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Optimized Design of Multi-Layer Absorber for Human Tissue Surface

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Abstract — In this paper, the structure optimization scheme of multi-layer absorber on the surface of human tissue is designed. The absorber uses graphite, foam and other materials to build a resistance loss layer. Solve the electromagnetic parameters of graphite through its characteristics, use the equivalent transmission line theory to calculate the reflection coefficient. Establish the objective function of the reflection coefficient, and use genetic algorithm to optimize the design of the absorbing device. The experimental results show that compared with the Jaumann type three-layer absorber, the reflection coefficient of the multi-layer absorber optimized by genetic algorithm in this paper has decreased by nearly 13 dB. From the analysis of error and sensitivity, it can be concluded that when the material thickness error is within the range of ±0.005 mm, the microwave absorption performance error of the multilayer absorber is about 5%. Within this error range, the performance of the multilayer absorber can be guaranteed. The sensitivity analysis results of the materials in each layer of the absorber indicate that the concentration and thickness of the graphite layer have the greatest impact on the performance of the absorber.

Key words — Electromagnetic wave, Multi-layer, Wave-absorber, Equivalent transmission line theory, Genetic algorithm, Electromagnetic parameters.

I. Introduction

With the continuous development of society and the continuous improvement of people's living standard, various kinds of pollution have also been produced. In addition to the familiar water pollution, air pollution and other pollution, electromagnetic radiation pollution, which is invisible pollution to our human body and has an increasing impact, has caused widespread concern. In daily life, the application of electromagnetic wave has been everywhere, we are always in a sea composed of electromagnetic wave. In normal circumstances, the right amount of electromagnetic waves will not affect the human body, on the contrary, excessive electromagnetic radiation will have many adverse effects on the human body. Because electromagnetic wave itself has certain penetrating ability, when excessive electromagnetic wave passes through human tissues, various cells in human body will block electromagnetic wave [1]. In this process, part of the electromagnetic radiation will be converted into heat and stay in the body. If the heat generated exceeds the safe limit, it will cause rapid dehydration of human cells and damage to organs and glands with high water content in the body [2], [3]. Enters the body when the high frequency electromagnetic wave transmission at the same time, with various molecular ionization effect in human body, can lead to protein, DNA and other molecules of molecular bond fracture, make its active cell loss lose their original function [4], if the cells to produce large degree of variation, may produce cancer threat to the human body [5]. Based on the electromagnetic induction effect, when a large number of electromagnetic waves into the body, will and tissue reaction induced current, and the body's nervous system is relying on low current to work [6], [7]. When the electromagnetic wave is excessive current, will affect the normal work of the nervous system, even will cause neurasthenia [8], [9].

Electromagnetic radiation has the influence and harm to human body, in order to protect the security of the human body, absorbing materials are widely used, such as graphite and absorbing structure composite material [10]. In this paper, based on the current research

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status and research designs a human surface tissue absorber, using multilayer absorbing material, make its overlapping, improve performance, solved the limitation of single absorbing material on the performance, the improved a great deal on the ability to absorb electromagnetic energy, make human body to avoid damage due to absorb excessive electromagnetic wave [11]. On top of that, today, for the use of electromagnetic waves on the medical field is very wide, when using terahertz wave detecting tumor, electromagnetic radiation will spread around. At this time shielding electromagnetic wave absorber is very important, so the design of a kind of absorbing material can be wield to the skin layer of human body, for further strengthening the popularity of tumor detection and early prevention of cancer, has an important significance [12]–[15].

II. Analysis of Absorbing Principle and Performance of Multi-Layer Absorber

1. A uniform plane wave is perpendicular to the interface

The vertical incidence of radar electromagnetic waves on the interface [16], [17], the radar electromagnetic waves are radiated vertically from medium 1 into medium 2. Fig.1 shows the vertical incidence of the interface between two ideal media.

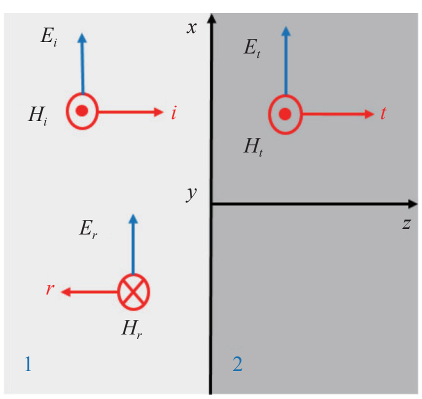

Fig. 1. Vertical incidence of the interface between two ideal media.

For an ideal dielectric surface vertical incidence [18], wave impedance η is defined as the ratio of electric intensity to magnetic intensity. $z<0$, medium parameters in medium 1 are μ_1, ε_1; $z>0$, medium parameters in medium 2 are μ_2, ε_2.

$$\eta_1 = \frac{\sqrt{\mu_1}}{\sqrt{\varepsilon_1}}$$
$$\eta_2 = \frac{\sqrt{\mu_2}}{\sqrt{\varepsilon_2}} \tag{1}$$

According to the boundary conditions of tangential electric field and tangential magnetic field, $z=0$.

$$E_1(z=0) = (E_{\rm im}+E_{\rm rm}) = E_{\rm t}(z=0) = E_{\rm tm}$$
$$H_1(z=0) = \left(\frac{E_{\rm im}}{\eta_1} - \frac{E_{\rm rm}}{\eta_1}\right) = H_2(z=0) = \frac{E_{\rm tm}}{\eta_2} \tag{2}$$

