Triangular Based Dual-band Metamaterial Absorber for C-band Applications

B.D Bala[1], S.M Salisu[1], M.A Yusuf Hotoro[2], I. S Madugu[1]
[1]Department of Electrical Engineering, Faculty of Engineering, Aliko Dangote University of Science and Technology, Wudil, 713281, Kano, Nigeria
[2]Department of Physics, Faculty of Science, Aliko Dangote University of Science and Technology, P.M.B. 3244, Wudil, 713281, Kano, Nigeria

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Corresponding Author:
B. D Bala
Department of Electrical Engineering, Aliko Dangote University of Science and Technology, Wudil. , 713281, Kano, Nigeria
bdbala2@kustwudil.edu.ng

ABSTRACT

This paper presents a dual band metamaterial absorber based on triangular resonator for C-band applications. Metamaterial absorbers finds applications in sensing devices such as thermal and explosive detection and sound absorption. The unit cell has compact electrical size of ($0.196\lambda_o$ x $0.196\lambda_o$) where λ_o is the wavelength at resonance frequency of 4.9 GHz. The circular slot etched on the triangular resonator accounts for the lower frequency at 4.9 GHz and the post placed besides the resonator account for upper frequency at 7.5 GHz. The propose absorber is simulated using CST® software. The electromagnetic constitutive parameters of the unit cell are retrieved to reveal its left handedness. An absorptances values of 99% and 78% were obtain at the resonance frequencies of 4.9 GHz and 7.5 GHz respectively. The absorber is polarization insensitive due to constant coefficient of absorption when E and H field are rotated for an oblique incident angle for θ at 0°, 20°, 40° 60° and 80°.

***Keywords**: Absorber · Metamaterial · Triangular Resonator · Polarization insensitive ·*

1. Introduction

Since the inception of the concept of metamaterials (MTM) in the late 60s by Veselago [1] Researchers from all walks of life took advantage of the exotic properties of MTM to develop and improved the electromagnetic properties of naturally occurring materials [2], [3]. Basically, MTM is made from naturally occurring materials whose properties are engineered. Usually, they consist of periodic structures of unit size smaller than the wavelength of the incident wave [4]. In naturally occurring materials, the constitutive Electromagnetic (EM) parameters such as permittivity and permeability are positive for all frequency ranges. However, in MTMs all or one of the parameters is engineered to be negative. This unusual phenomenon was studied by many researchers to design microwave and millimetre wave devices with improved performance such as microwave absorbers [5], [6], MTM antennas, super lenses, cloaks[7] etc. Literarily, absorptance is the ratio of radiation absorbed by a surface to the amount of radiation incident upon it. This implies that MTM absorbers (MTMA) are usually artificial materials designed to absorb electromagnetic (EM) waves in a given frequency band [8]. Conventional absorbers are ferrite, wedged-tapered absorbers [9], silicon based [10], flexible substrate [11] and Salisbury screen [12].

Several works on MTMA have been reported as in [13] An electric ring resonator and a thin wire or post at the back of the unit cell were used to achieve a nearly perfect absorber. An absorptance of 88% was achieved at 11.5 GHz. In [14] a V-shaped MTMA is presented with a peak absorption value of 98% at 15.5 GHz. While in [15] an 8 x 8 mm^2 absorber with a closed square ring resonator is presented with peak absorbance values of 98%, 97%, 94% and 96% at resonance frequencies of 4.3, 6.6, 8.5 and 10.6 GHz respectively. The works by [5] presented an absorber employing two concentric circular ring resonators for Dual-band applications. The absorbance value of 96.4% and 93.2 % were obtained at resonance frequencies of 9 and 11 GHz. Also, a gap couple Hexagonal split ring resonator is presented in [16] with peak absorbance of 99%, 98% and 88% at the frequencies of 4.2, 5.4 and 12.4 GHz respectively. In [17] a Polarization insensitive dual band metamaterial with absorptance for 5G sub-6 GHz applications was presented. The distinctive feature of the proposed couple ring enclosed circular geometric resonator (CRECGR) unit cell is its simple and unique structure with a high effective medium ratio (EMR) of 11.13, polarization insensitive up to 180°, and epsilon negative (ENG) properties, including a negative refractive index and near-zero permeability for 5G sub-6 GHz applications.

