Modeling Analysis of Frequency Selective Surfaces (FSS) for Wide Band Shielding in Electromagnetic Applications

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ABSTRACT-Frequency selective surface (FSS) is a repeated structure is transmitting, reflecting or absorbing based up on the mode of interest by using patches or slots. The patch and slot arrays effectively create stop band and pass band filters. Electromagnetic shielding is surrounding electronic equipments and cables with metallic or magnetic materials to block against incoming or outgoing emissions of electromagnetic frequencies (EMF). The FSS have potential applications in providing sufficient Shielding in the desired frequency ranges. The work proposed in this paper is to study & analyze the FSS structural requirements to shield against the some band of frequencies. This FSS, which consists of Greek cross and Circular rings printed on the opposite sides of a FR-4 substrate, exhibits a wide, 7.5-GHz stop band to provide shielding in X- and Ku-bands. This paper is primarily based on the simulation analysis of the designed FSS structures using EM software tools.

Key words: Frequency Selective Surface, Electromagnetic Frequency, Greek cross, Circular rings

1. INTRODUCTION

The subject of electromagnetic shielding was used extremely low frequency and very low frequency [1].There a necessity to protect circuits and radio-receiving equipment from disturbing effects of radiated fields. Nowadays Electromagnetic interference (EMI) shielding is highly used due to the increasing mobile phone and satellite technologies. The radio devices directly or indirectly impose potential hazards to human health and there exists a communication system due to radiated interference. This has led to find out the solutions for effective isolation from the interference signals. Although the main objective is to obtain all stop filter characteristics, to allow certain band of EMI to pass [1]–[4]. Generally, thin metal sheets are implemented to attenuate the unwanted radio frequency generated by the external sources.

Previously, ferrite cases and holed or plane mild steel tins have also been tested to provide the effective shielding. Electromagnetic band gap structures can also be used to block or guide the waves in certain directions by creating band gaps [5]–[6]. However, 2-D periodic structures like frequency selective surfaces (FSSs) have been attractive options because of their low profile and ease of fabrication. Frequency Selective Surface (FSS) is a repetitive structure acts as a filter and has wide range of applications such as radomes, lenses, RFID, Protection from electromagnetic interference, medical and military sectors These FSSs have been successfully tested as spatial filters, frequency absorbers, and polarizers [7]. Additionally, FSSs have also been proposed for electromagnetic shielding. Some FSSs also offer the advantages of transparency, less weight, and ventilation for considered applications [8]. The FSS is placed in the ground plane of a reflector array to achieve broadband operation by controlling the phase of the reflected wave. In some other recent articles, FSSs have been used as backing reflectors for extending the frequency range of usability [9]. FSSs have been sandwiched between the antenna and the ground plane, providing additional reflecting plane higher frequencies. In most of these designs, the operation of the FSS has been limited to a narrow frequency band [9], [10], although dual and wideband operation has also been considered in recent publications [11], [12]. In [13], a dual-layer FSS exhibited a linearly decreasing phase and low transmission coefficient to enhance the antenna gain, but this FSS does not fulfill certain requirements of low-profile and compactness due to its dual-layer configuration. Some wideband FSSs [14] were also tested for wide reflection bands. The metal films/surfaces [15] were designed and concluded to have angle-independent reflection and transmission properties; one should have the transverse surface susceptibilities sufficiently large, as compared to the normal component of the surface susceptibility; then, the metal films would exhibit this angle-independent property. The absorber and shielding designs in [16]–[19] have used different approaches to achieve larger absorptivity and increased bandwidth by using complex geometries such as perfect magnetic absorbers, high impedance surfaces, and split-ring resonators with magnetic inclusions, etc. However, in all these, the shielding bandwidths obtained are narrow. This paper presents a single-layer FSS that exhibits an attenuation of more than 10 dB with a wide 7.5-GHz stopband from 6.5 to 14 GHz range.

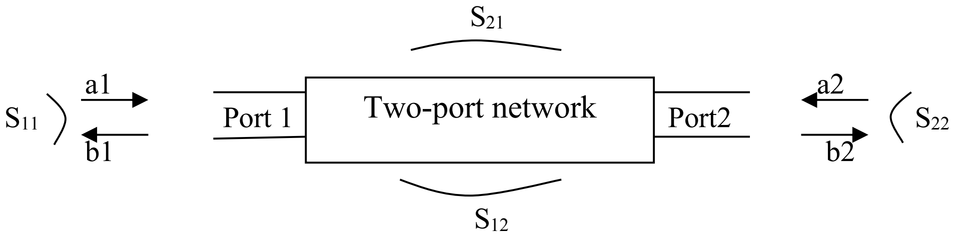

Figure1. Schematic of two-port network.