The ratio of the transmitted wave electric field strength ($E_{\rm tm}$) to the incident wave electric field strength ($E_{\rm im}$) is defined as the transmission coefficient Γ, i.e.,

$$\Gamma = \frac{E_{\rm tm}}{E_{\rm im}} = \frac{2\eta_2}{\eta_2+\eta_1} \tag{3}$$

From the above, the intensity of electric field and magnetic field of reflected wave in medium 1 can be deduced. Finally, the formula of total electric field and total magnetic field of junction in medium 1 can be deduced as follows:

$$\vec{E}_1(z) = \vec{E}_{\rm i}(z) + \vec{E}_{\rm r}(z) = \vec{e_x}E_{\rm im}(e^{-{\rm j}\beta_1 z} + \Gamma e^{{\rm j}\beta_1 z})$$
$$\vec{H}_1(z) = \vec{H}_{\rm i}(z) + \vec{H}_{\rm r}(z) = \vec{e_y}\frac{E_{\rm im}}{\eta_1}(e^{-{\rm j}\beta_1 z} - \Gamma e^{{\rm j}\beta_1 z}) \tag{4}$$

The electric and magnetic field intensity of transmitted wave in medium 2 is

$$\vec{E}_2(z) = \vec{E}_{\rm t}(z) = \vec{e_x}\tau E_{\rm im}e^{-{\rm j}\beta_2 z}$$
$$\vec{H}_2(z) = \vec{H}_{\rm t}(z) = \vec{e_y}\frac{\tau E_{\rm im}}{\eta_2}e^{-{\rm j}\beta_2 z} \tag{5}$$

2. The vertical incidence of uniform plane wave on the boundary plane of three layers of medium

The propagation of electromagnetic waves in multi-layer media has general practical significance [19]. Taking the multi-layer medium formed by three kinds of media as an example, illustrate the propagation process of plane wave in multi-layer medium and its solving method. According to the coordinate system established in Fig.2, we can analyze the field quantity relationship in the multi-layer medium.

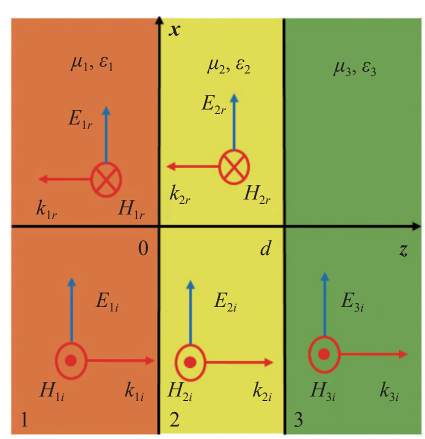

Fig. 2. Vertical incidence of uniform plane wave to the boundary plane of three-layer medium.

The expressions of the combined electric field and magnetic field in media 1 are

$$\begin{aligned}\vec{E_1}(z) &= \vec{e_x}(E_{1\text{im}}e^{-\mathrm{j}\beta_1 z} + E_{1\text{rm}}e^{\mathrm{j}\beta_1 z}) \\ &= \vec{e_x}E_{1\text{im}}(e^{-\mathrm{j}\beta_1 z} + \Gamma_1 e^{\mathrm{j}\beta_1 z}) \\ \vec{H_1}(z) &== \vec{e_y}\frac{E_{1\text{im}}}{\eta_1}(e^{-\mathrm{j}\beta_1 z} - \Gamma_1 e^{\mathrm{j}\beta_1 z}) \\ \Gamma_1 &= \frac{E_{1\text{rm}}}{E_{1\text{im}}}\end{aligned} \tag{6}$$

The combined electric and magnetic fields in medium 2 can be expressed as follows:

$$\begin{aligned}\vec{E_2}(z) &= \vec{e_x}[E_{2\text{im}}e^{-\mathrm{j}\beta_2(z-d)} + E_{2\text{rm}}e^{\mathrm{j}\beta_2(z-d)}] \\ &= \vec{e_x}\tau_1 E_{1\text{im}}[e^{-\mathrm{j}\beta_2(z-d)} + \Gamma_2 e^{\mathrm{j}\beta_2 z(z-d)}] \\ \vec{H_2}(z) &= \vec{e_y}\frac{\tau_1 E_{1\text{im}}}{\eta_2}(e^{-\mathrm{j}\beta_2(z-d)} - \Gamma_2 e^{\mathrm{j}\beta_2(z-d)})\end{aligned} \tag{7}$$

where $\tau = \frac{E_{2\text{im}}}{E_{1\text{im}}}$; $\Gamma_2 = \frac{E_{2\text{rm}}}{E_{2\text{im}}}$.

The combined electric and magnetic fields in medium 3 can be expressed as follows:

$$\begin{aligned}\vec{E_3}(z) &= \vec{e_x}E_{3\text{im}}e^{-\mathrm{j}\beta_1(z-d)} = \vec{e_x}\tau_1\tau_2 E_{1\text{im}}e^{-\mathrm{j}\beta_2(z-d)} \\ \vec{H_3}(z) &= \vec{e_y}\frac{\tau_1\tau_2 E_{1\text{im}}}{\eta_3}e^{-\mathrm{j}\beta_2(z-d)}\end{aligned} \tag{8}$$

3. The vertical incidence of uniform plane wave on the boundary plane of multi-layer medium

In multi-layer absorbing material, the first layer is in contact with the metal surface, while the outer layer is composed of multiple layers. The outermost layer is in contact with the tissue of the background material. The schematic diagram of the vertical incidence of plane electromagnetic wave on multi-layer absorbing materials with metal as substrate is shown in Fig.3.

