International Journal of Enhanced Research in Science, Technology & Engineering
ISSN: 2319-7463, Vol. 9 Issue 6, June-2020, Impact Factor: 6.754

A Polarization Insensitive Compact Frequency Selective Surface for Wide Band RF Applications

Pramod Kaushik[1], Taruna Sikka[2]

[1]M. Tech Student, Department of ECE, Satpriya Group of Institutions, Rohtak

[2]HOD, Department of ECE, Satpriya Group of Institutions, Rohtak

ABSTRACT

This paper presents a novel compact, polarization insensitive wide stop band Frequency Selective Surface (FSS) for RF applications. The unit cell of the proposed FSS consists of a combination of circular ring and Jerusalem cross dipole type FSS element designed on both sides of a 1.0 mm thick FR4 dielectric substrate. The geometric dimensions of the design has been optimized in the such a manner that a wide stop band with -10 dB bandwidth of 12.47 GHz from 7.89 GHz to 20.36 GHz has been achieved. The periodicity and overall thickness of the designed FSS structure corresponding to the centre frequency of its -10dB bandwidth is $0.39\lambda_0 \times 0.39\lambda_0$ and $0.0471\lambda_0$ respectively. Since the designed FSS structure is four fold symmetric it is polarization insensitive and results in a wide stop band for wide angles of incidence. It also exhibits angular stability up to 30° for both the TE and TM polarizations. A prototype of proposed compact FSS structure has been fabricated consisting of an array of 34× 34 unit cells and experimentally tested. The results measured from the fabricated FSS structure are very close to the simulated responses.

Keywords: Frequency Selective Surface, periodic structure, spatial filter, angular stability, polarization insensitivity.

1. INTRODUCTION

Originally for electromagnetic filtering applications frequency selective surface was developed [1, 2]. Frequency Selective Surface acts like a spatial filter, i.e. it transmits, reflects or absorb electromagnetic spectrum over certain frequency range. Frequency selective surface is a thin repetitive surface which consists of an assembly of conducting elements arranged in unitary or two dimensions infinite array [2].They are constructed by printing the metallic array of unit cells either on single side or both side of dielectric substrate. [11] The smallest identical element of any FSS array comprises of one or more elements known as unit cell. It is either made up of conductive patch type elements, an aperture type or a complimentary type element on the top of dielectric substrate. Depending on the nature of elements it displays the band pass and band reject property. Generally a patch type FSS acts like a band reject filter having a capacitive response which exhibits low pass characteristics. On the other hand aperture type FSS acts like a band pass filter having an inductive response which exhibits high pass characteristics. Complementary type FSS is the combination of both patch type and aperture type elements. A perfect conducting plane is obtained when these are placed on the top of each other [2].

FSS has wide variety of applications throughout the electromagnetic spectrum which include band pass radome to efficiently reduce the radar cross section (RCS) of the antenna [3-4], meander line polarizer[5], sub reflector for dual frequency reflector system[6], electromagnetic absorbers[7], beam splitters, optical filters, low / high pass filters etc.

The different characteristics of FSSs depends on the shape, size and spacing between the unit cell elements [8]. Various shapes of FSS are responsible for different applications. Different FSS shapes can be classified as centre connected, solid interior, loop type and combination of all these. FSS has different application requirements like cross polarization, angle of incidence of incident wave and bandwidth. Depending on these application requirements, different FSS design can be chosen. A thorough study showed that the dimensions of the elements of an FSS array must be nearly half of electromagnetic wavelength at the frequency of operation [9]. A frequency response is less sensitive to incident angle or angular stable when there is smaller periodicity in the periodic array. It has been shown that the large bandwidth is achieved

by using the FSS with smaller spacing between the unit cells. The different parameters of the FSS such as size, shape, periodicity, material of the elements, inter element spacing, substrate material used, angle of incidence and different polarization of the incoming wave can be varied to get the desired frequency response.

Over a past few decades a large number of Frequency Selective Surface for a wide band RF applications has been proposed and investigated. Various techniques for the bandwidth enhancement of FSS has been followed [4-11].

