

# A Novel Miniaturized Polarization Independent Frequency Selective Surface with UWB Response

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**Abstract.** *This study presents a novel Frequency Selective Surface (FSS) design with angularly stable and polarization independent band-stop response. The presented FSS comprises miniaturized unit cells printed on two layers of the dielectric substrates. The  $-3\text{dB}$  bandwidth of proposed FSS is between 2.98 GHz and 10.86 GHz frequencies. The unit cell dimension is  $0.064\lambda \times 0.064\lambda$  with the thickness of  $0.02\lambda$ , where  $\lambda$  is the wavelength of the lower operational frequency. The proposed FSS has angular stability up to  $60^\circ$  for TE polarization. The designed FSS is simulated and analyzed by using the commercial software, CST Microwave Studio. The simulation results are verified by measurements carried on a fabricated prototype and a good agreement is achieved.*

## Keywords

Angularly stable, miniaturized, FSS, UWB

## 1. Introduction

Frequency Selective Surfaces (FSSs) are periodic arrays that can be configured by the periodic arrangement of metallic or slot which show transmission or reflection behaviors to both incidence angle and polarization of incident electromagnetic wave [1], [2]. FSS is widely studied in radomes, Radar Cross Section (RCS) reduction, gain enhancement of antennas, absorbers, wireless security, missiles, EM shielding, mobile and satellite communication [3–5]. Thus, FSS topics have been attracted researchers with its features of compact size and low cost. In 2002 the Federal Communications Commission (FCC) allocated the frequency band between 3.1 GHz–10.6 GHz for license-free Ultra Wide Band (UWB) transmission [6]. Over recent decades license-free UWB frequency band technology has been used for exceeding limitation of traditional technologies [2]. Therefore, many FCC UWB components have been investigated intensely. UWB FSS components have been an attractive area for improving the design outputs and features. In the literature, there are some methods to design UWB FSS. In [3], [7] multiple resonant shapes,

having different frequency response and printed on two surfaces of the single dielectric layer are studied. Multi-layer UWB FSSs with metal plate are presented in [2], [8], [9]. UWB FSS design for antenna gain enhancement is explored in [4], [10]. A polarization independent UWB FSS which has the  $14\text{ mm} \times 14\text{ mm}$  ( $0.18\lambda \times 0.18\lambda$ ) dimension of the unit cell is reported in [11]. Polarization and angular independent compact band stop FSS design with the unit cell dimension of  $8\text{ mm} \times 8\text{ mm}$  ( $0.187\lambda \times 0.187\lambda$ ) is proposed in [12].

In this paper, a double layer band-stop UWB miniaturized FSS is introduced. The proposed UWB FSS has the advantage of the miniaturized size of the unit cell provided by the use of meandered lines. The overall dimension of the presented unit cell is compared with reported studies in the literature. In Tab. 2, comparison of the dimensions with frequency is given. Additionally, the proposed UWB FSS has the advantage of wide angular stability and polarization insensitivity features.

This study is organized as follows: In Sec. 2 unit cell configuration is described and design parameters are detailed. Simulation and measurement results of the proposed unit cell are illustrated in Sec. 3. Section 4 concluded the design with results.

## 2. Design of Unit Cell

In [1], to obtain the desired resonance frequency for band-stop filtering characteristic, a conventional square loop element has been introduced. Based on this study, many miniaturized FSS geometries are proposed in the literature. In [13], a miniaturized rotated cross dipole element is presented for X-band applications. In this study, a novel miniaturized FSS geometry is introduced. The geometry of the unit cell is depicted in Fig. 1(a). The presented unit cell consists of double layer dielectric substrates separated from each other with three parts of metallic elements. Each part of metallic elements is composed of rotated cross dipoles and meandered lines which are printed on the front surface of dielectric substrates. The first dielectric substrate is chosen as AD300A with a thickness  $h_1$

and it has  $\epsilon_r = 3$  dielectric constant. The second one is chosen as AD600 dielectric substrate with  $h_2$  thickness and it has  $\epsilon_r = 6.15$  dielectric constant. Each of three parts of metallic elements contributes to the UWB response.

