Enclosure Design for EMC

Most equipment manufactures choose to design custom housings for their electronics products in order to differentiate them in the market place. Usually enclosure design is driven by the two beasts of beauty and cost, with EMC requirements an irritating afterthought.

The ideal enclosure from an EMC point of view is the perfect Faraday cage. Take the PCBs that make up a typical product, wrap them in a seamless monolith of copper without apertures and bingo! You've fixed it. Unfortunately this solution is impractical.

The art of good enclosure design is therefore to get "as close as is necessary" to the Faraday cage, without sacrificing the aesthetic appeal of the product or significantly increasing its cost.

For most designers "As close as is necessary" is usually defined as meeting standard or type specific requirements. This usually involves at least:

(i) Containing Radiated Emissions
(ii) Providing Radiated Immunity
(iii) Providing ESD Immunity
(iv) Providing Fast Transient Immunity

In designing a compliant enclosure the designer needs to look at the following:

(i) Mechanical components - their material composition and coatings
(ii) Electrically bonding the enclosure components
(iii) Electrically bonding the internal hardware and its interfaces to the enclosure
(iv) Dealing with apertures in the enclosure
(v) Screening and partitioning inside the enclosure
(vi) Earthing the product

Component Material and Coatings

Generally the enclosure designer will work with components made from folded steel or aluminium alloy or bulk extruded alloy and possibly vacuum formed aluminium or plastic. Where the volumes of finished product justify the tooling expense, the designer might also use injection moulded plastic or rubber or die cast aluminium.

Often housings made entirely of conductive metal components form poor EMC enclosures simply because the individual components have been painted or coated in a non-conductive material.

There are however a wide range of affordable conductive coatings available. For example:

For aluminium components - alochrome plating rather than non-conductive anodising.

For steel components - zinc galvanising or passivated zinc plating (zinc and chromate passivated) for corrosion resistance. Where aesthetic appeal is important - bright nickel or chromium plating. Note: Zintec is a sheet steel with conductive zinc coating and can be used as an alternative to plating where corrosion at the cut edges of a component is not an issue.

For plastic components - internal metalisation or conductive carbon coating. Partially conductive carbon loaded plastics can be used but often the strength and flexibility of a loaded plastic is inferior to an unloaded component.

Forming a Faraday Cage from Enclosure Components

If the various components of a product housing are not properly electrically connected to each other to form an effective overall shield (Faraday Cage) an enclosure becomes an EMC accident waiting to happen.

When designing the fixing and bonding points there is one simple aim for EMC. That is “to minimise electrical apertures and incidental antennas.” It is important to note that where you have an electrical aperture you invariably create an antenna. Consider Figure 1 where a top plate is both fixed and bonded to a folded metal box.

