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Analysis on Electromagnetic Interference with Different Polarization of Electric Field

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Abstract

A simplified modeling of shielding cavity with a wire penetrated was established, in order to study the coupling effects of electromagnetic pulse (EMP) with different incident angles when the shielding cavity has a penetrated wire. Finite-Difference Time-Domain (FDTD) was applied to analyze the rule of variation of coupling current magnetic field on the penetrated wire, with the variation of angles of incident wave. Further study shows that the electromagnetic energy coupled by penetrated wire when incident wave radiates aslant is more than the coupling energy when incident wave radiates the target vertically in the condition of vertical polarized direction of electric field, and less in the condition of horizontally polarized direction of electric field. And compared with the situation of horizontal polarized direction of electric field, more electromagnetic energy is coupled when the direction of electric field is vertically polarized.

***Keywords**: electromagnetic pulse, polarized direction of electric field, finite-difference time-domain, penetrated wire, incident angles*

1. Introduction

With the development of modern science and technology, a variety of electronic and electrical equipment provide great help for people's daily life and social construction. Meanwhile, the electromagnetic radiation and electromagnetic interference generated by electronic and electrical equipment during operation restrict the production and life of human beings [1, 2]. On the other hand, the electromagnetic radiation also has bad impact on electronic equipment, producing serious interference on nearby electronic equipment and precision instruments, affecting the normal working. It is necessary to improve the ability of electrical and electronic equipment to work in complex electromagnetic environment. In the design of electromagnetic compatibility, although seamless metal plates have high shielding effectiveness, the device can not be masked completely, for the particular reason of ventilation, cooling, power cables and communication wires so that the presence of electromagnetic interference is inevitable [3, 4]. So far, the research on electromagnetic coupling of aperture and penetrated wires through shielding cavity has had great progress. And with the extensive application of electromagnetic waves and fast development of computer technology, various methods have been more in-depth studied, such as the Method of Moments (MoM), Finite Element Method (FEM), the Boundary Element Method (BEM) and Finite-Difference Time-Domain (FDTD) method, and so on [5-9]. And FDTD is a direct time-domain algorithm that solving Maxwell differential equations [10]. Z. Youwen did modeling and calculation to study the effects of coupling current in the circuit in the shielding cavity from the interference electromagnetic [11]. Z. Shi et.al compared and analyzed the electromagnetic coupling energy that coupled by irregular aperture on the sheilding cavity in the condition of vertical polarization of electric field [12]. S. Pengfei researched the rule of electromagnetic pulse with different angles of incidence coupled into the cavity with holes on it,in the conditions of horizontal and vertical polarized direction of E field respectively [13].

Those researches did well on electromagnetic coupling of aperture and penetrated wires through shielding cavity, and had good guide to the design of anti- interference of electromagnetic in the shielding cavity. Although the situations of different polarized direction with wires penetrated into shielding cavity were involved, the modeling and analysis were not thorough enough. Finite-Difference Time-Domain (FDTD) is applied for modeling the coupling of

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an incident electromagnetic pulse (EMP) with a conducting wirepenetrated into a shielding cavity with a hole. Simulation and analysis are done by different incidence angles of EMP in the conditions of horizontally and vertically polarized direction of E field respectively, to analyze the rule of variation of coupling current magnetic field on the penetrated wire, with the variation of angles of incident EMP. The results show that the electromagnetic energy coupled by penetrated wire when incident wave radiates aslant is less than the coupling energy when incident wave radiates the target vertically in the condition of vertical polarized direction of E field, and more in the condition of horizontal polarized direction of E field, however. Futhermore, compared with the situation of vertical polarized direction of E field, the magnetic energy of current coupled by penetrated wire with incident wave radiating aslant is a little complex and more than the situation of horizontal polarized direction of E field.

