this is pretty close to the risetime criteria mentioned above.

If your source is a transient - ESD is the principal transient tr = 1 nsec, or fmax = 300 MHz

If your source is an external radio source, f is actual frequency. In the case of a regulatory test, fmax is usually 1 GHz = 1000 MHz

B. Given the maximum frequency, we can compute the wavelength of the highest problem frequency:

λ= 300/f, where f is frequency in MHz and λ is wavelength in meter.

Metallic members start to become effective antennas above 1/20 wavelength. This is relevant to the maximum dimension of an opening, or the maximum length of a wire penetration piercing the shield. Table 1 gives some representative examples:

Table 1. Wavelength/Frequency Relationship for Some Frequencies

Frequency	λ	λ/20
1 MHz	300 m	15 m
10 MHz	30 m	1.5 m
30 MHz	10 m	0.5 m
100 MHz	3 m	15 cm
300 MHz	1 m	5 cm
1000 MHz	30 cm	1.5 cm

The 1/20 wavelength criteria will be applied in the following paragraphs.

2. MATERIAL SELECTION

Given a reasonably conductive material, high frequency shielding is highly effective, nearly independent of conductor thickness. At higher frequencies, the "skin effect" forces the currents on the shield to the surface. Most current travels within one skin depth of the surface. Skin depth is given by:

$\delta = 0.066/\text{sqrt}(f*\mu r*\sigma r)$, ($\delta$ in mm, f in MHz)

$\delta = 0.0026/\text{sqrt}(f*\mu r*\sigma r)$, ($\delta$ in inch, f in MHz)

Where mr is relative permeability and sr is relative conductivity (both relative to copper). Table 2 gives the conductivity and permeability of some common materials:

Table 2. Conductivity and Permeability of Common Materials

Material	σr	μr
Silver	1.05	1
Copper	1	1
Gold	0.7	1
Chromium	0.65	1
Aluminum	0.61	1
Zinc	0.3	1
Cadmium	0.25	1
Nickel	0.2	100
Steel	0.17	1000
Tin	0.15	1
Stainless	0.02	500

σr = relative conductivity of media
σ(cu) = 5.8x10E7 siemens/m
R = 1/σ*t (Ω/square), t is thickness

Given these properties, we can calculate the skin depth of the most common shielding materials.

Table 3. Skin Depth of Common Shielding Materials

		Skin depth (inch)		
Frequency	Copper	Aluminum	Steel	Mu-metal
100 Hz	0.260	0.333	0.026	0.011
1 kHz	0.082	0.105	0.008	0.003
10 kHz	0.026	0.033	0.003	
100 kHz	0.008	0.011	0.0008	
1 MHz	0.003	0.003	0.0003	
10 MHz	0.0008	0.001	0.0001	
100 MHz	0.00026	0.00003	0.00008	
1 GHz	0.00008	0.0001	0.00004	

Thus, we note that for any frequency above about 1 MHz, the material thickness is not important - it is the conductivity at the surface that counts.

Copper is an excellent conductor, but aluminum is not far behind. In practice, even steel is good enough for most shielding needs or, for that matter, most metals. Since the thickness is not an important issue, metallized coatings provide more than adequate shielding effectiveness. In principal, any metal coating can be used - in practice, aluminum coats well and is very effective.

The only major exception is low frequency magnetic field shielding, primarily related to electric power line interference. To cope with magnetic fields, you need a thick permeable material, such as steel or “mu-metal”, Fortunately, low frequency magnetic fields don’t affect most electronics (CRTs and electron microscopes are among the vulnerable).

3. PENETRATIONS TO THE SHIELD

In practice, the principal reason for shielding failure is not the material itself, but in the penetrations to the shield, see Figure 1.

