

Polarization dependent FSS for X and Ku-band frequency response

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A novel polarization dependent and angle resolved dual band FSS structure with band reject response is discussed in this letter. The proposed single layer FSS functions as a band stop filter with three resonant frequencies 10 GHz, 12.1 GHz, and 17.8 GHz respectively. It works as a shielding component for X and Ku-band operations. In addition, the proposed dual-band FSS is asymmetrical in nature, thereby providing different band stop responses for both TE (Transverse Electric) and TM (Transverse Magnetic) operation modes. It also exhibits highly angular stability for different angles of incidences. The measurement results agree well with the simulation results.

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1. Introduction

Frequency Selective Surface (FSS) is an array element, arranged in a periodical manner on the dielectric substrate. The design of FSS was used for reflection, transmission, and absorption of the electromagnetic field [1]. FSS usually offers band stop or band pass operation, frequency selectivity, angle of incidence, and polarization of the incident wave depends upon the array element [2]. FSS consists of two or three-dimensional structures, but, in the case of miniaturization and low profile structure, two-dimensional FSS is always preferred compared to the three-dimensional structure [8], [9] and [10].

Nowadays FSS structures are widely used for many applications that include shielding, radomes, frequency scanned antenna, Radar Cross Section (RCS), microwave absorber, reflectarray, spatial filters and especially in the medical field for protection to the equipment's from electromagnetic interference (EMI) [12]. Current investigation in the field of satellite and space have made X and Ku- band as a major consideration due to many real time applications in that specific satellite frequency band like radar is the major application for X-band frequency and Ku-band used for editing and broadcasting satellite television application.

A capacitively loaded ring slot resonator FSS structure with close spacing band design provided a dual band operation at 2.5 and 3.5 GHz [3]. In [4] two different convoluted crooked cross shape structure patterns bands are designed and closely spaced to each other provided a dual band response in S-band frequency range for the application of shielding and also offered the stable response for different angles with the band reject characteristics is mentioned. The left-handed unit cell was designed and placed on the front side (top side) of the dielectric substrate and a capacitive grid placed on the back side of the substrate achieved the dual band response

of Ku-band and Ka-band as mentioned [5]. A meander line FSS was printed on the single layer dielectric substrate obtained dual-band frequency response with band-stop characteristic for application of spatial filters and also provided a polarization independent behavior with highly angular stable condition [6]. An anchor-shaped FSS structure with dual band frequency of 2.5/5 GHz for the application of WLAN is discussed [7]. A fractal design using Peano pre-fractal patch elements achieved multiband frequency response and covers the frequency range of 1 GHz to 13.5 GHz are discussed in this letter and it is used for the major application of wireless building and antenna systems [11], [15]. The complementary FSS structure is designed to achieve a dual band frequency response in S-band frequency and the structure simultaneously achieved dual passband and dual stopband response [14]. Two metallic patches are printed on both sides of the single dielectric substrate provided triband frequency response, covering a frequency range of WiMAX, WLAN, and X-Band [16].

A novel single layer FSS structure achieved dual-band frequency response with highly stable angular stability for different angles of incidence and also provided polarization dependent characteristics. The Transverse Electric (TE) mode exhibited a high bandwidth response of 4 GHz in X-band with a center frequency of 10 GHz and the Transverse Magnetic (TM) mode, providing two resonant frequencies in Ku-band at 12.1 GHz and 17.8 GHz with corresponding bandwidth of 996 MHz and 1.66 GHz respectively with 10 dB insertion loss. The main objective of this letter is to verify the angular stability for both TE and TM mode. This structure provides highly angular stability for various angles of incidence upto 60° measured.

This paper is organized as follows. Section II, a detailed view of the proposed unit cell FSS structure geometry. Section III deals with the evolution of the

proposed structure. Section IV reports on the simulation results. Section V provides details of the measurement setup of FSS with its results. The measured results are compared with simulation results.

2. Unit cell design

The front view of the proposed FSS structure unit cell is shown in Fig.1. The single layer FSS structure has been designed to be in the shape of a square loop. The inside of the square loop the etched rectangular shape has been designed to enable the achievement of the dual band frequency of X-band and Ku-band. The PEC material (patch) is used with a thickness of 0.00175mm and the Roger Duroid 6002 substrate is used with a thickness of 0.8mm. The overall unit cell dimensions of the proposed FSS are 8mmx8mm.

