Simulation of PCB Enclosure with Aperture for Shielding 5G High Frequency

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ABSTRACT

5G frequency is a new area of research, with minimal rollout in many countries. It can be sectioned into low band frequency, sub-6 GHz, and millimeter wave (mm Wave). Millimeter wave deals with frequency ranging from 24 GHz to 100 GHz. Such signals do not travel very far despite having a high transmission rate. Due to this most objects placed far away do not face electromagnetic interference (EMI) from 5G frequencies. However, the object most likely to be in danger of EMI from 5G frequencies are integrated circuit chips (ICs) on printed circuit boards (PCBs) that are found in 5G cell phones. As they are packed close to the 5G frequency source, the implementation of PCB shielding becomes imperative. In an ideal world, a perfect shield will have no aperture or defects, and shall have a very high shielding effectiveness of 100 dB. Yet, apertures are needed for thermal ventilation, inserting input or output ports, inserting microstrips as well as for visibility. Therefore, having a PCB shield with apertures and good shielding effectiveness is needed for the functionality of wireless communication technology. Recent studies have shown advances in frequency selective surface (FSS) materials, where certain frequency bands are filtered off, allowing certain bands to pass through. This paper analyzes different aperture shapes and sizes of frequency selective surfaces (FSS) to mitigate the EMI from the 5G 28 GHz high frequency range. It was found that a 1 mm x 1 mm size aperture in Christian cross shape provided shielding effectiveness of 33.7 dB at 28 GHz frequency range.

Keywords: Millimeter Wave (mm Wave), Electromagnetic Interference (EMI), Printed Circuit Board (PCB), Shielding Effectiveness (SE).

1 Introduction

The Federal Communications Commission has finalized its initial 5G spectrum auctions in the 28 GHz range [1]. 5G is planned to support a greater number of users and deliver a higher data rate compared to the older generation. Unfortunately, the issue of electromagnetic interference (EMI) is predicted to persist, if not worsen. As a result, experts from all over the world have focused their attention on shielding such frequency ranges according to their specific needs [2, 3]. Numerous shielding techniques have been proposed, including nanocomposites [4, 5], metamaterials [6, 7], and frequency selective surfaces (FSSs) [8-10]. When electromagnetic shields incorporate apertures, lower frequencies are prevented from propagating through the aperture due to the aperture's broad cut-off wavelength. However, protecting small circuits such as PCBs with holes becomes more difficult with 5G high frequency. Board level shielding (BLS) is a frequently used technique in electromagnetic shielding for isolating electromagnetic interference, particularly on circuit boards with purposeful RF emission [11]. In this paper Frequency Selective Surfaces (FSS) has been used to attempt shielding 28 GHz high frequency. Extensive deliberation has been carried out on the ideal perforated patterns and materials that would satisfy not only the design requirements, but also provide effective of shielding.

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2 Methodology

The shielding effectiveness of an aperture type shield was assessed through modelling an FSS, simulating the design, and analyzing the result using Ansys HFSS software. The range of 5G frequency selected for PCB shielding was 28 GHz.

2.1 Materials and Methods

The unit cell feature is used in HFSS. This feature models a single element as though it were in an infinite array environment. The infinite array environment is accounted for by enforcing field periodicity through Master/Slave boundary pairs. Use of the unit cell also reduces RAM and solving time. This is because the field excited for a single unit cell is calculated and extrapolated for the entire surface. Moreover, the magnitude of electromagnetic wave excited was assumed uniform.

