A Multi-layered Broadband Frequency Selective Surface for X and Ku band Applications

Ayan Chatterjee
Dept. of Electronics & Communication Engineering
Supreme Knowledge Foundation Group of Institutions
Mankundu, Hooghly 712139, West Bengal, India
ayanmrinal26@gmail.com

Susanta Kumar Parui
Dept. of Electronics & Telecommunication Engineering
Bengal Engineering and Science University
Shibpur, Howrah – 711 103, West Bengal, India
arkapv@yahoo.com

***Abstract*—Design and theoretical investigations are presented for a broadband frequency selective surface (FSS) with perfectly conducting rectangular patch elements. The structures have been developed in two steps. In the first step, two single-band FSS screens were designed to obtain resonant frequencies at 13.98 GHz and 17.82 GHz, each one with about 6 GHz bandwidth and overlapping -10 dB reflection bands. In the second step, these single FSS screens were cascaded and separated by an air gap layer to achieve a broadband response.The proposed designs have been investigated theoretically using ANSOFT DESIGNER® software. In comparison to both the single layer conventional patch type Frequency Selective Surface (FSS), the cascaded multilayered structure can provide a huge reflection bandwidth up to 93% covering the X band (8-12 GHz) and the Ku band (12-18 GHz). Transmission response for the cascaded structure has been studied for different air gap.**

Index Terms*— Frequency Selective Surface, Method of Moments, Cascaded FSS, Bandwidth, Broadband FSS.

I. INTRODUCTION

Filters play a very important role in the RF circuits that controls the frequency content of the signal for mitigating noise and unwanted interference. Frequency-selective surface (or dichroic or FSS) structures to space waves are the wireless counterparts of filters in transmission lines. Similar to the frequency filters in traditional radio frequency (RF) circuit, the FSS may have band-pass or band-stop spectral behaviour depending upon the array element type. The patch type FSS is used where transmission is minimum at resonating frequency i.e. reflection is maximum. Below and above the resonating frequency, transmission gradually increases and finally reaches its maximum value. Reverse situation arises for aperture type frequency selective surfaces. Here transmission is maximum at resonating frequency i.e. reflection is minimum. Below and above the resonating frequency, transmitted electric field gradually decreases and finally becomes zero. Transmission and reflection band separation of the Frequency Selective Surfaces should be prominent and the reflection or transmission band should be broad for some of its applications [8] like reflector antenna system of a communication satellite [1] or a deep space exploration vehicle [2-3] for multi frequency operations. Multilayered structures composed of band pass or band reject FSS structures have been studied [4-6] so far for different purposes like GPS applications, DCS1800 mobile communication, and microwave absorber for the antennas with dual or multiband responses with narrow bands. To analyse different types of FSS structures theoretically, basically three methods are used – Finite Difference Time Domain (FDTD) method, Finite Element Method (FEM) and the Method of Moment (MoM). Among these three, Method of Moment is the most complicated but its accuracy is the best.

A simple multilayered structure consisting two patch type FSS and air gap between them will be discussed in this paper where the purpose is to enhance the overall reflection bandwidth covering maximum portion of the X band (8-12 GHz) and Ku band (12-18 GHz). MoM based simulation results will be used to study the performance of the structure. The electrical design with equivalent circuit model, performance and trade-off of the design will also be discussed.

II. DESIGN OF THE FSS

In this paper at first, two single band patch-type FSS structures have been studied to have different resonating frequencies. Both the structures have been analyzed on the same substrate with Glass-PTFE as the dielectric material of dielectric constant (ε_r) 2.5 and dielectric loss tangent of 0.002 with the thickness of 1.6 mm. Secondly, a composite structure has been designed with two separate structures as the two layers and air as the separation between them of variable height forming the multilayered FSS structure. The side view of the proposed multilayered FSS is shown in the Fig. 1(a) whereas the unit cell is shown in the Fig. 1(b) which is a common figure for both the patches used in the tow separate FSSs. The cell has periodicity T_x and T_y in x and y directions, respectively. The rectangular conducting patch has width W and length L.

