Broadband and Tunable Active Microwave Absorbing Element

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Abstract. In this paper, a new type of electrically tuned microwave absorbing material working in microwave band is proposed. The metamaterial unit consists of composed three layers of metal and two dielectric substrates spaced apart like a sandwich structure. The varactor diodes and lumped element are embedded as active circuit components in slots of the top metal patch. By adjusting the bias voltage of the varactor diodes, the absorption band can be adjusted, that is to say, the absorption frequency can be reconfigured. The active absorbing material has great application potential and lays a foundation for the next generation of intelligent absorbing materials.

1. Introduction

With the development of metamaterials and metasurface technologies, traditional communication devices combined with them have achieved great achievements, such as reflectarrays, perfect lenses, digitally encoded antennas and absorbing materials [1-6]. In recent years, with the appearance of "invisibility cloak", the design and analysis of active microwave absorber has attracted more and more attention because of its potential to produce so-called “Perfect Absorbing Materials”. In addition, with the miniaturization and integration of electrical equipment, compact and controllable absorbing materials become an urgent problem to be solved. So far, many tunable absorbing materials have been successfully realized by mechanical or electronic means. H. Y. Zheng et al [3] designed a tunable dual-band perfect absorber based on extraordinary optical-transmission (EOT) effect and Fabry-Perot cavity resonance. They can switch a single-band absorber to a dual-band absorber by changing the distance between two metallic layers and/or incident angle. In [4], exploited the metamaterial properties of a thick metallic grating with extreme sub-wavelength slits on a metallic slab to achieve complete absorption of transverse magnetic polarized microwaves.

Then, metamaterial and metasurface electrically tunable microwave absorbing materials are proposed. Heijun Jeong and Sungjoon Lim [6] loaded PIN diodes on the ground of the metamaterial, and by adjusting the bias voltage load on the diodes, the proposed SGP can switch the absorption frequency bands. However, the PIN diodes have only a limited adjustment state, and the varactor diode can be adjusted for greater flexibility.
In this paper, we propose a frequency reconfigurable metamaterial absorber using a novel harmonizable patch. The varactor diodes and lumped elements are embedded in slots of the top metal patch. By adjusting the bias voltage of the varactor diodes, the absorption frequency can be reconfigured. The active absorbing material has great application potential and lays a foundation for the next generation of intelligent absorbing materials. This paper is organized as follows. In section II, the structure of active microwave absorbing metamaterial (AMAM) unit is presented, operational principle of tuning the absorption bandwidth of an incident LP wave is proposed and the simulation results are described. Finally, the paper is concluded in Section III.

2. Design and analyses

2.1. Structure of the AMAM unit

The unit of the proposed AMAM is illustrated in Fig. 1. The 3-D topology view is shown in Figure 1(a), which consists of three metal layers, varactor diodes, and two dielectric layers. These metal layers are composed of a metal ground on the back of the dielectric slab and two patches. Two identical metal patches are internally slotted hexagons, like metal grids. Here, the directions of the inner grooves of the upper and lower metal patches are different by 120°. The varactor diodes and the lumped elements are respectively mounted inside the groove of the upper patch. And the lumped components contain resistors with R=10Ω and inductors with C=0.5nF.

The top view and side view of the AMAM element is depicted in Figure 1(b). By optimization, the geometric parameters of the unit element are as follows: the hexagonal patch with edge length L1=8mm. The slots of patches with width g1=0.5mm. The thickness and edge length of the both F4B substrates are t=2.5mm and W=17mm. In addition, the length and width of the metal floor are as large as the length and width of the dielectric substrate, respectively.

In this study, MACOM MAVR-000120-1141 is employed as the varactor diode in this paper [7]. The capacitance value of a varactor diode changes with the bias voltage across it, and the two approximate a linear function relationship. For different voltages, the capacitance of the varactor varies from 0.1pF to 1pF. This diode operates up to 70G Frequency band and has a high quality factor, making it ideal for this study.

2.2. Analysis and simulation results

When the incident electromagnetic wave is LP wave with the electric field in the y-direction and travels toward z-direction. The entire active metamaterial unit can be regarded as an LC resonant structure. The specific model diagram is shown in Figure 2. The metamaterial coupling behavior is further discussed in the microwave field by employing well-known LC theory. We use frequency-dependent impedance to describe the electromagnetic characteristics of all components. The impedance expression of the metamaterial element is as follows:

\[ Z(w) = \frac{1}{jwC_e + \frac{1}{R_e + jwL_e + 1/jwC_1}} \]

(1)

where \( C_e \), \( R_e \) and \( L_e \) denote the total capacitance, resistance and inductance of the metamaterial unit, respectively. Based on this formula, we can quantitatively analyze the relationship of our absorber’s behavior with the inserted diode and lumped element. Furthermore, the resonant frequency of the metamaterial element can be obtained by the impedance. It should be noted that the resistance and inductance loaded on the unit are also used to adjust the LC resonance characteristics of the unit.
Figure 1. Structure of the proposed AMAM unit cell (a) 3-D topology structure. (b) top view and side view.

