Study of Grounding Schemes Utilized in Conformal Shielding Applications

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Abstract

There are many different shielding technologies available for electromagnetic interference (EMI) shielding in radio frequency (RF) applications. We will investigate various EMI shielding technologies, one of which is RFMD's MicroShield™ Integrated RF Shielding technology's conformal plating process that encapsulates the device with a solid sheet of metal. This novel technology provides improvements in form factor, ease of use, and lower cost as compared to traditional shielding approaches.

We will compare ground designs within the substrate to determine maximum EMI shield performance. An examination of ground structures, layer grounding, and external ground connections will be analyzed. The test device structure will be comprised of a radiating element on the top surface of the laminate. A thorough look at the advantages and limitations between these different EMI grounding configurations will be discussed. This data will be used to quantify grounding effectiveness which will, in turn, be used to generate design guidelines.

Key words: EMI Shielding, Radio Frequency, RF, Conformal Plating, Module Packaging, MicroShield™, SiP

Introduction

In the marketplace there is a need to continually add value to product offerings. This can be done by reducing the customers' placement cost, inventory, and complexity. One of the largest cost drivers for original equipment manufacturers (OEMs) is the placement of an external shield. The majority of RF products require a shield over their components to prevent electromagnetic interference (EMI). The shield is used to prevent interference in three typical fashions: radiated emissions from sources inside the shield to outside, radiated immunity from sources outside the shield to inside, and to prevent cross talk between components under the manufacturer's shield on the printed circuit board (PCB). If individual components can be shielded just as effectively, then the overall solution can be reduced in size and complexity. This interference typically presents itself when the device is placed in its application. A shift in performance from the intended specification is normal. This effect can even cause a major redesign for other similar RF applications.

The industry standard for EMI shielding is a stamped and formed metallic sheet. These are typically called "cans." This kind of shielding can be found in many electronic devices such as cell phones and MP3 players. The main issues with external shields are an increase in component height, complication of rework, additional weight, and complexity in the supply chain.

With an extensive vendor base located worldwide and ready availability, etched and stamped shields may have an advantage. This type of shield can be formed into compartments to divide components from one another. As stamping and forming are one of the final manufacturing processes, they do not see all manufacturing steps. Still, despite their ready availability and seeming advantages, standard shield designs also contain many disadvantages, including unique designs for each application, large keep-out areas, and high costs.

To overcome the limitations associated with standard shielding methods, conformal shielding was developed. This technology, developed by RF Micro Devices and discussed in this paper, is MicroShield™ Integrated RF Shielding technology. This technology improves the overall form, fit, and function of the package and simplifies the design for most applications (see Fig. 1). Many different shielding techniques and methods were evaluated. MicroShield™ was deemed the best shielding technology for system-in-package (SiP) modules. MicroShield advantages include an 80 to 90 percent reduction in the shielding cost, compartmental shielding within the SiP module, and ease of applications design for customers.

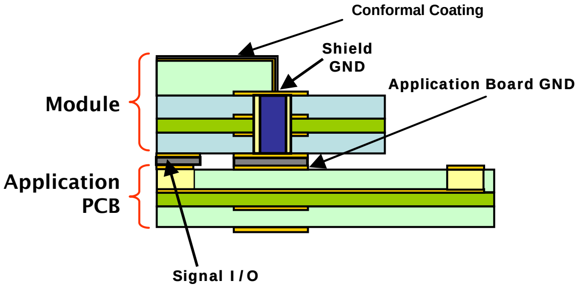


Fig. 1 Conformal shield and grounding method.

Conformal Shielding Process

The process to apply MicroShield™ to the module utilizes standard industrial equipment. The process starts with a fully populated laminate exiting the front end of the line. Prior to reaching the final singulation, the molding compound is sawed through to expose a grounding pad. This grounding pad is located around the entire periphery of the module and is critical in ensuring that the shield maintains continuity. A plating process (see Fig. 2) is then employed utilizing electroless and electrolytic plating typically seen in high density interconnect laminates. The plating takes place on the front side of the module with the I/O side protected from the plating chemicals. This is to ensure that the final device is not shorted to the shield. A final singulation process takes place to yield the final device. Figure 4 shows an example of each step in this process.

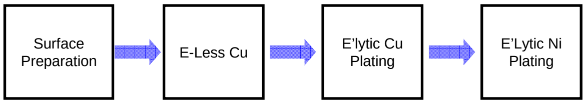


Fig. 2 Process flow for plating application.