In this paper, a MTMA using a triangular resonator with a circular slot and a thin wire post is presented for dual-band applications. The C-band covers the 4-8 GHz frequency spectrum with potential applications in Wi-Fi devices, satellite communications and Radar for navigation. The novelty of the proposed absorber is its progressive development in stages and polarization insensitivity. The constitutive parameters of the unit cell are extracted based on the popular Nicolson-Ross-Weir (NRW) algorithm to verify its lefthanded properties [18].

2. Metamaterial Absorber Design and Simulation

2.1 Unit Cell Design

The proposed absorber unit cell is designed on Flame Retard (FR-4) substrate with a thickness of (H) of 1.6 mm and dielectric constant of 4.3 and tangential loss of 0.025. The resonator is placed on the top part of the substrate and the full ground plane beneath the substrate as shown in Figure 1(a). The unit cell consists of a triangular patch of size (d and e) with a circular slot of radius (r) at the centre. Slits or gaps (g) are created on the resonator. Two post or thin wires of size (a x b) are etched on the two sides of the resonator. Figure 1(b) shows the annotated diagram of the unit cell. Figure 2 shows the progressive development of the unit cell. The dimension of the unit cell is shown in Table 1.

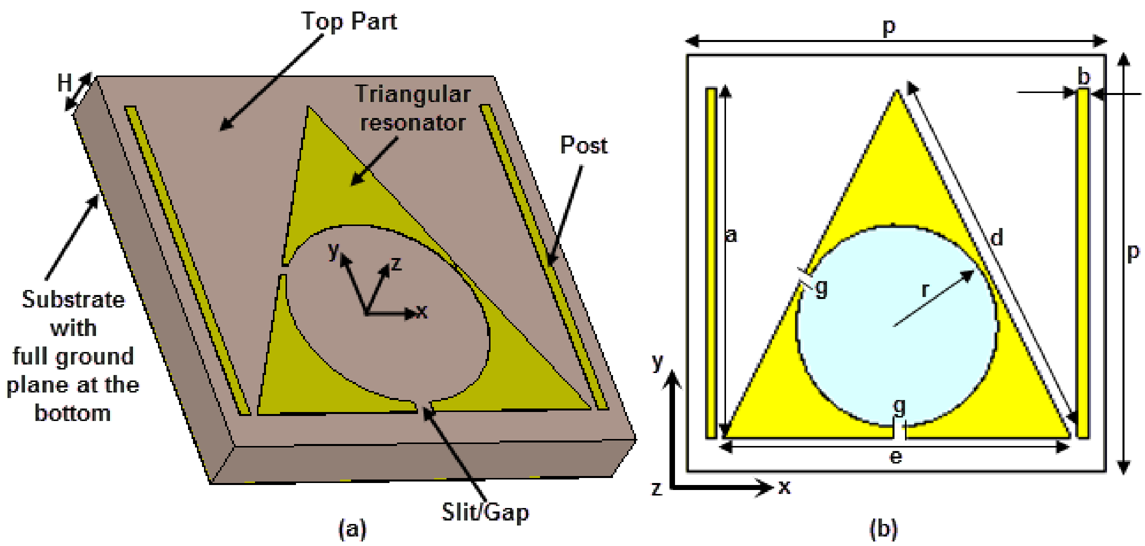


Figure 1: (a) Perspective view (b) Annotated unit cell

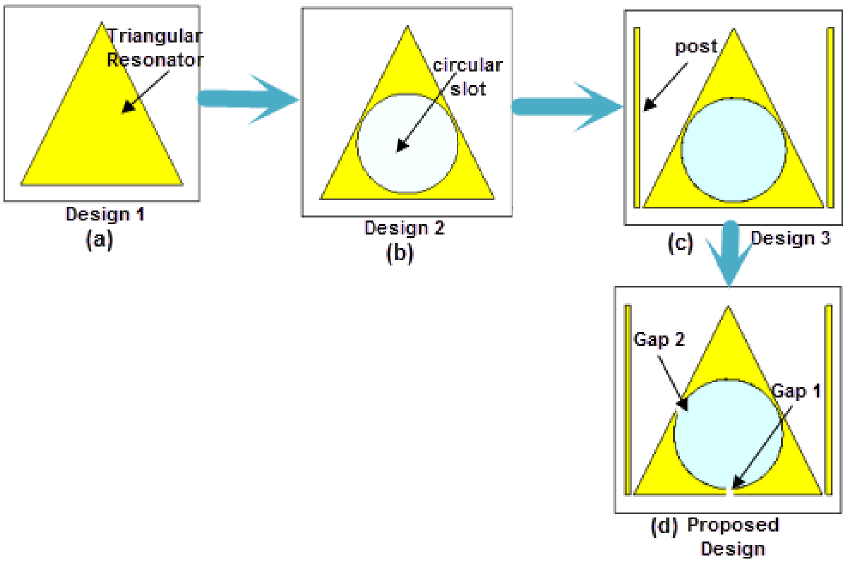


Figure 2: Progressive development of the unit cell design (a) triangular resonator (b) Resonator with circular slot (c) Resonator with circular slot and a post. (d) Resonator with circular slot, a post and two gaps.

