Design of Frequency Selective Structures for Radio Wave Propagation

S.Lalitha Nachal, B.Monica , M.Ramani

Student(M.E Applied Electronics), Department of Electronics And Communication Engineering, Velammal Engineering College, Chennai, Tamil Nadu, India

Abstract— Frequency Selective Surfaces (FSS) are periodic structures with either patch or slot elements placed in a periodic substrate that have frequency filtering properties which is implemented in single or multiple frequency band-pass or band-stop filtering, dichroic plates in reflector systems, circuit analog absorbers, etc. The specification of FSS is to pass, or reflect, electromagnetic (EM) waves at a particular frequency by influencing the insertion and return loss characteristics. The proposed system investigates the application of FSS in WLAN. The design and simulation was performed in Computer Simulation Technology (CST) Microwave Studio. The proposed hybrid model blocks the specified WLAN frequencies and also controls the radio wave propagation. The predominant merit of this structure is that there will be no interference from the WLAN frequency signals and this can be applied in antenna measurement chambers like anechoic chamber. The proposed system is an ongoing research work in which the designed FSS has been fabricated and the results are to be verified practically in EMC lab.

Index Terms — Band stop filters, Frequency Selective Surfaces, WLAN, anechoic chambers.

I. INTRODUCTION

Radar antenna dome covers or radomes are used for protecting antennas operating in adjacent frequency bands from interfering with each other. Their results are compared in terms of insertion phase delay IPD. Both single and multi-layer configurations are used. The major drawback is that they were presuming the angle of incidence and polarization. Thus there is a mismatch in the simulation results when compared to real time testing. This can be overcome by using a Frequency Selective Surface FSS where angle of incidence and polarization plays a crucial role.

A Frequency Selective Structure (FSS) is an array of periodic elements (unit cells).
They can be either slots on a conducting sheet or metallic patches on a substrate. When an electromagnetic wave is incident on the surface, each element (unit cell) resonates and disbands the energy around its resonance frequency. The incident EM wave is partly transmitted through the structure and partly reflected. They are passive array.

The metallic patches on the substrate FSS configuration is referred as capacitive FSS. They behave like low pass filter. The performance of the surface depends on its dimensions, structure, periodic spacing, thickness, conductivity of patch and permittivity of substrate.

FSS can be categorised as four types [2]. Centre connected elements resonates when the largest tip to tip is approximately equal to half the wavelength. The elements must be closely spaced to arrive at a better output. The loop types resonate when their average circumference is equal to one wavelength. This can be used for miniaturizing as these can be reduced to three tenth of the wavelength without the substrate. So by using this we can exploit narrow bandwidth to super wide bandwidth. Solid interior types too have to be half the wavelength but also include many other factors. The combination types have too many considerations. And there are a huge 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. Yet estimating the curve will be equally tougher. Thus a lot of fine tuning will be required in this case.

II. RELATED WORKS

Ming yang and Anthony K. Brown [1] discussed the application of FSS to screen certain frequency bands within an indoor building environment to avoid interference and to increase security and bit rate.

Arezou Edalati and Tayeb A. Denidni [3] proposed a design of FSS in beam switching by sectoring a cylinder using a metallic sheet in to six equal parts with each sector covering 60 degrees. Dipoles with pin diode in their centre for ON/OFF switching were connected in all sectors. Metallic cones were attached to the top and bottom to increase the directivity. It is being designed as to ensure only one sector is active at a time.

K. Delihacıoğlu [4] proposed that when double and triple strips of unequal lengths were placed in the same unit cell, it exhibits multiple resonances. This can be used in multi band frequency applications.

Meng and Nader Behdad [5] discussed about the power handling capability of FSS and their role in high power application with peak power of 25 kW.

These FSS High Power Microwave (HPM) elements are constructed of non resonating materials.

Jeremy A. Bossard, Douglas H. Werner, Theresa S. Mayer, and Robert P. Drupp [6] discussed that FSS can be reconfigured by interconnecting the grid of metallic patch elements by a matrix of switches to exploit the desired response using genetic algorithm.

Mudar A. Al-Joumayly and Nader Behdad [7] discussed the application of FSS for closely spared dual band which can be constructed by placing multiple layers of patches and substrates in a specific sequence on a single unit cell.