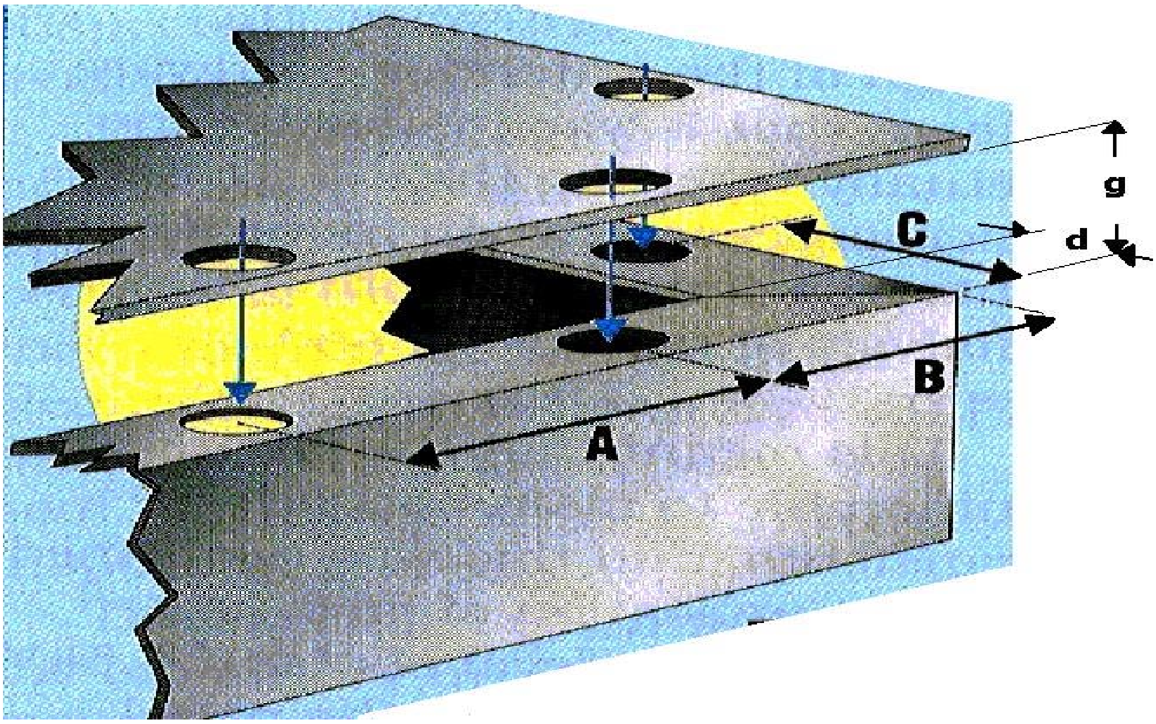


Figure 1 - Folded Metal Example

The distance between adjacent points along one edge is A and the distances from end points and box corner are B and C. Assuming these are the only points of electrical contact then we have created electrical apertures of length A, B and C respectively (even though there may be no physical aperture). The metalwork between these points are antennas, both in the folded box and the top plate. The electromagnetic properties of these antennas and the frequencies they will radiate is complicated by many physical factors. We can use an approximate rule of thumb that A will radiate at = 2A and B and C at λ = 4B and λ = 4C respectively. From this we determine a radiating frequency $f_r = c/\lambda$ where c is the speed of light. The first design aim is to ensure that this frequency f_r is much greater than the highest frequency radiated significantly by the enclosed electronics. The second that f_r is much greater than the highest frequency to which the electronics are susceptible. Or by default f_r is the upper limit set by applicable standards (usually 1GHz).

Wave-guide Below Cutoff

For 1 GHz the fixing separation would be less than 15 cm which may be excessive for larger enclosures. In this case we can extend the fold distance d to create a wave-guide operating below its cutoff frequency[1]. With this arrangement little EM radiation will pass in either direction provided that: $g < \lambda / 4$. The depth of fold gives the shielding effectiveness (SE):

$$SE \approx 27\ d / g \quad \text{(dB)}.$$

The only caveat when using this technique is that neither component must ‘carry’ a signal. Therefore the designer must be careful what circuitry is bonded (or coupled) to which mechanical component.

Bonding at Fastening Points

In most cases the designer, wishing to save cost, will consider bonding at the fastening points of the enclosure. The previously described simple techniques allow the designer to create a radiation tight bonded enclosure by connection only at the enclosure fastening points. Nevertheless where additional bonding is required it can be achieved in a number of ways:

(i) Direct contact of conductive faces.
(ii) Contact via conductive fingers, clips or gaskets.
(iii) Indirect contact via capacitive coupling.

The first technique is inexpensive and requires only that the component surfaces are conductive and in good electrical contact. Where a good electrical contact can’t be guarantied due to mechanical tolerances or flexing and distortion additional measures must be taken. An inexpensive method is to press small point dimples into one of the mating faces which themselves act as point contacts. Other more costly methods include fitting conductive gaskets or beryllium-copper /phosphor-bronze contact strips.

Electrically Bonding Painted Components

Even if all enclosure components are metallic some will inevitably be painted or powder coated. Masking off contact areas prior to painting is a frequently used technique for creating electrical bonding points. There are problems with the technique especially if masking is used near contact edges where the masked off area may become visible giving the finished product a poor finished appearance. Painted steel components that have exposed masked off areas should first be plated to ensure the exposed area doesn’t corrode. As steel starts to rust its electrical surface conductivity is quickly lost as those of us who own older cars will readily testify. Note that both the plating and masking processes add cost to the finished enclosure.