The dimensions of the proposed FSS structure are shown in Fig. 1. The proposed FSS unit cell had dimensions of $L1=L2= 8\text{mm}$, $L3= 7\text{mm}$, $L4= 5.6\text{mm}$, $L5= 2.4\text{mm}$, $L6= 5.8\text{mm}$, $L7= 5.4\text{mm}$.

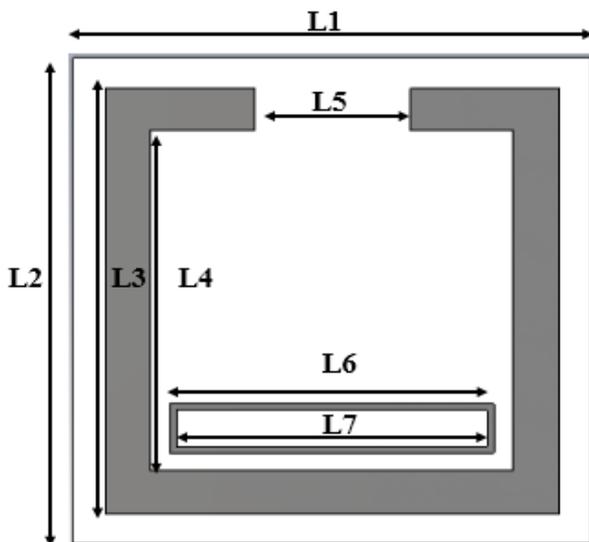


Fig. 1. Proposed FSS unit cell structure

3. Evolution of the unit cell

The proposed single layer with polarization dependent, FSS design was constructed from the basic structure of square loop design [13]. The unit cell evolution of the proposed design with its various stages is shown in Fig. 2. Initially, the root of the construction of the proposed design was the basic square loop design. The square loop was then etched. Third, the etched rectangular shape was placed bottom of the square loop. Finally, the above stages were combined together to enable the achievement of a band reject FSS unit cell. The proposed FSS structure was asymmetrical nature and provided a polarization dependent operation. Fig. 3 shows, the different stages of the proposed design and corresponding frequency response is shown clearly.

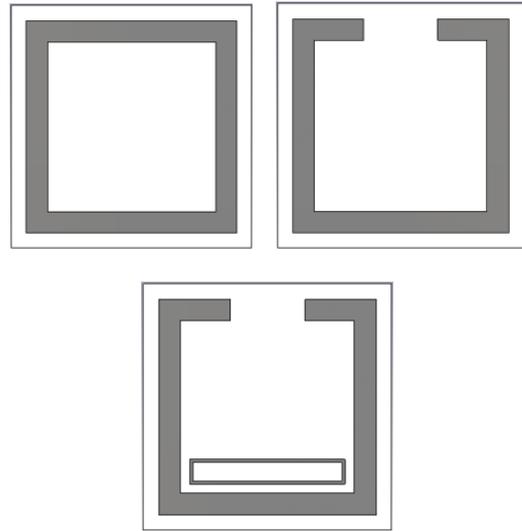


Fig. 2. Evolution of the Proposed FSS Structure

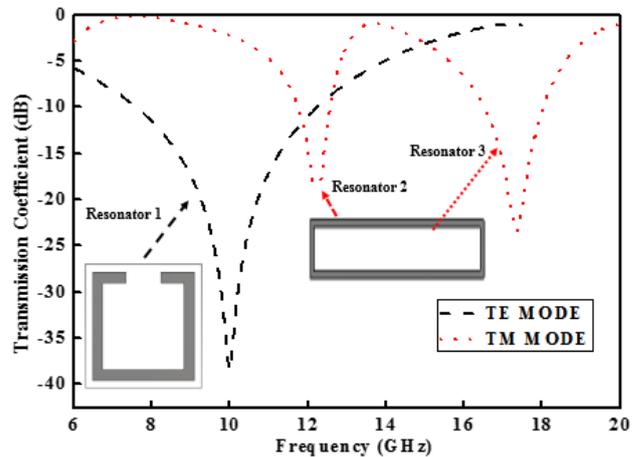


Fig. 3. Transmission coefficient for different resonators and different stages are shown (color online)

4. Simulation results

The proposed FSS unit cell structure is designed with the help of a CST studio and is shown in Fig.1. The patch thickness of the proposed FSS is 0.0175 mm. The single layer FSS structure contains the Roger Duroid substrate and the thickness is 0.8mm with the dielectric constant of 4.3 and the loss tangent value of 0.02. The asymmetrical FSS structure has led to different frequency responses for the TE and TM mode configurations. Fig.4 shows the simulation results conveying the dual band with the band reject characteristics at X-band and Ku-band obtained by the proposed FSS. The TE mode exhibits X-band at the center frequency of 10 GHz with the broadband frequency response of 4 GHz bandwidth. The TM mode exhibits Ku-band with the resonant frequency of 12.1 GHz and 17.8 GHz with the bandwidth of 996 MHz and 1.66 GHz respectively.

