A Model of Frequency Selective Surface for Radio Wave Propagation

Polineni Kala Mounika[*] **and M. Susila**[**]

Abstract: FSS is a periodic structure with either patches or slot elements placed on a substrate. It operates for the frequency range of 2GHz to 11GHz, it reviews the applications of FSS in WLAN and filters the unwanted frequency which is not required for the operation. The proposed structure is designed and simulated using 3D Electromagnetic Simulation software and it is observed that the structure resonates at WLAN frequency with a transmission coefficient S21 of –40 dB. FSS model can also be used to control propagation within building and surrounding environment at different frequencies like (2.4 GHZ & 5.6 GHZ). FSS can reduce interference and isolate coverage in wireless indoor and outdoor environment by increasing transmission loss in particular parts of frequency spectrum. The predominant merit of this structure is that there will be reduction in interference from the WLAN frequency signals and these can be applied in antenna measurements like anechoic chamber and also for radomes.

Keywords: FSS, anechoic chamber, radome.

1. INTRODUCTION

Frequency Selective Surface (FSS) is said to be a periodic structure with either patch or slot elements placed on a substrate which is implemented in single or multiple frequency and it is mainly used for filtering purpose [1], dichroic plates in reflector systems [2], circuit analogue absorbers [3] etc., The specification of FSS is to pass or reject electromagnetic waves (EM waves) [4] at a particular frequency by influencing the insertion and return loss characteristics.

A group of metallic patches on a substrate, or a conducting sheet systematically perforated with apertures, consist of frequency selective surface (FSS) to electromagnetic [EM] waves. Such structures have been well known in antenna theory for over decade at microwave wavelengths, such designed structures were easy to manufacture and employ in antenna design [5]-[8].

Construction of FSS in array of filters for the near-infrared wavelength regime are no longer difficult to manufacture Radar antenna dome covers or randomness are used for protecting antennas operating in adjoining frequency bands from interfering with each other. Their results will be compared in terms of insertion phase delay IPD of the structure. Both single and multi-layer configurations are used.

The major drawback of these structures is that they were presuming the angle of incidence and polarization [9]. Thus there will be a mismatch in the simulation results when compared with the real time testing. This can be overcome by using a Frequency Selective Surface In FSS the angle of incidence and where polarization plays a crucial role. A Frequency Selective Structure (FSS) is an array or group of periodic elements (unit cells). These can be either slots on the conducting sheet or metallic patches on the substrate. When an EM(electromagnetic) wave is incident on the surface, every element (unit cell) resonates and disbands the energy about its resonance frequency [10]. The incident EM wave is partly transmits through the structure and partly reflected. These were said to be a passive array. The metallic patches on the substrate FSS properties are referred as capacitive FSS. They can also behave like low pass filter.

---
[*]   PG Scholar, Department of Telecommunication Engineering, SRM University, Chennai, Kancheepuram District. *Email: mouny238@gmail.com*

[**]   Assistant Professor, Department of Telecommunication Engineering, SRM University, Chennai, Kancheepuram District. *Email: susilasrm@gmail.com*

FSS can be categorized as four types. Center connected array of elements oscillates when the largest tip to tip is approximately equal to one half of the wavelength. The elements must be closely spaced to arrive the better output. The loop structures resonates when their average circumference is equal to half wavelength and this can be used for miniaturizing and these might be reduced to three tenth of the wavelength without any substrate. Therefore by using this we can exploit narrow bandwidth to super wide bandwidth. Solid interior types should also be half the wavelength and also include many other factors. The combination types have too many considerations. And there are a large number of designs based on this type. Combination types are usually preferred to shape the resonant curves to the needs of the designer since they allows them without many constraints, still estimating the curve will be equally tougher. Therefore a lot of fine tuning will be required in this case.

