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The application of improved FDTD algorithm based on mode-matching in shielding cavity

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Abstract. Due to the increasing complexity of the electromagnetic environment, the cavity with apertures are used more and more widely in electromagnetic shielding. At present, the time domain finite difference (FDTD) method has a good application effect for the transmission line response problem of a double-layer shield cavity with apertures, but this method usually encounters the boundary problem of semi-open and open areas. Due to the limited computing resources, the truncation of the FDTD region has an impact on the accuracy and speed of the calculation because that is very important. Based on that, this paper puts forward a method of combining mode-matching method with FDTD algorithm, which overcomes the limitation that mode-matching method can only be used for regular waveguide analysis and uses mode-matching method to solve FDTD boundary problems. The improved FDTD algorithm based on mode-matching method enhances the accuracy of the algorithm and guarantees the calculation speed.

1 Introduction

The electromagnetic environment has become increasingly complex, the fully sealed shielding cavity has good shielding effect, but it is inevitable to open some apertures on the surface of the shielding cavity[1-3]. The existence of these apertures can reduce the shielding effectiveness of the shield layer and even have greater influence to inner devices, so the study of the shielding effectiveness of the cavity is necessary.

At present, FDTD method is the main method to analyze the shielding effectiveness of multi-layer metal cavity[4-5]. This method can be used to model complex problems, but the calculation process is time consuming. In the case of limited computing resources, it is crucial to truncate the FDTD area. In addition, the time step of FDTD algorithm needs to satisfy the time stability condition, which makes it less efficient in the simulation model with small structure[6]. Mode-matching method has the advantages of high solving precision and small memory consumption, but it can only be used to analyze regular objects[7-8]. This paper studies the terminal response of a transmission line in a double-layer shield cavity under external field excitation. Combining mode-matching method with FDTD has obvious advantages in calculating time and accuracy.

2 Improved algorithm derivation

It has been pointed out in literature [9], when the distance between the transmission line and the reference conductor is small in comparison with the wavelength, the radiation effect of the transmission line can be ignored. However, the equivalent distribution voltage source and current source are only related to the incident electric field component, which are independent of the scattering electric field component of the transmission line. Therefore, when modeling complex electronic systems, transmission lines within the system can be removed.

As shown in fig.1, the multi-layer metal cavity can be considered as the cascade of several metal waveguides. The external rectangular cavity size is $a \times b \times d$ and the internal rectangular cavity size is $a \times b \times h$, The size of the aperture opened on the wall of the cavity are both $l \times w$.

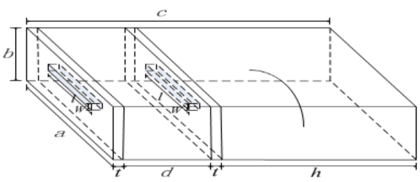

Fig.1 Schematic diagram of two-layer metal cavity

Correlations of amplitude coefficients of modes are propagated in Regions I and IV:

$$A^{V+} + A^{V-} = M_{tot}(A^{II+} + A^{II-}) \quad (1)$$

$$M_{tot}^{T}(A^{V+} - A^{V-}) = A^{II+} - A^{II-} \quad (2)$$

the relationship of the mode amplitude coefficient of its propagation can be written as:

$$A^{V+} = - L^{V} A^{V-} \quad (3)$$

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$$L^{V} = diag\{e^{-2h\Gamma_k^{V}}\}, \quad k = e, \; h \tag{4}$$

The matrix equation of the relationship between the amplitude coefficients of the propagation mode in Area II are:

$$A^{II+} = \rho A^{II-} \tag{5}$$

$$\rho = (U + P)^{-1}(U - P) \tag{6}$$

$$P = M_{tot}^{T}(L^{V} + U)(U - L^{V})^{-1}M_{tot}^{T} \tag{7}$$

Bring equations (3) ~(7) into equations (1) and (2) and finally gets the matrix equation:

$$A^{V-} = (U - L^{V})^{-1}M_{tot}^{T}(\rho + U)A^{II-} \tag{8}$$

The multi-conductor transmission line coupling model under electromagnetic wave action can be described by the transmission line equation as:

$$V_f(x,t) = \frac{\partial}{\partial x}V(x,t) + RI(x,t) + L\frac{\partial}{\partial X}I(x,t) \tag{9}$$

$$I_f(x,t) = \frac{\partial}{\partial x}I(x,t) + GV(x,t) + C\frac{\partial}{\partial X}V(x,t) \tag{10}$$

$V(x, t)$ and $I(x, t)$ represent the voltage and current vectors on the transmission line; L, R, C, and G are the matrix of inductance, resistance, capacitance and conductivity distribution parameters per unit length of the transmission line, respectively; $V_F(x, t)$ and $I_F(x, t)$ are the equivalent distributed voltage sources and the equivalent distributed current sources of the transmission line equation, respectively.