III. EXISTING SYSTEM

The existing system [8] is a two layered structure. The first layer consists of conducting cross dipoles placed on FR4 substrate of thickness 0.8 mm. A circular ring slot is present in the centre of the cross conducting dipole. The diameter of the slot is 0.6 mm. This layer is a reflecting layer. It resonates at WLAN frequency of 5GHz. The width of the dipole is specified as 0.6 mm. The FR4 substrate is kept on either side of the conducting dipoles in this layer. The next layer uses FR4 sheet with the same dielectric constant and thickness as in the reflecting layer. This layer has resistive cross dipoles of width larger than the conducting cross dipoles placed on the substrate. The width of the resistive cross dipoles are mentioned as 2.8 mm. a slot is present on the centre of the reflecting cross dipoles with the same diameter as in the conducting cross dipoles. The resistive dipoles have the characteristics of absorbing the signals at their resonating frequency and this layer is the absorbing layer. The resonating frequency of this layer too is the WLAN frequency cantered at 5 GHz. Thus this layer tends to absorb the signals that passed through the reflecting layer and hence their dipole width is kept larger than that of the reflecting layer. The two layers are separated by a distance of 7.1 mm. This two layer combination acts as reflection/absorption filter.

The structure has shown good reflection and absorption properties in the WLAN frequency range at 5 GHz. The system also had shown good transmission characteristics in the mobile band frequencies at 900/1800/1900 MHz The transmission and reflection characteristic curve of the system shows that its transmission in the adjacent bands outside the intended WLAN band is not satisfactory. They attenuate the adjacent frequency bands as well and thus blocking them from passing through the surface which is not desirable in case of adjacent bands were needed to be allowed inside the measuring chamber covered with the reflection/absorption surfaces. Also this structure has two FR4 sheets in the reflection layer with conducting cross dipoles between them and another FR4 sheet with resistive cross dipoles placed on it. And thus occupies more space since they were separated by a distance of 7.1 mm.

It also proposes another FSS layer of FR4 sheet of same thickness with resistive cross dipoles placed on them in the other side of the reflecting layer which makes them occupy more space. Though the double absorbing layer would provide a more secured communication by protecting from any intruder, it further will not allow any adjacent bands which may not be desirable in certain applications.

IV. THE PROPOSED FSS STRUCTURE

We present a few designs we tried Fig 1-4 to overcome the drawbacks of the existing system and finally arrived at the final proposed structure Fig 6 after getting good desirable transmission outside the intended WLAN band. The reflection characteristics at 5 GHz WLAN band are also acceptable.

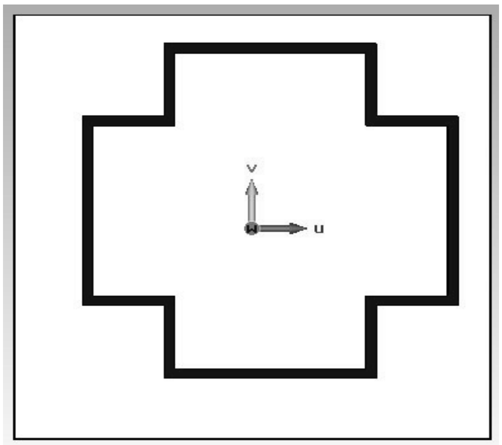

Fig.1 FSS structure as shown in [1] with a different substrate material and dimensions.

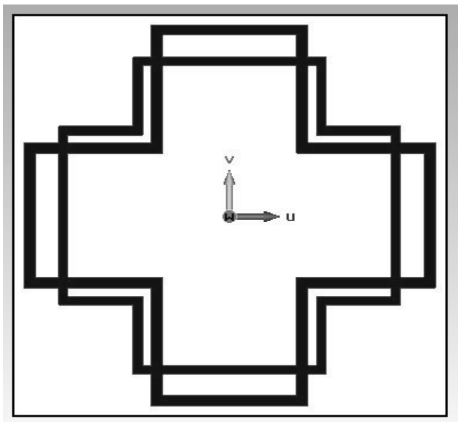

Fig.2 Modified double layers of stepped square patch on both sides of the substrate.