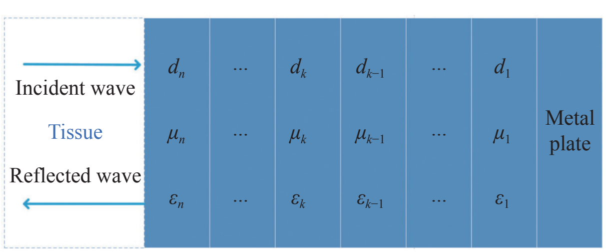

Fig. 3. Schematic diagram of electromagnetic wave incident to multi-layer structure absorbing material.

The incident port of electromagnetic wave is forward along the z-axis, and the boundary conditions of electromagnetic wave vertically incident in the direction of the x-axis and y-axis are set as periodic boundaries. In Fig.3, d_k, μ_k, ε_k are the thickness, relative complex permeability, and dielectric constant of k-th layer respectively. μ_0 is the magnetic conductivity in vacuum; ε_0 is the dielectric constant in vacuum.

According to Kraus's transmission line impedance conversion equation and the transmission line theoretical model of electromagnetic wave propagation, the overall theoretical reflectivity can be calculated according to the equivalent electromagnetic parameters of each layer of the model and the transmission line theory and the reflectivity calculation formula [20], [21].

η_k and γ_k are the characteristic impedance and electromagnetic wave propagation coefficient of the k-th layer respectively.

$$\begin{aligned}\eta_k &= \eta_0\sqrt{\frac{\mu_{rk}}{\varepsilon_{rk}}} \\ \gamma_k &= \mathrm{j}w\sqrt{\tilde{\mu}\tilde{\varepsilon}} = \mathrm{j}w\sqrt{\mu_0\varepsilon_0\tilde{\varepsilon_k}} = \mathrm{j}\frac{w}{c_0}\sqrt{\tilde{\varepsilon_k}} = \mathrm{j}\left(\frac{2\pi f}{c_0}\right)\sqrt{\mu\varepsilon}\end{aligned} \tag{9}$$

According to (9), the input impedance of the first layer is used as the load impedance of the second layer, and so on, so the input impedance $Z_{\text{in}(k)}$ at the k-th layer of the multi-layer material is

$$Z_{\text{in}(k)} = \eta_k\frac{Z_{\text{in}(k-1)} + \eta_k\tanh(\gamma_k d_k)}{\eta_k + Z_{\text{in}(k-1)}\tanh(\gamma_k d_k)} \tag{10}$$

where $Z_{\text{in}(k)}$ is the input impedance at the $(k-1)$th layer, when $k=1$, $Z_{\text{in}(k-1)}$ represents the input impedance of the metal backing, for ideal conductor, $Z_{\text{in}(0)}=0$, $Z_{\text{in}(1)} = \eta_k\tanh(\gamma_k d_k)$.

η_0 is natural impedance of free space, $\eta_0 = 377\ \Omega$. μ_{rk} and ε_{rk} are the relative complex magnetic conductivity and dielectric constant of the k-th layer medium, $\mu_0 = 4\pi 10^{-7}\ \text{H/m}$, f is the electromagnetic wave frequency (3–8 GHz), c_0 is velocity of light in vacuum, and j is the imaginary unit.

When electromagnetic waves are emitted vertically from biological tissues into multi-layer absorbent materials, in biological tissues, we have

$$\begin{aligned}\eta_{\text{T}} &= \sqrt{\frac{\tilde{\mu}}{\tilde{\varepsilon}}} = \sqrt{\frac{\mu_0}{\varepsilon_0}}\cdot\frac{1}{\sqrt{\tilde{\varepsilon_0}}} = \frac{\eta_0}{\sqrt{\tilde{\varepsilon_0}}} = \frac{377}{\sqrt{10-\mathrm{j}4}} \\ \gamma_{\text{T}} &= \mathrm{j}w\sqrt{\tilde{\mu}\tilde{\varepsilon}} = \mathrm{j}w\sqrt{\mu_0\varepsilon_0\tilde{\varepsilon_{\text{T}}}} = \mathrm{j}\frac{w}{c_0}\sqrt{\tilde{\varepsilon_{\text{T}}}} = \mathrm{j}\frac{2\pi f}{c_0}\sqrt{10-\mathrm{j}4}\end{aligned} \tag{11}$$

where the dielectric constant of the tissue is $\tilde{\varepsilon_{\text{T}}} = 10-\mathrm{j}4$, magnetic permeability $\mu_{\text{T}}=1$.

For most materials, $\mu_{\text{r}k}=1$. The relative magnetic permeability of the k-th layer material is

$$\mu_{\text{r}k} = 1 \tag{12}$$

The relative dielectric constant (complex permittivity, real part ε' and imaginary part ε'') of the k-th layer material is

$$\varepsilon_{rk} = \varepsilon'_{rk} - j\varepsilon''_{rk} \tag{13}$$

where ε' describe the ability of materials to store electromagnetic field energy; the loss factors ε'' measures the loss of energy of the electromagnetic wave by the material.

