Research of Enhancement Efficiency of Field Strength Coupled into Slots

Bing Cao
School of Mechanical Engineering, Nanjing University of Science and Technology
Nanjing, 210094, China
caobing202815@163.com

Chenglong Liu
Weichai Power Co., Ltd
Weifang, 261041, China
john.fly@163.com

***Abstract*—This paper studies the enhanced efficiency of the field strength coupled into slots by using the finite difference time domain method. The coupled field strength with the different slots shape, size, and polarization direction is assisted, some useful rules are concluded. The easiest to form enhanced efficiency of field strength is rectangular slots, square slots are the second, and the most difficult slots are round. For aspect ratios (long side/short side) of the rectangular slots, the bigger the more easily to form enhanced efficiency. When the polarization direction is perpendicular to the short side of rectangular slots, it is harder to form slots enhanced efficiency. This paper provides a practical method to research enhanced efficiency, it also provides theory basis for the slot shape selection, slot size design, and the polarization direction selection to improve the efficiency of the shield.**

***Index Terms*—slots, field strength enhancement, simulation, FDTD, strong electromagnetic pulse, shielding box, damage efficiency**

I. INTRODUCTION

Electrical equipment can't avoid open slots to meet the requirements of ventilation cooling, information transmission and an external circuit. High power microwave pulse can easily couple into the electronic equipment through the slots, and then it will damage the electronic components. In modern information war relied on electronic equipment, it gives birth to the threat of electronic equipment electromagnetic weapons, especially high power ultra-broadband electromagnetic weapons. In electronic warfare and electronic against, high power microwave weapons key striking object is the one of the other side of the computer system.

According to development of the computer and high power microwave technology, people have done a lot of theory and experimental research on pulse slots coupling. They have deeply studied the phenomenon of harmony, polarization characteristics, resonant effect, recessed enhanced efficiency, thickness effect, incident direction, slots shape and slots array, etc, and for the influence of slots field enhanced efficiency of the shape and the slots polarization direction is less. This paper will research the enhanced efficiency of the field strength from the slot shape, rise time, and the polarization direction.

II. EXCITATION SOURCE SELECTION

At present, people have done a lot of researches on all sorts of electromagnetic pulse, just like lightning pulse, static pulse, nuclear electromagnetic pulse, etc. The explosion wave form of the electromagnetic pulse bomb is shown in Fig. 1.

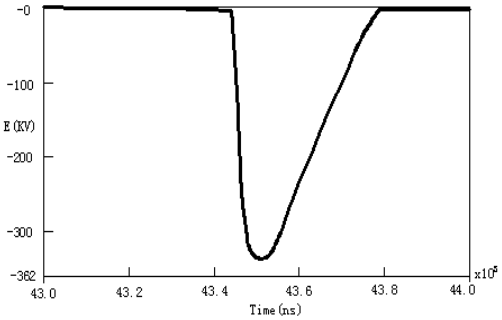


Figure 1. Time domain of electromagnetic pulse bomb

Through extensive researches, people summarize some kind expression of time domain and frequency domain of the electromagnetic pulse, and get their time domain and frequency domain model, such as double exponential pulse, Sine modulation Gaussian pulse, Gaussian pulse, etc.

