Design of an ultra-thin magnetic radar absorber embedded with double period frequency selective surface for entire L-band microwave absorption

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Abstract. In this paper, a thin, broadband and low frequency with high absorption (more than 90% absorption) radar absorber (RA) consisting of magnetic-type material substrate and double period frequency selective surface (FSS) is demonstrated. The geometric parameters were investigated for its contribution towards absorption by the finite-difference time domain (FDTD) method. The effects of incidence angles of electromagnetic radiation were also discussed. The simulation indicates that the use of the double period FSS makes a remarkable increase of operational bandwidth and moves the resonant frequency to the lower frequency comparison with single magnetic radar absorption materials (SMRA). Due to the excellent symmetric nature of the proposed structure, the reflectivity is insensitive to incident angle from 0° to 30°. The reflectance of RA lower than -10 dB (over 90% absorption) is obtained in the whole frequency range of L-band which is 1.5 times wider than the bandwidth of the same thickness SMRA when the structure thickness is only 2.62 mm. The simulation method is verified by comparison with the experiment in the literature. Thus, the presented RA breaks the limitation of the thickness (λ/4) for the traditional low-frequency band absorbing material and has wide application prospect in electromagnetic shielding and low-frequency stealth.

1. Introduction

The stealth technology of weapon equipment has been the key technology to determine its survivability. Therefore, many scholars carry out research on stealth technology [1, 2]. Among them, the research of radar absorbing material (RAM) and radar absorbing structure (RAS) are the key points [3]. For traditional RAM, the absorbing performance is strongly due to permeability and permittivity of composites consequently, many researchers focus on the preparation of absorbent [4, 5]. The mixed type of microwave absorbing materials that consolidated magnetic and dielectric losses are researching [6]. Many researchers use frequency selective surface(FSS) or period structure of metallic patches in the modern design, because of the absorption performance can be easily improved and controlled by adjusting the geometric dimensions and patterns [7, 8]. However, most of the absorption band in the study is mainly concentrated in the C-band or above C-band, like X band, terahertz band, visible light and infrared band, etc. There are few ultra-thin absorbing materials or absorbing structures involved in
L-band [9]. Although an RAS that had a absorption performance in L-band had designed by Haiyan Chen, it did not cover the entire L band [9].

In this letter, a novel thin, broadband and low frequency with high absorption (more than 90% absorption) radar absorber (RA) based on magnetic-type material substrate and double period frequency selective surface (FSS) is proposed and numerically characterized. The effects of design parameters on the reflectivity of RA were investigated. The microwave absorbing performance of SMRA was improved by FSS in the frequency range of 1-2 GHz (L-band)

2. Design
As shown in Figure 1, the structure of the considered RA in this letter consists of a double periods FSS and magnetic-type absorbing material based on perfect conductor ground. Here, the double periods FSS described in Figure 1(b). The FSS layer contains two orders of two-dimension periodic array of square ring cell. The cycles of the FSS layer are $d_0$ and $d_1=d_0/2$, respectively. The magnetic-type absorbing material is the material in reference [9], and its relative permittivity $\varepsilon$ and relative permeability $\mu$ are shown in Figure 2. $\varepsilon'$ and $\varepsilon''$ represent the real part and imaginary part of relative permittivity of the materials. $\mu'$ and $\mu''$ represent the real part and imaginary part of relative permeability of the materials. We performed computer simulations of our design using the commercial finite-difference time domain (FDTD) solver microwave studio by CST that has been proved to be successful in similar types of analysis [10]. The program simulated a single unit cell with appropriate boundary conditions, as unit cell boundary on the side of the modal. The Floquet port was used to simulate the plane wave. The material properties and structure parameters are also defined in the simulation system. We simulated the electromagnetic parameter of RA at normal and oblique incidence condition.

![CST simulation model](image1.png)
![Structure of the FSS-embedded RA](image2.png)

**Figure 1.** (a)The CST simulation model; (b) Structure of the FSS-embedded RA.

![Electromagnetic characteristics](image3.png)

**Figure 2.** Electromagnetic characteristics of the magnetic-type absorbing materials [9]
3. Results and discussion

The geometry and size of the unit cell is optimized by numerical simulation to obtain a good microwave absorption performance. The optimized detailed parameter dimensions of the absorber are listed in Table 1.

| Parameter | Value  | Parameter | Value  |
|-----------|--------|-----------|--------|
| d0        | 10 mm  | t2        | 0.02 mm|
| d1        | 5 mm   | t3        | 0.9 mm |
| a0        | 2.8 mm | c0        | 0.1 mm |
| a1        | 2 mm   | c1        | 0.1 mm |
| t1        | 1.7 mm |           |        |

Table 1. Dimensions of the absorber

The reflectivity properties of the double period FSS-embedded RA are proposed in Figure 3. At the same time, the magnetic-type absorbing materials are also simulated and compared with the experimental data in reference [9], that is proved that our simulation results are basically consistent with the experimental results. The reflectivity of the magnetic-type absorbing materials is agreed with the experimental data. The operating bandwidths of 0.9~2.1 GHz of the double period FSS-embedded RA is obtained, but the operating bandwidth of the magnetic-type absorbing materials is only 0.97~1.75 GHz. Just like the results in Figure 3, we can observe that the operating frequency bandwidths for the double period FSS-embedded RA can be greatly increased and shifted to low frequency as compared to the magnetic-type absorbing materials only.