2. Research Method

2.1. Theoretical Foundation

Let the grid of FDTD is cube, namely space grid stepping $\Delta x = \Delta y = \Delta z = \delta$. Considering the influence of FDTD numerical dispersion errors, δ is:

$$\delta \le \frac{\lambda_{\min}}{N} \tag{1}$$

in which $\lambda_{\min}$ is corresponding wavelength, N=10. If the computational domain contains only free space and perfect conductor, then:

$$\lambda_{\min} = \frac{c}{f_{\max}} \tag{2}$$

in which c is the speed of wave in free space (medium), $f_{\max}$ is the maximum value of concerned frequency. The grid size of FDTD can be determined by $f_{\max}$. In fact, FDTD space grid is equivalent to a low-pass filter that the frequency components of the pulse which is higher than $f_{\max}$ is filtered out when passing the FDTD space grid in the excitation pulse, which the results will have a great errors. And to guarantee the stability of the numerical counts in the iterative calculation FDTD, the time of stepping Δt is:

$$\Delta t \le \frac{1}{c\sqrt{(1/\Delta x)^2 + (1/\Delta y)^2 (1/\Delta z)^2}} \tag{3}$$

When there are currents and magnetic flux in uniform medium, the Maxwell's equations can be

$$\begin{aligned} \nabla \times \overline{E} &= -j\omega\mu\overline{H} - \overline{J_m} \\ \nabla \times \overline{H} &= j\omega\varepsilon\overline{E} - \overline{J} \end{aligned} \tag{4}$$

in which:
$\overline{E}$ is the intensity of electric field, V/m,
$\overline{H}$ is the intensity of magnetic field field, A/m,
μ is the permeability of the medium, H/m,
ε is the permittivity of the medium, F/m,
$\overline{J}$ is the density of current, A/m^2,
$\overline{J_m}$ is the density of magnetic flux, V/ m^2.

The radiation field of current and the magnetic flux is:

$$\overline{E} = -\nabla\times\overline{F} + \frac{1}{j\omega\varepsilon}\nabla\times\nabla\times\overline{A}$$
$$= -\nabla\times\overline{F} - j\omega\mu\overline{A} + \frac{1}{j\omega\varepsilon}\nabla\left(\nabla\bullet\overline{A}\right) \quad (5)$$

$$\overline{H} = \nabla\times\overline{A} + \frac{1}{j\omega\mu}\nabla\times\nabla\times\overline{F}$$
$$= \nabla\times\overline{A} - j\omega\varepsilon F + \frac{1}{j\omega\mu}\nabla\left(\nabla\bullet\overline{F}\right) \quad (6)$$

in which $\begin{matrix}\overline{J} = \overline{e_n}\times\overline{H} \\ \overline{J_m} = -\overline{e_n}\times\overline{E}\end{matrix}$, and $\begin{matrix}\overline{A}\left(\overline{r}\right) = \int\overline{J}(\overline{r}')G(\overline{r},\overline{r}')dV' \\ \overline{F}\left(\overline{r}\right) = \int\overline{J_m}(\overline{r}')G(\overline{r},\overline{r}')dV'\end{matrix}$, $\overline{A}$ and $\overline{F}$ are vector potential functions, and $G(\overline{r},\overline{r}')$ is Green's function of free space.

When FDTD is applied in calculations for radiation, it will be divided into the total field area and the scattered field area. FDTD is used for calculating electric field in the total field, which is sum of incident field and scattered field. The strength of magnetic field H is proportional to the current. The strength of magnetic field of induced current is the strength of magnetic field of the current.

