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A Tri-Band Electromagnetic Absorber with Insensitive Properties

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Abstract—In this paper, we present a tri-band electromagnetic absorber with insensitive properties. A rotational symmetry structure with a metallic ground is proposed for the design of the metamaterial absorber. Calculation results show that the absorber has three perfect absorption points at 4.76 GHz, 7.61 GHz and 10.84 GHz with the corresponding absorption rates of 96.7%, 97.8%, and 99.3%. An experiment is given, and the results verify our design. Such a tri-band absorber has the merits of high absorption rate, stable performance with various incident angles and different polarizations.

1. INTRODUCTION

Metamaterials are a kind of artificial structure, which exhibit special physical properties that cannot be observed in naturally-occurring materials, such as negative index of refraction, reversed Doppler shift, and reversed Cerenkov radiation [1–3]. Based on these special electromagnetic properties, a lot of new microwave devices have been explored and studied theoretically and experimentally. Studies have been done on perfect lens [4], cloaks [5, 6] absorbers [7], etc. Since Landy et al. experimentally demonstrated a perfect metamaterial absorber at 11.5 GHz for the first time in 2008 [7], a great number of novel metamaterial absorbers have been proposed [8–12]. In some applications such as novel multi-band antennas, sensors, modulators, multiband absorbers are needed for designing novel microwave devices. In [13], an ultra thin and triple-band metamaterial radar absorber is designed and experimentally investigated. A four-band metamaterial absorber based on flower-shaped structure is proposed in [14]. Dincer et al. designed a dual-band metamaterial absorber based on isotropic resonator [15]. Numerical studies show that such dual-band MA can provide perfect absorption at wide angles of incidence for both transverse electric (TE) and transverse magnetic (TM) waves. A polarization-insensitive triple-band microwave metamaterial absorber based on rotated square rings was proposed in [16].

With the great potential applications in medical technologies, sensors, modulators, and wireless communication, the design of multi-band metamaterial absorbers is still attractive [17–23]. In this paper, we present a tri-band electromagnetic absorber with insensitive properties. A rotational symmetrical structure with a metallic ground is proposed for the design of the metamaterial absorber. Calculation results show that the absorber has three perfect absorption points at 4.76 GHz, 7.61 GHz and 10.84 GHz with the corresponding absorption rates of 96.7%, 97.8%, and 99.3%. Moreover, such a tri-band absorber keeps stable performance with various incident angles and different polarizations.

The paper is organized as follows. A rotational symmetry absorber structure is designed in Section 3. Its absorption and insensitive properties are analyzed in Section 4. In Section 5, an experiment is implemented and discussed to verify our design.

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2. DESIGN

Figure 1 shows the front view of the absorber structure. It is a single-layer structure with a metallic ground on the back of the substrate. The metallic structure etched with rotational symmetry lines. Both the ground and structure are copper material. Dimensions of the structure are $p = 9.5$ mm, $s = 0.4$ mm, $w = 0.41$ mm, $L_0 = 9.4$ mm, $L_1 = 1.72$ mm, $L_2 = 1.45$ mm, $L_3 = 2.1$ mm, $L_4 = 2.9$ mm, $L_5 = 2.25$ mm, $L_6 = 3.05$ mm, $L_7 = 3.7$ mm, $L_8 = 4.5$ mm, $L_9 = 3.85$ mm. The FSS uses a FR4 substrate with relative permittivity of $\varepsilon_r = 4.3$, loss tangent of 0.025 and thickness of $h = 1.0$ mm.

We use the CST Microwave Studio to calculate its transmission and reflection characteristics. The four sides of the unit cell are set to be unit cell conditions. The single unit cell is excited by an incident plane wave with different incident angles and polarizations. Because of the metallic ground on the back of the substrate, the transmission is zero in the whole frequency range. Thus the reflection is the only factor to determine the absorption. Therefore, the absorption rate is calculated by $A(w) = 1 - R(w) = 1 - |S_{11}|^2$. Reflection and absorption rates of the triple-band absorber for electromagnetic wave normal incidence are shown in Figure 2. It can be seen from Figure 2 that three distinct absorption peaks are obtained at 4.76 GHz, 7.61 GHz and 10.84 GHz with the corresponding absorption rates of 96.7%, 97.8%, and 99.3%, respectively. The three reflection responses can be demonstrated by power loss density distribution diagrams shown in Figure 3. Figure 3 shows that

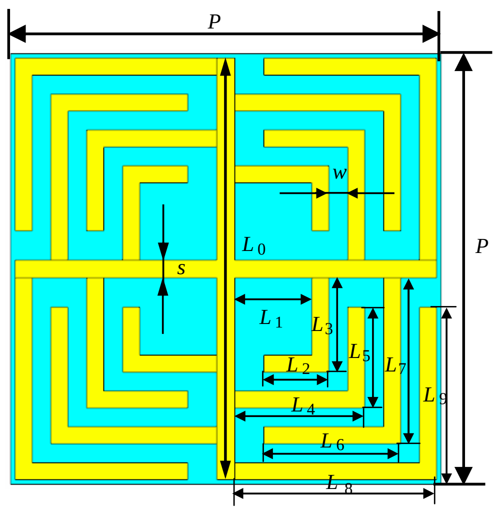

Figure 1. Geometrical configuration of the unit cell. The absorber is a single-layer structure with a metallic ground on the back of the substrate.