2.2 Design Specification

Material: Perfect Electrical Conductor

Physical Parameters: Thickness = 10 μm, tan S = 0.02

Operating Frequency: 28 GHz

The unit cell dimension: 12.5 mm x 12.5 mm

Aperture dimension: 1 mm x 1 mm in the centre and 1.5 mm x 1 mm on the edge

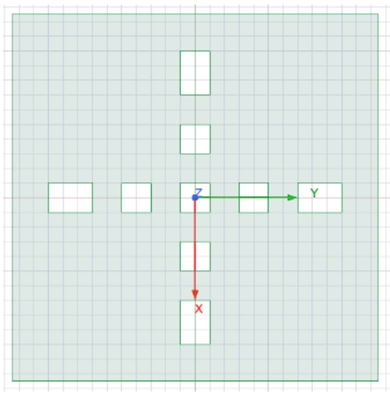


Figure 1: *Single Layer Christian Cross sliced Aperture*

3 Theory and Calculation

Complete shielding of electromagnetic interference of a material is achieved mainly by three mechanisms: reflection (SER), absorption (SEA) and multiple reflection (SEM) [12-14]. Shielding due to reflection is caused by the interaction between electromagnetic waves and free charges on the material surface.[15] Therefore, perfect electrical conductors are useful for shielding by reflection. Dielectric or magnetic dipoles usually assist in shielding through absorption [16]. However, at very high frequency the ability of magnetic material to absorb is reduced [17]. Shielding through multiple reflection is caused by internal reflection inside the enclosure, usually with bigger enclosures with greater surface area [15]. Usually shielding due to multiple reflection is considered negligible if the total shielding effectiveness is over 15 dB [18].

Therefore, shielding through reflection and absorption are the primary ways for EMI shielding. The shielding effectiveness of a conductive material without seams and apertures may be expressed using equations 1-3 as below [19, 20].

$$SE(R) = 39.5 + 10\log\left(\frac{\sigma}{2\pi f\mu}\right) \quad (1)$$

$$SE(A) = 8.7t\sqrt{\pi f\mu\sigma} \quad (2)$$

$$SE = 39.5 + 10\log\left(\sigma/(2\pi f\mu)\right) + 8.7t\sqrt{\pi f\mu\sigma} \quad (3)$$

Where the frequency of electromagnetic wave is represented by f, μ is the magnetic permeability, σ is the conductivity and t represent the sample thickness. It can be known that shielding effectiveness due to reflection and absorption will increase with the conductivity and that absorption is proportional to sample thickness.

3.1 Mathematical Expressions and Symbols

Using the HFSS software and performing simulation, the parameters (S_{11}, S_{12}, S_{21}, S_{22}) were obtained. This result was converted from transmission coefficient to shielding effectiveness using the following equations 4 – 6[21].

$$SE(\text{ Total }) = 10\log\frac{1}{|S_{12}|^2} = 10\log\frac{1}{|S_{21}|^2} \quad (4)$$

$$SE(R) = 10 \times \log\left(\frac{1}{(1 - S_{11}^2)}\right) \quad (5)$$

$$SE(A) = 10 \times \log\left(\frac{(1 - S_{11}^2)}{S_{12}^2}\right) \quad (6)$$

Where S_{11}, S_{12} and S_{21} are the forward reflection coefficient, reverse transmission coefficient and forward transmission coefficient respectively.

4 Results and Discussion

After conducting several simulations, it was found that when double layer of metal sheet was placed with apertures in Christian cross pattern the shielding effectiveness was seen to increase significantly. It was also seen that reduced aperture dimension alleviated the EMI shielding. On another experiment, three layers of metal layer was used whilst keeping the aperture dimension constant. The result showed no significant enhancement of shielding effectiveness and the output result remained similar to the result found with double metal layer. It was also seen that with the other apertures used, for example swastika aperture or three-legged aperture, there was no increase in shielding effectiveness and uneven shielding was seen in the 28 GHz range. Therefore, the new model prepared was two sheets of Christian cross with reduced aperture dimension along with a 0.1 mm air gap in between. The unit cell as shown in Figure 2 below was 12.5 mm by 12.5 mm. The aperture dimension was 1 mm x 1 mm in the center and 1.5 mm x 1 mm on the edge. The model was simulated.