When electromagnetic waves are emitted vertically from biological tissues to multi-layer absorbing materials, according to the connection conditions of the medium on the interface, the following relations exist between incident wave E_i, reflected wave E_r and transmitted wave E_t:

$$\begin{aligned} &E_i + E_r = E_t, \\ &\frac{E_i}{\eta_T} - \frac{E_r}{\eta_T} = \frac{E_t}{Z_{in(k)}} \end{aligned} \tag{14}$$

When $Z_{in(k)}$ is obtained, substituting it into (14), Γ can be calculated as

$$\Gamma = \frac{E_r}{E_i} = \frac{Z_{in(k)} - \eta_T}{Z_{in(k)} + \eta_T} \tag{15}$$

The transmission coefficient τ can be obtained from the following formula:

$$\tau = \frac{E_t}{E_i} = \frac{2Z_{in(k)}}{Z_{in(k)} + \eta_T} \tag{16}$$

The outermost layer is in contact with the tissue. According to the background material of the design, η_T is the characteristic impedance of the tissue $\eta_T = \frac{377}{\sqrt{10-j4}}$. The reflection loss (RL) of the absorbing material can be expressed as

$$\mathrm{RL} = 20\log|\Gamma| \tag{17}$$

where $|\Gamma|$ is the modulus of the reflection coefficient Γ.

Based on the above analysis, the reflection loss as the objective function (the minimum value of RL) can be obtained.

Since the absorber loaded with the all-metal ground plate has a transmittance of 0, we only need to consider the reflection loss of the absorbing property.

Optimization model of multi-layer composite absorbing materials with (1)–(13) as the limiting conditions:

$$\min \mathrm{RL} = 20\log|\Gamma| \tag{18}$$

Requirements: RL < -20 dB. The smaller the RL value, the less the incident electromagnetic wave is reflected, and the better the absorbing properties of the material is.

For example, when RL $= -10$ dB, only 10% of the electromagnetic waves are reflected and 90% of the electromagnetic waves are absorbed.

III. Computing Method

The problem of multi-layer absorbing materials is the reflectivity (reflection loss) of the coating. Therefore, the reflectance is the target, which is strongly associated with the frequency of the incident wave, arrangement of electromagnetic shielding materials, the electromagnetic parameters of the absorbing material, and the thickness of each layer [22], [23].

The absorbing properties of the material are related to its electromagnetic parameters (ε and μ), thickness d and frequency f of the incident electromagnetic wave [24].

Reflection loss is calculated by MATLAB software. We can through the model and formula to get the best performance of composite absorbing material combinations, the reflection coefficient is solved as follows:

$$\begin{cases} \min \mathrm{RL} = 20\log|\Gamma| \\ \Gamma = \dfrac{E_r}{E_i} = \dfrac{Z_{in(k)} - \eta_T}{Z_{in(k)} + \eta_T} \\ Z_{in(k)} = \eta_k \dfrac{Z_{in(k-1)} + \eta_k \tan h(\gamma_k d_k)}{\eta_k + Z_{in(k-1)} \tan h(\gamma_k d_k)} \\ \eta_k = \eta_0 \sqrt{\dfrac{\mu_{rk}}{\varepsilon_{rk}}} \\ \gamma_T = \gamma_1 = jw\sqrt{\tilde{\mu}\tilde{\varepsilon}} = jw\sqrt{\mu_0\varepsilon_0\tilde{\varepsilon_T}} \\ \quad = j\dfrac{w}{c_0}\sqrt{\tilde{\varepsilon_T}} = j\dfrac{2\pi f}{c_0}\sqrt{10-j4} \\ \mu_{rk} = 1 \\ \varepsilon_{rk} = \varepsilon'_{rk} - j\varepsilon''_{rk} \\ f \in (3,8)\ \mathrm{GHz} \\ 1 \le k \le n \\ \eta_T = \eta_1 = \dfrac{377}{\sqrt{10-j4}} \\ Z_{in(0)} = 0 \\ \eta_0 = 377\ \Omega \end{cases} \tag{19}$$

Input the relevant parameters $(\mu', \mu'', \varepsilon', \varepsilon'', d)$ of each layer of material at a specific frequency f, and finally obtain the reflection loss value of absorbing material.

$$\Gamma = F(f, C, d_1, d_2, \ldots, d_n) \tag{20}$$

where C is a different combination of materials.

Therefore, by calculating the reflection loss of materials with different thickness, the combination of materials with the best performance can be obtained.

IV. Optimization Design

When the totality reflection coefficient of the absorbing material is the minimum, the electromagnetic parameters of per layer of material are the data we need.

Then F becomes the objective function (as shown in (18)), C is the different combination of materials, and the objective function of the optimized design of multi-layer absorbing materials is

$$\begin{cases} \min \mathrm{RL} = 20\log|F| \\ \sum_{1}^{n} d(k) \le D \\ 0 \le d(k) \le D \end{cases} \tag{21}$$

where, D refers to the total thickness of the absorbing material, and $d(k)$ refers to the thickness of per layer of absorbing material.

The solution of the objective function. According to the basic principle and application steps of genetic algorithm, the equivalent transmission line method calculates the reflectivity of multi-layer absorbing materials and the method of solving the objective function by Newton-Cotes numerical integration [25]–[29].

