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Design and analysis of Hexagonal loop inscribed square shaped unit cell for frequency selective surface

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Frequency Selective Surface (FSS) has been playing vital role in applications like antenna radomes, reflectors, absorber, electromagnetic shielding and many more. Hence, this paper has been proposed the design and analysis of novel FSS unit cell. Initially, square loop shaped unit cell has been designed which provides Band Stop characteristics for the designed frequency of 7.5 GHz. Subsequently, the hexagonal loop within the square loop shaped unit cell has been inscribed which provides both Band Pass and Band Stop characteristics at 7.4 GHz and 9.9 GHz respectively. Angular stability of the proposed unit cell has been determined by analyzing the TE and TM Polarization from 0° to 40° in the interval of 10°. The proposed FSS unit cell has been arranged in 2x2 array for obtaining the meta surface characteristics and the corresponding results have been presented. All the simulations have been carried out using HFSS 2019 R2.

Keywords: Band pass characteristics, Band stop characteristics, Frequency selective surface (FSS)

1 Introduction

Frequency selective surface has been constructed by the periodic arrangement of unit cells. Several types of unit cells such as straight element, Jerusalem cross, anchor shaped, square spiral, different kinds of loops, different patch shapes, etc. have been used for the design of FSS structure[1]. These surfaces have widely been used for the design of antenna reflectors[2], reduction of Radar Cross-Section (RCS)[3], avoiding harmful radiations in the hospitals[4], design of RADOME for military applications[5] etc.

Unit cells are the important element in FSS[6]. Periodic arrangements of the unit cell form the basis for the characteristic of FSS. Still the thrust for the best unit cell for specific application is unquenched. Unit cells have been analyzed using the Scattering Parameter Retrieval Method[7]. Recently, there are more researches going on in the design of FSS. Though FSS finds wide applications, there are few limitations which needs to be overcome[8].

The existing FSS unit cells have been proposed for Wi-Fi, WiMAX, WLAN, X-band applications, etc. which were of huge size. Hence, the design of compact FSS unit cell is paramount consideration in recent research.

The existing characteristics of most of the FSS are having narrow bandwidth. And also, the design of FSS for multiband operation is complex.

The complicated structures give lower frequency response with compact size. But the structures are hard to fabricate.

More than one layer of FSS gives desired frequency characteristics. But, the fabrication cost is high.

The design of FSS with good angular stability is also important. It needs to be analyzed properly. But, most of the existing literatures have not carried out the angular stability analysis.

The above points necessitate the design of FSS with good characteristics and proper analysis. FSS used for the RADOMES need to be conformal to the geometry on which it is placed[9]. RADOMES are used as a protecting cover for the antenna. FSS has been used as the reflecting surface to improve the gain of an antenna[10]. It also increases the directivity[11]. In recent years, FSS have been designed with vias called SIW FSS[12]. By optimizing the structural parameters of the FSS unit cell, the Frequency Selective Surface is created for particular application[13].

2 Materials and Methods

2.1 Design construction of FSS unit cell

This paper proposes the design of novel unit cell for FSS. The brief comparison about the existing unit cells dimension, substrate material, its result and applications were one given in Table 1.

Figure 1 shows the design flow of FSS unit cell. In step A, only the square loop structure was

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Table 1 — Comparative analysis of different existing FSS unit cell[14, 15, 16, 17, 18]

Unit cell dimension	Details of unit cell	Number of operating bands	Frequency band and applications
10 x 10 x 1.6 mm	FR4	3	WiMAX, WLAN and X-band Filtering mechanism
7 x 7 x 0.8 mm	FR4	1	GSM Shielding
4 x 4 x 0.5 mm	Arlon	2	Ku, K and Ka band applications
8 x 8 x 0.4 mm	RT/duroid 6002	1	RCS reduction
10 x 10 x 1.6 mm	FR4	2	Perfect reflector at dual requencies

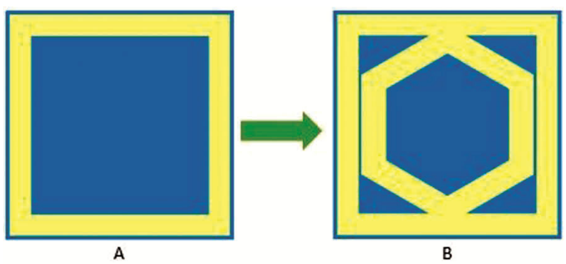

Fig. 1 — Design flow of FSS unit cell.

analyzed. In step B, hexagonal loop was inscribed within the square loop. Two vertices of the hexagonal loop were touching the square loop. Both the structures were merged for the unit cell analysis in HFSS.

