Design and Analysis of a Wideband Metamaterial Absorber Applied to Radome

Zhiwen Mao, Shaobin Liu, Xiangkun Kong, Borui Bian, Beiyin Wang, and Lin Chen
Key Laboratory of Radar Imaging and Microwave Photonics, Ministry of Education
College of Electronic and Information Engineering
Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China

Abstract— In this paper, a detailed study of a single-layer wideband metamaterial absorber (MMA) applied to radome, which is transparent at the operating frequency and is absorption at frequencies ranging from 2.4 GHz to 7.1 GHz. The design is discussed by the unit cell and equivalent circuit model. A unit cell of the periodic structure for the absorber is designed and simulated. The MMA consists of a two-dimensional periodic array of resistor-loaded square loops and crosses. The composite structure is thoroughly analyzed by an efficient equivalent circuit approach and by full-wave numerical simulations. Simulation results show that the proposed MMA has a wideband absorption range that covering most of the C-band and S-band. A pass-band at the frequency 11.75 GHz is obtained, which is operating in X-band. It also shows that the MMA sample is polarization insensitive for TE and TM incident wave.

1. INTRODUCTION

Metamaterials (MMs) have been effectively used to produce highly absorbing structures which led the microwave engineers to research a new scientific field, with a direct impact on modern microwave systems. As an artificial medium, the permittivity and permeability of the MMs can be tuned by changing geometric dimension and shape [1]. Multi-band operation properties of MMs also can be realized by multiple-frequency resonators design [2, 3]. Generally, there will be more or less power losses occur when electromagnetic (EM) wave impinge on MMs. In 2008, Landy et al. [4], first presented a perfect matematerial absorber (MMA) in a narrow-band which can absorb all the incident EM waves by tuning the magnetic and electrical resonances. In recent years, researchers have further studied the MMA in the GHz and terahertz (THz) frequency ranges to achieve dual working band [5, 6], broader bandwidth [7, 8], and polarization insensitive MMAs. Gu et al. [9] embedded resistors into MMA structures to lower the Q factor to increase the bandwidth in the GHz regime. Tao et al. [10] used the split-ring resonators (SRR) and bottom metallic layer structure to realize highly flexible materials in THz which can operate over wide angles of incidence for both transverse electric (TE) and transverse magnetic (TM) radiations.

In this paper, we present a novel wideband MMA based on a two-dimensional periodic array of resistor-loaded square loops and crosses. This structure is proposed using low profile single dielectric layer which shows absorption at a range that covering most of the C-band and S-band.

2. DESIGN OF THE STRUCTURE

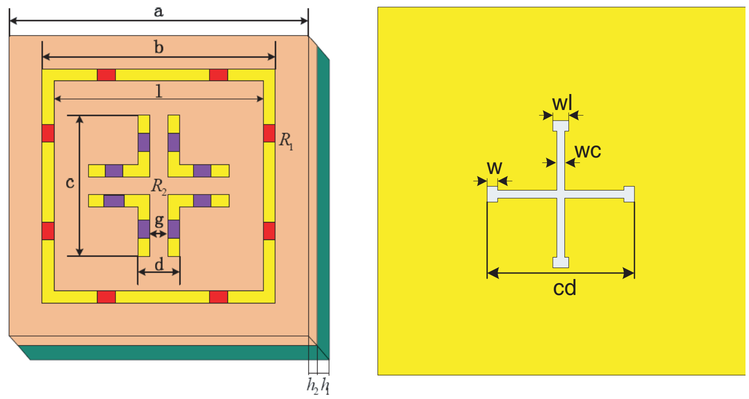
The front and bottom view of the basic unit cell of the proposed wide-band MMA based is shown in Fig. 1. The designed MMA consists of two metallic layers separated by a dielectric substrate, each of the metallic layers is copper with frequency independent conductivity $\sigma = 5.8 \times 10^7$ S/m. The thickness and relative permittivity of the spacer are $h_1 = 12$ mm and $\varepsilon_1 = 1$, respectively. In addition to the spacer, another thin layer of substrate is introduced to facilitate the fabrication of this absorber. The thickness and relative permittivity of the spacer are $h_2 = 0.3$ mm and $\varepsilon_2 = 4.3$, respectively. The optimized geometry dimension parameters of the unit cell are as follows: $a = 24$ mm, $b = 18$ mm, $c = 12$ mm, $d = 2.6$ mm, $g = 1.5$ mm, $l = 16.8$ mm, $R_1 = 100\,\Omega$, $R_2 = 800\,\Omega$, $cd = 8$ mm, $wl = 2$ mm, $wc = 1$ mm, $w = 1$ mm.

