Addressing 5G High Frequency EMI

A Laird Performance Materials Application Note

To paraphrase Ben Franklin, there are two certainties in high speed electronic systems, electromagnetic interference and high thermal output. These are common issues in systems operating in the lower microwave band. Both issues become more acute as operational frequencies rise into the millimeter wave band. Shielding effectiveness of common EMI solutions used at lower frequencies is reduced at higher frequencies in part because of the smaller wavelength which makes it easier for energy to leak through a gap. This is not the only reason shielding effectiveness is reduced as we will address later in this paper.

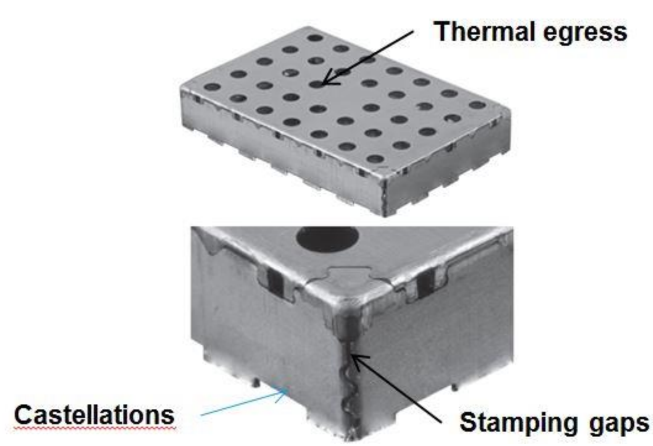
At millimeter wave frequencies, thermal issues also become worse. The same circuit functions are now performed over a smaller area. While we have seen recent gains in thermal efficiency, many mmWave systems exhibit increasing thermal problems. Traditionally Thermal Interface Materials (TIMs) which have very high thermal conductivity are used to quickly channel heat away from the source. Often TIMs are used in conjunction with an EMI solution such as a Board Level Shield (BLS) to manage both issues at once.

These BLS-TIM combinations can experience unforeseen problems as the operational frequencies increase and indeed the TIM material can often reduce the shielding effectiveness. While it is counterintuitive as to why the presence of a material inside a shield can worsen the shielding effectiveness, advanced computer modeling identifies cavity resonance as the culprit.

Additionally, best thermal performance is seen by reducing the distance from a heat source to a heat sink. Heat sinks are generally made of metal and the close proximity of the heat sink to, for example, a MIMO antenna array can have a large impact on array performance.

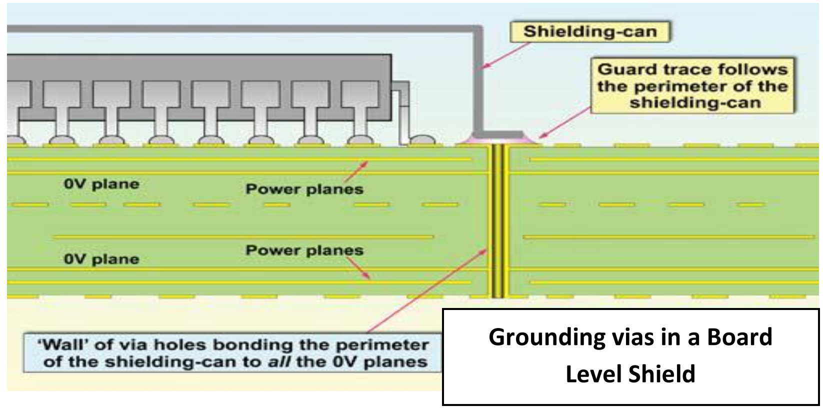
Shielding at millimeter wave frequencies

Board level shields are generally stamped out of flat metal sheets. Some designs enable 'fully drawn' metal shields where the metal stretches and results in a shield with no gaps. Other designs bend the metal and the corners of the shield fold closely together. This can create a gap which can be straight or somewhat jagged to improve EMI performance. Other designs include holes in the shield to allow thermal energy to escape. Still another type of design uses two metal parts with a fence and a lid. This type is used if access to the components inside is desired following the solder reflow process for tuning or repair. The lid then snaps onto the fence to create the shield.



Typical Board Level Shield with castellations, corner gaps and holes for thermal egress

Other gaps in a shield arise from the need for vias to connect the shield to the PCB ground plane. A board level shield is generally provided with 5 sides with connection to the ground plane needed to create the sixth side for a true Faraday Cage. The vias through the PCB provide the connection but there will always be gaps between the vias through which energy can leak.



