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Study on the Design of Multi-Layer Absorbing Materials by Genetic Algorithm

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Abstract

Multilayer medium is one of the most studied objects in an electromagnetic field. In this paper, the problem of genetic algorithm design for multilayer microwave absorbing materials is studied. By using the genetic algorithm, this paper minimizes the reflection coefficient of electromagnetic waves, which is the objective function. Genetic algorithm is used to solve the problem of optimizing the configuration of absorbing materials. Finally, the simulation results are implemented and confirm the effectiveness of the proposed method.

Subject Areas

Electric Engineering

Keywords

Electromagnetic Wave Reflection Coefficient, Genetic Algorithm, Microwave Absorbing Material

1. Introduction

In the design of absorbing materials, optimization problems are often encountered. For example, the thickness, permittivity, permeability and other parameters of the multi-layer dielectric absorbing material covering the metal surface can be selected in the actual design. It is always hoped that when the electromagnetic wave incident vertically on the material, the reflection coefficient is the smallest, the bandwidth is the widest, and the thickness of the material is the thinnest. This is also a typical nonlinear, multi-objective optimization problem. The reflection coefficient, working bandwidth, material thickness and so on are the objective functions, while the dielectric layer thickness and electromagnetic parameters are the free variables. We give an example of a two-dimensional schematic diagram, see **Figure 1**. The circular areas of different colors represent materials with different absorption coefficients.

Layered media is one of the most studied objects in the electromagnetic field. The analysis of electromagnetic phenomena in layered media can be dealt with in the form of "Fields" in addition to using Maxwell's equations, which can also be based on the concept of voltage, and current, and the use of the "Road" concept to study. In most cases, absorbing materials are covered on the surface of metal objects to reduce the electromagnetic scattering of metal objects. In this case, a part of the electromagnetic wave into the absorbing material, and due to the material loss, electrical energy is into heat, thus reducing the reflected electromagnetic wave energy. Usually, the requirement of absorbing material is not only thin thickness, but also light weight, but also good absorbing property, high mechanical strength and so on. In the case of low frequency, the material thickness is particularly important, otherwise, the absorbing material is too thick.

However, single-layer dielectric materials are often difficult to meet the requirements. Therefore, in recent years, the introduction of magnetic microwave-absorbing materials in the field of research has become a hot spot. This is because a magnetic material with permeability greater than 1 can have a higher refractive index than a normal dielectric material, and therefore can be designed to be very thin in this case. At the same time, researchers proposed a multi-layer absorbing material design theory based on different thicknesses, and different materials. Through the optimization of thickness and material, they can achieve a relatively excellent absorbing effect, for this type of absorbing material design, using Genetic algorithm is more convenient. Mathematically, all optimization methods are to calculate the minimum value (or maximum value) of a multivariate function when the independent variable meets certain restrictions, and return the optimal independent variable corresponding to the minimum value (or maximum value).

Genetic algorithm is a classical optimization algorithm, which uses the principle of gene combination in evolutionary theory for reference. Compared with other algorithms, the genetic algorithm has a better ability for global adjustment and search, and its adaptive search process makes the algorithm more efficient. For

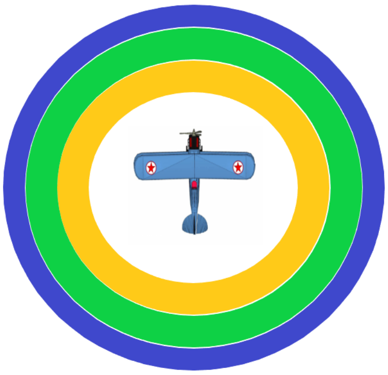

Figure 1. Picture of multi-layer absorber.

many problems in the field of electromagnetic field, this algorithm can get accurate and efficient results [1].

The multi-objective optimization design of a multilayer radar absorbing material is demonstrated in [2]. The MRAM's fast calculation algorithm is proposed and validated to be in good agreement with the commercial electromagnetic computing software in [2]. Based on composite a multilayer radar absorbing material is designed using a dual-objective optimization method butterfly optimization algorithm. Especially, the two objective functions regard total reflection involving total thickness and sub-reflection at the inner layers [3]. To improve the reliability of the design and maximize the radar absorbing performance of the absorbent, a design method for the gradient and multi-layer radar absorbing patch using carbon black as the absorbent was proposed in this paper [4]. Compared with the traditional rectangular form, the curvilinear architecture mitigates corner radius effects in both the additive manufacturing process and the electromagnetic performance.

