Prediction method of Ultra-wideband electromagnetic pulse coupling in slotted cavity

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Abstract—With the developmen of UWB electromagnetic pulse radiation systems, people are paying more and more attention to its serious threat to electronic equipment. The effect of UWB electromagnetic pulse has also become an important content in the field of electromagnetic compatibility. In an UWB radiation system, the distance between the device under test and the transmitting antenna is different, and the radiation field received is also different. Therefore, in actual tests, the test body is often placed at different distances from the antenna to perform multiple measurements to obtain test data as required. Based on this, this article takes the cavity as an example, and proposes a method of using the system transfer function to predict the response of the impulse field inside the cavity to simplify the test and quickly obtain the test data. Firstly, the impulse field response of a certain point with and without a cavity is measured respectively, and then the time domain response is inversely Fourier transformed to obtain the frequency domain transfer function of the test body. Finally, using the transfer function to convolute with the field to be measured, the response of the impulse field inside the cavity can be predicted under the condition of the field to be measured. It is verified by experiments that this method can better predict the response of the impulse field inside the cavity under different distance conditions, and has the characteristics of simple calculation and good prediction effect. At the same time, the transfer function obtained by this method can be used to predict the arbitrary impulse field response of the cavity in its frequency range.

1. Introduction

In the field of high-power electromagnetics, according to the bandwidth ratio and percentage bandwidth of the signal, the signal can be divided into narrowband signals, medium-band signals, sub-UWB signals, and UWB signals. The sub-UWB signals and UWB signals are all UWB signals. (UWB) The research category of electromagnetic pulse. Early research on UWB radiation systems mainly focused on theoretical research and low-power level radiation source research. After entering the 1980s, the realization of UWB electromagnetic pulses under high-power conditions became the focus of research\cite{1}. Its main features are: high peak power (greater than 1GW), coverage frequency bandwidth (relative bandwidth exceeds 25%, the frequency range extends from tens of megahertz to several gigahertz or even tens of gigahertz), short rise time (sub-nanosecond or In the order of picoseconds)\cite{2}.

Taking the US military MIL-STD-464C standard as an example, the UWB external electromagnetic environment at a distance of 100m is given, as shown in Table 1. It can be seen that
with the large-scale use of electronic equipment, the study of the impact of UWB radiation systems on electronic systems has strong practical significance.

Table 1  UWB pulse external electromagnetic environment (100m away from the source)[3]

| Frequency/MHz | Electric Field Strength/(KV/m) |
|---------------|--------------------------------|
| 30-150        | 33000                          |
| 150-225       | 7000                           |
| 225-400       | 7000                           |
| 400-700       | 1330                           |
| 700-790       | 1140                           |
| 790-1000      | 1050                           |
| 1000-2000     | 840                            |
| 2000-2700     | 240                            |
| 2700-3000     | 80                             |

The peak field strength of UWB electromagnetic pulse depends on the transmission power and the distance between the observation point and the source. Under the condition of a certain antenna transmission power, in order to obtain system response data under different field strengths, the test body is usually placed at different distances from the source.[4] Regarding the UWB radiation system, no matter how the radiation field changes, the range of its spectrum is certain. Therefore, as long as the frequency domain transfer function of the test body is obtained, the internal impulse field response of the test body can be derived under any field strength condition[5]. The frequency domain transfer function can be obtained by continuous wave sweep frequency experiment, but this method is more difficult to measure the phase information. In the acquisition of phase information, most of the test objects are assumed to be the minimum phase system, and the Hilbert transform is used to recover the phase information of the transfer function. However, in practice, many systems do not meet the conditions of the minimum phase system[6].

2. Test system construction and measurement steps

2.1. System composition
1) UWB radiation system
The entire radiation system consists of a pulse source, a feed module, and a transmitting antenna.[6] Among them, the pulse source is a solid-state pulse source based on an avalanche triode, and the irradiating antenna adopts a combined dipole antenna with gradual impedance. The main frequency of the entire radiation system is 1GHz.[7] The specific structure is shown in Figure 1.

