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COUPLING EFFECT OF UWB-EMP ON IRREGULAR CAVITY

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ABSTRACT

The electromagnetic coupling effect on the irregular cavity which is acted by ultra wide band electromagnetic pulse (UWB-EMP) is studied. First, an irregular cavity structure model is established by using electromagnetic numerical calculation software (CST). Second, based on the model, the influences of UWB-EMP on the irregular cavity coupling efficiency are analyzed, when its rise time and pulse width change. Simulation show that: the shorter the rise time is, the better the coupling efficiency is gotten; pulse width almost has no influence on coupling efficiency. Furthermore, the signal frequency distribution of the typical positions in the cavity model are analyzed, which helps to improve the electronic equipment anti intense electromagnetic pulse interference abilities. The research results have an important guiding significance to improve the protection ability of the typical electronic equipment to UWB-EMP in practice.

Keywords: *UWB-EMP, Coupling Effect, Irregular Cavity, Rise Time, Pulse Width*

1. INTRODUCTION

The competition between the electronic countermeasure (ECM) and electronic counter-countermeasure (ECCM) becomes increasingly in the future high-technology war. The research on how to strengthen the anti-electromagnetic interfere ability of the typical electronic devices has been paid more and more attention. As an important kind of electromagnetic pulse interference source, UWB-EMP features sharp rise edge, short pulse width, high peak power, and wide frequency band, which is harmful to electronic equipment[1-4]. At present, the researches of UWB-EMP influence on electronic equipment[5,6] mainly focus on the interference or damage of the semiconductor device in regular cavity, seldom concern the irregular cavity. Therefore, the study on electromagnetic energy coupled in irregular cavity has an important engineering significance. By using the electromagnetic numerical calculation software CST, a kind of irregular electronic equipment simulation model was established. As the rise time and pulse width of the UWB-EMP changes, the influences on the irregular cavity coupling efficiency, and the signal frequency distribution of the typical positions are analyzed. These results will provide reference for the electromagnetic protection technology.

2. SIMULATION MODEL

2.1 CST Simulation Model

As a kind of electromagnetic numerical calculation software, CST has a formidable 3D modeling function, a new ideal boundary fitting. Compared with other traditional simulators, its magnitude is improved in precision. The transient solver can get electromagnetic characteristics of the simulation component in the whole frequency band by only one calculation, and the time domain waveforms can be offered obviously [7].

The CST calculation model of typical electronic equipment is built in fig.1. The external size is about 110mm×60mm×60mm, and the thickness of cavity is 2mm. A round through-hole is at the left side of the top and a rectangular hole on the lateral wall. The cavity is made by PEC, and interior is a vacuum space. Setting a rectangular coordinate, the origin is at the center of the left top, and z axis is coincided with the symmetry axis of the cavity. The electromagnetic pulses propagate along $-z$ direction, and then it is polarized horizontally. The electric signals at certain locations can be measured by setting electric probes.

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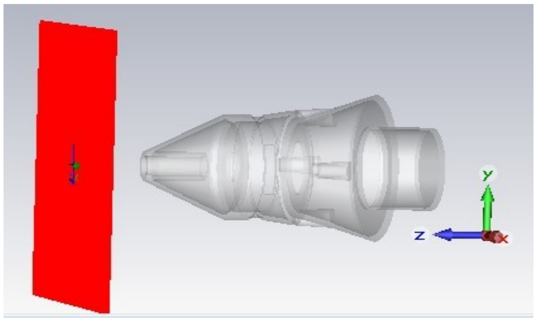

Figure 1: The Simulation Model

2.2 Coupling Efficiency Calculation

Mainly, there are two types of threats to electronic equipment, which caused by intense electromagnetic pulse[8]: one is the devices are interfered, and the results depend on peak field strength; the other is the sensitive devices are damaged, and the results depend on the energy of the field. The peak coupling efficiency and energy coupling efficiency are used to evaluate the coupling ability of electromagnetic pulse to the cavity in this paper.