In this paper, a compact, polarization insensitive, angular stable, wide stop band FSS has been designed using combination of modified Jerusalem cross and circular ring type FSS for a wide band applications. It is designed by printing a 0.03mm copper layer of array of 34 × 34 unit cells on both sides on 1.0 mm thick FR4 substrate in such a manner that one unit cell on top surface of substrate overlap with the unit cell on bottom surface of the substrate. The proposed design provides the wide stop band with -10 bandwidth of 12.47 GHz ranging from 7.89 GHz to 20.36 GHz. The unit cell dimensions of designed structure are 8.4mm × 8.4mm × 1.0mm (0.39λ × 0.39λ × 0.0471λ where λ is the operating wavelength at centre frequency of its -10 dB bandwidth). The overall size of unit cell is compact. This helps in reducing sensitivity of response to the angle of incidence and reduces the grating lobes. The design is polarization insensitive and has an angular stability up to 30° of incidence angle for both the TE and TM polarization. For simulations Ansys HFSS software is used. A prototype of 34×34 unit cells was fabricated and tested. The results measured from the fabricated prototype are observed to be in good agreement with the results obtained from the simulation in Ansys HFSS software.

This paper is organized as follows. Section 2 describes the unit cell design of proposed Frequency Selective Surface structure. Section 3 describes the design analysis and simulation results of designed FSS structure. In section 4, measurement setup for measuring the performance characteristics of designed FSS have been illustrated, whereas experimental results are presented in section 5. Lastly, the conclusion is discussed in section 6.

2. UNIT CELL DESIGN

Generally the FSS element type is designed based on specific criteria such as operating bandwidth requirement, frequency response stability under various angle of incidence and polarization. The unit cell of proposed FSS is designed by using the combination of circular ring and Jerusalem type FSS element as shown in Fig. 1.Cascading the periodic structure in between the dielectric substrate increases the bandwidth of the band stop filter [2]. The designed FSS consists of 0.03 mm thick copper layer of array of 34×34 unit cells printed on both the sides of FR4 dielectric substrate having thickness of h=1.0mm, relative permittivity $\varepsilon_r = 4.4$ and loss tangent tanδ =0.02. The overall thickness of the designed FSS structure is around 0.0471λ. The design is periodic with the periodicity of 8.4mm in both the x- and y-directions.

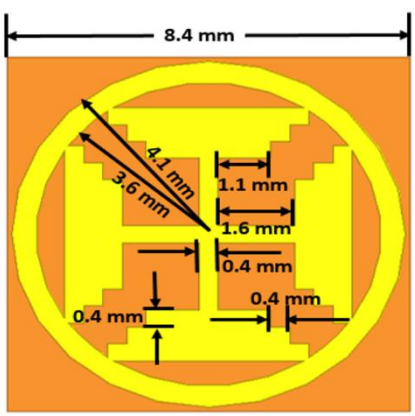

Fig. 1: Unit Cell Design of Proposed FSS Structure

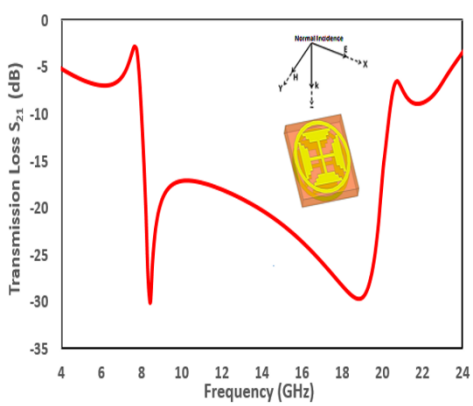

Fig. 2: Simulation Results of Proposed FSS Structure

Resonance frequency of typical FSS is determined by the formula $f=1/2\pi\sqrt{LC}$, where L and C are the effective inductance and capacitance of the structure respectively. The resonance frequency can be reduced by increasing either the inductance or capacitance or both in the structure. Large inductance is achieved by incorporating the large current path and large capacitance is achieved by keeping the smaller gap between the unit cells. Dimensions of the proposed design is optimized in such a manner that overall unit cell size is reduced, and increases the electric current path thereby increases the equivalent inductance of the design and hence decreasing the resonance frequency[1…]. The simulated transmission

response of proposed FSS for TE incident wave at normal incidence is shown in Fig. 2. The simulated result shows that the proposed structure provides the -10dB transmission bandwidth of 12.47 GHz ranging from 7.89 GHz to 20.36 GHz.