2. DESCRIPTION OF FSS

In the literature survey two generic geometries are typically discussed. The first geometry is commonly referred to as an inductive FSS, performs similar to the high-pass filter. The second case is referred to as capacitive FSS, which is similar to a low-pass filter. If the periodic array of elements within FSS posses resonance characteristics [11], [12] then the inductive FSS will exhibit the total transmission of wavelengths near the resonant wavelength, while the capacitive FSS will displays the total reflection.
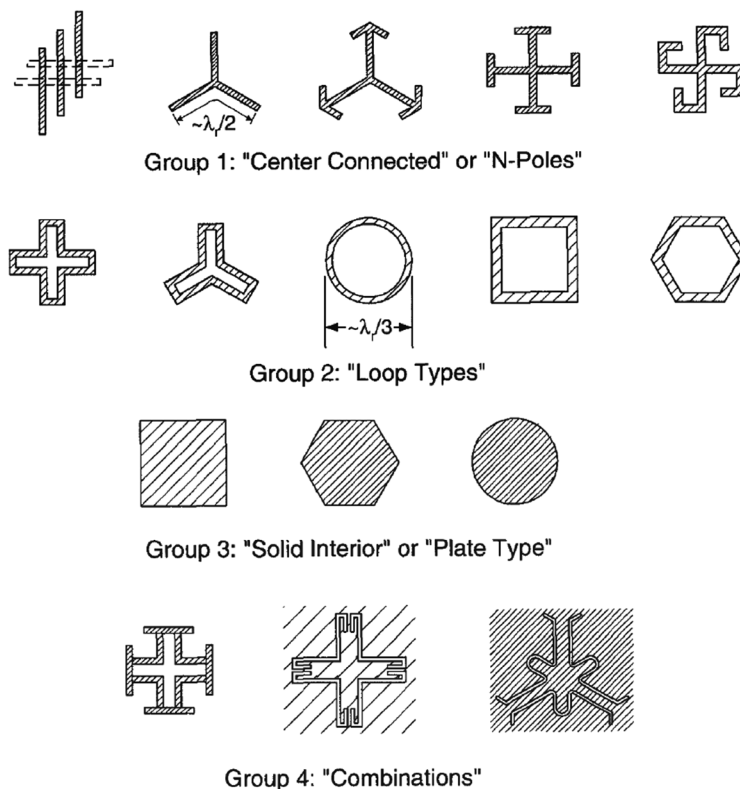

Group 1: "Center Connected" or "N-Poles"

Group 2: "Loop Types"

Group 3: "Solid Interior" or "Plate Type"

Group 4: "Combinations"

Figure 1: Types of FSS

When designing either a band-pass or band-stop FSS, the choice of the proper element may be of utmost importance. Some elements are inherently broad banded or narrow-banded than others, while some can be varied considerably by design. In this chapter we present the typical behavior of the most common element types available to the FSS designers of today. All the curves in the structure are shown at 45° angle of incidence for orthogonal as well as parallel polarization with a resonant frequency around 10 GHz. The curves presented in the following are mostly related to small inter-element spacing's resulting in the larger bandwidth and stable resonant frequency with respect to angle of incidence.

A.   Center Connected or *n*-poles

Although not particularly small in terms of wavelength, the unloaded tripole element has a very favorable feature: It can be packed tightly, thereby making the inter element spacing's small and the bandwidth large. It does, however, suffer from the same problem as the gangbuster element in general, namely excitation of the second harmonic for parallel polarization this leads to so-called super-dense surfaces. They are discussed in detail in Schneider's dissertation. These surfaces have the advantage of a much lower cross-polarization than the gangbuster type, but they are somewhat more complicated to manufacture due to registration requirements between the various layers.

B.   Loop Types

The development of this element is quite instructive. In Figure 1.1 we show a simple $h/2$ dipole with load impedance ZL under receiving condition; that is, its equivalent circuit is said to be a generator connected to its radiation impedance of the structure

ZA = RA + jXA in series with the load impedance ZL. Under resonant conditions $j = X A – 0$; that is, we obtain the strongest current for ZL = 0. Making an element smaller is usually a good idea because it enables us to pack the elements closer together, resulting generally in better resonance stability with angle of incidence and possibly greater bandwidth.

C.   Solid Interior Types

The third group of elements are comprised of plates of simple shapes such as squares, hexagons, circular disks, and the like, as shown in Figure 1.1 for the reflecting case. These types can be characterized as being made with solid interior as opposed to the loop types discussed above such as the three- and four-legged loaded elements as well as the hexagon element. These plate elements were actually among the first to be investigated, for example, by Kieburtz and Ishimaru [13] who considered a periodic surface of square apertures. Later contributions were made by Lee [14] and Chen [15]. Unfortunately, this class of surfaces leads to element dimensions close to $h/2$; that is, the inter-element spacing must be somewhat large leading to angle of incidence sensitivity and early onset of grating lobes.