The shield consists of three distinct plating layers as shown in Figure 3. The first layer is an electroless copper. This is used as a seed layer for the subsequent layers. The second layer is electrolytic copper, which creates a thick metal layer for attenuating the emissions. The final layer, made of electrolytic nickel, provides environmental protection.

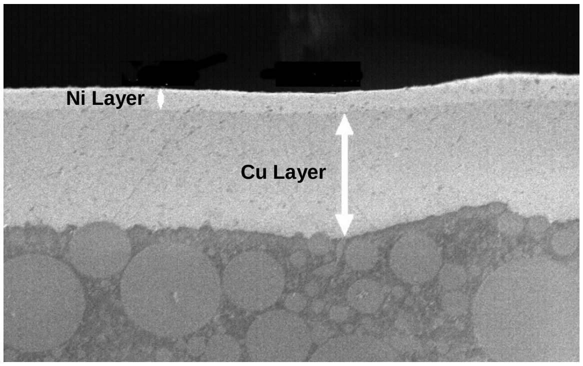
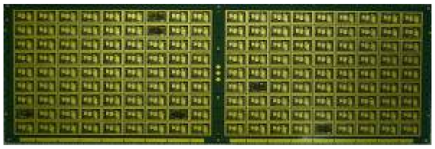
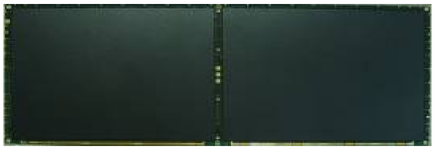


Fig. 3 The Cu/Ni plating material after application on top of mold compound.

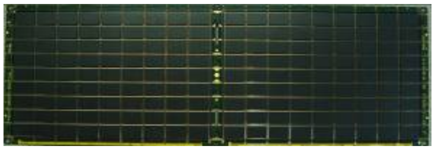
Since 2007 this plating process has been used in high-volume production on multiple front end and transceiver modules. During that time over two hundred million units have shipped. The manufacturing yield on the conformal shielding processes is above 99.6 percent.



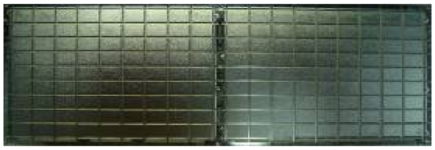
A) Laminate



B) Molded



C) Sub-diced



D) MicroShield

Fig. 4 Pictures illustrating the process flow of the laminates as processed for MicroShield™ technology.

Product Design Methodology

To bridge the gap between the lab and high-volume manufacturing of shielded modules, robust design techniques must be used. Care must be taken to ensure that the emissions of the different shields match. In addition, the grounding schemes utilized must be tested relative to each other. This will drive the design guidelines and give future product designs a good starting point for performance.

During the development phase of a new product, when conformal shields are utilized, issues with tuning of parts can arise. An advantage of can-style shields is that they can be placed and removed multiple times without issue. This allows for module device tuning and modification without removing the component from the evaluation board. Conformal shield techniques do not allow this because they utilize the molding compound for structural integrity.

To ensure that the performance of a can shielded product closely follows that of a product using MicroShield™, the inner dimensions of the can shield must match the outer dimensions of the molding compound. This ensures the radiating component maintains a consistent distance from the shield. The lip of the can will rest on the peripheral ground pad at the same location as the conformal coating. This distance, both height and width, is critical in shield performance, especially at higher order harmonics. During the assembly of the modules, the can is placed in solder paste either by hand or machine. A subsequent reflow is done to form a solid connection.

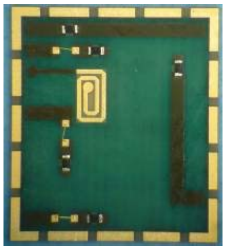


Fig. 5 Example of test vehicle with a ground ring around the periphery of the device.

The top metal ground ring and its connection through the laminate (see Figures 5 and 6) are critical components of the shield performance. The optimum performance will be achieved by forming a direct connection from the top of the laminate board to the bottom side. For most applications this is not feasible since required area is a premium. That means that the ground must be routed from the periphery of the laminate top to multiple bottom side pads. The location, spacing, and connection of this routing can have a large impact on the shield attenuation.