Table 1. Dimensions of the Unit cell

Parameters	Values (mm)
P	12
a	10
b	0.3
d	11.2
e	10
g	0.3
r	2.9
h	1.6

2.2 Constitutive Parameter Extraction

The absorber is simulated using commercial software CST® Microwave Studio. The constitutive parameters of the unit cell were retrieved from the scatter parameters (S_{xy}) obtained from the software and extracted using the well-known NRW algorithm as in [19] according to equations (1)-(3).
The relative permittivity, ε_r is given by:

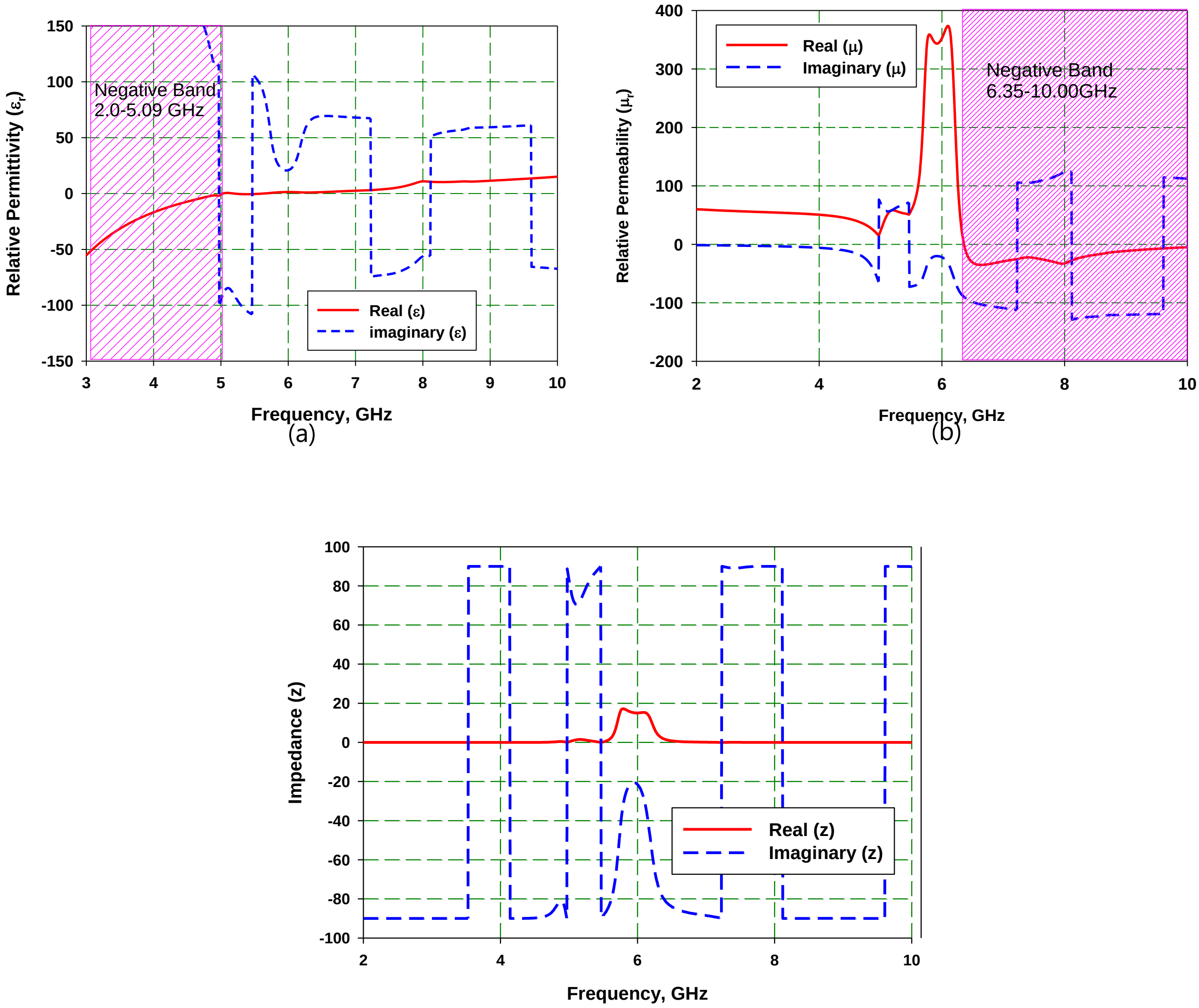
$$\varepsilon_r \cong \frac{2}{jK_o d} \times \frac{(1 - S_{11} - S_{21})}{1 + S_{11} + S_{21}} \quad (1)$$