2.2. Numerical Caculation

Establish the physical model of electronic equipment shielding cavity with a conducting wire penetrated, as shown in Figure 1. The dimension of cavity is 200mm × 200mm × 200mm. There is a hole of 12mm × 12mm in the center of one plane, and with a wire through the center hole. The radius of the wire is 0.51mm. The length of the wire is 100mm with the exposing length of the wire outside of the cavity 50mm. Incident radiation source is a uniform plane. The propagation direction is parallel to the wire when incident wave radiates the target plane with hole vertically. Choose Gaussian pulse as pulse wave source, which is:

$$E_i\left(t\right) = E_0 \exp\left(-\frac{4\pi\left(t-t_0\right)^2}{\tau^2}\right) \quad (7)$$

In which $E_i\left(t\right)$ is the strength of electric field of incident Gaussian pulse, E_0 = 1000V/m, τ determines the width of the Gaussian pulse, τ = 100Δt, length of space lattice stepping $\Delta x = \Delta y$ = Δz =1mm, and pulse peak appears at $t = t_0$.

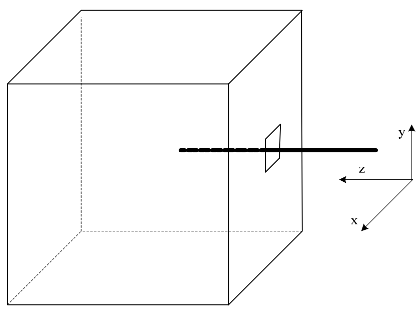

Figure 1. The Physical Model

Based on the setting of the model above, caculate the amplitude of coupling current on the wire which penetrated into the cavity during 0~30GHz, considering the influnence of different incident angles in the conditions of different polarized direction of electric field.

3. Results and Discussion

3.1. Vertically Polarized E Field

In the case of vertically polarized electric field, maintaining the constant electric field intensity of incident electromagnetic pulse, change the direction of incident electromagnetic pulse. The main components of electric field energy coupled into the shielding cavity by the penetrated wire are concentrated in the direction of x-axis and z-axis, and the magnetic field energy is concentrated in the direction of y-axis. Figure 3 shows the curve of H_y at one location on the wire penetrated into the cavity when the incident direction of EMP is taken 0°, 30°, 45°, and 60° respectively.

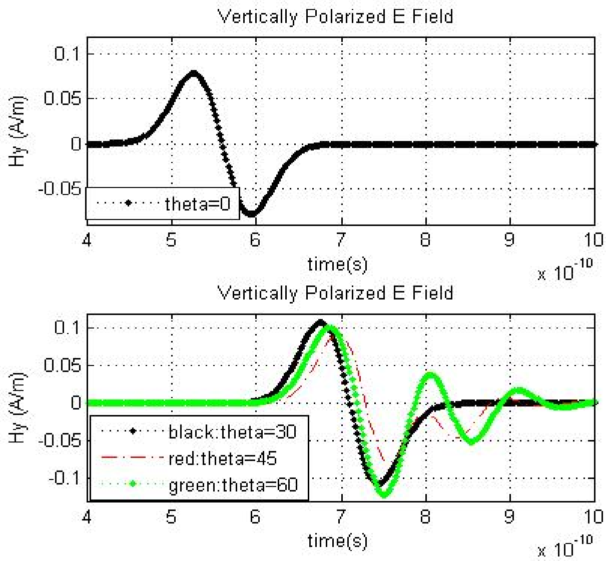

Figure 2. The H_y with Different Incident Direction of EMP

As can be seen from the Figure 2, in the conditions of the structure of shielding cavity and penetrated wire, the coupling rule of the Gaussian pulse in the case of vertically polarized E field is that the coupling magnetic field on the wire with the incident angle of EMP 0° (of 0.08A/m) is less than those of the angle of incidence of 30°, 45°, and 60°. It shows that coupling magnetic field energy of incident wave radiating the target vertically (angle of incidence EMP is 0°) is less than that of incident wave radiating aslant in the case of vertically polarized electric field.

3.2. Horizontally Polarized E Field

In the case of horizontally polarized electric field, change the incident direction of electromagnetic pulses (i.e. the angle between propagation direction and the z-axis), the electric field energy coupled into the shielding cavity by the penetrated wire is concentrated in the direction of y-axis, and the main components of magnetic field energy are concentrated in the direction of x-axis and z-axis. Figure 2 shows the curve of synthesis $|H|$ of H_x and H_z at one location on the wire penetrated into the cavity when the incident direction of EMP is taken 0°, 30°, 45°, and 60° respectively.