doi:10.4304/jsw.7.11.2494-2500

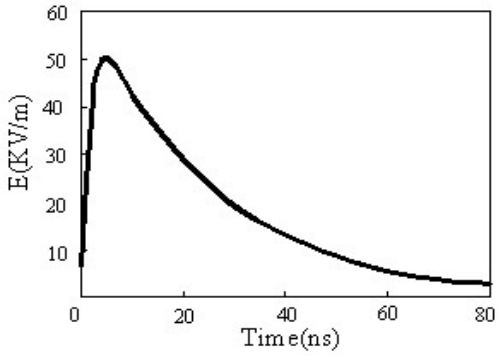


Figure 2. Time domain double exponential pulse waveform

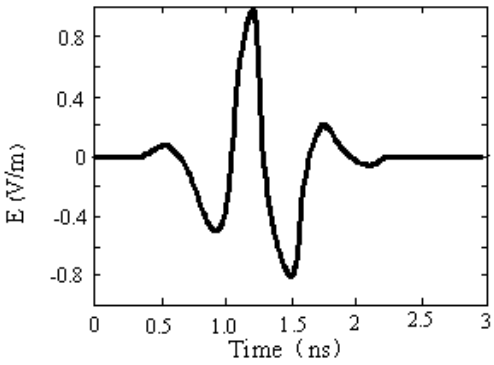


Figure 3. Time domain of Sine modified Gaussian pulse

The wave form of double exponential pulse is shown as in Fig. 1. Because the high power pulse can form the dense atmosphere ionization plasma, so that, continuous high power pulse tail can't pass through the plasma area, that seems like the tail being eaten, which is so-called erosion phenomena. For the double exponential pulse, the tail amplitude is small, the lasting time is long, and the relatively short time in for instantaneous power is not big. Considering all above factors, It is difficult for the end of double index pulse to couple into the shielding box, that is double exponential pulse isn't suited in this paper's simulation.

In the above pulse model, Gaussian pulse is the most commonly used model in the time domain analysis, it is also of the important signal form in ultra-wideband radio system. On the one hand, the shape and the actual pulse waveform are very similar to the waveform. On the other hand, due to the time domain waveform or the frequency distribution of Gaussian pulse has analytical expressions; it can simplify the process of analyzing problems, and help to realize the program for the quantitative analysis of the simulation results.

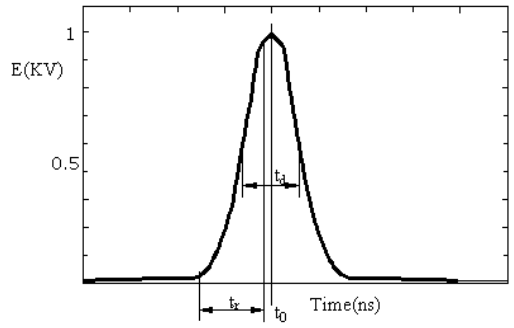


Figure 4. Time domain of Gaussian pulse

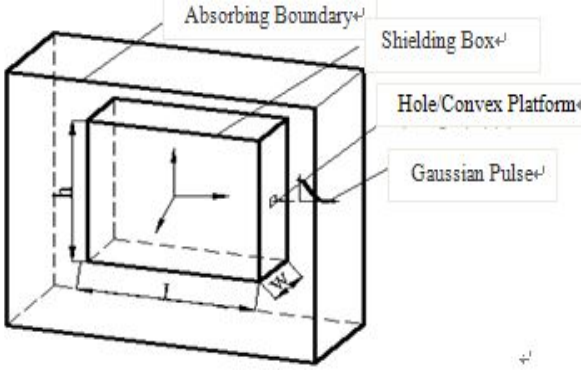
Where t_r is the rise time (refers to pulse amplitude of the 10% rise to pulse amplitude of the 90% of the time); t_d is the decrease time (up to 50% of the value of the fall amplitude of the 50% of the time), usually called half pulse width of time. Obviously, pulse steep rise, the richer the high coefficients, the high frequency components of ns levels of pulse is more of the order of magnitude of 10^4 than subtle levels of pulse.

III. THE CREATION OF SIMULATION MODEL

A standard computer box is selected as the simulation model, as shown in Fig. 5 (coordinate center is at the center of the case). Gaussian pulse is the incident source of plane wave, the slot size is $30\text{mm} \times 20\text{mm}$ (power supply socket), and the pulse width is different in this simulation research.

This simulation model is far away from electric dipole antenna, which is far greater than the maximum for microwave wavelength 1m. So this study can be seemed as the remote area, and the electromagnetic pulse can approximate for plane wave. This paper chooses Gaussian pulse as the plane wave source motivation.

The pulse's amplitude is selected 1KV/m, and the polarization direction is parallel to the slot's long side (+y along the direction). The grid size is needed much smaller than the smallest size of slots. For accurately simulation, this paper's grid size is selected $\Delta x < \lambda/10$, which is less than the minimum wavelength and minimum slots size.