Metallic elements of each layer are shown in Fig. 1(b). Metallic elements “a” are printed on the front

| Design Parameters | Dimensions [mm] |
|-------------------|-----------------|
| R <sub>in</sub>   | 4.1             |
| R <sub>out</sub>  | 4.5             |
| w <sub>1</sub>    | 0.2             |
| w <sub>2</sub>    | 0.2             |
| w <sub>3</sub>    | 0.27            |
| w <sub>4</sub>    | 0.32            |
| D                 | 6.4             |
| h <sub>1</sub>    | 1.524           |
| h <sub>2</sub>    | 0.508           |
| l <sub>1</sub>    | 1.34            |
| K                 | 1.2             |

Tab. 1. Design parameter of the first part of the metallic elements.

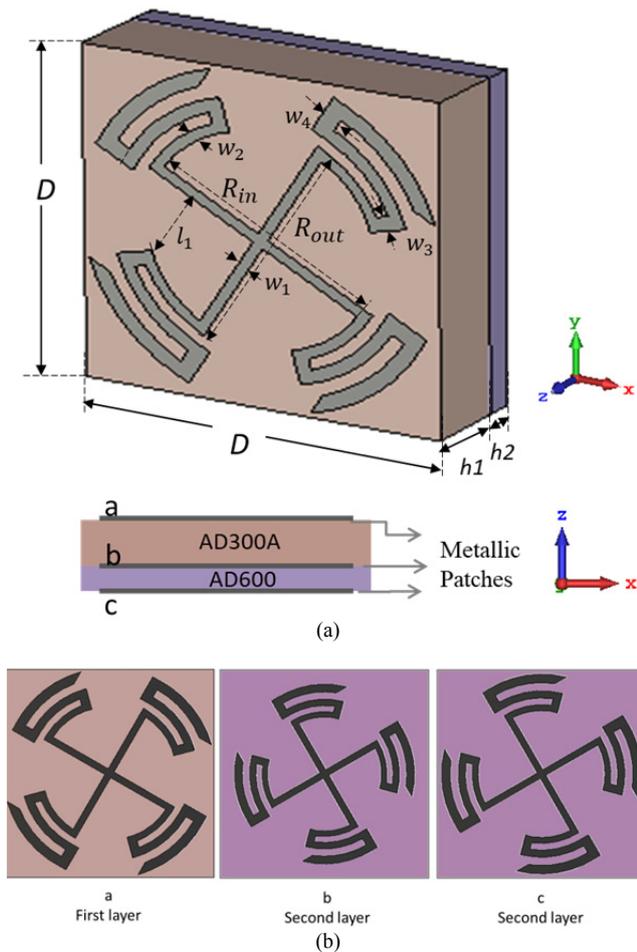


Fig. 1. (a) Geometry of the unit cell. (b) Metallic layer placements and their modification.

|          | Frequency [GHz] | The Overall Dimension     |
|----------|-----------------|---------------------------|
| Proposed | 2.98–10.86      | 0.064 $\lambda$ (6.4 mm)  |
| [2]      | 3.1–10.6        | 0.165 $\lambda$ (16.5 mm) |
| [4]      | 3.02–11.79      | 0.151 $\lambda$ (15 mm)   |
| [7]      | 6.5–14          | 0.26 $\lambda$ (12 mm)    |
| [8]      | 5.5–19          | 0.238 $\lambda$ (13 mm)   |
| [10]     | 4.42–13         | 0.206 $\lambda$ (14 mm)   |
| [11]     | 4–14            | 0.18 $\lambda$ (14 mm)    |
| [12]     | 7.04–10.55      | 0.187 $\lambda$ (8 mm)    |

Tab. 2. Comparison of the dimensions.