3. DESIGN ANALYSIS AND SIMULATION RESULTS

A three dimensional view of designed FSS is shown in Fig. 3. The FSS structure consists of a dielectric substrate sandwitched between two unit cell array structures. The design procedure of the proposed FSS is divided into various stages. Each stage has different resonance characteristics. In first step, a circular ring type and a Jerusalem cross type FSS element is chosen as basic element of designed FSS structure due to their wide band characteristics [2]. The simulated transmission response for optimized dimensions of ring type and Jerusalem type FSS element has been shown in Fig. 5 as a stage I and stage II respectively. It is observed that stage I exhibit stop band with a -10dB bandwidth of 3.89 GHz from 5.81 GHz to 9.70 GHz with respect to the transmission null at a frequency of 7.7 GHz and stage II exhibits the stop band with a -10dB bandwidth of 1.23 GHz from 8.10 GHz to 9.33 GHz with respect to the transmission null at a frequency of 8.7 GHz. As the combination of elements having nearby resonating frequency provides enhancement in bandwidth [25]. Both the optimized circular ring type FSS element in stage I and optimized jerusalem cross type FSS element in stage II are resonating at 7.7 GHz and 8.7 GHz respectively i.e they are resonating at nearby frequencies as shown in Fig.4. Hence a wide stop band response is achieved by combining the a jerusalem type FSS element of stage II to the basic circular ring type FSS elements of stage I in stage III as shown in Fig. 5. The simulated transmission response for stage III is shown in Fig. 5. It is observed that the stage III FSS exhibits a stop band with a -10dB bandwidth of 8.95 GHz ranging from 8.86 GHz to 17.81 GHz with respect to the transmission null at a frequency of 13.49 GHz.

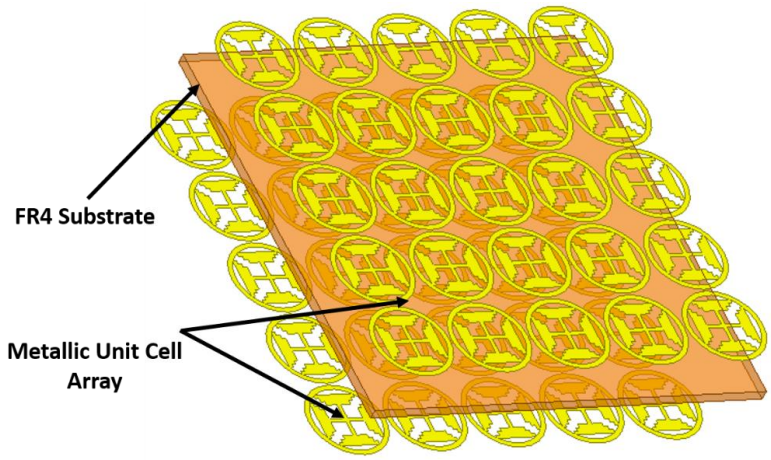

Fig. 3: A three dimensional view of designed FSS

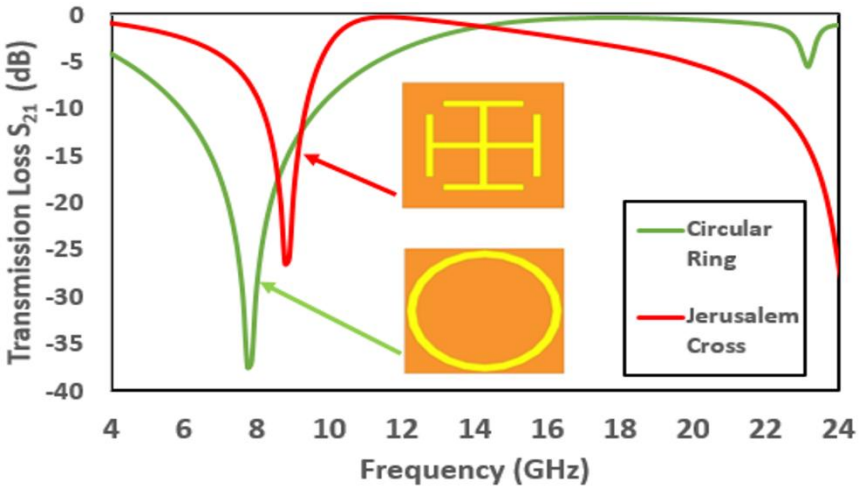

Fig. 4. Combination of individual responses of square loop and Jerusalem cross type FSS element.

