Design Method of Absorbing Electromagnetic Window Structure

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***Abstract*—The antenna cabin is a strong scattering source of various military platforms, and its stealth effect directly affects the stealth effect of military platforms such as missiles. Aiming at limitations of stealth FSS radome, design method of absorbing electromagnetic window structure is carried out in this paper. Based on the transmission line model, this paper introduces its working mechanism, proposes an analytical method and a complete design method. The structure proposed in this paper realizes pass-band at X-band (8-10GHz) and absorption in S-band (2-4GHz). After a series of simulations and optimizations, at least 10dB absorption in S-band and less than 1 dB insert loss in 8-10GHz are realized.**

Keywords—FSS radome; Absorber; elecromagnetic window

I. INTRODUCTION

Traditional FSS radome has some inevitable defect for bistatic detection and low-RCS configuration. Frequency selectively absorbing structure can be used as radome which can absorb the incidence wave out of the operate band while have less influence to the antennas' detection. Filippo Coasta and A.Monorchio has researched the equivalent circuit method of Frequency-selectively absorbers (FSA) and proposed some kinds of design [1-4]. In the paper published at 2011, A.Motevasselian and his colleagues designed a kind of FSA which is sensitive to the polarization, it has more than 75% absorbing bandwidth when parallel polarized wave incidence [5].

The aim of this paper is to propose a design method of absorbing electromagnetic window structure. The structure is realized by replaced the PEC-surface of circuit absorber with a FSS sheet. The design can be used as a radome to protect an antenna from incoming radar waves while letting energy radiate through, hence improve the stealth performance of antenna system significantly. In this paper we proposed a novel frequency-selective absorber with pass-band at 8-10GHz and absorption in S-band (2-4GHz), in following chapters we accomplish the design and optimization of this novel structure.

II. MODEL OF ABSORBING ELECTROMAGNETIC WINDOW STRUCTURE

Take the combination of cross dipole unit and square ring element as an example, establish its model and analyzing based on it. It's structure is shown in Fig.1 and the equivalent model is established as Fig.2.

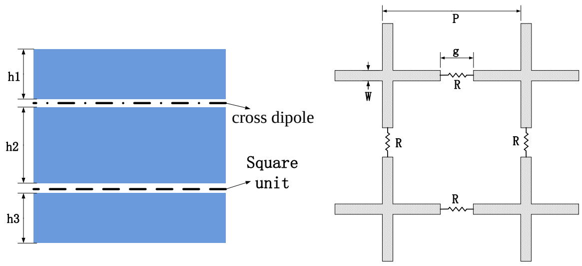

Fig.1 Schematic diagram of the structure

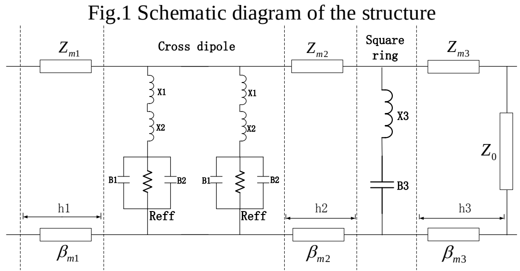

Fig.2 Equivalent model of the structure

We can get the normalized reactance of cross dipole as follow:

$$X_1 = \frac{L_1}{Z_0} = \frac{2(p-g-w)}{p} F(p,w,\lambda), X_2 = \frac{L_2}{Z_0} = \frac{2w}{p} F(p,p-g,\lambda)$$

The normalized captances are:

$$B_1 = \frac{C_1}{Z_0} = \frac{4w}{p} \varepsilon_{eff} F(p,g,\lambda), B_2 = \frac{C_2}{Z_0} = \frac{4(p-g-w)}{p} \varepsilon_{eff} F(p,p-w,\lambda)$$

The equivalent impedance:

$$R_{eff} = 1.7R/Z_0$$

The equivalent permittivity:

$$\varepsilon_{eff} = \varepsilon_r + (\varepsilon_r - 1)\left[\frac{-1}{\exp^{1.8}(10h/P)}\right]$$