$$\mu_r \cong \frac{2}{jK_o d} \times \frac{(1 - S_{11} + S_{21})}{1 + S_{11} - S_{21}} \quad (2)$$

Where $k_o = {}^{2\pi f}/_{c}$ is the wave number, c is the speed of light, f is the frequency and d is the substrate thickness and S_{11} and S_{21} are the reflection and transmission coefficient responses from the CST simulation of the unit cell. However, the normalized impedance z is given by:

$$z = \sqrt{{}^{\varepsilon_r}/_{\mu_r}} \quad (3)$$

Figure 3 shows the retrieved constitutive parameters of the unit cell to establish left-handedness of the unit cell as a metamaterial. From Figure 3(a) the permittivity is negative at the frequency range of 2.00-5.09 GHz which is a region for the first band of the absorbance. Figure (3b) shows the region where permeability is negative (6.35-10.00 GHz) this is the region where the second band of the absorber resonate. And finally, Figure 3(c) shows the normalized impedance of the unit cell.



(c)

Figure 3: Constitutive parameters of the unit cell (a) Relative Permittivity (b) Relative Permeability (c) Normalized impedance

3. Results and Discussion

3.1 Absorption Characteristics of the Unit Cell.

The simulated reflectance $R(\omega)$, Transmittance $T(\omega)$ and Absorptance $A(\omega)$ of the unit cell is shown Figure 4. The three parameters are related according to equation 4 as in [20].

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

The absorptivity is estimated by $A(\omega) = 1 - R(\omega)$ due to the complete ground plane introduced at the back of the unit cell. Hence the transmission coefficient $|S_{21}|^2 = 0$ and T(w) is zero, therefore, the absorptance in equation (4) reduces to