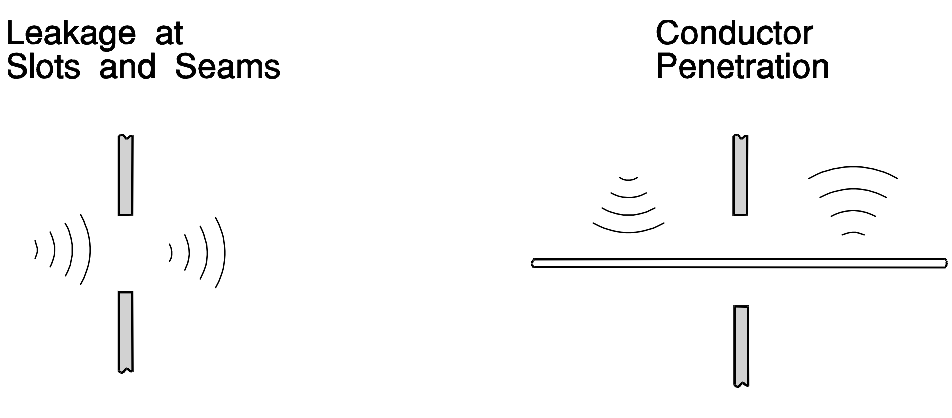

Figure 1. Principal Causes of Shielding Failure

An opening in the shield serves like a slot antenna, which is the analog of the familiar dipole antenna. Incident radio waves set up currents on the skin, circulating in a complex fashion. When these currents encounter an opening, they energize the slot, resulting in radiation in both directions from the slot. That which goes back where it came from is not a problem, but the half that goes in the other direction degrades the shield. Shielding effectiveness of the opening is given by:

SE = 20*log(λ/2L), where L is the longest dimension of the opening.

Here are some typical values:

L	SE (dB)
>λ/2	0
λ/20	20
λ/200	40
λ/2000	60

Our minimum criteria is that the maximum dimension of an opening should be less than 1/20 wavelength of the maximum frequency of concern, which will result in a shielding effectiveness of 20 dB. Even this may not be enough, but it does represent an amount that is reasonably achievable. Anything tighter than requires the use of conductive gasketing to close the openings.

4. ACHIEVING CONDUCTIVE CLOSURE

Materials scallop when forced together (figure 2), unless positive measures are taken to ensure more or less continuous contact. The only place you can rely on contact is under the footprint of the fastener, or by designing the surfaces so that a positive pressure is exerted along the run of the mating surfaces. If this is not feasible, then resilient conductive gasketing is needed to close the gaps.

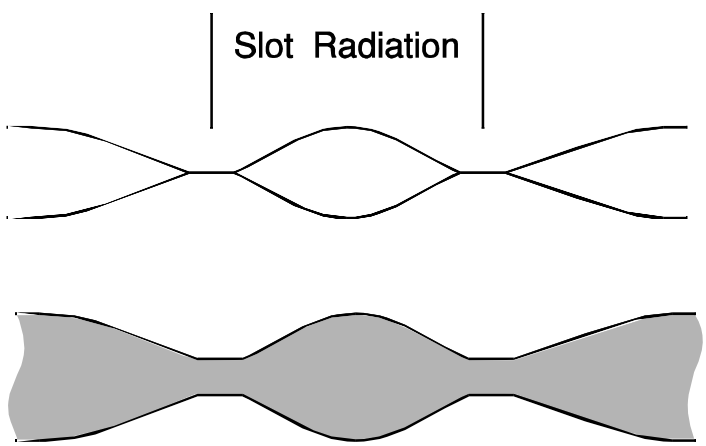

Figure 2. Openings at Seams Can be Closed with Conductive Gasketing

Tongue and groove can be used to avoid gasketing, as per figure 3.

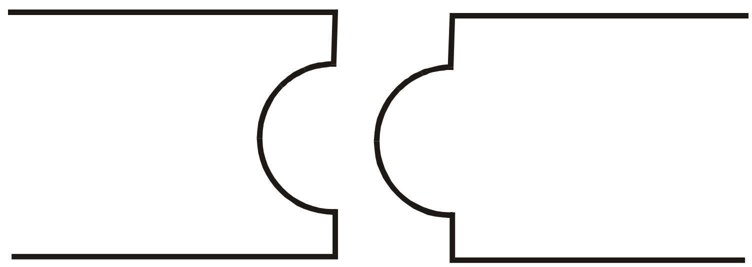

Figure 3. Tongue and Groove Facilitates Firm Conductive Mating

Note that both the tongue and groove mating surfaces must to be conductive.

