Study on Permittivity and Optimal Design of Metamaterial

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Abstract— Artificial electromagnetic materials in the recent years develop rapidly, both in the military aspects about stealth technology and in daily life to absorb harmful electromagnetic waves in nature. As the environmental impact of electromagnetic radiation become terrible. The importance of artificial electromagnetic materials becomes more prominent. Artificial electromagnetic materials have great potential in the antenna and microwave devices and other research fields, because Metamaterials can be produced by the restructure of traditional materials in nature. We use new technology to prepare artificial electromagnetic materials. Therefore, for the study of Metamaterials has become very urgent. This paper analyses the characteristics of the Metamaterials. By the homogenization method we can effectively deal with the periodic structure situation, therefore, faced a similar problems, we can generally use the method of homogenization to solve. Firstly, considering the scope of its application, a frequency selective surface structure was verified. For the homogenization method, scattering parameters results were obtained to compare with the original structure. Target structure uses S-parameter inversion to obtain equivalent electromagnetic parameters. The paper analyses the absorbing properties of the structure, it also pays attention to the energy dissipation. On this basis, using the honeycomb structure instead of the original structure, better absorbing effect can be obtained. As is known, honeycomb structure not only has absorbing effect but also with good mechanical properties. The absorbing materials can effectively absorb the incident electromagnetic wave and make it decay. Cause electromagnetic loss so that electromagnetic energy is converted into thermal energy or other energy forms. Finally, this paper proposes a kind of absorbing structure with better performance.

1. INTRODUCTION

The electromagnetic absorbing materials related to the electromagnetic field and wave theory and the preparation of materials, and many other disciplines. Containing reflection, refraction, is the intersection of many disciplines. Absorbing material not only has special strategic position into the military, but also becoming increasingly widespread in the civil. Therefore, countries are scrambling to invest a lot of manpower and material resources to carry out extensive research [1–4]. Frequency selective surface is formed by a large number of passive elements are arranged in a distributed manner that in accordance with a particular cycle of the quasi-planar layered structure. FSS has good selectivity in transmission and reflection of electromagnetic waves. Application of the frequency selective surface can reach terahertz. Italy Agostino Monorchio and Filippo Costa et al. make depth analysis in frequency selective surface [5–11].

This paper using homogenization method to analyzes the frequency selective surface with high impedance. Homogenization method is a commonly used method [12, 13], is often used to obtain characteristics and parameters of the artificial electromagnetic materials for analysis, methods are required for the given type of structure, and to consider the scope of the methods used. In this paper, we analysis a particular type of absorbing material, first obtain the equivalent electromagnetic parameters, and the effective dielectric constant of the original model for analysis. Then further explore its energy is dissipated in the absorbing material, on this basis, we improved the existing structure, using a honeycomb structure with a better performance on the mechanics and electromagnetism to replace the original structure. At last, better band absorbing properties of absorbing material could be obtained.

2. ELECTROMAGNETIC PARAMETERS OBTAINED BY INVERSION

Think about the Nicholson-Ross-Weir conversion process [14]. Through the S-parameter analysis of the original structure, the reflection coefficient Γ can be calculated, and then further transmission coefficient T. It should be noted that the absolute value of the reflection coefficient could not be greater than 1 to ensure that the result is correct. Then you can calculate the anti performances μ and ε results based on these data.

By the following two formulas:

$$S_{11} = \frac{\Gamma\left(1-T^2\right)}{\left(1-\Gamma^2 T^2\right)} \tag{1}$$

$$S_{21} = \frac{T\left(1-\Gamma^2\right)}{1-\Gamma^2 T^2} \tag{2}$$

The simulation results can be scattered to the parameters. From the above two formulas we can get the reflection coefficient.

$$\Gamma = X \pm \sqrt{X^2-1} \tag{3}$$

It should be noted that the absolute value of the reflection coefficient is less than 1.

