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Design of a thin and broadband microwave absorber using double layer frequency selective surface

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ABSTRACT

In this letter, a thin and broadband radar absorber structure (RAS) consisting of two frequency selective surface (FSS) layers and dielectric ceramic coating is introduced. The first FSS layer consists of square and circular metal period arrays which couple with each other, and the second layer consists of a period arrays with square patch. Ceramic coating is located below FSS layers. The effects of design parameters on microwave absorption spectroscopy of RAS were discussed, including the size and period of FSS, etc. Moreover, the effects of incidence angles for transverse electromagnetic (TE) and transverse magnetic (TM) waves on the reflection loss of RAS were also investigated. Numerical simulations indicate that the microwave absorbing properties of RAS can be improved by adjusting the unit dimensions of FSS, and reflection loss of RAS is stable from 0 to 35°. Finally, Genetic Algorithm is introduced to obtain a wideband RAS, simulated results indicate that the absorber based on two FSS layers are better than one and without FSS. Measured reflection loss of RAS below −10 dB (over 90% absorption) is almost up to 7 GHz (7.0 GHz–8.7 GHz and 9.2 GHz–14.8 GHz) in the frequency range from 5.85 GHz to 18 GHz. The simulated results were confirmed by experimental.

1. Introduction

Along with the development of the exploration and track technology by radar etc, Radar absorbing materials (RAM) and Radar absorbing structure (RAS) have become very important stealth technology for aircraft, missiles and warships in modern wars because they can allow an object to be partially invisible on radar or any other detection tracking systems, and can significantly improve the survivability of plane [1–3]. Consequently, many researchers focused on the development of RAS and RAM [4–7]. For traditional RAM, the microwave absorbing performance is closely related to permeability and permittivity of composites. In general researchers are now introducing mixed type of microwave absorbing materials where consolidated magnetic and dielectric losses, which exhibited good microwave absorbing performances. However, it will became unmagnetized in high temperature application, resulting in the change of electromagnetic performance [8–10]. In current research, the use of frequency selective surface (FSS) or period structure of metallic patches has become very popular in the modern design, because of the absorption performance can be easily improved and controlled by adjusting the shape, the size and period of FSS, and different FSS exhibits different absorbing properties for radar absorber [11–14]. There are several FSS approaches done by the researchers to improve absorption properties, such as use of Jerusalem cross array, cross dipole, square, hexagon, circular and other type of FSS [15–19]. Besides, FSS with multiple bands absorption are very desired for the increased potential applications.

Previously, we have investigated the dielectric properties and microwave absorption properties of TiO_2/Al_2O_3 ceramic coating [20]. However, the reflection loss spectra exhibits narrow absorption lines in the frequency range of X-band, and microwave absorption properties of these coatings are mainly dependent on its thickness and the TiO_2 content. As we all know, an excellent absorption material should not only has a little thickness, but also possess broadband absorption properties. According the principle of impedance matching in transmission line [21,22], when the impedance matching characteristics was good, the required thickness was limited by a quarter of a wavelength λ/4, the microwave absorption properties of materials will be reduced as the decreasing thickness [23,24]. Thus, these traditional dielectric coatings can hardly satisfy these requirement (a little thickness and broadband

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absorption properties). In facet, FSS can adjust the impedance of these materials by structural parameters of FSS layer. FSS layer could benefit impedance match between absorber and air [25].

In order to prepare wide-band absorber, a type of RAS consisting of TiO_2/Al_2O_3 ceramic coating and a double layer FSS has been presented in this study, the effects of FSS element period, geometry size on the reflection loss of RAS are investigated, and the incident angles of electromagnetic wave for both transverse electric (TE) and transverse magnetic (TM) polarization on the reflection loss of RAS are also studied. Finally, an improvement of RAS is obtained upon optimization through genetic algorithm (GA) approach, the main goal of this study is to improve the absorbing performance in the frequency range from 5.85 GHz to 18 GHz with thin thickness.

2. Design method

As described in Fig. 1, the structure of the considered RAS in this study consists of double layer FSS and TiO_2/Al_2O_3 coating based on metal plate. Here TiO_2/Al_2O_3 coating was fabricated by plasma spray technology. The first FSS layer contains a two-dimension periodic array of square cells, and the second layer contains a two-dimension periodic array of regular circular aluminum film and square cells, which were printed by Laser engraving technology. After that, the prepared FSS made by aluminum film were attached to the surface of coating through mucilage. To demonstrate the electromagnetic absorption properties of our design, the commercial software High Frequency Structure Simulator (HFSS) is used to simulate the electromagnetic parameter of RAS at normal and oblique incidence condition. Finite element method (FEM) is chosen to simulate the reflectivity characteristics of the designed structure, and the optimal structure parameters of RAS are determined by genetic algorithm (GA) approach [26,27]. Simulations are performed for a single period based on Floquet's theorem using Floquet port with periodic condition boundary. Master–slave boundary condition is set on the sides of this model. The material properties and structural parameters are also defined in the simulations system.