One of the big problems with conductive coatings is that it is hard to get conductive mating. Figure 4 shows two situations, both of which will result in shielding failure. This point cannot be overemphasized - *if the metal members don't conductively close, the shield will not work.*

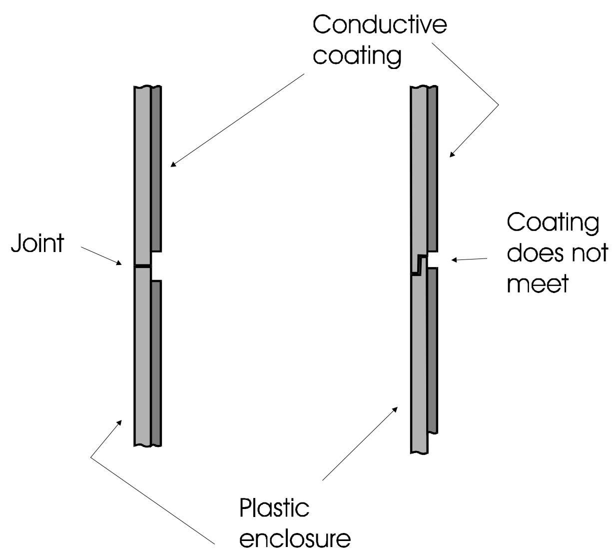

Figure 4. Conductive Coatings Fail to Close Gap

The argument that it is too hard to get conductive material to the mating surfaces is irrelevant - if you can't get closure, your shield won't work.

In many cases, it will be necessary to use conductive EMI gasketing to get satisfactory closure. The purpose in such gasketing is to provide a resilient conductive material to close the gaps, as seen in Figure 2.

In order to work, the gasket must be conductive, and the mating surfaces must be conductive. The gasketing need not be highly conductive, as long as there is reasonable continuity between the two surfaces.

There are a number of gasketing materials available. Which one to use depends more on mechanical constraints, including size and material compatibility. Some common gasket materials have been formulated to be reasonably compatible with common shielding materials.

Finger Stock
Wire Mesh
Metallized Cloth
Conductive Elastomer (may be die cut)
Conductive paste or caulk
Peel and Place
Form-in-Place
Pick and Place

For most applications, the gasket choice is made for material compatibility or mechanical reasons, as all EMI gaskets work pretty well if properly installed

For larger enclosures, the common gaskets are finger stock, woven mesh and metallized fabric. For smaller panels, head gaskets are appropriate. The advent of cell phones and other handheld devices has driven the development of small geometry gaskets, suitable for automatic insertion.

These technologies are pick and place, form-in-place and peel and place, all of which are found in cell phones. These technologies are very cost effective, even in small quantities. Pick and Place and peel and place use pre-formed gasket which is then set onto the proper place of the material. Form-in-place gasket is deposited directly onto the shield material using numerical control technology.

5, CONTROLLING THE PENETRATIONS

The last step in making the shield work is to control the wire penetrations: any current on a wire (signal or power) that pierces the shield will pass through the shield without being impeded in any way. Thus, any wire that carries conducted interference will pass through the shield in either direction. Additionally, any wire long enough to serve as an antenna, will intercept radio energy from either side and pass it through to the other side.

Thus, the interference currents must be prevented from passing through the shield. This can be accomplished in one of two ways, see figure 5. In the first case, shielded cable prevents radiated

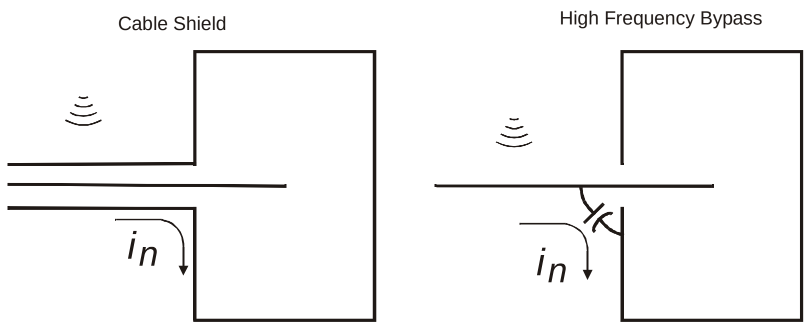

Figure 5. Controlling Wire Penetrations

interference from getting to the wires. In the second case, interference currents are diverted at the shield boundary using a filter capacitor (more complex filter combinations are often used).

Filtering is usually used for electrical power (AC or DC), as it is usually not feasible to shield. Low frequency signal lines, including low frequency analog input signals and discrete switched lines are also usually filtered.

Cable shielding is usually needed for high frequency digital signal lines, as filtering may degrade the signal quality.

Whichever method is used, the interference currents must be diverted at the shield boundary, lest the effectiveness be degraded. Specifically, filter capacitors need to be grounded to the shield, keeping internal currents inside and external currents outside.

