Dual Band thin Metamaterial Perfect Absorber Based on Triangle Shape

Khalid Saeed Lateef Al-badri*

1Physics Dept., University of Samarra, Iraq.
2Computer Centre, University of Samarra, Iraq.

Emails: khalidsaeed@uosamarra.edu.iq

Abstract. This work presents a multi-band electromagnetic metamaterial perfect absorber. It is shown typical an artificial microwave metamaterial absorber that can realize dual-band excellent absorption. The unit cell of the proposed structure is designed by using an analogy triangular resonator, an electric dielectric substrate, and a continuous copper plate. Two excellent absorption peaks with absorption rates are 98.05%, and 96.43%. The ratios of the structure thickness to the wavelengths of the proposed design are 1/39, and 1/23 at resonance frequency 3.84 GHz and 6.62 GHz respectively, which are very smaller comparing with wavelengths. By using the surface current distributions, the mechanism of the dual-band is explained. This absorber is non sensitive to the TE polarization wave and highly sensitive to the TM polarization wave. Furthermore, this design concept can be extended to many applications such as energy electromagnetic harvesting, reduce radar cross section RCS, sensors, antenna, thermal image, and detection.

1. Introduction

In the past ten years, electromagnetic metamaterials have rapidly become a hot topic in international research [1-20]. The design of electromagnetic metamaterials is based on a certain artificial structure with special functions. By adjusting the different parameters of the unit structure, it can achieve what natural materials do not have. Physical properties, such as left-handed LH characteristics [1-3]. Electromagnetic metamaterials have broad application prospects in high-directivity antennas [5], radars [14], focused microwave beams, electromagnetic wave stealth [14], satellite communications, etc. [15]. In recent years, metamaterials have been absorbing waves. The performance has attracted wide attention. In 2008, Landy et al. [2] proposed the concept of a perfect absorber for microwave range metamaterials [5-7, 18-25], which uses electric resonators, short metal wires and dielectric layers to form a perfect absorber, which is different from the electromagnetic components of incident electromagnetic waves. The coupling produces electrical resonance and magnetic resonance, so that the reflection coefficient and transmission coefficient are minimized at the same time, and the absorption rate is maximized to achieve perfect absorption. Because the perfect absorber is used in spectrum imaging, photodetectors, miniature bolometers and stealth, etc. At present, metamaterial absorbers have been continuously developed from microwave frequency bands to THz [19], infrared [2] and visible light [9] bands. From a single frequency band to a wide frequency band [4-7,10,13-16,20-25], many Frequency band [4-7] etc. Among them, multi-band absorbers include two-band, three-band, and four-band absorbers and more. Article [4] in 2016 shows a single absorption peak with single resonator,
thin structure and polarization sensitive response. Article [18] 2018, also one absorption band has been presented with the use thin design, single resonator and ability to tune absorption from one-band to dual-band, but also suffering from TE polarization sensitive. Furthermore, a tow absorption band with the periodical unit cell of two scales of Jerusalem resonators has been reported in [26] but this design has larger dimensions. This work shows dual-band absorption peaks, thin structure and unsensitive of TE polarization wave by using analogy triangular resonator shape in order to enhanced absorption response for S-band and C-band applications. Using the surface current distribution, the physical mechanism of perfect absorption in multiple frequency bands is explained. The material has strong absorption. Simulation verify the performance of the designed metamaterial absorber.

This article is organized as follows. The dual-band absorber structure designed in section 2, and the simulated results, physical mechanism, surface current and power loss are presented in section 3. Finally, the conclusion is shown in section 4.

2. Structural design

The metamaterial absorber structure is composed of three layers. The upper layer is a symmetric metal triangle structure, the middle layer is a dielectric substrate, and the bottom layer is a metal backplane. The dielectric substrate is made of FR-4 (FR indicates the material is flame retardant and the 4 indicates woven glass reinforced epoxy resin) lossy plate, and its dielectric constant is 4.3. The loss tangent value is 0.025 and the thickness is 2 mm. The metal is copper, its conductivity is $5.8 \times 10^7$ S/m, and the thickness is 0.035 mm. The triangle metal structure is composed of three identical sub-shape same to number-seven shape, as shown in the figure 1(a). As we all know, the design mechanism of a perfect metamaterial absorber is to match the impedance of the metamaterial absorber with the impedance of free space by continuously optimizing the structural parameters of the metamaterial, so as to minimize the reflectivity of the incident electromagnetic wave At the same time, the transmittance is infinitely close to zero because we used entire ground plate in back side of substrate, so that the absorption rate is depend only on reflection wave.