2. S-MATRIX AND SHIELDING EFFECTIVENESS (SE)

In discussing general filtering problems, S-matrix can play a very important role. Figure 1 gives the schematic of two-port network, in which a_i and b_i (i=1, 2) stand for normalized voltage incident wave and reflection wave, respectively, and they are determined by waves on the transmission line Through formula deduction, S-matrix can be written as the linear relation between reflection wave b and incident wave a, and it can be derived from the following
Formula (1)

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \quad (1)$$

Here, S-matrix is called scattering matrix of the two ports, and each of the four S parameters has definite physical significance. Specially, S_{21} is transmission coefficient of port1 when port2 connects matched load and it can be calculated from formula (2)

$$S_{21} = \frac{b_2}{a_1}\bigg|_{a_2=0} \quad (2)$$

The meaning of S21 is illustrated from the perspective of microwave transmission line theory, but in many cases, the energy loss due to the difference between EM impedance and the intrinsic impedance of shielding material is more intuitive for designers to characterize and evaluate the material. According to Schelkunoff Principle, for conductive monolithic materials without holes, the shielding effectiveness can be calculated from formula (3)

$$SE = SE_A + SE_R + SE_M = 10\log\frac{P_1}{P_2} \quad (3)$$

Where, SE represents shielding effectiveness, which means the attenuation degree of EM wave caused by shielding materials, and the unit is dB. SE_A stands for absorption loss, positively correlated with electrical conductivity, magnetic permeability, EM wave frequency and shield thickness; SE_R stands for reflection loss, positively correlated with electrical conductivity, while negatively correlated with magnetic permeability and EM wave frequency; SE_M stands for multiple-reflection loss, related to SE_A and can be ignored when SE_A is greater than 15 dB. P_1 and P_2 are received power without and with the tested material. Actually, S21 means the ratio of transmitted wave (equivalent to P2) to total incident wave (equivalent to P1) when EM wave passes through the medium. Therefore, S_{21} can be calculated from formula (4)

$$S_{21} = 10\log\frac{P_2}{P_1} = -SE \qquad (4)$$

As a medium in EM field, periodic structure, like FSS, can be also evaluated through S_{21} parameter. The FSS structure is to shield or make through EM wave with the frequency of 6.5-14GHz. Based on S_{21}, the simulation was accomplished and FSSs were fabricated.

3. DESIGN PROCEDURE

Figs. 2(a) and (b) depicts the geometry of the FSS unit cell and the use of two printed elements, namely a cross dipole and a ring. Fig. 2(c) shows the perspective view of the unit cell. The cross dipole and the ring are each printed on the two surfaces of an FR-4 substrate. The dimensions of this unit cell are 12 × 12 mm^2 along the *x*- and *y*-directions, respectively. The length of cross dipole is 11mm and its strip width is 0.6 mm.

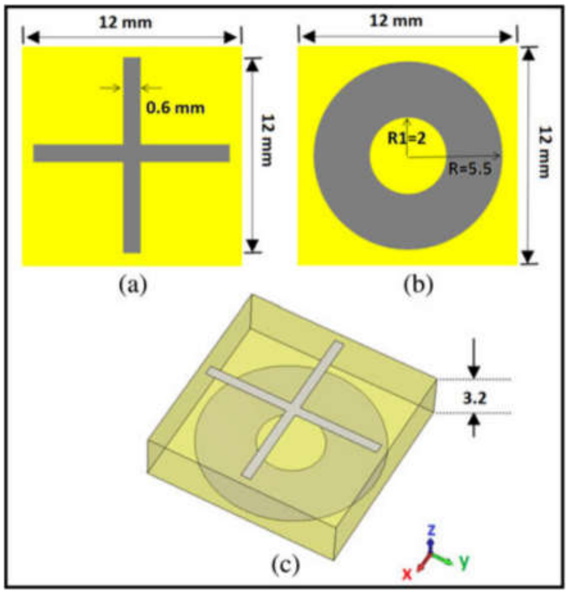

Figure2. (a) Top surface: Greek cross element. (b) bottom surface: ring patch element.
(c) Perspective view: both (all dimensions are in mm).

