Research on calibration method of uniformity of radiation interference field of intense electromagnetic pulse

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Abstract. With the rapid development of electronic and electrical products, the working frequency of the products is higher and higher, the influence frequency range of interference between electronic products is also expanding, the test frequency range of radiation anti-interference is improving, at the same time, more and more attention is paid to the requirements of radiation anti-interference test site. At present, the uniformity of radiation field is mainly realized by single point multiple test, which will inevitably lead to the measurement error due to the time-varying characteristics of the radiation signal itself; In addition, the test time is greatly increased and the test efficiency is low. In order to solve these problems, this paper designs a device which can realize multi-point test at one time and can automatically adjust the test area. The simulation shows that the device can meet the requirement of 9-point uniformity test of radiation field in 500mm × 500mm ~ 1500mm × 1500mm area. On this basis, experiments are carried out in 1000mm × 1000mm test area for 1.35GHz and 2.88GHz. The experiments show that the test device can meet the requirement of 9-point uniformity test and greatly improve the test efficiency and automation.

1. Introduction

The nuclear electromagnetic pulse (NEMP) simulator is widely used to simulate the generation of nuclear electromagnetic pulse (NEMP), which is widely used to carry out the strong electromagnetic pulse effect test [1]. Compared with the transmission or bounded wave simulators which use transmission lines, parallel plates, gigahertz transverse electromagnetic (GTEM) cells and transverse electromagnetic (TEM) cells as field forming devices, the radiation type nuclear electromagnetic pulse simulator adopts biconical antenna, cage antenna, electromagnetic field simulator and so on TEM horn antenna and other pulse radiation antennas produce electromagnetic pulse environment, which has a steeper front and a larger test area. The determination of its volume of uniform field is the precondition of EMP effect experiment. Field uniform area, also known as working volume, provides uniform field space for equipment under test (EUT). In the existing standards at home and abroad, there is no special test method for field uniformity area of radiation simulator, only for reverberation room, anechoic chamber, GTEM room and other radiation systems.

Nowadays, a large number of military and civil high-power radars and communication equipment radiate electromagnetic waves with different frequencies and energies to space, which makes the space electromagnetic environment worse and worse [2]. At the same time, the number of electronic devices in most systems is growing exponentially, which leads to the enhancement of the system electromagnetic sensitivity and the system performance degradation, damage and even damage due to electromagnetic interference. Electromagnetic environment effect experiment is an important means to study and verify the electromagnetic environment adaptability of electronic system. In order to ensure
the accuracy and reliability of the experimental data, higher requirements are put forward for the uniformity of the radiation field. In the experiment, it is necessary to test and evaluate the uniformity of the radiation field to ensure that the field around the EUT is fully uniform, so as to ensure the effectiveness of the experimental results. In the electromagnetic compatibility experiment, the constant power method or constant field strength method is used to ensure the uniformity of the radiation field, and the single point multiple test method is used to characterize the uniformity of the radiation field, so as to ensure that the field strength in the experimental area meets the uniformity requirements of the national military standard [3]. For the strong electromagnetic pulse source, due to the poor pulse consistency (transient characteristics), the pulse amplitude has large and irregular changes, so the single point multiple test method is difficult to fully meet the practical application requirements; Although Huang Jianling and others of Beijing Radio Metrology and testing institute proposed to use single point multiple test to evaluate the uniformity of transient electromagnetic field rs105, they did not give the evaluation results of field uniformity.

To meet the requirement of uniformity test in high-power microwave environment (a typical strong electromagnetic pulse field), a device which can realize multi-point test at one time and adjust the test area automatically is developed. The simulation results show that the device can meet the requirement of 500 mm × 500mm~1500mm × 9-point uniformity test of radiation field in 1500mm area; And at 1000mm × The experimental verification is carried out in a 1000 mm test area for 1.35ghz and 2.88ghz narrowband high power environment.

