Analysis and Design of Multi-band Absorber with Periodic Three-dimensional Square Ring Units

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Abstract— Multi-band electromagnetic (EM) wave absorbers have attracted considerable attention due to their wide practical applications such as antenna, stealth, and EM compatibility. In this paper, we present the simulation, implementation, and measurement of a unconventional multi-band metamaterial absorber, which appears as a cube and is composed of square ring resistive sheets with a metal plane laid at the bottom of the structure. The simulation and experiment results show that the proposed structure can eliminate the total reflection of planer structure and excite multi-resonant peaks at the same time. The proposed EM absorber could exhibits a promising and flexible method to control the propagation of the EM wave and to extend the absorption bandwidth greatly.

1. INTRODUCTION

Since N. I. Landy et al. proposed a perfect metamaterial absorber (MA) composed of electric resonators and cut wires, the researchers have shown extreme interest in the design of absorbers with nearly perfect absorption by means of using artificial electromagnetic metamaterials [1]. A great deal of efforts and works have been devoted to this field. But most of them focus on design an planer absorber exhibiting excellent performance with single-band or multi-band [2–4] and there is little information available in literatures about 3D multi-band absorbers [5, 6]. Especially, in the case of a absorber with a polyurethane foam substrate, the total reflect will occur at some frequencies for the reason that the thickness of the structure and the operating wavelength are equal.

Aiming at the above problems, the goal of this paper is thus to propose a novel multi-band metamaterial absorber, which appears as a cube and is composed of square ring resistive sheets with a metal plane laid at the bottom of the structure. By both numerical simulations and experimental measurements, the proposed structure eliminates the total reflection of planer structure quite well. Nearly perfect absorption can be achieved at resonant frequencies. The result demonstrated that the EM absorber could exhibits a promising and flexible method to control the propagation of the EM wave and to extend the absorption bandwidth greatly. Although the modeling and experiments are done in microwave frequencies, the absorber can be easily scaled to find applications at higher frequency regimes.

2. DESIGN AND SIMULATION

The proposed 3D multi-band metamaterial structure is shown in Fig. 1. Consider a uniform plane wave with $\vec{E}$ along the positive direction of y axis normally incident on the cubic absorber.

The absorbance can be expressed as: $A = 1 - |S_{11}|^2 - |S_{21}|^2$, where $S_{11} = \frac{Z-1}{Z+1}$ is the reflectivity and $Z = \sqrt{\frac{\mu_r}{\varepsilon_r}}$ is the characteristic impedance of the cube. In the expression of Z, ε_r and μ_r are the effective relative permittivity and permeability of the whole structure respectively.

Since the ground plane of the structure is metal the transmission coefficient S_{21} will be zero. Thus, the expression of A will become $A = 1 - |S_{11}|^2$. And the absorbance can be maximized by reducing the reflection from the structure.

In order to investigate the performance of the cube absorber in microwave region a full-wave electromagnetic simulation has been performed with a help of CST Studio Suite 2011. A unit cell boundary condition is set to calculate the reflective coefficient S_{11}. By parameters optimizing, the final geometric values of the cube are employed as $a_0 = 17$ mm, $a = 14$ mm, $w = 3.65$ mm, $R_{sq1} = 185\Omega/???$ and $R_{sq2} = 70\,\Omega/???$, respectively.

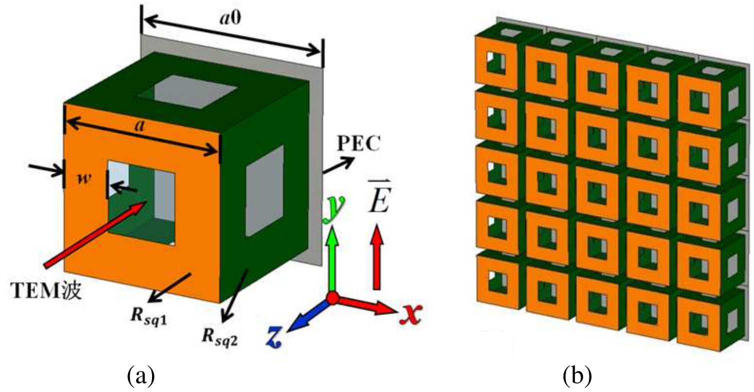


Figure 1: (a) One unit of the structure; (b) The 3D periodic array of the structure.

3. RESULTS AND ANALYSIS

According to the optimized model, the absorbance A is calculated by Microwave studio of CST Studio Suite 2011 and the result is shown in Fig. 2.

