A Frequency Selective Surface-Based Dual-band Electromagnetic Shield for SATCOM Applications

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***Abstract*—A miniaturized, dual-band polarization-insensitive frequency selective surface (FSS)-based electromagnetic shield is presented for SATCOM applications. The FSS unit cell comprises a modified Jerusalem crossed loop and a corner-modified square loop, printed on a Rogers 5880 laminate, offering effective shielding in the X- and Ku-bands. The FSS manifests an angularly stable and polarization-independent response for various incident angles for both polarization states of the EM waves. Moreover, an equivalent circuit model is designed to analyze the FSS working phenomenon. A prototype of the proposed FSS is fabricated and tested for its EM performance. The simulated and measured results of the FSS show a good correlation, making it a viable candidate for selective shielding applications.**

***Index Terms*—Angularly stable, Frequency selective surface, Spatial-filtering, Selective-shielding, Polarization-insensitive.**

I. Introduction

Frequency-selective surfaces (FSSs) as spatial filters manipulate electromagnetic waves, manifesting bandpass or band-reject response. Due to FSSs' frequency filtering characteristics, FSSs find widespread applications in antenna radomes [1], EM absorbers [2], polarization conversion [3], selective EMI shielding [4], and many others.

Several single-layer FSS designs are reported in the literature for mitigating the EMI. In [5], a T-type SRR arranged inside rectangular SRR functions in the X- and Ku-bands to filter out the unwanted frequencies. A single-layer flexible mm-wave FSS in [6] is reported for dual stopbands at 28 GHz and 38 GHz 5G EMI shielding. In [7], an FSS designed with multipole elements stops the WLAN communications but exhibits an angularly unstable response for the upper stopband. A fractal FSS structure based on the traditional Sierpinski fractal in [8] achieves a dual stopband response to suppress the 2.4 GHz and 5.4 GHz band frequencies. It shows good angular stability, but the attenuation decreases as the incident angle increases. In [9], a single-layer FSS structure based on a combination of Mike Kastle unit and square ring is investigated to accomplish a wide angular stable response. The FSS structure manifests good angular stability for both the TE and TM polarization modes. However, for the TM mode, the stop bandwidth decreases as the incident angle increases. Crossed dipoles with two folded arms structure in

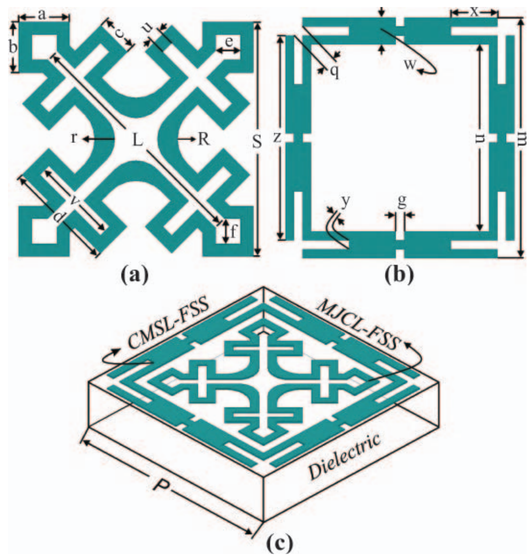


Fig. 1. FSS unit cell design layout and optimized parameters (a = b = 1, c = 0.75, d = 2.50, e = f = 0.50, g = 0.50, r = 1, R = 0.90, u = 0.25, v = 2.00, s = 4.65, L = 4.70, m = 6.75, n = 5.25, q = 0.35, x = 1.35, y = 0.50, z = 5.75, P = 7), all units are in mm. (a) MJCL-FSS Unit element (b) CMSL-FSS structure (c) 3D/Perspective view of the dual-band electromagnetic shield.

10 effectively reject the satellite downlink frequencies [10]. This FSS offers dual-band angularly stable and polarization-insensitive responses in the C- and X-bands. Furthermore, single-layered FSS structures utilizing the coupled technique in [11]-[12] accomplish broadband EMI shielding.

This article presents a compact dual-band FSS-based electromagnetic shield for SATCOM applications. The EM shield has a fore-fold symmetric structure and effectively mitigates EMI in the X-band uplink and Ku-band downlink frequencies, while maintaining angular stability up to ±75° and exhibiting a polarization-independent response. Moreover, an equivalent circuit model is devised to analyze its EM performance. The rest of the paper is organised as: Sections II and III reveal the design configuration and simulated results of the FSS. Section IV discusses the measured results and Section V concludes the paper.