2. Test system of 1 radiation type nuclear electromagnetic pulse simulator

The radiation type nuclear electromagnetic pulse simulator test system is mainly composed of Marx generator, sharpening device, linear TEM horn antenna and broadband pulsed electric field test probe. The Marx generator is designed with bipolar double-sided charging circuit, which is composed of six levels of 12 30nf high-voltage non inductive capacitors, current limiting resistor, isolation resistor and spark gap switch; The sharpening device is composed of 80pf coaxial capacitor and sharpening switch[4]. The fast edge pulse source is composed of Marx generator and sharpening device, which is placed on a movable lifting platform. After the console starts the input DC high voltage, after triggering, the output voltage of the pulse source is 12 times. The length of the antenna is 6m. It is made of 16 aluminum tubes with a diameter of 12mm. It is easy to remove and install. The end of the antenna is loaded with a 200 ohm resistance to reduce the reflection. The diameter of the antenna is 6m × 6m [5]. The broadband pulsed electric field test probe is shown in Figure 1. The electric field signal measured by the probe is transmitted to the photoelectric receiver through the electro-optic conversion via the optical fiber (to avoid the influence of the measured electric field), and then displayed by the broadband oscilloscope after the electro-optic conversion. The volume of the probe is very small and the interference to the test electric field is very small, so it is suitable for the test of electric field in small space; By using optical fiber to transmit signal, the problems of signal attenuation, band limitation, introduction of interference and change of measured field distribution in cable transmission are solved; The test bandwidth is wide, the nominal bandwidth is 0 ~ 1GHz; The nominal sensitivity is 1V / m; The dynamic range of the test is large, and the nominal value is more than 60dB, which can ensure the accurate measurement of nuclear magnetic pulse field.
3. Uniformity calibration and determination by the fixed power method

3.1. Introduction of the uniform domain

The uniform area is composed of 16 points 0.5m apart from the ground [6]. The uniform area is 3M away from the transmitting antenna (preferred), as shown in Figure 2.

![Figure 2 Point layout of a uniform domain](image)

3.2. Calibration method of uniformity

The calibration methods of field uniformity are divided into fixed power method and fixed field strength method. 16 point test below 1GHz and 0.5m * 0.5m area window method above 1GHz (antenna and area distance 1m) [7]. Uniformity requirements: 16 point test method under 1GHz: on 75% of the surface in the specified area, the field amplitude is in the range of - 0dB to + 6dB, that is, the field is considered to be uniform. Above 1GHz: within the range of 0.5m * 0.5m of window method, four points of the window shall meet the requirements of - 0dB - + 6dB.

Uniformity calibration below 1GHz

First, complete the layout of the site according to figure 2, connect the instruments, connect the directional coupler at the output end of the amplifier, and record the forward power of the amplifier output with power meter.

1. The omni-directional field intensity probe is placed at any of the 16 points in the uniform domain of Fig. 2 (usually the middle point is selected), and the output frequency of the signal generator is adjusted to 80MHz.
(2) Adjust the output strength of the signal generator, use the signal received by the field strength probe to display the standard value (3 V/m, 5.4 v/m, 10 V/m, 18 V/M) on the field strength meter, and record the output value of the signal generator and the display value of the power meter [8].

(3) Take the current frequency as the reference, complete the test according to the maximum increment of 1% until 1GHz. During the test, the output value of signal generator and the display value of power meter at each frequency point shall be recorded.

(4) At the other 15 points, test according to the output value of signal generator of each frequency in (3), and record the field strength value of each position and frequency under this condition [9].

