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MULTI-BAND AND POLARIZATION INSENSITIVE METAMATERIAL ABSORBER

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Abstract—The design and realization of a multi-band and polarization insensitive metamaterial absorber is presented. The structure with thickness 1.1 mm consists of six close rings which distribute in two metallic layers separated by FR4 fiber glass PCB substrates. Experimental results show that over 93.3% absorption can be achieved in this metamaterial absorber at multiple frequency bands (more than two). Due to the rotational symmetric pattern of the metamaterial, the performance of the absorber is insensitive to the polarization of the incident waves, indicating the superiority of the structure in the application.

1. INTRODUCTION

Metamaterials [1–25] have been used to design absorber structure for many years. It utilized artificial structures with the dimensions much smaller than the working wavelength to get a high absorption. Owing to its absorption properties, metamaterial absorbers were achieved in the microwave region [4–10], terahertz region [11–15], and visible frequencies [16–19]. The performance of the metamaterial absorber, in particular the bandwidth and the sensitivity to the polarization of the incident wave, has attracted more and more attentions. Dual band metamaterial absorber was presented in [4] with an absorption of 90% in the lower frequency band and an absorption of 92% in the higher frequency band. The bandwidth of the absorber was also improved in Ref. [11, 12] with numerical confirmation. However, the performance of the metamaterial absorber, e.g., the bandwidth and the sensitivity to the incident electric polarization, are still calling for improvement.

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In this paper, we proposed a metamaterial absorber design utilizing multilayered metamaterial structures to improve the performance of the absorber. The metamaterial absorber is composed of six close rings distributed in two metallic layers separated by FR4 substrates, with the total thickness of the absorber 1/20 times smaller than the working wavelength. Both numerical simulation and experiment measurements are carried out, showing that the proposed structure yields over 93.3% absorption at three frequency bands. The performance is also independent of the polarization of the incidence waves.

2. METHODS AND ABSORBER DESIGN

From the absorption formula $A(\omega) = 1 - T(\omega) - R(\omega)$, where the frequency dependent parameters, $A(\omega)$, $T(\omega)$ and $R(\omega)$, denote the absorption, the transmission and the reflection, respectively, we can see that, if we want to get the perfect absorption, i.e., $A(\omega) = 1$, we should make both $T(\omega)$ and $R(\omega)$ equal to 0. However, it is much difficult to get the two parameters to be 0 simultaneously. To simplify the design, here we adopt a ground plane which filled with copper to make sure that the transmission is 0 during the whole simulation and experiment measurement. Therefore, we only need to minimize the reflection in the absorber design.

Based on the considerations upwards, we proposed a multilayered metamaterial absorber shown in Fig. 1. The structure consists of three different copper layers and two dielectric layers, as shown in Fig. 1(b). The periodicity of the unit cell is 9.0 mm × 9.0 mm in the xy plane. On the top and the center copper layer, there are three square copper rings with width 0.2 mm. The dimensions of the square rings in the top layer are 8.0 mm, 5.6 mm and 3.4 mm, respectively, the dimensions of the square rings in the center layer are 7.0 mm, 5.0 mm and 2.4 mm, respectively. The bottom layer is filled with copper. The copper layers are printed on the dielectric layers, which are FR4 fiber glass PCB substrate with thickness 0.5 mm, respectively. All the copper layers have the thickness 0.035 mm. The thickness of the whole structure is around 1.1 mm.

3. SIMULATION AND EXPERIMENTAL RESULTS

Figure 2(a) shows the setup of the experiment. Two horn antennas are used as transmitter and receiver. The test sample has a dimension of 180 mm × 180 mm and includes 200 units. An R&S ZVB network analyzer connecting the transmitter and the receiver horn is used to record the measured S parameters. The experiment measurement is

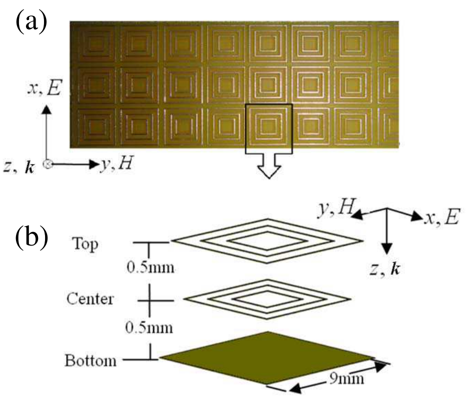

Figure 1. (a) Top view of the proposed structure. (b) A bird view of the unit cell from the top layer to the bottom layer.

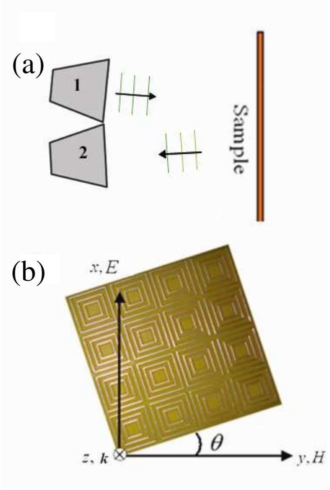

Figure 2. (a) The experiment setup, horn 1 is the transmitter and horn 2 is the receiver. (b) The parameter θ denotes the angle between the bottom side of the sample and y-axis.

carried out in three steps: Step I: we measured a ground copper plane with the dimension the same as the sample [22], we record S_{21} and use the result as measurement reference; Step II: we measured the sample of the metamaterial absorber and record the S_{21} parameters; Step III: we repeat Steps I and II but with different polarization of the incident waves. In this step, suppose θ is the angle between the bottom side of the sample and y axis, as depicted in Fig. 2(b), we change the value of θ by rotating the sample around the z axis to study the polarization sensitivity of the metamaterial absorber.

