RESEARCH ARTICLE

Design of Broadband Metamaterial-Based Ferromagnetic Absorber

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Abstract: In this paper, a metamaterial-based ferromagnetic absorber has been designed at microwave frequencies. The proposed absorber is composed of a periodic array of stacked circular ferromagnetic patches fabricated on the FR4 substrate. With the ferromagnetic property, the single-layer patch array generates a good resonant absorption mode. By stacking multiple ferromagnetic patches, the designed absorber with the absorption above 90% has a wide absorption bandwidth from 10 to 21 GHz. Due to the symmetric structure, the proposed absorber is polarization insensitive. At oblique incident with the incident angle of 45o, the good absorption more than 80% can be achieved in the whole operation band.

Keywords: Ferromagnetic; Metamaterial; Absorber; Broadband; Polarization Insensitive

1. Introduction

With rapid development of metamaterials, metamaterial-based absorbers[1] have caused increasing attentions in scientific community. Metamaterial-based absorbers are artificial composite structures that effectively absorb electromagnetic energy, which have various potential applications in radar cross section (RCS) reduction, sensors and emitters, etc. In 2008, Landy *et al*. proposed a thin metamaterial absorber made of metal-dielectric composite[2]. With electric and magnetic resonances, the absorber can absorb the incident wave without reflections, thus leading to a near perfect absorption characteristic. Since then, various absorbers have been designed from microwave to optics. Much efforts have been made on the design of metamaterial-based absorbers with wideband/multiband, polarization insensitive, wide incident angle, and tunable characteristics. By adopting multi-resonance metamaterial unit cells, the absorbers possess multiple narrow absorption bands[3,4]. The wideband absorbers have been achieved by stacking multiple resonating structures with gradually changed topology[5,6]. Introduction of lossy materials into the design of the absorbers, for instance indium tin oxide films[7], lumped resistors[8–11], etc., broadens the absorption band. Some tunable components and materials including diodes[12], microelectromechanical system[13], and graphene[14] are used for the design of tunable absorbers in microwave and terahertz frequencies.

In this paper, a metamaterial absorber with wideband and wide-angle polarization-insensitive characteristics has been designed. The metamaterial unit cell is composed of the stacked circular ferromagnetic patches fabricated on the FR4 substrate. The ferromagnetic circular patch generates a good resonance absorption mode. By stacking ferromagnetic patches with different sizes into a multilayer structure, the multiple resonance frequencies are overlapped, and thus the wideband absorption characteristic is achieved. Simulated results are given to show a good absorptivity over 90% from 10 to 21 GHz.

2. Design of metamaterial-based absorber

As shown in **Figure 1**, the proposed absorber consists of a periodic array of 8-layer circular ferromagnetic patches.

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The periodicity and thickness of the proposed metamaterial unit cell are 5.6 mm and 1.78 mm, respectively. Every two adjacent ferromagnetic patches are separated by a FR4 dielectric with relative permittivity of 4.4, loss tangent of 0.02, and thickness of 0.2 mm. The relative permeability and conductivity of each ferromagnetic patch are 4000 and 1.03×10^{7} S/m, respectively. The radiuses of 8 circular patches are 2.6 mm, 2.4 mm, 1.9 mm, 1.8 mm, 1.7 mm, 1.6 mm, 1.5 mm, 1.6 mm from the top to the bottom, and the thickness of each patch is 0.02 mm. There is a circular hole etched on each patch. The radiuses of the corresponding circular holes from the top to the bottom are 0.7 mm, 0.7 mm, 0.7 mm, 0.7 mm, 0.7 mm, 0.9 mm, 0.7 mm, 0.3 mm. A ferromagnetic metallic ground with a thickness of 0.02 mm is used.