D.   Combination Types

The list of elements above is not complete, only typical. Endless combinations and variations are possible and can easily be contemplated by anyone familiar with the state-of-the-art. When an FSS is produced by simple photo-etching [16], the shape of the elements is immaterial. However, if the surface is produced by an electro forming process, then it causes the problem if parts of the elements are —isolated, ‖ for example, the interior loading of the loop type elements. To alleviate this problem, several loaded elements have been developed without a —floating ‖ interior [17].

E.   The Unit Cell Approach

In this section, a brief explanation of method of analysis for FSSs is presented. As Mentioned before, FSSs are periodic arrangements of metallic patches of arbitrary geometries or their complimentary geometries having aperture array of elements that are similar to the patches within a metallic screen [18]-[23]. The inter-element spacing's in the *x*-direction (D*x*) are the same for all rows, and inter-element spacing's in the *z*-direction (D*z*) are same for all columns. The array is planar in both *x*- and *z*-directions with all elements identical to each other. Unit cell simulation, which is available in HFSS commercial software, is employed for the analysis of periodic FSS structures. HFSS is a 3D full wave solver utilizing finite integration method. This reference element is name as unit cell therefore; periodic boundary condition together with phase shifts

between the neighboring cells is sometimes called as unit-cell boundary. In the Unit-cell simulation, we illuminate the FSS with a plane wave from the front and Compute the transmission coefficient through the FSS (also reflection coefficient off the FSS), applying the unit-cell boundary condition to the four sides of FSS and radiation boundaries to the front and back of the unit-cell.

3. HFSS DESIGN

HFSS is a specialist tool for the 3D EM (electromagnetic) simulation of high frequency components. HFSS unparalleled performance making it first choice in the technology leading with R&D departments. whereas the tool enables the fast and factual analysis of high frequency (HF) devices such as antennas, filters, couplers, planar, multi-layer element of structures and SI and EMC effects. Exceptionally user friendly, HFSS quickly gives you an insight into the EM(electromagnetic) behavior of your high frequency designs. HFSS promotes Complete Technology for 3D EM. Users of the software are given greater flexibility in tackling a wide application among the range through the variety of available solving technologies. Beside the flagship module, the widely applicable Time Domain solver and the Frequency Domain solver, HFSS offers further solver modules for specific applications. Filters based on the import of specific CAD files and the extraction of SPICE parameters enhances design possibilities and save time. In addition, HFSS is embedded in various industry standard workflows through the HFSS design environment.

4. FSS PARAMETERS

A. Directivity

The directivity or gain of an antenna is defined as the ratio of the maximum value of the power radiated per unit solid angle, to the average of total power radiated per unit solid angle:

$$G = ((dp/d\Omega)\max)/(p/4\pi) \tag{1}$$

B. S parameter

S parameter is a parameter related to high frequency microwave circuits and denotes the properties of the network under high frequencies. It can be denoted as the transmission co-efficient, reflection co-efficient and help in ports, the no of parameters involved is n^2.

$$\text{Return loss [db]} = -20*\log(s11) \tag{2}$$

S11 (Return loss): Return loss is defined as the loss of signal power resulted from the reflection caused at a discontinuity of transmission line or optical fiber. This discontinuity can be a mismatched with the help of terminating load or with a device

$$RL(dB) = 10 \log_{10} p_i/p_r \tag{3}$$

S21 (forward transmission co efficient): It is the attenuation based on the wave travelling from port 1 to port 2. It has S21 has given by

$$S21 = (b2/a1) \text{ where } a2 = 0 \tag{4}$$

S12 (Forward gain): It is the attenuation of wave travelling from port 2 to port 1 It has S12 has given by

$$S12 = (b1/a1) \text{ where } a1 = 0 \tag{5}$$

S22 (Output reflection co efficient): A reflection coefficient describes either the amplitude of the signal or the intensity of a reflected wave which is related to the incident wave. The reflection coefficient is related closely to the transmission co efficient.

C. VSWR

It refers to voltage standing wave ratio of a network .it is defined as the ratio of maximum voltage to the minimum voltage occurring in a transmission line.