Another bonding technique for painted sheet metal is to use press fit captive nuts and washers (Figure 2).

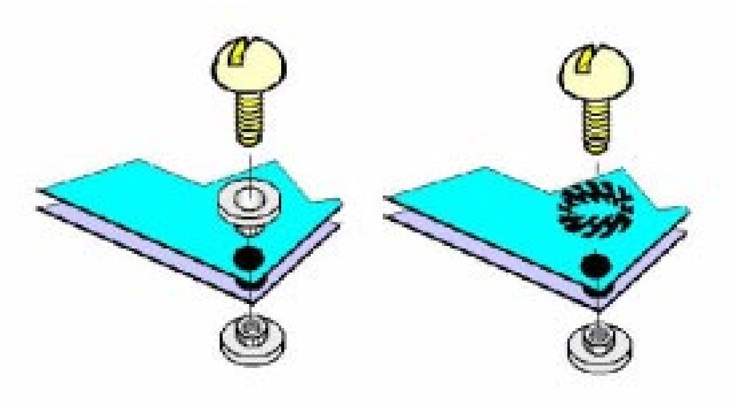


Figure 2 - Bonding Painted Metal

The captive nuts commonly available have a knurled section that bites into a pre-drilled hole in the sheet metal component. When they are pressed any residual paint is displaced and a good electrical contact is formed. It seems to this author that captive washers of the same design are impossible to get hold of! Often a crimp washer is used instead, but the danger is that it accidentally might not be fitted during production. Even if fitted it is not always guaranteed that a crimp washer will bite through a non-conductive coating. This is particularly true of durable powder coatings and stove enamelling.

Many designs also use earth cables to bond metal components attached via screw eyelets. This makes sense from a product safety point of view, for example: ensuring the lid of a housing is earthed even when the lid is open. This sort of bonding does not have a good EMC performance, as even relatively short wiring runs become highly reactive at radio frequencies.

<u>Electrically Bonding Metalised Plastic Components</u>

Captive nuts and threaded sleeves pressed into moulded plastic enclosure components are the most frequently used form of mechanical fastening. They cannot usually be relied upon to provide a good electrical bonding through the life of a product. This is because they will often move slightly within their pressed locations and will as a result break the direct contact with the thin metalisation layer.

For this reason metalised plastic parts are often bonded to the ground layer of the internal electronics (PCB) via conductive spring loaded fingers soldered directly to the PCB. These press against the housing component when the unit is assembled.

This author has also seen products where coiled springs have been used to the same effect. Coiled springs should be avoided from an EMC point of view as they are naturally highly reactive and give high impedance at radio frequencies.

<u>Capacitive Fold Coupling</u>

Capacitive fold coupling can be used to great effect to enhance the EMC performance of a metal enclosure at the top end of the RF spectrum. It can be a cost effective alternative to conductive fingers or contact strips. For example, consider Figure 3.