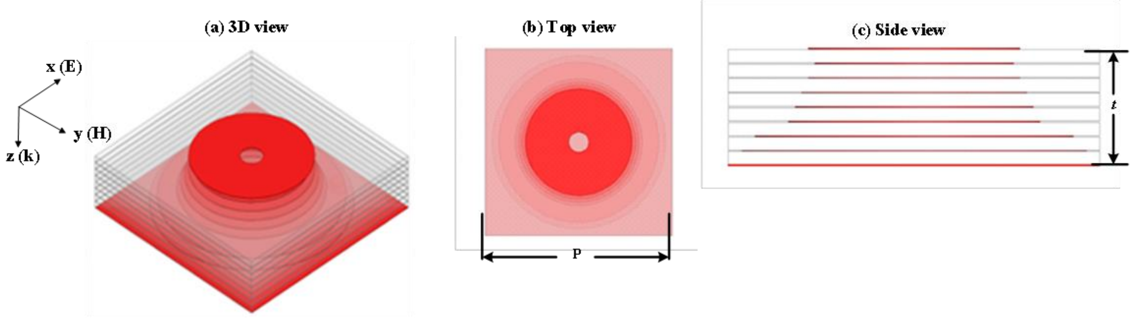


Figure 1; The proposed metamaterial absorber unit cell**.**

The absorbance of the proposed absorber is calculated from the scattering parameters as $A=1-|S_{11}|^2-|S_{12}|^2$. Due to the use of metallic ground, we have $|S_{12}|=0$, and thus the absorbance is reduced to $A=1-|S_{11}|^2$. To maximize the absorbance of the absorber, the reflection is minimized. A commercial finite-element solver is used, and the periodic boundary conditions and the Floquet ports are employed to simulate the infinite periodic cells. **Figure 2** shows the absorption of the proposed absorber at normal incidence. It can be seen that the absorbing bandwidth with an absorption above 90% covers a wide frequency range from 10 to 21 GHz.

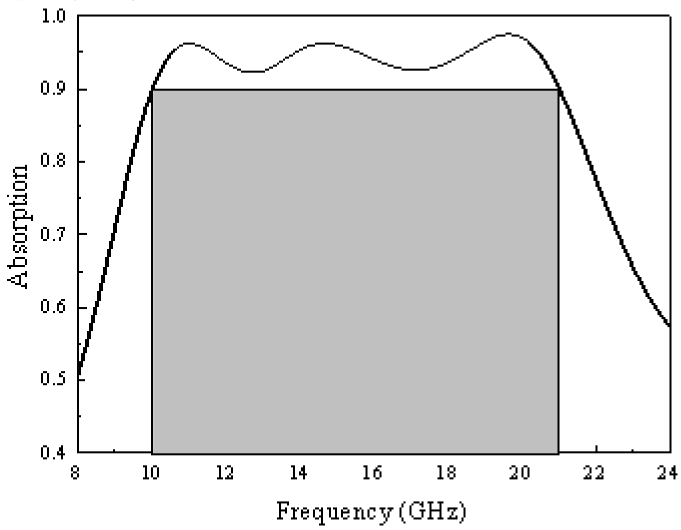


Figure 2; Absorption of the metamaterial absorber at normal incidence**.**

To understand the absorbing behavior of the proposed absorber, consider a single-layer circular ferromagnetic patch array fabricated on a FR4 substrate, as shown in **Figure 3.** The thickness of the single-layer structure is 0.6 mm, and inner and outer radiuses of the patch are 0.6 mm and 2.7 mm, respectively. It can be seen from **Figure 4** that the single-layer absorber possesses a resonance absorption mode, and the absorption band corresponding to the absorption larger than 90% covers 10.73-11.86 GHz. As the outer radius of the patch increases, the corresponding absorption band moves towards lower frequencies, as shown in **Figure 5**. Hence when the multiple ferromagnetic patches with gradually changed sizes are stacked, the multiple resonance absorption modes can be overlapped to generate a wide absorption band. **Figure 6** shows surface current distributions of the proposed absorber at some frequencies. It can be seen that at higher frequencies, the ferromagnetic patches at the upper layers become resonant. With the decrease of the frequencies, strong resonant currents move towards the lower layers. Due to slow variation of the adjacent patch sizes in the stacked structure, the resonant current is not localized on a single patch but diffuses into several neighboring patches. Further, the equivalent impedance of the proposed absorber is calculated as $Z_{in} = \eta_0 (1+S_{11})/(1-S_{11})$. According to **Figure 7**, we can observe that the equivalent impedance can be well matched to the free space impedance η_0 in a wide frequency band, which means that the electromagnetic wave can enter into the absorber without reflection. Note that the whole height of the proposed absorber is only 0.1246λ_{min} (λ_{min} is free space wavelength at 21 GHz), despite a stacked structure.

