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Band-Notched Polarization-Insensitive Frequency Selective Surface for RF Shielding Applications

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***Abstract*- This paper presents a novel and highly miniaturized single-layer frequency selective surface (FSS) for RF shielding. The FSS unit cell is comprised of a meandered crossed dipole structure designed over a low-profile laminate. The FSS achieves a shielding effectiveness of 43 dB at the 10 GHz frequency. Moreover, it provides a fractional bandwidth of 34% for the TE and 46% for TM mode at normal incidence. In addition, it exhibits highly stable spectral responses over a wide range of oblique angles for the vertical and horizontal polarization states. The unit cell is compact and has overall dimensions of 5×5 mm^2. Hence, the FSS has virtuous potential for EM field suppression applications.**

Keywords- Bandstop Filters, Electromagnetic Compatibility, Angular response, Polarization Insensitive, Shielding.

I. INTRODUCTION

Frequency selective surface (FSS) is an array of periodic units, which exhibits either reflection or transmission characteristics to the incident electromagnetic (EM) waves, depending upon their element type. The FSSs are being extensively investigated since the 1960s because of their numerous applications including radar cross-section reduction (RCS), airborne radome design, EM absorbers, reflectors, high impedance surfaces (HISs), antenna gain enhancement, satellite communication, EMI mitigation, and many more [1-8].

Recently, many techniques and structures have been studied to realize spatial FSS filters to accomplish desired band-reject characteristics. A modified Jerusalem crossed loop FSS-based EM shield in [8] is designed for X-band shielding applications. It exhibits highly stable spectral responses for the TE and TM modes up to 60°. A novel miniaturized stopband FSS in [9] having stable angular and polarization responses, effectively rejects the X-band frequencies. A meandered square loop structure realized using the screen-printing technique in [10] provides EM shielding for buildings. In another study [11], a band-reject FSS is investigated for polarization-independent operation at the C-band. It reflects 3.5 GHz signals with an attenuation of 43 dB. A single-layered miniaturized FSS with a wide bandstop provides shielding for the U- and V-bands [12]. A strong coupled FSS in [13], rejects the L-band signals with high angular stability for different oblique incident angles.

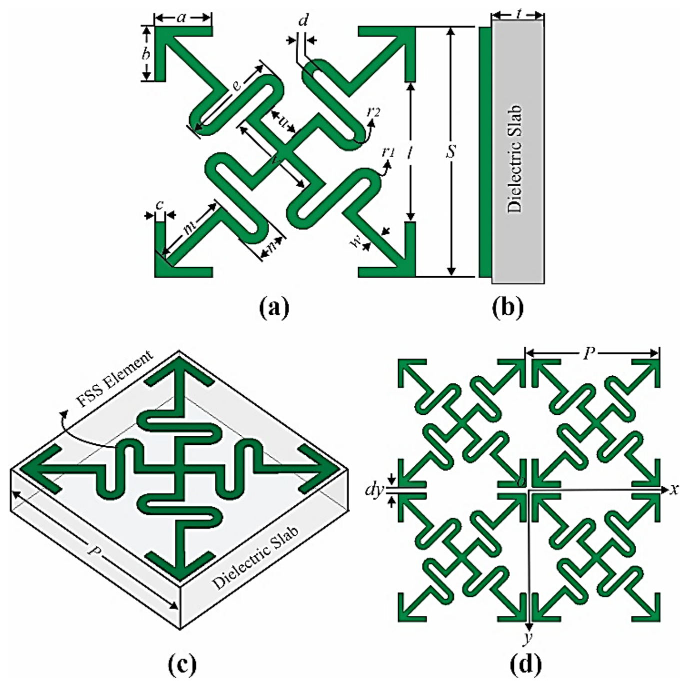

Fig.1. Unit cell geometrical representation and a 2×2 element FSS array where a=1.05 mm, b=1.05 mm, c=0.2 mm, d=0.2, e=1.8 mm, l=2.65 mm, m=1.42 mm, n=0.6 mm, u=0.65 mm, v=1.7 mm, w=0.2 mm, r_1=0.6 mm, r_2=0.2 mm, S=4.75 mm, t=0.762 mm, P=5 mm, and d_x=0.5 mm.

In addition, a single-layered metasurface-based FSS in [14] suppresses grating lobes and achieves miniaturization thereby providing high angular stability. Convoluted elements connected through vias in [15] shield L-band frequency at 1.5 GHz. However, the fabrication of such designs is complicated.