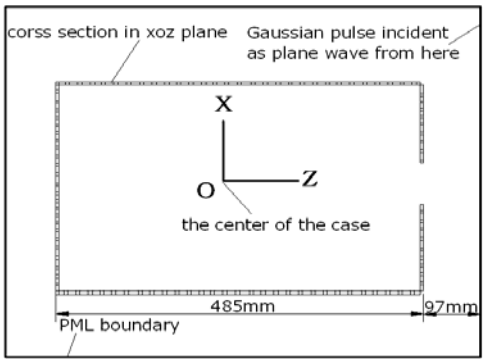


Figure 5. Simulation model and PML boundary

IV. Effect of Slots Shape to Field Strength Enhancement

A. The Field Strength Enhancement of Slot when the Slot Shape is Circular

The cooling slots (6mm in diameter) and mouse keyboard slots (14mm in diameter) are selected as the research objects, and the Gaussian pulse width is 0.1ns. The simulation results are shown as below.

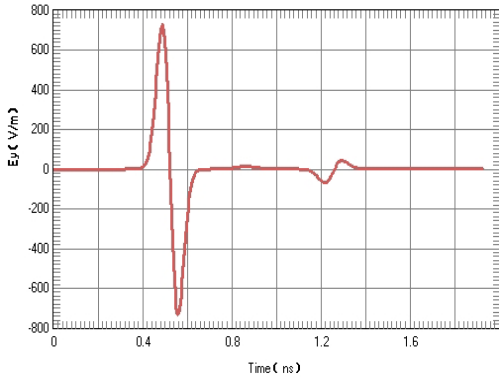


Figure 6. Field strength of small round slot' center

From the above simulation results analysis, we can obtain that: for the smaller round slots, it requires less time to form less enhanced efficiency; the coupled highest electromagnetic strength is much less than bigger slots. Namely, small round slots are much faster to form the enhanced efficiency than bigger round slots.

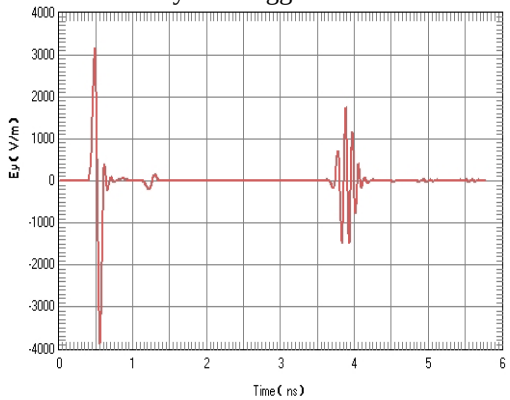


Figure 7. Field strength of big round slot' center

B. The Field Strength Enhancement of Slot when the Slot Shape is Square

The area of the square slots is equal to round slots, so the sides of the square slots should be 6mm and 12mm. The relationship between the slots' dimension and the enhanced efficiency will be analyzed. The other simulation settings are the same as the former, and the simulation results are as follows.

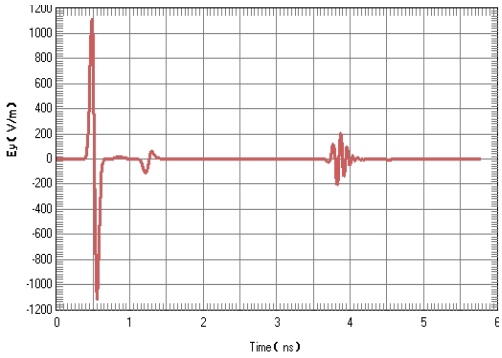


Figure 8. Field strength of small square slot' center

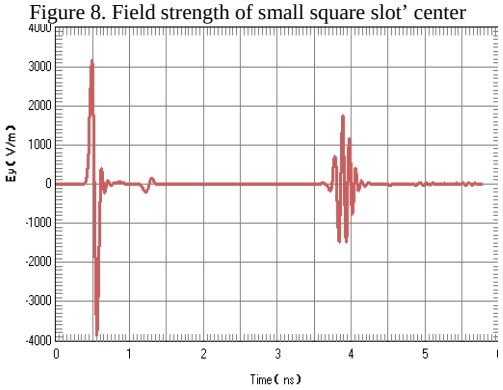


Figure 9. Field strength of big square slot' center

By the above simulation results analysis, the conclusions of square slots are the same as round slots, namely the rise time of small square slots to form the field of enhanced efficiency is far less than that of big square slots.