The expressions of permeability:

$$\mu_r = \frac{1+\Gamma}{\Lambda(1-\Gamma)\sqrt{\frac{1}{\lambda_0^2}-\frac{1}{\lambda_c^2}}} \tag{4}$$

And we can get the formula:

$$\frac{1}{\Lambda^2} = \left(\frac{\varepsilon_r * \mu_r}{\lambda_0^2} - \frac{1}{\lambda_c^2}\right) = -\left(\frac{1}{2\pi L}\ln\left(\frac{1}{T}\right)\right)^2 \tag{5}$$

In conclusion, we can get the formula about the dielectric constant:

$$\varepsilon_r = \frac{\lambda_0^2}{\mu_r}\left(\frac{1}{\lambda_c^2} - \left(\frac{1}{2\pi L}\ln\left(\frac{1}{T}\right)\right)^2\right) \tag{6}$$

We can get the permittivity and magnetic permeability through the above formula.

Assuming a homogeneous medium model size of 10 mm $*$ 10 mm $*$ 4 mm, its permittivity is 4 and the permeability is 1, External air cavity is 10 mm $*$ 10 mm $*$ 80 mm, as shown in Fig. 1.

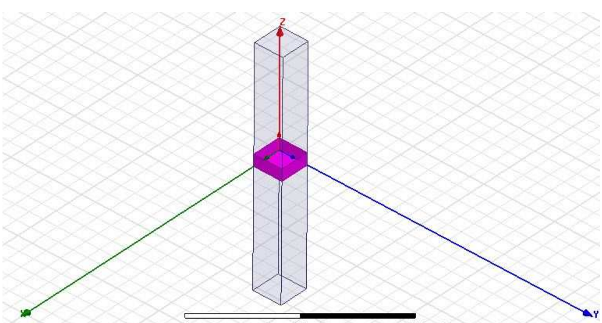

Figure 1: A unit structure.

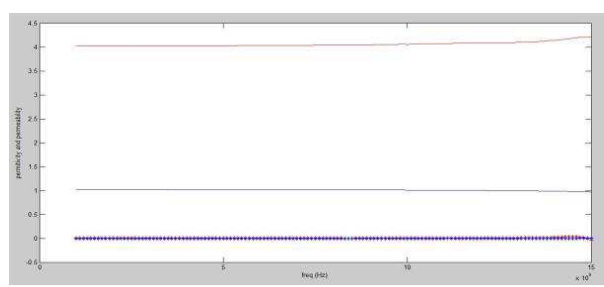

Figure 2: Equivalent permittivity and permeability.

In this situation, the incident wave from the Z direction. This method can get the S-parameter by simulation, then using MATLAB to deal with the data to can get the equivalent permittivity and permeability as shown in Fig. 2.

In the Fig. 2 the red lines are stand for the permittivity and the blue lines stand for permeability, the solid line representatives the real part and the dotted line representatives the imaginary part. The results are in line with our assuming. So we can get the conclusion that this method could be adopted in the range of 1 GHz to 10 GHz.

3. ANALYSIS OF DOUBLE FREQUENCY SELECTIVE SURFACE

In this model, we set the size as 10 mm $*$ 10 mm $*$ 4 mm, and dielectric constant is 3.5 [15]. There are two frequency selective surfaces. From the Z direction, the surfaces height is 2.4 mm and 3.1 mm from the bottom. The surface resistance value is 50 ohms. Shown in the Fig. 3.

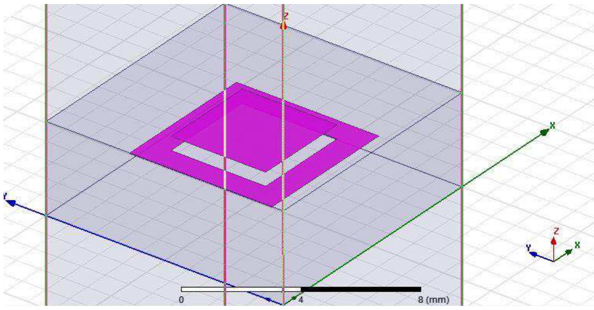

Figure 3: The model of the double frequency selective surface.

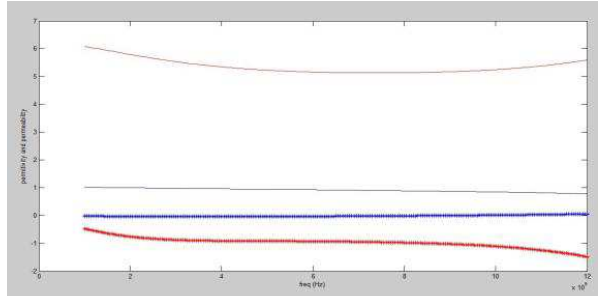

Figure 4: The equivalent permittivity and permeability.