$$A(\omega) = 1 - R(\omega) \quad (5)$$

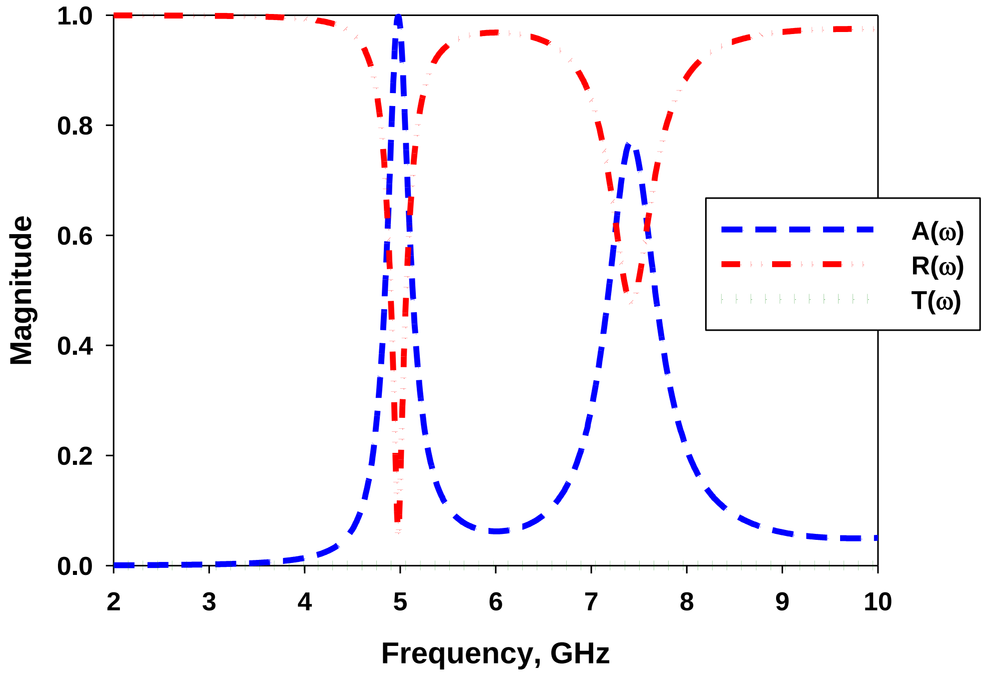


Figure 4: Absorption, Reflection and Transmission coefficients of the unit cell

Figure 5 depicts several design steps taken in achieving the proposed design. In design 1 with a triangular resonator as the radiator, a single band absorbance of 50% is obtained at a resonance frequency of 7.42 GHz. In design 2 with a circular slot introduced into the triangular resonator, a single band absorbance of 75% is obtained at the resonance frequency of 6.1 GHz. Design 3 involves the introduction of a post to design 2 in order to create an additional resonance band. Hence dual-band absorber is obtained with absorbances of 97% and 68% at the resonance frequencies of 7.6 and 6.0 GHz respectively. Finally, the proposed design is conceived by the introduction of two gap slots oriented 90° on the circular slot. Peak absorbances of 99% and 78% are obtained at the resonance frequency of 4.9 and 7.5 GHz respectively. The proposed absorber is polarization insensitive due to the constant coefficient of absorption when the E and H fields are rotated for an oblique incident angle for θ at 0°, 20°, 40° 60° and 80° as shown in Figure 6.