The absorptivity can be found out from Eq. (1), where $A(\omega)$, $|S_{11}(\omega)|^2$, and $|S_{21}(\omega)|^2$ are the absorptivity, reflectivity and transmissivity, respectively, at an angular frequency ω,

$$A(\omega) = 1 - |S_{11}(\omega)|^2 - |S_{21}(\omega)|^2, \tag{1}$$

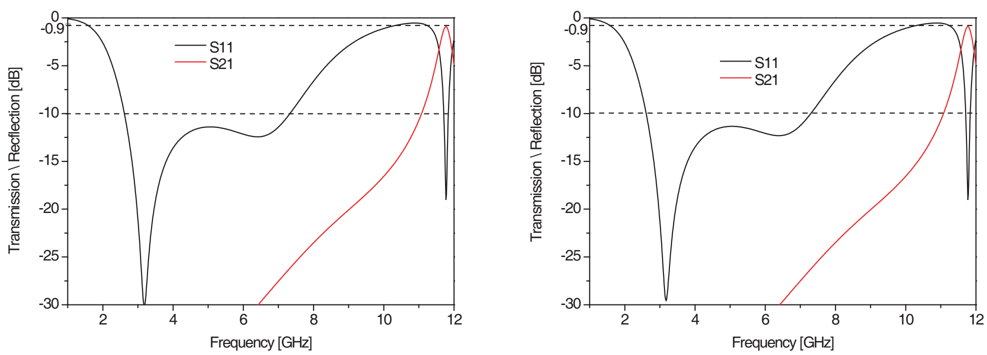
3. SIMULATED RESULTS

A full wave EM simulation was performed to get the reflection parameter S_{11} based on the commercial program, CST MICROWAVE STUDIO 2010. The simulation result of the reflection and



(a) (b)

Figure 1: (a) Perspective view of the proposed MMA structure unit cell. (b) The bottom view of the basic unit cell of the proposed wide-band MMA.



(a) (b)

Figure 2: Simulated result of the reflection and transmission curves of wideband absorber. (a) TE and (b) TM incident radiation.

transmission curves for both TE and TM polarizations as shown in Fig. 2. The absorption curve is shown in Fig. 3. The simulation results exhibit that there have been a broad absorption band ranging from 2.4 GHz to 7.1 GHz with absorption rates of 90%. In addition, it is observed that there is a transmission peak at frequencies of 11.75 GHz with insertion loss of -0.9 dB. It indicates that the impedance of proposed MMA can be tuned to approximate match to the free space in our interested frequency range. Due to the center of symmetry, the proposed MMA is polarization-insensitive.