C. The Field Strength Enhancement of Slot when the Slot Shape is Rectangle

Take round slots and party a large slots in the same area of the corresponding rectangular slots, take long side size is prior to the rectangular slots, rectangular slots is 30mm × 5mm, Take again the rectangular slots of 30mm × 13mm. Pulse polarization direction is vertical to long side.

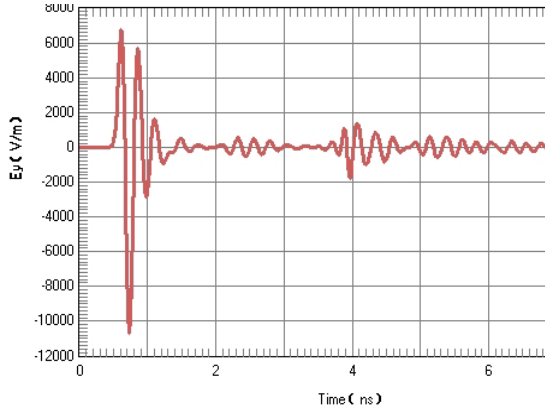


Figure 10. Field strength of small rectangle slot' center

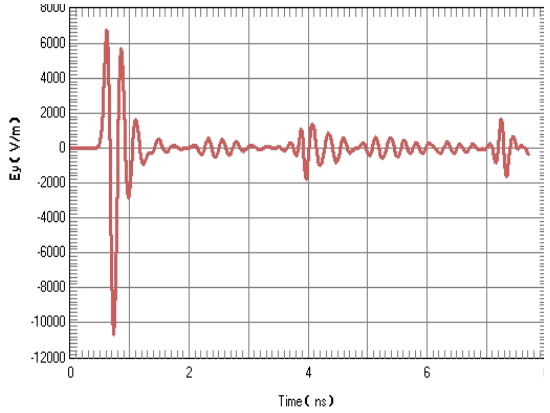


Figure 11. Field strength of big rectangle slot' center

By the above simulation result analysis:

- For rectangular slots he biggest rise time is much higher than round slots and square slots of the same area when forming enhanced efficiency of field. Thus, hen forming enhanced efficiency of field, the rise time of rectangular slots is the longest and it is also most likely to form the enhanced efficiency of the field, square slots is the second smallest, and also the most difficult slots of the minimum.
- For rectangular slots, when the long side is equal, The shorter the short edges is, the higher the rise time is when forming enhanced efficiency of the field.

D. Effect of Length-width Ratio of Rectangular Slots to Field Strength Enhancement

Below will study the rectangular slots whose short sides are equal and whose long side is different, in case that rectangular slots aspect ratio impact on enhanced efficiency of the field. Select the rectangular slots 50mm × 13mm and 70mm × 13mm. Pulse polarization direction is vertical to long side, other Settings are the same to former.