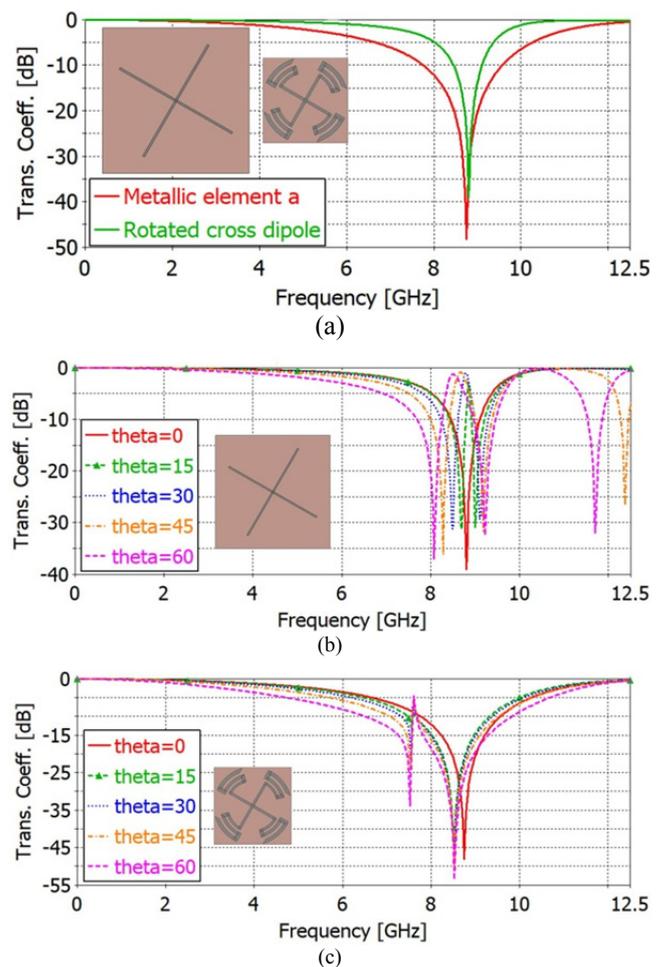


Fig. 2. Simulated transmission coefficients: (a) Comparison of the metallic element “a” and rotated cross dipole unit cell’s transmissions under normal incidence. (b) Transmission under different incident angles for rotated cross dipole unit cell. (c) Transmission under different incident angles for the metallic element “a”.

surface of the first dielectric substrate with the design parameters given in Tab. 1. Metallic elements which are called as “c” in Fig. 1(b), are obtained from scaling metallic element “a” with 0.95 and rotating by 60° for the purpose of enlarging the operating frequencies. Metallic ele-

ments “b” are obtained from scaling metallic element “c” by 0.9 and are settled on the second substrate as illustrated in Fig. 1(a). Also, w1 is excepted from these scaling processes. The unit cell is designed with the parameters given in Tab. 1 by using CST Microwave Studio. The overall dimensions of the unit cell in x and y directions are  $D \times D$  mm. The unit cell size for the lower cut off frequency equals to  $0.064\lambda \times 0.064\lambda$ , where  $\lambda$  corresponds to free space wavelength.

The overall dimension of the presented unit cell is compared with other works reported in the literature and is given in Tab. 2. The unit cell dimension is calculated considering the lower cut-off frequency where  $\lambda$  corresponds to free space wavelength. Adding meandered lines to the cross dipole is the simple structural modification which reduces the unit cell at the size. As seen in Tab. 2 the designed unit cell has the advantage with its miniaturized size.

When the metallic element “a” geometry which consists of rotated cross dipole and meandered lines is used instead of the rotated cross dipole, approximately the same transmission response is obtained with larger unit cell size (14 mm) when illuminated by a plane wave under normal incidence. Since the unit cell size is bigger than the proposed dimensions about 79.1%, the angular sensitivity increases depending on the unit cell size when a unit cell is illuminated by a plane wave under various incident angles. Transmission characteristics for rotated cross dipole and the metallic element “a” are demonstrated in Fig. 2.

### 3. Simulation and Measurement

Simulation results of the designed unit cell for both TE and TM polarizations at normal incidence angle are shown in Fig. 3. As seen in Fig. 3, the proposed structure exhibits band-stop filter characteristic between 2.98 GHz and 10.86 GHz considering -3dB level. The transmission and reflection coefficients are computed by considering unit cell boundary with frequency domain solver using CST Microwave Studio.

The simulation results of transmission responses under the various incidence angles for TE polarization are illustrated in Fig. 4. Thus, the angularly stable transmission characteristics at different incident angles  $\theta$  ( $0^\circ$ ,  $15^\circ$ ,  $30^\circ$ ,  $45^\circ$  and  $60^\circ$ ) for TE polarization can be observed from Fig. 4 and the simulation results introduce that the unit cell

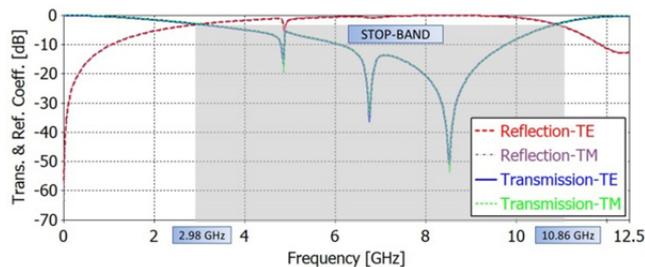


Fig. 3. Simulation results of transmission and reflection coefficients for TE and TM polarizations at normal incidence.