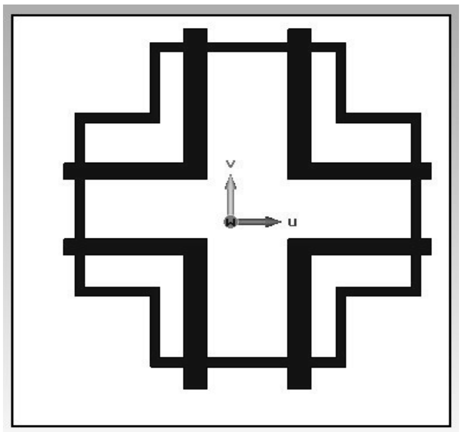

Fig.3 Stepped square patch in combination with an L shaped structure symmetrically placed on all quadrants of the unit cell.

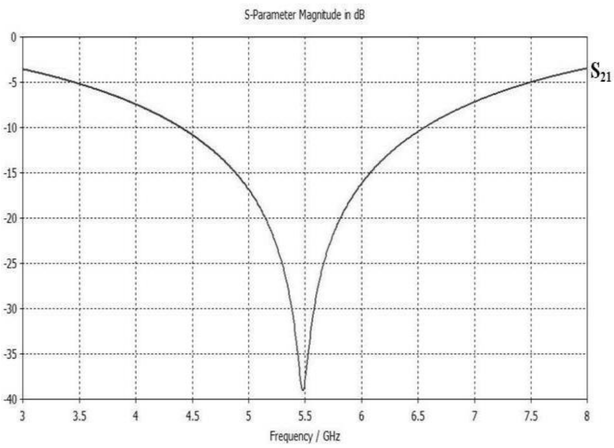

Fig. 5 Transmission characteristic curve for the L shaped structure symmetrically placed on all quadrants in combination with stepped square patch.

The structure shown in Fig. 1 is derived from [1] with a change in material of the substrate and the thickness of both the substrate and the patch. The material used for the structure in Fig 1 is FR4 sheet with a thickness of 0.8mm. The patch is a Perfect Electric Conductor PEC with thickness of 0.035 mm. The dimension of the unit cell is kept as 22*22 mm with the largest arm of length 10.5 mm. The frequency response of the structure is analysed and found that the bandwidth is narrow. It is then tested by placing the patch on both sides of the patch. It is observed that that the bandwidth gets better when the patch is placed on either sides of the substrate than when placed on only one side of the substrate. The response showed good reflection in the centre frequency but the attenuation at the edges of the band is not satisfactory as well as unwanted attenuations were observed outside the intended band.

To make the bandwidth wider in order to get good reflecting characteristic inside the WLAN frequency band a modified double layer of stepped square was designed as in Fig 2. The response of the design showed much improved bandwidth yet the attenuation outside the band is undesirable as it covered almost 2 GHz above and below the centre frequency of 5 GHz and thus blocking them from passing through the surface. The response also showed the structure resonating at two different frequencies. By bringing the two frequencies close within the band the response was better. But due to the constraints in the fabrication it was studied that the two resonating frequencies cannot be brought into the desired bandwidth. Thus instead of combining two stepped squares, an L shaped patch is kept along the stepped square patch symmetrically on all the four quadrants as shown in Fig 3.

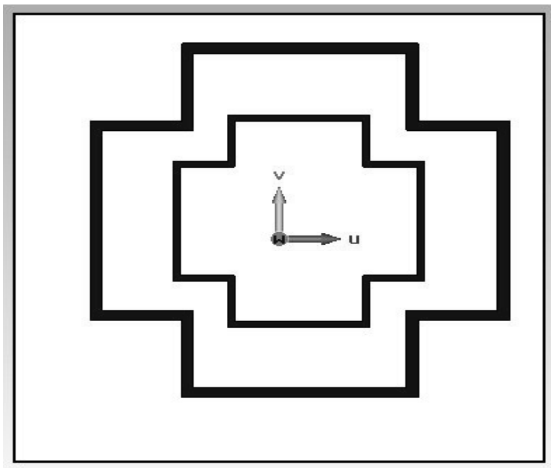

Fig. 4 Doble stepped square structure that is placed on either side of the substrate.

This structure showed good reflection characteristics inside the intended WLAN frequency band at 5 GHz but the bandwidth is much larger as shown in Fig 5. It is seen that this structure covered almost a range of 6 GHz from 2.7 to 8.3 GHz with an attenuation of over -3 dB which made it undesirable for the application of this class. Still the characteristics shown improved quality factor with attenuation close to -37 dB. Thus further experimentations were made without merging the two patch structures with one another.