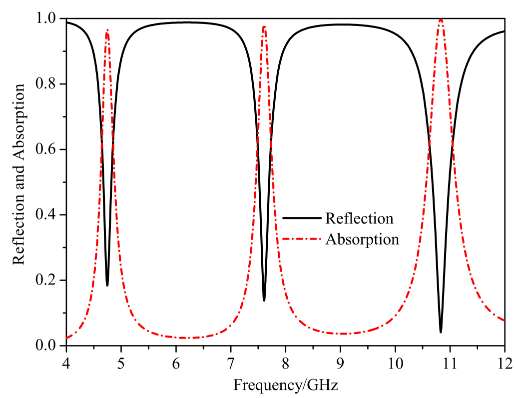

Figure 2. Simulated reflection and absorption rates of the triple-band absorber for electromagnetic wave normal incidence.

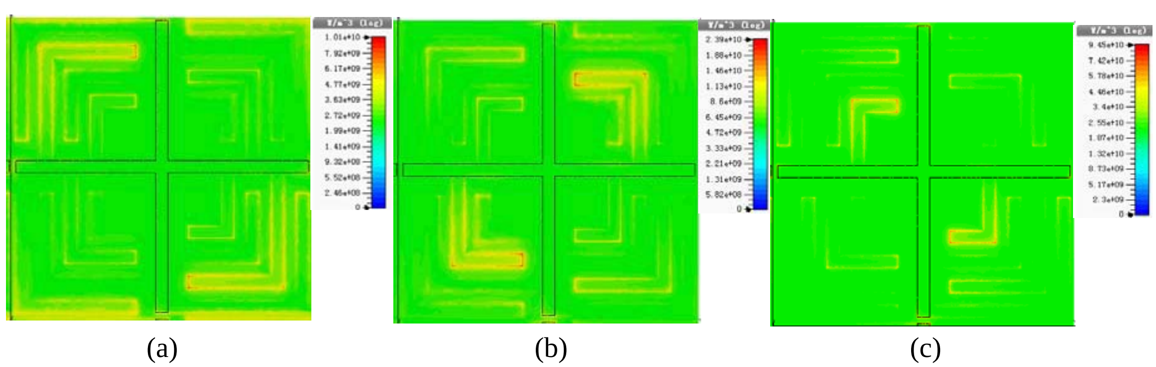

Figure 3. Power loss density distribution diagrams of the absorber at different frequencies. (a) 4.76 GHz, (b) 7.61 GHz, and (c) 10.84 GHz.

three resonances occur on the copper lines at their respective resonance frequencies on the metamaterial. Accordingly, the three absorption responses arise from enhanced absorption assisted by the metamaterial structure.

3. ABSORBER WITH STABLE PERFORMANCES

As an excellent absorber, it requires stable performance for both various incidence angles and different polarizations within its operating frequencies bands. Figure 4 and Figure 5 present the absorption rates under different incidence angles for TE polarization and TM polarization, respectively. It can be seen from Figure 4 and Figure 5 that the three absorption peaks are rather stable for various incident angles within 45 degrees and different polarizations. For TE polarizations, as incident angles increase the higher frequency, absorption peaks slightly shift to higher frequencies. For TM polarization, as incident angles increase the lower frequency, absorption peaks slightly shift to higher frequencies. And some absorption performance occurs in some frequency bands, but the absorption rates are very weak. Consequently, the tri-band absorber keeps good performances for various incidence angles within 45 degrees and different polarizations.

4. EXPERIMENT

An experiment was implemented to verify our design. The proposed absorber was fabricated using an FR4 substrate, whose permittivity is 4.3 and loss tangent 0.025. Figure 6 shows the prototype of

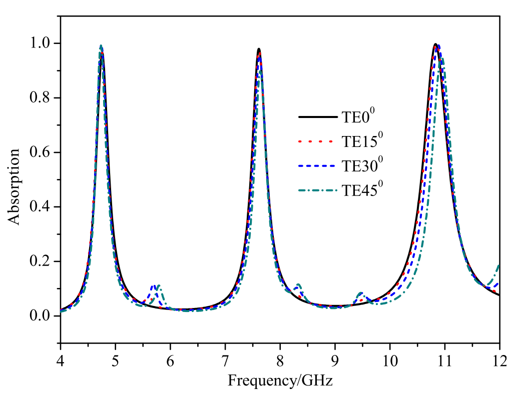

Figure 4. Absorption rates under different incidence angles and polarizations for TE polarization.