The peak coupling efficiency is defined[9] as

$$CE_p = 20\lg\frac{E_i}{E_o} \quad (1)$$

where E_i, E_o is the peak of electric field inside and outside the cavity respectively.

The energy coupling efficiency is defined as

$$CE_W = 10\lg\frac{W_i}{W_o} = 10\lg\frac{\int E_i^2(t)dt}{\int E_o^2(t)dt} \quad (2)$$

where W_i, W_o stands for the energy inside and outside the cavity respectively.

It is obvious that the higher the value of CE is, the stronger of coupling ability is, and vice versa.

3. SIMULATION AND DISCUSSION

The incident plane waves are UWB-EMP, and they are represented by a double exponential function. The time-domain expression of incident wave is

$$E(t) = kE_p(e^{-\alpha t} - e^{-\beta t}) \quad (3)$$

where E_p is the peak factor; k is the normalized coefficient; α and β are the rising and falling edge parameters of the pulse[10]. In simulation, E_p is set to 10kV/m, and the pulse rise time and pulse width can be changed by adjusting the value of k, α, and β. The frequency-domain expression of double exponential function is

$$E(f) = E_0 k(\frac{1}{\alpha + j2\pi f} - \frac{1}{\beta + j2\pi f}) \quad (4)$$

and its spectrum is shown in figure 2.

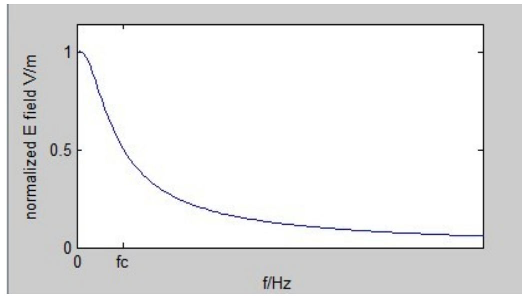

Figure 2: Spectrum Of The Double Exponential Function

3.1 The Influence of the Rise Time on Coupling Efficiency

Take a group of pulses with the same pulse widths and different rise time as the incident waves. As shown in figure 3, the 10%E_p pulse width is 0.5ns. The rise time is 20ps, 40ps, 73.4ps, and 100ps respectively.

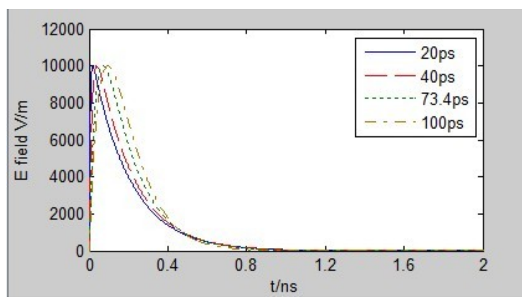

Figure 3: Incident Waveforms At Different Rise Time

The time domain waves can be obtained by using the electric field probes, when the incident pulses coupling into the irregular cavity. Taking the electric signals at (0, 0, -40mm) in simulation model as an example, the time domain waveforms are shown in figure 4.

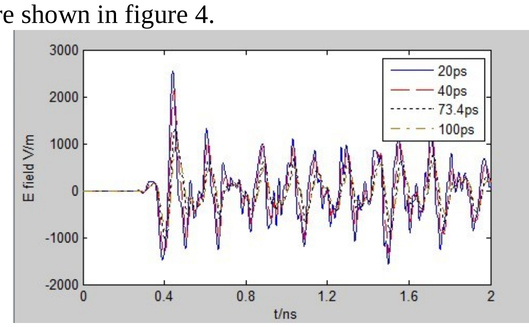

Figure 4: The Time Domain Waveforms At(0,0,-40mm)

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It can be inferred from figure 4. If the incident pulses width keeping the same and the rise time increasing the electric signals coupled into the cavity will be attenuated. That is because the slot in the cavity wall is equivalent to a high-pass filter, which has a low-frequency cut off frequency f_{Lc}. Only the components that are larger than f_{Lc} in the incident pulse spectrum can couple into the cavity. The bandwidth BW[11] of the double exponential function is defined as

$$BW = 0.35\frac{1}{t_r} \tag{5}$$

where t_r is the pulse rise time. The BW will be reduced and the pulse energy will focus on the low frequency part when the rise time t_r of incident pulse increases, which results in the reduction of the energy, coupled into the cavity and the electric field accordingly.