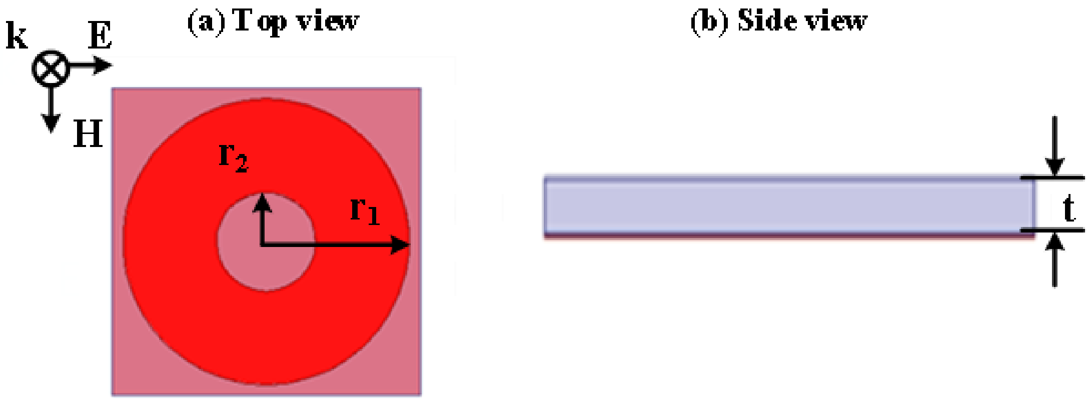


Figure 3; A single-layer circular ferromagnetic patch array.

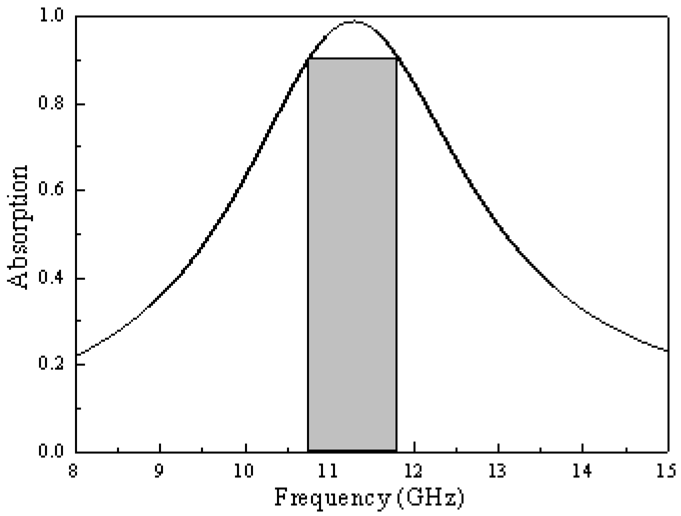


Figure 4; Absorption of the single-layer absorber.

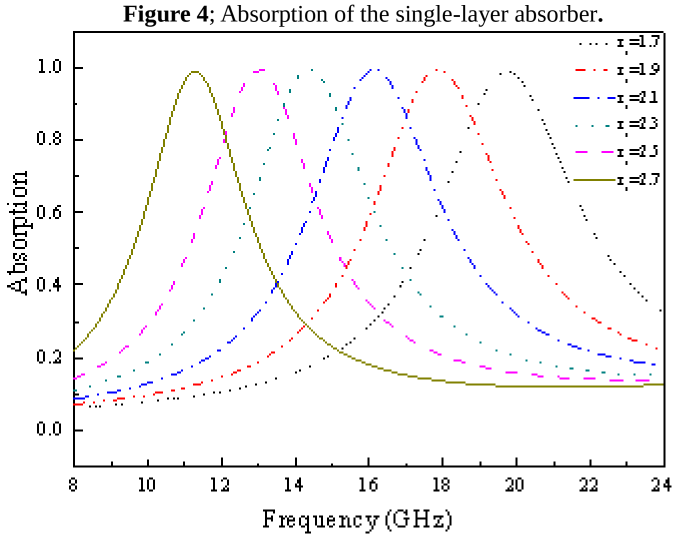


Figure 5; Variation of absorption with outer radius of the single-layer absorber.