The perimeter of the square loop 'P' was determined using Eq. 1[19],

$$P = \frac{c}{f_r\sqrt{(1+\varepsilon_r)/2}} \quad \ldots (1)$$

where, ε_r is the effective dielectric constant of the substrate. Rogers RT Duroid 5880 having relative permittivity of 2.2 and dielectric loss tangent 0.0009 is used as substrate[20]. The side length of square substrate is 8mm. The overall dimension of the unit cell is 8 x 8 x 0.635 mm^3. Conducting material of the unit cell was assigned as copper material with the thickness of 0.017mm. Width of the metal conductor 'S_w' is 0.8mm, gap 'g' is the space between individual unit cells is 0.5mm and the space between the square structure and hexagonal structure is 0.2 mm. Figure 2 shows the dimensions of the FSS unit cell.

3 Results and Discussion

3.1 Parametric Analysis

3.1.1 Parametric analysis for the width of the square patch

Figure 3 shows the parametric values for the width of the square loop in the proposed FSS unit cell.

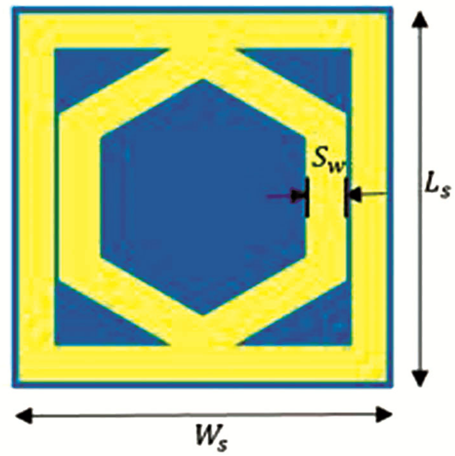

Fig. 2 — Dimensions of FSS unit cell.

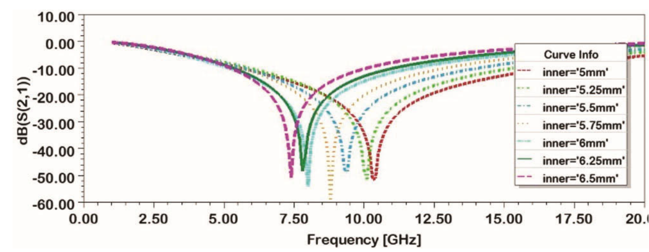

Fig. 3 — Parametric analysis of width of the square loop FSS unit cell.

Parametric analysis was carried out by varying the width of the inner square loop from 5 mm to 6.5 mm with step variation of 0.25 mm. The results were shown the frequency variation between 7.4 GHz and 10.4 GHz. These resonance frequencies are increasing when dimension is decreasing. The square loop dimension was optimized using these parametric results. The width of 6.25 mm was chosen for the square loop. This dimension is more suitable for the required resonance frequency. For all the dimensions in parametric, the corresponding resonant frequency and return loss value are listed in Table 2.

3.1.2 Parametric analysis for the substrate height – Hexagonal Square FSS unit cell

Figure 4 shows the parametric analysis for the height of the substrate from 0.62 mm to 0.645 mm with the interval of 0.005 mm. The results were shown the variation of resonant frequency from 7.4 GHz to 7.7 GHz. This optimization showed the decreasing value of frequency for increasing value of substrate height. The aim of this parametric is to get the height value for resonant frequency 7.5 GHz. Hence, the height of the substrate was chosen as 0.635 mm. For all the dimensions in parametric, the corresponding resonant frequency and return loss value are listed in Table 3.

3.1.3 Band pass and band stop characteristics

FSS unit cells were designed and analyzed using EM simulation software. First, the square loop structure was simulated. Its return loss and transmission loss characteristics are shown in Fig. 5. It can be observed that the square loop unit cell is providing band stop chracteristics. It provides the frequency of 7.8 GHz with transmission loss of -48.46 dB. It provides the bandwidth of 5.8 GHz.