Grounding vias in a Board Level Shield

A fully drawn Board Level Shield. Note the corners with no gaps

The amount of energy leakage through apertures or gaps depends on the size of the gaps in terms of a wavelength. Babinet's Principle tells us that the radiation characteristics of an aperture are identical to that of a driven antenna with the same dimensions. Antenna theory tells us that electrically small antennas are poor radiators but as the size increases the efficiency also increases. The wavelengths become quite small in the millimeter wave range so the apertures become electrically larger and radiate more efficiently. . A 2mm hole at 3GHz is about 2% of a wavelength in size. That same 2mm hole is 20% of a wavelength at 30 GHz.

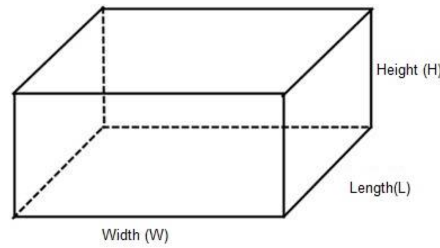
Shielding at mmWave frequencies can be improved with the use of fully drawn shields. Fully drawn shields avoid the corner gaps seen in stamped shields by stretching the metal and creating a continuous metal layer at the corners. Laird is a leader in this type of shield designs. Information can be found here.

To determine the amount of energy which radiates from an aperture we turn to antenna theory which tells us for antennas smaller than a wavelength the radiation efficiency of the antenna is proportional to the size of the antenna. Since the hole or gap acts as an aperture antenna the larger the hole in terms of a wavelength, the greater the radiation.

Cavity Resonance

A cavity resonance can occur in a conductive enclosure at a given frequency if the dimensions of the enclosure corresponds to one of that cavity's resonant frequencies. The general formula for calculating the resonant frequency of a cavity is

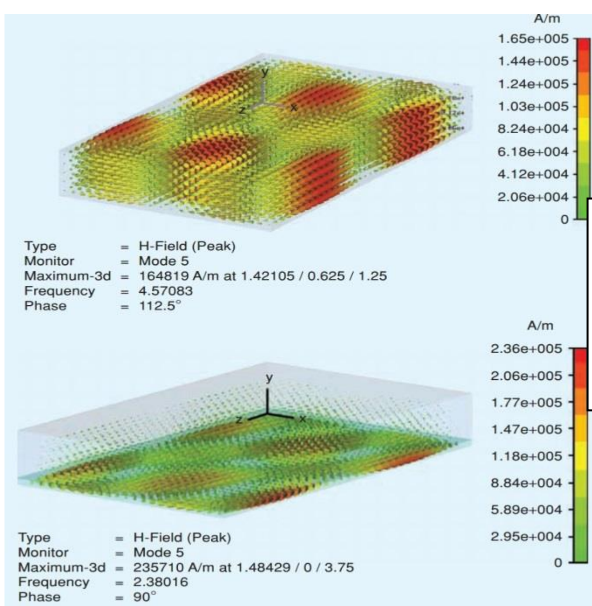
$$freq = \frac{1}{2\sqrt{\mu\epsilon}}\sqrt{\left(\frac{m}{H}\right)^2 + \left(\frac{n}{W}\right)^2 + \left(\frac{p}{L}\right)^2}$$



Where L, W, and H are the length, width and height of the cavity and μ *and* ϵ are the permeability and permittivity of the material which fills the cavity. For an empty cavity, $\frac{1}{\sqrt{\mu\epsilon}}$ is equal to c which is the speed of light ($3*10^{10}$ cm/sec). The variables m, n, and p are integers and every combination will generate a different resonant frequency for the cavity. If we use the convention that L>W>H then the lowest resonant frequency of the cavity occurs when m=0, n=1 and p=1. For example, a cavity with dimensions 4cm x 3cm x 0.5cm, the lowest resonant frequency occurs at about 6.25 GHz. Note that this corresponds roughly to the point where the largest dimension of the shield (corner to corner) is one wavelength. This is a good rule of thumb for determining the lowest cavity resonance frequency of a cavity.

Note that this equation pertains to an empty cavity. If there is anything inside the cavity (PCB, IC, other components) the cavity will resonate at a lower frequency due to the impact on the calculation of μ and/or ϵ being greater than 1.

At millimeter wave (mmWave) frequencies, the wavelengths are small (30 GHz->1cm wavelength) hence virtually all shielding enclosures will exhibit cavity resonance at mmWave. This can cause a serious deterioration in shielding effectiveness. Cavities which contain a lot of material (such as PCBs and components) or contain materials with very high dielectric or magnetic properties will have lower resonant frequencies than an equivalent cavity with nothing inside.