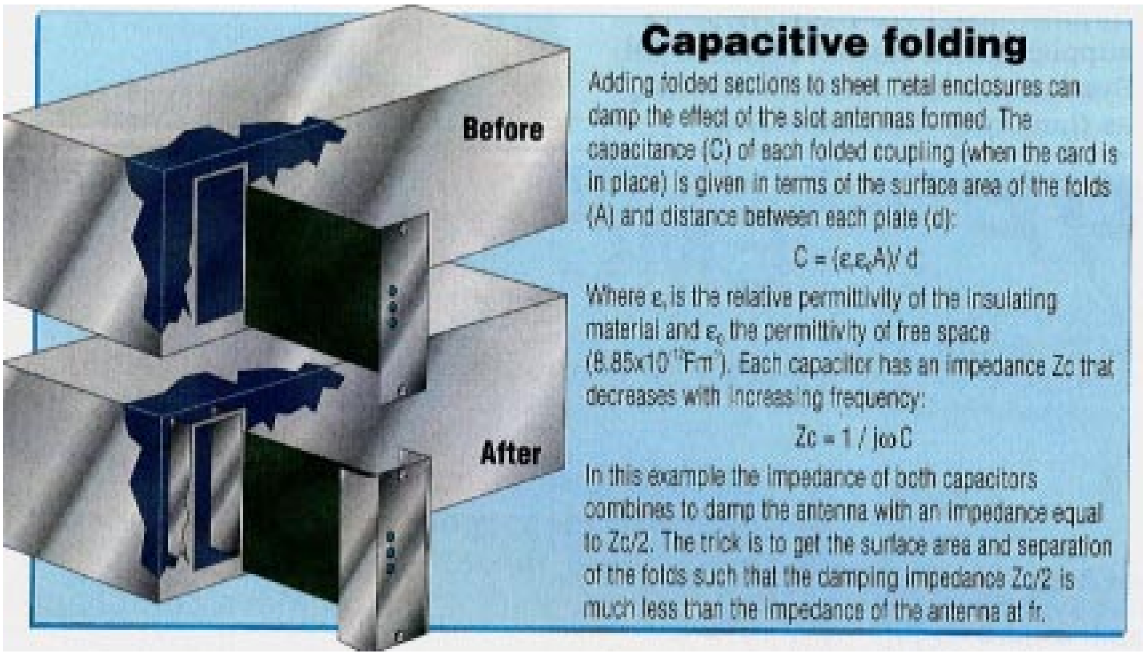


Figure 3 - Capacitive Fold Coupling

This is a common scenario where a metal housing has a slot cut in it to facilitate a removable card. The locking nuts on the card's front panel are used for both fixing and electrical bonding. We still have an aperture with an associated antenna of length L. We may judge from our rule of thumb that the antenna is likely to radiate unacceptably. We can reduce this radiation, damping the antenna by including a distributed capacitor along both edges of antenna. This is done by introducing folds in the sheet metal composing the card's front panel and the housing front panel.

We will assume that both front panels are painted with a non-conductive finish. In this example the non-conductive finish helps us, because it will usually have a greater permittivity than free space.

The capacitance (C) of each folded coupling (when the card is in place) is given in terms of the surface area of the folds (A) and distance between each plate (d):

$$C = \varepsilon_r \varepsilon_0 A / d$$

ε_r is the relative permittivity of the insulating material and ε_0 the permittivity of free space (8.85x10-12 Fm-1). Each capacitor has an impedance Zc that decreases with increasing frequency:

$$Zc = 1 / j\omega C$$

In this example the impedance of both capacitors combines to slug the antenna with impedance equal to Zc/2. The trick is to get the surface area and separation of the folds such that the slugging impedance Zc/2 is much less than the impedance of the antenna at fr.

This author has used this approach with some effect in the past. It should be noted however that there are potential pitfalls:

(i) If the antenna being slugged is predominantly inductive, then a resonant circuit is being created which will create a radiator tuned to peak at a resonant frequency. This can be a problem if the resonant frequency is an undesirable one.
(ii) The capacitance generated varies greatly with only small variations in the plate separation.
(iii) In reality wave-guides with low characteristic impedance are being created and not ideal capacitors.

Man Enclosure Interface

EMC problems are compounded where electronics meets man. The designer of housings for equipment incorporating displays and keyboards will have to create apertures in his enclosure for them. These apertures will allow radiation both in and out. Worst still for the machine, the man is a potentially lethal source of electrostatic discharges (ESD).

There are a number of techniques to defend the machine against the EMC problems caused by these annoying apertures:

(i) Fit a well bonded conductive plane immediately behind the keyboard or display of a size equal to or larger than the aperture. This will, to an extent, confine aperture radiation to that emitted by the display or keyboard.

(ii) For noisy displays (such as electro-luminescent and other high voltage technologies) cover the aperture with a see-through conductive gauze immediately below or embedded in the viewing screen. Again this should be well bonded to the enclosure

(iii) For membrane keypads pick a technology that doesn’t break down in the face of an 8kV ESD gun or otherwise be prepared to fit some serious protection to the electronics that the keypad connects to.

