Influencing Factors on Shielding Effectiveness of Board Level Shields

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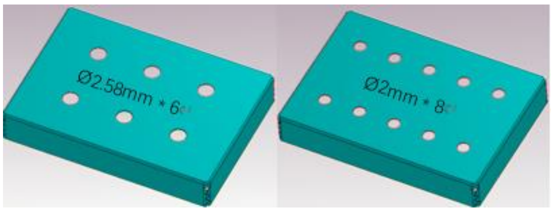
Board level shielding (BLS) is widely used in various electronic products or systems. They play an important role in solving EMC problems (e.g., EMI radiation, intra-system interference, RF problems). With the upgrading of end user requirements, the design requirements for BLS are becoming increasingly stringent. Customers now demand a higher frequency band, lighter weight, smaller size or low-height shields, and more. Therefore, how engineers evaluate the shielding effectiveness (SE) of BLS products has become crucial. This paper summarizes key factors that affect board level shielding performance through actual simulations and tests. It should provide a useful reference for engineers to design or choose EMI shielding solutions.

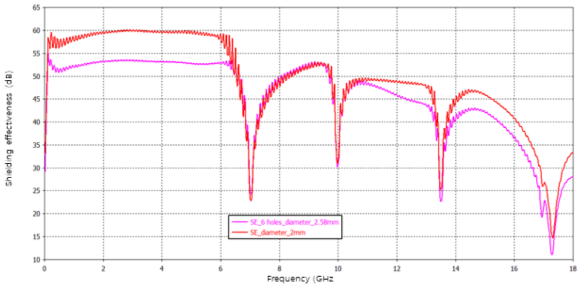
The impact of apertures on shielding effectiveness

It is unrealistic to design a completely enclosed BLS. Designers usually need to open some holes on the BLS for air ventilation, or signal traces pathing. Here we offer some typical design models of BLS by comparing the shielding effectiveness of these models. We can derive some useful design rules for BLS shielding application.

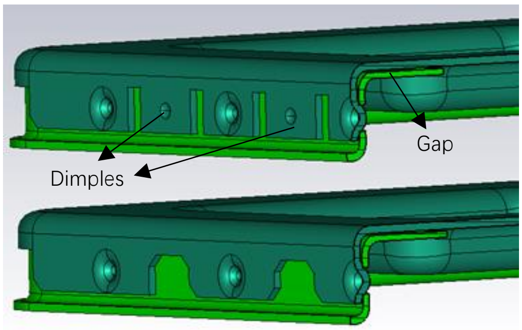
- The influence of hole size. In most application scenarios, the hole diameter is within 2mm, which is electrically small compared with the EMI wavelength. Therefore, a single hole couldn't form an effective antenna. Now imagine that we need to open a series of round holes on top of the BLS cover. Which of the following designs is better for EMI shielding? (the total area of the holes remains the same.)

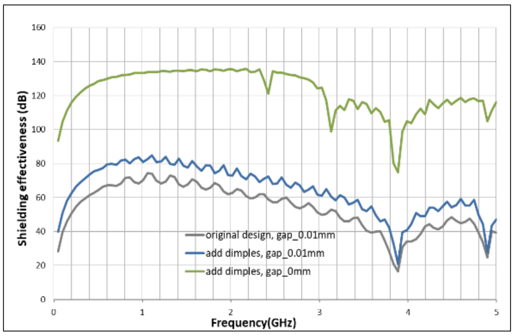


From a comparative EMI simulation, Laird obtained the SE data of the two design models. It showed that the SE of BLS with smaller holes is higher. That indicates the size of the holes has a greater impact on sheilding effectiveness than the number of holes.



- The influence of apertures / gaps. Striped apertures are often opened on the side walls or between the BLS frame and cover. For a two-piece BLS, there is a marked gap between the cover and the frame due to imperfect assembly. That forms a waveguide leading the EMI leakage. So we should consider adding some dimples to cut off the radiation path, The following example shows the difference in shielding effectiveness brought about by different designs. Note that even if we set the gap to 0.01 mm, this tiny aperture will still bring a huge drop in shielding effectiveness.