So, we can calculate the equivalent impedance of cross dipole as:

$$Z_{RFSS} = 0.5\left[j(X1+X2) + \frac{R_{eff}}{1+jR_{eff}(B1+B2)}\right]$$

Equally the equivalent impedance of square ring is:

$$Z_{FSS} = j\left(X_3 - \frac{1}{B_3}\right)$$

$$X_3 = \frac{L}{p} F(p,2*w,\lambda), B_3 = \frac{4L}{p} \varepsilon_{eff} F(p,p-L,\lambda)$$

Then, the reflection of this structure can be calculated as:

$$Z_{inp3} = Z_m \frac{Z_{L3} + Z_m \tanh(j\beta_m h_3)}{Z_m + Z_{L3} \tanh(j\beta_m h_3)}, Z_{L3} = Z_0$$

$$\Rightarrow Z_{L2} = Z_{inp3} \| Z_{FSS} = 1/\left(1/Z_{inp3} + 1/Z_{FSS}\right)$$

$$\Rightarrow Z_{inp2} = Z_m \frac{Z_{L2} + Z_m \tanh\left(j\beta_m h_2\right)}{Z_m + Z_{L2} \tanh\left(j\beta_m h_2\right)}$$

$$\Rightarrow Z_{L1} = Z_{inp2} \| Z_{RFSS}$$

$$\Rightarrow Z_{in} = Z_m \frac{Z_{L1} + Z_m \tanh\left(j\beta_m h_1\right)}{Z_m + Z_{L1} \tanh\left(j\beta_m h_1\right)}$$

$$\Rightarrow \Gamma = \left|\frac{Z_{in} - Z_0}{Z_{in} + Z_0}\right|$$

Finally, the translation of this structure can be calculated as:

$$Z_{m1} = Z_{m2} = Z_{m3} = Z_m = Z_0 / \sqrt{\varepsilon_r}\ ;\ \ \beta_{mi} = \beta_m = 2\pi\sqrt{\varepsilon_r}/\lambda$$

$$\Rightarrow [M_i] = \begin{bmatrix} \cos\left(\beta_m h_i\right) & jZ_m \sin\left(\beta_m h_i\right) \\ \dfrac{j\sin\left(\beta_m h_i\right)}{Z_m} & \cos\left(\beta_m h_i\right) \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} A & B \\ C & D \end{bmatrix} = [M_1] \begin{bmatrix} 1 & 0 \\ \dfrac{1}{Z_{RFSS}} & 1 \end{bmatrix} [M_2] \begin{bmatrix} 1 & 0 \\ \dfrac{1}{Z_{FSS}} & 1 \end{bmatrix} [M_3]$$

$$\Rightarrow \tau = \left|\frac{2Z_0}{AZ_0 + B + CZ_0^2 + DZ_0}\right|$$

The translation/reflection line are shown in Fig.3, which are calculated by equivalent model and CST respectively. It shown that there is good consistency between equivalent model and CST.

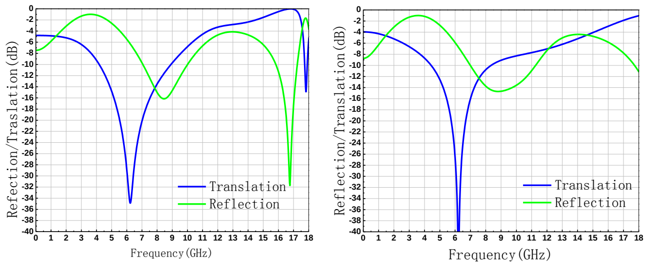

Fig.3 translation/reflection line of the structure

III. Design Method of Circuit Absorber

In the actual engineering design, the design method of absorbing electromagnetic window is shown in Figure 4. The key design process is as follows:

1. according to the engineering requirements (electrical properties, thickness, weight, strength, etc.), select the dielectric material used for the substrate.

2. We decompose the whole structure into two parts FSS absorber and FSS ground plane to design respectively.

3. When design of FSS absorber, we should consider both the absorption performance and insertion loss in the working band. First, determine the type of resonant unit which should have strong resonance in the absorbing band, and basically "transparent" in the working band. Then we inverse the equivalent reactance through transmission line model, and the suitable load impedance is chosen to match the impedance of the free space.