2. Representation of Layered Wave Absorption

Figure 2 shows a layered medium consisting of a wave-absorbing material, the material at the bottom covered with metal conductor plate; the uniform plane electromagnetic wave incident obliquely on the absorbing material from the air and the incident angle is θ. The direction of the electric field intensity is perpendicular to the incident plane, which is called the transverse electric mode (TE); correspondingly, if the magnetic field strength is perpendicular to the incident plane, it is called a transverse magnetic mode (TM).

Taking layer i medium as an example, we assume that the relative permittivity of the material is ε_{ir}, the permittivity is ε_i, the relative permeability is μ_{ir}, and the permeability is μ_i, the frequency of wave is ω_i. In TE mode, the corresponding transmission parameters are shown in (1) and (2).

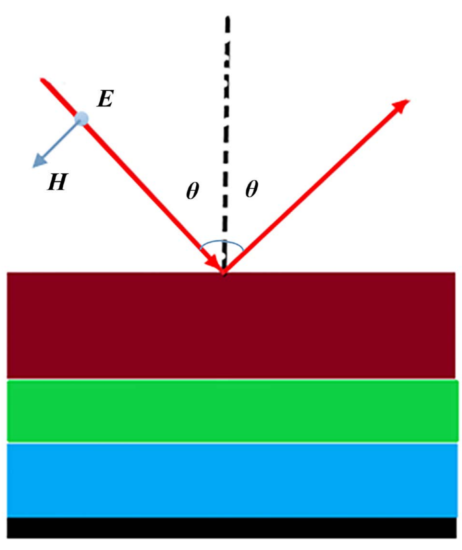

Figure 2. Picture of multi-layer absorber.

$$\beta_i = k_{iz} = k_0 \sqrt{\varepsilon_{ir}\mu_{ir} - \sin^2\theta}, \tag{1}$$

$$Z_{ic} = \frac{\omega_i \mu_i}{\beta_i}, \tag{2}$$

$$k_0 = \omega_0 \sqrt{\varepsilon_0 \mu_0}, \tag{3}$$

where k_0 represents the wave number in vacuum. For TM mode, the parameters of the corresponding transmission line are

$$\beta_i = k_{iz} = k_0 \sqrt{\varepsilon_{ir}\mu_{ir} - \sin^2\theta}, \tag{4}$$

$$Z_c = \frac{\beta_i}{\omega_i \varepsilon_i}, \tag{5}$$

In general, the wave absorbing materials composed of multilayer media can be represented by transmission line cascades. A standard method has been established to analyze the reflection coefficient of layered microwave absorbing materials using the transmission line method

3. Genetic Algorithm Design of Multilayer Microwave Absorbing Materials

In this paper, we consider using 4 layers of medium to realize the absorbing material in the frequency band of 8 - 12 GHz, the corresponding number of free variables is 8. The material variable takes the integer of 1 - 12 as the integer variable; we assume that the thickness of the absorbing material does not exceed 3 mm, then the average thickness of each layer is less than 0.75 mm. Therefore, the value range of each thickness variable is [0, 0.75]. In this paper, the reflection coefficient of electromagnetic wave is taken as the objective function, and the genetic algorithm is used to minimize the objective function.

Corresponding to the incident angle 0, $\pi/6$, $\pi/4$, $\pi/3$, the curve of the corresponding reflection coefficient of the optimized absorbing material is shown in **Figure 3** and **Figure 4**.

