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BAND STOP AND BAND PASS FREQUENCY SELECTIVE SURFACE WITH MINIATURIZED ELEMENT IN LOW FREQUENCIES

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Abstract

In this paper, two single-band frequency selective surfaces (FSS) for low frequency stop and pass band with miniaturized element have been proposed. A square loop patch is constructed to realize single stop band responses. Similarly, a square with slot is constructed to realize a single pass band response at lower frequencies. Pass band is realized by slot while stop band is realized by a patch. Both pass band and stop band FSS structure having dimensions 25mm×25mm×1.605mm. FSS structures are designed and simulated using CST MWS V'16 with unit cell boundary along X and Y axis and floquet ports. Simulated results show that proposed FSS structures for both pass band and stop band are independent of angle of incidence and polarisation. Axial ratio bandwidth of the proposed FSS structure (<3dB) for bandwidth 1GHz. Equivalent circuits of the stop band and pass band FSS structures shows series and parallel combination of inductance and capacitance respectively.

Keywords:

Frequency Selective Surface (FSS), FR4, Reflection, Transmission, Miniaturized, Single Square Loop (SSL), Angle of Incident (AOI)

1. INTRODUCTION

Frequency selective surface structures have been the subject of search over the years for a wide range of applications. Frequency selective surfaces (FSSs) are basically an arrays of conducting patches or apertures on substrate that act as band reject or band pass filters, respectively, for incoming electromagnetic waves [1-2]. Their features make them suitable to control the propagation of electromagnetic energy and therefore, they can be employed in radomes, diffraction gratings, frequency scanned antennas, microwave absorbers [3] and recently in applications associated with security and efficiency of the wireless network communications [1-4]. The frequency response of these periodic arrays depends upon geometry of the array elements. During the development period of FSS, typical geometries/shapes for the FSS were as dipole, square, rectangular, and circular shaped patches, or apertures [5]. Particularly, frequency selective surfaces are used to control the transmission and reflection properties of the incident plane wave [6-7]. Various techniques have been developed for analysing the periodic structures of frequency selective surfaces such as the finite element method (FEM) [8], methods of moments (MOM) [9], the finite difference time domain method (FDTD), Equivalent circuits methods (EC) [10-11-12]. But out of these best and simple technique is EC technique. By adopting this technique FSS unit cell may be modelled in the form of lumped circuits having inductance and capacitance hence it is easy to analyse. Performance of FSS also depends upon the dielectric substrate [13] and shape of it's the unit cell.

The patch-type and slot-type FSS structures ideally show total reflection and transmission, respectively, in the neighbourhood of the fundamental resonance frequency. There is different type of geometries such as double square loop [14], spiral structure [15], fractal geometry [16], Stacks/multilayers FSS [17] has been offered by many researchers. The type of element geometry, size, inter-element spacing, dielectric substrate parameters and presence or absence of super-substrate, which constitutes the unit-cell element, determines the overall resonance frequency, bandwidth and dependency on the AOI as well as polarization of the planar incoming wave. But the overall all performance of FSS basically effected by the angle at which incoming electromagnetic wave impinging on FSS and polarisation [18] of the incoming wave. Therefore, in order to design a FSS structure for a desired frequency response, the appropriate selection of geometrical parameters is of prime importance because these parameters have potential to significantly vary the frequency response.

2. MATHEMATICAL USED

$$S_{21} \text{ (transmission parameter)} = V_{out2}/V_{in1}$$

$$V_{out2} = \text{output at } 2^{nd} \text{ port}$$

$$V_{in1} = \text{input at } 1^{st} \text{ port}$$

$$\text{If } S_{21} \leq 0.33 \text{ (stop band)}$$

$$S_{21} = 20\log10\, |S_{21}| \text{ transmission parameters in decibel}$$

The normalized inductive impedance expressions of the strip grating were given by Marcuvitz as in [19]:

$$XTE = F(p,w,\lambda) = \frac{p\cos\theta}{\lambda}\left[\ln cosec\left(\frac{w\pi}{2p}\right) + G(p,w,\lambda,\phi)\right] \quad (1)$$

where XTE is inductive impedance; λ is wavelength; w is width of square loop; p is periodicity of FSS $G(p,w,\lambda,\phi)$ is correction factor