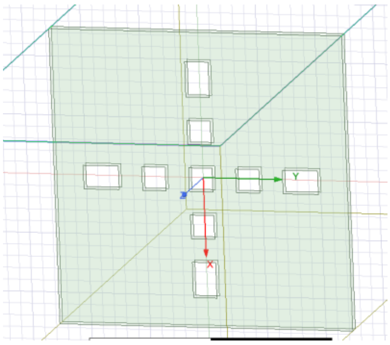
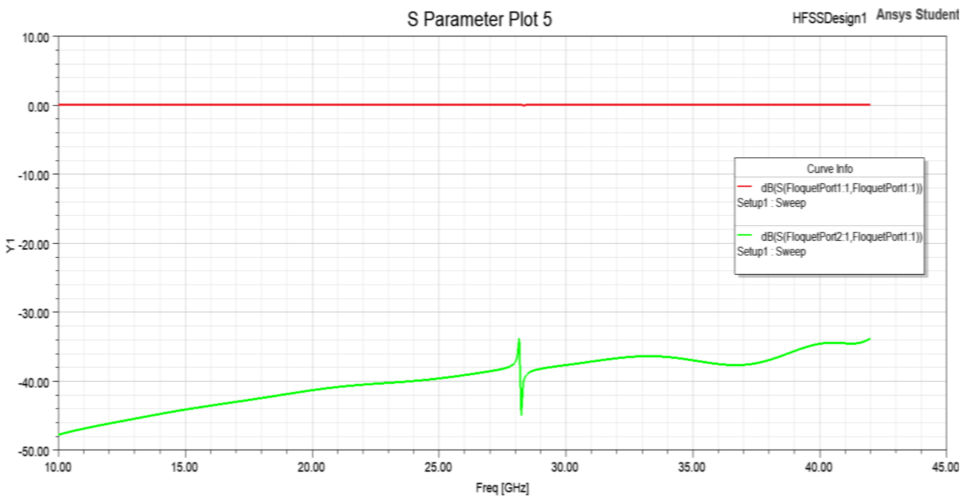
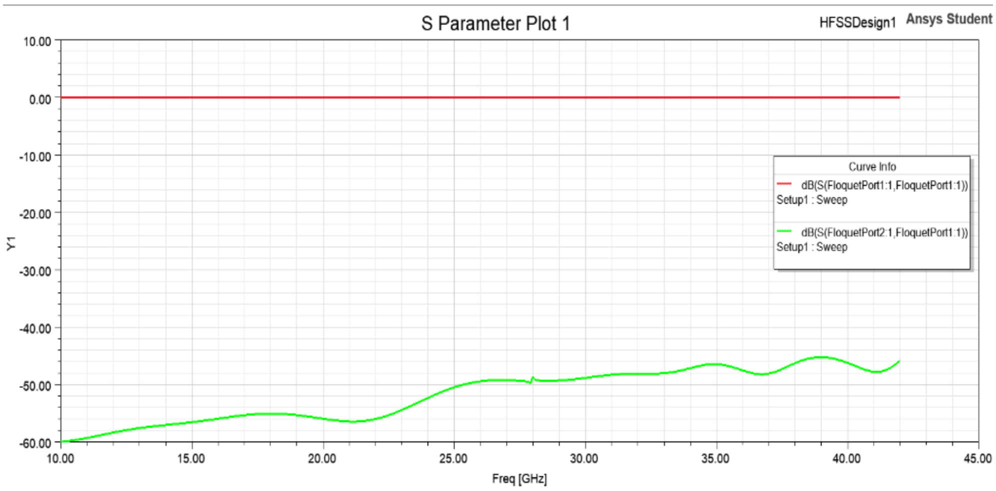


Figure 2: *Double Layered Christian Cross Aperture with 0.1 mm Air Gap*

The simulated results in Figure 3(a) below show that at 28 GHz a transmission loss of 34 dB was obtained for single layer aperture whereas a transmission loss 49 dB was obtained for double layered aperture as shown in Figure 3(b). This was a massive improvement compared to the simulation result from a single sheet. An increased transmission loss of 15 dB was obtained by doubling the shielding layer. Moreover, the curve obtained for double layered FSS model had a reduced resonance compared to single layer model which is demonstrated by the reduced spike at 28 GHz frequency.