5. DESIGN SPECIFICATIONS

The minimum operating frequency is chosen as 0 GHz and the upper most frequency is chosen as 11 GHZ. it blocks a particular frequency of 5.2 GHz – 5.6 GHz to the indoor building environment. The design parameters are given in the table below. The thickness of the substrate and the thickness of the patch are specified as per the industrial standards. The final FSS design is shown in Figure 2 and it is observed that the structure is circular to be angularly stable.
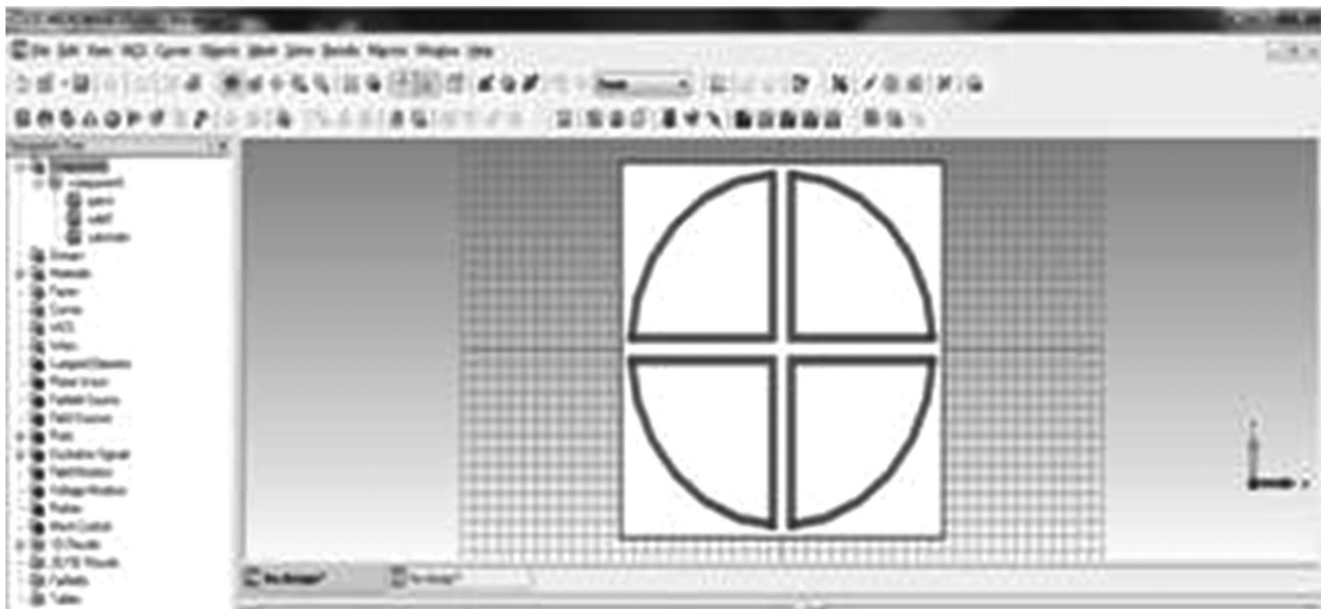

Figure 2: Final FSS Design

6. DESIGN ANALYSIS

Using the basis FSS design, analysis is made by varying the parameters to arrive at better result. Materials like Teflon, FR-4 have been included in the design and results are analyzed to get the optimum substrate material.
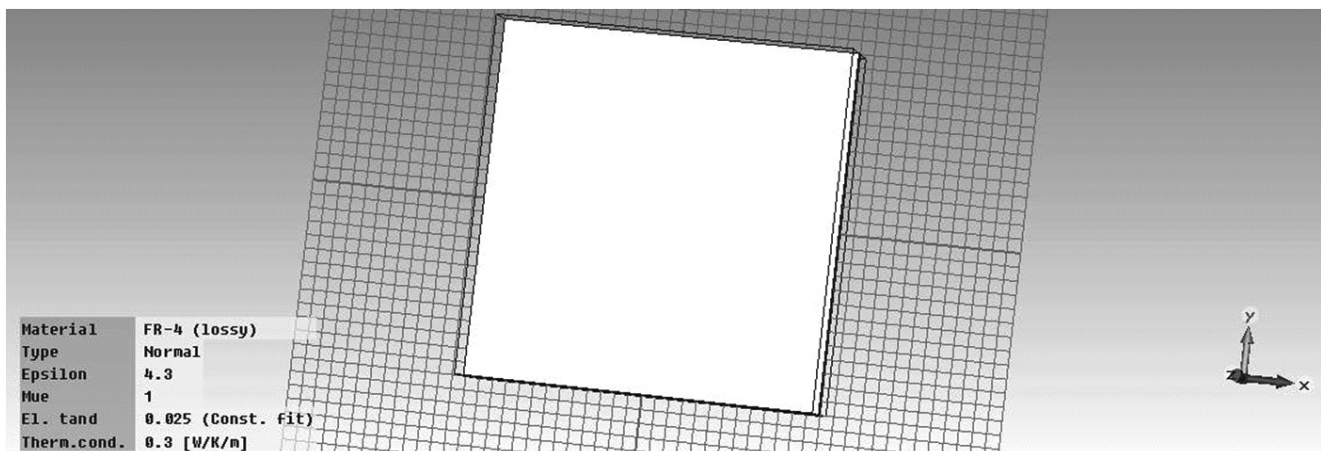