In stage IV a rectangular patch is added below the end loading of Jerusalem cross type FSS element in such a way that the electrical length of the combined element is increased. Due to this increased electrical length broader bandwidth is achieved. The simulated transmission response for stage IV design is shown in Fig. 5. It is observed that the stage IV FSS exhibits a stop band with a -10dB bandwidth of 9.51 GHz ranging from 8.58 GHz to 18.09 GHz with respect to the transmission null at a frequency of 13.97 GHz. Although, it provides a broder bandwidth, but its resonance frequency has been shifed toward the higher side. Thereafter in stage V, stage IV has been modified by adding the rectangular patch just below the patch that is added in stage IV design. By doing this the path for the electric current is increased. Due to this increased in electric current path broader bandwidth is achieved. The simulated transmission response for stage V design is shown in Fig 5. It is observed that the stage V FSS exhibits a stop band with a -10dB bandwidth of 9.75 GHz ranging from 8.40 GHz to 18.15 GHz. with respect to the transmission null at a frequency of 14.27 GHz. Although, it also provides a broder bandwidth, but its resonance frequency has been shifed toward the higher side. Stage VI is the final stage of the proposed structure. In stage VI, stage V design has been modified by printing a 0.03mm copper layer of array of 34 × 34 unit cells on both sides on 1.0 mm thick FR4 substrate. The simulated response of stage VI design is shown in Fig. 5. It is observed that the stage VI FSS exhibits a wide stop band with a -10dB bandwidth of 12.47GHz ranging from 7.89 GHz to 20.36 GHz. with respect to the transmission null at a frequency of 8.4 GHz.

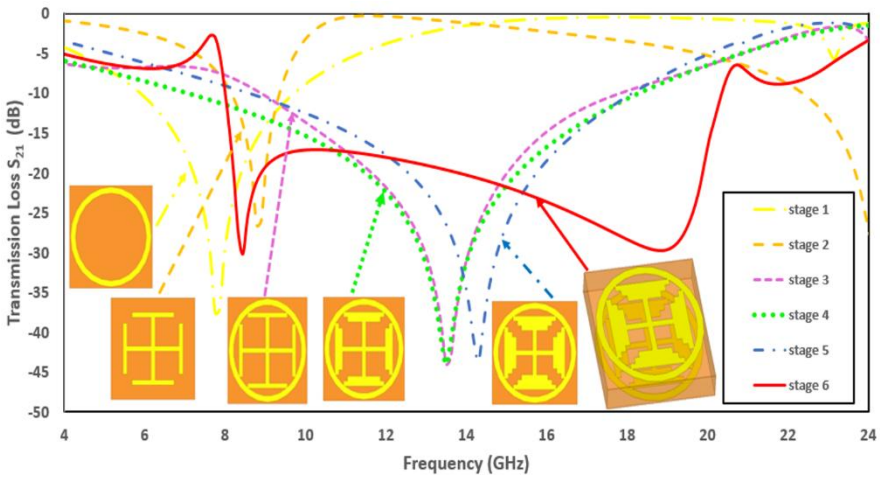

Fig. 5. Simulation Results of Various Design Stages of Designed FSS Structure

The proposed FSS has been investigated for various angles of the polarization. The simulated response for the polarization has been shown in Fig. 6. It is observed that due to four fold symmetry of the design, the proposed FSS structure is polarization insensitive and therefore offers similar response for all polarization angles from 0º to 90º.

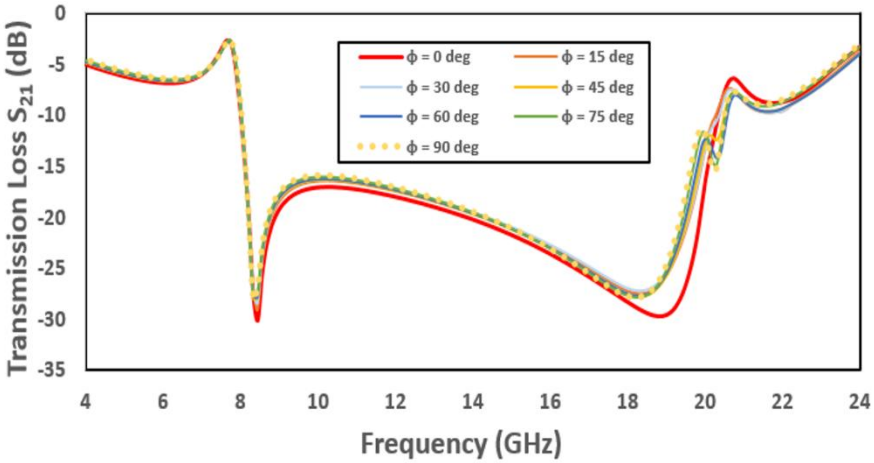

Fig. 6. Simulated Transmission Response at Different Angles of Polarization.

The angular stability of the proposed FSS is tested by carrying out simulations for different angles of incidence wave under TE and TM polarization. The simulated response for various incident angles (Θ= 0º, 15º, 30º, 45º) of TE and TM polarization has been shown in Fig. 7(a) and Fig. 7(b) respectively. It is observed that the proposed design shows the angular stable behaviour upto 30º for both the TE and TM polarization.