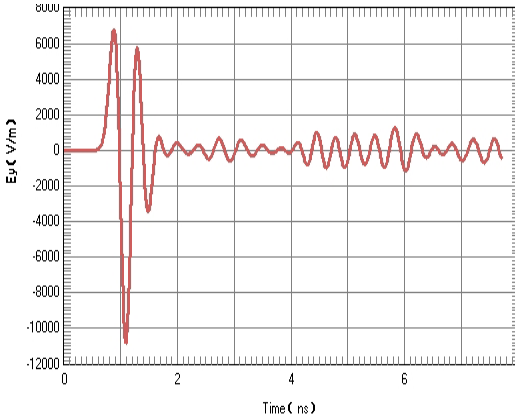


Figure 12. Field of slot center with 50mm × 13mm

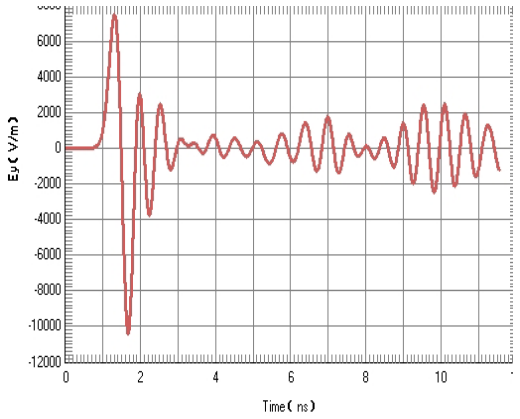


Figure 13. Field of slot center with 70mm × 13mm

From the above analysis, for rectangular slots, when the polarization direction is perpendicular to the long side of the rectangular slots, short sides are equal, the longer the long side is, longer the biggest rise time is, when slots enhanced efficiency of the field is formed, the easier to form slots enhanced efficiency of the field.

Considering the actual electromagnetic pulse the rise time, due to the rise time of round slots and square slots is much smaller than the 0.1 ns, when slots enhanced efficiency of the field is formed. Again by the above analysis shows that, rectangular slots aspect ratio has influence on the biggest rise time influence on the biggest rise time when slots enhanced efficiency of the field is formed. So, the main research will be based on the fact that long and short side edge are fixed, the influence law of rectangular slots aspect ratio to the biggest rise time when slots enhanced efficiency of the field is formed.

DA. Influence of rectangular slots aspect ratio to the biggest rise time to form enhanced efficiency

When the short side is fixed, rectangular slots' aspect ratio and the largest rise time to form enhanced efficiency are shown in Table I.

TABLE I.
WHEN THE SHORT SIDE IS FIXED, THE LARGEST RISE TIME AT SELECTED ASPECT RATIO

Aspect ratio	30/13	50/13	70/13	90/13	110/13
Largest rise time (ns)	0.17	0.3	0.55	0.57	0.58

From the table above, when the short side is fixed, the fitting curve and equation are obtained, shown as in Fig. 12 and Eq. (1).

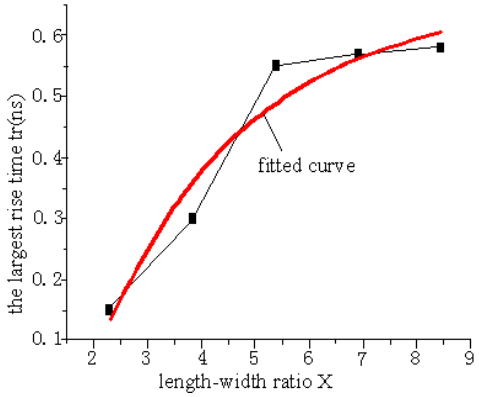


Figure 14. Curve of length-width ratio and largest rise time

$$t_r = -1.21 \times \exp\left(\frac{-x}{2.71}\right) + 0.66 \qquad (1)$$

From the above fitting curve and formula, the biggest rise time changes with the increasing of rectangular slots aspect ratio x of short edges exponentially; The bigger aspect ratio x is, the greater the biggest rise time t_r is; The maximum error of about 9%. So, fitting curve and the type have certain theory reference and practical value.

DB. Influence of the biggest rise time on rectangular slots' aspect ratio to form enhanced efficiency

When the long side fixed, Rectangular slots aspect ratio and the largest rise time when slots enhanced efficiency of the field is formed are shown in Table II.

TABLE II.
WHEN THE LONG SIDE IS FIXED, THE LARGEST RISE TIME AT SELECTED ASPECT RATIO

Aspect ratio	30/5	30/7	30/9	30/11	30/13	30/15
Largest rise time (ns)	0.26	0.23	0.22	0.20	0.17	0.16

From the table above, fitted curve and equation of rectangular slots aspect ratio and the largest rise time when slots enhanced efficiency of the field is formed as well as the long side is fixed, as shown in Fig. 13 and Eq. (2).