Material	FR-4 (lossy)
Type	Normal
Epsilon	4.3
Mue	1
El. tand	0.025 (Const. fit)
Therm.cond.	0.3 [W/K/m]

Figure 3:

Teflon gives better results during simulations but the cost involved in the fabrication is more. Hence for fabrication, FR-4 was used as the substrate which is comparable to Teflon. The substrate is shown in Figure 4.
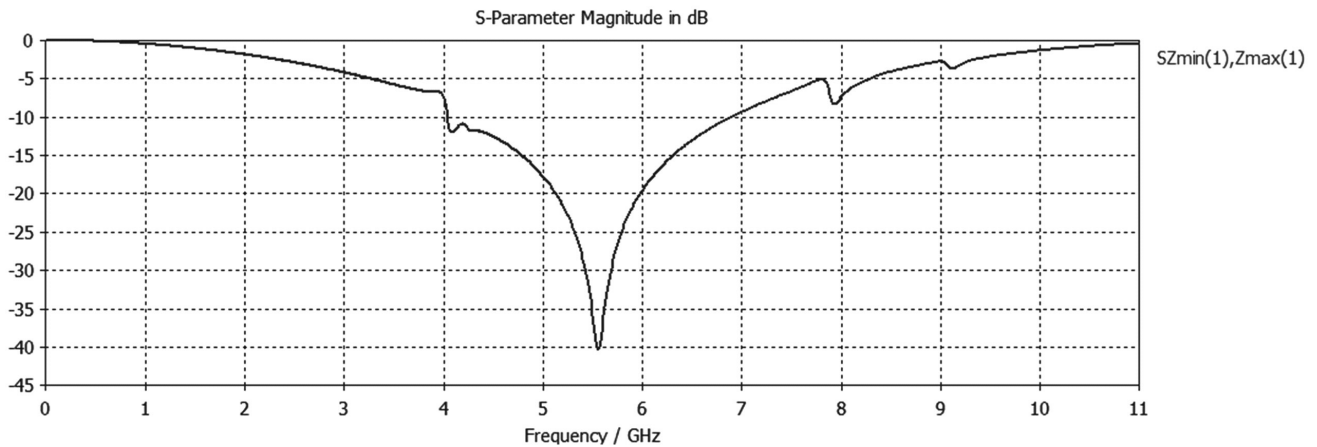

Figure 4: S21 – TE Mode

The following figure shows the scattering parameter (in decibels) plot of the basis FSS. The TE mode characteristics is shown in Figure 4.2 and the TM mode.
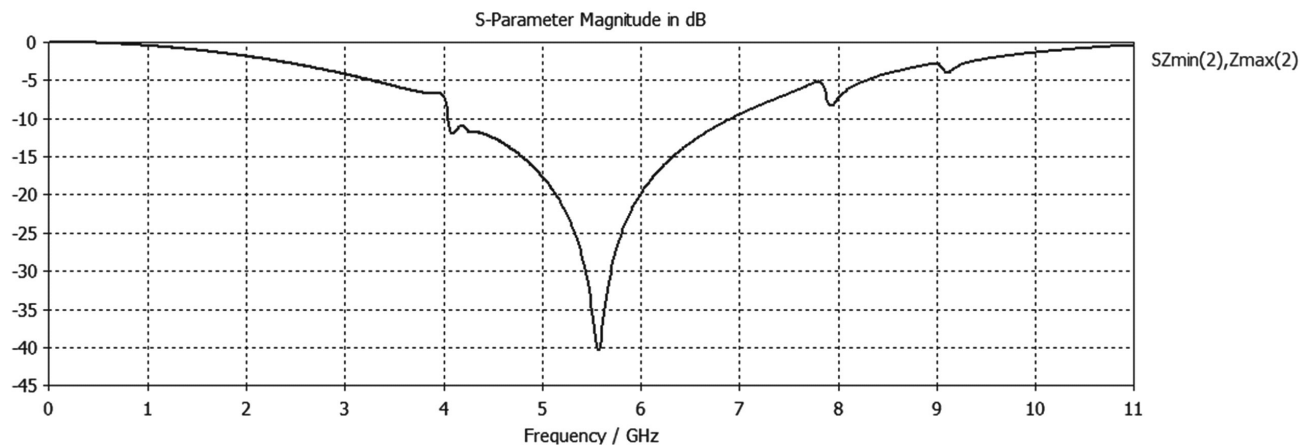