To better understand the physical mechanism and the origin of the five-band CSR MMA, we have studied the equivalent circuit model is shown in Fig. 4(a). It may be mentioned that R_1, L_1 and C_1 represent the equivalent circuit of the outer loop, while R_2, L_2 and C_2 denote the inner cross. The short-circuited transmission line section of length h_1 represents the conductor-backed spacer, while the short transmission line section of length h_2 denotes the thin substrate. The transmission line of characteristic admittance Y_0 stands for the half free space above the MMA. For the transmission line circuit shown in Fig. 2, we can obtain the reflection coefficient Γ as follows:

$$\Gamma = \frac{Y_0 - Y_{in}}{Y_0 + Y_{in}} \tag{2}$$

$$\text{where } Y_{in} = Y_{LP} + Y_{CR} + Y_d \tag{3}$$

$$Y_{LP} = \frac{1}{R_1 + j\left(\omega L_1 - \frac{1}{\omega C_1}\right)} = G_1 + jB_1 \tag{4}$$

$$Y_{CR} = \frac{1}{R_2 + j\left(\omega L_2 - \frac{1}{\omega C_2}\right)} = G_2 + jB_2 \tag{5}$$

$$Y_d = \frac{Y_{02}\left(Y_{02}\tan\left(\beta_2 h_2\right) - Y_{01}\cot\left(\beta_1 h_1\right)\right)}{Y_{02} + Y_{01}\cot\left(\beta_1 h_1\right)\tan\left(\beta_2 h_2\right)} = jB_d \tag{6}$$

and $Y_{0i} = Y_0\sqrt{\varepsilon_{ri}}$, $\beta_i = 2\pi\sqrt{\varepsilon_{ri}}/\lambda$, $i = 1, 2$, $\omega = 2\pi f$, Y_0 is the characteristic admittance of free space. The values of lumped resistors (R_1, R_2) are determined for optimum frequency response. The circuit model simulation in Fig. 4(b) is conducted using the following values: $R_1 = 100\,\Omega$, $L_1 = 13\,\mathrm{nH}$, $C_1 = 0.222\,\mathrm{pF}$, $R_2 = 800\,\Omega$, $L_2 = 8.25\,\mathrm{nH}$, $C_2 = 0.065\,\mathrm{pF}$, $R_1 = 100\,\Omega$, $R_2 = 800\,\Omega$, $h_1 = 12\,\mathrm{mm}$, $h_2 = 0.3\,\mathrm{mm}$. It is observed that the results from circuit model and CST simulations are in good agreement.

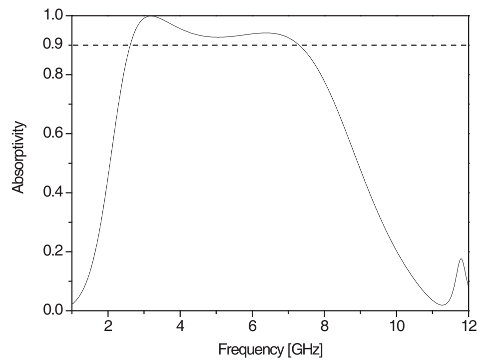


Figure 3: Simulated absorptivity of the absorber with wide-band configuration.

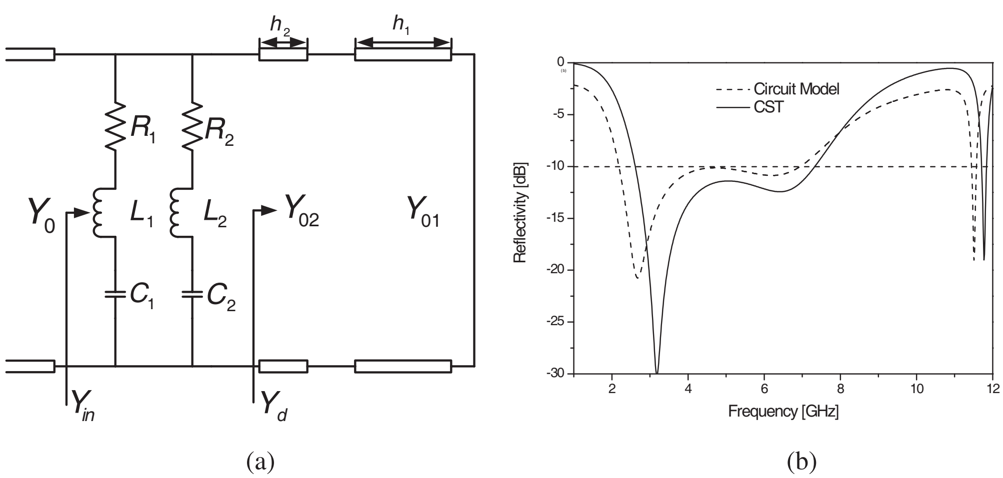


Figure 4: (a) Equivalent circuit model of the wideband MMA. (b) Reflectivity of the absorber calculated from the equivalent circuit model and CST using periodic boundaries for normal incidence.