The equations (9) and(10) are discrete according to the central difference format of the FDTD. Then the iterative equations for the voltage and current on the transmission line are:

$$I^{(n+1)}(k+2) = \left[\frac{R}{2} + \frac{L}{\Delta t}\right]^{-1} * \left(\left[\frac{L}{\Delta t} - \frac{R}{2}\right]I^{n-\frac{1}{2}}\left(k+\frac{1}{2}\right) - \frac{V^n(k+1) - V^n(k)}{\Delta x} - \frac{E_T^n(k+1) - E_T^n(k)}{\Delta x} + \frac{E_L^n(k+1) - E_L^n(k)}{\Delta x}\right) \tag{11}$$

$$V^{(n+1)}(k) = \left[\frac{G}{2} + \frac{C}{\Delta t}\right]^{-1} * \left(\left[\frac{C}{\Delta t} - \frac{G}{2}\right]V^n(k) - \frac{I^{n+\frac{1}{2}}\left(k+\frac{1}{2}\right) - I^{n-\frac{1}{2}}\left(k-\frac{1}{2}\right)}{\Delta x} - C\frac{E_T^{n+1}(k) - E_T^n(k)}{\Delta T}\right) \tag{12}$$

3 Application of the model

The improved FDTD algorithm based on mode-matching method is applied to shielding effectiveness calculation. The outer size of the shielded cavity is $0.3m \times 0.12m \times 0.1m$, and the inner size is $0.3m \times 0.12m \times 0.3m$. The outer and inner apertures($0.1m \times 0.005m$) are both in the center of the plane, the thickness of the shield cavity is $t = 0.0015m$, and the incident wave is vertical. Assuming that the consumption on transmission lines is 0, the length of the wire is 0.1 m, the conductor spacing is 0.01 m, and the conductor radius is 0.3 mm.

The curves of shielding effectiveness value at the center of the double-layer shield cavity are shown in Figures 2. The left one shows that the shielding performance has gone through four stages of rapid reduction, gentle reduction, rapid reduction and the final rise. The shielding effectiveness is the lowest at 6-7 GHz, where resonance occurs. The right one shows that when the frequency is relatively low, the shielding cavity has the best shielding effect. As the frequency increases, the shielding effectiveness floats, but the final maximum frequency does not exceed 100dB.

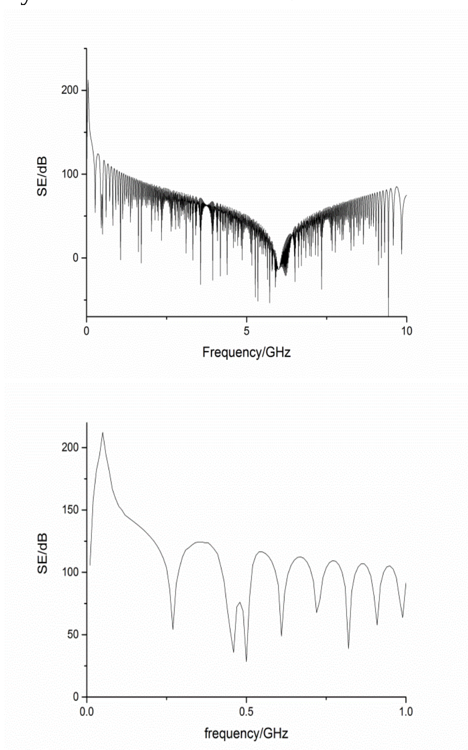

Fig.2 The shielding effectiveness curve at the center of the double shielding cavity

The terminal response of the built-in transmission line of the double shield cavity under the excitation of the incident electromagnetic wave is shown in Figure3. In the high-frequency segment, the induction voltage peaks at multiple frequencies, which will have a certain impact on the devices of the electronic system in the cavity. Therefore, in the design of electromagnetic compatibility protection, double shield should be applied to the shielded cavity with open holes to enhance the s shielding effectiveness.

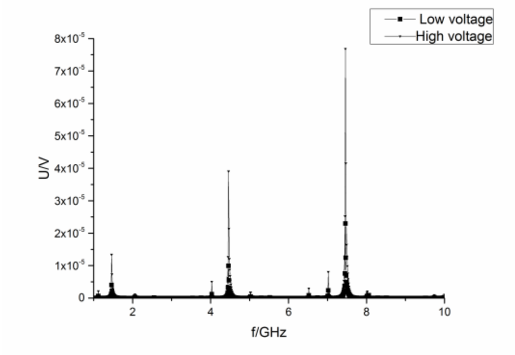

Fig.3 The terminal response of an internal transmission line in a double shielding cavity under the excitation of incident electromagnetic wave

Take the lower voltage as an example, the simulation time is 8 minutes and 10 minutes respectively by using this method and CST software. The result in Figure4 shows that the curve obtained by our method fits for the actual result especially when the frequency is less than 4 GHz. With increasing frequency, the resonance peak of the simulation is different, but the trend is consistent. There are two reasons: a) The number of modes is limited; b) Because of the resonance of the wire and the resonance inside the cavity, but the result still reflects the different resonance frequencies inside the shielding cavity with apertures, which proves the correctness of our method.

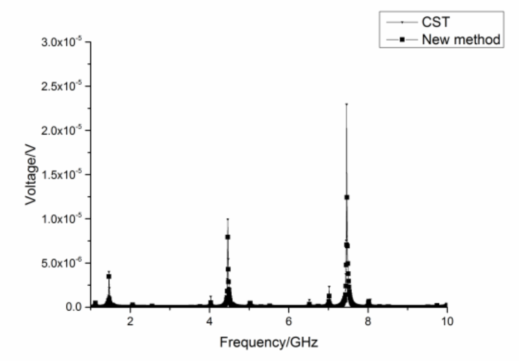

Fig.4 Comparative results of CST and this Method

4 Conclusion

In this paper, an improved FDTD algorithm based on mode-matching method is used to study the terminal response of a double-layer shield cavity with internal transmission lines and apertures. This method first uses the mold-matching method to calculate the electromagnetic distribution in a double-layer shield cavity with apertures on the transmission line position, but without transmission line. The FDTD method uses the result to calculate the response voltage over the transmission line which is embedded in a double-layer shield cavity with apertures. The results show that the improved FDTD algorithm with mode-matching method can effectively reduce the memory consumption of the computer, cut down the calculation time and obtain a reasonable result of the internal transmission line response of the double-layer shield cavity with apertures.

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