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Flexible EM Wave Absorber with High Angular Stability and Low Cross Polarization Reflection Level

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Abstract

In this work, a flexible radar absorber structure is presented which offers high absorbance within X band. The proposed structure is designed by integrating two different resonators which provides high angular-stability properties. The theoretical and experimental results indicate that the proposed absorber is polarization insensitive and angular stable up to 60^0 in both the TE and TM polarization cases. Apart from conventional absorptivity analysis, the cross-polarization reflection of the proposed absorber is also calculated. The simulated results indicate that the proposed FSS configuration behaves as proper absorber and not a polarization convertor. The Radar Cross Section (RCS) of the proposed absorber is also calculated and compared with the RCS of a reflective sheet to analyze its suitability for practical applications at 10.95 GHz frequency in X band. The fabricated absorber is also tested for different angle of bend to test the effects of its flexibility on absorption. The simulation and measurement results indicate that the proposed absorber is highly suitable for absorption application within X-band.

1 Introduction

Frequency selective surfaces (FSSs) are artificially designed surfaces which either pass, stop or provide phase specific reflection to the incident Electromagnetic (EM) waves. FSSs can be used for various RF application such as polarization converter, microwave absorber design, filters design etc. [1-2]. One of the most important application of FSS is towards development of Radar absorbing structures or EM wave absorbers [3]. The EM wave absorbers are widely used for reduction of radar signature or Radar cross section (RCS).

The dimensional constrain of the conventional absorbers such as geometrical transition absorber, Jauman absorber, Salisbury absorber, limits their practical applications [2]. The FSS or metamaterial-based absorber uses resonating structures which transforms the absorber's impedance into free space impedance at the air-absorber interface [4]. These absorbers are compact in nature with typical sheet thickness of about $\lambda/15$ to $\lambda/10$ [3], (where λ is operating wavelength). The first metamaterial inspired absorber was reported in [5]. This absorber had limitation towards the polarization sensitivity. For most of the practical applications such as RCS reduction, Radom design etc. the EM wave absorbers should be polarization insensitive, angular stable and frequency independent. In recent years, several polarization insensitive, angular stable, wideband, and multiband absorbers have been reported in [6-9]. Most of these absorbers are designed on non-conformal printed circuit board (PCB). It is also important to analyze the absorber for its cross-polarization reflection or polarity conversion aspect. The absorber configurations reported in [10],[11] do not provide any analysis on the polarization conversion ratio or cross-polarization reflection for the respective absorbers. Hence, its exceedingly difficult to comment whether these reported absorbers work as an EM wave absorber or polarization converter.

In this work, a novel single band, polarization insensitive, angular stable and flexible absorber with low cross polarization reflection level is presented. The proposed configuration is designed by combining the effective properties of two different FSS unit cell to achieve effective absorption at 10.95 GHz in X band. In this work we have used CST microwave studio simulation software for theoretical characterization of the absorber. To validate the performance of the proposed absorber parameters such as absorption mechanism, surface current distribution and effective impedance characteristics are studied and presented. Polarization conversion characteristics of the proposed absorber configuration is also analyzed to checking the cross-polarization level. Finally, proposed absorber is fabricated using PCB technology and Absorbance/absorptivity is measured.

2 Design of Unit Cell and Its equivalent circuit.

The proposed FSS absorber unit cell is a three-layer configuration. The top layer consists of metallic FSS pattern, which transform the impedance of the absorber to free space impedance at the air-absorber interface. The bottom layer is complete copper laminate and the dielectric substrate with dielectric constant of 4.4 and loss tangent of 0.025 is sandwich between top and bottom layers. As mentioned above, that the bottom side of the unit cell (substrate) is completely laminated with copper. This ensures that there is no transmission of EM wave through the structure. However, the reflection from the structure will be minimum only if the input impedance seen by the EM waves at air- absorber interface equals to the free space impedance. This matching condition can be achieved by creating a resonance circuit as reported in [12]. Here, in this work structure-B and C are convolved to each other for enhance the angular stability and resultant structure is named as structure- D. The front view of proposed unit cell (structure-D, final design) with its dimensions and its equivalent circuits are shown in the Fig. 1.