The ring's outer radius is 5.5 mm while the inner radius is 2 mm. The supporting FR-4 substrate thickness is 3.2 mm and its dielectric constant is 4.4 with a loss tangent of 0.02. In the numerical simulations, the conducting elements printed on the opposite surfaces of the substrate have been modeled as perfect electric conductors with zero thickness. The design process starts with the designing of individual unit cell elements shown in Figure. 2(a) and (b). Fig. 3 presents the transmission, i.e., the magnitude of the S21 scattering parameter, of the proposed single-layer FSS. It was found that when the rings are absent, the greek cross resonate at 7.7 GHz yielding a very narrow stop-band of 0.86 GHz wide at –10 dB level. With only the rings printed on the substrate, the FSS resonates at 12.18 GHz, exhibiting a stopband that is 5.3 GHz wide. However, with both elements together, a very wide 7.5 GHz stopband from 6.5 to 14 GHz is achieved at –10 dB.

4. SIMULATION AND RESULTS

The unit cell geometry of proposed FSS was built in FEKO using periodic boundary conditions as shown in Figure3. The FSS structure composed of two layers. The upper layer was greek cross FSS structure and the lower layer was circular ring FSS structure. The FSS structure is assumed as perfect electric conductor in modeling with zero thickness. The periodic boundary condition is applied to the FSS structure because of its repetitiveness.