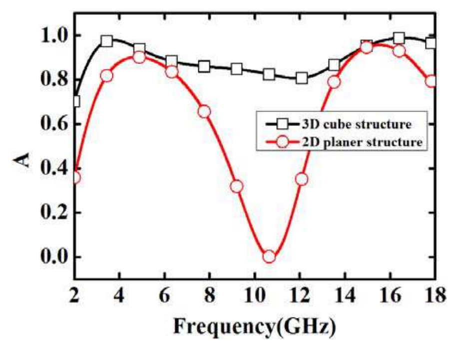


Figure 2: Result of simulation: A-1 is the absorbance of 3D cube structure and A-2 is the absorbance of corresponding planer having no lateral resistive sheets

In case of having no lateral resistive sheets of the cube, the structure will turn as a planar construction with a large thickness. When a uniform planer TEM wave irradiate on the surface of the structure, a total reflection, as shown in Fig. 2 will occur at 10.7 GHz for the reason that the thickness of the structure equals to half of the operating wavelength. However, if there are four resistive sheets printed on each side of the lateral surface, the total reflective peak at 10.7 GHz will be avoided since the interaction between these resistive sheets and the incident electromagnetic wave, as shown in Fig. 2. For 3D cube structure, the resonant peaks of planer structure at 4.8 GHz and 15.5 GHz shift to 3.7 GHz and 16.6 GHz. The absorbance is improved largely. The 90% absorbing bandwidth is from 2.7 GHz to 5.8 GHz and 14 GHz to 18 GHz. During almost the whole frequency range, from 2.5 GHz to 18 GHz, the absorbance is larger than 80%.

To gain a physical insight into the origin of the absorption peaks, electric field distribution in the absorbing structure at various resonant frequencies is obtained (see Fig. 3).

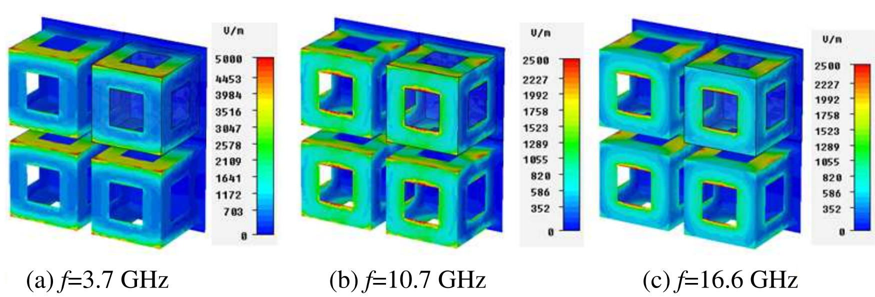
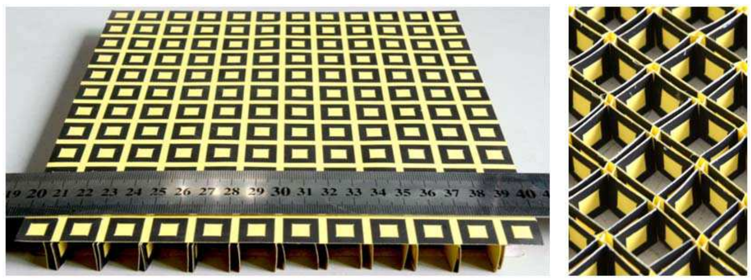


Figure 3: The electric field distribution of the proposed structure at different frequencies.

Benefiting from the loss of electric power by the square ring resistive sheets which are perpendicular to the metal plane, the total reflection of planer structure with thickness equaling to half of the operating wave length is eliminated quite well as shown in Fig. 3(b). In addition, due to the interreaction between the lateral square ring resistive sheets of the cube and the incident wave, the square ring resistive sheets near the top of the cube offers strong absorption for low frequency EM wave at 3.7 GHz while the ones near the bottom of the cube strongly absorb the high frequency EM waves at 16.6 GHz as shown in Figs. 3(a) and (c).

4. EXPERIMENTAL VERIFICATION

Based on the simulation setups, experiments have been also done to validate the absorption behavior of the proposed absorbing structures with a typical schematic photo shown in Fig. 4.



(a) (b)

Figure 4: The fabricated absorbing structure with resistive square ring: (a) plan view and (b) partial enlarged view of the resistive sheets perpendicular to PEC.

The resistive sheet of the structure is produced by silk screen printing technology and the total dimension is 200 mm $*$ 200 mm. Before test, the surface resistance of the resistive sheet is measured with a four-point resistivity test system and the results show that there is a reasonable resistance error (about $\pm 10\%$) between the simulation requirement and the practical printing.

Finally, the absorbance of the proposed absorber is measured. The result dovetailed quite well is shown in Fig. 5 compared with simulation. Two absorbing peaks are obtained at 3 GHz and 14 GHz, while the total reflective peak is restrained very well at 10.7 GHz.

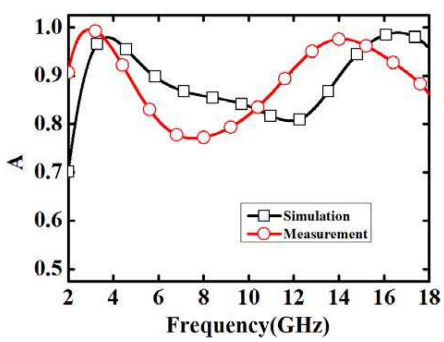


Figure 5: Absorbance comparison of the simulation and measurement.

5. CONCLUSIONS

In summary, a unconventional multi-band metamaterial 3D-cube absorber was proposed for multi-band microwave absorption in frequency range of 2–18 GHz. By the means of calculating the reflective coefficient and analyzing the distribution of the electric field, it is demonstrated that the cube absorber can eliminate the total reflect of the planer structure quite well. Meanwhile, the absorbing strength is largely improved compared with the planer absorber. This word provides a new solution to design multi-band absorbing structure without inducing the phenomenon of total reflect. Although the modeling and experiments are done in microwave frequencies, the absorber can be easily scaled to find applications at higher frequency regimes.

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