The reflectivity formula shows that the reflectivity of the absorbing material to the incident electromagnetic wave is related to the thickness of per layer of material, the electromagnetic parameters $\varepsilon', \varepsilon''$ of the materials of each layer and the frequency of incident electromagnetic wave. The electromagnetic parameters of the multi-layer absorbing materials are related to the dielectric materials selected for each layer [30]. The frequency characteristics of incident electromagnetic waves are reflected in the bandwidth characteristics of the absorbing materials, which are related to the electromagnetic parameters and structural parameters of the materials [31], [32]. So, if we want to optimize the absorbing material, it means to optimize its structural parameters. The optimization method adopted in this paper is genetic algorithm, and the operation process is shown in Fig.4.

As shown in Fig.4, first, the number of material layers and genetic algebra are determined, and the initial population is coded to calculate its fitness. Then, new individuals are selected and created to join the population by means of selection, crossover and variation until there are qualified individuals in the population [33], [34].

The reflectivity F is always negative after taking the logarithm, assuming that the fitness function of individuals in the population is F and $Fi = -Si$, so solving the minimum value of the reflectivity objective function is equivalent to solving the maximum value of the fitness function. Selection, crossover and variation value design: The proportional selection method (roulette rule) was used to select the single point crossover operator as the total crossover operator and the basic mutation operator as the total mutation operator in the population, and the mutation rate was set as P_{m}. Optimization program numerical setting: the initial parameter is set as population size $M = 100$; Genetic algebra $I = 1000$, crossover probability $P_{\mathrm{c}} = 0.77$, mutation probability $P_{\mathrm{m}} = 0.03$.

The properties of absorbing materials should be light and thin, thickness should be considered in design [35], [36].

Therefore, it is necessary to pay attention to this problem when decoding the thickness. The total thickness of the decoded absorbing coating material must be within a limited thickness range. But how can we meet this design requirement?

We can use reverse-thinking methods to get a solution to this problem.

After the coding method and the decoding scheme are determined, random generation of primary population, according to the principle of survival of the fittest and the evolution, generation by generation evolution to produce better and better approximate solutions, until the desired results are obtained [37].

V. Results and Analysis

Putting the equivalent electromagnetic parameters of the multi-layer structure into (1)–(20), can obtain the theoretical reflectivity of the model and the results compared with the simulation and the actual test results (contrast derivation, simulation and reflection loss comparison of physical sample test). The electromagnetic parameters of actual samples can be detected by U.S. Agilent E8363C vector network analyzer [38].

1. Parameter design of absorbent

In this optimization design, the absorber uses a mixture of graphite and acrylic paint to form the resistance loss layer required by the multilayer absorber. After a detailed examination of the effects of graphite concentration and layer thickness on conductivity and surface resistivity, the results now available indicate that numerical analysis of graphite concentration can be performed to predict the permittivity of different concentrations of graphite in paint mixtures. For the composite material M, real part of permittivity ε_{M} and conductivity σ_{M} can be expressed by the following formula:

$$\begin{aligned} \sigma_{\mathrm{M}} &= K_1 f^{x} + K_2 \\ \varepsilon_{\mathrm{M}} &= K_3 f^{-y} + K_4 \end{aligned} \tag{22}$$

K_{1-4}, x, and y vary with the concentration of conductive additive. K_{1-4}, x, and y vary with the concentration of conductive additive:

$$K_i = a_i \times m^3 + b_i \times m^2 + c_i \times m + d_i, \quad i = 1,2,3,4 \tag{23}$$

