Shielding effectiveness testing method of pulse electric field based on GTEM cell

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Abstract. In order to evaluate the shielding ability of materials under the radiation of electromagnetic pulse (EMP), a test method based on GTEM cell is put forward. And the test theory and the components of test system are introduced. The shielding box method is verified to be reasonable with simulation. The shielding effectiveness (SE) of one material is tested with this method, and the test results are compared with the results based on the coaxial method. The results show this test method can be used to test the effect of SE on EMP, and the test results can reflect the true shielding ability of the test material.

1. Introduction
With wide application of the microelectronic device, electric device and electric system become sensitive and vulnerable under the radiation of EMP. The hazards of EMP on the microelectronic device are realized by people. Shielding technique can effectively improve the vulnerable parts in the bad electromagnetic environment. The test methods of SE are vital to evaluate the SE of materials. There are different results depending on different test methods [1].

The test methods of SE are introduced in GJB6190-2008 in detail, in which input wave is continuous wave. At present, the SE of materials mainly formulates with the changing frequency. With the research of high power EMP jamming effect, frequency domain SE of materials can not substitute the time domain SE [2, 3]. On the shielding problem of EMP, due to the "dispersion" effect, the SE of EMP could not apply the single frequency SE formula to calculate. More appropriate define is worthy of study [4].

Through a large number of experiments, Bihua Zhou analyzed the EMP SE and the relation of electromagnetic pulse rise time, pulse width and peak value, and put forward an SE calculation formula including pulse rise time [5]. L. Klinkenbusch got the EMP SE with the calculation of the energy with and without test materials according to the same position [6]. Waveform reconstruction method based on the minimum phase system is introduced [7-9], using Hilbert transform to evaluate system impulse response characteristics according to frequency domain measurement results. This method provides an approach for using the system transfer function of the amplitude-frequency characteristic to evaluate system time response characteristics, especially suitable for solving electromagnetic pulse measurements. A "specimen" method is proposed to test the EMP SE [10]. This method overcomes the shortcoming of "windows" method, such as bad low frequency response and measurement error. And it solves the problem of engineering material EMP SE. Pulse electric field SE

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measurement system is reported [11] and it is mainly for the metal bridge, control cabinets, shielding
tents, conductive cement concrete. The SE of material is got according to the pulsed electric field peak
attenuation [12].

Above-mentioned test methods are mainly for larger buildings or material products, and this paper
presents a pulse electric field SE measurement method aiming at a smaller plane material, namely
shielding box method. The shielding box method is proved to be reasonable through simulation
analysis and one material was tested with this method. Comparing test results of this method with
flange coaxial method, it proved the test method feasible.

2. Test theory and component of test system
In order to get the SE under the radiation of EMP, the shielding box is placed in the GTEM cell, using
pulse source and GTEM cell to produce a high power EMP radiation. The SE is got by testing the
waveform in the centre of shielding box with and without material on the test window.

2.1. Test principle
Generally, SE refers to the ratio on the same incentive level, the received electric field or power
without shielding material and the electric field or power with shielding material. And the computation
formula is:

$$S = 20\log_{10}\frac{E_0}{E_1} = 10\log_{10}\frac{P_0}{P_1}$$

(1)

In the formula, $S$ refers to SE; $E_0$ and $P_0$ refer to the electric field strength and the received power
at a point without shielding material respectively; $E_1$ and $P_1$ refers to the electric field strength and the
received power at the same point with shielding material respectively.

As for shielding room method, signal transmitting equipments are standard signal source and the
antenna, and the signal receiving equipments are antenna and spectral analyzer. Signal generating
devices of the shielding box method are mainly the standard pulse source and GTEM cell, and signal
receiving device is a pulse sensor. A test box with window (equivalent to a small shielding room) is
placed in the GTEM interior. Through testing the waveform of the same point loading and unloading
material on the test window, the SE of material is got. Test schematic diagram is shown in figure 1.

![Figure 1. Sketch of test system.](image)  ![Figure 2. Model of shielding box.](image)

Shielding box is placed in the GTEM cell, and the peak value and pulse width of the pulse are set
up. Firstly, the test waveform is derived from pulse sensor when there is no test material. Then test
material is loaded and the waveform is got, keeping the pulse sensor position unchanged position.
According to the formula (1), the SE of the material is calculated from the pulse peak value of
waveform.
2.2. Test equipments

- GTEM cell. GTEM cell is Gigahertz transverse electromagnetic cell, and the working frequency ranges from DC to gigahertz. It has the trait of internal large free field area and several advantages of other test method, such as open field shielding room and TEM cell. And it overcomes the limitations of other methods, with the advantages of high quality and low price.

- High voltage pulse source. Pulse source used in high-frequency noise generator which made in Japan NOISENKEN Company. Model: INS-4040. It can generate square wave pulse, the peak value is less than 4 kV, the rise time is less than 1 ns, and the pulse width is optional.