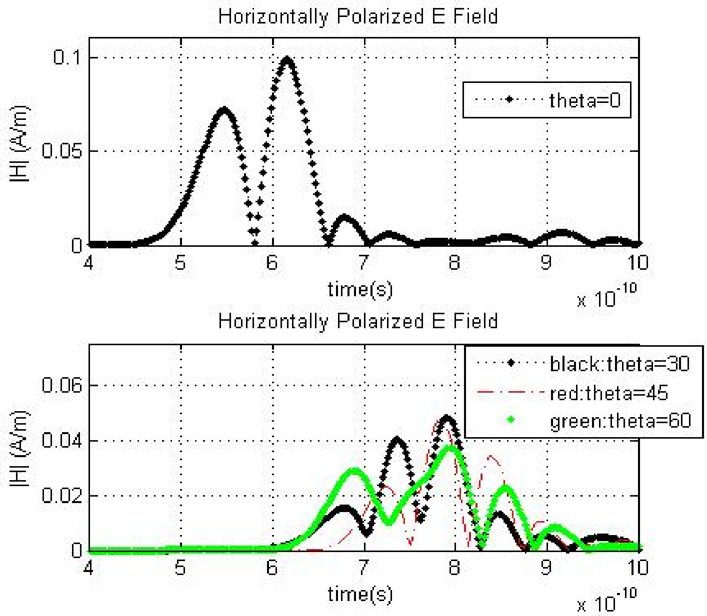

Figure 3. The Synthesis $|H|$ with Different Incident Direction of EMP

As shown in Figure 3, in the conditions of the structure of shielding cavity and penetrated wire when the E field is horizontally polarized, the coupling rule of the Gaussian pulse is that the coupling magnetic field on the wire reaches the maximum (0.1A/m) when the angle of incident EMP is 0°, and decreases with angle of incidence becoming larger, after comparing the total amplitude of the magnetic field that synthesized from the coupling magnetic field component H_x and H_z. It indicates that the energy of magnetic field coupled into the cavity decreases with increasing angle of incident EMP. It also shows that coupling magnetic field energy of incident wave radiating the target vertically (angle of incidence EMP is 0°) is greater than that of incident wave radiating aslant in the case of horizontally polarized electric field.

3.3. Comparition

Compared Figure 2 with Figure 3, we can see the difference of magnetic energy coupled into cavity by the penetrated wire between the two situations of vertically and horizontally polarized E field, that is, the magnetic field strength of coupling current in the conditions of vertically polarization electric field is greater than that of horizontally polarization electric field. It indicates that more coupling energy is introduced by the penetrated wire in the case of vertically polarized E field than that of horizontally polarized E field.

The innovation in this paper is that the coupling effects introduced by penetrated conducting wire are compared, with different polarization directions of E field and different incidence angles of electromagnetic pulse, to get the rule of variations of the coupling field.

4. Conclusion

Simulation and analysis are done by different incidence angles of EMP in the conditions of horizontally and vertically polarized direction of E field respectively, to analyze the rule of variation of coupling current magnetic field on the penetrated wire, with the variation of angles of incident EMP. Results show that the electromagnetic energy coupled by penetrated wire when incident wave radiates aslant is more than the coupling energy when incident wave radiates the target vertically in the condition of vertical polarized direction of electric field, and less in the condition of horizontal polarized direction of electric field. And compared with the situation of horizontally polarized direction of electric field, more electromagnetic energy is coupled when the direction of electric field is vertically polarized. Therefore, conducting wire penetrated into opening cavity must be strictly controlled, to avoid affecting stable operation of the internal electronic circuit in the cavity that from the outside interference.

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