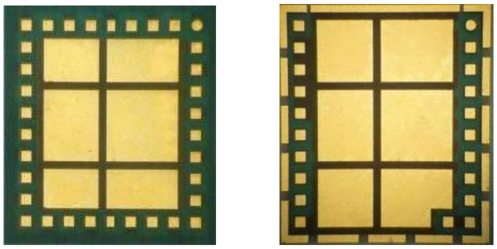


Fig. 6 Examples of test vehicle with bottom metal ground and signal connections.

With routing needed to form a connection to the ground, via structures are needed. These structures can be either round or slotted depending on the process. Both of these via styles are created using a laser drill operation. This is a standard process used by all major substrate manufacturers. Plating processes are then employed to create a metal connection between laminate layers. The spacing and distance of the via connections is critical for reducing part emissions. This is because the radio waves have a set size depending on the frequency. As the frequency increases, the wavelength decreases. For most applications (0.4 GHz to 12.0 GHz), the wavelength will vary between 750 mm and 25 mm depending on the relationship

$$\lambda = \frac{v}{f}$$

λ Wavelength

v Velocity of the wave (default is velocity of light in vacuum: 300.000 Km/s)

f Frequency

Eq. 1 Sinusoidal waveform traveling at constant speed.

There were 10 different grounding schemes employed (Table 1). Each of these is different and represents a typical module configuration. The variables used in these variations are noted as via, connection point, and ground. The via consists of either a round or slotted style. The connection point references on which laminate metal layer the shield is routed to ground. All samples form the initial connection to the shield on laminate layer one. The two, three, or four denotes which layer (out of four) the routing occurs to the ground. The ground column references to metal four pads where the connection to ground is made. The ground and signal pads on the bottom are located at a pitch of 800µm.

Design Variation	Via	Connection Point	Ground Pads
Can	Round	Layer 4	Periphery
1	Round	Layer 4	Periphery
2	Round	Layer 3	Every other pad
3	Round	Layer 3	Every third pad
4	Slot	Layer 4	Periphery
5	Round	Layer 3	Every third pad Signal Change
6	Slot	Layer 2	Every other pad
7	Slot	Layer 3	Every other pad
8	Slot	Layer 3	Every third pad
9	Round	Layer 3	Corner only

Table 1: Design variations

Fig. 7 Examples of non-plated and shielded parts.

Electrical Testing

Shielding effectiveness is based on a comparison between shielded and unshielded parts. Each design variation is compared to its unshielded counterpart to get a relative shielding effectiveness. All of the shielding samples were measured using a Gigahertz Transverse Electromagnetic Cell (GTEM™). Using a GTEM™ chamber, one measures the emissions in three orthogonal axes. An algorithm is then used to create an equivalent emission measurement. To ensure that the boards were not radiating and impacting the measurements, the test samples were mounted on shielded PCB boards. A known signal was applied to the part through an open trace. A receiver in the chamber then measured the output signal. For this application, the goal is to determine the best attenuation.

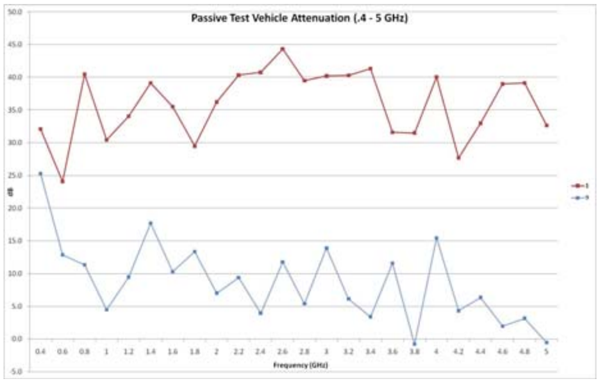


Fig. 8 Measurement data of the best and worst shielding methods (variations 1 and 9). All data is normalized to the non-shielded reference part.

The chart in Figure 8 shows the attenuation of shielded parts that are normalized to unshielded samples. The chart extends to 5.0 GHz. Typical frequencies for the cellular market are below 3.0 GHz. This figure illustrates the shielding effectiveness using the best and worst sample parts. As shown in this chart, a wide range of attenuation can be achieved based on the way the shield is connected to ground. The best case (top line) is ground variation one. This has a via connection around the entire periphery of the laminate connecting through to a corresponding connection on the test board. The worst case (bottom line) is design variation number nine. The metal one ground is connected only in the corners of the laminate. This means that the laminate pads are only grounded in the corners. The signal can escape along the entire edge of the laminate.