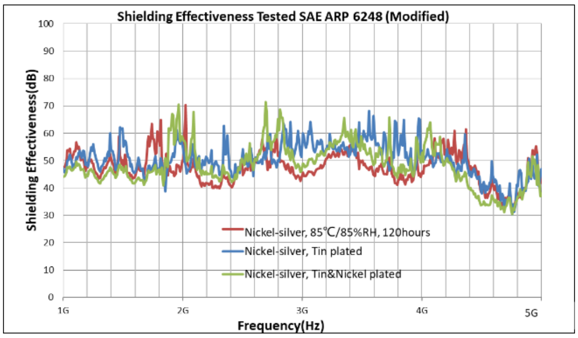


There are more cases proving that the long-side dimension of the aperture plays a decisive role in the shielding effectiveness, regardless of the short-side dimension. Therefore, in practical application, engineers should avoid some long slit aperture designs, even if the gap width is small.

The impact of material on shielding effectiveness

The most common raw materials for BLS are cold rolled steel, stainless steel, and nickel silver. These materials are extremely conductive. Given this, we can ignore the permeability effect when calculating the shielding effectiveness. The theoretical equation of SE is:

$$SE \approx R = 20 \cdot \lg(\eta_0 / 4\eta)$$



Where η_0 is the characteristic impedance of EMI source, which is 377ohm for plane wave; η is the impedance of shielding material. It could be expressed simply by:

$$\eta = \sqrt{\frac{\pi\mu f}{\sigma}}$$

Therefore, the material conductivity (σ) is the key factor affecting SE. To investigate the SE of BLS formed by different materials, Laird is accustomed to running many comparative simulations and tests. All of these experiments show that the SE of different materials are almost the same. Even after completing a high temperature and humidity aging test, the SE result doesn't change significantly.

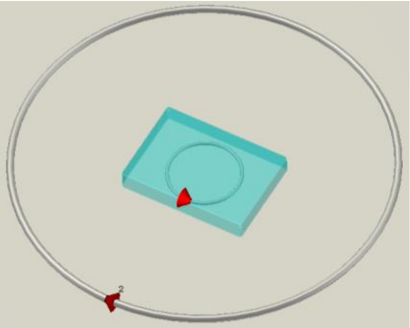
One additional and important factor on shielding is the skin effect. This means that the high frequency current tends to go through the outer surface of a conductor rather than the inner side of the conductor. So if there is plating material for EMI shielding, the shielding performance is mainly dependent on the plating material; the substrate material becomes unimportant.

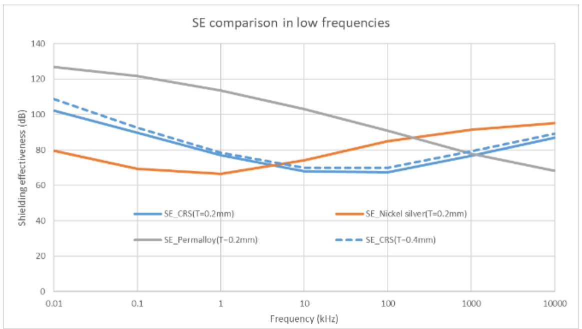
In low frequencies, BLS products are often used to restrain magnetic fields which are usually caused by low impedance sources (e.g., inductors, transformers). In these cases, the mechanism of EMI shielding becomes more complicated. In the quasistatic magnetic field, the magnetic flux will be induced to go through the materials with higher permeability. Therefore, the shielding effectiveness is determined by the structure of the shielding, the material thickness, and the permeability. When the frequency gets higher, the reflection loss caused by eddy currents will become more dominant. That means the material conductivity becomes the key factor influencing the shielding effectiveness. In order to quantitatively analyze the SE of different materials at low frequencies, we set up a model to calculate the SE of BLS. Two coils were placed inside and outside of a BLS, and a perfect ground plane was set under the BLS. Then we calculated the S21 data of the coils with and without the BLS in place, then the shielding effectiveness could be expressed by:

$$SE\ (dB) = S21_{without\ BLS} - S21_{with\ BLS}$$

Material	**Conductivity**	**Relative permeability**
CRS(cold rolled steel)	$6*10^{6}$(S/m)	100
Nickel silver	$3.57*10^{6}$(S/m)	1
permalloy	$1*10^{6}$(S/m)	200e0