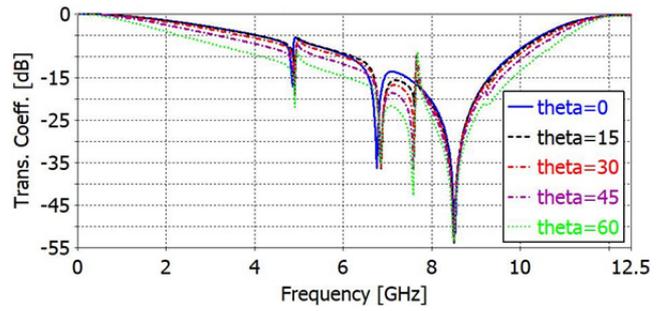


Fig. 4. Simulation results of transmission coefficient at different incidence angles for TE polarization.

| Incidence Angle (TE Polarization) | Lower Cut-off Frequency at -3 dB [GHz] | Higher Cut-off Frequency at -3 dB [GHz] |
|-----------------------------------|--|---|
| $0^\circ$                         | 2.98                                   | 10.86                                   |
| $15^\circ$                        | 2.92                                   | 10.95                                   |
| $30^\circ$                        | 2.65                                   | 11.03                                   |
| $45^\circ$                        | 2.2                                    | 11.17                                   |
| $60^\circ$                        | 1.58                                   | 11.39                                   |

Tab. 3. Cut off frequencies of the transmission response at -3dB for different incidence angle for TE polarization.

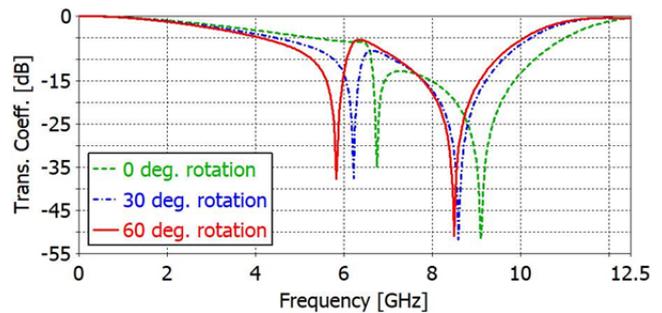


Fig. 5. Simulation results of transmission coefficient at normal incidence for the rotational variation of the metallic element “c”.

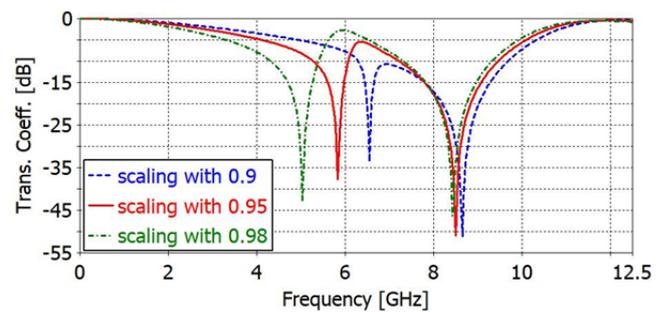


Fig. 6. Simulation results of transmission coefficient at normal incidence for the scaling variation of the metallic element “c”.

has an angularly stable transmission characteristic due to its miniaturized size.

In Tab. 3 lower and higher cut-off frequencies at oblique incidence angles up to  $60^\circ$  for TE polarization are given. According to the results represented in Fig. 4 and Tab. 3 it can be easily seen that the designed FSS comprises UWB range defined by FCC at each analyzed incidence angle value.

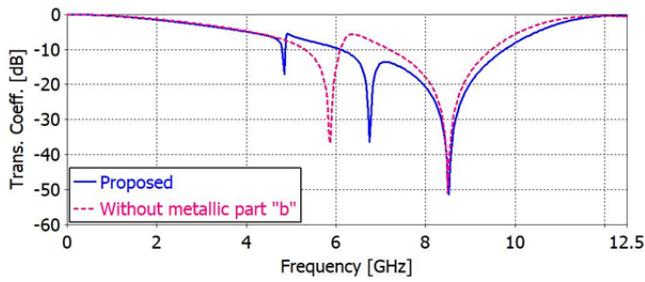


Fig. 7. Comparison of transmission coefficients at two design stages.

