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Probe-Caused Error Correction Based on Time-Frequency Domain Analysis

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Abstract

With the application of time-domain near-field antenna measurement, the performance of broadband and ultra-wideband antenna can be obtained with a single test. Correction for probe-modulation-caused error is essential to guarantee the accuracy of the results. In this paper, an error correction method based on time-frequency domain analysis is proposed. Simulation and experimental results are provided to verify the effectiveness of this method.

1 Introduction

Time-domain near-field antenna measurement is derived from frequency-domain near-field measurement and was firstly proposed in 1994 by University of California, Los Angeles [1]. This method maintains the characteristics of near-field measurement in the frequency domain such as good confidentiality, all-weather and all-time capability. Besides, near-field measurement in the time domain has its special advantages. For example, it can efficiently manage ultra-wideband measurements, improve the testing accuracy with signal processing technology and also acquire transient field information, which is of great significance in studying high-power high-accuracy antennas [2]. Time-domain near-field measurement has shortcomings compared with frequency-domain measurement. The excitation signal used in time-domain measurement is pulse signal [3]. Limited by its output amplitude, the received signal has a low signal-to-noise ratio, which makes error correction extremely important [4]. Researches on error analysis of near-field time-domain measurement mainly focus on probe error, sampling position error, and sampling plane truncation error, etc [5]. In this paper, a numerical analysis method based on time-frequency domain analysis is proposed to modify errors caused by probe modulation.

The structure of this paper is as follows. First, probe modulation is analyzed and probe modulation function is provided. Then an error correction method based on time-frequency domain analysis is proposed. Simulation results and experimental results are provided to verify the effectiveness of this method.

2 Analysis of probe modulation

Probe modulation is mainly caused by different responses of the probe to electromagnetic waves with different frequencies and dispersion effects of electromagnetic waves propagating inside the probe. The first paper published about time-domain probe error correction was published in 1995 by T. B. Hansen [6]. In this paper, a theoretical model is proposed. Its main idea is to use time-domain deconvolution to deduct the time-domain receiving characteristic of the probe from the received signal. But it is very difficult to realize. Taking the open waveguide probe as an example, although there are analytical expressions for its interface and far-field EM field distribution, due to the dispersion characteristic of the waveguide, there are a large number of zeros in its transmission function, which cause the abnormal points in deconvolution operation and inaccuracy of the calculation. Luckily, a waveguide is a passive device, amplitude attenuation and phase change of the signal at the same frequency point are consistent. The frequency-domain signal obtained by the Fourier transform is the same as the signal directly obtained by frequency-domain near-field measurement. This makes the adoption of Fourier transform possible and provides a solution for error correction based on time-frequency domain analysis.

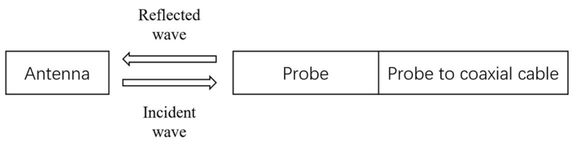

Figure 1. Signal receiving procedure in the near-field antenna measurement system

Probe modulation represents the deformation of the time-domain signal after received by the probe. By analyzing the procedure of signal receiving, probe modulation function can be obtained. Assume an open waveguide is used as the detection probe. As shown in Fig.1, probe modulation of receiving signal consists of three parts: waveguide propagation attenuation, waveguide interface reflection, and mismatch between the waveguide and coaxial cable. Based on system cascade principle, the modulation function of the waveguide probe can be expressed as [7]:

$$H = I_1 \cdot I_2 \cdot I_3. \quad (1)$$

I_1, I_2, and I_3 represent waveguide propagation attenuation, waveguide interface reflection, and mismatch between the waveguide and coaxial cable, separately. When only main mode transmission is considered and mismatch between the waveguide and coaxial line is ignored, H can be calculated and represent as [7]:

$$H = jw[1 + ref + (1 - ref)\frac{\beta c}{\omega}]\frac{be^{-(\alpha_c+\alpha_d+j\beta)\cdot d}}{\pi^2 c}. \quad (2)$$

Where w represents angular frequency, ref represents the reflection coefficient, β represents wave number, c represents the speed of light, α_c represents attenuation constant caused by waveguide, α_d represents attenuation constant caused by medium, and d represents waveguide length. H is a function of frequency. It can be expressed in the time domain by Fourier transform. Time-domain modulation function of the waveguide probe is as follows:

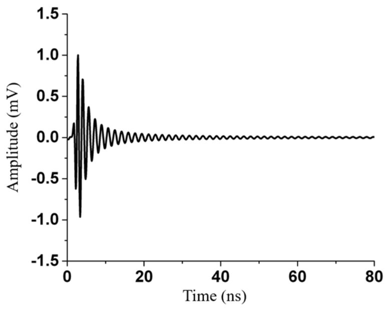

Figure 2. Time-domain modulation function of the probe.

3 Probe modulation correction

In traditional time-domain correction, the deconvolution error caused by zero points leads to unsatisfactory result of signal correction. In this paper, a new idea using time-frequency domain analysis is proposed.