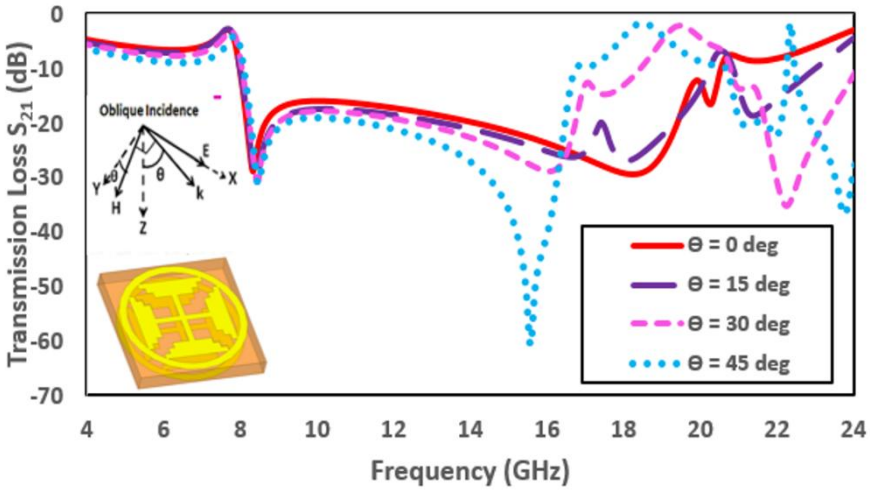

Fig. 7(a). Simulated Transmission Response of the Proposed FSS at Different Angles of Incidence for TE Polarization

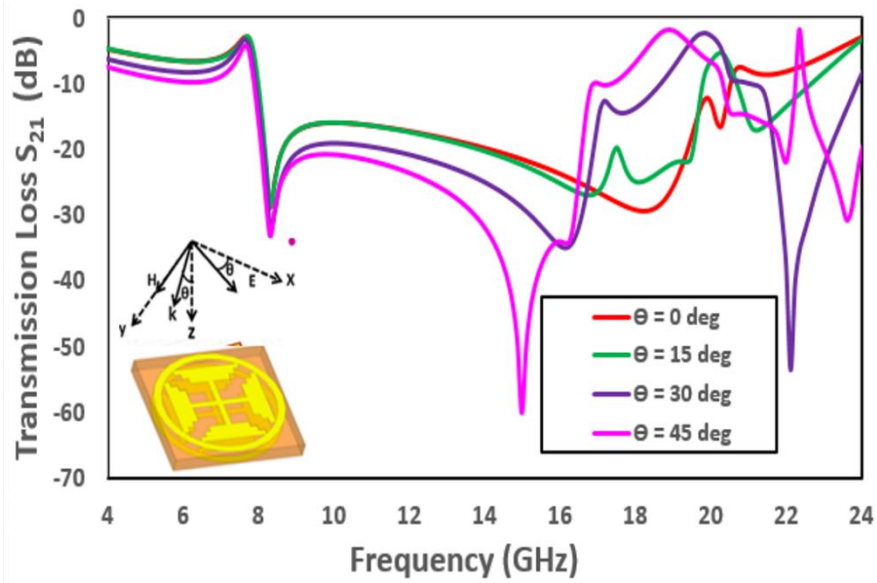

Fig. 7(b). Simulated Transmission Response of the Proposed FSS at Different Angles of Incidence for TE Polarization.

To understand the physical mechanism (operation) of unit cell of designed FSS structure, magnitude of induced electric field vector and surface current distribution at their respective resonance frequencies on both the top and bottom metallic layers are shown in Fig. 8 and Fig. 9 respectively. From the Fig. 8 and Fig. 9, it is observed that the electric filed vector is along the X- direction of proposed FSS and surface current distribution is along the Y- direction of proposed FSS. Arrows in Fig. 9 represents the direction of current flow while the colour represents the intensity. It is clear from the Fig. 9 the current is mainly contributed on the horizontal leg of Jerusalem cross FSS element while the current on the other parts of proposed FSS is weak.