Detailed description of the dimensions of two separate FSS structures are given in the table I where structure I and II corresponds to the structures as labelled in the Fig 1(a) representing the two separate layers of the FSS structures which are again separated by a spacing of air. Fig 1(b) represents the unit cell dimension which is specified in the table I for both the square as well as rectangular shaped patches along with the spacing between the patches.

 ISBN: 978-81-923777-9-7

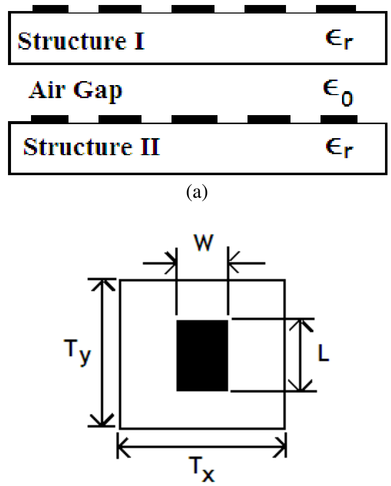

Fig. 1 FSS geometry: (a) cascade structure and (b) unit cell

TABLE I: Dimensions of the Isolated FSS Structures I and II

Parameters	Structure I	Structure II
W	9 mm	11 mm
L	12 mm	11 mm
T_x	14 mm	14 mm
T_y	14 mm	14 mm

A three dimensional view of the multilayered structure can be seen in the Fig. 2 where two patch type FSSs structured on dielectric substrates of height (h_1=h_3=1.6mm) have been cascaded vertically and a layer of air with dielectric constant (ε_r = 1) and variable height (h_2) has been selected as the coupling layer.

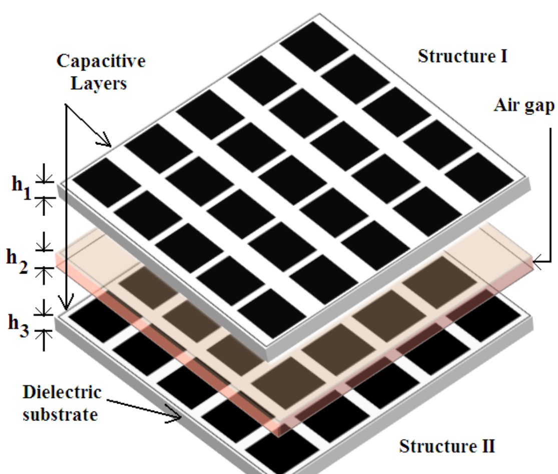

Fig. 2. Topology of the multilayered FSS

III. EQUIVALENT CIRCUIT MODEL

To understand the principles of operation of the cascaded structure as shown in the Fig. 1, it is helpful to consider its simple equivalent circuit shown in Fig. 2, which is valid for normal incidence [7].

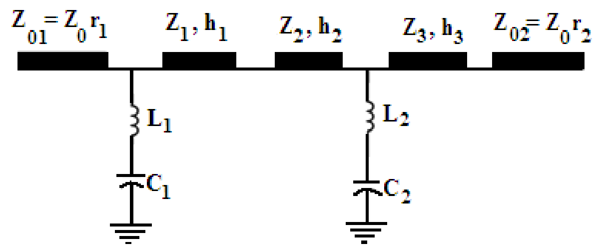

Fig. 3 A simple equivalent circuit model for the cascaded FSS of Fig. 2

Both the band reject patch type FSS layers are modelled with combination of inductors (L_1 and L_2) and capacitors (C_1 and C_2) representing the structure I and structure II as specified in the table I for the cascaded structure. The dielectric substrates corresponding to the top as well as bottom capacitive layers are represented by two short pieces of transmission lines with characteristic impedances of $Z_1 = Z_0/\sqrt{\varepsilon_{r1}}$ and $Z_3 = Z_0/\sqrt{\varepsilon_{r3}}$ and lengths of h_1 and h_3, where ε_{r1} and ε_{r3} are the dielectric constants of the substrates (ε_{r1}= ε_{r3}=2.5 here) and Z_0=377Ω is the free space impedance. The two metallic structures along with their dielectric substrates are coupled by a layer consisting of air with characteristic impedance Z_2 = Z_0=377Ω of varying thickness h_2. The half-spaces on the two sides of the FSS are modelled with semi-infinite transmission lines with characteristic impedances of Z_{01}=$Z_0 r_1$ and Z_{02}=$Z_0 r_2$, where r_1 and r_2 are normalized source and load impedances and r_1= r_2=1 for free space as considered in this case.