Band Pass and Band Stop characteristics of only square loop and square loop with hex loop are shown in Figs 5 and 6 respectively. It can be observed that the structure is providing both Band Pass and Band Stop characteristics at different frequencies. At 7.4 GHz and 17.7 GHz, it exhibits the Band Stop characteristics with transmission loss of -39.74 dB and -59 dB and bandwidth of 2.5 GHz and 8.51 GHz respectively. This structure exhibits the Band pass characteristics at 9.9 GHz with the return loss of -34.56 dB.

In order to determine the angular stability of the proposed unit cell, TE and TM polarization of the unit cell were analysed. The proposed unit cells behaviour is analyzed by applying signals from different angles. Both the TE and TM polarizations were analysed from 0° to 40° with step of 10°. From this, it is clear that the proposed unit cell is having good anaular stability with negligible variation in resonance frequency but the deviation is within the bandwidth of operation. The similar TE and TM polarization analysis were carried out at second stop band response i.e., at 17.7 GHz. These are shown in Figs 7 and 8. It can be observed that the variations in

Table 2 — Parametric values for width of the square loop

Inner dimension	Resonant frequency	Return loss
5 mm	10.4 GHz	-51.06 dB
5.25 mm	10.1 GHz	-51.50 dB
5.5 mm	9.4 GHz	-48.88 dB
5.75 mm	8.8 GHz	-59.46 dB
6 mm	8 GHz	-54.08 dB
6.25 mm	7.5 GHz	-48.46 dB
6.5 mm	7.4 GHz	-50.82 dB

Table 3 — Parametric results for the height of the substrate

Substrate height	Resonant frequency	Return loss
0.62 mm	7.7 GHz	-35.76 dB
0.625 mm	7.65 GHz	-46.26 dB
0.63 mm	7.6 GHz	-47.42 dB
0.635 mm	7.5 GHz	-49.25 dB
0.64 mm	7.45 GHz	-45.07 dB
0.645 mm	7.4 GHz	-37.99 dB

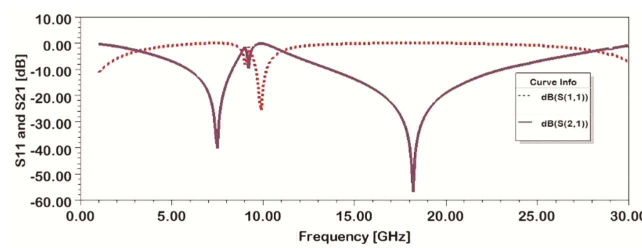

Fig. 6 — Band Pass and Band Stop characteristics of FSS unit cell with both square loop and hexagonal loop.

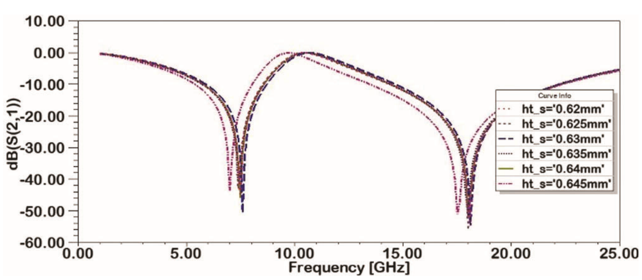

Fig. 4 — Parametric analysis of height of the FSS unit cell.

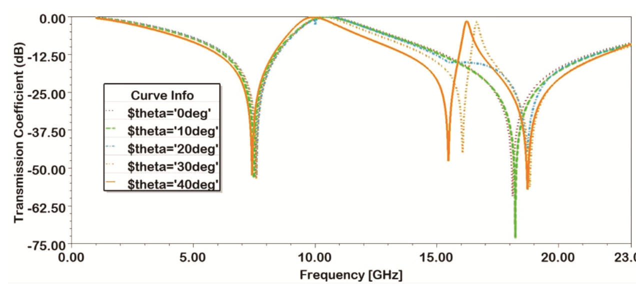

Fig. 7 — TE Polarization for the propsed FSS[12] unit cell.