2) Electric field probe
The electric field probe adopts a dual-polarized planar progressive conical dipole antenna, which is composed of two pairs of orthogonal planar ACD antennas crossed together. The two pairs of antennas can respectively measure the incident electric field whose polarization direction is parallel to its axis. The signal measured by this antenna is the differential signal of the pulse field, so it needs time-domain integration processing to get the pulse field time-domain waveform.[8] The antenna baluns are designed with a combination of broadband patch transmission line transformers and power combiners produced by Mini-Circuits, and their working frequency bands are 4.5MHz-3GHz and 5MHz-2.7GHz respectively.[8]

Before the start of the test, the probe was calibrated in the time domain using standard TEM horn wires in a microwave anechoic chamber[9]. The rise time (10%-90%) of the electric field pulse at the calibration point measured with a horn antenna is about 160ps, the half-height width of the main pulse is about 214ps, and the bandwidth is about 2.2GHz. Using the electric field probe to measure the pulse rise time (10%-90%) at this point is about 156ps, the main pulse half-height width is about 215ps, and the probe coefficient n=5.26×10^{12} is measured[10]. The electric field probe is shown in Figure 2.
2.2. Construction of the test system

Place the UWB transmitter system on a table with a height of 70cm, and connect the pulse source to 220V/m city power. The pulse field can be approximated as a plane wave at a distance of 3m from the transmitting antenna, and the distance from the transmitting antenna is 3m, 4m, 5m, 6m, and 7m as the points to be measured. The specific test environment is shown in Figure 3.

2.3. Measurement procedure

1) Measurement steps

After calibrating the probe, place it at a height of 70cm from the ground, and collect the electric field waveforms at 3m, 4m, 5m, 6m, 7m without the cavity, and use the oscilloscope to integrate the acquired signal to obtain the measurement point. The actual electric field distribution. Then the cavity is placed in the radiation field, the probe is placed inside the cavity, keeping the distance from the ground 70cm unchanged, and the electric field waveforms at 3m, 4m, 5m, 6m, and 7m away from the antenna are collected and integrated.

In order to ensure the accuracy of the results, during the measurement process, each measurement point is tested for 3 times, and the peak fluctuation of the pulse field does not exceed 1% as valid.

2) Transfer function calculation

Multiply the waveform integrated by the oscilloscope by the probe coefficient n to obtain the pulse field $E_0(t)$ without a cavity and the pulse field response $E_1(t)$ with a cavity. After Fourier transform of $E_0(t)$ and $E_1(t)$, the frequency domain responses $E_0(f)$ and $E_1(f)$ are obtained. The transfer function $H(f)$ can be expressed as:
After the frequency domain transfer function $H(f)$ is obtained, the inverse Fourier transform is performed on it, and the time domain expression $H(t)$ of the transfer function is obtained. The impulse field response in the cavity under the impulse condition can be predicted by convolving the impulse signal to be predicted with the transfer function $H(t)$. Since the frequency domain responses $E_0(f)$ and $E_1(f)$ obtained by this method are directly Fourier transformed through the time domain response, they contain phase information, so there is no need to perform phase reconstruction and transfer function based on the minimum phase system assumption. The calculation process is shown in Figure 4.

\[
H(f) = \frac{E_1(f)}{E_0(f)}
\]

Fig. 4 Transfer function solution process

3. Prediction of the coupling law of cavity UWB electromagnetic pulse

Select the measured data at 5m to solve the transfer function, and the impulse response when there is no cavity at 5m and with cavity is shown in Fig.5.

Fig. 5 Impulse field response without cavity and with cavity at 5m

According to formula (1), Fourier transform is performed on the two sets of data to obtain the cavity frequency domain transfer function.

It can be seen from the amplitude frequency spectrum of the transfer function that the response of the cavity to different frequency points is not the same. In general, the shielding effectiveness of the cavity at high frequencies is better than at low frequencies.

After inverse Fourier transform of the frequency domain transfer function, the time domain expression $H(t)$ is obtained. We convolve the impulse field waveform to be predicted with the transfer function $H(t)$ to obtain the impulse field response inside the cavity. Compare this with the measured response, and the result is shown in Figure 6.
From Figure 6 we can see that the predicted impulse field response is in good agreement with the measured impulse field response.

Through comparative analysis, the following conclusions can be drawn:

1) The method of solving the system transfer function through the time domain response of the system, while simplifying the test steps, better predicts the impulse field response of the system under different distance conditions, and the result is more accurate high.

2) In the process of solving the transfer function, the frequency domain information is obtained using the Fourier transform of the system time domain response. Compared with the direct frequency domain measurement, this method does not need to be based on the minimum phase system assumption to restore the phase information, which is convenient and fast at the same time Has more general applicability.

3) Due to the uneven energy distribution of the pulse field in the entire frequency band, the data collected by the probe is lost, which will cause a certain error in the prediction result.

4. Conclusion

Based on the UWB radiation system, this paper uses the time domain impulse response to obtain the frequency domain transfer function of the system, predicts the impulse field response of the system under different field strength conditions, and verifies the effectiveness of the method by comparing with the measured impulse field response. Compared with the frequency domain measurement system transfer function, this method can directly obtain the phase information of the transfer function. At the same time, the system transfer function obtained by this method can be used to predict the arbitrary impulse field response of the system within the frequency band of the transfer function.

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