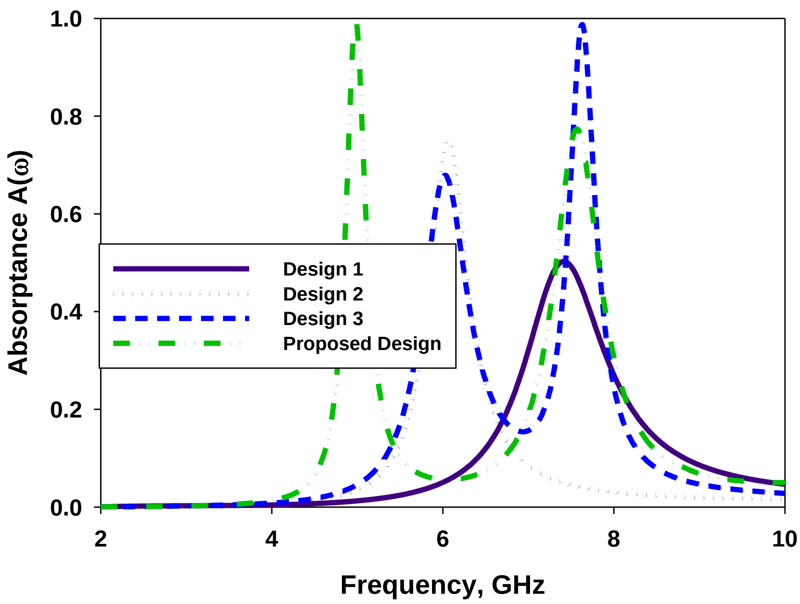


Figure 5: Absorptance for various design steps

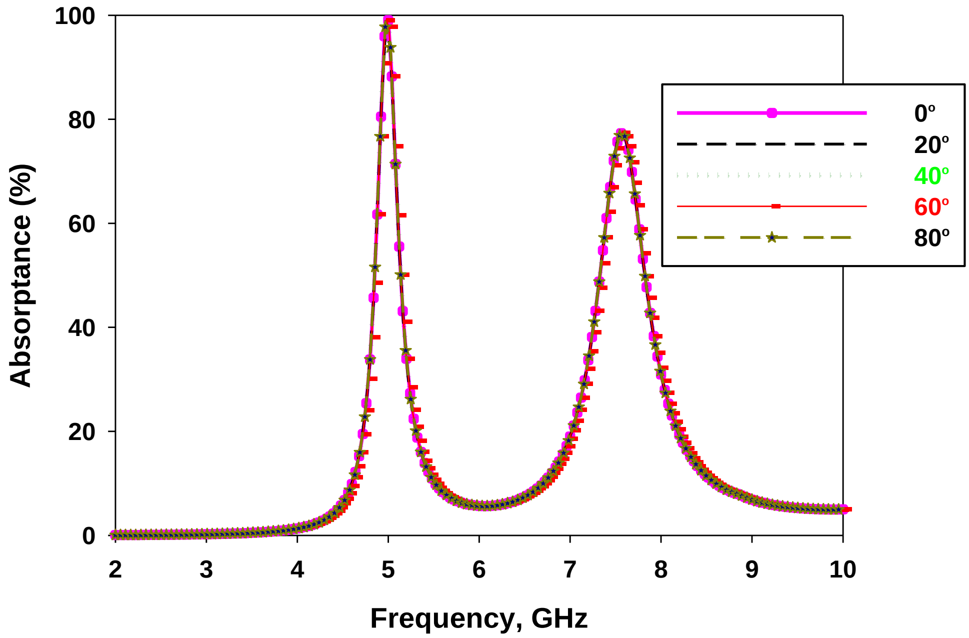
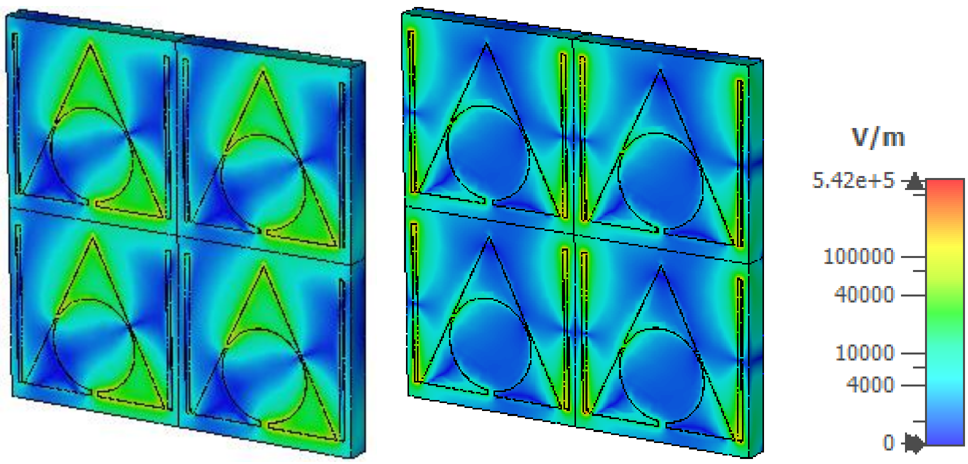


Figure 6: Absorptance for various oblique TEM angles

3.2 Absorber field Characteristics.

The E- and H-field distributions were simulated as shown in Figures 7 and 8. Strong vertical E-field can be observed at the vertices of the triangular resonator as in shown in Figure 7 (a) which indicates parts of the resonator that contributes to the resonance at 4.9 GHz. However, at the resonance frequency of 7.5 GHz the vertical post makes a strong contribution as shown in Figure 7 (b). H-field distribution is shown in Figures 8a and 8b with horizontal field concentration at the middle of the slanting length of the resonator and the thin wire post for frequencies at 4.9GHz and 7.5 GHz respectively.



(a) (b)

