Analysis of Resonance Elimination in a Shielding Enclosure with Aperture Using CBP Material

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Abstract: ***The resonance elimination for the shielding enclosure is theoretically investigated. An absorbing nanomaterial, one-dimensional carbon nanotube @ barium titanate @ polyaniline composite (CBP), is used at different positions in the enclosure with an aperture to eliminate the resonance. Modified equivalent circuit model is applied to calculate the shielding effectiveness (SE) and analyze the elimination of the resonance. Results show that 20mm and 30mm thick CBP attached to the back of the aperture plate, end of the enclosure or both can improve the minimum of the SE and eliminate the resonance obviously. And the case of two pieces of 30mm thick material attached to the back of the aperture plate and the end of the enclosure meanwhile is the best.***

Keywords: Shielding enclosure, absorbing nanomaterial, equivalent circuit model, resonance

1. Introduction

With the widespread use of electronic devices, the electromagnetic environment becomes increasingly complex in spatial region [1-6]. The potential electromagnetic interference will occur and electronic devices may be damaged [7-10]. In order to increase their immunity and reliability, the rectangular metal enclosure is typically used to protect electronic devices [8-10]. The shielding ability of enclosure is technologically described by shielding effectiveness (SE). Calculated results of SE from existing literatures [10-14] show that at most frequencies the enclosure has high SE and the ability to protect the electronic devices. While at some frequencies, the enclosure resonates, leading to negative SE and strong electromagnetic interference. In this situation, the electronic devices in the enclosure may be seriously damaged. Therefore, it is necessary to eliminate the resonance. Various approaches can be used. According to [2], the size of the enclosure can be change to avoid the resonance frequency. But the choice of the geometric size of the enclosure is not always flexible. L. P. Wang pointed out that one should make the response frequency of the circuit in the enclosure away from the resonance frequency as much as possible while designing the circuit [3]. However, for certain circuit whose frequency is fixed, this design is not achievable sometimes. M. Bahadorzadeh pointed out that the resonance can also be suppressed by using lossy dielectric as an aperture load in the end of the enclosure [6]. This is a good way but the choice of the lossy dielectrics is important in engineering. Recently Q. Q. Nie et al proposed a novel material called one-dimensional carbon nanotube @ barium titanate @ polyaniline composite proposed (CBP) which exhibits excellent microwave absorption property [15]. In order to analyze its potential for eliminating the resonance, SE of the enclosure with CBP in it should be analyzed.

The method of equivalent circuit model has the advantages of fast calculation, clear concept and simple structure [10]. Robinson et al have proposed an equivalent circuit model to calculate the SE of enclosure with an aperture. Recently, this equivalent circuit model has been improved by P. A. Du et al [11-14]. Among these improvements, the validity of this equivalent circuit model was verified by numerical simulation. So in this paper, based on our previous studies [8, 9], the modified equivalent circuit model is used to analyze the SE of the enclosure with CBP in it for the resonance elimination.

This paper is organized as follows: the properties of the CBP is introduced in Section 2. In Section 3, the equivalent circuit model of enclosure filled with lossy media is provided and verified with the numerical simulation. Results are shown in Section 4. Conclusions are presented in Section 5.

2. The properties of CBP

The CBP is a kind of nanomaterial which has the wave absorption property [15-17]. It is well known that the absorption properties of an absorber are highly associated with its complex relative permittivity ($\varepsilon_r = \varepsilon' - j\varepsilon''$) and complex magnetic permeability ($\mu_r = \mu' - j\mu''$), where the real parts represent the storage of electric and magnetic energies and the imaginary parts represent the loss. The complex relative permittivity and the magnetic permeability at various dispersed frequencies between 0-15 GHz are measured [15]. According to [11-14], the frequency band of 0-3GHz is commonly used in the equivalent circuit model. So through data fitting method, the complex relative permittivity and the magnetic permeability between 0-3 GHz is obtained as

$$\begin{cases} \varepsilon' = -0.1752 f^3 + 1.1923 f^2 - 3.8767 f + 16.505 \\ \varepsilon'' = -0.0808 f^3 + 0.565 f^2 - 1.6787 f + 5.8719 \\ \mu' = -0.0019 f^3 + 0.00843 f^2 + 0.0006 f + 1.2439 \\ \mu'' = 0.0045 \end{cases} \tag{1}$$

where f is the frequency in GHz.

