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THE STUDY ON A NEW TYPE OF WIDE FREQUENCY ABSORBING COATING /618*

Feng Lin Lu Cuong Shiao[1]

Abstract

A new type of wave-absorbing composite coating is made by inserting a wave frequency selecting surface into Dallenbach coating. Analysis of the absorbing capability of the coating with virtual circuit and transmission line theory showed that it is far superior to Dallenbach coating.

Key Word: stealth technology, RAM, decrease of RCS, wave selecting surface.

INTRODUCTION

Use of RAM is one of the most important technical means in reducing target electromagnetic scattering and improving stealth technology. Study on RAM plays an extremely crucial role in pursuing electromagnetic stealth technology. E.F. Krate et al(1)summarized the latest developments in single and multiple layer magnetic absorber, circuit simulating absorber and mixed complex absorber. Some of these have found practical uses. Although studies such as these have been done domestically and multi-purpose wave absorbers have been developed, very few of these have found any practical usage.

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* Numbers in margins indicate foreign pagination. Commas in numbers indicate decimals.

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Dallenbach coating is an evenly consumable layer on a metal plate which absorbs oscillating waves. Due to its extreme thinness, it is very suitable for spraying over the surface of a flying target. But the characteristic resistance of the consumable material of Dallenbach coating is generally not equal to the one in the air, hence a greater reflection is present on the surface of the coating. As a result, wave absorption is affected. Furthermore, the rate of absorption by Dallenbach coating is sensitive to wave frequency, only a narrow spectrum of wave can be absorbed. Typically only a single sharp absorbing point exists for this kind of thin layer absorber in the microwave range (8-18 GHZ).

By using electronic parameter fluctuating material or layered media, we can eliminate direct reflection of incoming waves by the surface of coating, consequently we can improve the absorption. But this will invariably lead to thickening of the coating, which will not be permissible in some cases such as overlaying the surface of a flying object. Another way of improving is to insert single or multi-layered chips with resistance in order to gradually change effective resistance in the direction of absorber thickness. Such an absorber is named Jaumann absorber. If this series of resistant chips has been changed to suitably shaped conducting material(i.e. symmetry, cross, triangle), a variable region can be introduced and adjustments of many more parameters will become available. This will give a great flexibility in the designing process, and give rise to a so called circuit analogous absorber.

Our discussion will focus on composite coating.
A higher absorbing composite coating is made by inserting composite metal coat into Dallenbach coating. In fact, it is

a kind of circuit analogous absorber,except it has a different working principle.

2. The Absorbing Properties of Dallenbach Coating

When a planar magnetic wave vertically hits a wave absorbing coating with a d thickness, the coating is equivalent to a transmitting segment which has a $\eta_0\sqrt{\mu_r/\varepsilon_r}$, characteristic resistance and length d. This material has a relative constant $\varepsilon_r = \varepsilon'_r + j\varepsilon''_r$, and a relative magnetic transmission rate $\mu_r = \mu'_r + j\mu''_r$, η_0 , is the characteristic resistance in vacuum. The metal lining in the back of the coating is equivalent to a short circuit negative carrier. The reflecting wave coefficient of the coating can be obtained by

$$R = \frac{j\sqrt{\mu_r/\varepsilon_r}\,\mathrm{tg}(kd) - 1}{j\sqrt{\mu_r/\varepsilon_r}\,\mathrm{tg}(kd) + 1} \qquad (1)$$

in which k= $\omega\sqrt{\mu\varepsilon} = \omega\sqrt{\mu_0\varepsilon_0}\sqrt{\mu_r\varepsilon_r} = k_0\sqrt{\mu_r\varepsilon_r}$, is the angular rate of the incoming wave.

Fig. 1 is a mirror reflecting coefficient of a optimized simple coating. The electronic parameter $\varepsilon'_r=10$, $\varepsilon''_r=0.3$, $\mu'_r=1.25$, $\mu''_r=0.75$; the thickness of the coating is 1.3mm (curve a in fig.1) and 1.9mm (curve b in fig.1). As it was shown, when the thickness d=1.3mm, the best absorbing point occurs around 15 GHZ; when d=1.9mm, the best absorbing point occurs around 10 GHZ. The two absorbing curves both have sharp peaks; at 10GHZ, -20dB band width is about 1GHZ, -10dB band width is about 4 GHZ; at 15GHZ, the corresponding band width is 15GHZ and 6GHZ respectively. At two different thicknesses, there is only one absorbing point in the frequency range used.