As can be observed from this figure, the combination of the inductor L_1 and the capacitor C_1 at the input side represent a first order band stop filter whereas similarly, the inductor L_2 and the capacitor C_2 at the output side represent another first order band stop filter. These two band stop filters are having their band stop responses at slightly different but closely spaced (with -10 dB reference) frequency bands that are overlapping each other in the cascaded structure as will be observed shortly. The two band stop filters are coupled by the combination of the transmission line impedance Z_1 and the free space impedance Z_0 as seen from Fig. 3 and the proposed FSS structure in the Fig. 2 will act in a manner similar to that of a coupled resonator band-stop filter.

IV. RESULTS AND DISCUSSION

Transmitted electric field for each single-band FSS consist of a periodic array of rectangular and square conducting patch elements on a dielectric isotropic layer is calculated by Ansoft Designer® software in the frequency range of 8 GHz. to 18 GHz and the result is shown in Fig.4 by solid line for the FSS structure I and dotted line for the FSS structure II.

ISBN: 978-81-923777-9-7

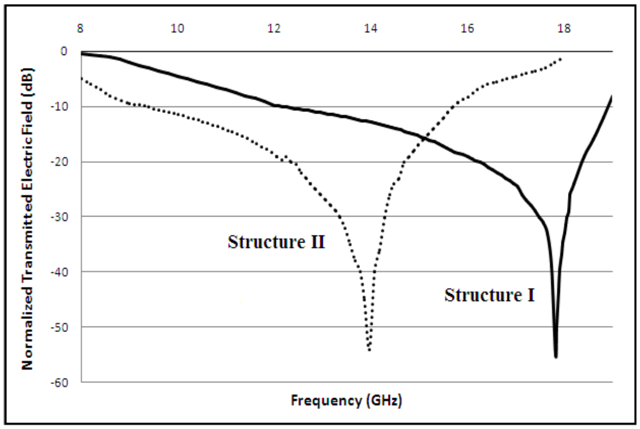

Fig.4 Simulated and result of the transmitted Electric Field versus frequency for the isolated FSS structures I and II as seen from Fig. 1(a)

Different parameters like resonant frequency, percentage bandwidth for the transmission characteristics of the separately designed structures (Structure I and II) as seen from the Fig. 4 are given in the table II.

TABLE II: Results of the FSS Structures I and II

FSS	Resonating Frequency (GHz)	Band Separation (dB)	-10dB Bandwidth (GHz)	Percentage Bandwidth
Structure I	13.98	-54.6	6.2	44.3%
Structure II	17.82	-55	5.9	33%

The cascaded structure composed of both the structures I and II coupled by air gap between them has also been investigated theoretically using Ansoft Designer® for various heights (h_2) of the air gap and the simulation results are given in the Fig 5 for comparison purpose.

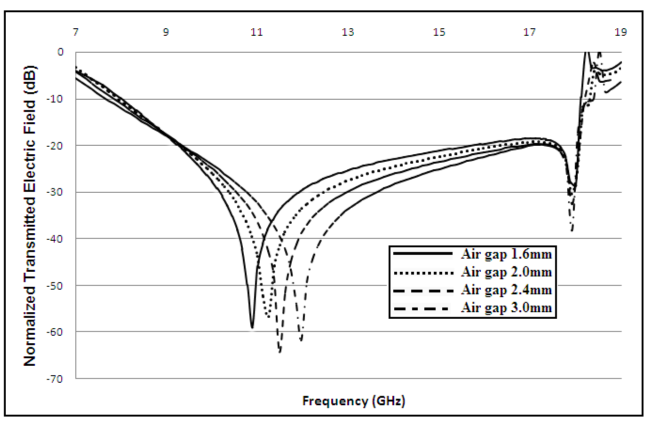

Fig.5 Study of Transmitted Electric-field Vs. Frequency for the Cascaded FSS structure with different Air gap.