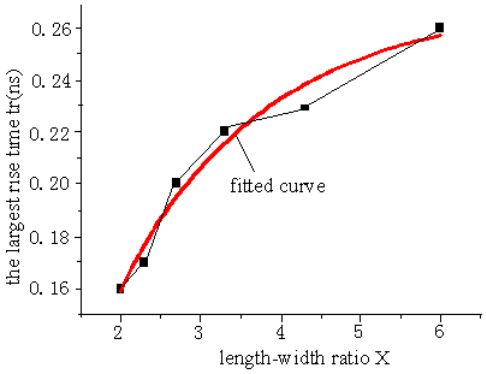


Figure 15. Curve of length-width ratio and largest rise time

Fitting curve of rectangular slots aspect ratio and the largest rise time when slots enhanced efficiency of the field is formed as well as the long side is fixed

Equation of rectangular slots aspect ratio and the largest rise time when slots enhanced efficiency of the field is formed as well as the long side fixed:

$$t_r = -0.34 \times \exp\left(\frac{-x}{1.79}\right) + 0.27 \qquad (2)$$

By the above fitted curve and equation, the biggest rise time changes with the increasing of rectangular slots aspect ratio x of short edges exponentially; The bigger aspect ratio x is, the greater the biggest rise time t_r is; The maximum error of about 4%. So, fitting curve and the type have certain theory reference and practical value.

V. THE EFFECT OF POLARIZATION DIRECTION TO FIELD EFFECT ENHANCEMENT

A. The Effect of the Field Enhancement of Polarization Direction to Round Slots and Square Slots

The above is the polarization direction along the +y direction, that is the polarization direction is perpendicular to the long side of rectangular slots, and it also may be perpendicular to short side of the rectangular. The different will be researched, and the simulation results are shown as below.

Contrasting Fig. 16, Fig. 17 and Fig. 7, Fig. 9, the following conclusions are obtained. When the pulse width is the same, the polarization direction has no effect on coupled field strength of round slots and square slots. This is because the round and square slots in the x, y direction is symmetric, the polarization direction changes do not affect its port distribution of charge.

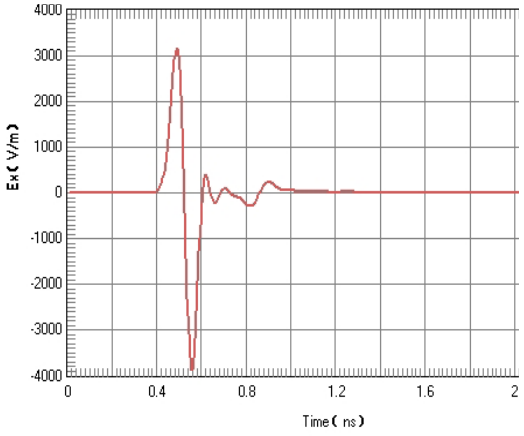


Figure 16. 14mm radius hole in the center of the field

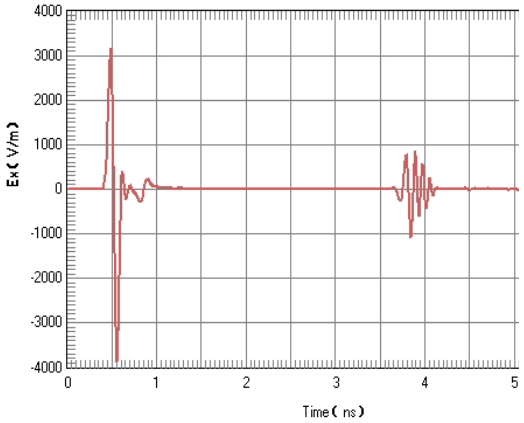


Figure 17. 12mm square slots in the side of the field center

B. The Effect of the Field Enhancement of Polarization Direction to Rectangular Slots

The selection of rectangular slots size can refer to two standards. When the long side is constant, the influence of the short side to the enhanced efficiency will be researched, and the simulation results are shown as below.