Figure 5: S21 – TM Mode

To make the wider range of bandwidth in order to get good reflecting characteristic inside the WLAN frequency band of a modified double layer and stepped square was designed as in Figure 4.2. The response of the design shows much improved bandwidth but still the attenuation outside the band is undesirable as it covered almost 2 GHz above and below the center frequency of 5 GHz and thus blocking the frequencies from passing through the surface. The response also showed the structure resonating at two different frequencies.

The FSS structure is analyzed with the help of HFSS software. Instead of computing the entire infinite array of the selective surface only a single unit cell is computed. The numerical calculations are carried out by the tool. The simulation is done by applying the boundary condition of the unit cell in x and y direction and thereby deriving the floquet mode excitations. This makes the simulation process less time consuming. The S parameters from the simulated results exhibit the transmission and reflection properties of the frequency selective surface. The propagation of the higher order floquet modes depends on the periodic spacing between the elements, the range of frequencies defined, and the spherical angle of incidence plane wave. The simulation is being done by the frequency domain solver of HFSS.

It is observed that the structure resonates at WLAN frequency which is centered at 5 GHz with a transmission coefficient S21 of –37 dB. The surface exhibits good reflection in the intended band. It also shows good transmission characteristics outside the band. The transmission coefficient is 0 to –3 dB outside the band which makes this structure desirable as this will not stop any adjacent bands from entering the surface. This highly recommends this structure for certain class of applications. The comparison of simulated and measured is provided which indicates the similarity of the curves. The reflection characteristics are also explained that they pass all other frequencies within the range 0-10 GHz.

It showed good response in the center frequency of the range covering the intended band, along with another frequency band blocked with lower attenuation. It is further observed that placing metallic patches on either sides of the substrate improves the frequency response. Changes were made for trying to eliminate the unwanted glitches in the frequency response. The width of the inner patch arms were reduced when comparing to the outer patch. By placing a slot on all four sides of the inner stepped square the response shown it single frequency band getting rejected and few other glitches were also seen in the adjacent bands. It was noted that the glitches were attenuated up to –5 dB. This made them undesirable as the adjacent bands has to be transmitted through the surfaces for which no attenuation or attenuation less than –3dB has to be observed. Thus to eliminate those glitches a small notch pointing towards the center of the structure is added to the slots provided on all four sides. This structure showed good desirable response within as well as outside the WLAN band.

7. RESULT ANALYSIS

As shown in Figure 4 and 5, the TE mode and TM mode characteristics match each other which make the FSS to block the intended frequency signals irrespective of its polarization. Figure 5.22 shows the angular stability of the proposed FSS and the variations are very minimal and the structure blocks the intended frequency for any angle. It is observed that the FSS structure resonates at WLAN frequency cantered at 5.5 GHz with a transmission coefficient S21 of –40 dB. The surface exhibits good reflection in the intended band. It also shows good transmission characteristics outside the band. This highly recommends this structure for certain class of applications. The comparison of simulated results for various angle of incidence is provided which indicates the similarity of the curves. The reflection characteristics are also explained that they pass all other frequencies within the range 0-11 GHz.