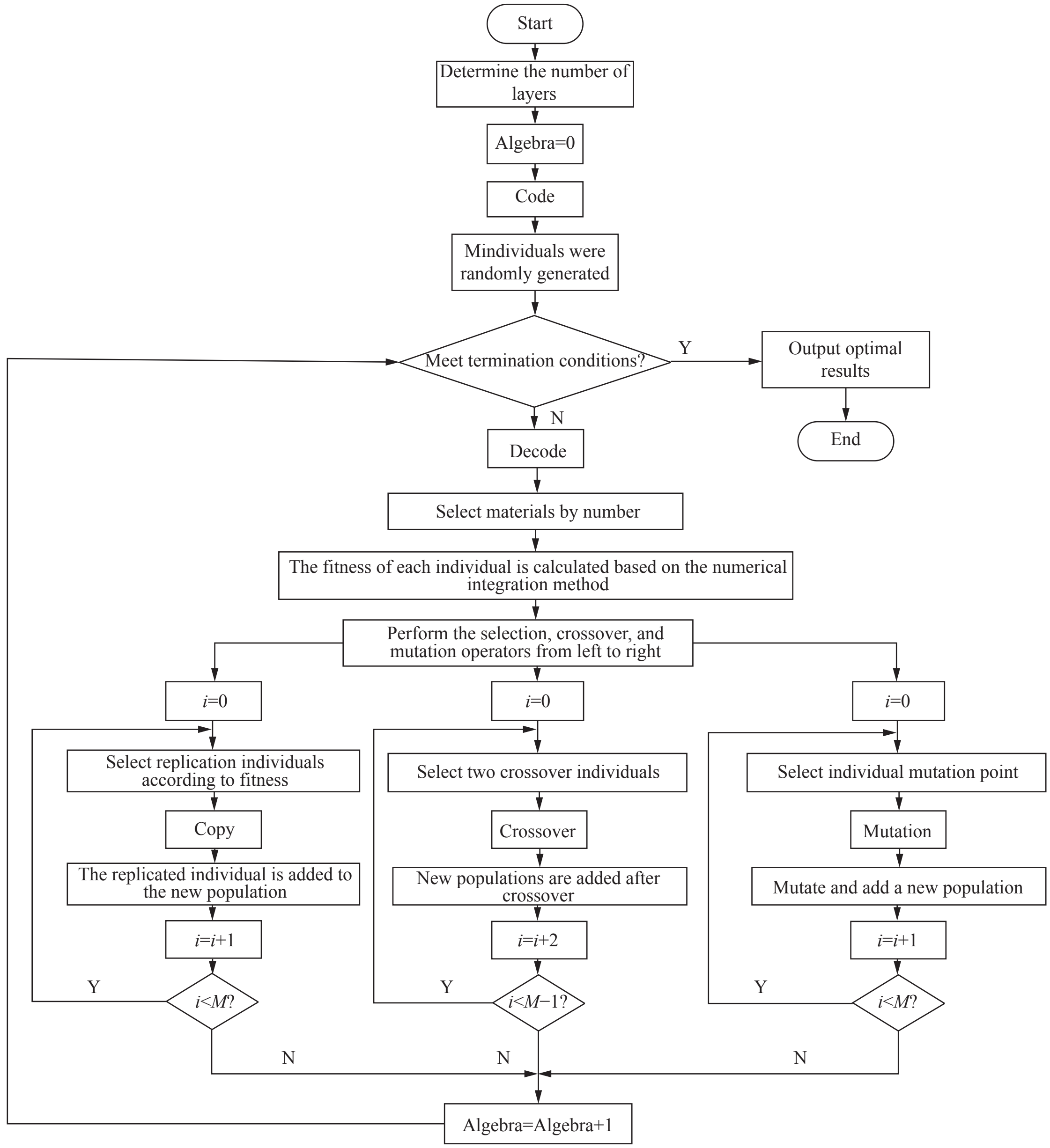

Fig. 4. Genetic algorithm optimization process.

where a_i, b_i, c_i and d_i are polynomial values and m is graphite concentration. K values at different concentrations are shown in Table 1.

The former coefficients of K_1–K_4 in the polynomial, a_i, b_i, c_i, d_i are constants, which are obtained through a large number of experimental statistics. The value is shown in Table 2.

The absorption band of the absorbing material refers to the frequency range in which the reflectivity of the material is lower than a certain required value. Under the same conditions, the wider the absorption band and the lower the reflectivity, the better the absorbing performance. Therefore, the structure of multilayer absorber is optimized by taking the type, thickness and absorber concentration of each layer of materials as variables and taking expanding the absorption band

Table 1. *K* values at eight different graphite concentrations

	1	2	3	4	5	6	7	8
$m\%$	3	5.9	8.9	11.9	17.8	26.7	32.6	38.6
K_1	0.0148	0.0234	0.034	0.0507	0.1187	0.3743	0.6954	1.1869
K_2	2.6278	3.3272	2.76	1.461	0.9628	4.2108	20.048	51.684
K_3	2.5495	2.4265	2.8755	4.7418	15.790	63.132	124.23	218.37
K_4	3.9184	5.0506	6.38	7.9571	12.110	22.260	32.527	46.651

Table 2. K_1–K_4 coefficients in the polynomial

	K_1	K_2	K_3	K_4
a	0.0000277	0.003626	0.00519	0.000532
b	−0.0004	−0.13747	−0.05983	−0.0005
c	0.004836	1.241693	0.170852	0.362121
d	0.003163	0.042248	2.435287	2.82223

width of materials and reducing reflectivity as the optimization goal.

Programming with MATLAB. The electromagnetic parameters of each layer of materials are calculated and set, the reflectivity of the multilayer absorber is calculated by using the equivalent transmission line theory [39], [40], genetic algorithm is used to optimize the final data. The final results are shown in the table and graph below.

The material and its parameters used in this optimization procedure are H60 foam material and wave transparent layer in multilayer materials. Pu is dimensional polyurethane, which is used as the package of multilayer absorber and as the protective layer of absorbing material; $P1$ and $P2$ are the concentration of graphite in the absorption layer.

In the structure shown in Table 3, the first layer is the encapsulated Pu, whose thickness is 0.874 mm; The second layer is H60 foam transmission layer, thickness of 0.5 mm; The third layer is the absorbing layer $P1$, the graphite concentration is 32.6%, the thickness is 0.087 mm; The fourth layer is H60 foam permeable layer with a thickness of 8.654 mm. The fifth layer is the absorbing layer $P2$, with a graphite concentration of 29.7% and a thickness of 0.453 mm. The sixth layer is H60 foam permeable layer with a thickness of 0.949 mm. The last layer is a metal reflecting plate.

As shown in Fig.5 and Fig.6, the horizontal axis is frequency f and the vertical axis is reflection loss RL. The less the reflection loss, the better the absorbability.