The following graphic shows the simulation model and results. Three typical materials were modeled. The electrical parameters are shown in the table. Laird found that permalloy performs the best in frequencies below 100kHz. CRS material is also useful to use in low frequencies, above 00k Hz, Nickel silver becomes the best shielding material overall. Furthermore, if we double the thickness of the material, we can see that the shielding effectiveness will also be improved.





** Note that the permeability we set for simulation is a constant number, In reality the permeability of metal materials will drop sharply as the frequency increases.*

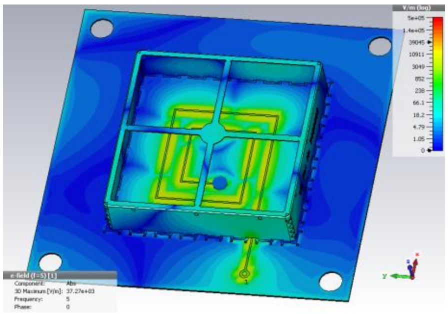
Other factors (EMI source, grounding)

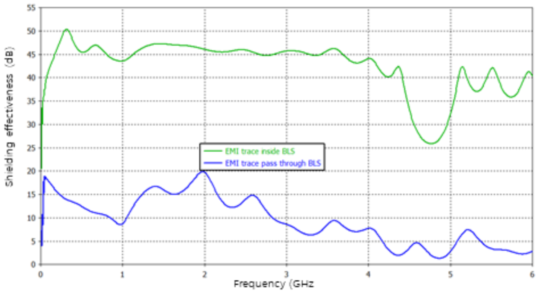
In essence, the goal of EMI shielding is to provide a Faraday cage to isolate the electromagnetic field from inside to outside. But the BLS only provides five sides for shielding. It should be grounded to the PCB to form a complete cage. There is a need to consider other factors which can affect the overall shielding performance. Here is a discussion of Laird's findings.

– EMI source

First, Laird has noticed that the impedance of the EMI source (antenna) could slightly affect the shielding effectiveness. Usually, a high impedance antenna (like dipoles) leads to higher SE or dynamic range. Still, we cannot give a quantitative comparison as different antenna structures also affect outcomes. Another point worth considering is the distance between the apertures and the EMI source. If the EMI source is near the leaking point, obviously it will lead to the SE degradation. A typical example can be seen. Whenever there are some signal traces going through the apertures of the BLS, the EMI leakage will become quite serious.

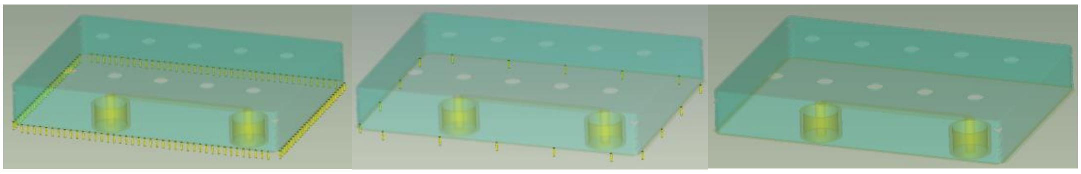
The picture below shows how the electromagnetic field distributes when the signal traces go through the castellation slot of the BLS. If we set the comparison test, we will find that there is a huge SE difference between the two scenarios (EMI trace inside BLS & go through the BLS).