Similarly, cable shields need to be terminated directly to the shield boundary. This means the cable shield needs to conductively mate to the shield without discontinuity. Circumferential closure is best, pigtail terminations are never acceptable (figure 6)

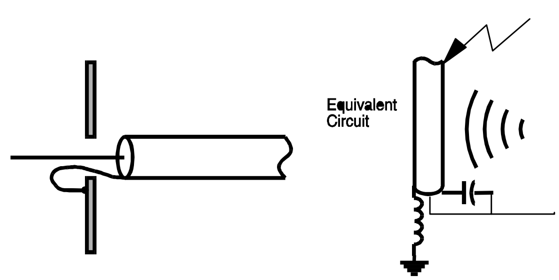

Figure 6. Pigtail termination converts cable into an antenna

The key in effective cable shielding is to ensure that the cable shield is well fastened to the shield boundary as shown in figure 7.

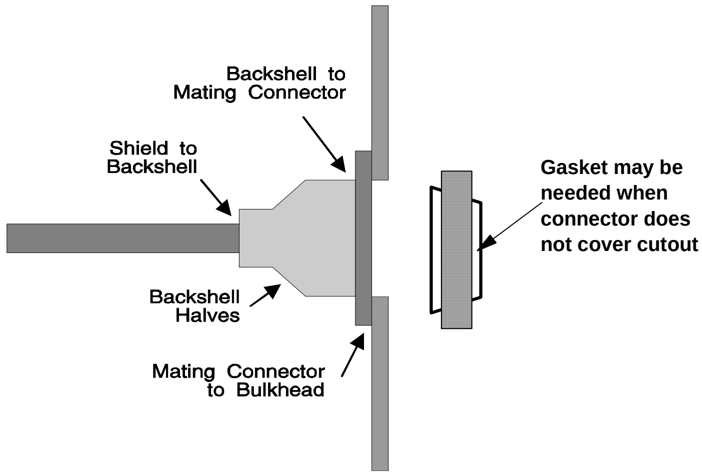

Figure 7. Good cable shield termination

6. ELECTROSTATIC DISCHARGE (ESD)

As mentioned, the high frequency EMI rules also apply to ESD, as well, but there are several new aspects to be considered with ESD. Figure 8 shows several penetrations that are particularly significant with ESD. ESD currents can arc across surprising distances to metal members within.

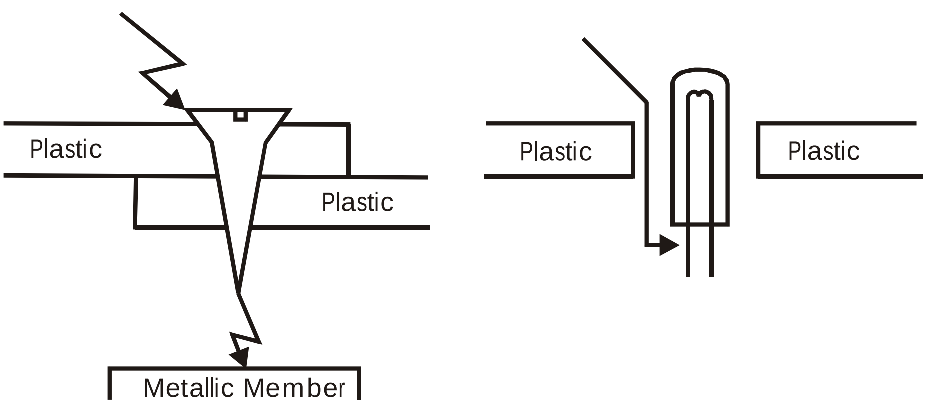

Figure 8. Penetrations with unshielded enclosure

These penetrations would generally not be significant for radiated EMI. Figure 9 shows how an unshielded and a shielded enclosure affects the path of the ESD currents.