Table 3. Material types and parameters after optimization

	$P1$(%)	$P2$(%)	Pu(mm)	H60(mm)	$P1$(mm)	H60(mm)	$P2$(mm)	H60(mm)
1	32.6	44.5	0.874	0.500	0.087	8.654	0.453	0.949
2	38.6	32.4	8.280	5.437	0.051	6.035	0.067	5.587
3	20.8	29.7	9.177	3.343	0.228	3.717	0.346	1.248
4	5.9	23.7	6.035	9.327	0.370	1.098	0.327	6.335
5	38.6	14.8	2.220	9.476	0.118	7.307	0.142	3.567

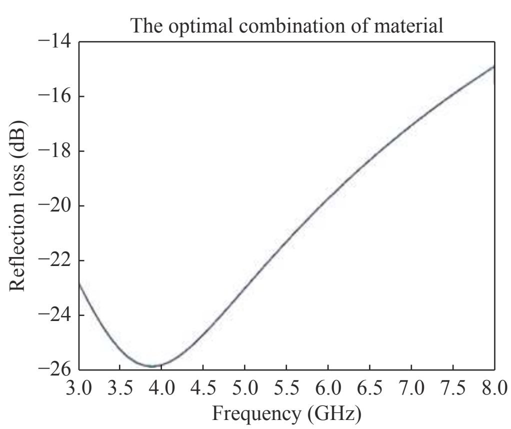

Fig. 5. The optimal combination of material I.

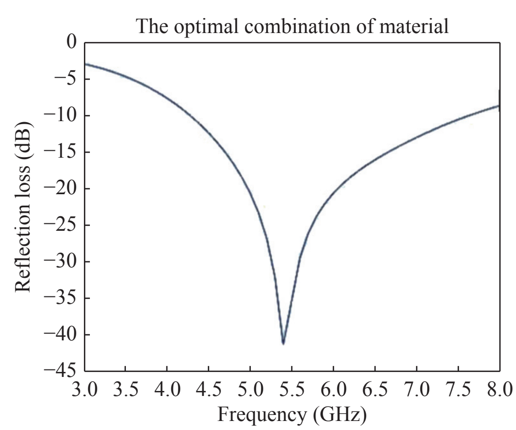

Fig. 6. The optimal combination of material II.

2. Optimization simulation experiment

After five groups of structures with small reflection coefficient and meeting the thickness and graphite concentration required by the optimal design are selected through MATAB program, the first two groups of structures are selected for simulation verification. It is necessary to test the performance of the data optimized by genetic algorithm, the first groups of data are selected from Table 4 for simulation test. In the simulation process, take a point every 0.5 GHz and calculate the electromagnetic parameters of graphite at this frequency. Using the first set of data for simulation, the dielectric constant and tangent loss corresponding to 32.6% and 44.5% graphite are calculated respectively, and brought into the HFSS simulation software.

Fig.7 shows that reflection loss of this group of data is near −48.74 dB to −49.08 dB, which meets the requirement that the reflection loss is less than −20 dB in this optimization design scheme. The overall reflection loss performance is better than the radar absorber mentioned in Amiet et al. [41].

3. Analysis

In order to be able to analyze the influence of machining error on the performance of multilayer ab-

Table 4. Electromagnetic parameter data of the first group of graphite at different frequencies

Frequency (GHz)	$P1$ dielectric real part	$P1$ dielectric imaginary part	$P2$ dielectric real part	$P2$ dielectric imaginary part	$P1$ loss tangent	$P2$ loss tangent
3	73.94	132.63	181.13	648.31	1.7937	3.5793
3.5	68.02	115.47	164.52	560.49	1.6975	3.4069
4	63.59	102.60	152.05	494.62	1.6135	3.2529
4.5	60.13	92.58	142.36	443.39	1.5396	3.1146
5	57.37	84.58	134.61	402.41	1.4741	2.9895
5.5	55.12	78.02	128.26	368.88	1.4156	2.8759
6	53.23	72.56	122.98	340.94	1.3631	2.7723
6.5	51.64	67.94	118.51	317.29	1.3157	2.6775
7	50.28	63.98	114.67	297.03	1.2727	2.5903
7.5	49.09	60.55	111.35	279.46	1.2334	2.5098
8	48.06	57.55	108.44	264.09	1.1975	2.4354

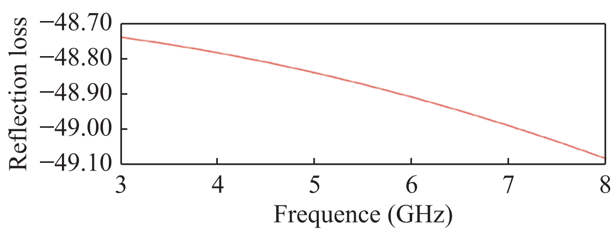

Fig. 7. First group of structural frequency and reflection loss diagram (curve information: dB (S (Floquet port 1:1, Floquet port 1:1), Setup 1:sweep).

sorber according to the manufacturer's conventional machining error; MAPE (mean absolute percentage error) and thickness sensitivity of per layer are further analyzed in this summary to determine the design requirements that may lead to the deterioration of multilayer absorber performance.

1) MAPE analysis

Δh_j is material thickness error values (unit: mm);

$$MAPE = \frac{1}{N}\sum_{x=1}^{N} \left|\frac{y(x+\Delta h) - y(x)}{y(x)}\right| \times 100\% \quad (24)$$

MAPE is the mean absolute percentage error. The relationship between MAPE and thickness error is shown in Fig.8.