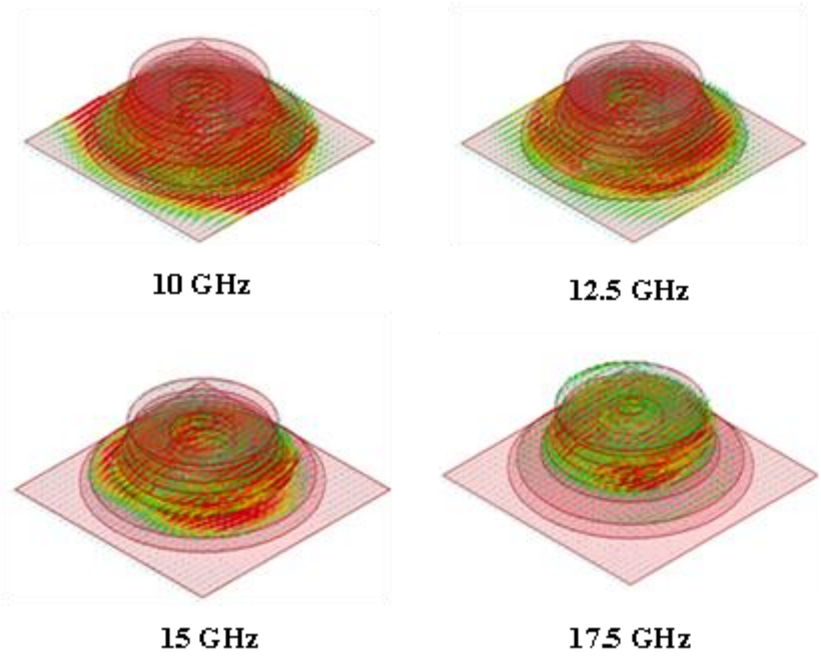


Figure 6; Surface current distribution of the proposed absorber**.**

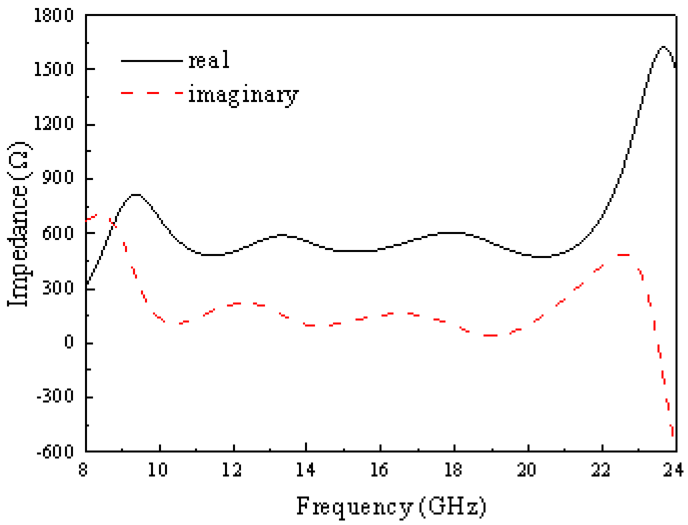
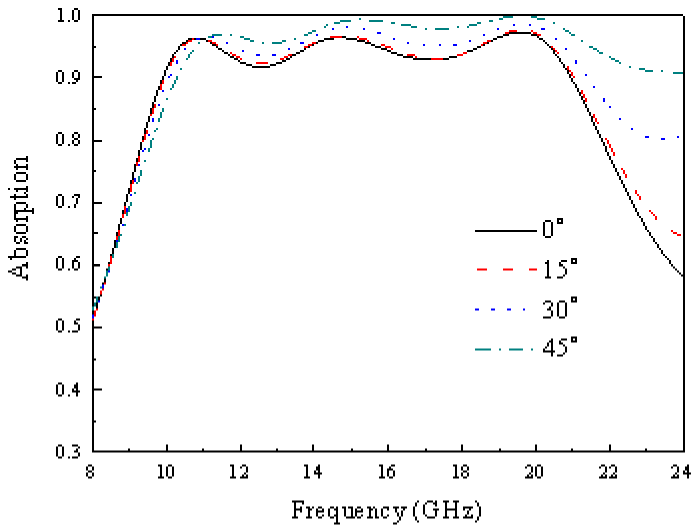