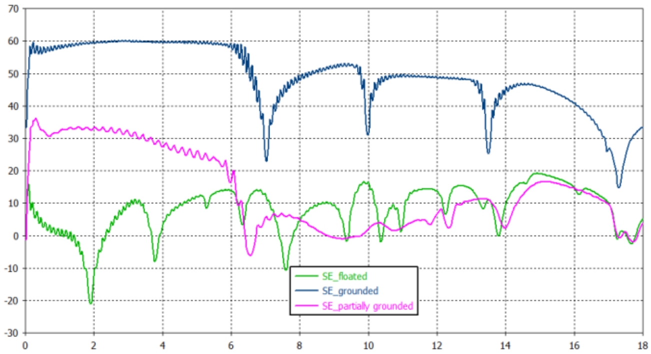


– Grounding of the BLS

Most BLS is soldered onto the PCB by surface mounting. In some cases, there is still though-hole assembly. This is actually partial grounding for the BLS. The number of grounding vias may also affect the shielding quality. Accordingly, Laird has completed research to simulate three kinds of grounding methods. The methods include perfect grounded (via gap_0.8mm), partially grounded (via gap_7mm), and floated (no GND vias). The picture below shows models of the three different grounding methods.



Apparently, a complete grounding delivers the highest SE result. This is followed by the partial grounding. Floated grounding achieves the lowest data. Moreover, when the BLS is floated on the PCB, the parasitic capacitance plays an important role for shielding. Laird has found that the resonance points have been changed and the SE result in some frequencies could be negative.



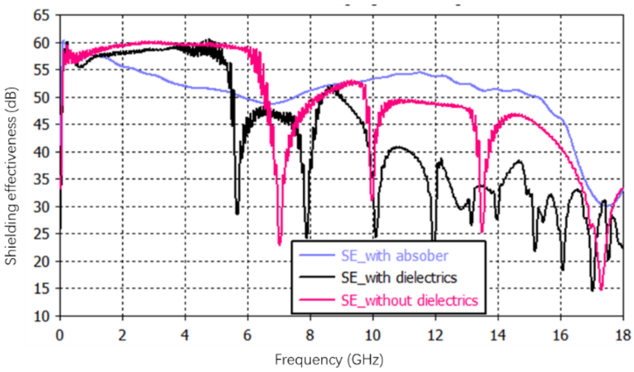
– Dielectric materials inside the BLS

In previous research, we did not consider the dielectric material effect on SE. However, in real engineering applications, there are numerous dielectric components mounted inside the BLS (e.g., PCB material, thermal pads, EMI absorbers). These dielectrics will affect the shielding effectiveness, especially changes in the resonance frequency points. Generally, the dielectric materials will compress the wavelength of the electromagnetic wave traveling inside it. This is to the fact it has higher primitivity than air or vacuum ($\boldsymbol{\varepsilon}$=1). The wavelength inside the dielectric material ($\boldsymbol{\varepsilon}_{\mathrm{r}}$) is

$$\lambda = \frac{\lambda_0}{\sqrt{\varepsilon_r}}$$

Where λ_0 is the wavelength in vacuum. ε_r is the primitivity of the dielectric material.

The wavelength compression leads to two results on shielding. First, the cavity resonances will be shifted to lower frequencies. Second, as the wavelength gets shorter, the electromagnetic waves are more likely to leak from the apertures. Thus, the SE will be driven lower.



Absorbers applied inside the BLS will get different results as shown in the graph. With absorber material attached inside, the BLS becomes a loss cavity. The resonance points are all removed. This is the typical application for a BLS and absorber combined solution, which Laird frequently refers to as a multifunctional solution.

Conclusions

Examined as a structure only, the BLS is simply is a piece of bent meta. In terms of EMI shielding performance however, there remains a multitude of factors which could determine actual SE. In general, the primary consideration of BLS is the apertures / holes. Factors pertaining to material conductivity and permeability are not as important but should be considered for low frequency shielding. In higher frequencies, the cavity resonance makes the shielding effectiveness decrease sharply. However, it has been proven that full wave EMI simulation is especially useful in addressing these problems. Combined with absorber materials, high frequency EMI radiation could be mitigated effectively and significantly. Laird Performance Materials (a Dupont business) provides end-to end solutions for customers. From structural design, SE simulation and testing to mass production and shipment, Laird strives to help manufacturers enable and protect electronic devices so they produce maximum benefits.