

A compact dual-band metamaterial absorber using square split rings for C-band and X-band sensors applications

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Abstract—A novel dual-band metamaterial absorber is proposed to achieve narrow-band absorption in the microwave range, making it highly suitable for sensor applications. Comprising two split-ring resonators one operating in the S-band and the other in the C-band the absorber is designed to operate simultaneously in both bands, providing narrowband absorption for different angles of incidence. The proposed absorber can achieve absorption peaks of greater than 99.5% and 96.9% in the respective bands. The physical mechanism of the proposed absorbers is demonstrated, along with the representation of its permeability and penetrability values, as well as its electric and magnetic field distributions. The metamaterial features a planar structure, showcasing polarisation-insensitivity and angle-insensitive absorptive properties. Furthermore, the absorber has a compact size, making it suitable for sensing, EMI, and EMC applications.

Index Terms—metamaterial absorber, polarisation insensitive, dual band, compact.

I. INTRODUCTION

In recent decades, metamaterial perfect absorbers (MPAs) have garnered significant attention due to their crucial role in various promising applications, such as thermal emitters, sensors, and solar cells. The fundamental principle behind MPAs lies in the suppression of reflection from incident electromagnetic waves. This is achieved by employing an optically thin metallic layer backed on the substrate of a metamaterial absorber to block transmission. Consequently, the widely adopted metal-dielectric-metal (MDM) configuration in research [1], [2] utilizes perfect absorption based on geometric and material characteristics. In the MDM configuration, perfect absorption is attainable by manipulating the geometric and material features. The structure of MDM absorbers is designed to control the resonance absorption band. Sensors exhibiting multiband absorption responses are potentially valuable in chemical and biomedical applications. Recent studies have showcased various plasmonic structures with multiple absorption bands [3], [4], [5]. For sensor applications requiring precise absorption frequency detection, MPAs with a narrow absorption band are essential. In microwave metamaterial absorbers, near-unity absorption bands

are scarce. However, a multiband absorber can detect multiple frequencies, enhancing the metamaterial absorber's utility as a sensor. The literature presents several examples of multi-band metamaterial absorbers [6]–[12].

The paper proposes a dual-band metamaterial absorber on a metal-backed dielectric substrate with a square split-ring geometry. The design focuses on minimizing the reflection coefficient at the resonance frequency. The detailed design of the unit cell geometry is presented in Section II, while Section III describes the absorption characteristics, including the surface current field distribution of the metamaterial. To conclude, Section IV provides a brief summary of the design and its characteristics. Utilizing low-cost materials with simple designs offers additional advantages compared to pre-existing designs [13]–[15].

II. UNIT CELL DESIGN

The proposed structure, illustrated in Fig. 1, is designed to minimize the reflection coefficient of the unit cell [13]. The unit cell patch comprises a circular split-ring resonator enclosed by a square-ring resonator. The two rings are connected using conduction in the stings of dimension 'd,' and the corners of the square consist of square patches of dimensions 'b1' and 'b2' to enhance mutual coupling between the two resonators at higher frequencies. A metal plate is placed on the back of the substrate. The structural parameters are tailored for an FR4-epoxy dielectric substrate with a thickness of 1.6 mm. The optimized parameter values are 'a' = 23 mm, 'b' = 22 mm, 'd' = 20.5 mm, 'l' = 7 mm, 'w' = 0.4 mm, 'b1' = 3.2 mm ('b2' is also set to 3.2 mm), 'g' = 0.2 mm, 'g1' = 1 mm, and 'h' = 1.6 mm. These dimensions are optimized to enhance the performance of the metamaterial absorber for use in sensor and electromagnetic detector applications. Both the top and bottom are constructed using copper metal with a thickness of 0.035 mm on an FR4 substrate with a thickness of 1.6 mm, a relative permittivity of 4.4, and a loss tangent of 0.02. The proposed unit cells are simulated using the commercially available software HFSS under a periodic boundary condition with a normal incidence of electromagnetic waves.Å

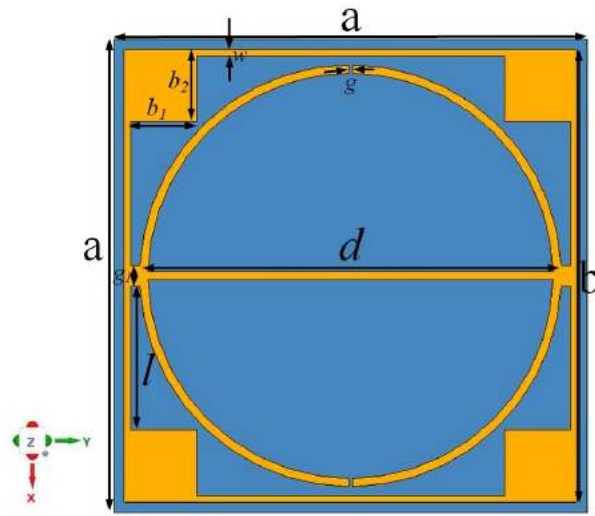


Fig. 1: unit cell geometry top view.