(5) For calculation and comparison, take 80MHz 5.4v/m as an example, as shown in Table 1. The frequency in Table 1 is 80MHz, and the FW power is the full waveform high power of the spot field. The field intensity values of each point are arranged in the order from low to high, and the minimum value is taken as the base point (node 2 in this example). The logarithm values of other points are calculated by taking 20log field intensity value / 5.05 [10]. The results show that the logarithm values are in the range of 0-6db, 100% consistent.

| Freq(MHz) | Power(dBm)/Point | Field Strength(V/m)/Field Strength(dB) |
|-----------|------------------|-----------------------------------------|
| 80        | 42.9             | 5.48 5.05 5.4 5.19 6.33 6.35 6.29 6.06 6.41 6.51 6.66 6.68 6.05 5.93 5.92 5.81 |

(6) According to (5), all frequency points in the whole frequency range are calculated and the results are obtained. All frequency points and positions should meet the requirements of 0-6db for more than 75% of the points. Replace the mechanical property of the antenna to make the antenna meet the requirements in both vertical and horizontal states.

(7) Replace the antenna to make the antenna meet the requirements in both vertical and horizontal states.

4. Simulation Analysis

4.1. Computational modeling
In CST, the computable electromagnetic modeling of the designed test device is carried out according to the scale of 1:1, as shown in Figure 5; Under the condition of plane wave irradiation, the field strength of nine probe points in the square uniform test area is simulated and analyzed, and the test area sizes are 500mm × 500mm, 1000mm × 1000mm, 1500mm × 1500mm. In order to save computing resources, the simulation waveform pulse width is set as 20ns, the field strength is 1kV / m, and the carrier frequency is 1.35 GHz and 2.88ghz respectively.

4.2. Data processing
In order to ensure the field uniformity of the experimental data, it is necessary to perform a quantitative analysis on the field uniformity. For each test simulation area, under the excitation of different carrier frequency signals, the signal waveform $S(t)$ collected by each probe is recorded, and the Hilbert transform is used to obtain the following results:

$$\hat{S}(t) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{S(t)}{t-\tau} d\tau = S(t) \frac{1}{\pi t}$$

Amplitude envelope $a(t)$ of $S(t)$:

$$a(t) = \sqrt{\hat{S}(t)^2 + [S(t)]^2}$$

In fact, $S(t)$ and $\hat{S}(t)$ are discrete signals, and so there are:
In formula (3), \( n = 1, 2, \ldots, M \) represents the sampling time and \( M \) represents the total number of sampling points.

Then the root mean square of the amplitude envelope signal in the pulse width time is calculated, which is the average value of the field strength measured by the \( k \)-th probe.

\[
RMS_k = \sqrt{\frac{1}{M} \sum_{n=1}^{M} |a_k(t_n)|^2}
\] (4)

In formula (4), \( t_1 \) represents the leading edge of the pulse and \( t_2 \) represents the trailing edge of the pulse.

Then, when the simulation test area and carrier frequency are specified, the maximum error value of field uniformity calibration test simulation can be expressed as:

\[
MaxEr = 201g(RMS_{max}) - 201g(RMS_{min}) = 201g \frac{RMS_{max}}{RMS_{min}}
\] (5)

The field uniformity can be quantitatively analyzed by formula (1) ~ (5): the smaller \( MaxEr \) is, the better the field uniformity is; The larger \( MaxEr \) is, the worse the field uniformity is. When \( MaxEr > 3dB \), the cross-section field is considered to be nonuniform.

### 4.3. Uniformity calibration of window method above 1GHz

The test distance is 1 meter. According to figure 2, nine windows and four points in each window are calibrated. The calibration steps and calculation process are the same as those in section 2.2.1 (1) - (5).

The window method requires that four points meet the requirements of 0-6db 100%, as shown in table 2 and Figure 3.

| Freq(MHz) | FW Power(dBm)/Pos | Field Strength(V/m)/Field Strength(dB) | Relative To Reference SG(dBuV) Min F/Strength |
|----------|------------------|----------------------------------------|---------------------------------------------|
| 1000     | 29.5             | 5.93 5.83 6.15 6.03                    | 100 83 5.83                                 |
| 0.15     | 0                | 0.46 0.29                              |                                             |

Table 2 Calculation examples above 1GHz

Figure 3 Test results of the window method show

Through the above calibration methods and actual calculation examples, the laboratory can be used for reference in the actual calibration, which facilitates the calibration and data arrangement of the
laboratory, ensures the uniformity of the test site, and ensures the accuracy and stability of the actual test results.

