A Broadband Metamaterial Microwave Absorber Utilizing Both Magnetic and Electric Resonances

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***Abstract*—This paper introduces a thin wideband metamaterial microwave absorber. It employs both magnetic and electric resonances in the unit-cell design, and has a measured -10dB absorption level from 6.52 GHz to 16.51 GHz, which agrees well with the simulation results. The relative bandwidth is 86.7%. The absorber maintains a -10dB absorption level from 6.80 GHz to 14.32 GHz within 30° TE mode incidence, and from 7.56 GHz to 16.97 GHz within 30° TM mode incidence.**

Keywords—metamaterial; wideband absorber

I. Introduction

Thin broadband electromagnetic absorbers have a wide application in electromagnetic compatibility technology. Conventional absorbers like the Jaumann absorbers do not exhibit a wide absorption band unless layers are stacked on each other so that they are too thick to be used in some practical applications [1]. Later on, the emergence of metamaterial has provided a remedy to this problem. By introducing a metamaterial that exhibits complex impedance match to the incident waves, the metamaterial absorber can offer both a wide absorption band and much less thickness simultaneously.

In recent years, various metamaterial absorbers exhibiting good performance have been published [2-5]. They all have a relative bandwidth larger than 85%, of which the widest one is designed by Shen et al [2], reaching up to 126.8%. These absorbers are formed by stacking one or more planar FSSs on a metallically grounded substrate. Under normal incidence, the metal FSSs resonate electrically. In contrast, few attempts have been made to utilize magnetic resonance.

In this paper, we tried to exploit metallic loop structures to enable both magnetic and electric resonances, and designed a new metamaterial absorber which exhibits a relative bandwidth of 86.7%. This paper introduces our new absorber in four aspects: its design, its resonance modes, its simulation results, and its experimental performances.

II. Design and Simulation

The unit cell of the proposed structure is based on a ring resonator, as shown in Fig. 1(a). The side length of the unit cell is 13.02 mm. It consists of two substrates with permittivity of $\varepsilon = 2.2$. The thickness of the substrate on the top is 1.5 mm, while the thickness of the substrate on the bottom is 2.8 mm. The back of the bottom substrate is completely covered by copper sheet. A cross-shaped structure, connected to the four arrow-shaped structures at the very top through copper-covered via, is sandwiched between two substrates. Resistors of size 1.0 mm× 0.5 mm×0.5 mm and 200Ω resistance are soldered across the gaps. All resistors are modelled with nickel ends and lossy

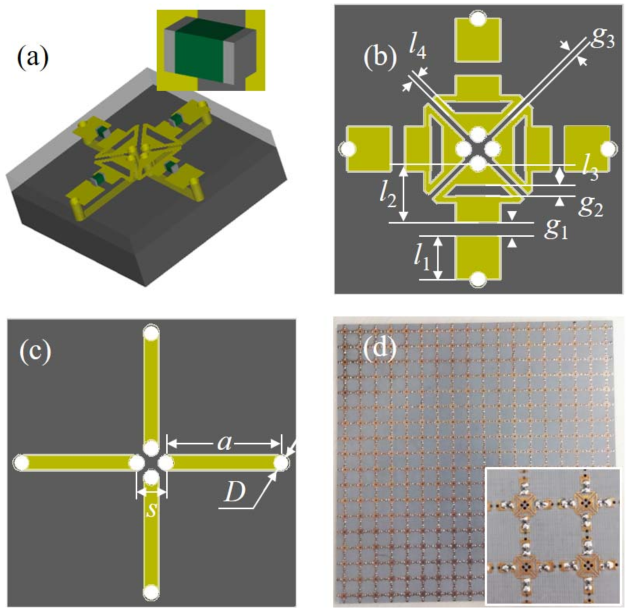

Fig. 1. The unit cell. Fig. 1(a) is the perspective view, (b) is the top view, (c) is the structure sandwiched in the middle, and (d) is the fabricated sample. The inset in (a) is the structure of resistors. The inset in (d) is a magnified view. In (a), (b) and (c), black color represents F4B, yellow represents copper. White circles are copper-covered via.