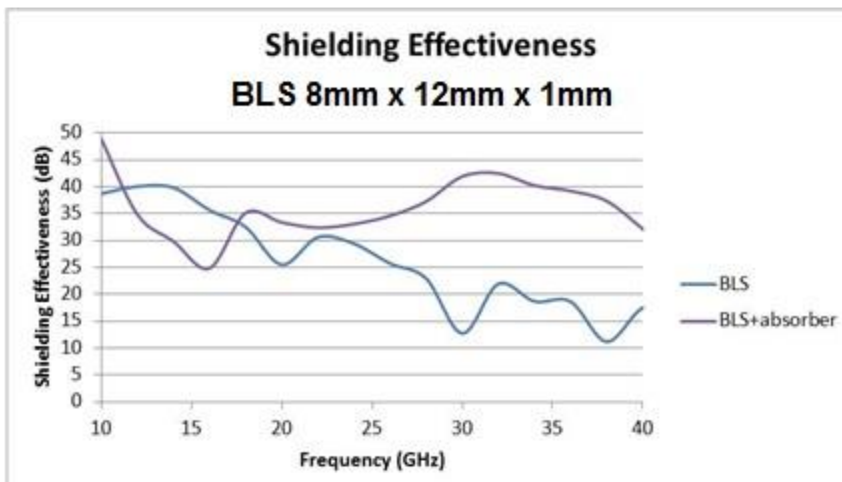
Cavity resonance:
Top-empty shield
Bottom-shield with ECCOSORB BSR-1 absorber

BLS with absorber

How does cavity resonance impact shielding effectiveness? As mentioned above, the radiation from any aperture or in a BLS is a function of the shape of the aperture and the size in terms of a wavelength. It is also a function of the magnetic field strength across the aperture. At cavity resonance frequencies, the fields 'fit' into the shield as an integral number of wavelengths. Electromagnetic theory tells us that on a conductive wall, the tangential electric field is zero. It also tells us that on a conductive wall, the tangential magnetic field is a maximum. The result of this is that at the cavity resonance frequencies, the magnetic field is maximized across any apertures in the shield, which maximizes the radiation leakage from each aperture which has a serious effect on shielding effectiveness.

As mentioned earlier, in the mmWave band, it is difficult to create a shield small enough to not exhibit cavity resonance that is still large enough to contain a component. A common technique from the RF/microwave world regarding cavity resonance can easily be implemented at mmWave. A small amount of absorber material inside a BLS can effectively reduce the cavity resonance and regain shielding effectiveness.

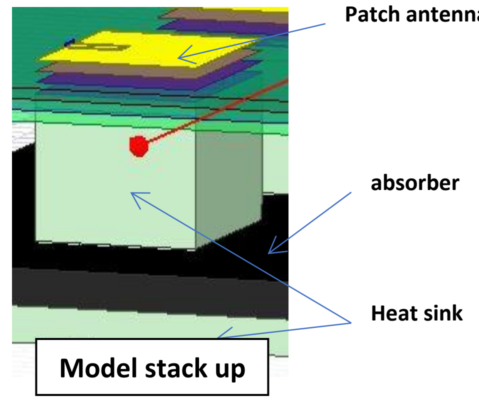
The graph at right compares the shielding effectiveness of an empty shield to one with a small amount of ECCOSORB 5G-MeF 1 which is a magnetically loaded silicone absorber deisgned specifically for use in the low mmWave band. This shield has a first cavity resonant frequency at around 20 GHz. Note the reduction in SE of the empty shield at that frequency. Adding the absorber has the effect of reducing the cavity resonant frequency. Note the SE for the BLS+absorber case pulled to the left. Above the cavity resonant frequency, however, the shielding effectiveness is greatly enhanced by the absorber. Laird offers BLS with absorber pre-installed.



Shielding Effectiveness comparison-empty BLS vs BLS with absorber

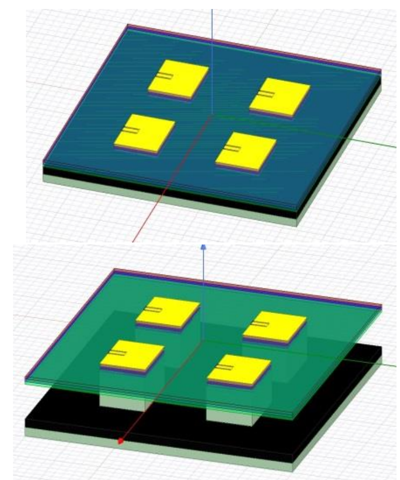
5G MIMO Arrays

5G systems which deliver high amounts of data will be used in the mmWave range. There is insufficient spectrum available at current frequencies in the microwave band. Due to the high transmission loss seen at mmWave and the desire to increase total data rates and users via spatial multiplexing, MIMO array technology will be used. A MIMO (Multiple In-Multiple Out) antenna uses several simultaneous beams to communicate with multiple users. This is done by creating a phased array of individual antennas. When properly excited in field strength and phase the antenna radiation will combine for form high gain signals in the user's direction. Typical MIMO arrays at mmWave use 64 elements (8x8 array) or 128 elements (16x8 array).