The susceptance for TM-incidence can be found from Babinet's duality conditions as:

$$BTM = F(p,w,\lambda) = \frac{4p\cos\phi}{\lambda}\left[\ln cosec\left(\frac{g\pi}{2p}\right) + G(p,w,\lambda,\phi)\right] \quad (2)$$

Certainly, Eq.(1) and Eq.(2) are valid if $w << p$, $d << p$, and $p<<\lambda$. Similarly, the TM-incidence inductance and the TE-incidence capacitance can be written as follows [6]:

$$XTM = \frac{p\sec\phi}{\lambda}\left[\ln cosec\left(\frac{w\pi}{2p}\right) + G(p,w,\lambda,\phi)\right] \quad (3)$$

$$BTE = \frac{p\sec\theta}{\lambda}\left[\ln cosec\left(\frac{g\pi}{2p}\right) + G(p,w,\lambda,\theta)\right] \quad (4)$$

For a given FSS structure, the resonance response varies with the AOI and periodicity of the FSS structure, therefore in order to avoid the grating lobes to occur, the periodicity is related to the wavelength as follows.

$$(1 + \sin\theta) < \lambda \tag{5}$$

3. DESIGN OF UNIT CELL FOR FSS

Here we use single square loop FSS equivalent circuit technique which is given by Marcuvitz and further used by various researchers to extract the circuit lumped parameters such as inductance (L) and capacitance (C) associated with the structure. For design a FSS unit cell it is required to having its parameter such as its periodicity (p) of FSS, width (w) of single square loop FSS, length (L) of single square loop FSS and for find all these parameter we use Eq.(1)-Eq.(5) as mentioned in above section. After finding all above parameter for 2.4GHz frequency we optimized the single square loop FSS using CST to miniaturized its size. The Fig.1(a) and Fig.1(b) shows the front view of the FSS structure for both band stop and band pass respectively. FSS structure for band stop is a single-layer structure with no metal on the back of the substrate. A single square patch of copper arranged periodically on dielectric substrate which transmit or reflect specific frequency similarly as spatial filter. Dimensions of the structure are periodicity p is 25mm, outer length of square loop L_2 is 22.5mm, inner length of square loop L_1 is 20.5mm, and thickness of patch is 0.035mm. This structure uses a FR-4 substrate with relative permittivity of 4.4, loss tangent of 0.24 and thickness substrate is 1.57mm. This square patched structure with substrate at bottom work as a stop band while complimentary of structure means a slot etched on copper patch which placed on substrate as shown in Fig.1(b) work as pass band for specific frequency. A band stop FSS structure has been converted into band pass by replacing the conducting material part by the slot and the vacant part of the FSS structure by the conductor. In this case, the p remains same, w is replaced by the slot-width and d becomes the size or length of the slot. Here grey portion shows substrate and yellow portion shows copper.

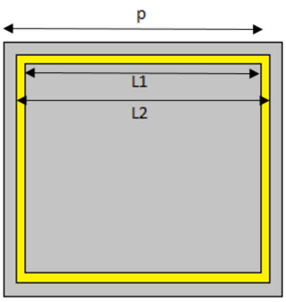


Fig.1(a). Front view of stop band unit cell

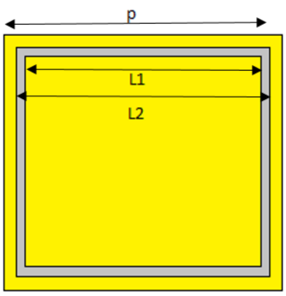


Fig.1(b). Front view of pass band unit cell

4. EQUIVALENT CIRCUIT OF SQUARE LOOP FSS

The admittances of the SL-FSS for band stop and band pass can be calculated by using the equivalent circuits depicts in Fig.2 and Fig.3 and given as [20]:

$$Y = 1/(X_1 + B_1) \tag{6}$$

where,

X_1 is inductive reactance and can be write as:

$$X_1 = \omega L_1 = \frac{d}{p} F(p,w,\lambda) \text{ and}$$

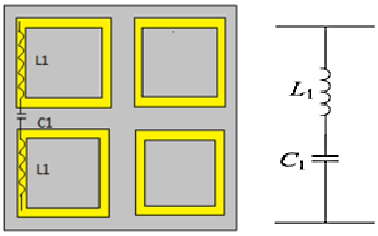
B_1 is capacitive susceptance and can be write as

$$B_1 = \omega C_1 = 4\frac{d}{p}\varepsilon F(p,2g,\lambda)$$

Similarly, admittance for pass band can be find as:

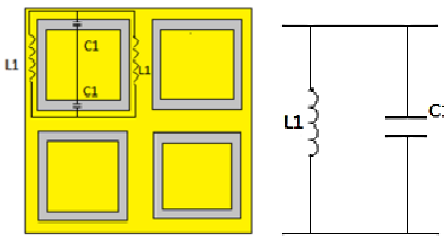
$$Y = (X_1 + B_1) / (X_1 \cdot B_1) \tag{7}$$

Here L1 is the inductance of copper strip while capacitance C1 produced because of air gap between two unit cells. For stop band FSS L_1 and C_1 formed series combination while for pass band FSS both L_1 and C_1 formed parallel combination as shown in Fig.2(b) and Fig.2(c) respectively.



(a) (b)

Fig.2. Equivalent circuit for band stop FSS



(a) (b)

Fig.3. Equivalent circuit for band pass FSS

5. SIMULATION RESULTS

The proposed FSS is designed and simulated using CST MWS V'16. Simulation is accomplished with unit cell boundary conditions along X and Y axis and floquet ports. The single unit cell is excited by an incident plane wave with different incident angles. The band stop and band pass square loop structure are shown in Fig.1(a) and Fig.1(b) and their corresponding simulated transmission coefficients (TE mode and TM mode) are shown in Fig.4 and Fig.5 respectively. Here from Fig.4 we see that if return loss less than -10dB then in case of stop band no signal pass through means frequency range from 1.88GHz to 2.89GHz are blocked by FSS structure and resonance peak occur at 2.4GHz. This stop band FSS structure allows frequency from below 1.88GHz and frequencies onward to 2.89 to pass through. But for band pass FSS structure frequencies from 1.08GHz to 4.5GHz are allowed to pass through but frequencies before to 1.08GHz and beyond to 4.5 are blocked by FSS structure. It is important to note that resonance for pass or stop band occurred at same frequency which is 2.4GHz.