Figure 7: E-field distributions (a) 4.9 GHz (b) 7.5 GHz

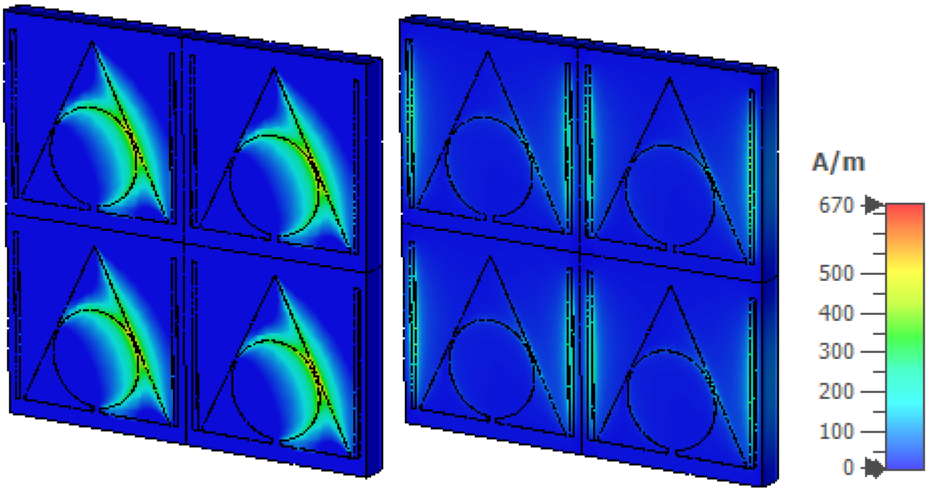


Figure 8: H-field distributions (a) 4.9 GHz (b) 7.5 GHz

As predicted, the surface current distribution is anti-parallel on the top patch and the bottom ground plane as observed in Figure 9. At a lower frequency of 4.9GHz, high current distribution can be seen on the triangular resonator (Figure 9a) while at a higher frequency of 7.5 GHz, It concentrates more on the vertical post. However, more dispersive current can be seen on the ground plane (Figure 9c) than on the top patch. This is an indication that strong magnetic excitation exists between the two layers of the substrate hence the Counter-circulating current accounts for magnetic absorption in the material.

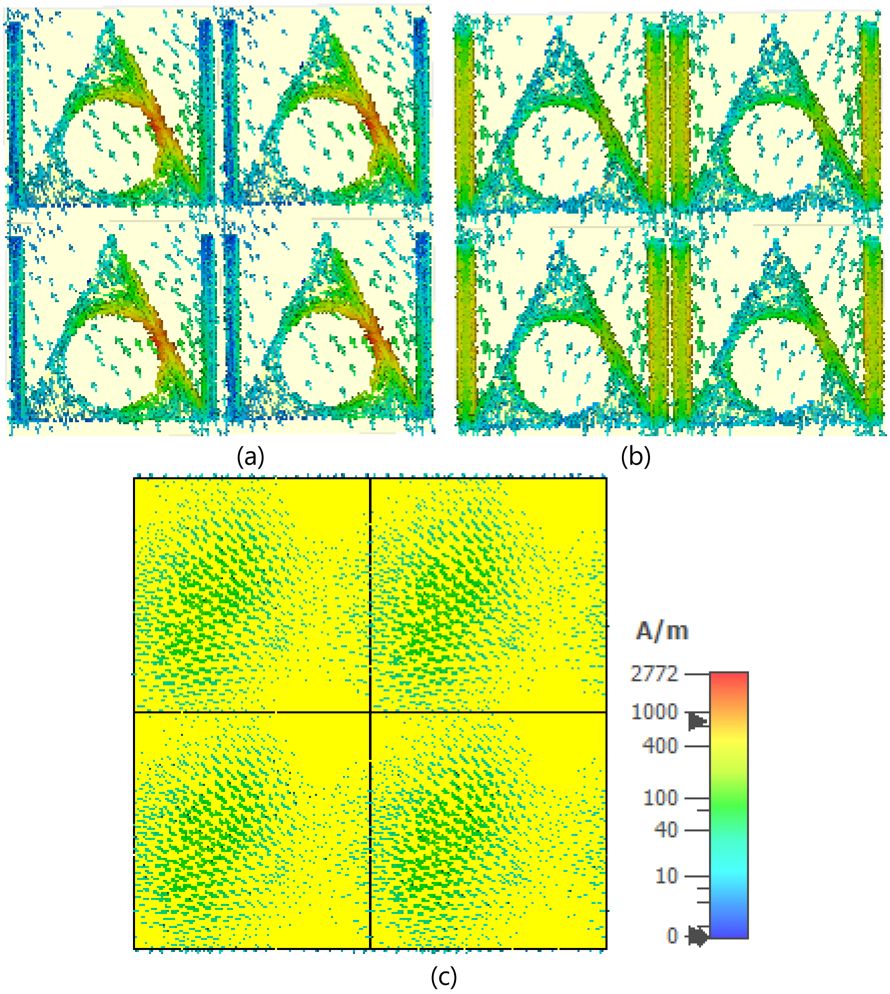


Figure 8: surface current distributions (a) 4.9 GHz (b) 7.5 GHz (c) Ground plane at 4.9GHz

4 Conclusions

In this paper, a triangular MTMA absorber has been designed and simulated for C-band application. The constitutive electromagnetic parameters of the absorbers' unit cell have been extracted to reveal its MTM properties. An absorptance values of 99% and 78% was obtained at the resonance frequencies of 4.9 GHz and 7.5 GHz respectively. The proposed absorber is insensitive to different oblique angles. Due to its compact size, an array of 2 x 2 was used for EM field analysis. Only simulation result was considered. The excellent performance of the absorber shows it can be used for multi-band microwave applications.

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