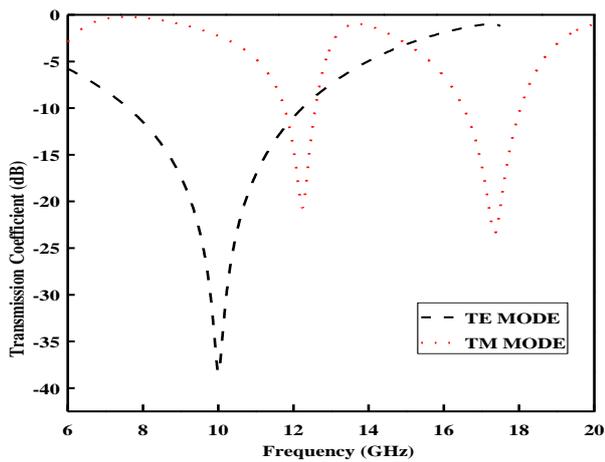


Fig. 4. Transmission coefficient for both TE and TM mode operation

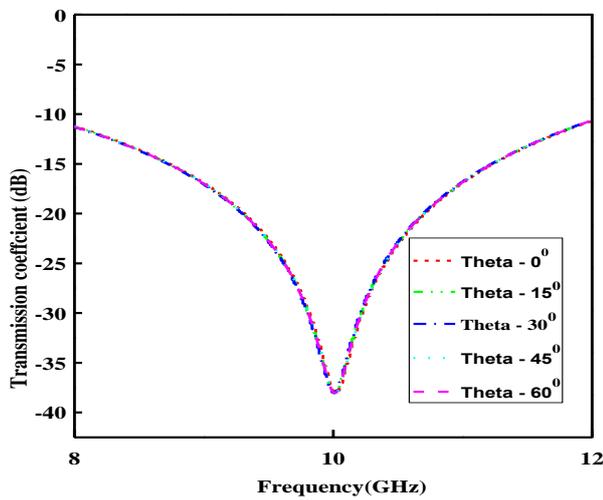


Fig. 5. Angular stability of TE mode for different angles upto 60° (color online)

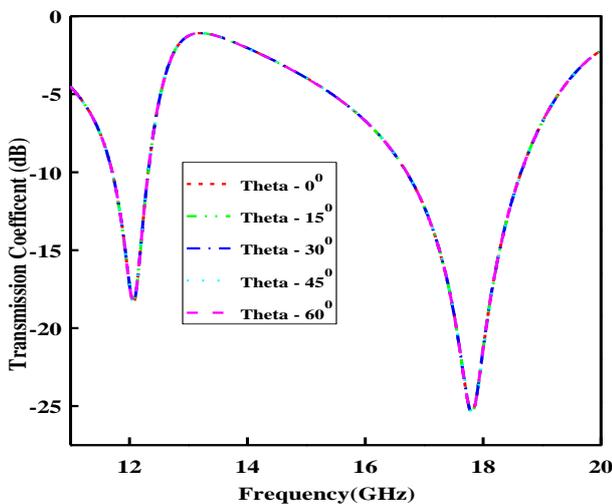


Fig. 6. Angular stability of TM mode for different angles upto 60° (color online)

Fig. 5 and Fig. 6 show the angular stability for both TE and TM mode of the proposed FSS structure. The frequency response of the different resonators achieved a highly stable angular stability for various angles of incidence upto 60° for TE and TM modes.

The parametric sweep of the FSS structure is shown in Fig.7. When the resonant length of L5 was changed from 2.5mm to 2.0mm and 0mm contributed to the increasing frequency response and from 2.5mm to 3.5mm and 3.6mm contributed to the decreasing frequency response. So the variation of parameters describes that, if the electrical length size decreased the frequency response will increase while the electrical length size increased and frequency response will decrease. Depending upon the electrical length the frequency response will shift accordingly. The parametric study shows the proposed FSS structure measurement as the best for the achievement of to achieve a dual band response with band reject.