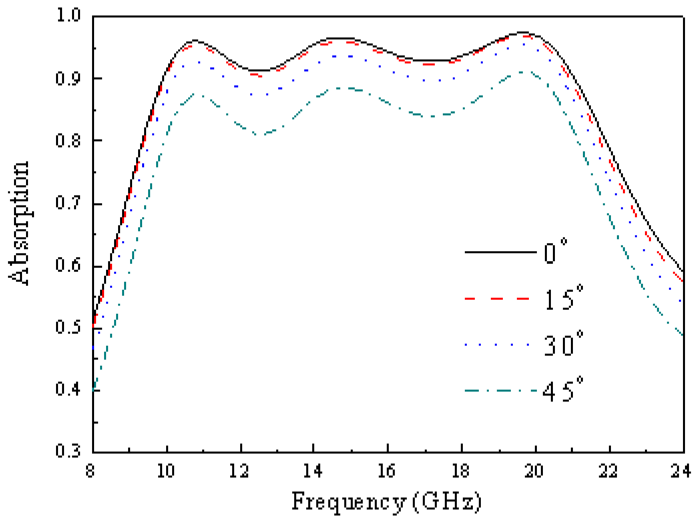
Figure 7; Equivalent impedance of the proposed absorber**.**

3. Numerical results and discussions

The polarization and angular dependences of the proposed absorber are discussed. Due to the symmetric structure, the absorbing characteristic of the designed absorber is independent of the polarization angles (φ). On the other hand, when an oblique incident angle (θ) of transverse magnetic (TM) polarized waves varies from 0° to 45°, the absorbing frequency band corresponding to the absorption better than 90% keeps unchanged, as shown in **Figure 8.** For transverse electric (TE) polarized case, the absorption decreases with the increase of θ in the whole band covering 10-21 GHz. When θ=45°, the absorption of the proposed absorber is larger than 80%.



(a)



(b)

Figure 8; Absorption of the metamaterial absorber. (a) TM polarized oblique incidence; (b) TE polarized oblique incidence**.**

In order to study effect of the ferromagnetic material on the absorbing performance, we consider some following scenarios. The first case is that the FR4 substrate in the proposed absorber is replaced by a lossless substrate with same permittivity. As shown in **Figure 9**, the absorption bands for the FR4 and lossless substrates are nearly same, which means that the absorbing characteristic of the proposed absorber is unrelated to the loss of the FR4 substrate. In the second case, all ferromagnetic patches in the proposed absorber are replaced by the perfectly electric conductors (PEC). It can be seen from **Figure 10** that the absorbing characteristic disappears for the PEC patch case. It means that the absorbing characteristic of the proposed absorber depends on the ferromagnetic patches. In the third case, all ferromagnetic patches in the proposed absorber are replaced by nonmagnetic metal patches with the same conductivity. We can observe from **Figure 11** that the absorbing structure composed of the nonmagnetic metal patches cannot absorb electromagnetic waves. Hence, the absorbing performance of the proposed absorber is due to the ferromagnetic characteristic of the patches.