Depending on the shape of the structure, its dimensional values, the complexity of the design, the frequency range defined and the accuracy level the computation time of the HFSS tool varies. For the structure specified in Figure 5.20 with normal incident plane wave with spherical angle of incidence as 0 the running time is approximately 42 minutes in the frequency domain solver for the range of frequency of 0-11 GHz with dual core CPU @ 2.4 GHz.
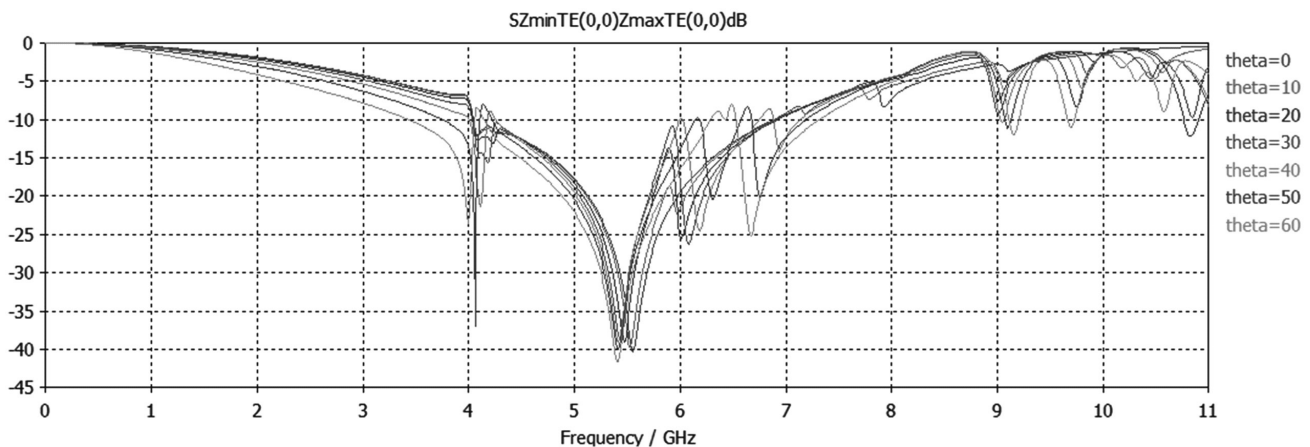

Figure 6: Angular Stability of the Proposed FSS

8.   CONCLUSION AND FUTURE SCOPE

A combination type of FSS structure is proposed to block the 5.6 and 2.4 GHz WLAN frequency band from entering into an indoor measuring environment to ensure the absence of interference and to allow all other frequency bands.

The major advantage of this proposed structure is that it exhibits good transmission in all other frequency bands in the range 0-10 GHz. The transmission coefficient ranges between 0 to –3 dB and thus recommending for this class of applications. Depending on the shape of the structure, its dimensional values, the complexity of the design, the frequency range defined and the accuracy level the computation time of the HFSS tool varies. For the structure specified in Figure 6 with normal incident plane wave with spherical angle of incidence as 0 the running time is approximately 42 minutes in the frequency domain solver for the range of frequency of 0-10 GHz with dual core CPU @ 2.8 GHz.

Some noise in the transmission is observed for the frequencies 7.6, 8.45 and 9.28 GHz. Their transmission coefficient ranges between –1.8 to –2.98 and therefore the transmission will not be affected much in those frequencies. Thereby enhancing good transmission at the adjacent frequency bands. This work can be extended to exploit an ideal band stop curve with the maximum attenuation ranging over the entire intended band. It can also be extended to block multiple frequency bands with good transmission characteristics(ideally 0 dB attenuation) outside the intended band.

References

1.   Meng And Nader Behdad, ―Frequency Selective Surfaces For Pulsed High-Power Microwave Applications, IEEE transactions on antennas and propagation, Vol. 61, No. 2, pp. 679 – 686, February 2013.

2.   Arezou Edalati And Tayeb A. Denidni, ―Frequency Selective Surfaces For Beam-Switching Applications, IEEE transactions on antennas and propagation, Vol. 61, No. 1, pp. 195 – 200, January 2013.

3.   K. Delihacglu, ―Frequency Selective Surfaces With Multiple-Strip Group Elements, IEEE antennas and wireless propagation letters, Vol. 11, October2012.

4.   A. Edalati and T. A. Denidni, ―High-Gain Reconfigurable Sectoral Antenna Using An Active Cylindrical FSS Structure IEEE trans. antennas propagation, Vol. 59, No. 7, March 2011.