4. The FSS ground plane is generally based on the antenna working frequency band, low frequency corresponding to the patch form, and high frequency corresponding to the slot array.

5. Merging the two parts, we construct the transmission line model of the absorber, and optimize the overall structure according to the calculation results.

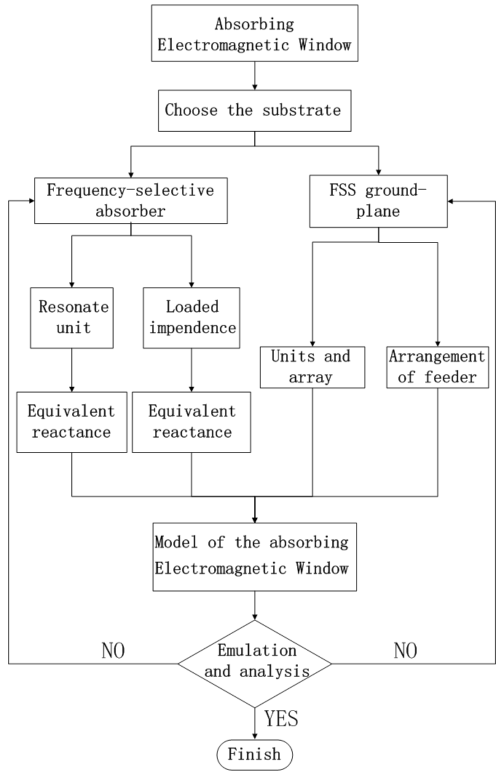

Fig. 4. Flow of the design method

IV. Design and Simulation of FSS Absorber

For an absorber, the dielectric layers and the loss FSS layer have specific roles in the performance of the absorber. By adjusting the thickness and permittivity of the dielectric layers and optimizing the geometry parameters and resistance of loss FSS unit, a good performance of absorbing will be obtained. In this paper a irregular three legs loop metal patch loaded with resistance elements was selected as the loss FSS unit, and the shape of period is a combination of three hexagons. Structure of loss FSS unit is shown in fig.5. Resisters are loaded at the intersect point of each leg, and the resistance of them is 127Ω.

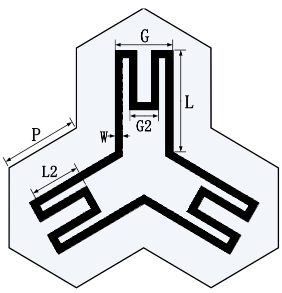

Fig. 5. Loss FSS unit

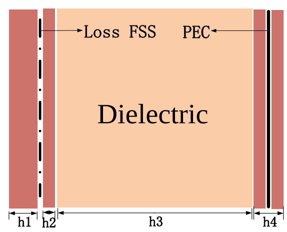

Fig. 6. Structure of Circuit Absorber

Figure 6 shows the geometry of absorber, which comprised of dielectric slabs, loss FSS sheet and backed PEC layer. The thickness, dielectric constant and loss tangent of the dielectric layer are h, εr and tanδ. The physical and geometrical parameters of this design are presented in table I.

Table.1 Physical parameters of the absorber

Parameter	P	L	L2	w	G
value	**12.7mm**	**10mm**	**3.95mm**	**0.2mm**	**6.6mm**
Parameter	h1	h2	h3	h4	G2
value	**2mm**	**12mm**	**1.5mm**	**3mm**	**2mm**

The reflection line of the absorber is shown in Fig.7, the figure gives that form 2GHz-6GHz this structure has at least 10dB absorption, and from 8GHz -10GHz will have a good performance in transmission.

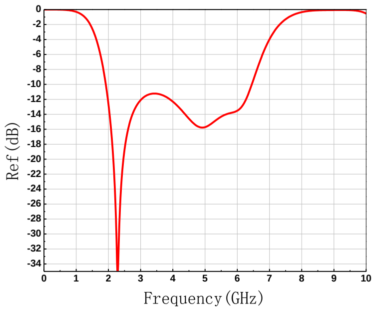

Fig. 7. Reflection line of low frequency absorber

V. DESIGN AND OPTIMIZATION OF ABSORBING ELECTROMAGNETIC WINDOW

In the last section, we proposed a high performance circuit absorber which has a potential pass band at 8-10GHz, hence a high-pass FSS is needed to replace the backed PEC. Fig.8 shows the type of band-pass FSS structures, and it's transmission line in different parameters are shown in Fig.8.