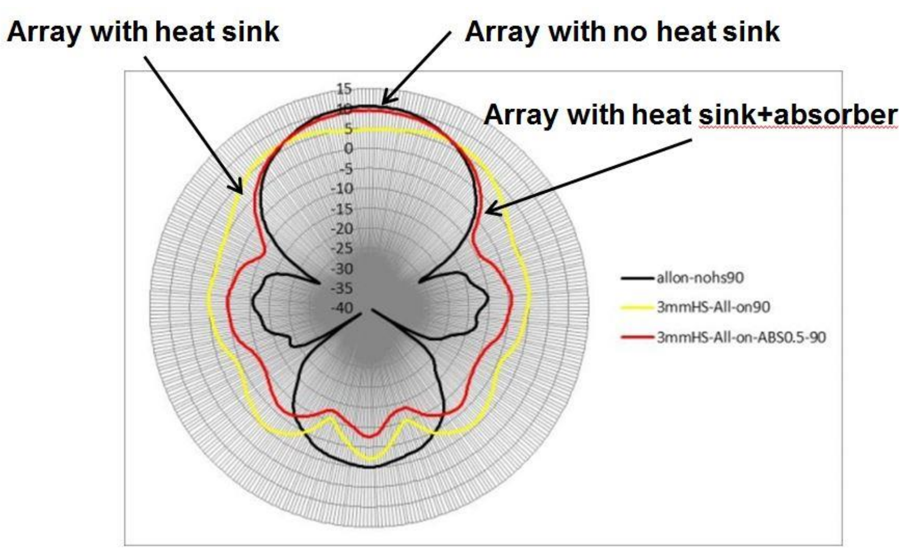


Model stack up

It is well known that thermal output can be an issue in MIMO arrays. Each element (or group of 4 elements) must have its own electronics including power amplifiers and analog to digital (or digital to analog) converters. These must all be contained in a relatively small area. A typical 8x8 array at 28 GHz may be as small as 8cm on a side. That is a lot of heat to dissipate. Common thermal solutions include transferring the heat to a heat sink. Thermal theory tells us that this heat transfer is more efficient if the distance between the heat source and heat sink is small. A Thermal Interface Material (TIM) is used to span the gap. Laird has a large selection of TIM's for these applications, including a selection with lower dielectric constants to minimize EMI effects. Now most heat sinks are made of metal and the presence of a large piece of metal in close proximity to an antenna can have adverse impacts.


1mm and 3mm heatsink distance

Electromagnetic modeling was used to gauge the effect on an antenna array of a heat sink in close proximity. In this model we used a 2x2 array of patch antennas optimized for performance at 28 GHz. This array was placed on the top of a PCB. A simulated source IC was placed on the bottom of the PCB. The heat sink was placed at varying distance from the PCBs with protrusions to the ICs which would help with thermal transfer. In reality these would be made of metal. In the model, they are perfect conductors. In one version, a magnetically loaded absorber [ECCOSORB 5G-MeF_1](#) is placed on the heat sink around the protrusions. The goal is to calculate the antenna pattern of the 2x2 array with and without the heat sink to determine the effect.



We would then calculate the antenna pattern with absorber included on the heat sink to see if coupling through this cavity behind the elements is affecting the antenna parameters.

The modeled antenna patterns are seen at left. The pattern with no heat sink is shown in black. The pattern with array plus heat sink at a distance of 3mm is shown in yellow. There is a large deterioration in directivity caused by the introduction of the heat sink. This is likely due to the fact that 3mm is about ¼ wavelength at 28 GHz. The antenna pattern of the array, heat sink plus absorber is shown in red. Note that the pattern in the forward direction has been restored to very close to the directivity without the heat sink.

Laird 5G materials

We're experts at creating high quality EMI and thermal solutions for some of the top names in the technology sector. The advent of 5G poses new, complex heat and interference challenges and we have a world-renowned portfolio of products and team of engineers who can help you solve all the issues from start to finish.