An ultra-thin and broadband absorber using slotted metal loop with multi layers

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ABSTRACT

An ultra-thin and broadband absorber is proposed in this paper. It is composed of a periodic array of slotted metal loop-dielectric multilayered structure and the thickness of the absorber is only 3.4 mm. Moreover, the absorption at normal incidence is above 90% (S11 < −10 dB) in the frequency range of 7.8–22.2 GHz. The design results are verified using FEM and FDTD and the experimental results are also given. They are very consistent. Then, we analysed above results based on the anti-reflection and resonance theory.

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1. Introduction

Absorbing material has been a hot research field in the military, aerospace and communication. It has an important role in the stealth technology, improving the performance of radar antenna and electromagnetic compatibility. But making the absorber ultra-thin, improving its broadband and achieving machinable are also big problems for the researchers. At present, many researchers are dedicated to periodic structure metamaterial of absorbing and make a series of progress [1–5]. According to impedance characteristic of the surface, it can be divided into lossy absorber [6] and lossless absorber [7]. Lossy absorber has thin thickness and broadband because its high impedance surface can consume the electromagnetic wave. But it is difficult to process the high impedance surface precisely [8]. Lossless absorber is composed of metal surface which is easy to process, but the narrow band is a problem, such as the first metamaterial absorber put forward by Landy in 2008 [9]. Since there are many researchers improving the structure by multi-resonance method and the bandwidth can be expended, but the bandwidth is also limited [10]. Using the method of multi-resonance also makes the absorber’s thickness increase greatly.

In this paper, we propose multi-layer absorber composed of slotted metal loop by the theory of anti-reflection and multi-resonance. The absorption is above 90% from 7.8 GHz to 22.2 GHz and the thickness is only 3.4 mm. The design results are verified by FEM and FDTD and we also measure the processed absorber using free space measurement. Finally, we analyzed above results using the theory of anti-reflection and multi-resonance.

2. Design and results

The unit of the periodic absorber is shown in Fig. 1. It consists of 3 slotted metal loops, 1 metal ground, 1 PTFE matching layer and 3 FR4 dielectrics. The top layer is PTFE (permittivity = 2.65), which operates by overcoming the impedance mismatch between free space and absorber. The remaining three dielectrics are FR4 (permittivity = 4.5). Every slotted metal loop and its underlying FR4 layer compose a metamaterial layer, which may be treated as a uniform layer. These metamaterial layers can change their refractive index by controlling the loop’s electromagnetic parameters, so as to cooperate with metal ground to achieve the purpose of incident wave and reflected wave offset each other and realize the absorbing performance. The parameters of the metamaterial absorber are shown in Table 1.

We simulate this period structure using FEM and FDTD and absorption curves of the two methods are shown in Fig. 2 (because the bottom layer is metal, the absorption A = 1 – |S11|²). The consistency of the results show that the absorber has a good absorbing performance from 7.8 GHz to 22.2 GHz (absorption >90%). In order to illustrate the superiority of the absorber in this paper, we compare it with several mainstream absorbers, as shown in Table 2.

Then, we make this multi-layer absorber, as shown in Fig. 3. Due to the limitation of experimental conditions, we only measure the frequency band from 7.8 GHz to 16 GHz [13] and the measured results are consistent with the simulated results, as shown in Fig. 4.

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Table 1
The parameters of absorber.

<table>
<thead>
<tr>
<th></th>
<th>Height 1 (mm)</th>
<th>Height 2 (mm)</th>
<th>Height 3 (mm)</th>
<th>Height 4 (mm)</th>
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<tbody>
<tr>
<td>Fig. 1(b)</td>
<td>H1 = 1.2 mm</td>
<td>H2 = 0.6 mm</td>
<td>H3 = 1 mm</td>
<td>H4 = 0.6 mm</td>
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<tr>
<td>Fig. 1(c)</td>
<td>R1 = 0.9 mm</td>
<td>D1 = 0.8 mm</td>
<td>D2 = 0.3 mm</td>
<td>G3 = 0.1 mm</td>
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<tr>
<td></td>
<td>G1 = 0.1 mm</td>
<td>G2 = 0.3 mm</td>
<td>G3 = 0.1 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W2 = 0.2 mm</td>
<td>W3 = 0.3 mm</td>
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</tr>
</tbody>
</table>

![Fig. 1](image1)

Fig. 1. The unit of the period structure: (a) 3D view; (b) top view; and (c) side view.

![Fig. 2](image2)

Fig. 2. The comparison of FEM and FDTD.

![Fig. 3](image3)

Fig. 3. The processed absorber.

![Fig. 4](image4)

Fig. 4. The comparison of measured results and simulated results.

![Fig. 5](image5)

Fig. 5. The electromagnetic wave propagation in absorber: (a) the reflection model of 4 layers; (b) the reflection model of equivalent.

3. Absorber based on the anti-reflection and resonance theory and discussion

We can get the four layers absorber’s total reflection coefficient expression (as shown in Fig. 5(a)) from the reflection coefficient formula of uniform plane wave in ideal multilayered medium [14–16].

Table 2
Comparisons of this and some other broadband absorbers.

<table>
<thead>
<tr>
<th>ID</th>
<th>Absorption bandwidth (GHz)</th>
<th>Thickness (mm)</th>
<th>Layers</th>
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<tr>
<td>Paper [10]</td>
<td>7.8–14.7</td>
<td>5</td>
<td>20</td>
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<tr>
<td>Paper [12]</td>
<td>8.37–21</td>
<td>3.75</td>
<td>4</td>
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<tr>
<td>This paper</td>
<td>7.8–22.2</td>
<td>3.4</td>
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