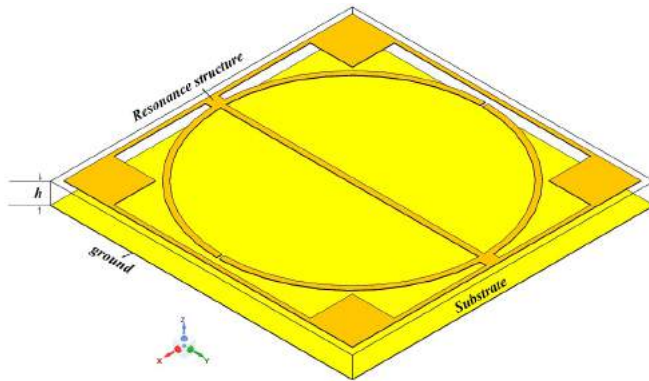
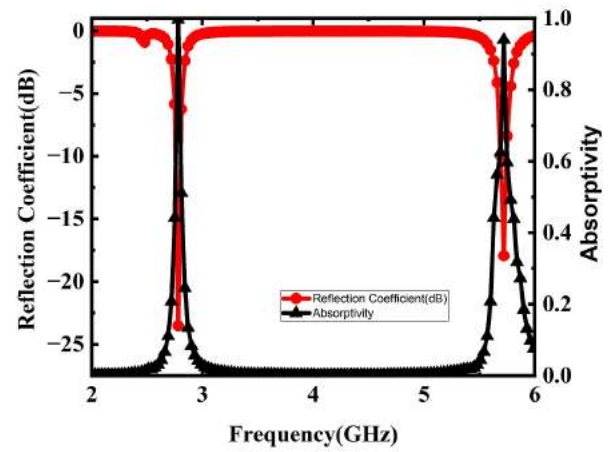


Fig. 2: unit cell geometry Isometric view.

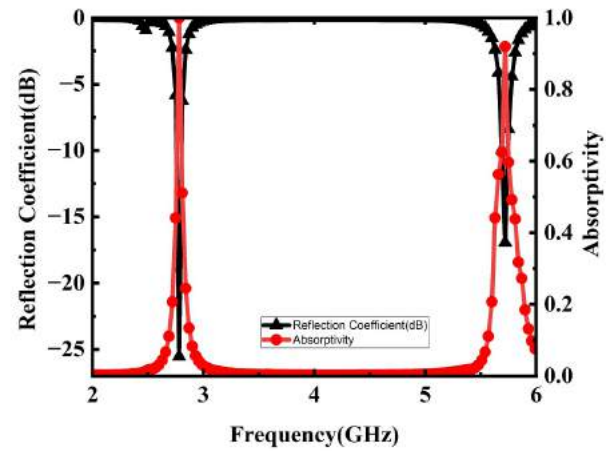
The simulated results of the proposed structure is shown in Figure 3. From Fig.3(a,b) it is observed that the reflection coefficient is -24.2 dB and -18.6 dB at the frequencies 2.78 GHz and 5.78 GHz respectively and also the absorptivity is 99.5% and 96.9%.

III. RESULTS AND ANALYSIS

To calculate the absorption by reflection and transmission coefficients, the following formula is used: $A(\omega) = 1 - R(\omega) - T(\omega)$ [16], where $R(\omega)$ is the reflection coefficient as a function of frequency and $T(\omega)$ is the transmission coefficient as a function of frequency. Maximum absorption occurs when the minimum reflection of the incident wave happens at the surface. The simulated reflection coefficient and absorptivity for TE and TM modes are shown in Fig.3.



(a)



(b)

Fig. 3: Simulated reflection coefficient and absorptivity for (a) TE (b) TM..