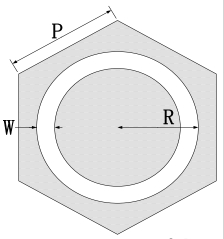

Fig.8. Structure of the FSS

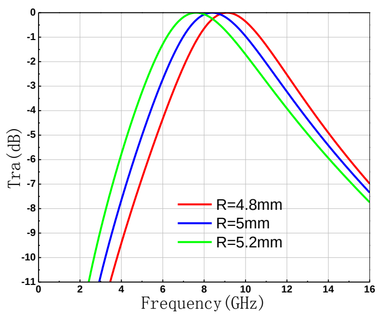

Fig.9. Transmission line of unit

From Fig.8 and Fig.9 it can be found that the cirque slot unit with R=4.8mm provides a pass-band in 8-10GHz, and it has a good cut-off performance in low-frequency. Then by replacing the back-metal layer of absorber designed in section 2 by the metal FSS, we obtain the FSA. It's absorption line and transmission/reflection line is shown in Fig.10 and Fig8 respectively. Figures show that the proposed structure has at least 10dB absorption in S-band and less than 1dB insert loss in 8-10GHz.

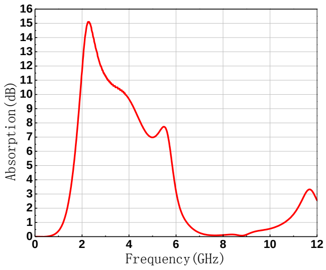

Fig.10 Absorption line of structure

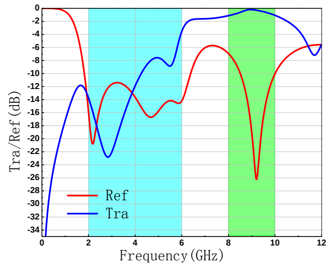

Fig.11 Tran/ref line of structure

As can be seen from figure11, the metabsorber has transmission below -10dB with reflection below -30dB form 8GHz to 14GHz, in addition, it's transparent properties is more than -1dB under 1.5GHz. The absorption characteristic curve of the structure can be obtained by formula followed, and is shown in figure 10. What's more the metabsorber has more than 16dB absorbing effect in the 8-12GHz, while the 7-13GHz has more than 10dB absorbing property.

VI. CONCLUSION

In this paper we proposed a design method of absorbing electromagnetic window structure, and a frequency-selective absorber with a pass-band worked in X-band and a absorb-band in S-band was realized by this method. The structure consists of dielectric slabs, loss FSS sheet comprised of irregular three legs loop metal patches loaded with resistance elements and cirque slot metal FSS sheet. After a series of simulations and optimizations, the design structure got at least 10dB absorption in S-band and less than 1dB insert loss in 8-10GHz.

References

[1] Filippo Costa, Agostino Monorchio, and Giuliano Manara. An Equivalent Circuit Model of Frequency Selective Surfaces Embedded within Dielectric Layers.

[2] F. Costa, S. Genovesi, and A. Monorchio, *"On the bandwidth of high-impedance frequency selective surfaces,"* IEEE Antennas Wireless Propag. Lett., vol. 8, pp. 1341, 1344, 2009.

[3] Filippo Costa, Agostino Monorchio, and Giuliano Manara. *Efficient Analysis of Frequency-Selective Surfaces by a Simple Equivalent-Circuit Model.* IEEE Antennas and Propagation Magazine, Vol. 54, No. 4, August 2012

[4] F. Costa , C. Amabile, A. Monorchio, and E. Prati, *"Waveguide Dielectric Permittivity Measurement Technique Based on Resonant FSS Filters,"* IEEE Microwave and Wire less Components Letters, 21, 5, May 2011, pp. 273275.

[5] A. Motevasselian B.L.G. Jonsson *"Design of a wideband rasorber with a polarization sensitive transparent window"* Published in IET Microwaves, Antennas & Propagation 10.1049/iet-map.2011.0444