The occurrence of absorbing point in the simple coating, is a result of wearing of the material itself. It is also affected by the amplitude and phase of the wave reflected by the coating and the metal lining. The best absorbing point is the result of cancellation of these two effects. Apparently this cancellation is contingent upon the frequency of magnetic wave and the thickness of the material used which determine the sensitivity of the absorbing coating. For a single material, the thicker the coating the lower the corresponding oscillation absorbing frequency; the thinner the coating, the higher the corresponding oscillation absorbing frequency. This is shown clearly in the fig.1.

3. THE ANALYSIS OF ABSORBING PROPERTIES OF COMPOSITE COATING

In order to improve the absorbing properties of Dallenbach coating at 8-18GHZ, multiple absorbing points have to be achieved in this frequency range. Here we will discuss a two absorbing point condition in the typical range of microwave(8-18 GHZ). By adopting two absorbing points on coating, important improvements can be made. When these two absorbing points approach each other, absorbing spectra near relative minima will expand.

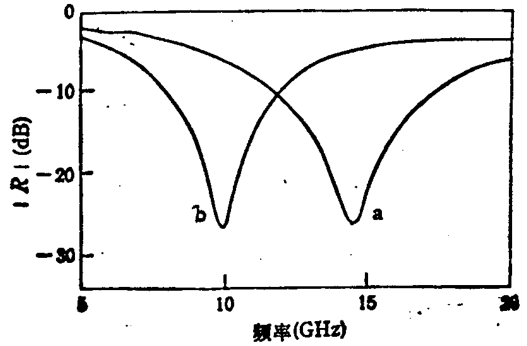


Fig.1 The reflecting coefficient of the simple coating

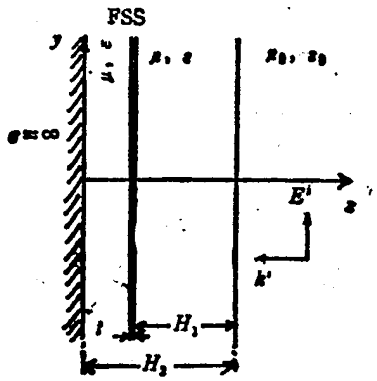


Fig.2 Schematic diagram of the structure of the composite coating

If a FCC were inserted into the coating so that a total reflection of 2 cm magnetic waves would be accomplished, at the same time 3 cm and other frequency wave would be able to pass through (fig.2), two effective reflective surfaces would be formed. By adjusting H_1 and H_2 and the reflecting points on FSS, a simultaneous absorption of 2 cm and 3 cm wave can be achieved by this structure. This would lead to two absorbing points in the range of 8-18 GHZ. This is the working principle of composite coating. Certainly FSS can not ensure total reflection or transmission of waves. Contrarily, it affects the phases of the reflecting and transmitting wave. Therefore, H_1 and H_2 may differ from the corresponding composite coating in thickness.

FSS which is made up of periodically organized metals can be considered equivalent to parallel resistance of transmission line, the value of resistance is determined by the format and order of metal pieces. Here we use a Jerusalem cross oscillator lattice as shown in fig.3. The equivalent resistance of the surface of this periodic structure (assuming the incoming magnetic wave is perpendicular to the surface) [5]:

$$Z = jX_g\eta_0, \quad (\eta_0 \text{ characteristic resistance}) \tag{2}$$

$$X_g = X(w) - 1/B(g,t), \ (t\text{为金属片厚度}) \tag{3}$$

$$X(w) = p\{\ln[\csc(\pi w/2p)] + F(\lambda,w)\}/\lambda \tag{4}$$

$$B(g,t) = 4d\{\ln[\csc(\pi g/2p)] + F(\lambda, g) + \pi t/(2g)\}/\lambda \tag{5}$$