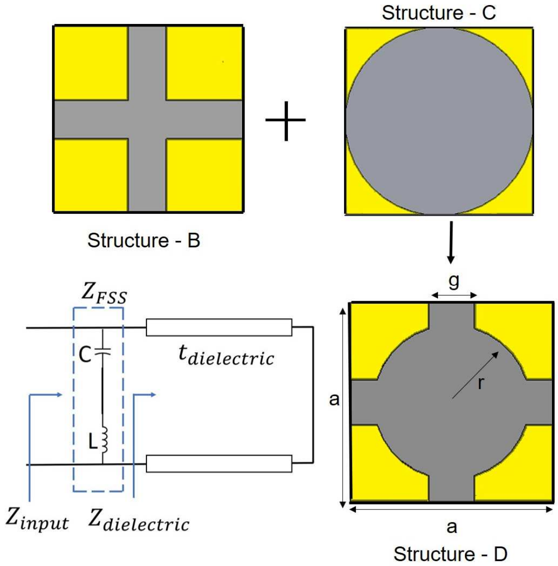


Figure 1. Proposed unit cell with its equivalent circuit. (dimensions of unit cell: a = 10, g = 2.25, r = 3.85 and, t_d = 0.25; all dimension in millimeter)

Here, in the equivalent circuit model, $Z_{dielectric}$ is the impedance of metal backed dielectric substrate and it can be calculated using the formula given in [13] and the impedance of frequency selective surface (Z_{FSS}) is given by the Eq No. 1

$$Z_{FSS} = j\omega L + \frac{1}{j\omega C} \tag{1}$$

Here, L and C are the inductance and capacitance due to metal in the unit cell and slot in FSS. The values of inductance (L) and capacitance (C) of FSS can be calculate with the help of techniques reported in [7],[14]. The inductance and capacitance for structure-D are calculated as 1.1797 nH and 0.133668 pF, respectively. The input impedance seen by the incident wave at the air-absorber interface is given as

$$Z_{input} = Z_{FSS} \| Z_{dielectric} \tag{2}$$

Reflection coefficient 'Γ_{input}' at air-absorber interface is given by.

$$\Gamma_{input} = \frac{Z_{input} - Z_0}{Z_{input} - Z_0} \tag{3}$$

At the resonance frequency the input impedance (Zinput) becomes purely real. When this Z_{input} matches with free space impedance (Z_0) the reflections become minimum, which leads to maximum absorption. The frequency dependent absorptivity is given by Eq no. (4)

$$A(\omega) = 1 - |S_{11}(\omega)|^2 - |S_{21}(\omega)|^2 \tag{4}$$

Where, $|S_{11}(\omega)|^2 = |R_{xx}(\omega)|^2 + |R_{xy}(\omega)|^2$ for TE Polarized EM wave and $|S_{11}(\omega)|^2 = |R_{yy}(\omega)|^2 + |R_{yx}(\omega)|^2$ for TM polarized EM wave. Here, R_{xx} , R_{yy} represents reflected co-polarized EM wave and R_{xy} , R_{yx} represent reflection of cross polarized EM wave whereas transmission through the absorber configuration will be zero due to complete copper laminates on bottom side.

3 Results and Absorbance Mechanism

The full wave simulation of unit cell is done with the help of frequency domain solver of CST microwave. The calculated reflection coefficient due to co/cross polarization and absorptivity of unit cell for normal angle of incident is shown in the Fig.2. It is observed from the Fig.2 that the proposed structure exhibit's nearly 1 and 0 value of reflection coefficient, while the value of calculated absorptivity is almost 100%. This indicates that the proposed FSS configuration is working as an absorber at 10.95 GHz frequency. The simulated absorbance bandwidth offered by proposed structure is 230 MHz for more than 80% of absorbance.