The effect of the variation of air gap (h_2) on the transmission characteristics are clearly shown in the table III with the specified parameters like resonating frequency, percentage reflection bandwidth, band separation etc.

TABLE III: Results of the Cascaded FSS Structures for different Air Gap

Air Gap	Resonating Frequency (GHz)	Band Separation (dB)	-10dB Bandwidth (GHz)	Percentage Bandwidth
1.6 mm	10.88	-59	10.12	93%
2 mm	11.23	-56.37	10.3	91.7%
2.4 mm	11.5	-64	10.4	90%
3 mm	12	-62.5	10.7	89%

It can be clearly observed from the Fig 4 that the two separate single layered FSS structures having different resonant frequencies of 13.98 GHz and 17.82 GHz share some portion in their reflection bands with respect to -10dB level of transmission. After cascading the two structures with an air gap between them the reflection band of the multilayered structure was broadened up to 93% as can be seen from the Fig 5 where transmission response (dB) for different air gap has been shown. It can also be observed that with the broadening of reflection band the resonating frequency is also shifted towards low value of about 11 GHz corresponding to the structure I and at the resonating frequency corresponding to the structure II has a lower band separation of about -40 dB in the transmission response of the cascaded structure.

V. CONCLUSIONS

It is concluded from the theoretical analysis that the first and secondly designed FSS structures give an overall -10 dB reflection bandwidth of about 6 GHz which can be enhanced to around 10 GHz simply by cascading both the structures with air gap between them which basically couples the two band stop structures. The coupling of two FSS structures can be effected by varying the air gap and the increased air gap shifts the resonating frequency towards high value but at the same time enhancing the reflection bandwidth but not by a large amount comparable to that of the resonating frequency. So the percentage bandwidth is not very much affected and remains in the range of 89% - 93% which is no doubt a huge bandwidth. The cascaded structure covers the X band and the Ku band so converting the conformal structure into a curved one it can be used as a RADOME for covering stealth aircraft to reduce its RCS (RADAR Cross Section) as the structure will reflect all the signals falling under these bands in a direction other than the RADAR receiver or the source because of its curvature.

VI. REFERENCES

[1] B. A. Munk, “Frequency Selective Surfaces – Theory and Design”, Wiley, New York, 2000.

[2] S. W. Lee et al, "Design for the MDRSS Tri Band Reflector Antenna" paper presented at the Int. IEEE AP-S symposium, Ontario, Canada, 1991, pp. 666-669.

ISBN: 978-81-923777-9-7

[3] T.K. Wu, “Frequency Selective Surface and grid array”, *A Wiley Interscience publication, pp. 5-7, 1995.*

[4] Ji-Chyun Liu, Chin-Yen Liu, Ching-Pin Kuei, Ching-Yang Wu and Yaw-Shun Hong, “Design and Analysis of Broadband Microwave Absorber Utilizing FSS Screen Constructed with Circular Fractal Configurations”, *MOTL Vol. 48, No. 3, pp. 449-453, March 2006.*

[5] P.T. Teo, X.F. Luo and C.K. Lee, “Frequency-selective surfaces for GPS and DCS1800 mobile communication, Part 1: Quad-layer and single-layer FSS design”, *IET Microw. Antennas Propag., 2007, 1, (2), pp. 314–321.*

[6] Antonio L. P. S. Campos, Robson H. C. Maniçoba, Lincoln M. Araújo and Adaildo G. d’Assunção, “Analysis of Simple FSS Cascading With Dual Band Response”, IEEE TRANSACTIONS ON MAGNETICS, VOL. 46, NO. 8 pp. 3345-3348, AUGUST 2010.

[7] Xiao- Dong Hu, Xi- Lang Zhou, Lin- Sheng Wu, Liang Zhou and Wen-Yan Yin, “A Novel Dual-Band Frequency Selective Surface (FSS)”, 978-1-4244-2802-1/09/$25.00 ©2009 IEEE.

[8] Mei Li, Shao Qiu Xiao, Yan-Ying Bai and Bing-Zhong Wang, “An Ultrathin and Broadband Radar Absorber Using Resistive FSS”, IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 11, pp. 748-751, 2012.

ISBN: 978-81-923777-9-7