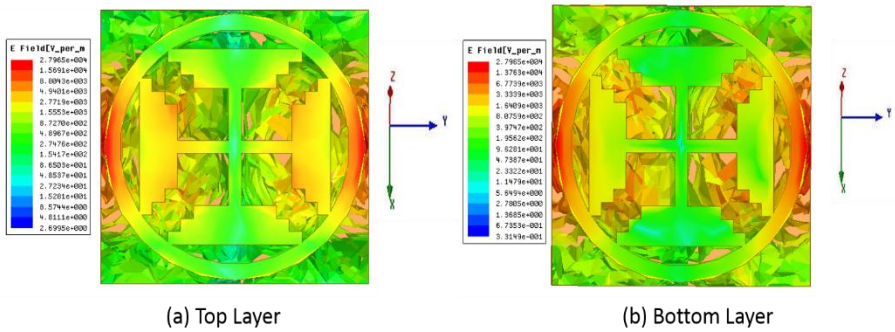

Fig. 8. Magnitude of electric field vector in the unit cell of designed FSS, (a) Top FSS layer and (b) Bottom FSS layer.

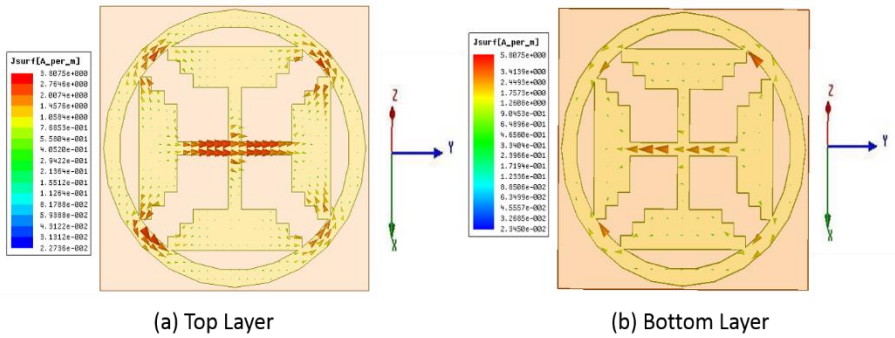

Fig. 9. Surface current distribution in the unit cell of designed FSS, (a) Top FSS layer and (b) Bottom FSS layer.

It is observed that as the design changes from the stage I to stage VI the bandwidth gets increased from 3.89 GHz to 12.47 GHz. The overall unit cell size with respect to mean frequency (14.125 GHz) of the stop band is 0.39 λ × 0.39 λ and thickness of unit cell with respect to mean frequency (14.125 GHz) of stop band is 0.0471λ. Therefore it is concluded that the proposed design is polarization insensitive, angular stable and compact. A comparison of bandwidth and transmission null for different design stages is depicted in Table 1.

Table 1: Comparison of different design stages.

Design Stage	Unit Cell Design	Transmission Null (GHz)	Bandwidth (GHz)
I		7.7	3.89
II		8.7	1.23
III		13.49	8.95
IV		13.97	9.51
V		14.27	9.75
VI		8.4	12.47

4. MEASUREMENT SETUP

In order to measure the transmission characteristics, the array of the proposed FSS with 34 × 34 unit cells (28.56cm × 28.56cm) has been fabricated on both sides of 1.0 mm thick FR4 dielectric substrate with $\varepsilon_r = 4.4$ as shown in Fig. 6. The measurement setup for the Experimental verification of proposed FSS is shown in Fig. 10. The two double ridge UWB horn antennas with operating range 1 to 18 GHz connected with Agilent N5222A vector network analyzer (VNA) are used in measurement setup. The distance between the transmitting (Tx) and the receiving antennas (Rx) is 1m.

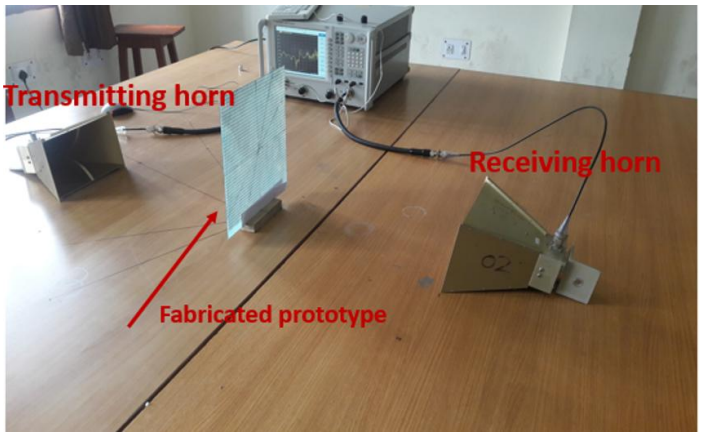

Fig. 10: Measurement setup for the experimental verification of proposed FSS.

The measurement is carried out in two steps. Firstly, in order to calibrate the test environment the transmitted power is measured, between the transmitting (Tx) and receiving (Rx) horn antennas. Secondly, the transmitted power is measured, by placing FSS sample between the two horn antennas. The difference between the two measured transmitted powers will be considered as the actual transmission power.