The structure shown in fig. 4 consists of two stepped square patches with no physical connections to one another. It showed good response in the centre frequency covering the intended band, but with another frequency band blocked with lower attenuation. It is further observed that placing patches on either sides of the substrate improves the response. Changes were tried to eliminate the unwanted glitches in the 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 with 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 centre 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.

The structure is the proposed unit cell FSS as shown in fig. 6. Further more changes were made on their dimensions to fine tune the response. Dimensions thus obtained are mentioned. The thickness of the substrate is 0.75mm and that of the patch is 0.035mm. The length and width of the substrate sheet for a unit cell sh=sw=20 mm, the periodic space between the elements in the x and y axis in each unit cell gx=gy=0.5 mm, the length of the largest arm in the outer patch pw=10mm, the width of each arm at the outer patch pd=0.5 mm, the spacing between the inner and outer patch gp=3.5 mm,the width of the slot np=0.25 mm, the length of the notch nh=0.5 mm, the width of each arm in the inner patch that was made smaller than the that in the outer patch nd= 0.25 mm, the length of the arm in the inner patch gw=1.5 mm.

V. SIMULATED VS MEASURED RESULTS

The FSS structure is analysed with the help of Computer Simulation technology Micro Wave Studio CST MWS. Instead of computing the 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 floquent 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 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 the CST. The number of floquet modes used is 2.

The surface is tested for frequency range of 0-10GHz. The transmission coefficients are obtained for an incident plane wave of spherical angle of incidence Θ =0 and $\varnothing$ = 0. The response is shown in Fig 7. It is observed that the structure resonates at WLAN frequency cantered at 5 GHz with a transmission coefficient S_{21} 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. 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 CST tool varies. For the structure specified in Fig 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 coeffients are between -1.8 to -2.98 dB though. Thus the transmission will not be affected much in those frequencies.

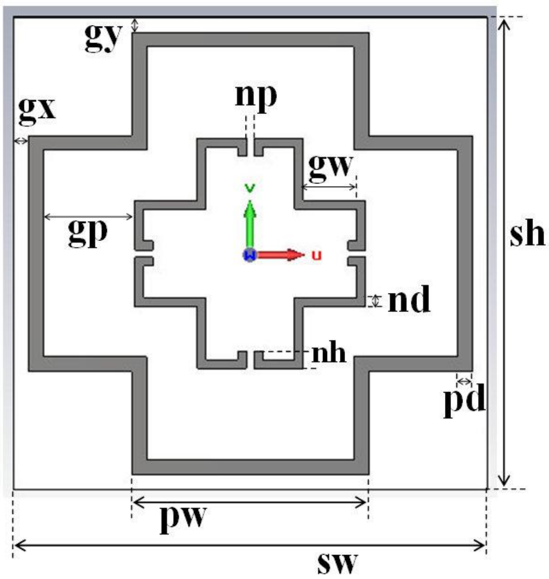

Fig. 6 the proposed unit cell FSS structure.

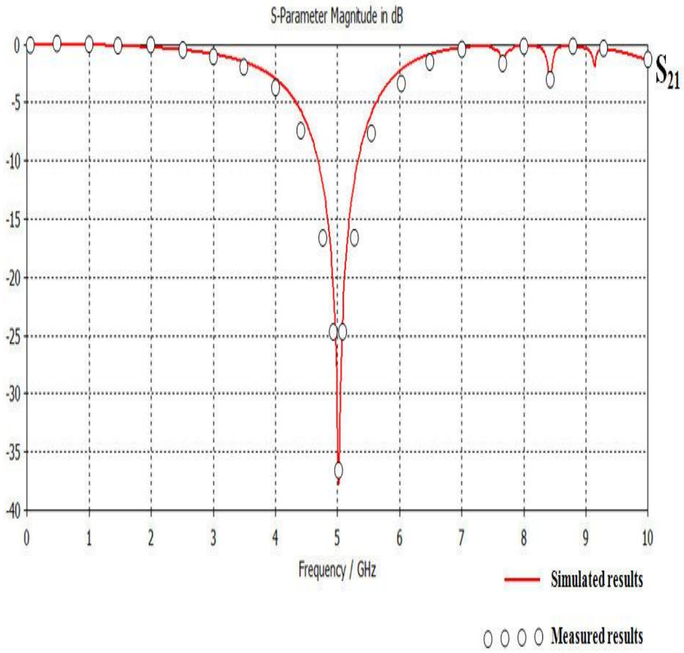

Fig. 7 Transmission characteristic curve for the proposed FSS structure in fig 6 showing the comparison of the simulated and the measured results with good transmission outside the intended band.