To verify the design functionality and explore the absorbing properties of the AMAM, the HFSS 15.0 is used to analyze and optimize the proposed element. We use the unit cell demonstrated in Figure 2 and appropriate perfect electric on yz-plane and perfect magnetic on xz-plane to imitate the actual sample. For simplification, the inserted diodes are replaced by pure capacitance and resistance. Simulations produce the reflection coefficient by individually sweeping the value of the capacitance and resistance to mimic the actual electrical control of the diodes.

Figure 2. Equivalent resonant circuit of the AMAM element.

Figure 3. Relationship between absorbing properties of active metamaterial absorber and thickness of dielectric substrate.
Measuring the absorbing performance with a -10dB bandwidth. As shown in Figure 3, the reflection coefficient of the unit varies with the thickness of the single-layer dielectric substrate, and as the thickness of the dielectric substrate becomes larger, the reflection coefficient becomes smaller. It can be seen from the figure that when the thickness of the single-layer substrate is greater than 2.48 mm, the influence of the thickness of the substrate on the absorbing ability of the metamaterial is negligible. Here, in order to make the material thinner and lighter, the thickness of the substrate is set to 2.56 mm.

As shown in Figure 4, the absorbing frequency bandwidth of the metamaterial unit is related to the capacitance value of the varactor. Figure 4(a) shows that the two diodes change simultaneously, that means the two diodes are biased with the same power supply. As shown in the figure, as the capacitance value of the varactor changes, the absorbing frequency band of the metamaterial changes correspondingly. When the capacitance value becomes larger, the absorption frequency band is narrowed. Absorbing material can adjust the absorption band, effectively. Figure 4(b) and Figure 4(c) show the reflection coefficient of the metamaterial element when only a varactor is adjusted. Here, the absorbing properties of the cell are different when the capacitance values of the two diodes are different. In addition, it is found from the figures that the absorbing sensitivity of the metamaterial can be adjusted by adjusting the configuration of the diodes capacitance values.

![Figure 4](image)

*Figure 4. The relationship between the absorption frequency bandwidth of the absorber and the capacitance value of diode. (a) The absorption frequency bandwidth when the diodes change simultaneously. (b) Absorbance frequency bandwidth when the capacitance of one diode is C=0.4pF and the other diode’s capacitance is changed. (c) Absorbance frequency bandwidth when the capacitance of one diode is C=0.7pF and the other diode’s capacitance is changed.*

3. Conclusion

In this paper, a new type of electrically tuned microwave absorbing material working in microwave band is proposed. When the capacitance values of the two varactors are simultaneously adjusted, the reconfigurable absorbing frequency bandwidth can be achieved. When the capacitance values of the two diodes are separately adjusted, the sensitivity of the absorbing material can be adjusted. Compared with the traditional absorbing materials, this material has more flexible absorbing properties, small size and light weight, and has great application potential in the field of electromagnetic compatibility of electrical equipment.

Acknowledgments

This work was supported by the Economic and Electrical Research Institute of Shanxi Electrical Power Company of SGCC.

References

[1] N. I. Landy et al, “Perfect Metamaterial Absorber,” Phys. Rev. Lett. 100 (2008) 207402.
[2] X. Wu, C. Hu, Y. Wang, et al., “Active microwave absorber with the dual-ability of dividable modulation in absorbing intensity and frequency,” AIP Advances, 3 (2013) 022114.

[3] H. Y. Zheng et al, “Tunable dual-band perfect absorbers based on extraordinary optical transmission and Fabry-Perot cavity resonance,” Optics Express, Volume 20, Issue 21, pp. 24002–24009, Oct. 2012.

[4] N. Mattiucci et al, “Tunable, narrow-band, all-metallic microwave absorber,” Appl. Phys. Lett., 101 (2012) 141115.

[5] V.F. Fusco et al, “Ultra-thin tunable microwave absorber using liquid crystals,” Electron. Lett., 44 (2008) 37-38.

[6] H Jeong, S. Lim, “Broadband frequency-reconfigurable metamaterial absorber using switchable ground plane,” Scientific Reports, 8 (2018) 9226.

[7] Mouser Electronics. Skyworks Solutions, Inc. MAVR-000120-1141 Varactor Diode Data.