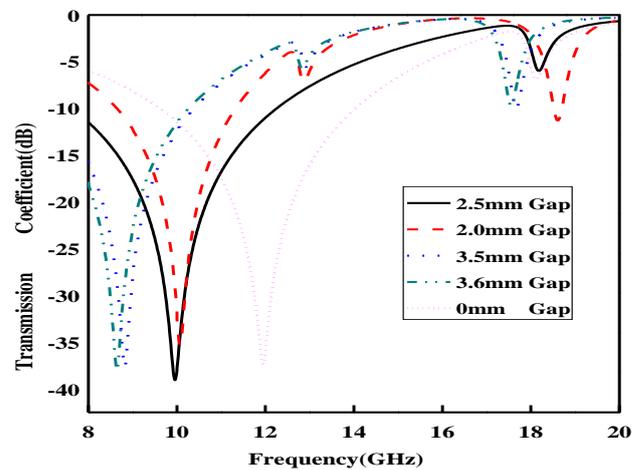


Fig. 7. Parametric study of proposed structure (color online)

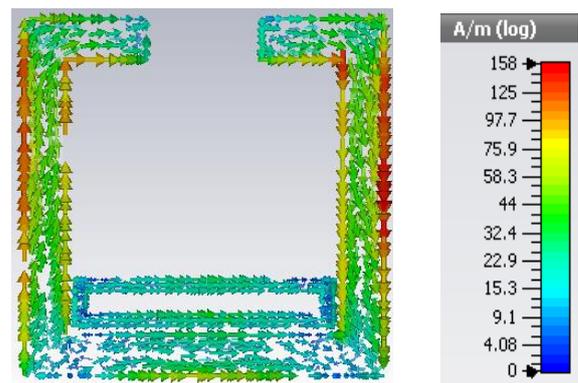


Fig. 8. TE mode configuration (color online)

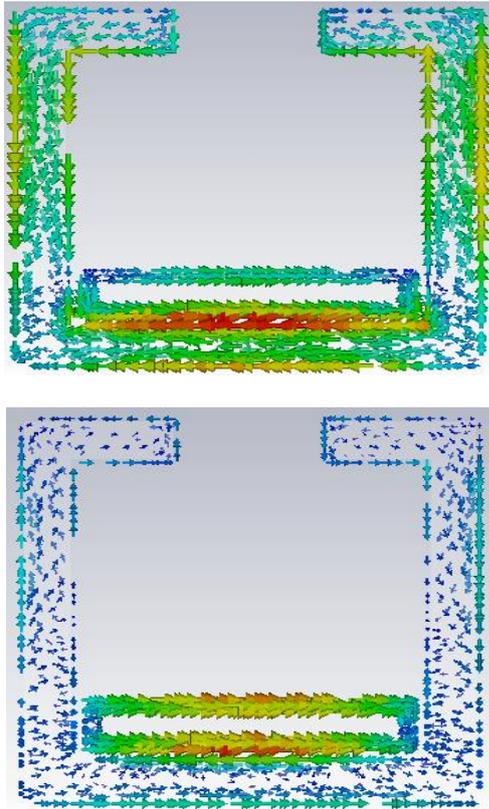


Fig. 9. TM mode configuration (color online)

Surface current distributions at 10, 12.1 and 17.8 GHz are depicted in Figs. 8 and 9, respectively. The contribution of the lower resonance to the increased electrical length and higher resonance of a small electrical length was seen. Variation in current flow varies depending upon the resonator and frequency response. The red color denotes high current distribution and the blue color denotes low current distribution

5. Measured results

The experimental setup had two pairs of antennas, one for transmission and the other for receiving the signals between that tunable FSS stand placed are shown in Fig. 10. This was meant for the measurement of the transmission coefficient characteristics of the proposed FSS structure. An anechoic chamber covered the entire setup. The anechoic chamber was used for the absorption of unwanted electromagnetic signals. Initially, the transmission response was measured without the FSS structure. Later, the transmission characteristics were measured with FSS structure and measurement data on the VNA was updated. The distance of the antenna and FSS structure are 1m apart. The tunable FSS stand was used for the measurement of the transmission coefficient for a different angle of incidence to find the angular stability of the structure. Fig.11 shows a clear view of the proposed FSS structure with the unit cell of 40x40 used.