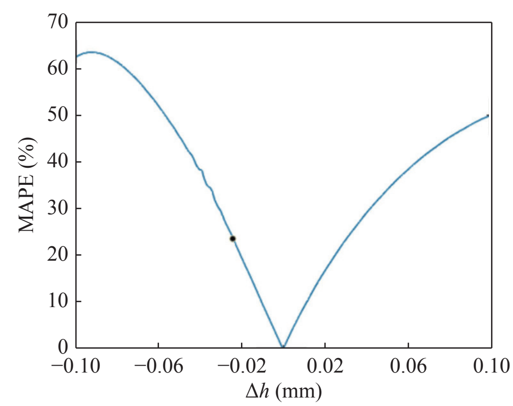

Fig. 8. MAPE absolute percentage error

From the above figure:

$$\begin{aligned} \Delta h &= -0.005 \text{ mm}, & \text{MAPE} &= 4.878\% \,(\approx 5\%) \\ \Delta h &= 0.005 \text{ mm}, & \text{MAPE} &= 4.634\% \,(\approx 5\%) \\ \Delta h &= -0.002 \text{ mm}, & \text{MAPE} &= 1.926\% \,(\approx 2\%) \\ \Delta h &= 0.002 \text{ mm}, & \text{MAPE} &= 1.865\% \,(\approx 2\%) \end{aligned} \quad (25)$$

Therefore, the thickness of each layer of material is within $h \pm 0.002$ mm, and the error does not exceed 2%, the thickness of each layer of material is within $h \pm 0.005$ mm, and the error does not exceed 5%.

2) Sensitivity analysis

Sensitivity analysis was performed on the material thickness of the composite absorbing material (six layers).

Material thickness error:

$$\Delta h_j \approx 0.01 \times h_j, \quad j = 1, 2, \ldots, 6 \quad (26)$$

Sensitivity formula:

$$\text{SA} = \frac{\partial \Gamma}{\partial h_j} = \frac{\Gamma(h_j + \Delta h_j) - \Gamma(h_j)}{\Delta h_j} \quad (27)$$

Γ is the reflection coefficient. The obtained results are shown in Fig.9.

Fig.9 shows that the sensitivity of the graphite layer (the second and fourth layers) is significantly higher than that of the other layers, indicating that the thickness of the graphite layer has a great influence on the experimental results [42]. The sensitivity of the other four layers is relatively small, indicating that the thickness of these four layers has little influence on the experimental results.

VI. Conclusions

At present, tumor has become one of the important causes of death, and how to improve the cure rate and reduce the number of deaths due to tumor has always been the focus of scientific research. Among them,

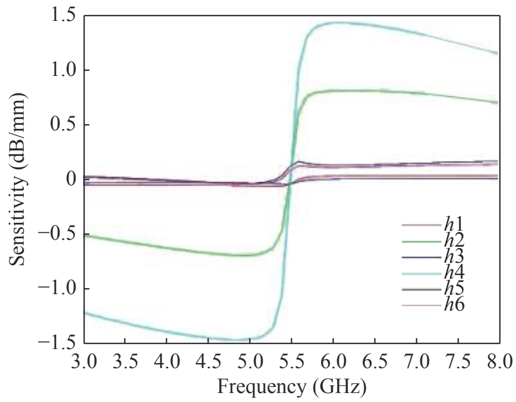

Fig. 9. Sensitivity analysis.

the use of electromagnetic wave to detect tumors can be rapid and noninvasive detection, which is the best choice for early detection of tumors. When using electromagnetic waves to detect tumors, high-frequency electromagnetic waves will be used. Medical research shows that when the human body receives too much electromagnetic radiation for a long time, it will do harm to the human nervous system and immune system. Therefore, a microwave absorber used to isolate electromagnetic waves and prevent their diffusion when detecting tumors is of great significance at present.

In this paper, a kind of absorber applied to the surface tissue of human body is designed according to the absorbing material needed to shield electromagnetic wave in electromagnetic wave detection. The optimization design mainly uses the characteristics of graphite to solve its electromagnetic parameters, calculates the reflection loss through the equivalent transmission line theory, the equivalent transmission line theory can calculate the reflection loss of multilayer structure on the premise of knowing the electromagnetic parameters and thickness of each layer material, and use the value of reflection loss to evaluate the absorbing performance of materials. Then establishes the objective function of reflectivity and uses the Newton-Cortez integral method to solve, uses the genetic algorithm to optimize the thickness of each layer material and graphite concentration. The reflection loss obtained by HFSS simulation is close to −48.74 dB to −49.08 dB, far less than −20 dB, which verifies the effectiveness of this method in optimizing human absorber parameters.

Limited by the computing power of the computer used in the simulation, we calculated the electromagnetic parameters of graphite by taking points every 0.5 GHz in 3–8 GHz. However, in the practical application process, the electromagnetic parameters of graphite change with the frequency in real time. Hence, in the future research, the influence of frequency on the electromagnetic parameters of graphite can be further optimized.

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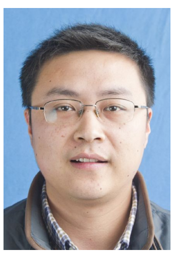

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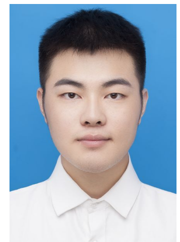

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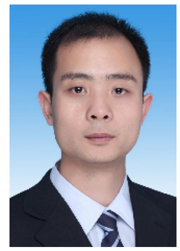

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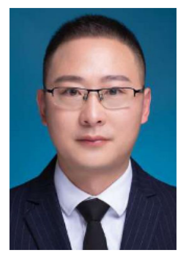

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