The Nicolson-Ross-Weir technique is used to obtain the effective medium parameters such as relative permittivity, relative permeability, refractive index, and relative impedance, as shown in Fig. 4. From Figure 4(a, b), at frequency 2.78 GHz, the relative permittivity and relative permeability values are negative, and at frequency 5.78 GHz, the relative permeability is negative and the relative permittivity is near zero. Due to this, there is a maximum absorption 99.8% at 2.78 GHz and 99.6% absorption at 5.78 GHz, and their impedance is near unity, as shown in Figure 4(d).

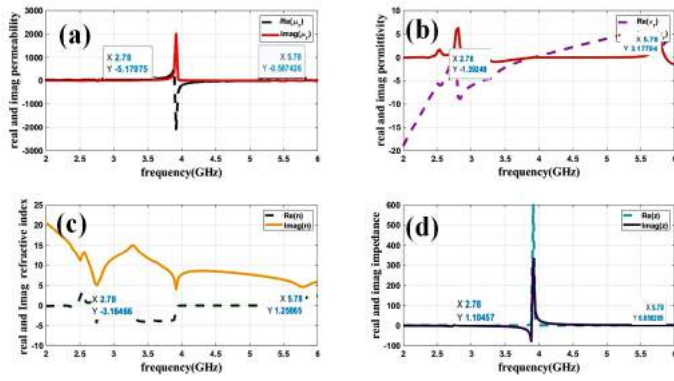


Fig. 4: Real and Imaginary parts of effective medium parameters.

A description of the physical mechanism of the proposed metamaterial absorber is given in Figures 5, 6, and 7 as a function of the electric field distribution and the surface current distribution. The electric field distributions and surface current distributions are analyzed to gain insight into the generated resonance bands. At a frequency of 2.78 GHz, it can be claimed that the inner circle has an electric and magnetic resonance that causes absorption. The absorption at 5.78 GHz is due to the presence of the outer ring structure. The strong electric field and current distribution are presented for both bands, as illustrated in Figs. 5 and 6. In Figs. 6 and 7, there is an opposite current at the bottom, because of which there is a strong magnetic field present. Because of this, there is a simultaneous magnetic and electric field, causing strong resonance.

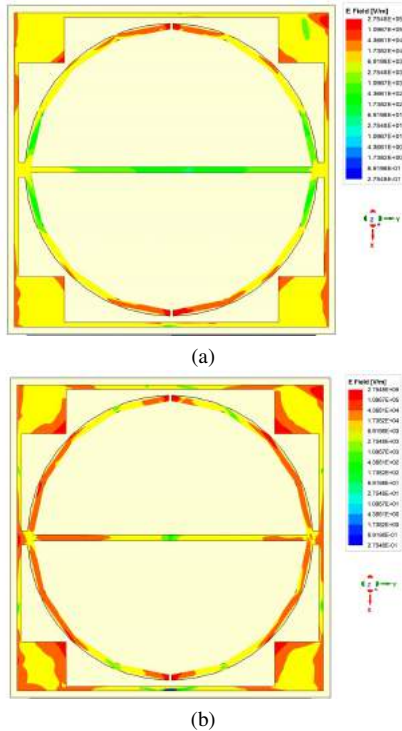


Fig. 5: The electric field distribution (a) 2.78 GHz (b) 5.78GHz

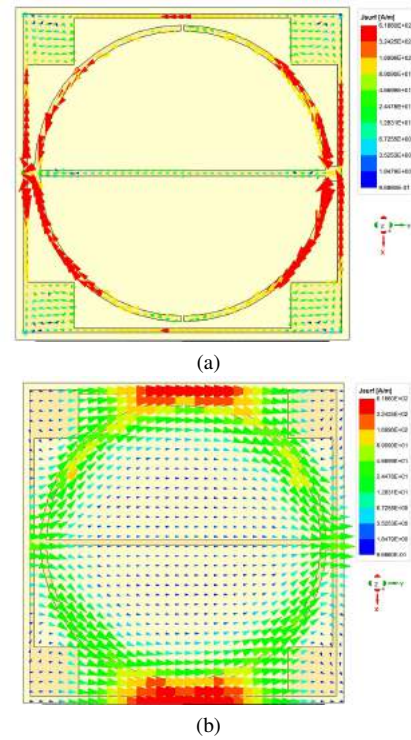


Fig. 6: The surface current distribution (a) 2.78 GHz Top view (b) 2.78 GHz Bottom view .