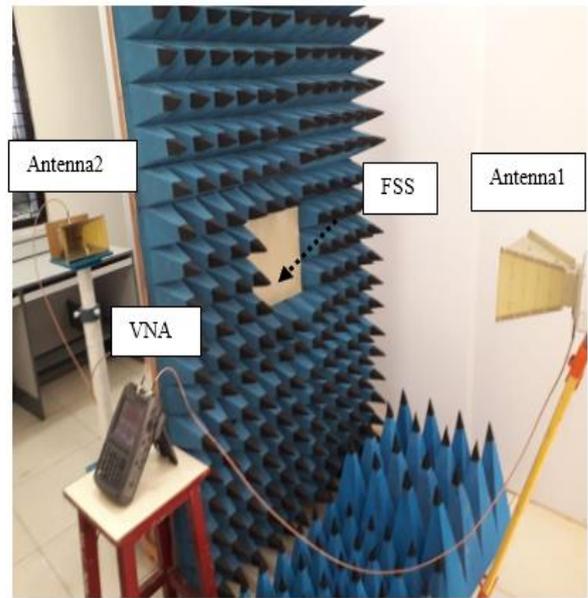


Fig. 10. Measurement setup of FSS structure (color online)

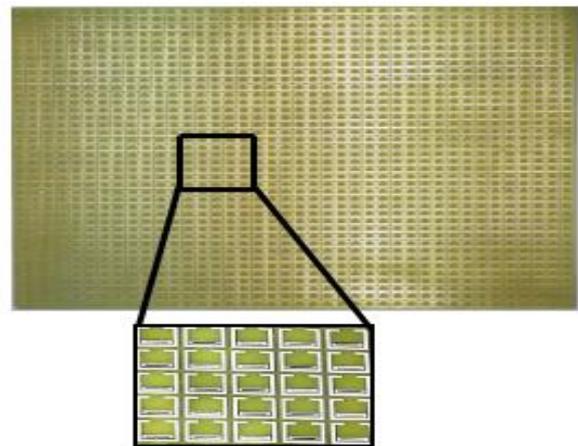


Fig . 11. Photography of fabricated FSS structure with its clear view of unitcell (color online)

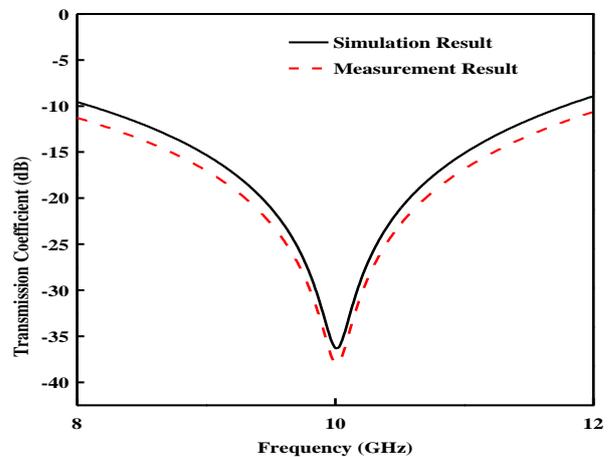


Fig. 12. Comparison of simulated and measured results for TM Mode (color online)

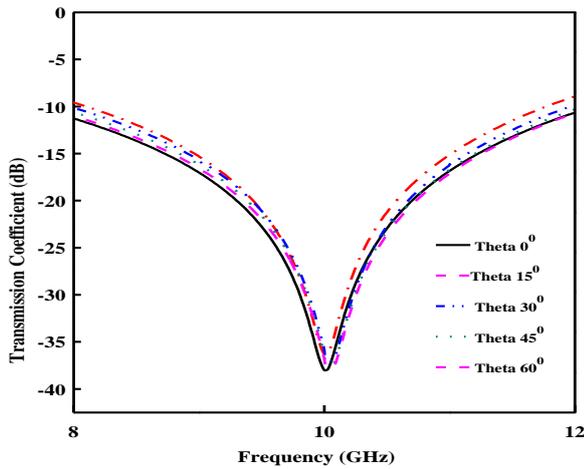


Fig. 13. Measured Results for TE mode with different angles upto 60° (color online)

Fig. 12 shows the simulated and measured results of TE mode compared with these of the proposed structure helping achievement of the same frequency response for 8-12 GHz at center frequency of 10 GHz with a transmission coefficient of 35 dB. In Fig. 13 shows the angular stability of the Transverse Electric Mode, because of the achievement of same frequency response for different angles of incidence upto 60° achieved highly angular stability and is measured by using the operating frequency of 1-12 GHz horn antenna (JR-12).