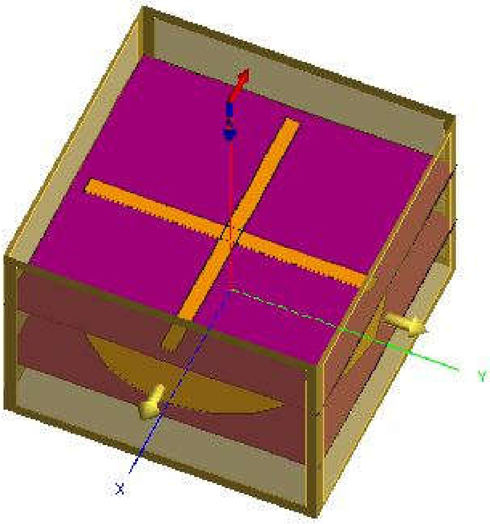

Figure3. Unit cell geometry in FEKO

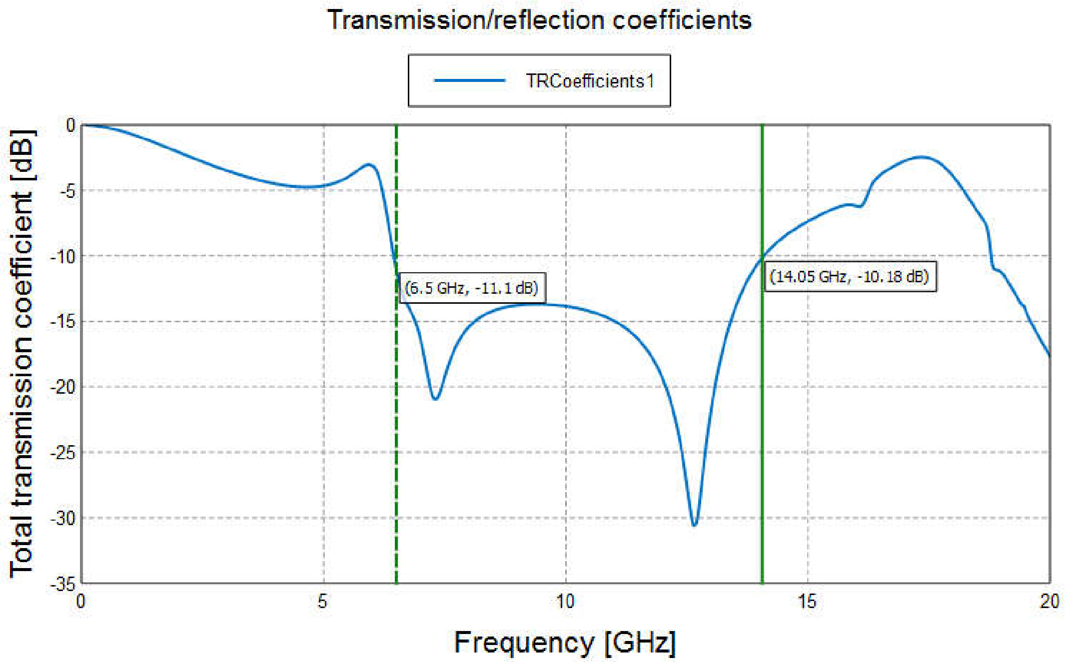

Figure4. Transmission coefficient (S_{21}) of Proposed FSS

The transmission characteristics (S21) of the proposed FSS design is given in Figure 4. The length of each element is designed to reflect some frequency band. Simulation results for FSS, the bandwidth is 7.5GHz which ranges from 6.5GHz to 14GHz.

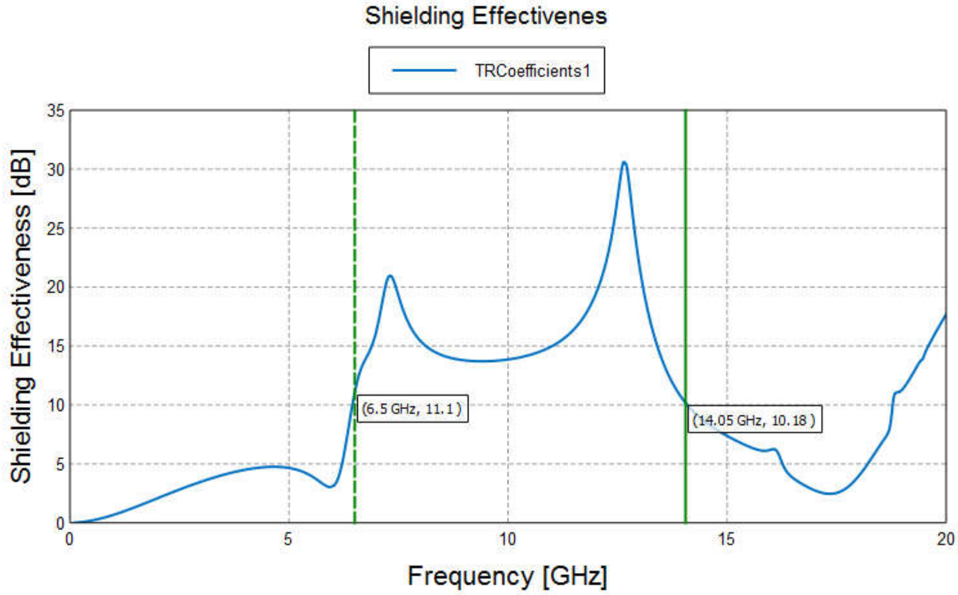

Figure5. Shielding Effectiveness (SE) of Proposed FSS

Shielding effectiveness of FSS is shown in figure 5. The simulation result for FSS, shielding effectiveness is more than 20-35dB over a wide band of 7.5GHz ranging from 6.5GHz to 14GHz. In the unit cell of FSS only the greek cross structure presents in the CAD modeling is shown in figure 6.