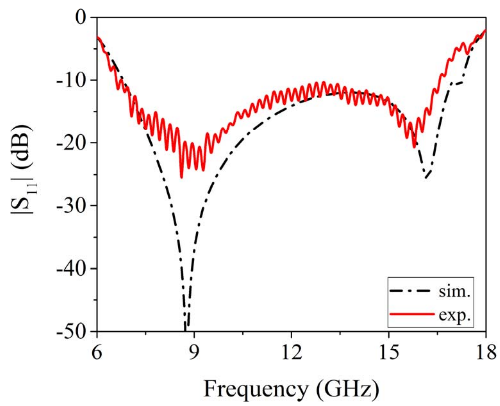

Fig. 2. Simulated and measured $|S_{11}|$ curve under normal incidence.

material. All copper sheet has a thickness of 0.018 mm. Other parameters are (unit mm): $D = 0.70$, $a = 5.19$, $s = 1.32$, $l_1 = 1.95$, $l_2 = 2.97$, $l_3 = 1.28$, $l_4 = 0.28$, $g_1 = 0.62$, $g_2 = 0.54$, $g_3 = 0.28$.

Simulations were conducted using a full-wave electromagnetic simulator, and the result is plotted in Fig. 2. As can be seen, the -10dB reflection band is 6.80 GHz - 17.27 GHz under normal incidence, with a relative bandwidth of 87.0%.

To fully understand the working mechanism of the absorber, surface current at two absorption peaks, i.e., 8.77 GHz and 16.2 GHz, were investigated. The result is shown in Fig. 3. As it demonstrates, at 8.77 GHz, the surface current on copper forms a loop, suggesting a magnetic resonance. At 16.2 GHz, it can be seen that the distribution of surface currents on the loop resonator is a superimposition of both a loop current and two parallel currents in the same direction. Even so, the surface currents on the top layer and the middle layer are mainly in phase, suggesting a dominating electric resonance. Therefore, by utilizing both magnetic and electric resonance, a wide absorption band has been achieved.

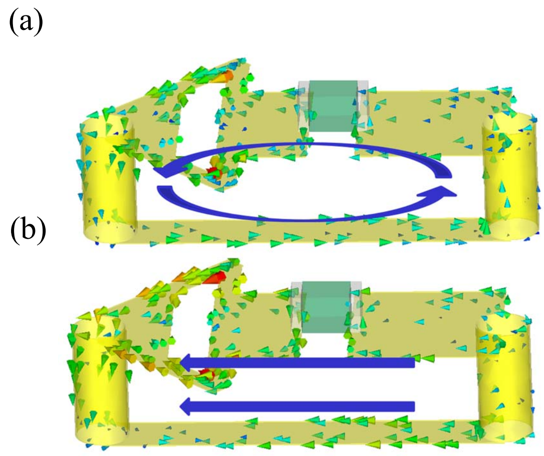

Fig. 3. Surface current distribution on the loop at (a)8.77GHz and (b)16.20GHz. To make pictures clearer, both pictures only draw a quarter of a unit cell, with substrates and copper ground hidden, leaving loop structures for display. Surface currents are plotted in logarithmic scale. Long blue arrows are indicators of surface current direction.

III. Experiment

A sample of size 234.36 mm × 234.36 mm has been fabricated, as shown in Fig. 1(d), and its performance has been measured in an anechoic chamber. Two microwave horn antennas operating from 2 GHz to 18 GHz are used. Both antennas are connected to the Agilent vector network analyzer.

The absorption performance is given in Fig. 2. It can be seen that simulation and experiment results agree with each other well. The measured -10 dB reflection band is 6.52 - 16.51 GHz (86.8%), while the simulated one is 6.80 - 17.27 GHz (87.0%). The slight difference comes mainly from inevitable fabrication errors, like substrate thickness, etc.

The performance under oblique TE and TM mode incidences have also been measured. The results are drawn in Fig. 4. The simulation and experiment results agree roughly well. As incident angle becomes larger, both resonating peaks (8.77 GHz and 16.20 GHz under normal incidence) become shallower because of the mismatch between wave impedance in air and the surface impedance of the absorber.

Measured absorption bands are listed in TABLE I. It can be concluded that an absorption bandwidth over 70% can be achieved under an incidence angle up to 30°.

