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Ultra-broadband metamaterial absorber using slotted metal loops with multi-layers and its anti-reflection analysis

Yu Ze (✉), Lu Guizhen, Guo Qingxin

School of Telecommunication Engineering, Communication University of China, Beijing 100024, China

Abstract

An ultra-thin and broadband absorber which consists of periodic rings with gaps is proposed in this paper. The periodic rings are printed on the middle metallic layers in a four-layer substrate of total thickness is only 3.4 mm. Simulation results, which are gotten by using finite element method (FEM) and finite-difference time-domain (FDTD), show that the absorption is higher than 90% cover the frequencies range from 7.8 GHz to 22.2 GHz. The measurement results of the absorption agree with simulated ones very well. We also discuss the working mechanism according to the anti-reflection theory in the paper.

Keywords metamaterial, broadband, anti-reflection, periodicstructure, absorption

1 Introduction

Absorbing material, which play an important role in the stealth technology, reducing the radar cross-sections of aircraft and electromagnetic compatibility, has attracted much attention in the military, aerospace and communication fields. However, it is an enormous challenge to design an absorbing material with wideband operating frequencies, ultra-thin construction and machinable simultaneous. Keeping pace with the vigorous development of military technology, a wide variety of the metamaterial absorbers (MAs) with periodic structure have been proposed during the past two decades [1–5]. According to the surface impedance characteristics, those MA can be divided into two categories, namely, the lossy absorber [6] and the lossless absorber [7]. Although it is a tough task for building the high impedance surface precisely as the desired value [8], the lossy absorber has the advantages of thin thickness and wide operating band owing to its high impedance surface which consume the power of the electromagnetic wave. In contrast, the lossless absorber which is usually composed of the metallic surface, has narrow operating frequency band, but it can be constructed easier, just as the MA which is proposed by Landy et al. in 2008 [9]. A multilayered metallic-dielectric absorber, which is composed of 20 metal patches whose width tapered linearly from the top layer to the bottom layer, has been presented by Ding et al. in 2012 [10]. By using multi-resonance method, the wideband performance of the absorber is obtained but the thickness is increased significantly.

By applying the anti-reflection theories, an ultra-thin and broadband MA with multi-layers is designed in this paper. In contrast to the previous researches by utilizing the strong resonance loss to achieve broadband, this proposed structure utilizes the destructive interference mechanisms. The numerical simulation results and the measurement results of the presented MA are obtained and compared. The theoretical explanation of the structure using anti-reflection and multi-resonance are also investigated.

2 Design and results

The configuration of the matematerial absorber, which is designed as periodic construct with 60×60 cells on a substrate with four layers, is shown in Fig. 1. The cross-section view of the four-layer substrate is illustrated in the Fig. 1(b). The top layer of the substrate is

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Corresponding author: Yu Ze, E-mail: cuc_yuze@163.com
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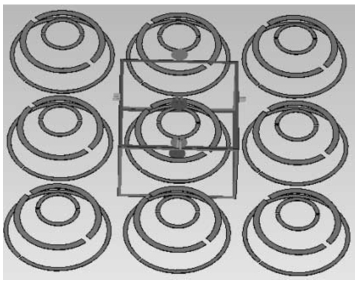
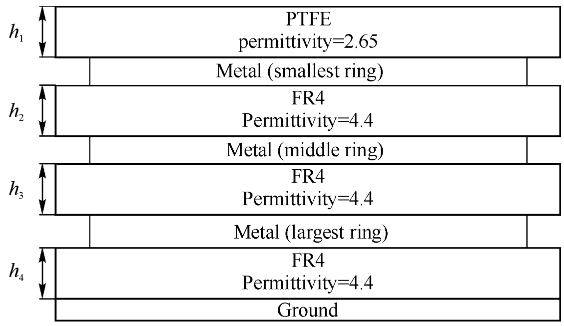
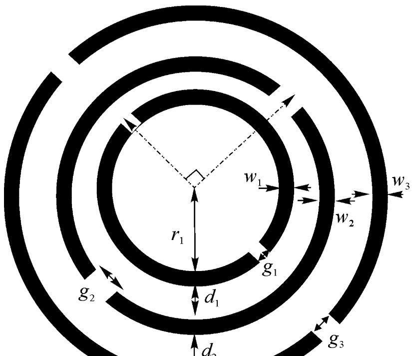
polytetrafluoroethylene (PTFE) membrane with a dielectric constant of 2.65, and the other three layers of the substrate are FR-4 with dielectric constant of 4.4. In between adjacent substrate layers, there is a layer with metallic ring, and below the bottom substrate layer, there is a grounded metallic layer. Fig. 1(c) plot the layout of each cell which comprise of three different diameter rings with gaps. These rings are printed on different middle metallic layers, namely, the smallest ring is printed on the top metallic layer and the largest ring is placed on the third metallic layer from the top, respectively. The detailed dimensional parameters for the optimum design are given in the caption of Fig. 1.



(a) Configuration



(b) Cross-section of the substrate



(c) Layout of the each cell

Fig. 1 Configuration of the matematerial absorber (h_1= 1.2 mm, h_2=0.6 mm, h_3=1 mm, h_4=0.6 mm, r_1=0.9 mm, d_1= 0.8 mm, d_2=0.3 mm, g_1=0.1 mm, g_2=0.3 mm, g_3=0.1 mm, w_2=0.2 mm, w_3=0.3 mm)

The matematerial absorber was simulated and optimized using FEM and FDTD. The absorption spectrums of the two numerical methods are plotted in Fig. 2. It is evident that the presented structure exhibits a good absorbing performance in the frequencies range from 7.8 GHz to 22.2 GHz with the absorption >90%. It is necessary to mention that the absorption is defined as $A=1-|S_{11}|^2$ because the metallic layer adhered the bottom substrate will reflect most of the power of electromagnetic wave. To show the advantages of the proposed configuration, a comparison with other structures that can be found in the literature is summarised in Table 1. The proposed structure exhibits a much wider bandwidth compared with the configurations in Refs. [10–12], which cover 7.8~14.7 GHz, 8.2~12.4 GHz and 8.37~21.00 GHz, respectively. Moreover, the thickness of the absorber proposed in this paper is only 3.4 mm, which is the thinnest one.

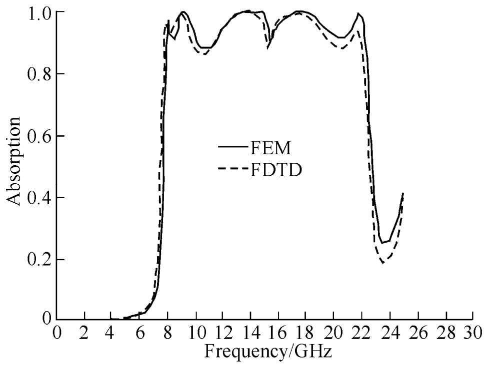


Fig. 2 Comparison of FEM and FDTD

Table 1 Comparisons between proposed absorber and previous works

Number	Bandwidth/GHz	Thickness/mm	Layers
Ref. [10]	7.8~14.7	5	20
Ref. [11]	8.2~12.4	10	5
Ref. [12]	8.37~21.00	3.75	5
This paper	7.8~22.2	3.4	4

The presented ultra-thin and broadband MA is fabricated and its photo is shown in Fig. 3. Fig. 4 plots the measured S_{11} and compares the result to the simulated one. We only measure the frequency band from 7.8 GHz to 16 GHz due to the limitation of our experimental conditions. From Fig. 3, we see that the measurement results agree with the simulation results in the testing frequencies [13].