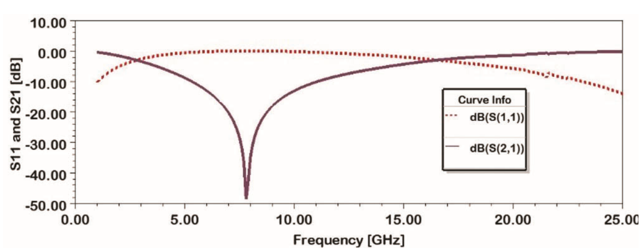

Fig. 5 — Band Stop characteristics of FSS unit cell with only square loop.

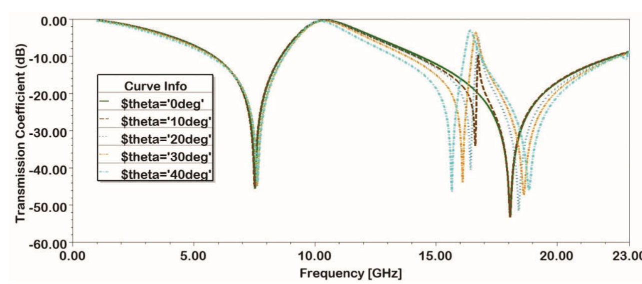

Fig. 8 — TM Polarization for the propsed FSS[12] unit cell.

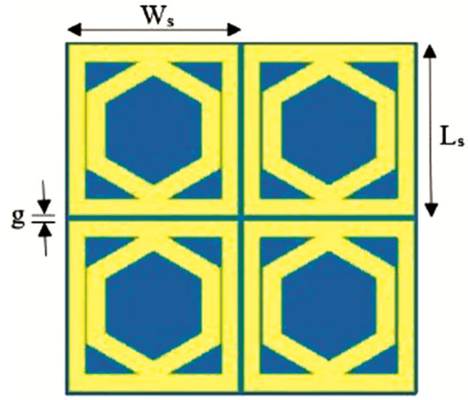

Fig. 9 — 2 x 2 frequency selective surface.

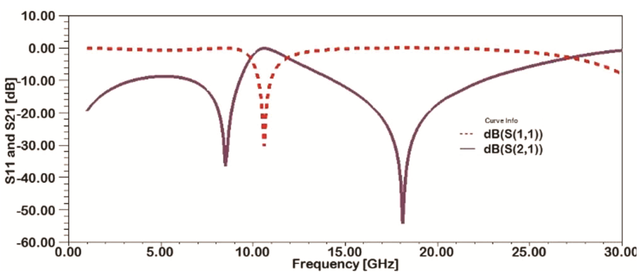

Fig. 10 — $S_{11}$and S_{21} characteristics of 2 x 2 array FSS[12].

resonance frequency was very large and can be concluded that the proposed unit cell's performance is better at 7.4 GHz.

3.1.4 Frequency selective surface using proposed unit cell

Frequency selective surface was created using the proposed unit cell. The unit cells are arranged as a 2 x 2 array in a periodic manner with equal spacing. The spacing between each unit cell is 0.5 mm. Figure 9 shows the pictorial representation for the FSS arrangements. The corresponding frequency response is shown in Fig 10. It provides two band stop characteristics and band pass characteristics. The bandwidth of 2.42 GHz and 7.94 GHz were obtained for two band stop characteristics. The bandwidth of 700 MHz was obtained for band pass characteristics. So, the proposed FSS unit cell can be used a reflector at band stop response and absorber at band pass response. The proposed surface is suitable for C-band frequencies.

4 Conclusion

FSS unit cell has been analyzed using the scattering parameter retrieval method. The square shaped loop has analyzed and the band stop characteristics have observed at 7.5 GHz. To improve the performance of the square loop unit cell, a hexagonal shaped loop has been introduced within it. It exhibits the band stop and band pass characteristics at different frequencies. Parametric analysis for width of the square loop and substrate height has been carried out. Angular stability of the proposed FSS unit cell has determined by taking the TE and TM polarization. A very small deviation in the frequency response shows that the proposed FSS unit cell possesses good angular stability. The 2 x 2 array frequency selective surface has been designed and the return loss characteristics have also observed. From the analysis, it has been concluded that the proposed unit cell can be used for Wi-Fi, WiMAX, WLAN and C-band applications.

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