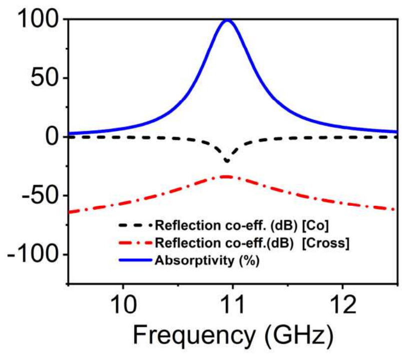
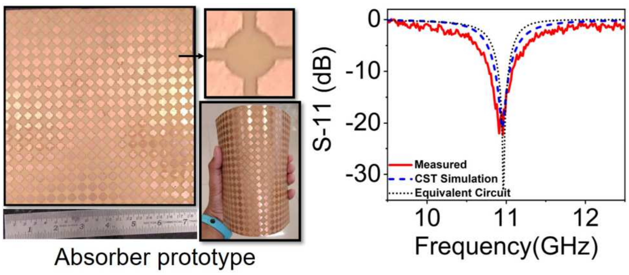


Figure 2. Simulated reflection coefficient and absorbance for normal incident angle.

The validation of simulation results is done by fabricating an absorber protype on 0.25 mm thin double sided copper coated FR-4 substrate using printed circuit board (PCB) technology and tested it for its absorptivity in an anechoic chamber environment. The dimension of the fabricated prototype is 150 mm x 150 mm x 0.25 mm as shown in the Fig. 3 (a). The fabricated absorber is tested with the help of two identical horn antennas (working as: transmitter and receiver) and a VNA. The comparison of the measured, calculated, and simulated reflection coefficients of proposed structure for normal angle of incident is given in the Fig. 3 (b). It is noted from the Fig.3 (b) that the simulated and calculated reflection coefficient is well matched with the measured result, which verifies the effectiveness of the proposed absorber at 10.95 GHz. The measured bandwidth offered by the absorber is 287 MHz for 90% of absorptivity.

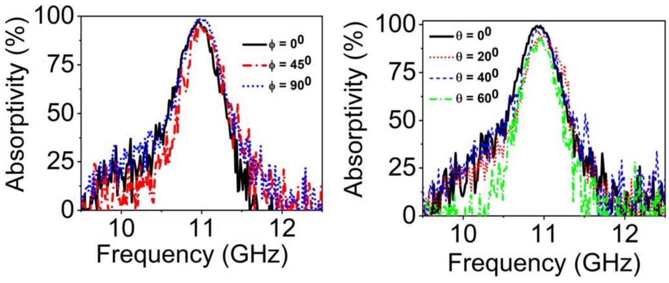


(a) **(b)**

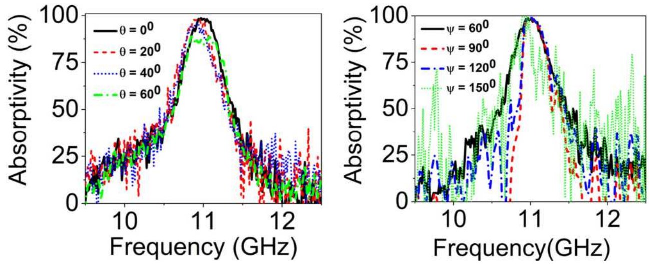
Figure 3. (a) prototype of proposed absorber (b) comparison of simulated, calculated, and measured reflection coefficient of proposed absorber

To verify the polarization insensitive nature, absorbance is measured for different angle of polarization and measured absorbance is given in the Fig.4 (a). It can be observed that for the different values of ϕ (from 0^0 to 90^0) the measured absorption for 10.95 GHz is nearly equal, which confirm polarization insensitive nature of the structure. The polarization insensitive nature of this absorber structure is basically due to presence of four-fold symmetry of the unit cell.

To check the angular stability of proposed structure, absorbance is measured for different angle of incident (θ) in both the TE and TM polarization cases as shown in Fig. 4 (b) and (c), respectively. The measured results indicate that for the angle of incident up to 60^0 in both TE and TM polarization cases the absorbance at 10.95 GHz is more than 90%. This validates that the proposed absorber configuration is highly angular stable with angular stability up to 60^0.