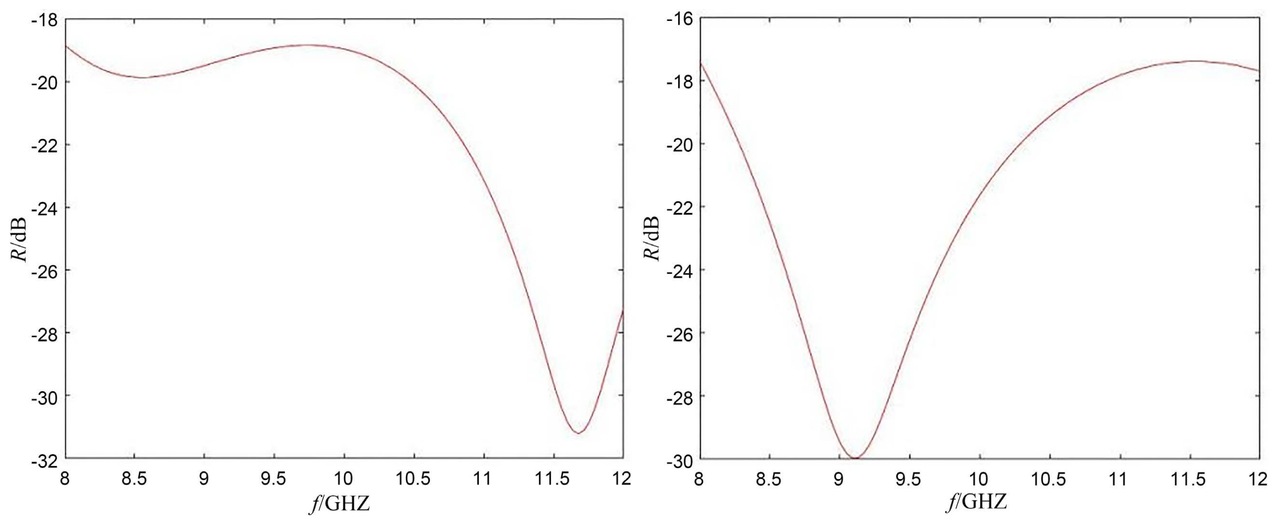

Figure 3. Angle of incidence 0, $\pi/6$.

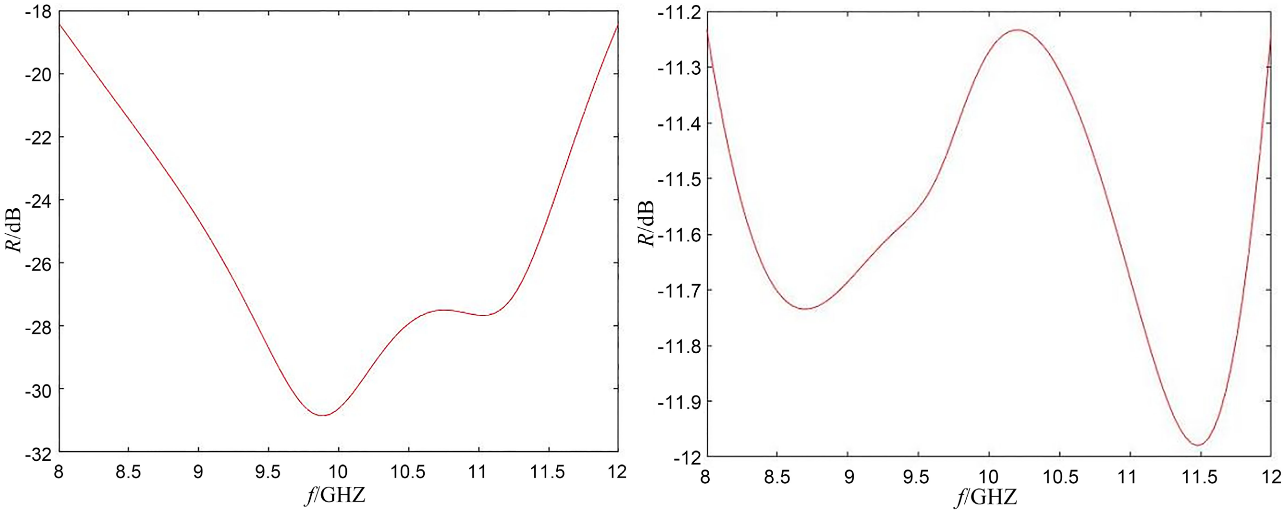

Figure 4. Angle of incidence $\pi/4$, $\pi/3$.

Angle	Parameter	First	Second	Third	Fourth
0	material number	1	1	2	4
0	material thickness	0.6481	0.6873	0.6595	0.2414
$\pi/6$	material number	1	2	2	2
$\pi/6$	material thickness	0.5885	0.2748	0.6407	0.6142
$\pi/4$	material number	3	1	5	4
$\pi/4$	material thickness	0.6446	0.4727	0.7497	0.2678
$\pi/3$	material number	3	1	4	2
$\pi/3$	material thickness	0.7444	0.5886	0.2320	0.7051

Figure 5. Thickness of the microwave absorbing material.

See **Figure 5** for the corresponding material number and thickness of the microwave absorbing material optimized by the genetic algorithm.

From **Figure 3** and **Figure 4**, the absorbing material optimized by the genetic algorithm has a very small reflection coefficient in the 8 - 12 GHz frequency band, and its thickness is less than 3 mm, that is, 1/8 of the shortest working wavelength. It can be seen that genetic algorithm can greatly improve the performance of microwave absorbing materials. The disadvantage is that the genetic algorithm has randomness in the selection of the initial population, so each time when the genetic algorithm is running, it gets different results.

4. Conclusions

Genetic algorithm is widely used in the field of material design. Recently, the design ideas of multilayer absorbing materials with different materials and thicknesses have also been put forward continuously. Through the optimization of thickness and materials, relatively ideal absorbing effects can be achieved.

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Conflicts of Interest

The authors declare no conflicts of interest.

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