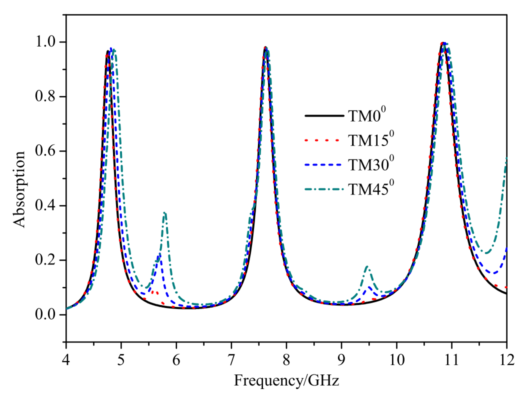

Figure 5. Absorption rates under different incidence angles and polarizations for TM polarization.

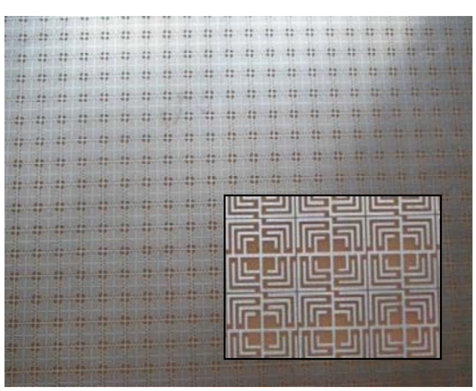

Figure 6. Sample of the fabricated absorber.

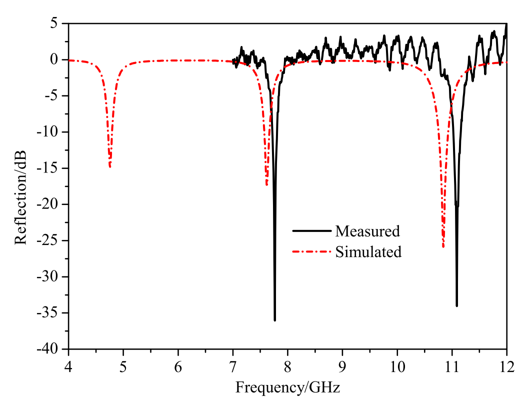

Figure 7. Experimental results versus simulation ones for normal incidence.

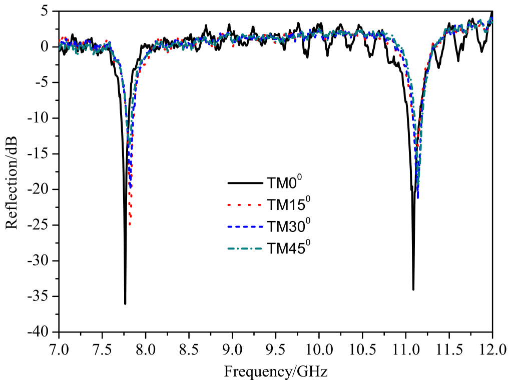

Figure 8. Measured reflection responses under TE polarizations and various incident angles.

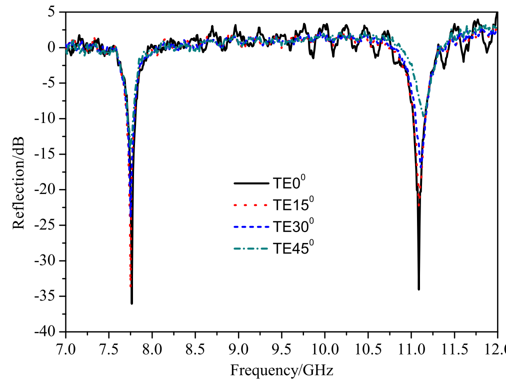

Figure 9. Measured reflection responses under TM polarizations and various incident angles.

the fabricated structure. It is made up of an array of 30×30 unit cells, so the overall size of the structure is $285 \times 285\,\text{mm}^2$. Free-space measurement system was used to take the experiment. Limited by the experimental equipment conditions, we did not find a pair of horn antennas operating at C-band. So we just give the measurement results from 7 GHz to 12 GHz. Figure 7 shows the experimental results versus simulation ones for normal incidence. It can be seen from Figure 7 that although the measurement results below 7 GHz are not given, the measurement results from 7 GHz to 12 GHz agree well with the simulation ones. Reflection curve shifts to higher frequencies, because the permittivity of the FR4 substrate used in the experiment may be lower than 4.3. Figure 8 and Figure 9 give the measured reflection responses under different polarizations and various incident angles. From Figure 8 and Figure 9 we can observe the stable performance for both various incidence angles and different polarizations within its operating frequencies bands. Measured results are not so perfect but can still prove our design.

5. CONCLUSION

In this paper, a tri-band electromagnetic absorber with insensitive properties is presented. The design process and relevant results are given and discussed. Experiments are carried out to verify our design. The proposed tri-band electromagnetic absorber has advantages of high absorption rates and stable performances. Such a tri-band electromagnetic absorber may have many potential applications in medical technologies, sensors, modulators, wireless communication, etc.

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