A novel miniaturized bandstop FSS is studied in this paper for EMI suppression applications. A meandered crossed dipole structure is employed to realize a miniaturized unit cell design. The FSS reveals angular stability for TE and TM polarized waves because of its inherent design symmetry. The rest of the paper is organized as Section II, III, and IV describing the design procedure, results and discussions, and comparative study. Finally, Section V, concludes the paper.

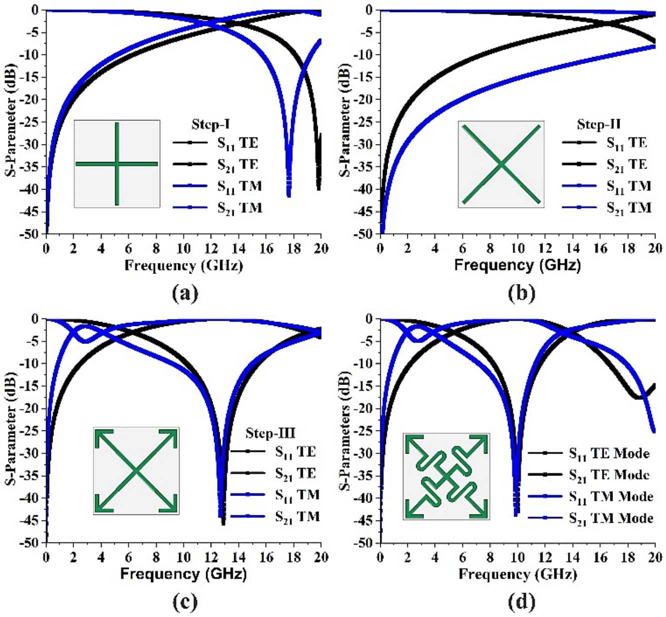

Fig.2. Design process of the FSS structure

II. FSS Unit Element Design

The unit cell of the FSS based on a meandered crossed dipole geometry as depicted in Fig.1. It is designed on a low-profile Rogers RO4350 dielectric with a thickness of 0.762 mm and a dielectric constant of 3.66. Therefore, overall size of the unit cell is 5×5 mm^2. The unit element geometry is evolved through a step-by-step approach and its responses are plotted in Fig.2. Initially, a conventional crossed dipole structure is considered as depicted in Fig.2 (a). The crossed dipole structure is rotated at 45^o and increased its length which results in lowering the resonant frequency i.e., 12 GHz. In step III, the arms of the dipole are loaded with arrow shape stubs to achieve resonant length in a confined space. Finally, a meandered profile with two meander peaks on each arm of the crossed dipole is introduced to obtain a miniaturized size. The meander-line increases the overall inductance of the structure and it resonates at 10 GHz as in Fig.2 (d).

III. Simulation Results and Discussions

A. *Angular Stability*

FSS unit cell is designed and analyzed in HFSS for its EM performance. Fig.3 (a) reveals the s-parameter response of the design at normal incidence. It is noticed that the FSS manifests alike spectral characteristics for both polarization states (TE and TM) owing to its mirrored symmetry along x- and y-axis. Moreover, Figs.3 (b) and (c) portray the trans. coefficient plots over oblique angle variations. The incident angle is changed from 0 to 60^o at a step size of 15^o. The FSS shows fractional bandwidth of 34% and 46% over TE and TM modes. In addition, Figs.3 (d) and (e) exhibit spectral responses of the FSS over varying polarization angles at normal incidence towards TE and TM polarized waves. Thus, the proposed FSS ensures high angular as well as polarization stabilities.