The influence of the rise time on coupling efficiency can be obtained by equation (1) and (2). The peak coupling efficiency and the energy coupling efficiency at (0, 0, -40mm) in simulation model are shown in table1, when the rise times are 20ps, 40ps, 73.4ps, and 100ps respectively.

Table 1: The Influence Of The Rise Time On CE

Rise time(ps)	CE_p(dB)	CE_w(dB)
20	-10.889	-7.762
40	-12.250	-9.239
73.4	-16.029	-12.747
100	-18.215	-15.505

As shown in table 1: (1) both the peak coupling efficiency and the energy coupling efficiency reduce with the increase of the rise time, and then the energy coupled into the cavity reduces accordingly. Because the frequency distribution of double exponential pulse is determined by the rise time, the shorter rise time is, the greater bandwidth and the more high frequency component will be. Therefore, the energy coupled to the cavity increases and the coupling ability gets stronger. (2) by comparison, the peak coupling efficiency is always smaller than the energy coupling efficiency. That is because the energy coupled into the cavity appears oscillation which decreases slowly, leading to the increase of integral to E_i in equation (2).

3.2 The Influence of the Pulse Width on Coupling Efficiency

Take a group of pulses with same rise time but different pulse width as the incident waves. As shown in figure 5, the rise time is 40ps and the $10\%E_p$ pulse widths are 0.25ns, 0.5ns, 1ns, and 2ns respectively.

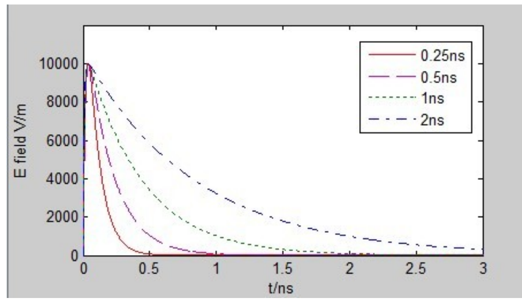

Figure 5: Incident Waveforms With Different Pulse Width

The time domain waveforms of the electric signals at (0, 0, -40mm) in simulation model are shown in figure 6.

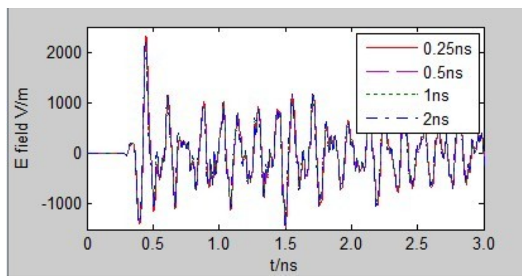

Figure 6: Time Domain Waveforms At (0,0,-40mm)

As shown in figure 6, the coupled electric signals change a little, when the rise time of the incident pulse keep the same and the pulse widths increase. That is because the high frequency component of the pulses with same rise time and different pulse widths change very little, so the energy coupled into the cavity through the slot is almost the same.

The influence of the pulse width on the coupling efficiency can be obtained by equation (1) and (2). The peak coupling efficiency and the energy coupling efficiency at (0, 0, -40mm) in simulation model are shown in table 2, when the pulse widths are 0.25ns, 0.5ns, 1ns, and 2ns respectively.

Table 2: The Influence Of The Pulse Width On CE

Rise time(ns)	CE_p(dB)	CE_w(dB)
0.25	-11.421	-6.341
0.50	-12.250	-9.238
1.00	-12.094	-11.718
2.00	-12.058	-14.465

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As shown in table2: The peak coupling efficiency changes very little but the energy coupling efficiency reduces, when the double exponential pulse rise time is invariable and the pulse width increases. Because the same pulse rise time the same high frequency component, and it has little influence on the peak coupling efficiency. But the pulse width is closely related with the energy. The wider the pulse width is, the greater the integral is to E_i in equation (2) in time domain, and the more energy is focused on the low frequency component in frequency domain. Therefore, the energy coupling efficiency reduces with the increase of the pulse width.