The basic schematic structure of the FSS unit cell is presented in Fig. 2. Before the calculation, the initialization values were set in the model firstly, and all the parameters of FSS are defined as follows: the thickness of all the FSS are set as $t_1 = t_2 = 0.01$ mm. The unit element's total length (parameter C) is 14.8 mm × 14.8 mm in (x, y) directions. The diameter of the circle metallic period structure (parameter R) is 3.0 mm, and the side length of square metallic period structure including in the first and second FSS layer (parameter a and b) are $a = 2.5$ mm and $b = 2.3$ mm, respectively. In this study, the laser printer instrument named Laser marking machine was produced by Beijing Leijieming Laser Technology Co., Ltd. The metal aluminum FSS layers were carved by Laser marking machine through a designed image files. After that, the prepared FSS layers were stuck to the surface of coating through adhesive.

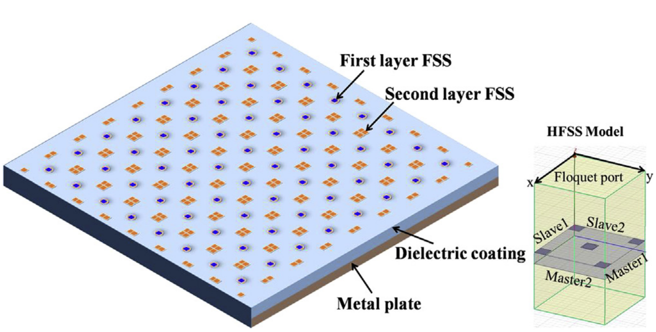

Fig. 1. Sketch of the FSS radar absorber structure and HFSS simulation model.

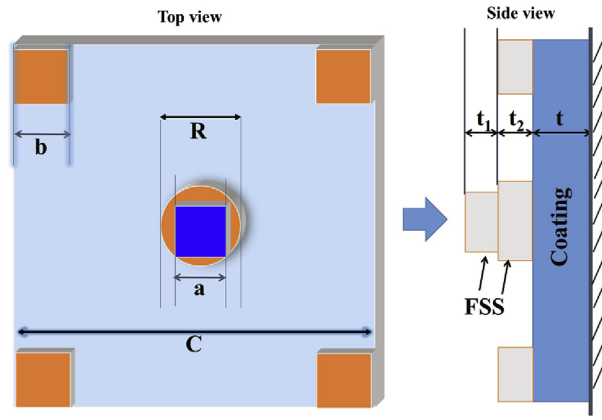

Fig. 2. Schematic structure of the FSS unit cell. C is the period of the FSS, R is the diameter of the circle, a and b are side length of the square including in the first and the second layer FSS, respectively. t_1, t_2 and t are the thickness of the first and second layer FSS, and the coating, respectively.

Here the complex dielectric constant of TiO_2/Al_2O_3 coating was measured by E8362B PNA network analyzer with wave-guide method. Fig. 3 shows the complex dielectric constant of TiO_2/Al_2O_3 coating measured in the frequency range of 5.85 GHz–18 GHz (C_2-band, X-band and Ku-band). The testing specimens were cut into three rectangular blocks. The dimensions of C_2-band sample is 15.42 mm (width) × 34.48 mm (length), X-band sample is 10.16 mm (width) × 22.86 mm (length) and Ku-band sample is 7.85 mm (width) × 15.76 mm (length) for the measurement of dielectric properties. The loss tangent of coating can be calculated by the formula [28,29]: $\tan\delta = \varepsilon''/\varepsilon'$, ε' and ε'' represent the real part and imaginary part of dielectric constant of the materials, respectively. Thus, the loss tangent result for coating is approximately 0.1667. The thickness of coating t is equal to 2.2 mm.

3. Results and discussion

The influences of real part and imaginary part of dielectric constant of ceramic coating on the reflection loss of RAS are given in Fig. 4 (a) and (b), respectively. From the results in Fig. 4(a), the greater the real part of dielectric constant, the narrower the absorption bandwidth of reflection loss, and the absorption peak will shift to lower frequency. From the results in Fig. 4(b), the greater

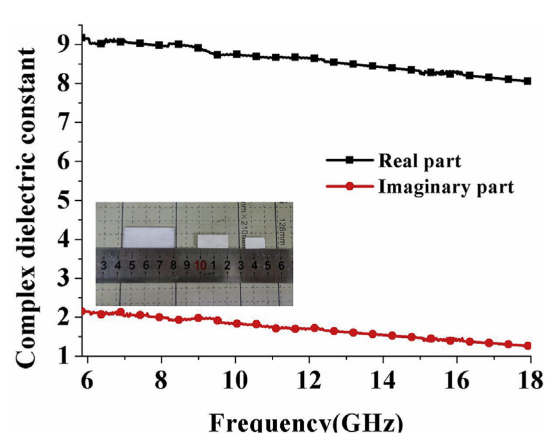

Fig. 3. The real and imaginary part of complex dielectric constant of coating.