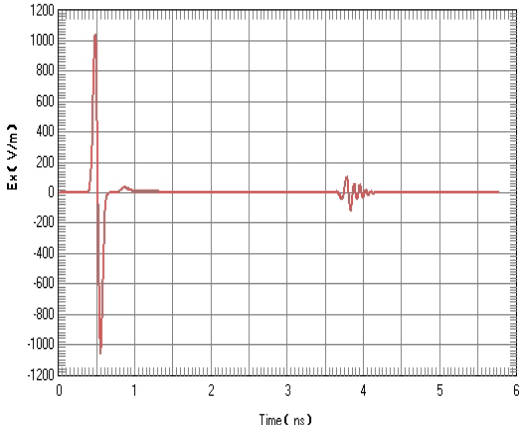


Figure 18. Field of slots' center with 30mm × 6mm mm sides

When the shorter edge is constant, the effect the long side to enhancement will be researched, and the simulation results are shown as below.

From the above graph available simulation:

- When polarization direction is perpendicular to the short side of rectangular slots, even if the rise time is 0.1 ns, rectangular slots center field is far less than that of the field to the incident. So, right now the narrower the biggest pulse width is, the shorter rise time is, the more difficult to form the slots enhanced efficiency. This is more difficult to form the slots enhanced efficiency than that when the polarization direction is perpendicular to long side of rectangular slots.

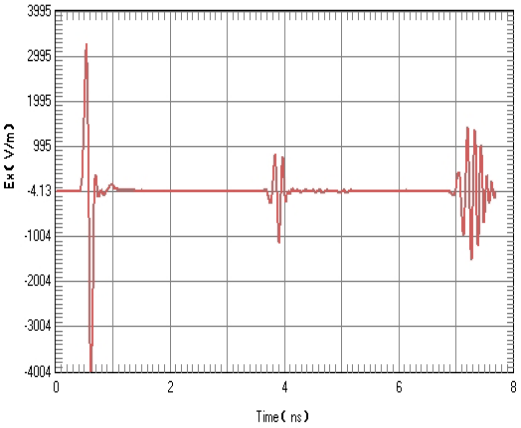


Figure 19. Field of slots' center with 30mm × 13mm sides

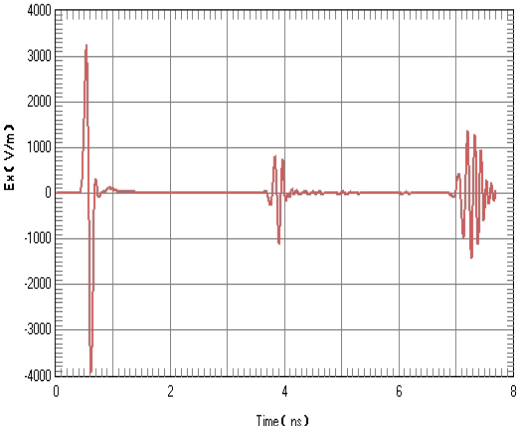


Figure 20. Field of slots' center with 30mm × 13mm sides

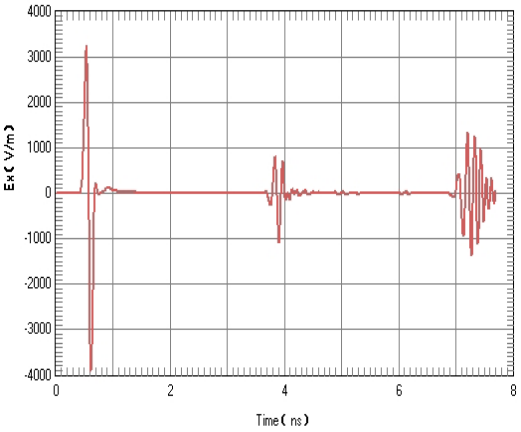


Figure 21. Field of slots' center with 70mm × 13mm sides

- When polarization direction is perpendicular to the short side of rectangular slots, both rise time and long side of rectangular slots are of the same, the shorter the short side is, the smaller the center field of slots is; when short sides are the same, long sides have no effect on the center field of the slots of the.