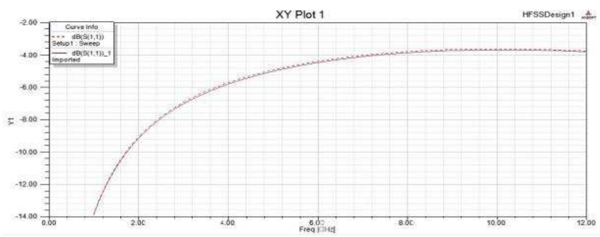

Figure 5: The S_{11}.

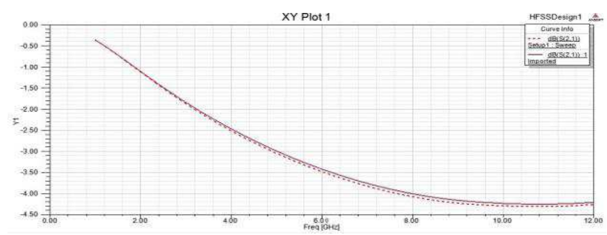

Figure 6: The S_{21}.

Using the formula mentioned earlier, we can get the equivalent permittivity and magnetic permeability of the model. Handled with the scattering parameters, we can draw the equivalent permittivity and permeability. Shown in the Fig. 4.

And similar to the above, the red lines stand for the permittivity and the blue lines stand for permeability, the solid line representatives the real part and the dotted line representatives the imaginary part. Then, we can compare the original data with the equivalent data to discover the difference.

The solid line stands for original structure and the dotted line stands for the homogenization structure.

The solid line stands for original structure and the dotted line stands for the homogenization structure. From the comparison, we can see in the extent applicable, the curves of scattering parameters match. So the method is effective.

It was found that the return loss caused by the impedance boundary, that leads to the absorber with complex permeability and complex permittivity. Attenuation of electromagnetic energy is mainly due to the impedance boundary layer, obtaining absorbing effect. The absorbing materials effectively absorb the incident electromagnetic wave, then the attenuation of electromagnetic waves to produce electromagnetic loss, electromagnetic energy changes to thermal energy or other forms of energy. Conductivity controlled within a certain range in order to achieve better performance absorbing effect. The absorption ability of medium for electromagnetic wave generally expressed as dielectric loss tangent and Magnetic loss tangent such as $\tan\delta_e = \frac{\varepsilon^i}{\varepsilon^r}$ and $\tan\delta_e = \frac{\mu^i}{\mu^r}$, the greater the value, the stronger the ability of absorbing. Where i is the imaginary part and r is the real part. Therefore, the imaginary part is relatively bigger, the better the absorbing effect.

The solid line stands for original structure and the dotted line stands for the homogenization structure. We can be found within the application range, return loss less than negative 10 dB, in line with our requirements

$$R = 20\log\left(\frac{\sqrt{\frac{\mu_0}{\varepsilon_0}}\cdot\sqrt{\frac{\mu}{\varepsilon}}\cdot\tanh\left(\frac{i\cdot 2\pi fd}{c}\sqrt{\mu\varepsilon}\right)-\sqrt{\frac{\mu_0}{\varepsilon_0}}}{\sqrt{\frac{\mu_0}{\varepsilon_0}}\cdot\sqrt{\frac{\mu}{\varepsilon}}\cdot\tanh\left(\frac{i\cdot 2\pi fd}{c}\sqrt{\mu\varepsilon}\right)+\sqrt{\frac{\mu_0}{\varepsilon_0}}}\right) \tag{7}$$

where R is the return Loss [16], and d is the thickness of the medium, effective electromagnetic parameters are ε and μ, the frequency is set to f. If we want to achieve the desired result of R, we could set R to zero, so we should meet the condition that $\varepsilon = \mu$. So when the case is the value of ε close to μ, the best results can be achieved for absorbing materials. To achieve this purpose,