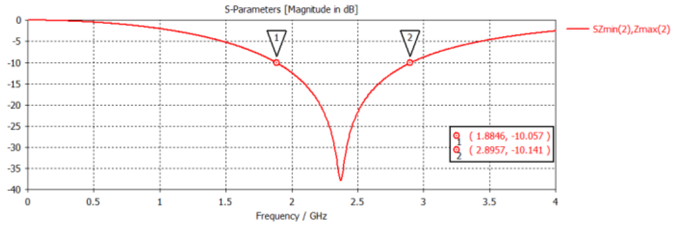


Fig.4. Transmission parameters (stop band) for TE and TM mode

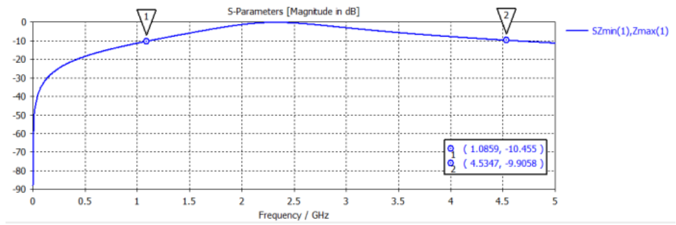


Fig.5. Transmission parameters (pass band) for TE and TM

5.1 INCIDENCE ANGLE VARIATION

As illustrated in Fig.6 and Fig.7, the incident angle (θ) has been varied from 0º to 80º to see the behaviour of insertion loss and frequency response for both TE and TM waves. At 0º maximum signal is transmitted and with the increase in incidence angle transmission is less and absorption is more. Also at larger incidence angle (80º), undesired resonating frequency are introduced. Similarly, for pass band FSS structure variation in angle from 0º to 80º are shown in Fig.8 and Fig.9. This shows that if there is increase an angle beyond 50º (TE) the effect of grating lobs on filtering goes on increasing but this effect can be tolerating because this is minor effect and can be neglecting while for TM mode of polarisation harmonics are introduce at higher angles as shown in Fig.9. From Eq.(5) we find that for maximum AOI the relationship between wavelength and periodicity is established as long as inequality is satisfied. Theoretically, with the increase in AOI, the value of p is reduced and the array becomes densely packed and at lower incidence angle, the FSS array is loosely packed. On this way, it is seen that with the certain relaxation in the accuracy, the mathematical expression is used for loosely as well as densely packed FSS array.

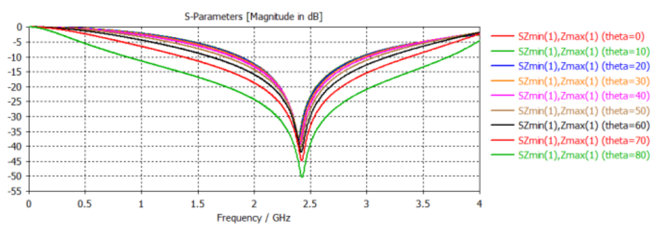


Fig.6. Incidence angle variation of stop band unit cell in TE mode

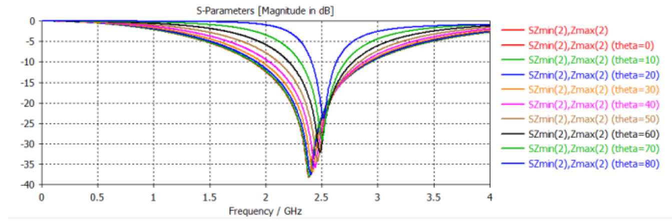


Fig.7. Incidence angle variation of stop band unit cell in TM mode

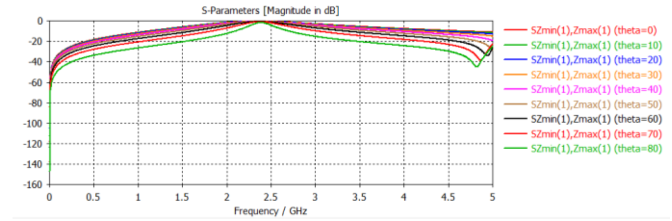


Fig.8. Incidence angle variation of pass band unit cell in TE mode

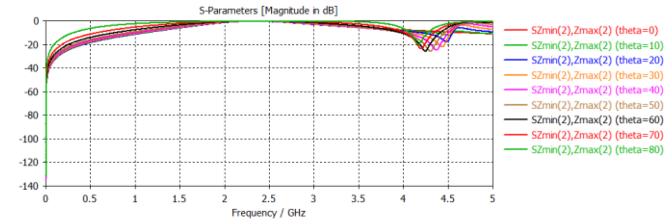


Fig.9. Incidence angle variation of pass band unit cell in TM mode

5.2 POLARISATION INDEPENDENT

Here from the Fig.10 it is clear that proposed FSS structure is independent of modes. It will give the same transmission null for both TE and TM polarisation. The reflection and transmission parameters (TE) for FSS are represent by $SZ_{max}(1)$, $Z_{max}(1)$ and $SZ_{min}(1)$, $Z_{max}(1)$ respectively. Similarly for TM mode reflection and transmission coefficient are represent by $SZ_{max}(2)$, $Z_{max}(2)$ and $SZ_{min}(2)$, $Z_{max}(2)$. We see that transmission and reflection coefficient for both TE and TM mode overlapping each other at each and every point. For verifying the polarisation independency of the proposed system the simulated axial ratio bandwidth [21] depicts in Fig.11. This is the verification that proposed FSS design is independent of polarisation as axial ratio bandwidth is below 3dB.