The CBP can be pressed into rectangle panel with different size and thickness. And fill the enclosure in different positions with this nanomaterial to eliminate the resonance.

3. Modified Equivalent Circuit Model

As shown in Fig.1, there is a rectangular enclosure with an aperture, containing lossy media (CBP in this paper) in it, exposed to a plane electromagnetic wave. The size of the enclosure is $a \times b \times d$ and the aperture is $l \times w$. The thickness of the enclosure is t. Point P is at the geometric center of the enclosure so $p = d/2$. The plane wave incidents vertically and the long side of the slot is shown normal to the E-field. The lossy media can be attached to the end of the enclosure or the back of the aperture plate. The situation of attached to the end of the enclosure is shown in Fig. 1. Shaded part means the lossy media. The thickness of the lossy media is L.

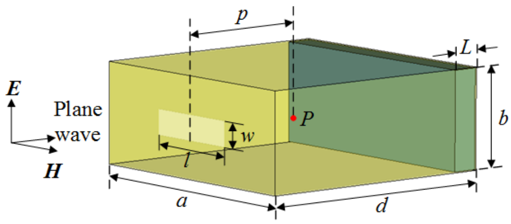

Figure 1: The enclosure with an aperture and the lossy media in it

The equivalent circuit model of the enclosure is shown in Fig. 2. The model is based on the theory of the waveguide and the transmission line. The radiating source is represented by voltage V_0 and impedance Z_0=377Ω which is the inherent impedance of free space, the aperture is modeled by impedance Z_{ap} and the rectangular enclosure is represented by the transmission line whose characteristic impedance and the propagation constant are Z_g and k_g. Besides, the lossy media is represented by the lossy transmission line whose characteristic impedance and the propagation constant are Z'_g and k'_g.

When the lossy media is at the end of the enclosure, the impedance of the aperture is

$$Z_{ap} = \frac{1}{2}\frac{l}{a} jZ_{0s} \tan\frac{k_0 l}{2} \quad (2)$$

and its characteristic impedance is

$$Z_{0s} = 120\pi^2 \left[\ln(2\frac{1+\sqrt[4]{1-(w_e/b)^2}}{1-\sqrt[4]{1-(w_e/b)^2}}) \right]^{-1} \quad (3)$$

When the lossy media is attached to the back of the aperture plate, Z_{ap} should be modified as

$$Z_{ap} = \frac{1}{2}\frac{l}{a} jZ_{0s} \tan\frac{k_e l}{2} \quad (4)$$

and the characteristic impedance is

$$Z_{0s} = 120\pi^2 \sqrt{\frac{\mu_e}{\varepsilon_e}} \left[\ln(2\frac{1+\sqrt[4]{1-(w_e/b)^2}}{1-\sqrt[4]{1-(w_e/b)^2}}) \right]^{-1} \quad (5)$$

where $\mu_e = (\mu_r + 1)/2$, $\varepsilon_e = (\varepsilon_r + 1)/2$, $k_e = (k_0 + k'_0)/2$ [18] and μ_r and ε_r are given by equation (1).

The characteristic impedance and the propagation constant of lossy transmission line are

$$Z'_g = \frac{Z_0\sqrt{\mu_r/\varepsilon_r}}{\sqrt{1-\left(\frac{\lambda'}{2a}\right)^2}} \quad (6)$$

$$k'_g = k'_0\sqrt{1-\left(\frac{\lambda'}{2a}\right)^2} \quad (7)$$

where $k'_0 = 2\pi\sqrt{\mu_r\varepsilon_r}/\lambda$, $\lambda' = \lambda/\sqrt{\mu_r\varepsilon_r}$, $\lambda = c/f$ and c is the light speed. The other details of the derivation for SE are given in [10].