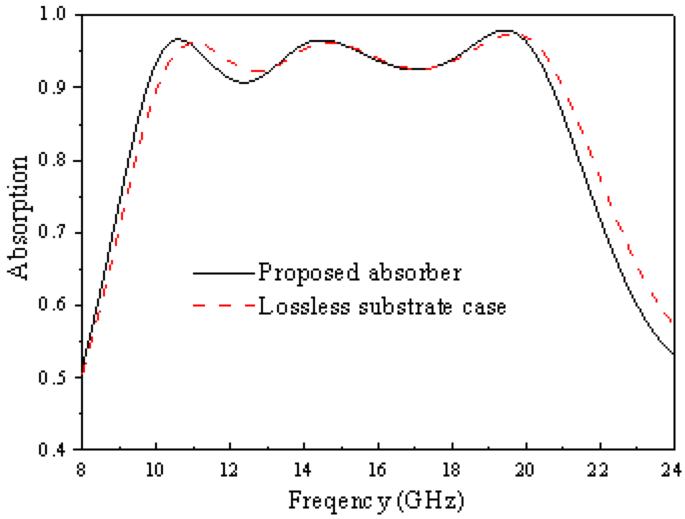


Figure 9; Absorption comparison between the proposed absorber and lossless substrate case**.**

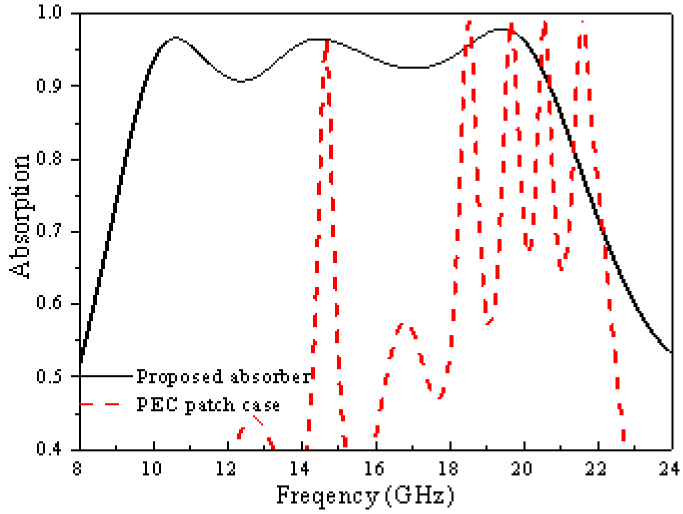


Figure 10; Absorption comparison between the proposed absorber and PEC patch case**.**

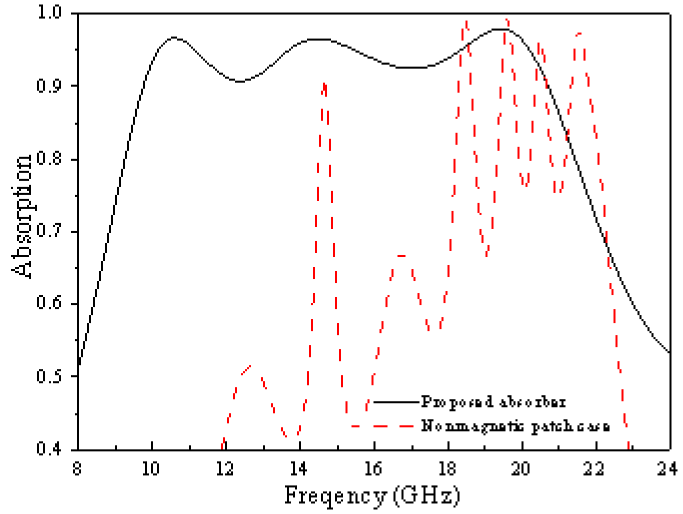


Figure 11; Absorption comparison between the proposed absorber and nonmagnetic patch case**.**

4. Conclusion

In this work, a broadband metamaterial absorber has been designed. With the use of the ferromagnetic patch, the good resonant absorption mode is generated. By stacking multiple ferromagnetic patches with gradually changed sizes, a wide absorbing band is achieved by overlapping multiple resonant absorption modes. Due to the symmetric structure, the proposed absorber has the wide-angle polarization-insensitive characteristics. Simulation results are given to demonstrate the wide absorption band from 10 to 21 GHz with the absorption better than 90%.

Acknowledgement

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