VI. Conclusions

From the above analysis, some useful conclusions are obtained as following:

- For round slots and square slots, the smaller the slots size is, when slots enhanced efficiency electromagnetic pulse field is formed, the rise time is shorter, the more difficult to form the enhanced efficiency of the field. Namely, for small round slots, the required time to form the enhanced efficiency is far less than that of big circle slots.
- For rectangular slots, the biggest rise time is much higher than round slots and square slots with the same area when forming enhanced efficiency of field. Thus, hen forming enhanced efficiency of field, the rise time of rectangular slots is the longest and it is also most likely to form the enhanced efficiency of the field, square slots is the second smallest, and also the most difficult slots of the minimum.
- The bigger aspect ratios (long side/short side) of rectangular slots is, the wider the maximum pulse width to form the slots enhanced efficiency is; the longer the rise time is, the more easier to form slots enhanced efficiency of the electromagnetic field strength.
- For rectangular slots, when the long side is equal, the shorter the short edges is, the higher the rise time is when forming enhanced efficiency. For rectangular slots, when the polarization direction is perpendicular to the long side of the rectangular slots, short sides are equal, the longer the long side is, longer the biggest rise time is, when slots enhanced efficiency of the field is formed, the easier to form slots enhanced efficiency of the field.
- When polarization direction is perpendicular to the short side of rectangular slots. The rise time required to form enhanced efficiency field of slots is shorter, namely, it is more difficult to form the slots enhanced efficiency.

References

[1] Mottahed B.D, Manoochehri S. Joint design methodology based on the electromagnetic shielding effectiveness capabilities. *IEEE transactions on components, packaging, and manufacturing technology. Part B, Advanced packaging*, v 19, n 1, p 238-247, Feb 1996

[2] Zhi-Hong Lai, Kiang J-F. Long-range pulse propagation over different surfaces using domain-decomposition FDTD method. *2011 IEEE International Workshop on Electromagnetics; Applications and Student Innovation (iWEM 2011)*, p 214-16, 2011

[3] Yuan Feng , Lu Chun-Lan. Application of electromagnetic band-gap structure to receive antenna of the satellite. *Journal of PLA University of Science and Technology (Natural Science Edition)*, v 8, n 3, p 226-9, June 2007

[4] Mottahed B.D , Manoochehri S. Effects of angle of cut and gap size on the electromagnetic shielding effectiveness. *1994 International Symposium on Electromagnetic Compatibility (IEEE Cat. No.94TH0680-9)*, p 128-31, 1994

[5] Saito T. Shielding performance of open-type magnetic shielding box structure. *IEEE Transactions on Magnetics*, v 45, n 10, p 4640-3, Oct. 2009

[6] Li Xu, Yu Ji-hui, Li Yong-ming, Wang Quan-di. Simulation of electromagnetic interference to circuits inside shielding box by wire penetrated with aperture. *Journal of System Simulation*, v 19, n 17, p 3891-3, 3954, Sept. 2007

[7] Tominaga T, Shirai T, Kosukegawa. Study on simple magnetic shield for AC magnetic standard. *JEMIC Technical Report*, v 33, n 1, p 1-7, 1998

[8] Wang Liu-Ping, Gao You-Gang. Shielding effectiveness of PCB loaded rectangular cavity with aperture arrays to front rising electromagnetic pulse. *High Power Laser and Particle Beams*, v 20, n 1, p 162-6, Jan. 2008

[9] Nagano Isamu , Yoshimura Yoshiyuki. Estimation of the electric parameters of thin electromagnetic shielding materials. *Electrical Engineering in Japan*, v 147, n 1, p 1-9, 15 April 2004

[10] Thottappillil, R. Electromagnetic pulse environment of cloud-to-ground lightning for EMC studies .*IEEE Transactions on Electromagnetic Compatibility*, v 44, n 1, p 203-13, Feb. 2002

Bing Cao was born in Henan, engineering from Nanjing University of science and Technology, where he is currently an associate professor. He has implemented several projects of National Natural Science Foundation and National Defense Foundation, etc. He has published more than 30 papers, his current research interests include Electromagnetic field and wave technology, electromagnetic mutilate and electromagnetic protection technology.

Chenglong Liu was born in Shandong, China in 1986. He will receive his master degree from Nanjing University of science and Technology in April. 2012. He has implemented the project for the research on the strong electromagnetic to satellite system. He has published three papers and current research interests is electromagnetic mutilate and protection technology