$$F(\lambda,y) = Qc^2/(1 + Qs^2) + [pc(1 - 3s)/(4\lambda)]^2 \tag{6}$$

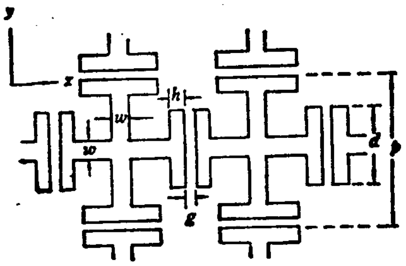
$$Q = [1 - (p/\lambda)^2]^{-1/2} - 1 \tag{7}$$

$$C = \cos^2[\pi y/(2p)] \tag{8}$$

$$S = 1 - C \tag{9}$$

By introducing equivalent resistance for FSS, composite coating structure can be transformed into a transmission line as shown in fig.4. By applying transmission line theory, input resistance Z_{ia} of input terminal a-b, the surface of coating can be calculated:

Fig.3 Jerusalem cross oscillator lattice coating.



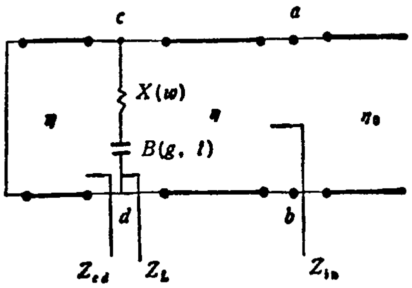


Fig.4 Virtual circuit of composite coating.

$$Z_{ed} = j\eta \operatorname{tg}[k(H_2 - H_1)] \tag{10}$$

$$Z_L = \frac{Z Z_{ed}}{Z + Z_{ed}} \tag{11}$$

$$Z_{in} = \eta \frac{Z_L + j\eta \operatorname{tg}(kH_1)}{\eta + jZ_L \operatorname{tg}(kH_1)} \tag{12}$$

$$R = \frac{Z_{in} - \eta_0}{Z_{in} + \eta_0} \tag{13}$$

or expressed as

$$R(\mathrm{dB}) = 20 \lg |R| \tag{14}$$

3. CALCULATION AND DATA ANALYSIS

When we compare the absorbing capacity of the simple and composite coating, the following data obtained is very similar to the one used by composite material, i.e. $\varepsilon'_r = 10$, $\varepsilon''_r = 0.3$, $\mu'_r = 1.25$, $\mu''_r = 0.75$. Such kind of wave absorbing coating has been used domestically. The polarizing direction of electric field started from the x axis. In fact, the assumption of polarizing direction has no effect on the result of calculation. This is because the chosen FSS structure has no polarizing selectivity.

In fig.5, different reflecting coefficient in composite coating with different thickness are listed, in which w=h=0.1mm, d=0.3mm, p=4mm, the thickness of the coating H1=1.5mm, H2=2.2mm(corresponds to the curve a in fig.5) and 2.0mm(the curve b in fig.5). As it was shown, there are two absorbing points near 10GHZ and 15 GHZ. Apparently, these two points also serve as oscillation absorbing points for the metal lining and FSS reflecting surface. Generally, an absorbing point in the low terminal is contingent upon the thickness of coating H2, while the absorbing point at the high end depends on the position of FSS H1 and its oscillation reflecting frequency. As we mentioned before, FSS affects the amplitude and phase of reflecting wave and transmitting wave. Therefore, the absorbing point at the low end formed by reflection of the metal lining is dependent on the structure of FSS and its position H1. H1,H2 and the structure of FSS also affect the depth of these two oscillation absorbing points. When H1 is constant, H2 decrease from 2.2mm to 2.0mm, the absorbing point at the low end increases from 9.5GHZ to 10.1GHZ. This is because of the decrease of thickness which leads to the increase of frequency being absorbed. Obviously, the change in thickness invariably leads to the change in absorbing intensity at the lower end absorbing point. At the same time, the absorbing point of the higher end remains unchanged, but there is considerable increase in the absorbing intensity of oscillation. This is not totally due to reflection of the magnetic wave, the transmitted electromagnetic wave through FSS is certainly going to change in reflection rate with the change in H2.