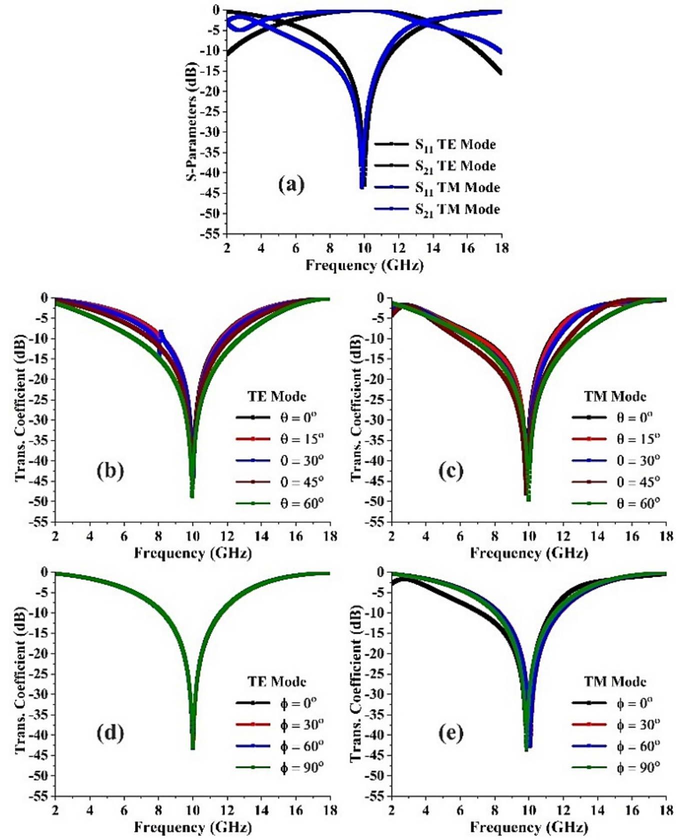

Fig.3. Spectral responses of the FSS: (a) s-parameter plot under normal incidence for TE and TM modes, (b) and (c) S_{21} plots at oblique incidences for TE and TM polarized waves, (d) and (e) S_{21} plots for varying polarizations angles at ($\boldsymbol{\theta}^{\circ}$)

B. *Electromagnetic Shielding*

EM shielding performance of a band-reject FSS is measured through its shielding effectiveness (SE), which is a ratio of incident E-field to transmitted E-field as:

$$SE\ (dB) = 20 \times log_{10} \left| \frac{E_{incident}}{E_{transmitted}} \right| ---- (1)$$

This FSS accomplishes SE of 43 dB at 10 GHz X-band frequency. Fig.5, illustrates SE versus frequency curves of the FSS unit cell at various angles for TE and TM polarization modes. It is observed that the FSS has an identical shielding response owing to its inherent symmetrical design.

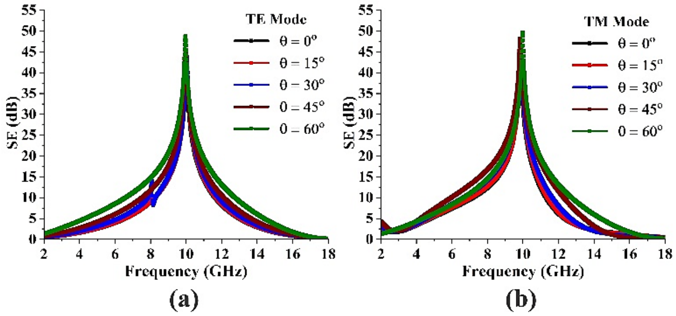

Fig.4. SE of FSS over varying incident angles

C. Rejection Bandwidth Analysis

In general, crossed-dipole or modified crossed-dipole FSSs structures show narrow-band spectral responses. However, the proposed FSS exhibits virtuous stopband bandwidth due to the incorporation of a meandered profile. The meandered profile is not only used to achieve unit cell miniaturization but also enhances rejection bandwidth. Table 1 shows SE and fractional bandwidth variations over various angles.

Table 1 10-dB stop-bandwidth variations for various angles

Incident Angle	SE TE/TM mode (dB)	TE-mode FBW (%)	TM-mode FBW (%)
θ^o	43.1/43.6	34	46
15^o	43.4/44.2	35	47
$3\theta^o$	43.9/46.3	40	55
45^o	45.5/48.1	47	63
$6\theta^o$	48.8/49.5	63	69

IV. COMPARATIVE STUDY

Table 2 reviews a comparison performed based on, unit cell size, the band of operation, angular, and polarization stabilities for [8-11]. The proposed FSS is electrically small and shows angularly stable and polarization-insensitive spectral responses due to symmetric geometry. Thus, it is a suitable candidate for selective filtering applications.

Table 2 Comparative study of various reported FSS designs

Ref.	Size (mm)	Freq. Band	Angular Stability	Polarization insensitivity
[8]	5.25×5.25	X-band	$0-60^o$	Yes
[9]	4.975×4.975	X-band	$0-80^o$	Yes
[10]	16×16	UMTS	$0-60^o$	N/A
[11]	25×25	WiMAX	$0-60^o$	Yes
This work	**5×5**	**X-band**	$\mathbf{0-60^o}$	**Yes**

V. CONCLUSION

A highly miniaturized single-layered FSS is proposed in this paper, for RF shielding applications. The FSS unit cell contains a meandered crossed dipole structure. It offers a shielding effectiveness of more than 43 at 10 GHz. The FSS manifests angular and polarization-independent operation with fractional bandwidth of 34% for TE and 46% for TM wave mode at normal incidence. In particular, the FSS is scalable to other band frequencies and can be used for multi-layer FSS design in the future. Hence, it has the potential to effectively alleviate EMI occurring in X-band communications.

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