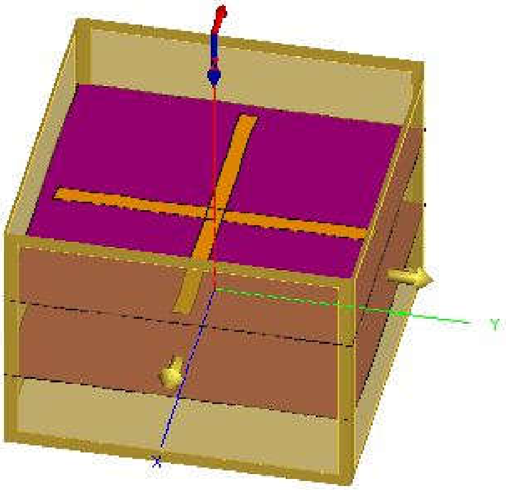

Figure6. Unit cell geometry of Greek Cross FSS in FEKO

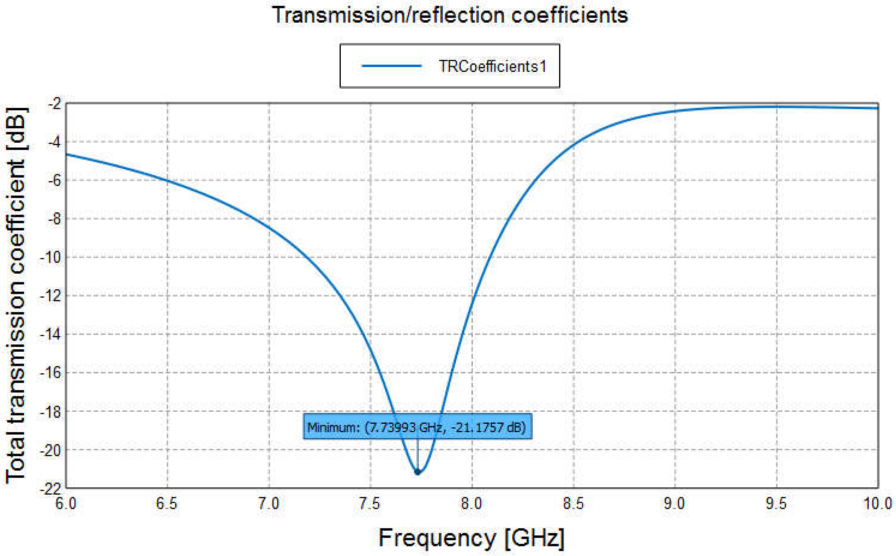

Figure7. Transmission coefficients (S21) of Greek cross FSS

The transmission coefficient of Greek cross FSS is resonates at 7.7GHz is -21.17dB. The bandwidth is very narrow that is ranges from 7.2GHz to 8GHz. The proposed FSS only the circular rings are present as shown in figure 8.

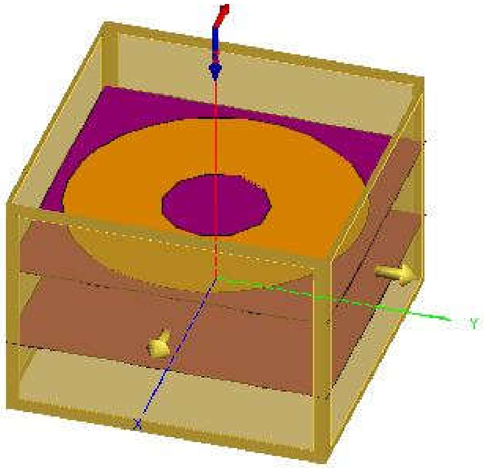

Figure8. Unit cell geometry of Circular ring FSS

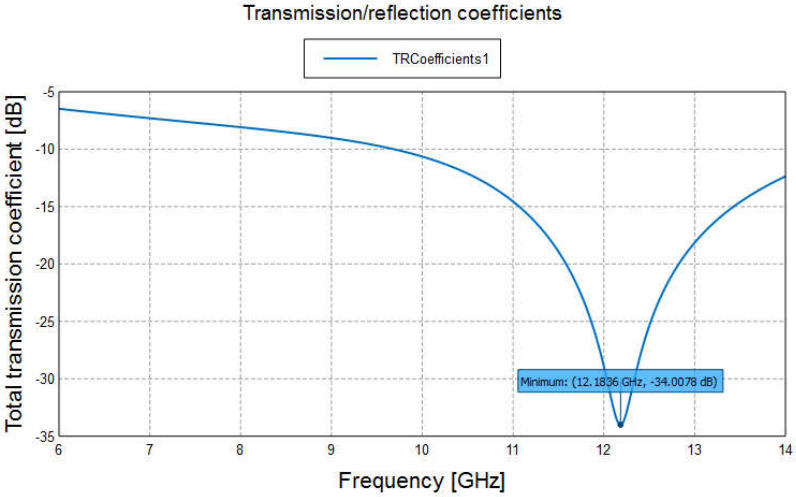

Figure9. Transmission coefficient of Circular ring FSS

The transmission coefficient of proposed FSS with only Circular rings presents on the structure that is resonates at 2.18GHzis -34.0078dB. The bandwidth is 5.3 GHz ranges from 9.2GHz to 14.5GHz

6. CONCLUSION

A new design and a unique approach to obtain an effective shielding over a wide band have been successfully demonstrated by numerically. The FSS uses greek cross and rings printed on the opposite surfaces of a thin dielectric substrate. This design provides a wide 7.5GHz stop band from 6.5 to 14 GHz, with a shielding effectiveness is around 20-35dB.

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