![Figure 3. Reflectivity of RA and single magnetic-type absorbing materials](image)

To understand the source of resonant absorption, seven main dimensional parameters, d0, a0, a1, c0, c1, t1, t3, are studied to examine their effects on the reflectivity of the absorber. The influences of period d0 and d1 of the double period FSS on the reflectivity of RA are given in Figure 4, while other parameters are kept unchanged. From the simulated results, two resonance peaks were observed at 0.7 GHz and 1.7 GHz when d0 is equal to 6 mm, and the resonance absorbing peak appear at different frequencies with variable d0. With the increasing of the period of double period FSS unit cell, the value of low-frequency resonance peak at about 0.7 GHz gradually decrease, whereas the high-frequency resonance peak gradually increases firstly and decrease secondly and then increase slightly. This result mean that we can change the period of the FSS to adjust the absorptive bandwidth range. As observed, there is a single resonance peak at about 1.1 GHz with increasing d0 above 10 mm. At the same time, a broad bandwidth is obtained with a reflectance lower than -10 dB in the frequency range from 0.9~2.1 GHz which cover the entire L band.
The calculated reflectivity of RA with different values of thickness for the magnetic-type material $t_1$ and $t_2$ are presented in Figure 5, respectively, while other parameters are kept unchanged. As observed, there is one resonant peak at about 1.14 GHz when $t_1=1.7$ mm, $t_3=0.9$ mm, which indicates that the impedance of RA matches with the free space at this resonance point. Hence, the absorber can absorb the electromagnetic wave energy at this point. As observed in Figure 5(a), with the increase of $t_1$, the resonance frequency absorption peak gradually shifts to the lower frequency, and the intensity of the absorption peak gradually increases, whereas the operating bandwidths gradually decrease. Unlike the results of Figure 5(b), the intensity of the absorption peak gradually decreases firstly, and then increase with increasing $t_3$. The reflectivity in Figure 5 have significance variations trend, which resonance point and intensity were changed regularly. This result can be explained by the principle of impedance matching in transmission line.

Figure 5. Simulated reflectivity of the RA versus frequency for different $t_1$, $t_3$.

The simulated reflectivity of the RA with different values of $a_0$ and $a_1$ are shown in Figure 6. As observed in Figure 6(a), the resonant absorption peak shifts toward low-frequency region firstly and then to high-frequency region with the increase of $a_0$. The intensity of the resonance peak gradually decreases to the minimum and then increase, whereas the absorption bandwidth with a reflection coefficient lower than -10 dB in the frequency range from 0.9 GHz to 2.1 GHz covers the entire L band when $a_0$ is equal to 2.8 mm. The calculated reflection spectra of the absorber with different $a_1$ are presented in Figure 6(b). From the simulated results, one resonance peak was observed at about 1.22 GHz when $a_1$ is equal to 1 mm, and the resonance absorbing peak appear at different frequencies with variable $a_1$. With increasing $a_1$, the value of resonance peak at about 1.22 GHz gradually decrease to the minimum then increase to the maximum and finally increase to about 1.5 GHz. With the increase of $a_1$, the intensity of resonance peak gradually decreases to the minimum then increased as the $a_1$ increase.
from 1 mm to 5 mm. The absorber has the widest absorption bandwidth which cover the entire L band when $a_1$ is equal to 2 mm.

**Figure 6.** Simulated reflectivity of the RA versus frequency for different $a_0$ and $a_1$.

Figure 7 shows the reflection coefficient of the RA when the line width of the zero FSS $c_0$ and the line width of the first FSS $c_1$ are variable and other parameters are kept unchanged. As shown in Figure 7, the resonant absorption peak and the low-frequency position don’t move with the increase of $c_0$ and $c_1$. However, the high-frequency position small shifts toward high-frequency region with the increase of $c_0$, and small shifts toward low-frequency region with the increase of $c_1$.

**Figure 7.** Simulated reflectivity of the RA versus frequency for different $c_0$ and $c_1$.

In order to make better use of the design, the reflection for TE-polarized and TM-polarized waves at different incident angles from 0° to 30° were given in Figure 8. As shown in Figure 8, in case of TE-polarized waves, the bandwidth with reflection coefficient below -10 dB gradually reduces with the increase of incident angles, whereas the bandwidth slowly increases with the incident angles from 0° to 30° under TM-polarized waves. As the incident angle increases, the minimum reflection coefficient for the TE polarization slightly increases, whereas that for the TM polarization smoothly decreases. The resonant frequencies at 1.13 GHz is stable with respect to the angle variation. This confirms that the resonant peak of designed RA is insensitive to incident angle from 0° to 30°.
4. Conclusion
A thin and broadband low frequency RA consisting of magnetic-type material substrate and double period FSS has been presented. The influences of geometric parameters on absorption properties are investigated. The structure research shows that we can adjust the absorption frequency and bandwidth lightly by changing the geometry of the structure. The frequency response of the proposed structure provides a thin (2.62 mm thick), broadband (0.9 GHz~2.1 GHz) and low frequency (cover the entire L band) with high absorption (more than 90% absorption) which resulted from the strong electromagnetic resonance that are produced by the intense coupling of the frequency selection surface with the magnetic medium and the metal substrate. Under TE and TM polarization, the absorption capabilities of the suggested RA structure have been investigated at different incident angles. The reflectivity of the designed RA is insensitive to incident angle from 0° to 30°. Moreover, the validity of the simulation method is verified by comparison with the experiments in the literature. Thus, this work reported a design for a new low frequency and broadband absorber which breaks through the limitation of the thickness of the traditional low-frequency band absorbing material and has wide application prospect.

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