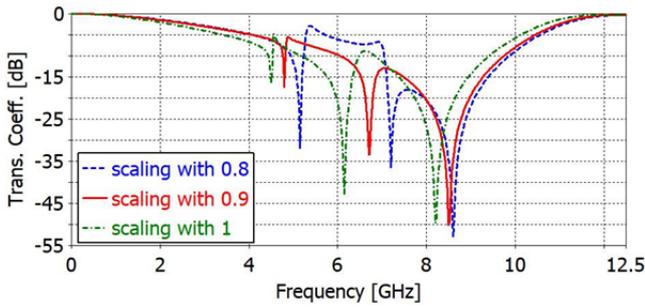


Fig. 8. Simulation results of transmission coefficient at normal incidence for the scaling variation of the metallic element “b”.

During design procedure metallic element “c” is placed at the different rotational angles to obtain lower operational frequency under 3.1 GHz. As seen in Fig. 5, under the  $-3$  dB transmission level, the desired frequency is provided by  $60^\circ$  settlement. After rotating process metallic element “c” needs to shrink to fit into the unit cell without affecting the operating frequency. The various scaling factors are tested as seen in Fig. 6.

During the design process, some structural studies are carried out in order to get a design covering the whole UWB frequency range. The trial design unit cell was not containing metallic element “b”. The transmission characteristic of this design with two metallic parts does not provide FCC UWB standards with the 3.12–10.5 GHz cut-off frequencies as seen in Fig. 7. So that the transmission characteristic given in Fig. 7 is obtained by adding to the third metallic element called “b” to the structure of smaller size to influence the higher frequencies in the transmission response. By adding a smaller sized metallic element “b” into the middle of two dielectric layers, the upper frequency band is enlarged. The parametric analysis is performed for different scaling ratios that caused the metallic element “b” to enlarge the upper operational frequency at  $-3$  dB transmission level. The obtained transmission characteristics for various scaling factors are illustrated in Fig. 8. Thus, scaling metallic element “b” with 0.9 allows the whole structure to achieve FCC UWB standards with 2.98 GHz–10.86 GHz at 3 dB.

Each two dielectric substrates with three parts of metallic elements contribute to UWB frequency response. These contributions are shown in Fig. 9 for each dielectric layer separately. The transmission characteristic of the first layer with metallic element “a” is enhanced by adding the

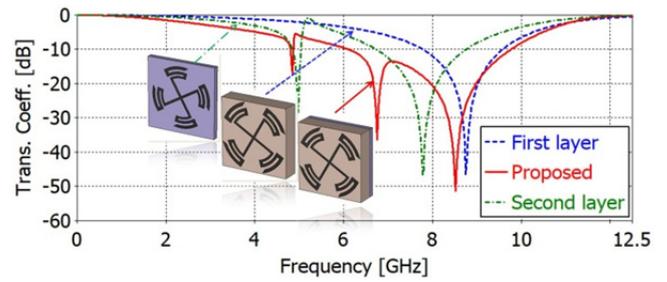


Fig. 9. Effects of each two layers of the unit cell.

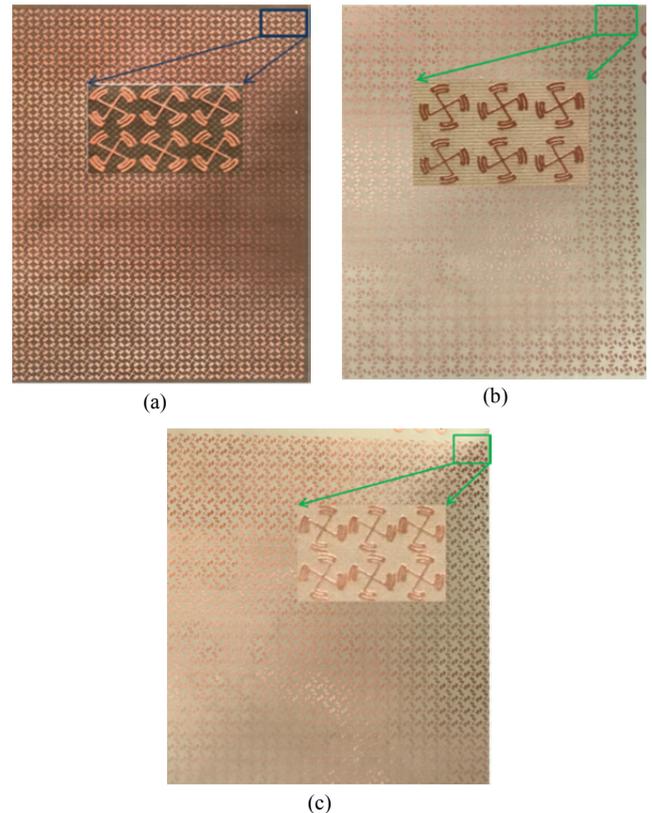


Fig. 10. Fabricated FSS prototype.

second layer with two parts of metallic elements “b” and “c” on the opposite surfaces to the structure.