There is also a large variation within each curve as shown in Figure 8. It can be seen that the response is frequency dependent. There are multiple reasons for this. First, the input signal wave reflects on the surfaces of the shield and test chamber. As the waves bounce within the chamber, there is an additive and subtractive component. Second, the attenuation is calculated relative to an unshielded module. The unshielded module does not track at the same emission level as the shielded version. Finally, the material properties of the test coupon have a dielectric component. This can affect the frequency measurement by absorbing or reflecting signals depending on the frequency level. At the higher frequency levels as shown in Figure 9, the delta between designs decreases. This is due to the shorter wavelength's ability to escape containment.

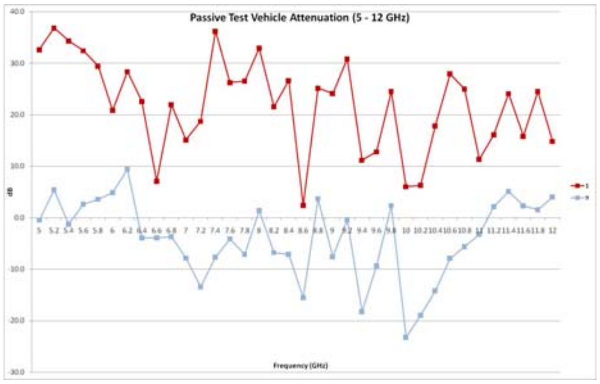


Fig. 9 Higher frequency measurements of Figure 8 design comparison.

For comparing the designs, the variation in the measurement can be averaged over different frequency ranges. This is shown in Figure 10. The averaging ranges are split between 0.4 to 3.0 GHz and 3.2 to 12.0 GHz. The lower range represents the typical cellular bands. The higher range represents harmonic waves seen in some applications. As the frequency increases, the performance of all the grounding schemes decreases. This is directly related to the wavelength's decrease in size. The ground cannot isolate the source as effectively due to the decrease. The waves escape containment and radiate outward.

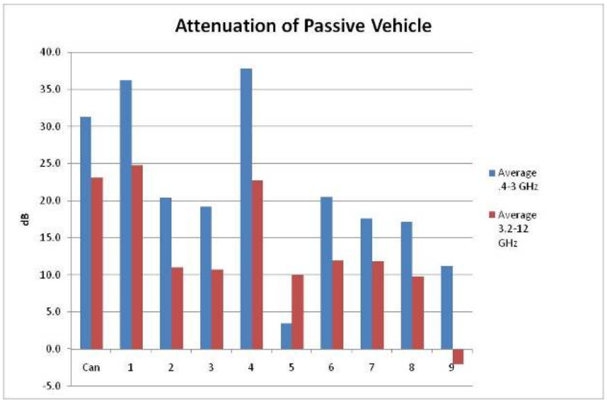


Fig. 10 Average attenuation of all design variations. Each design's average is shown over two different ranges.

As expected, the laminate ground versions that are directly tied to the test board performed best. These are the can, 1, and 4 versions. Intuitively this result follows logic. The entire laminate is shielded from the top to the bottom all the way around the periphery. One can also infer that there is little difference between via design and ground pad spacing. Designs 2, 3, 6, 7, and 8 all vary either the via style or spacing. The attenuation variation is within 3 dB. This is within the measurement error of the test setup. The biggest anomaly is Version 5. This design has a surface-mount resistor connected to the shield ground. At lower frequencies this acts similar to an antenna. At the higher level the emissions are absorbed by the surface mount device and are not radiated at as high a level. Version 9, which grounds the laminate in the corners, has nearly 10dB of attenuation. This is much lower than all other designs. At higher frequencies, the part actually behaves as an antenna. This attenuation is much lower than the samples that ground on a tighter pitch.

Conclusions

From a shielding performance standpoint, almost all design iterations were acceptable. The optimum is forming a ground around the entire periphery of the bottom of the laminate. For most applications this is not possible due to customer requirements. As shown, the ground can be routed effectively from the top of the laminate to the bottom through intermediate layers without an impact in performance. The via configuration and style of the routing is not critical. It is crucial to have ground connection spaced on the sides and not exclusively in the corners.

Based on the measurement results future manufacturing and design rules can be created. Can style shields may be employed in prototyping. As long as the inner dimensions X, Y, and Z match that of conformal shielding, attenuation correlation will be achieved. For this application, the can shield has 6 dB less attenuation than an equal conformal design. For product development purposes, this is well within acceptable levels.

Acknowledgments

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