- Pulse sensor. The bandwidth of the sensor is from DC to 1 GHz, dynamic range is 44 dB, and it has good linearity.

2.3. Shielding box development

The shielding box is placed in the GTEM cell. And in order to minimize the electromagnetic reflection in GTEM cell caused by shielding box, the box designs into a certain wedge-shaped cavity. The angle of tilt of the box surface is the same as the surface of GTEM cell. The box model is shown in figure 2. Top opening of shielding box is 0.6 m × 0.6 m, bottom size is 0.8 m × 0.9 m, and height is 1 m. In order to suppress the electromagnetic reflection and resonance in the cavity, absorbing materials are placed in the bottom of shielding box.

Only high SE of the shielding box itself, the SE of test material should not be affected by the test system. Generally, the SE of the shielding box is 6 dB more than the test material.

3. Simulation analysis

In order to analyze the wave of the pulse sensor in the centre of shielding box, the pulse waveform through simulation analysis is illustrated as follows. It is helpful to analyze the SE of EMP.

CST-MWS software is based on the time domain finite integral. The simulation model of shielding box corresponds to the actual model. The thickness of test material is 0.001 m, relative dielectric constant is 1, the relative permeability is 1, and the conductivity is 1000 S m⁻¹.

Figure 3 shows that the input pulse is ideal square wave pulse, the peak value is 1 kV m⁻¹, and the pulse width is 50 ns. When the input pulse transmits inside the box, the waveform tested by the pulse sensor is shown in figure 4. The pulse waveform changes greatly mainly due to the shielding box. The reason is that the low frequency signals are difficult to access. Figure 5 shows that, because of the test material, the amplitude of wave becomes lower, and the shape of wave changes little. So the signal inside the shielding box is mainly high frequency signal corresponding to rising and falling edges of the square wave pulse. With and without test material, the amplitude of pulse changes only, and the
waveform changes little. According to the amplitude changes of waveform with and without test material, the SE for the pulse of the material can be calculated.

4. Test experiment
Last section shows that the shielding box method is validated to test the SE of the material with simulation. Generally, the SE could be got to evaluate the shielding ability through the experiment.

4.1. Waveform analysis
The test system is build up according to figure 1. The waveforms tested by the pulse sensor with and without test material in the shielding box are shown in figure 6 and figure 7.

![Waveform unloading test material](image1.png)  ![Waveform loading test material](image2.png)

Figure 6. Waveform unloading test material.  Figure 7. Waveform loading test material.

Figure 6 and figure 7 show that the waveform has little change with and without test material, and the amplitude of the pulse changes only. Based on the definition of SE, the SE can be calculated for 15.8 dB according to the maximum peak value of the pulse.

The peak voltage of input square wave is 3 kV when the SE of the material is tested, and the electric field strength at the test point in the GTEM cell is about 1.5 kV m\(^{-1}\). From the figures, we know that the material is under the radiation of high electromagnetic pulse. The shielding box method can realistically simulate the bad electromagnetic environment. So the SE of the material is tested in close proximity to the actual environment of strong electromagnetic field, and it is helpful to accurately grasp the SE of material.

4.2. Time domain, frequency domain comparison
In order to further analyzing test results, the SE of the material is tested again with flange coaxial method. The test result is shown in figure 8.

Comparing the coaxial test curve with peak value SE, it is found that the peak value SE and the SE of frequency 700 MHz are consistent, and it shows that the pulse peak value SE is corresponding to a frequency point in the frequency range of the SE. According to the Schelkunoff shielding theory, the SE is related to the test frequency. The pulse peak value SE is corresponding to the SE of single frequency in frequency domain test results, but the pulse SE is tested under the radiation of strong electric field. It has the unique characteristics of strong electromagnetic field test.

For linear material, the SE curve tested through a weak field can reflect the SE of the material; as for the nonlinear material, the SE is related to the input pulse peak value, and the SE which is measured by inputting weak electromagnetic field was not a true SE that can not represent the shielding ability for strong electromagnetic field. So, it is very effective to input strong electromagnetic pulse to simulate actual environmental when testing SE, and it can make the SE of the materials to be more accurate and reliable for electromagnetic field shielding capability.
5. Conclusion

This paper presents pulse electric field SE test method. A shielding box with absorbing material inside the box was made and placed in the GTEM cell, and the pulse sensor is placed in the centre of the shielding box. The SE is got through testing the waveform with pulse sensor with and without test material. And the shielding box method is verified by simulation and experiments to illustrate the application. In this method, the SE is got under the radiation of strong electromagnetic pulse. And using this method, SE will be more accurate with simulating the bad electromagnetic environments, and it is the special characteristic of this method.

Acknowledgments

The authors are grateful to an anonymous reviewer; and to Xiaodong Pan and Xiang Chen for comments that helped improve the paper.

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