4. CONCLUSION

In summary, the absorption properties of a single-layer wideband metamaterial absorber are studied. The CST simulation results show the absorption range can cover most of the C-band and S-bandwith absorptivity over 90%. In addition, there have been a transmission peak in X-band with insertion loss of $-0.9\,\mathrm{dB}$. Furthermore, the simulation result exhibits that the absorption of the designed MMA is nearly unchanged for different polarization angles with TE and TM modes. Such a design can have some potential applications in EM spatial filter, wavelength selective radiation and radom.

ACKNOWLEDGMENT

This work was supported by Funding of Jiangsu Innovation Program for Graduate Education (No. CXZZ13_0166), the Fundamental Research Funds for the Central Universities (No. NZ2013302), Youth Funding for Science & Technology Innovation in NUAA (NS2014039), the Chinese Specialized Research Fund for the Doctoral Program of Higher Education (No. 20123218110017), the Jiangsu Province Science Foundation (No. BK2011727), and the Foundation of Aeronautical Science (No. 20121852030).

REFERENCES

1. Gorkunov, M. V., I. V. Shadrivov, and Y. S. Kivshar, "Enhanced parametric processes in binary metamaterials," arXiv preprint physics/0510103, 2005.
2. Chen, H., L. Ran, J. Huangfu, et al., "Metamaterial exhibiting left-handed properties over multiple frequency bands," *Journal of Applied Physics*, Vol. 96, No. 9, 5338–5340, 2004.
3. Sydoruk, O., O. Zhuromskyy, E. Shamonina, et al., "Phonon-like dispersion curves of magnetoinductivewaves," *Applied Physics Letters*, Vol. 87, No. 7, 072501, 2005.
4. Landy, N. I., S. Sajuyigbe, J. J. Mock, et al., "Perfect metamaterial absorber," *Physical Review Letters*, Vol. 100, No. 20, 207402, 2008.
5. Wen, Q. Y., H. W. Zhang, Y. S. Xie, et al., "Dual band terahertz metamaterial absorber: Design, fabrication, and characterization," *Applied Physics Letters,* Vol. 95, No. 24, 241111, 2009.
6. Li, M., H.-L. Yang, X.-W. Hou, Y. Tian, and D.-Y. Hou, "Perfect metamaterial absorber with dual bands," *Progress In Electromagnetics Research*, Vol. 108, 37–49, 2010.
7. Cheng, Y. Z., Y. Nie, R. Z. Gong, et al., "Multi-band metamaterial absorber using cave-cross resonator," *European Physical Journal-Applied Physics*, Vol. 56, No. 3, 4184, 2011.
8. Zhang, F., L. Yang, Y. Jin, and S. He, "Turn a highly-reflective metal into an omnidirectional broadband absorber by coating a purely-dielectric thin layer of grating," *Progress In Electromagnetics Research*, Vol. 134, 95–109, 2013.
9. Gu, S., J. P. Barrett, T. H. Hand, et al., "A broadband low-reflection metamaterialabsorber," *Journal of Applied Physics*, Vol. 108, No. 5, 064913, 2010.
10. Tao, H., C. M. Bingham, A. C. Strikwerda, et al., "Highly flexible wide angle of incidence terahertz metamaterial absorber: Design, fabrication, and characterization," *Physical Review B Condensed Matter and Materials Physics*, Vol. 78, No. 24, 241103R, 2008.