5. EXPERIMENTAL RESULTS

Array of 34 × 34 unit cell of proposed FSS are fabricated and measured. Fig. 11 shows the comparison between the measured and simulated transmission response of proposed FSS for incident TE wave at normal incidence. The simulated transmission response provides the wide stop band with a -10dB bandwidth of 12.47GHz ranging from 7.89 GHz to 20.36 GHz with respect to the transmission null at a frequency of 8.4GHz and the measured transmission response provides a -10dB bandwidth of -----GHz ranging from -----GHz to -------GHz, with respect to the transmission null at a frequency of -------GHz. As can be seen the measuredtransmission response are in good agreement with simulated transmission response, except for a slight difference, which is caused by assembly and truncation errors. The prcentage error between the measured and simulated transmission response is observed to be--------.The measured transmission response of proposed FSS for the various angle of incidence is shown in Fig. 12. It is observed that proposed FSS design is polarization insensitive.

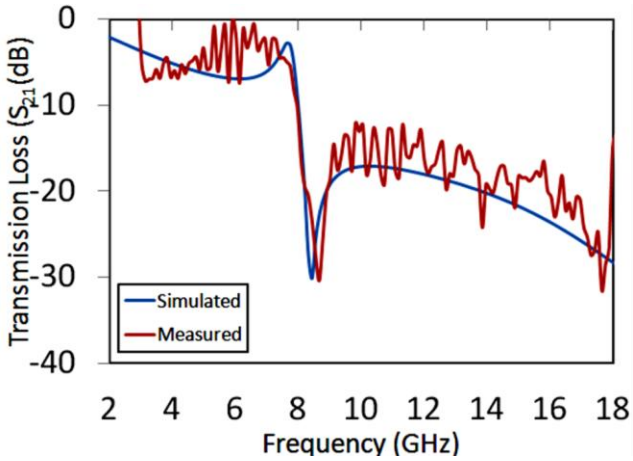

Fig. 11. Comparison between the measured and simulated transmission response of proposed FSS for incident TE wave at normal incidence.

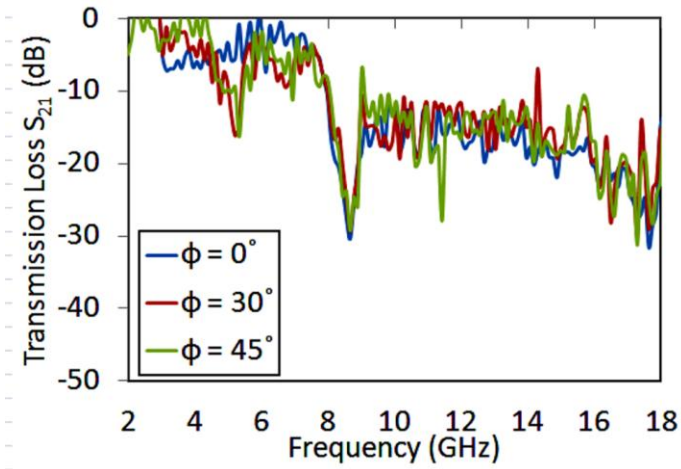

Fig. 12: Measured transmission response of proposed FSS for the various angle of incidence.

Table 2: Bandwidth corresponding to different dimension of Unit cell

Ref	-10 dB Bandwidth (GHz)	Unit cell size (mm)	Thickness
[9]	6-13 (73%)	8 ($0.25\lambda_0$)	1.6 ($0.05\lambda_0$)
[10]	6.5–14 (74%)	12 ($0.41\lambda_0$)	3.5 ($0.11\lambda_0$)
[11]	6–16 (91%)	12 ($0.44\lambda_0$)	3.2 ($0.12\lambda_0$)
[12]	2.8-11 (119%)	16 ($0.37\lambda_0$)	1.8 ($0.04\lambda_0$)
[13]	8–13 (45%)	20 ($0.70\lambda_0$)	1.6 ($0.05\lambda_0$)
[14]	4.91-14.41 (98%)	15 ($0.47\lambda_0$)	8 ($0.25\lambda_0$)
[15]	4-14 (100%)	14 ($0.47\lambda_0$)	1.6 ($0.05\lambda_0$)
[16]	4-7 (54%)	11 ($0.20\lambda_0$)	6.4 ($0.12\lambda_0$)
[17]	3-12 (120%)	8 ($0.20\lambda_0$)	0.635 ($0.02\lambda_0$)
Proposed FSS	7.89-20.36 (88.28%)	8.4 ($0.39\lambda_0$)	1.0 ($0.0471\lambda_0$)