(a)



(b)

Figure 3: (a) *Transmission Coefficient for Christian Cross Aperture Single Layer,* **(b)** *Transmission coefficient for Christian Cross Aperture with Double Layer and 0.1 mm Air Gap*

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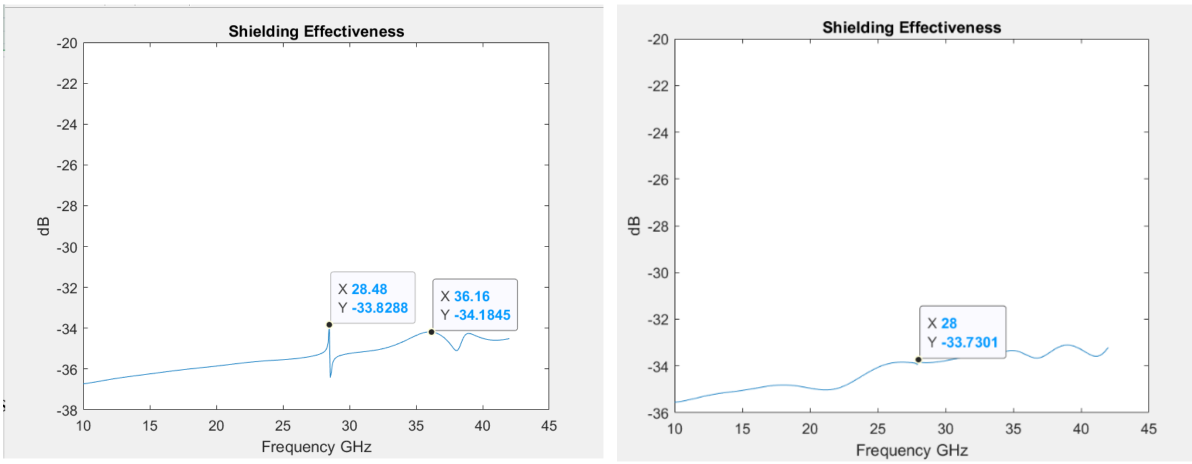
The Figure 4(b) below shows that applying double layer sheet has higher shielding effectiveness as compared to when single layer sheet with same aperture dimension was implemented (Figure 4(a)). Moreover, the point of resonance was removed at 28 GHz frequency for double layer metal sheet. This is approved by observing no spike in the shielding effectiveness curve for the double layered sheet, which is otherwise present in the single layered shielding material as seen in Figure 4(a). At 28 GHz frequency a 33.73 dB shielding effectiveness was obtained for double layered Christian cross aperture.



(a) (b)

Figure 4: (a) *Shielding Effectiveness of Christian Cross Aperture Single Layer,* **(b)** *Shielding Effectiveness of Christian Cross Aperture with Double Layer and 0.1 mm Air Gap*

5 Conclusions

The paper focused on creating a shielding enclosure for PCB from 28 GHz high frequency range of 5G signals. Using HFSS software several FSS structures were created and simulated with several aperture sizes and shapes. Several combinations of absorbing and dielectric materials were used to obtain the maximum shielding effectiveness at 28 GHz range of frequency. The shielding effectiveness of each aperture along the way was analysed to obtain the final aperture design. When Christian cross aperture was etched out of a metal sheet and double layer was provided, a shielding effectiveness of 33.7 dB was observed at 28 GHz frequency range region. Moreover, a similar shielding effectiveness was observed from 10 GHz – 40 GHz region confirming that the shield could be used universally because different countries have different frequency ranges for 28 GHz region. All those frequency ranges were shielded by the final simulated shield model. However, the results are based on simulation and implementation on a hardware may bring in some external EMI influences or heat generation within the PCB shield.

6 Declarations

6.1 Study Limitations

A major limitation in this research is due to lack of previous studies conducted for shielding effectiveness at 28 GHz frequency range. Since 5G is a new area of research, few papers were found focusing on high frequency range as such 28 GHz. Lack of scope of discussion is another limitation which compromises the depth of discussion in the paper.

6.2 Acknowledgements

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6.3 Competing Interests

There is no conflict of interest.

6.4 Publisher's Note

AIJR remains neutral with regard to jurisdiction claims in published maps and institutional affiliations.

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