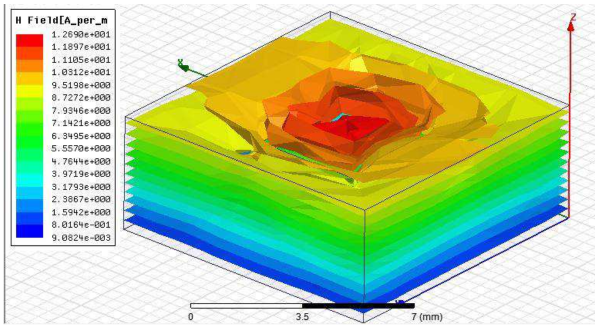

Figure 7: Internal magnetic field.

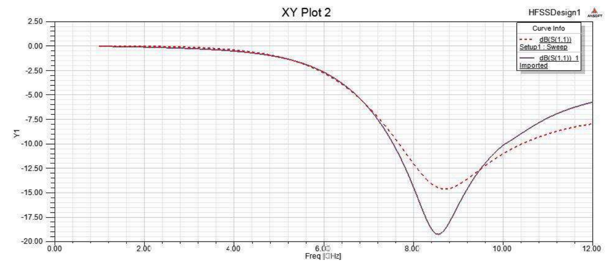

Figure 8: The S_{11} in the condition that bottom has the perfect electric boundary conditions.

we have to match ε and μ as much as possible. Because with a substantial change in frequency, its permittivity and permeability will also change, so we can only match the permittivity and permeability to the extent possible, permittivity and permeability's variation changes its absorption. After the data processing from the literature [17] the frequency selective surface can be drawn as a thin resistive impedance boundary patch. The size, patch square resistance and the thickness of the dielectric material changes all will affect the results. After simulation analysiswe can decide the size of the model, and the resistance value is turn out to be 50 ohms.

4. HONEYCOMB STRUCTURE IMPROVEMENTS

The arrangement of the original changes from rectangular to hexagonal, such as shown in the Fig. 9.

The return loss of the two results are compared in Fig. 10.

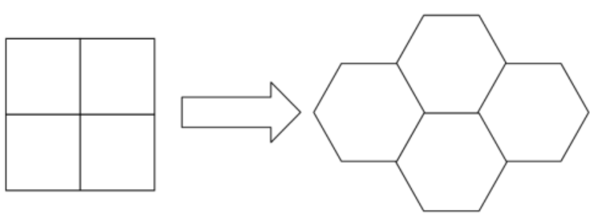

Figure 9: From rectangular to hexagonal.

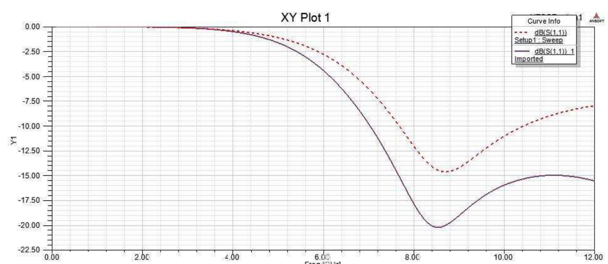

Figure 10: Compare the return loss in original structure and the honeycomb structure.

From the figure, we can clearly see that in the frequency range corresponding to the return loss of the honeycomb structure could reach −15 dB, and the original structure only reach −10 dB. As we know, the honeycomb structure also has a variety of excellent properties and stable in mechanical. Thus, this improvement is effective attempt.

5. CONCLUSION

Traditional absorbing materials mainly to the strength of the absorption capacity, new absorbing materials are required to meet more requirements, such as thin, light, wide, and other characteristics. The Insufficient about absorbing properties lead to the limit on the research and application of radar absorbing materials. This paper adapts the resistive losses in absorbing structure. Its attenuation of electromagnetic energy in the material is resistive, the main attenuation of electromagnetic energy on chip resistor, we can change its impedance to control the conductivity value variation. Using electric loss tangent to represents the attenuation ability of electromagnetic waves. First this article verifies the method for homogenizing, and then base on these, we use the honeycomb structure instead of the original structure to improve the absorbing effect. Not only the electromagnetic parameters were optimized but also the structure were been adjusted. It is believed that with the development of preparation techniques, absorbing structures have better results will also appear as soon as possible.

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