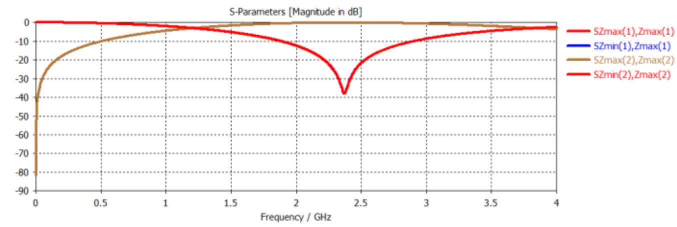


Fig.10. TE and TM reflection and transmission response for stop band

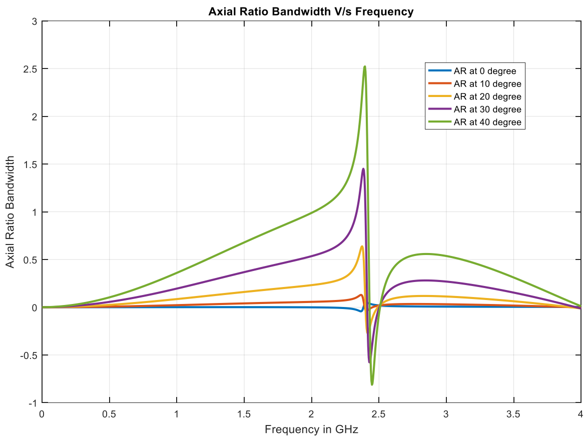


Fig.11. Axial Ratio Bandwidth v/s Frequency

5.3 VARIATION IN RESONANCE FREQUENCY BY CHANGING WIDTH OF *w*

Here we see that if there is change in the width of patch *w* (L_2-L_1) from 1mm to 6mm there is shifting in transmission null point from 2.4GHz to 5.6GHz means resonance is shifting from lower to higher frequencies. It can be observed from the Fig.12 that transmission null point downshifted and transmission null point bandwidth increased as we change width of single square loop structure. This is because by increasing the width inductive effect reduce which causes the increase in width of scattering parameter. It is clear that by varying the value of the w the desired band of rejection of the signal is achievable.

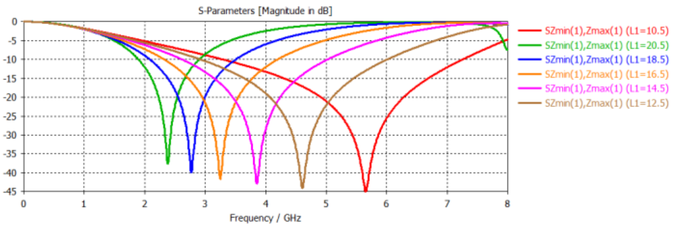


Fig.12. Variation in width of single square loop FSS structure (stop band)

6. CONCLUSIONS

This paper proposed two frequencies selective surface that act as both stop band and pass band respectively for low frequency signals. Stop band FSS unit cell is designed as a square loop of copper on substrate while pass band is designed as a single square shaped slot in copper which placed on substrate. Equivalent circuit of the FSS design has been modelled using capacitance and inductance. Simulated results for both stop band and pass band has been discussed. Proposed FSS is independent of polarisation and for angle of incidence of coming electromagnetic waves. Since, axial ratio bandwidth for FSS is below (<3dB) hence it is valid proof that proposed FSS is independent of polarisation. From the simulated results for both stop band and pass band it is verified that stop band (TE and TM mode) is independent of angle of incidence for all angle of incidence of electromagnetic waves while pass band shows independency for angle of incidence till angle 50 degree. Proposed structures are miniaturized, simple, stable and independent of angle of incident and polarisation. Therefore, can be used for filtering undesirable signals for lower frequencies applications.

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