![Figure 1](image_url)

**Figure 1:** (a) Schematic diagram, (b) unit cell.
CST MWS Computer Simulation Technology Microwave Studio is a specialist tool for the 3D EM simulation of high frequency components [28]. CST MWS is used to perform full-wave simulation of the designed metamaterial absorber. The simulation model is shown in Figure 1 (b). During the simulation, electromagnetic waves are incident perpendicularly to the metamaterial absorber along the z direction, electric field is along x and magnetic field is along y directions. The boundary conditions are set as the unit cell boundary. The optimized structure parameters are as follows: the long side of seven-number \(L_1 = 16\) mm, the short side \(L_2 = 8\) mm, \(L_3 = 5.5\) mm, \(L_3 = 13.5\) mm, the seven-number structure gap \(g = 1.4\) mm, and line width \(w = 2.5\) mm. The S parameters \(S_{11}, S_{21}\) of the metamaterial absorber are obtained by frequency domain solver, in addition, the reflectance \(R(f) = |S_{11}|^2\) and the transmittance \(T(f) = 0\), and the absorption rate \(A(f) = 1 - R(f) = 1 - |S_{11}|^2\), the obtained absorption rate is shown in Figure 2. Strong absorption peaks appear at 3.84 GHz and 6.62 GHz, and the absorption rates are 98.05\% and 96.43\% respectively.

3. Results analysis and discussion

In order to further analyse the physical mechanism of the dual-band absorption, the resonance of the two absorption peaks is explained from the surface current distribution and the energy loss density distribution respectively. Figure 3 (a) corresponds to the surface current distribution at absorption peak-1 (\(f = 3.84\) GHz), the right long side metal of the triangle structure has the strongest current distribution. Under the action of the surface current distribution, the direction of current represents electric dipole oscillations along the long metal line, resulting in strong localization between the upper and lower adjacent metal.

Figure 3 (b) shows the current distribution at the frequency \(f = 6.62\) GHz corresponding to the absorption peak 2. The figure clearly shows that the current strongest distribution in the short side of the triangle structure. The current distribution is also just the opposite direction of current in back metal, i.e. strong coupling between the triangle and ground plate. The distribution of energy loss density is given, the red colour curve represents the loss in the substrate layer i.e. FR-4 layer and the green curve represents the loss in entire ground plate and triangular resonator. It can be seen that the loss comes from the dielectric loss see Figure 4. About 0.46W in FR-4 substrate and 0.02W in copper layers.

The electric field distribution enhances the dielectric loss in this area see figure 5. The electromagnetic field keeps mutual conversion, the strong electric resonance concentrates the energy of the incident electromagnetic wave mainly in this area, which is lost in the form of heat, and finally the magnetic field is also lost, proving once again that the strong absorption comes from the electric resonance.
Figure 3. The surface current distribution: (a) at $f = 3.84$ GHz (b), at $f = 6.62$ GHz.

Figure 4. Power loss in dielectrics and metals.

Additionally, can obtain a dual-band metamaterial absorption wave response comprehensive of polarization studies were carried out on the two parameters TE and TM polarization. Because the symmetric of the triangle resonator around z axis has a great influence on the polarization wave. It can be seen from Figure 5 that as the gradual increase from $0^\circ$ to $90^\circ$, the response of the metamaterial perfect absorber does not change for the two peaks. Figure 6 shows the behaviour of the TM polarization mode of the proposed design as a function of $\theta$. It can be seen that when the $\theta$ gradually increases from $0^\circ$ to $75^\circ$, the absorption level of the two peaks change in a more complicated manner, but generally peak one is above 90% until $\theta = 45^\circ$. In addition, as the $\theta$ further increases, the absorption level rapidly decreases. Finally, on the basis of the aforementioned polarization parameter study, comprehensively considering the influence of each of the two parameters, phi $\varphi$ and theta $\theta$ on the behaviour of the absorber, this design is a reasonable high-performance, perfect absorber, and ultrathin structure.
Additionally, compared with previous metamaterial design presented in some earlier work, the TE polarization performance of our analogy triangular metamaterials resonator can be significantly good responses than [4], [18], [26], [27], as presented in Table 1. Consequently, it has TE polarization unsensitive performance and it is can be used to energy electromagnetic harvesting, reduce radar cross section RCS, sensors, antenna, thermal image, and detection applications.

| Configuration | Number of bands | TE polarization sensitivity |
|---------------|----------------|-----------------------------|
| This work     | 2              | No                          |
| [4]           | 1              | Yes                         |
| [18]          | 2              | Yes                         |
| [26]          | 2              | Yes                         |
| [27]          | 2              | Yes                         |

Table 1. Comparison with previously proposed dual-band MAs.
4. Conclusion

This paper designs and simulated an ultra-thin dual-resonance metamaterial absorber based on a triangle structure. The thickness of the absorber (2 mm) is approximately its working frequencies =3.84 GHz and 6.62 GHz. Under the action of an external electric and magnetic fields, at 3.84 GHz and 6.62 GHz the peak absorptivity reaches 98.05%, and 96.43% respectively, achieving strong multi-band absorption. The study found that the resonator in the absorber can operate at two adjacent frequencies within 3-7 GHz electric dipole resonance is generated, and the resonant frequency calculated by using the resonant wavelength is basically consistent with the resonant frequency obtained by simulation under frequency solver based on CST simulator, which further explains the physical mechanism of multi-band absorption. The TE polarization φ-response of the design is unsensitive. But the structure is strongly sensitive to TM polarization (θ-response) incident wave.

5. References

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