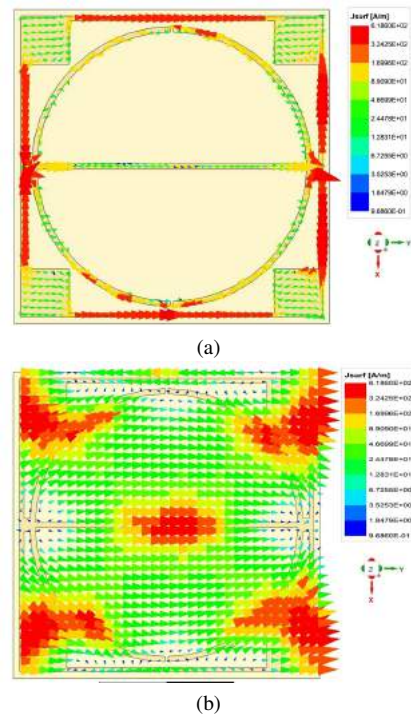


Fig. 7: The surface current distribution (a) 5.78 GHz Top view (b) 5.78 GHz Bottom view.

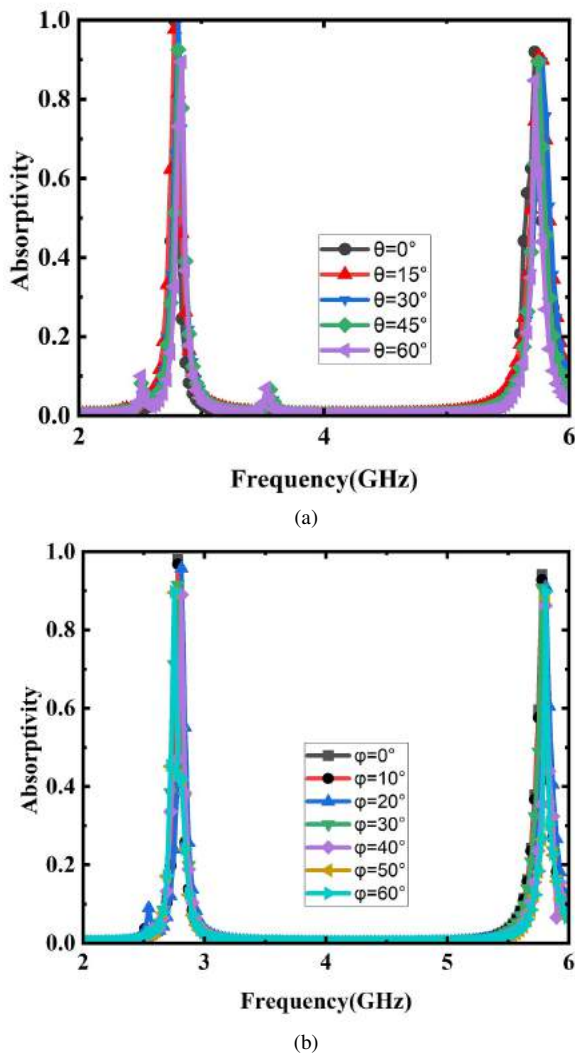


Fig. 8: The oblique incidence angle for proposed absorber TE and TM.

The simulated reflection coefficients of dual-band absorbers with TM polarised waves and TE-polarized waves are presented in Fig. 8. From the figures, it is evident that the proposed absorber has a wide range of angular stability 60° . The absorption band at two resonance frequencies is 0.1 GHz and 0.14 GHz. The bandwidth is calculated as the range of the frequency width at half maximum (FWHM). The consequent quality factor ($Q = f/\text{FWHM}$, where f indicates resonance frequency) is between 32.6 and 34.04. Furthermore, due to its symmetrical geometry, it exhibits polarization insensitivity under normal incidence. As a result, the designed effective absorber can be used as a sensor and EM detector for GHz frequencies.

IV. CONCLUSION

This paper proposes a dual-band metamaterial absorber on a metal-backed dielectric substrate for applications in the S and C bands. Using a square and circular split-ring geometry, the structure produces two absorption bands at 2.78 GHz and 5.78

GHz. Additionally, the device is polarization-insensitive and stable under the oblique incidence of EM waves, which makes it a good candidate for practical wireless applications. To understand the structure's characteristics, we examined its current distribution patterns and surface power loss density. There is a design parameter that can be used to tune the resonance frequencies of the proposed structure. The proposed design has a high quality factor, which is an important factor for sensing applications. The metamaterial absorber is proposed for use in sensors and EM detectors.

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