The experimental results for $\theta = 0°$ are shown in Fig. 3, where numerical simulation results carried out from the Microwave CST studio [21] are also shown for comparison. We see that the absorption peaks appear at 4.76 GHz, 8.65 GHz and 13.55 GHz. From the results, we can calculate out the absorbance are 93.3%, 93.6%, 94.9%. The three absorptions are at C, X, and Ku bands, respectively. In other frequency ranges not shown in the figure, the absorptions are close to 0 dB. There is a systematic shift between these values in all three bands for the reason of slightly discrepancy of the thickness

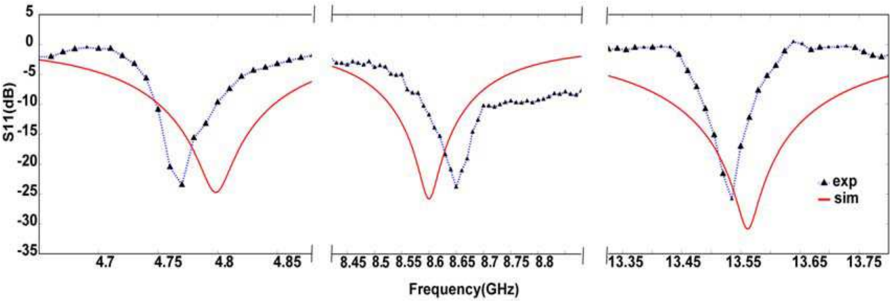

Figure 3. Numerical and experimental measured reflection coefficients of the metamaterial absorber for vertical polarization wave ($\theta = 0°$).

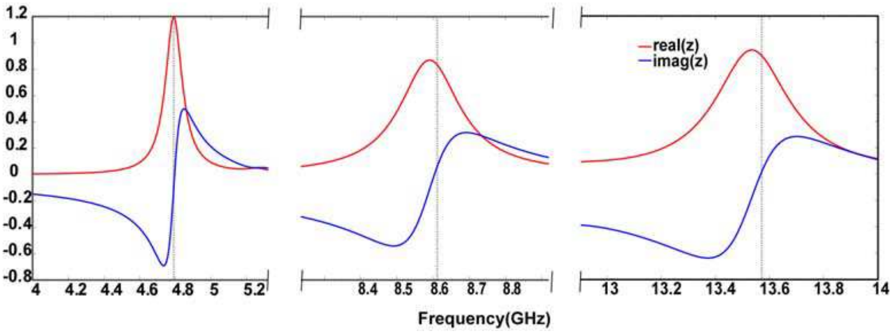

Figure 4. The real part and the imagine part of the retrieved impedance, Z, from the numerical simulation data. The dashed vertical lines represent the frequencies at which the absorption reaches the maximum in the three frequency bands.

between the simulation and experimental sample. In addition, due to the background noise, the simulation peaks are symmetric while experimental peaks are not, especially for high-frequency band.

Figure 4 shows the retrieved effective impedance of the metamaterial absorber using the retrieval algorithm [20]. We can see that at the three points which displayed nearly perfect absorption, the proposed metamaterial sample exhibits impedance nearly matched to the free space. The impedance matched to free space ensures the reflection of the incident wave at the interface between the free space and the metamaterial to be small. In addition, as there is no transmission ($S_{21} = 0$) because of the conducting plane in the bottom layer, the incident wave should be totally absorbed by the metamaterial absorber, indicating that the imaginary part of the refractive index

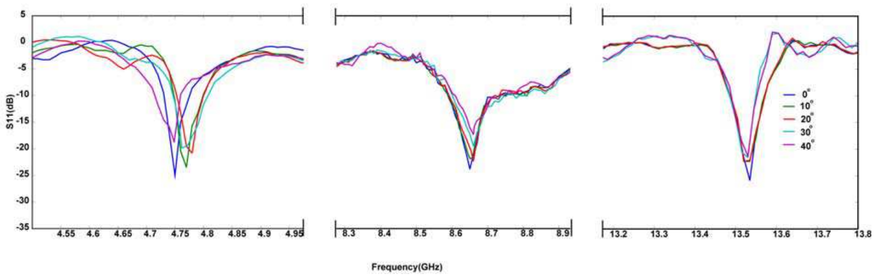

Figure 5. Measured reflection coefficients of the metamaterial absorber for different polarizations of the incident wave.

should be very large. The effective refractive index of the metamaterial absorber cannot be accurately obtained by the retrieval algorithm as S_{21} is zero for all the frequency bands [20]. But we roughly see it from the relation of the refractive index with the scattering parameters [20], i.e., $e^{ink_0d} = S_{21}/(1 - S_{11}\frac{Z-1}{Z+1})$. We can see that in order to make the right side of the equation to be zero, the imaginary part of the refractive index should be very large. The large imaginary part of the refractive index ensures that the wave significantly attenuates as propagating inside of the sample.

Due to the symmetric pattern of the closed rings, the metamaterial absorber is almost insensitive to the polarizations of the incident wave. Fig. 5 shows the performance of the metamaterial absorber for different polarizations of the incident wave. We can see that, with θ change from $0°$ to $40°$ (the measurement for θ from $50°$ to $90°$ is same to that from $0°$ to $40°$ due to the rotational symmetric of the closed rings), the absorption frequency only shift 0.8% and the absorptions are all lower than 15 dB, reflecting the insensitiveness of the metamaterial absorber to the wave polarizations.

4. CONCLUSION

In conclusion, we present a metamaterial absorber that works at multiple frequency bands. It is achieved by fabricating six closed rings on a multiple layered dielectric substrate system. Due to the symmetric pattern of the closed rings, the metamaterial absorber is insensitive to the polarizations of the incident wave. The multiple working frequencies and the polarization-insensitive property, indicates the superiority of the structure in the application.

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