According to formula (2), the modulation function of the probe is determined once the structure of the probe is determined, which can be obtained by numerical calculation. Convolution in the time domain can be considered as point multiplication in the frequency domain. According to the probe input signal a and probe-sampled signal c, the corresponding frequency domain signals A and C can be obtained with Fourier transform. Then the frequency domain expression of the probe modulation function B can be obtained. With the inverse Fourier transform, time-domain expression of the probe modulation function can be acquired. The whole procedure can be expressed as function (3).

$$a = ifft(A) = ifft(C/B) \quad (3)$$

Now traditional deconvolution problem is replaced by one time Fourier transform and one-time division of complex numbers. The number of sampling points has little influence on calculation speed, which makes it a fast way to process. The uniqueness of Fourier transform and inverse Fourier transform can guarantee the solvability of the problem.

Simulation results based on the above principle are given below. An S-band standard horn antenna is excited with 2.6 – 4 GHz Gaussian signal, the distance between sampling probe and standard horn antenna is 300 mm, the sectional dimension of the sampling waveguide probe is 72.14 mm × 34 mm and the length of the probe is 80 mm. Fig.3 shows the input signal, the received signal, and the calculated time-domain waveguide modulation curve. This time-domain waveguide modulation function can be used for all-band signal correction received by this waveguide probe.

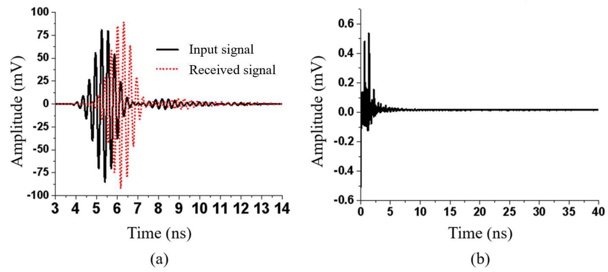

Figure 3. (a)input signal and received signal (b)the calculated time-domain waveguide modulation curve.

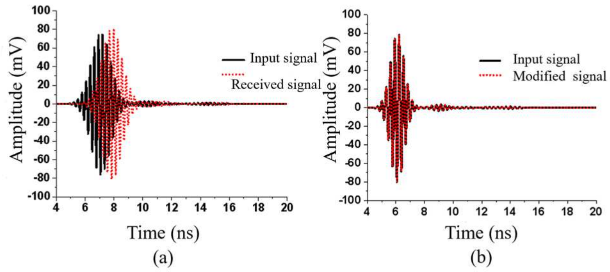

Figure 4. S-band experiment results (a)input signal and received signal (b)input signal and modified signal.

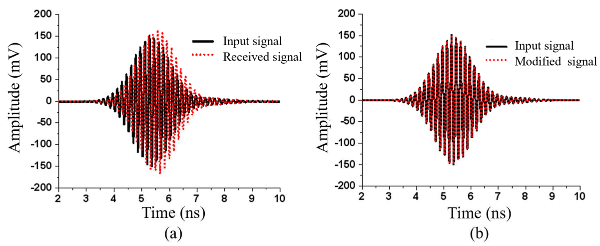

Figure 5. C-band experiment results (a)input signal and received signal (b)input signal and modified signal.

To verify the correctness of the calculated time-domain waveguide modulation function, experiments are carried out with S-band and C-band signals respectively. The results of the simulations are shown in Fig.4 and Fig.5, respectively. Amplitude differences between modified signals and input signals are both less than 1.2mV, which is less than 1% of the input signal amplitude. However, deconvolution is realized by division, in practical situations, numbers can be unable to divide, so this minor error will be inevitable.

Similar to the simulation results, experimental results also prove the effectiveness of the method. NSI standard horn and standard open waveguide are used. An experiment was carried out in C-band, waveguide used here is NSI-RF-WR137 with a working band of 5.8-8.2GHz. The waveguide probe is placed in the center of the sampling plane, facing the horn antenna. Waveguide modulation function is obtained by simulation firstly and the input signal is assumed to be the simulated signal. The experimental results are as follows.

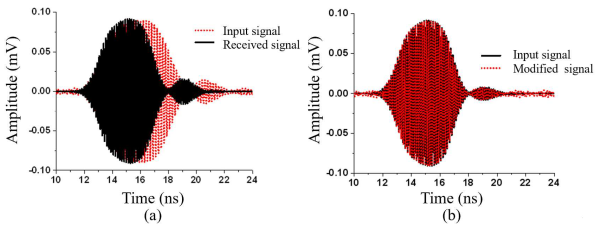

Figure 6. C-band experiment results (a)input signal and received signal (b)input signal and modified signal.

The comparison between the modified signal and the input signal shows that error caused by waveguide probe modulation can be corrected with the proposed method. It should be noted that due to the noise and system error in the testing environment, the performance of the correction method will be degraded compared with the performance under simulation conditions.

4 Conclusions

In this paper, the signal error caused by probe modulation is analyzed. Firstly, the mathematical expression of waveguide probe modulation is given by analyzing the signal transmission procedure. Then an error correction method based on time-frequency domain analysis is proposed. The feasibility of the method is proved by simulations and experiments.

Time-domain near-field antenna measurement can realize broadband and ultra-wideband measurement with a one-time test, which can greatly improve measurement efficiency and reduce cost. However, further research still needs to be done on error analysis and correction to realize the engineering application.

5 Acknowledgements

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6 References

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