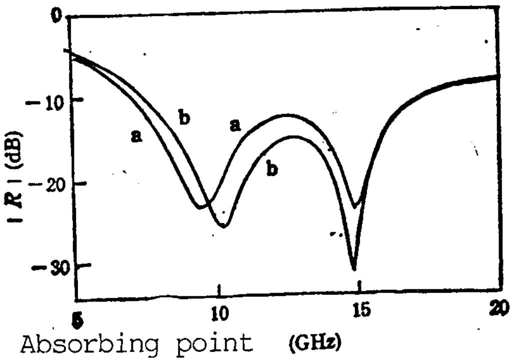


Fig. 5 The reflecting coefficient of composite coating.

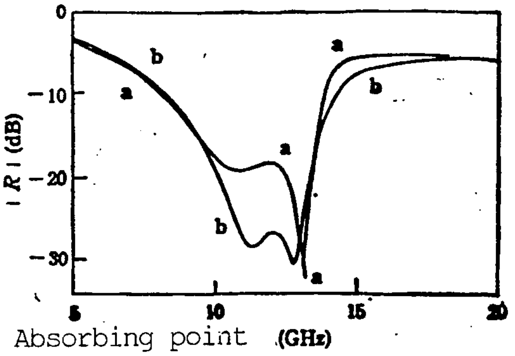


Fig. 6 The reflecting coefficient of composite coating.

The parameters of curve a in fig.6 are w=h=0.3mm, d=0.6mm, p=4.5mm, H2=2.0mm, H1=1.8mm. Because of the increase in the size of FSS,the reflected oscillating frequency decreases; accordingly, thickness increases simultaneously. This will cause the oscillation absorbing point at relative maxima which corresponds to FSS reflecting surface to move down(within the vicinity of 13 GHZ). In addition, the absorbing rate at relative minima will be reduced considerably(thickness decrease). This may be due to a reduced transmission to low frequency wave. If w=h=0.1mm, and d=0.4mm, the absorbing capability at relative minima will be improved dramatically, the absorbing intensity at these points will be increased (fig.6 curve b).

Within the 8-18 GHZ range, composite coating has two absorbing points, the intensity and width of -20dB spectrum at these two points maintain the same level as Dallenbach coating(compare curve b in fig.5 and curve a and b in fig.1). This shows that a composite coating can transform the single wave absorbing Dallenbach coating into double wave absorbing coating. This greatly expands the applicative range of wave absorbing coating material. From curve b in fig.5, we can see that the reflecting rates of composite coating almost all are lower than -10dB within the whole range of 8-18 GHZ. This is very significant in practical applications. Furthermore, as it is shown in curve b in fig.6, the width of -20dB spectrum reaches as high as 3 GHZ as 2 absorbing points approach each other within certain range. This is a great improvement in comparison to the width of spectrum at 1 GHZ within the vicinity of 10 GHZ(curve b in fig.1) and at 1.5 GHZ within the vicinity of 15 GHZ (curve a in fig.1). This marks an important improvement in the absorbing capability of Dallenbach coating, and the implication is profound.

4. CONCLUSION

The object of inserting FSS into Dallenbach coating is to improve the absorbing capability of the coating by forming a reflective surface and two oscillation absorbing points via selective reflection and cancellation of oscillation by FSS, and by optimizing the absorption near the two points or by widening the absorption spectrum at one of these points. Because the positions and intensities of these two absorbing points can be affected by many factors, such as coating thickness H1 and H2, and structure and components of FSS, therefore the design of composite coating can be very complicated. It often needs a large volume of optimizing calculations. The goal of this study is to explain the working principle of composite coating and to analyze the structure and to seek the possibility of improving wave absorbing capacity of Dallenbach coating, and to provide a theoretical basis for the practical optimizing design. Clearly, this is shown to be feasible.

Very thin wave absorbing coating material which is used as RAM to minimize reflection by metal target, plays very important roles in stealth technology. Dallenbach wave absorbing coating discussed here has found applications domestically. But the capability of the coating remains to be enhanced, therefore further study needs to be done. This paper intends to detail this study: The new type of wave absorbing coating proposed here is far superior to Dallenbach coating with a marginal increase in overall thickness. This makes it specially important in engineering application. Therefore, the application prospect for this composite coating is greater than Dallenbach coating.

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