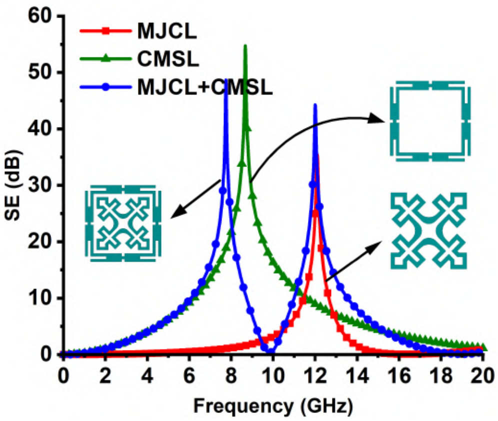


Fig. 2. The EM performance of the MJCL-FSS and the CMSL-FSS individual and in the co-planner arrangement.

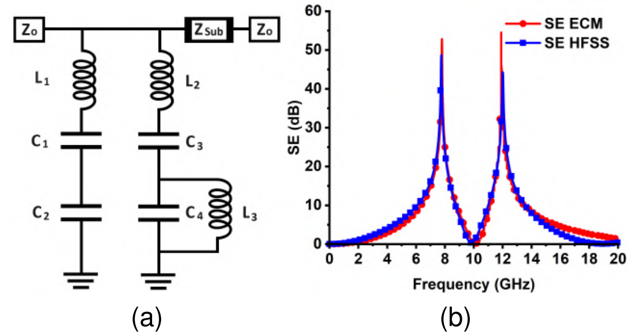


Fig. 3. (a) Circuit model of the FSS and lumped parameter optimized values obtained using ADS, (L_1 = 1.31nH, C_1 = 1.13pF, C_2 = 0.16pF, L_2 = 0.52nH, L_3 = 0.40nH, C_3 = 0.18pF, C_4 = 0.16pF,) (b) SE performance comparison of EM simulation and circuit model.

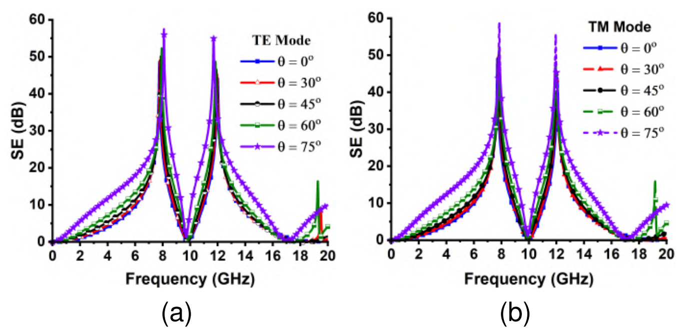


Fig. 4. SE of the FSS at various oblique angles (a) TE Mode, (b) TM mode.

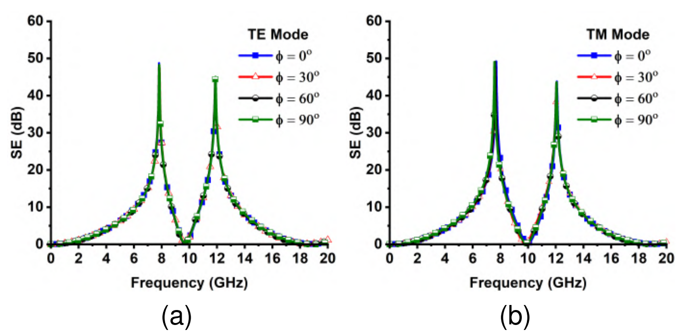


Fig. 5. SE at different polarization angles (a) TE Mode, (b) TM mode.

II. Design Configuration

Figure 1 illustrates the design layout of the proposed dual-band EM shield. The unit cell comprises a modified Jerusalem crossed loop (MJCL) and a corner truncated square loop (CMSL) arranged in a co-planar configuration and designed on RT/duroid 5880 laminate of thickness 0.787 mm. Figs. 1(a) and (b) present the FSS unit cell elements (MJCL and CMSL). Fig. 1(c) signifies the 3D view of the unit cell in co-planner configuration. The unit cell is $0.18\lambda \times 0.18\lambda \times 0.02\lambda$, in dimensions where "$\lambda$" is concerning to lower stopband.

III. Results and Discussions

The performance of the EM shield can be evaluated in terms of its shielding effectiveness (SE), which can be characterized in (1) by the ratio between the transmitted field and the incident field.

$$SE\,(\mathrm{dB}) = -20\log_{10}\left|\frac{E_t}{E_i}\right| \tag{1}$$

Initially, each element of the FSS is analyzed for its SE and then arranged in a co-planner configuration. Figure 2 specifies that the MJCL and CMSL operate at 12 GHz and 8.4 GHz frequencies, however, in the co-planner arrangement, the resonant frequencies are shifted towards the lower frequency due to the mutual coupling effects between elements. Thus, the FSS shield suppresses frequencies of 7.9 GHz, X-band uplink, and 11.9 GHz, Ku-band downlink.