3.3 Signal Frequency Distribution at Typical Position

According to the resonant cavity theory, the external electromagnetic field coupled into the cavity through the slot can create a resonance frequency. If the resonance frequency is close to the operating frequency of the electronic equipment in the cavity, it will have an adverse impact on the normal performance of electronic equipment. The resonance frequency can be calculated by the internal dimension for the regular cavity [12]. But this theoretical calculation becomes difficult for irregular cavity due to complicated structures. In order to obtain the frequency distribution at typical position of irregular cavity, a FFT can be done on the time domain signal by numerical simulation.

Taking incident wave with the rise time of 40ps and the 10%Ep pulse width of 0.5ns as an example, the signal frequency distributions at typical position can be analyzed.

(1) Vertical comparison

The electric signals at symmetry axis (0,0, -10mm), (0,0, -30mm), (0,0,-40mm), and (0,0,-80mm) are compared and the frequency distributions are shown in figure 7.

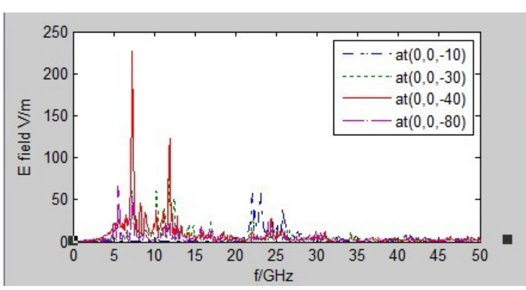

Figure 7: Spectrum Of Electric Signals At Symmetry Axis

As shown in figure 7, the frequency distributions at different positions are irregular, which is due to the irregular vertical structure of the cavity of irregular cavity. At the same time, the main resonance frequencies are different, so are the numbers of the resonance frequencies.

(2) Horizontal comparison

The electric signals at (10mm,0,-40mm), (-10mm,0,-40mm), (0,10mm,-40mm), and (0,-10mm,-40mm) in z=-40mm cross section are compared and the frequency distributions are shown in figure 8.

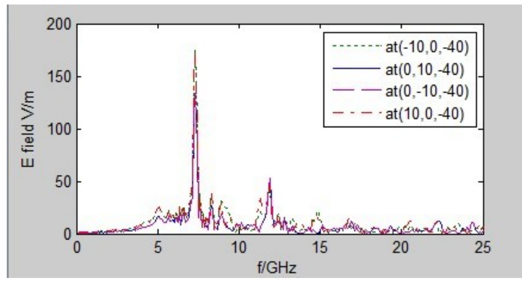

Figure 8: Spectrum Of Electric Signals In Z=-40mm Cross Section

As shown in fig.8, the resonance frequencies at different positions are almost the same, because the horizontal structure of the cavity at z=-40mm is regular.

According to the above comparison, the inside structure of the cavity have a great influence on the resonance frequency distribution. For regular cavity, the resonance frequency distributions at different positions are almost the same. But for irregular cavity, the resonance frequency distributions are different. Although most electronic equipment cavities are irregular in actual project, the signal frequency distributions at typical positions can be calculated by numerical simulation.

4. CONCLUSION

The influences of the double exponential pulse rise time and pulse width on the irregular cavity coupling efficiency are analyzed by using the software CST. In this paper, when the rise time and pulse width of the double exponential pulse change, the influences on the irregular cavity coupling efficiency are analyzed by using the software CST. Results show that the shorter rise time is, the better coupling efficiency is gotten, and the pulse width has little influence on coupling efficiency. That is mainly because the slot in the cavity wall is equivalent to a high-pass filter, and the high frequency component of the double exponential pulse is determined by its rise time. On that basis, the signal frequency distributions at typical

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positions of the irregular cavity are analyzed, which can provide the guidance for the operating frequency of the electronic equipment to avoid the resonance frequencies. The research results of this paper have an important significance on UWB-EMP protection for electronic equipment in practice.

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