6. CONCLUSION

A compact frequency selective surface is fabricated on both sides of dielectric substrate FR4 and is investigated for wide band RF applications such as RCS reduction. The designed FSS consists of combination jerusalem dipole and circular ring type FSS element. As the proposed FSS exhibit the four fold symmetrical profile, thus facilitating the excellent polarization independent behaviour and also offer angular stability up to 30º angle of incidence for both TE and TM modes of operation . The simulated result shows the -10dB bandwidth of 12.47GHz ranging from 7.89 GHz to 20.36 GHz. Therefore the proposed design is suitable as for antenna applications over the C, X, Ku and Ka-band. The experimental results are observed to be in good agreement with the simulated results.

REFERENCES

[1]. Marconi, G. and Franklin, C. S., 1919, U. S. Patent No. 1301473.

[2]. Munk, B. A. (2000). *Frequency Selective Surfaces: Theory and Design*. New York: John Wiley and Sons,inc.

[3]. Sun, R. Q.; Xie J.; and Zhang, Y. W. (2016). Simulation Research of Band- Pass Frequency Selective Surface (FSS) Radome, *progress in Electromagnetic Research Symposium (PIERS)*,1186-1193, Shanghai, China

[4]. Monni, S.; Gerini, G. and Neto, A. (2006). Frequency Selective Surfaces for the RCS reduction of low frequency antennas. *1st European Conference on Antenna and Propagation*, Nice , France.

[5]. Joyal M. A. and Laurin, J. J. (2012). Analysis and Design of Thin Circular Polarizer's Based on Meander line. *IEEE Transactions on Antennas and Propagation*, 60(6), 3007-3011.

[6]. Agrawal, V. D. and Imbriale, W. A. (1979). Design of a Dichroic Cassegrain Sub-Reflector, *IEEE Transaction on Antenna and Propagation*, 27(4), 466-473.

[7]. Yoshida, T.; Matsushita, M.; Kubota, T. and Yoshikado, S. (2016). Fabrication and Evaluation of Electromagnetic Wave Absorbers using Frequency Selective Surface, *Progress In Electromagnetic Research Symposium (PIERS)*, 1138-1144, Shanghai, China.

[8]. Wu, T. K. (1995). *Frequency Selective Surfaces and Grid Array*, John Wiley and Sons inc.

[9]. Baisakhiya, S.; Sivasamy, R.; Kanagasabai, M. and Periaswamy, S. (2013). Novel compact UWB Frequency Selective Surface for angular and polarization independent operation, 40, 71-79.

[10]. Sohail, I.; Ranga, Y.; Esselle, K. P. and Hay, S. G. (2013). A frequency selective surface with a very wide stop band, *7th European conference on Antennas and Propagation*, 2146-2148, Gothenburg, Sweden.

[11]. Syed, I. S.; Ranga, Y.; Matekovits, L.; Esselle, K. P. and Hay, S. G.(2014). A single layer Frequency Selective Surface for ultrawideband Electromagnetic Shielding.*IEEE Transactions on Electromagnetic Compatibility*, 56(6), 1404-1411.

[12]. Kushwaha, N.; Kumar, R.; Krishna, R. V. S. and Oli, T.(2014). Design and Analysis of New Compact UWB Frequency Selective Surface and its Equivalent Circuit, *progress in Electromagnetics Research c*, 46, 31-39.

[13]. Braz, E. C. and Campos, A. L. P. S. (2014). Dual/wide band multifractal frequency selective surface for application in S and X band, *Microwave and Optical Technology Letters*, 56(10), 2217-2222.

[14]. Sohail, S. I. and Zarar, M. Electromagnetic Shielding by Frequency Selective Surface. *Journal of Engineering and Applied Sciences*, 10(19), 8873-8877.

[15]. Sivasamy, R.; Moorthy, B.; Kanagasabai, M.; George, J. V.; Lawrance, L. and Rajendran, D. B. Polarization independent single layer ultra-wideband frequency selective surface. *International Journal of Microwave and Wireless Technologies*, 9, 1-5.

[16]. Chatterjee, A. and Parui, S. K. A dual layer frequency selective surface reflector for wideband applications, *Radioengineering*, 25(1), 67-72.

[17]. Yahya, R.; Nakamura, A. and Itami, M. Compact single layer UWB frequency selective surface, *IEEE international symposium on antenna and propagation*, 957-958,Fajardo, Puerto Rico.