(a) **(b)**

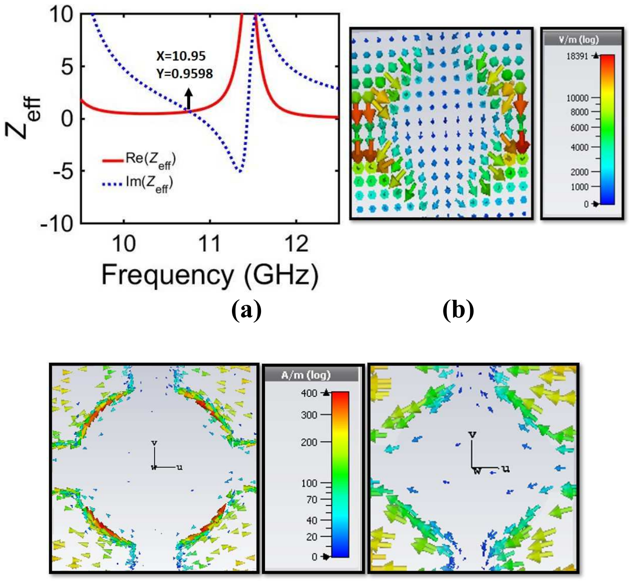


(c) **(d)**

Figure 4. Measured absorptivity for: (a) different polarization, and different angle of incident in case of (b) TE polarization, (c) TM polarization and (d) for different angle of bend (ψ)

The fabricated absorber prototype is flexible in nature. So, it is important to study the effects of the bend on the absorbance. The measured absorbance for different angle of bend (ψ) is given in Fig.4 (d). It can be observed from the Fig.4 (d) that the fabricated protype have almost same absorbance of more than 90% from the $\psi = 60^0$-120^0 and for $\psi = 150^0$ the frequency of absorption shifts towards lower frequency. Hence it can be concluded that the proposed absorber can be used for the angle of bend up to 120^0.

3.1. Absorbance Mechanism- The mechanism of microwave absorbance can be understood form effective input impedance (Z_{eff}), surface current distribution and electric(E) field distribution. The Z_{eff} curve of the proposed structure is shown in Fig.5(a). Where, $\mathrm{Img}\left(Z_{eff}\right)$ and $\mathrm{Re}\left(Z_{eff}\right)$ are the imaginary and real part of normalize input impedance, respectively. It is observed from the Fig.5(a) that the values of $\mathrm{Re}\left(Z_{eff}\right)$ and $\mathrm{Img}\left(Z_{eff}\right)$ are near unity and zero, respectively at 10.95 GHz which indicates a matched impedance condition, which further verifies that the proposed structure absorb EM wave at 10.95 GHz frequency. The E-field distribution of unit cell at top surface is shown in Fig.5 (b) which indicates that the coupling of electric field in the structure is maximum at 10.95 GHz. The surface current distribution of the absorber unit cell at 10.95 GHz is shown in the Fig.5 (c). It is observed that the surface currents at top and bottom surface of the absorber are flowing in opposite direction. These surface currents form a close loop and represents maximum excitation of magnetic field at 10.95 GHz. These coupling of electric filed and magnetic field at 10.95 GHz (287 MHz bandwidth) validates absorptive nature (for EM wave) of the proposed structure [7],[10].



(a) **(b)**

(c)

Figure 5. **(a)** Normalize effective input impedance **(b)** Electric field distribution at top surface and **(c)** surface current distribution at top and bottom surface at 10.95 GHz

4 Conclusion

In this work, an ultrathin, polarization insensitive, angular stable and conformal absorber is presented which absorb EM wave at 10.95 GHz for a bandwidth of 287 MHz within X band. The performance of the proposed absorber is validated through circuit analysis, design simulations and experimental measurements. Based on both theoretical and experimental analysis it is concluded that the proposed absorber is both polarization insensitive in nature and angular stable up to 60^0. The experimental analysis also indicates that the proposed absorber design works as perfect absorber and not a polarization convertor. The experimental analysis further indicates that the proposed absorber can be used for RCS reduction especially for cylindrical surface at 10.95 GHz in X band.

6 Acknowledgements

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