VI.CONCLUSION AND FUTURE WORK

In this paper, a combination type of FSS structure is proposed to block the 5 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 coefficients with 0 to – 3 dB. Thus recommending for this class of applications.

It can be observed from fig. 7 that still there are still some glitches, these glitches can further be reduced if not nulled. 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.

ACKNOWLEDGMENT

We would like to express our deep and sincere gratitude to our supervisor, Asst. Prof. Sel. Gr. Mr. M. B. Sridhar. His wide knowledge and his logical way of thinking have been a great value for us. His understanding and guidance have provided good basis for our work.

We also thank Easwari Engineering College for their support during this work.

REFERENCES

[1] Ming yang and Anthony K. Brown, "A Hybrid Model for Radio Wave Propagation through Frequency Selective Structures (FSS)", SEPTEMBER 2010.

[2] Ben A. Munk, "Frequency Selective Surfaces – Theory and Design", A Wiley-Interscience Publication, 2000.

[3] Arezou Edalati and Tayeb A. Denidni, "Frequency Selective Surfaces for Beam-Switching Applications", January 2013.

[4] K. Delihacıoğlu, "Frequency Selective Surfaces with Multiple-Strip Group Elements", IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 11, 2012.

[5] Meng and Nader Behdad, "Frequency Selective Surfaces for Pulsed High-Power Microwave Applications", February 2013.

[6] Jeremy A. Bossard, Douglas H. Werner, Theresa S. Mayer, and Robert P. Drupp, "A Novel Design Methodology for Reconfigurable Frequency Selective Surfaces Using Genetic Algorithms", April 2005.

[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] 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.

[9] E. A. Parker and S. B. Savia, "Fields in an FSS screened enclosure," in *IEE Proc. Microw. Antennas Propag.*, Feb. 2004, vol. 151, pp. 77–80.

[10] 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.

[11] 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, 2006.

[12] A. Edalati and T. A. Denidni, "High-gain reconfigurable sectoral antenna using an active cylindrical FSS structure," *IEEE Trans. Antennas Propag.*, vol. 59, no. 7, 2011.

[13] A. Edalati and T. A. Denidni, "Beam-switching antenna based on active frequency selective surfaces," presented at the IEEE Antenna and Propagation Society Int. Symp., Jul. 2011.

[14] 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, Dec. 1988.

[15] T. K. Wu, Ed., *Frequency Selective Surface and Grid Array*. New York: Wiley, 1995.

[16] A. C. de C. Lima, E. A. Parker, and R. J. Langley, "Tunable frequency selective surface using liquid substrates," *IEE Electron. Lett.*, vol. 30, no. 4, pp. 281–282, Feb. 1994.

[17] T. K. Chang, R. J. Langley, and E. A. Parker, "Active frequency-selective surfaces," in *Proc. IEEE Microwaves, Antennas Propag.*, vol. 143, Feb. 1996, pp. 62–66.

[18] B. Philips, E. A. Parker, and R. J. Langley, "Active FSS in an experimental horn antenna switchable between two beamwidths," *IEE Electron. Lett.*, vol. 31, no. 1, pp. 1–2, Jan. 1995.

[19] J. C. Vardaxoglou, P. Y. Lau, and M. Kearney, "Frequency selective surface from optically excited semiconductor on a substrate," *IEE Electronics Letters*, vol. 34, no. 6, pp. 570–571, Mar. 1998.

[20] J. Shaker, R. Chaharmir, and H. Legay, "Investigation of FSS-backed reflectarray using different classes of cell elements," *IEEE Trans. Antennas Propag.*, vol. 56, no. 12, pp. 3700–3706, 2008.

[21] F. Bayatpur and K. Sarabandi, "Multipole spatial filters using metamaterial-based miniaturized-element frequency-selective surfaces," *IEEE Trans. Microw. Theory Tech.*, vol. 56, no. 12, pp. 2742–2742, Dec. 2008.

[22] M. Al-Joumayly and N. Behdad, "A generalized method for synthesizing low-profile, band-pass frequency selective surfaces with nonresonant constituting elements," *IEEE Trans. Antennas Propag.*, vol. 58, no. 12, pp. 4033–4041, Dec. 2010.