To verify the simulation results, the proposed FSS structure is fabricated and measured. The designed FSS prototype which is performed by numerical simulations is realized on an AD300A and AD600 substrates with the thickness of 1.524 mm and 0.508 mm, respectively.

Figure 10 demonstrates the photo of the fabricated UWB FSS prototype. Each double layer FSS prototypes have approximately  $210 \text{ mm} \times 297 \text{ mm}$  dimensions. The standard free space measurement technique was used to obtain the fabricated band-stop UWB FSS performance as shown in Fig. 11. The measurements are performed with transmitting and receiving identical broadband SMA waveguide horn antennas with nominal 11 dB gain and Rohde& Schwarz ZVB 20 VNA (Vector Network Analyzer) with the low-loss coaxial cable. The aperture of used horn antennas is  $244 \text{ mm} \times 164 \text{ mm}$  with the taper lengths of

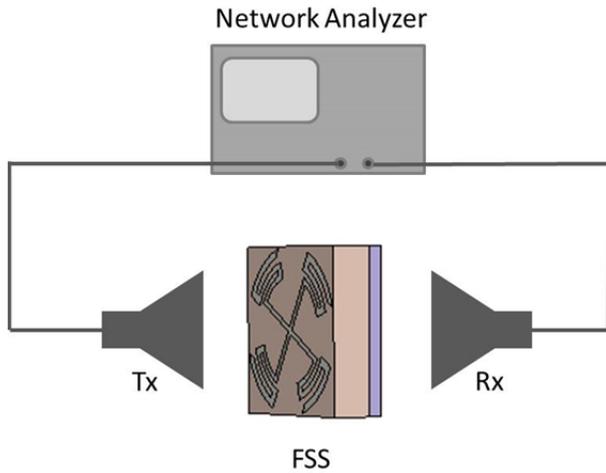


Fig. 11. Measurement setup.

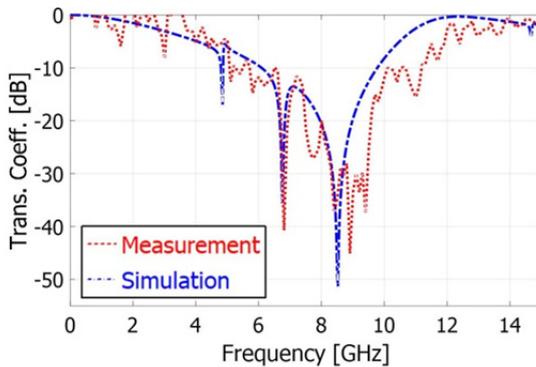


Fig. 12. Transmission response of simulation and measurement results.

204 mm. The receiving and transmitting antennas are positioned at the same height on the line of sight direction.

In Fig. 12 transmission characteristic of the simulation and measurement results of the proposed FSS under normal incidence for TE polarization is illustrated. A good agreement is obtained between the simulation and measurement results.

## 4. Conclusion

In this study, a novel FSS structure with angularly stable and polarization independent band-stop response is presented for UWB applications. The designed unit cell has band-stop UWB transmission response between 2.98 GHz and 10.86 GHz under  $-3$  dB transmission. Due to the miniaturized size of the unit cell, the proposed structure exhibits an angularly stable response to the oblique angles of incidence (up to  $60^\circ$ ) for TE polarization. Although the structure is configured using two layers, the overall thickness of the unit cell is  $0.02 \lambda$ . Also, the dimension of the unit cell for lower cut-off frequency is  $0.064 \lambda \times 0.064 \lambda$ , where  $\lambda$  corresponds to free-space wavelength. The designed unit cell is performed with CST Microwave Studio. The designed FSS was fabricated and measured to confirm the simulation results. Simulated and measured results have a good agreement.

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