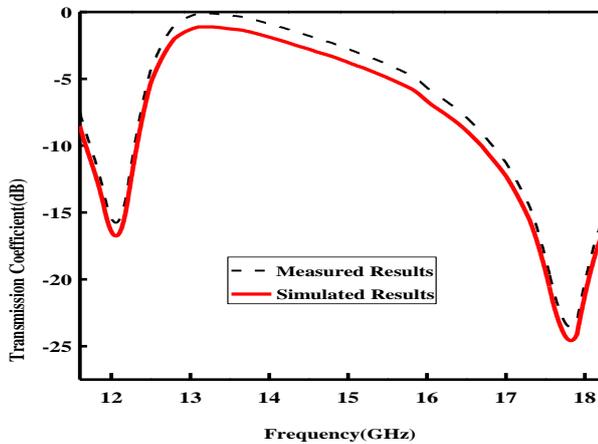


Fig. 14. Comparison of simulated and measured results for TM mode (color online)

Fig. 14 shows a comparison between the simulated and measured results of TM and providing same frequency response. Fig. 15 shows the achievement of the same frequency for different angles of incidence by this proposed structure and the frequency range of 12-18 GHz (Transverse Magnetic Mode) is measured by using the operating frequency of 12-18 GHz horn antenna (KU5086). The simulated results and measured results were the same and offered highly angular stability for different angles of incidence upto 60° for both TE and TM mode.

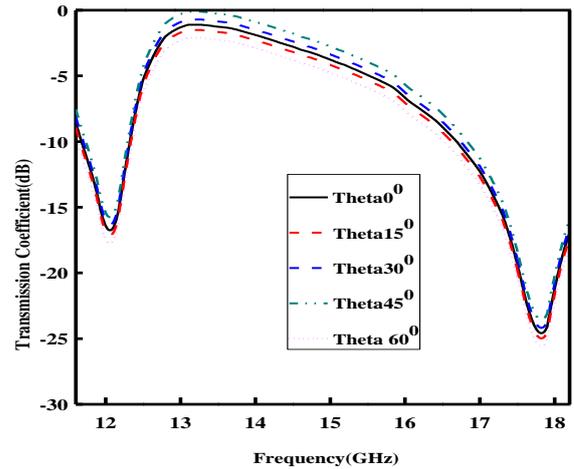


Fig. 15. Measured results for TM mode with different angles upto 60° (color online)

Table 1 presents a comparison between the proposed FSS structure and other existing. The proposed work has miniaturized the dual band FSS structure with highly stable angular stability and providing a high bandwidth response. Even some of the existing works have achieved stable frequency response but the structure fails in bandwidth and size. Especially in reference [4] provides a miniaturized FSS structure but has not achieved a stable frequency response. So the proposed work provides miniaturization and stable response with high bandwidth.

Table 1. Comparison of proposed work with alternate design

Ref	Unit cell size, thickness (mm)	Frequency Band in GHz	Angular stability	Bandwidth with insertion loss
[3]	10x10, not specified	S-Band	Maximum shift of 0.7%	150 MHz
[4]	10.4x10.4, 1.6	S-Band	Stable response upto 60°	315 MHz, 178.5MHz
[5]	4.3x4.3, 0.254	Ku and Ka-	Maximum shift of 0.4%	GHz range bandwidth
[6]	8.4x8.4, 0.8	S-Band	Stable response	100 MHz and 300 MHz range
[13]	24.4x24.4, 10	L and S-Band	Stable upto 30° and then deviation started	0.31 GHz and 0.26 GHz
[14]	11x11, 1.6	S-Band	Unstable after 30°	Not specified
[16]	10x10, 1.6	WiMAX, WLAN, and X-Band	Stable response only upto 30° and then slight	0.5 GHz, 0.5 GHz, and 3.5 GHz respectively

Ref	Unit cell size, thickness (mm)	Frequency Band in GHz	Angular stability	Bandwidth with insertion loss
			changes in resonance frequency	
This work	8x8, 0.8	X, and Ku-Band	Highly stable response upto 60°	4 GHz, 996 MHz, 1.66 GHz for resonant frequency

6. Conclusion

A novel polarization dependent transmission characteristic with high angular stability FSS structure is designed in this letter. It achieved the band rejection property in X and Ku-bands. The design was fabricated using a low cost Roger substrate. The designed FSS structure exhibits an asymmetrical structure and offers polarization dependent operation. The structure exhibited angle independent transmission characteristics up to 0°-60°. The miniaturized FSS structure was used for the application of shielding purpose. The simulated result and fabricated measurement results were found to be in good agreement with each other.

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