RF De-tuning

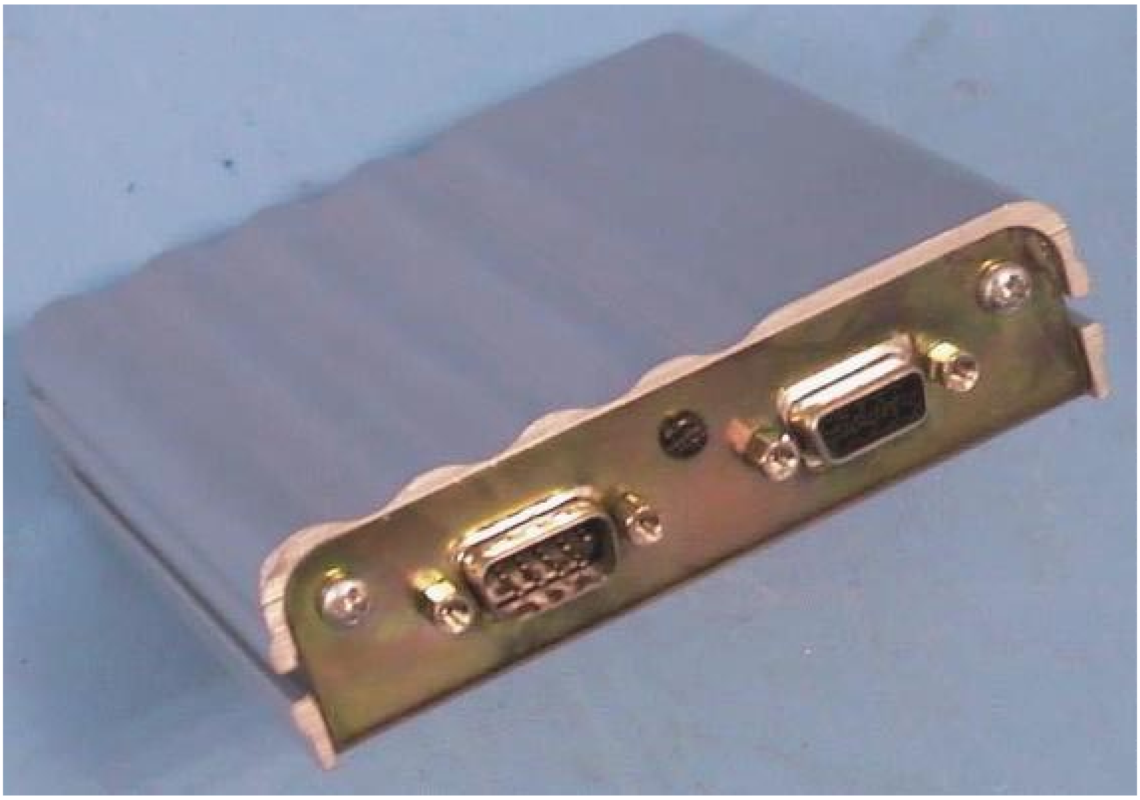
It's worth noting that metallic enclosures affect the performance of electronics circuits placed in them. This is most noticeable with high frequency oscillators where earthed sheet metal planes are in close proximity to them. The net affect is for the oscillator to be de-tuned. For example a free running oscillator running at 200 MHz on the bench may drop to 180 MHz when situated 10mm from the metal face of its enclosure.

Although this is not an EMC issue it may explain why some designs I have encountered that worked well on the development bench failed to operate satisfactorily in the housings designed for them.

A Practical Example

The following example is an enclosure for a radio modem product. The modem attaches to existing FM radio transceivers and has to greatly exceed the standard requirements for radio emission in order not to block the radio's receiver. Notice the positioning of fixing screws that form electrical bonding points for the two components of the housing and the internal PCB as well as fixing all three components together.

The top part of the enclosure is alochromed extruded aluminium. The bottom part is zinc and chromate passivated folded sheet steel. The photograph shows a prototype unit. Production units are painted on the outside only. Bonding occurs between the unpainted interior via the dimples depressed in the sheet steel which also form recesses to prevent the heads of the fixing screws protruding and scratching surfaces on which the modem is placed.



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