4.4. Precautions
First of all, pay attention to whether the amplifier is saturated. We need to test the uniformity under the normal value of field strength and 1.8 times of the modulated field strength. The output signal of signal generator should not be modulated. In order to master the testing situation of floor type products, it is necessary to record the field strength of four points corresponding to the uniform area 0.4m above the ground. Within the range of 3% of the whole test frequency range, it is allowed that the tolerance is greater than + 6dB ~ 10dB, but not less than - 0dB. The actual tolerance value shall be recorded in the test report.

4.5. Analysis of simulation results
Firstly, the relationship between the pulse peak value and the distance from the antenna aperture surface is determined: the probe is placed in the center of the aperture surface, 3m, 5m, 7m, 8m and 10m away from the aperture surface respectively, and the input voltage of the console is 18.9kV. The main parameters (peak value, half peak pulse width and rise time) of the radiation field pulse waveform are shown in Table 3.

| Distance(m) | Peak value(kV/M) | Pulse width(ns) | Rise time(ns) |
|------------|-----------------|----------------|--------------|
| 3          | 33.13           | 149.5          | 2.5          |
| 5          | 22.35           | 132.8          | 1.4          |
| 7          | 13.06           | 70.3           | 6.2          |
| 8          | 10.12           | 19.6           | 6.4          |
| 10         | 8.22            | 47.6           | 5.2          |

The length of the simulator antenna is 6 m, and the near-field area is from 3 m to 10 m in front of the aperture plane. The peak value of radiation field pulse decreases linearly with the increase of distance, and the pulse width decreases with the increase of distance. The rise time has little relationship with distance due to the randomness of gas discharge and different trigger time. Due to the influence of the surrounding environment, the waveforms 10 m away from the aperture surface are not smooth enough, the peak value and pulse width are small, and the reflection ripple and bottom noise are too large to be referenced. Therefore, the uniform test area of the radiation simulator should be defined according to the pulse peak value in the near-field area, and only the change of the pulse peak value should be considered in the uniform area.

The simulation results are as follows:

Figure 4 Simulation results with carrier frequency of 1.35GHz
According to the formula (1) ~ (5), the simulation results of Fig. 6 and Fig. 7 are calculated respectively, and is obtained 500 mm× 500mm, 1000mm × 1000mm, 1500mm × 1500mm. The results are shown in Table 4.

Table 4 Maximum deviation value of field uniformity at different frequencies and different test areas

| Frequency/GHz | 500mm×500mm | 1000mm×1000mm | 1500mm×1500mm |
|---------------|-------------|---------------|---------------|
| 1.35          | 0.20        | 0.47          | 1.13          |
| 2.88          | 0.16        | 0.83          | 1.10          |

It can be seen from table 4 that at 500mm × 500mm ~ 1500mm × 1500mm test area, the influence of the test device on the field uniformity can be controlled within 1.13db; In addition, at the same carrier frequency, with the increase of the size of the test area, the field uniformity becomes worse, and the influence of the device on the field uniformity becomes greater; With the increase of the test area, the probe position is closer to the square nylon frame, and the influence on the field becomes greater. This not only better guarantees the validity and repeatability of the test, but also improves the efficiency of daily testing, saving equipment costs and testing time.

5. Conclusion
Aiming at the requirement of strong electromagnetic pulse radiation field uniformity test, a test device is designed and developed, which can realize one-time multi-point test and flexible movement. The simulation results show that the device can satisfy the 9 points automatic test of the radiation field uniformity in the area of 500mm × 500mm ~ 1500mm × 1500mm, effectively avoid the measurement error caused by the transient characteristics of strong electromagnetic pulse radiation field, reduce the calibration error and improve the test efficiency.

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Figure 5 Simulation results with carrier frequency of 2.88GHz
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