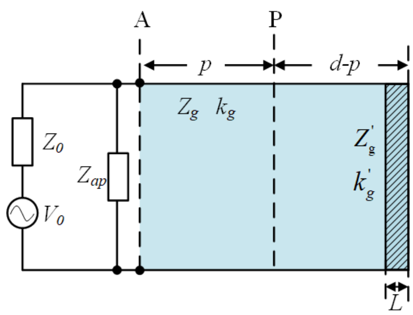

Figure 2: The equivalent circuit model (the blue region means the transmission line).

4. Copyright and release information

In this section, various cases of the CBP in different positions and with different thickness are analyzed. The size of the enclosure is 300mmx300mmx120mm, the thickness is 1mm and the aperture is 100mm×5mm. The frequency is 0-1GHz.

4.1 Attached to the End of the Enclosure

Attach the CBP to the end of the enclosure and calculate the SE at point P. The equivalent circuit is shown in Fig. 2. The thickness of the CBP, L, is set to 20mm and 30mm, respectively. Compared with the case of the empty enclosure in [10], results are shown in Fig. 3. It is can be seen that the SE is lower than 0dB and strong resonance exists in the cases of empty enclosure around 710MHz. While L=20mm and

L=30mm, the minimum of the SE is higher than 0dB and resonance is eliminated obviously.

In order to verify the correctness of results above, numerical simulation is applied to calculate the SE of the situations above. Fig. 4 shows the results of analyzed and numerical simulation when L=20mm and L=30mm, respectively. Good agreements between the analyzed results and the simulated results can be seen. It is believed that the modified equivalent circuit model used in this paper can calculate the SE accurately. So in the following part of this paper, the modified equivalent circuit model is used directly to analyze the SE and the verification is omitted.

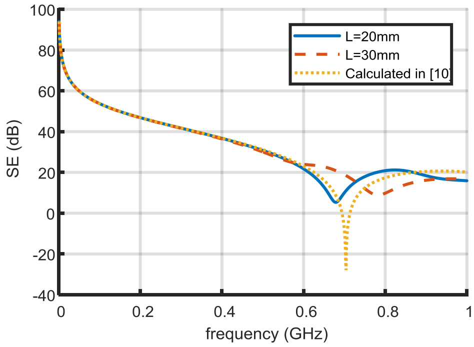

Figure 3: SE of thickness of 20 mm (blue solid line), 30 mm (red dotted line) and no CBP (calculated in [10], yellow points).

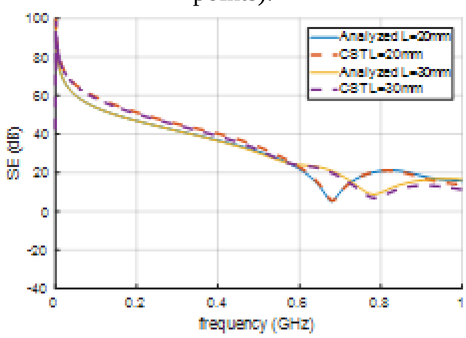

Figure 4: SE of analyzed result (solid line) and simulated result (dotted line) when the CBP is attached to the end of the enclosure when L=20mm and L=30mm, respectively.

4.2 Attached to the Back of the Aperture Plate

Attach the CBP to the back of the aperture plate and calculate the SE at point P. The equivalent circuit is shown in Fig. 5. Results of the case of no absorber and different thickness of 20 mm and 30 mm are shown in Fig. 6. It is can be seen that the SE is higher than 0dB and the resonance is eliminated in both cases of L=20mm and L=30mm. While in the case of L=30mm, the minimum of the SE is much higher than that in case of L=20mm.

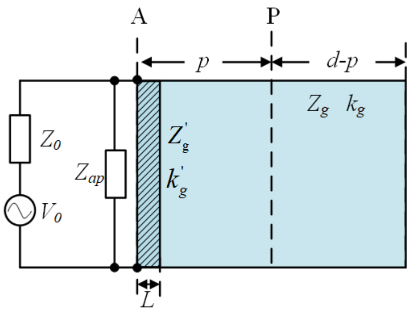

Figure 5: The equivalent circuit when the CBP is attached to the back of the aperture plate.