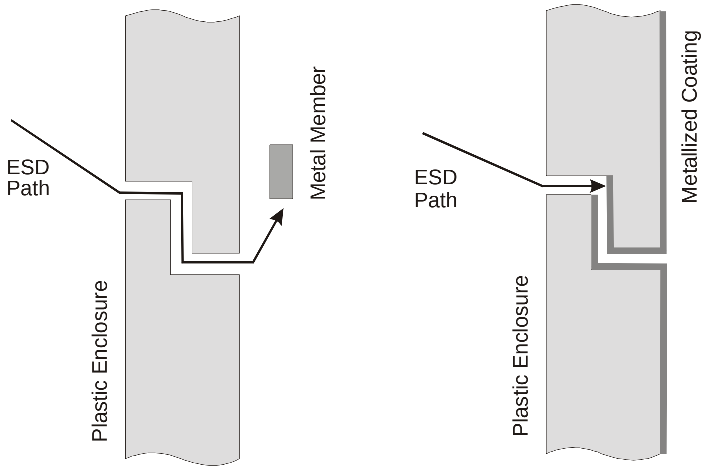

Figure 9. Conductive coating alters the ESD path

For an unshielded enclosure, the ESD has to reach into an internal member - depending on the location of internal metal, the path may be too long for ESD to occur. For a shielded enclosure, ESD path is nearly on the surface, so discharge is inevitable. As long as the mating seams are closely spaced, the shield performs and the ESD currents don't penetrate to the electronics within. But there are additional factors to consider. Figure 10 shows several possible penetration paths into the enclosure. In one case, the switch is ungrounded, so the ESD currents flow down

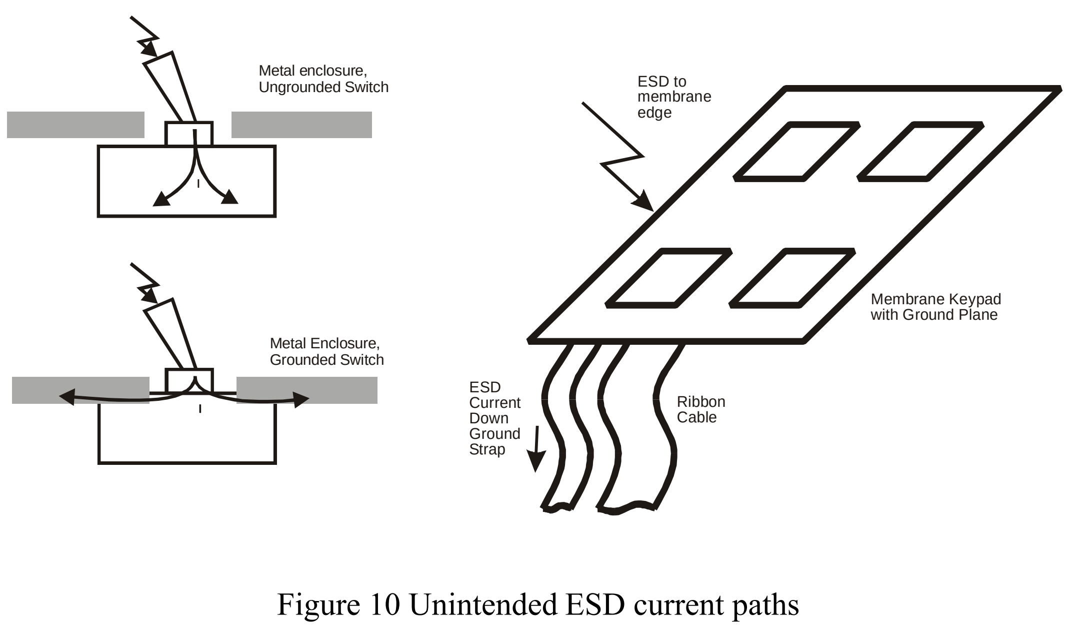

Figure 10 Unintended ESD current paths

the wire to the circuits within. In the second case, an ungrounded keypad serves as a discharge point - the current flows down the ground path to a potentially vulnerable location within. In both cases, the solution is to ground the metal members directly to the enclosure shield.

7. SUMMARY

Effective shielding requires the openings be minimized, and the wire penetrations be blocked. The openings can be minimized by providing for positive conductive contact along the entire path, perhaps with the aid of EMI gasketing. The penetrations can be blocked using cable shields or filters placed immediately at the penetration point.

Conductivity of shielding materials is almost never a pacing factor - you need to do a very good job on closing the openings and blocking the wire penetrations before the shielding material even enters into the equation.

But make no mistake - if you don't control the openings and penetrations, your shield won't work.

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William Kimmel, PE is a principal in the engineering consulting firm of Kimmel Gerke Associates, Ltd, specializing in electromagnetic interference. The company works in a wide range of business areas, including military, avionics, medical, industrial and commercial electronics. They do troubleshooting, design reviews and EMI seminars. For more information, go to **www.emiguru.com**