A. Equivalent Circuit Model

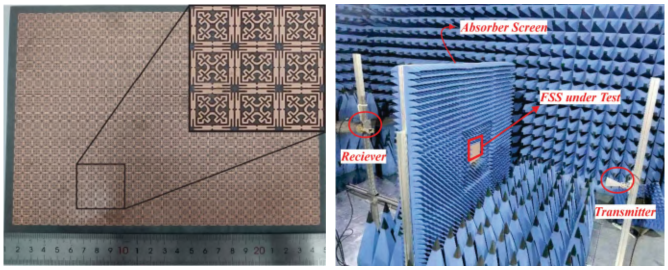
The proposed EM shield's equivalent circuit model (EMC) is designed, as shown in Fig. 3(a). The metallic traces are modelled as inductors and the gaps as capacitors. The input impedance Z_{FSS} of both FSS elements is derived separately from the lumped parameters.

$$Z_{\text{CMSL-FSS}} = \frac{(j\omega L_1)\left(\omega^2 C_1 C_2\right) - (j\omega)(C_1 + C_2)}{\omega^2 C_1 C_2} \tag{2}$$

$$Z_{\text{MJCL-FSS}} = \frac{1 - \omega^2 L_2 C_3}{j\omega C_3} + \frac{j\omega L_3}{1 - \omega^2 L_3 C_4} \tag{3}$$

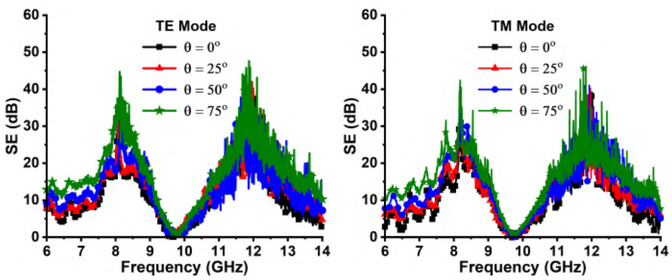
B. Angular Stability

FSS shield is thoroughly analyzed under various oblique angles and polarization states. Due to its four-fold symmetry, the design exhibits a similar response for both the TE and TM polarization modes. Figs. 4 (a) and (b) illustrate the angular performance of the FSS over various incident angles, for both the TE and TM wave modes. Figs. 5(a) and (b) reveal the SE of the shield for different polarization angles under normal incidence. The FSS structure exhibits identical responses for the TE and TM modes up to 90°. Hence, FSS offers highly selective, angularly insensitive, and consistent performance.



(a) (b)

Fig. 6. (a) Fabricated EM shield, (b) Measurement Setup.



(a) (b)

Fig. 7. (a) EM performance of the FSS at various incident angles for the TE mode, (b) SE response of the shield for oblique angle variations for the TM polarization mode.

IV. Experimental setup and Measurements

A prototype was fabricated and tested to validate the simulated electromagnetic shielding of the FSS structure. Fig. 6(a) shows a finite FSS array comprising 25×33 unit cells, which is tested using a free space measurement setup inside an anechoic chamber as illustrated in Fig. 6(b). Moreover, Figs. 7(a) and (b) reveal the SE of the FSS for TE and TM wave modes under various incident angles. The FSS provides an identical response for both polarization modes, making it effective for selective shielding applications.

A. Comparative Study

Table I summarizes reviewed FSSs, signifying the advantages of this FSS over previous works. It is observed that the EM shield is miniaturized, featuring angular stability up to $\pm75°$ and polarization-insensitive spectral responses.

TABLE I
Comparison of dual-band FSS Shield with previous works

Ref. No.	Unit Cell Size (λ)	Operation Band	Incidence Angle	Polarization Insensitive	Band Ratio
[4]	$0.33\lambda \times 0.33\lambda$	X	$0-60°$	Yes	N/A
[5]	$0.26\lambda \times 0.26\lambda$	X/Ku	$0-45°$	Yes	1.8
[10]	$0.15\lambda \times 0.15\lambda$	C/X	$0-80°$	No	1.87
[11]	$0.20\lambda \times 0.20\lambda$	X/Ku	$0-75°$	Yes	N/A
This work	$0.18\lambda \times 0.18\lambda$	X/Ku	$0-75°$	Yes	1.52

V. Conclusions

This paper presents an FSS-based dual-band electromagnetic shield designed for satellite communications. It is realized on a low-loss dielectric and offers a measured SE of at least 35 dB at 7.9 GHz for the X-band uplink and 40 dB at 11.9 GHz for the Ku-band downlink frequencies. In addition, it is structurally symmetric and achieves a highly stable up to $\pm75°$ and polarization-insensitive dual-band filter response for TE and TM wave modes. An equivalent circuit model is designed in ADS and its performance is compared to the EM simulation. Finally, a finite prototype is fabricated and tested. There is a good correlation between the simulated and measured results, making the proposed EM shield a versatile candidate for selective EMI mitigation applications.

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