4.3Both the End and the Back

Combine these two situations above and use two piece of CBP to eliminate the resonance. One of them is attached to the end of the enclosure and another is attached to the back of the aperture plate. The equivalent circuit model is shown in Fig. 7. Compared with the empty enclosure, results of the cases of L=20mm and L=30mm are shown in Fig. 5(b). It is can be seen that the SE is much higher than 0dB and resonance is eliminated especially in the case of two piece of CBP whose thickness is 30mm.

Table I shows the minimum of the SE (SEmin) of various cases.   It is can be seen that when two pieces of 30mm thick CBP are attached to the back of the aperture and the end of the enclosure respectively, SEmin reaches to the maximum. And in the same situation, the case of L=30mm always has a higher SEmin than the case of L=20mm.

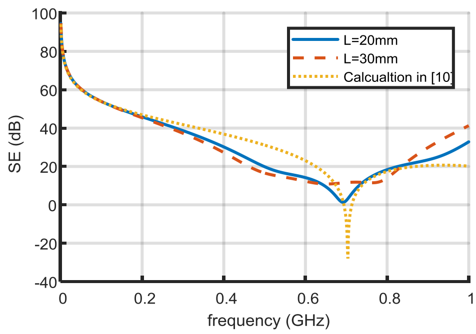

Figure 6: SE of thickness of 20mm (blue solid line), 30 mm (red dotted line) and no CBP (calculated in [10], yellow points)

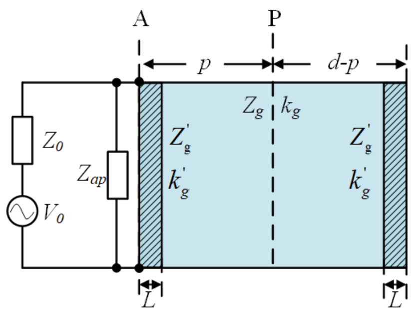

Figure 7: The equivalent circuit when two CBP plates are attached to the back of the aperture plate and the end of the enclosure, respectively

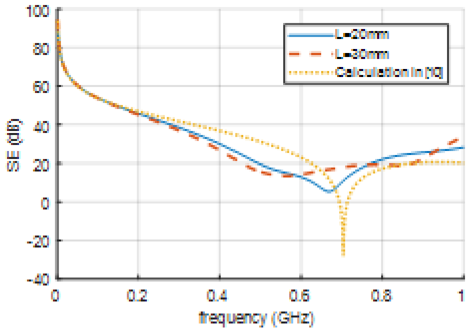

Figure 8: SE of thickness of 20mm (blue solid line), 30 mm (red dotted line) and no CBP (calculated in [10], yellow points)

Table 1: Various cases of the minimum value of SE

Case	SEmin(dB)
A: L=20mm	5.32
A: L=30mm	8.91
B: L=20mm	1.32
B: L=30mm	10.86
C: L=20mm	5.53
C: L=30mm	13.68

5. Conclusion

In this paper, the potential application of a novel CBP absorbing material to eliminate the resonance in the shielding enclosure is analyzed through modified equivalent circuit model. Firstly, the electromagnetic properties of CBP is introduced. Then the equivalent impedance of the aperture plate is amended to analyze the application of CBP in the enclosure. The modified equivalent circuit model is used to analyze the SE when CBP is attached to different locations. The numerical simulation is applied to prove the validity of the modified equivalent circuit model. Results show that the resonance is eliminated more if the CBP is thicker. And when two CBP plates are attached to the back of the aperture plate and the end of the enclosure respectively, the resonance is eliminated more.

Through the verification, it is believed that the modified equivalent circuit model can calculate the SE of an enclosure with lossy dielectrics in it fast and accurately. Results in this paper are helpful for the potential application for CBP material and the protection of electronic devices.

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