5.   A. Edalati and T. A. Denidni, ―Beam-Switching Antenna Based On Active Frequency Selective Surfaces, presented at the IEEE antenna and propagation society int. symposium, July 2011.

6.   M. Al-Joumayly and N. Behdad, ―A Generalized Method For Synthesizing Low-Profile, Band-Pass Frequency Selective Surfaces With Non-resonant Constituting Elements, IEEE trans. antennas propagation., Vol. 58, No. 12, pp. 4033 – 4041, December 2010.

7.   Mudar A. Al-Joumayly and Nader Behdad, ―Low-Profile, Highly-Selective, Dual-Band Frequency Selective Surfaces With Closely Spaced Bands of Operation, December 2010.

8.   Ming Yang And Anthony K. Brown ―A Hybrid Model For Radio Wave Propagation Through Frequency Selective Structures (FSS), IEEE Transactions On Antennas And Propagation, Vol. 58, No. 9, pp. 2961 – 2968, September 2010.

9.   J. Shaker, R. Chaharmir, And H. Legay, ―Investigation Of FSS-Backed Reflect array Using Different Classes Of Cell Elements, IEEE Trans. Antennas Propag., Vol. 56, No. 12, pp. 3700–3706, April 2008.

10.   F. Bayatpur and K. Sarabandi, ―Multi pole Spatial Filters Using Meta material-Based Miniaturized-Element Frequency-Selective Surfaces, IEEE Trans. Microwave Theory Tech., Vol. 56, No. 12, pp. 2742–2742, Dec 2008.

11.   Ghaffer I. Kiani, Kenneth L. Ford, Karu P. Esselle, Andrew R. Weily, and Chinthana J. Panagamuwa, ―Oblique Incidence Performance of a Novel Frequency Selective Surface Absorber, October 2007.

12.   G. H. Sung, K. W. Sowerby, M. J. Neve, and A. G. Williamson, ―A Frequency-Selective Wall For Interference Reduction in Wireless Indoor Environments, IEEE Antennas Propag. Mag., Vol. 48, pp. 29–37, Oct 2006.

13.   G. H. Sung, K. W. Sowerby, and A. G. Williamson, ―Modeling a Low-Cost Frequency Selective Wall for Wireless-Friendly Indoor Environments, IEEE Antennas Wireless Propag. Lett., Vol. 5, pp. 311–314, Feb 2006.

14. Jeremy A. Bossard, Douglas H. Werner, Theresa S. Mayer,and Robert P. Drupp, ―A Novel Design Methodology For Reconfigurable

15. E. A. Parker and S. B. Savia, ―Fields in an FSS Screened Enclosure, In IEEE Proc. Microwave. Antennas Propagation., Feb 2004, Vol. 151, pp. 77–80.

16. Ben a. munk, ―frequency selective surfaces – theory and design, a Wiley interscience publication, July 2000.

17. J. C. Vardaxoglou, P. Y. Lau, And M. Kearney, ―Frequency Selective Surface From Optically Excited Semiconductor On A Substrate, IEEE Electronic Letters, Vol. No. 6, pp. 570–571, Mar 1998.

18. T. K. Chang, R. J. Langley, and E. A. Parker, ―Active Frequency-Selective Surfaces, In Proc. IEEE Microwaves, Antennas Propagation., Vol. 143, Februaury. 1996, pp. 62–66.

19. T. K. Wu, Ed., Frequency Selective Surface and Grid Array. New York: Wiley, October1995.

20. B. Philips, E. A. Parker, And R. J. Langley, ―Active FSS in an Experimental Horn Antenna Switchable between Two Beam widths, IEEE Electronic Letters, Vol. 31, No. 1, pp. 1–2, January 1995.

21. A. C. De C. Lima, E. A. Parker, And R. J. Langley, ―Tunable Frequency Selective Surface Using Liquid Substrates, IEEE Electronic Letters., Vol. 30, No. 4, pp. 281–282, Februaury 1994.

22. R. J.Mittra, C.H. Chan, and T. A. Cwik, ―Techniques For Analyzing Frequency Selective Surfaces—A Review, Proc. IEEE, Vol. 76, pp. 1593–1614, December 1988.

23. C. C. Chen, ―Transmission Of Microwave Through Perforated Flat Plates Of Finite Thickness, IEEE Trans. On Microwave Theory and Techniques, Mztt- 21(1), 1-6, January 1973.