TABLE I. Measured Absorption Band under Oblique Incidence.

Incident Angle	Measured -10dB Absorption Band	
	TE mode	TM mode
15°	6.80-15.94GHz (80.4%)	6.89-16.91GHz (84.2%)
30°	6.80-14.32GHz (71.2%)	7.56-16.97GHz (76.7%)
45°	6.85-11.39GHz (49.8%)	9.83-16.10GHz (48.4%)

IV. Conclusion

In summary, a double-layered metamaterial absorber utilizing both magnetic and electric resonances is proposed. The structure we propose exhibits magnetic resonance at a lower frequency, and electric resonance at a higher frequency. The -10

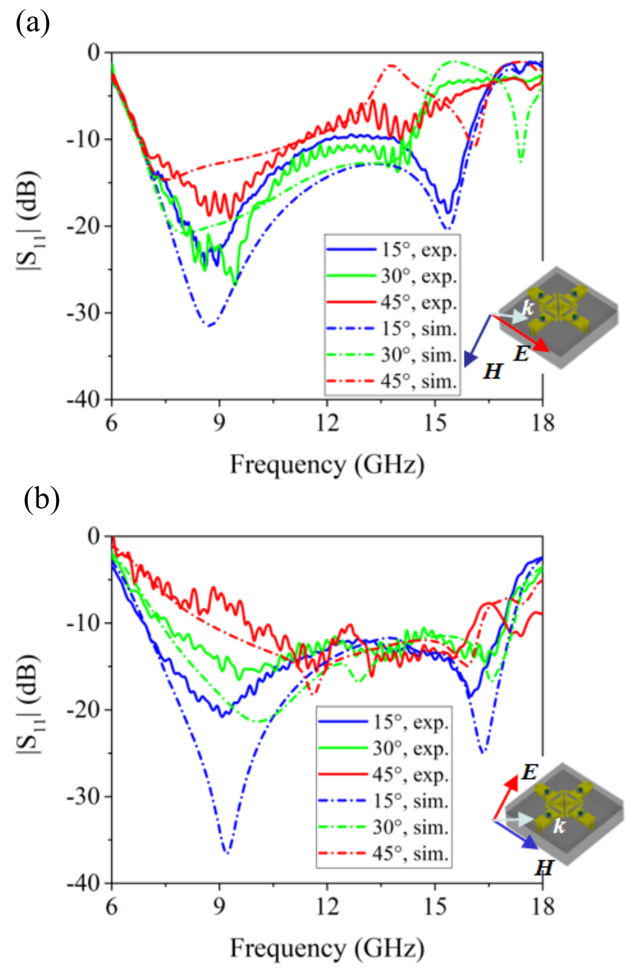

Fig. 4. Reflections of (a)TE mode and (b)TM mode. Mode definitions are given in the insets of (a) and (b), respectively.

dB absorption band is 6.52 - 16.51 GHz (86.8%). The absorber could maintain a relative absorption bandwidth over 70% under oblique incidence up to 30°.

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REFERENCES

[1] E. F. Knott, J. F. Shaeffer, and M. T. Tuley, *Radar Cross Section*, 2nd. Raleigh, NC, USA: SciTech, 2004.

[2] Y. Shang, Z. Shen, and S. Xiao, "On the Design of Single-Layer Circuit Analog Absorber Using Double-Square-Loop Array," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 12, pp. 6022–6029, Dec. 2013..

[3] Y. Han and W. Che, "Low-Profile Broadband Absorbers Based on Capacitive Surfaces," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 74–78, 2017..

[4] W. Che, H. Ye, Y. Xiong, Y. Chang, and C. Christopoulos, "A fast and efficient method for design of circuit analog absorbers consisting of resistive square loop arrays," in *2015 IEEE International Conference on Computational Electromagnetics*, 2015, pp. 35–37.

[5] X. Q. Lin, P. Mei, P. C. Zhang, Z. Z. D. Chen, and Y. Fan, "Development of a Resistor-Loaded Ultrawideband Absorber With Antenna Reciprocity," *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 11, pp. 4910–4913, Nov. 2016.