Analysis and comparison of window functions based on arch measurement system

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***Abstract* — In this paper, the method of eliminating the interference signals of the arch measurement system is investigated deeply according to IEEE STD1128 1998. Based on the time domain signals converted from the frequency domain data simulated in Microwave Studio CST, the interference signals, such as self-coupling energy, spurious coupling energy, and multiple reflection energy are discussed. Several different window functions are presented and compared to eliminate the interference signals in time domain, so as to increase the accuracy of arch measurement system.**

***Index Terms* — arch method, absorbing materials, spurious coupling, filter**

I. Introduction

Absorbing materials are more and more widely used in military and civil fields with the rapid development of EMC and stealth technology. The measurement and research on the performance of absorber are also increasingly attracting the attention of the researchers. IEEE STD1128-1998[1] is a recommended and widely accepted standard for evaluating the reflectivity which is one of the key parameters in evaluating the properties of absorbing materials[1]. There are some methods for measuring the reflectivity of absorber, such as time-domain measurement approach, enclosed-waveguide method, low-frequency coaxial reflection method, and arch method, etc. The arch method is usually suggested as the main method to measure the reflectivity of absorber among those ways for its simplicity and practicality with high accuracy.

The traditional arch method was firstly invented by the Naval Research Laboratory (NRL). It is proved to be a feasible method with simple measurement system and sterling evaluation performance, and able to measure absorber's reflectivity with different angles and polarization[2]. There are two main reasons that affect the measurement accuracy of absorbing materials by using arch method. First, the dimension of the sample to be measured has a greater influence on the measurement result in the arch method[1], because the edge scattering effect will increase with the decrease of the size of sample. Therefore, the size of the sample should be appropriately increased to reduce negative effects. Secondly, the spurious coupling between the two working horn antennas and self-coupling of the antennas, which is even greater than the electromagnetic energy reflected by those samples with good performance. It is possible to reduce the coupling energy by putting an isolation plate in the middle of the two horn antennas [3], however, this method has the limitation on those antennas with large incident angle, as the transmitted energy from one antenna can be received directly by another one. Moreover, it is known that the reflected signals from sample under test (SUT) and directly coupled signals have different time duration, which provides possibility of removing the coupled signals by adding an appropriate window function in time domain efficiently. There are so many different window function, however, the existing arts in arch measurement process mainly focus on rectangle window[2], which have some shortcomings, for example, it has high sidelobe in frequency domain ,which is accomplished with energy leakage and it will attach negative impact on the results[4].

In this paper, we reviewed the method to eliminate the influence of interfering signals without isolation plate. The approach is to convert frequency domain data into time domain, and add a time-domain window function which can filter out useless signals, and then, reconvert the filtered signals back to the frequency domain to obtain the true reflectivity of the absorbing materials. A variety of window functions are investigated to deal with the collected signals and their effects are compared for discussion.

II. Principle of arch method

The reflectivity of sample is a key index to evaluate their properties, which can be measured by using arch method. The principle of arch method is that the electromagnetic wave is emitted by the emission antenna and received by the other receiving antenna reflected from the sample, the reflection coefficient of the measured sample can be calculated according to the power received, as shown in Fig. 1. It is known that the electromagnetic wave generated by the antenna should be similar to the plane wave as much as possible to increase the accuracy of the evaluation, thus, calculating the dimension of arch radius is the primary task before arch measurement system designing, as the radius of the arch must satisfy the far-field condition:

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$$R = \frac{2d^2}{\lambda} \tag{1}$$

where R is the distance between the measured sample and antennas, d is the diameter of the antennas, and λ is the working wavelength of the antennas.

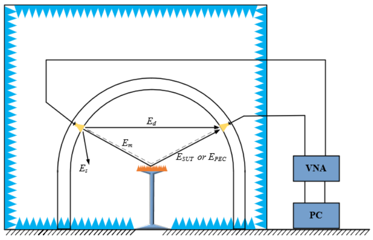

Fig. 1 Schematic diagram of arch structure.

It is possible to obtain the reflectivity of the SUT directly based on the equation as below:

$$\Gamma = 20\lg\left(\frac{E_{SUT}}{E_{PEC}}\right) \tag{2}$$

where the E_{PEC} and E_{SUT} are the received magnitudes of electromagnetic field by putting the standard metal plate or SUT at the center of the arch, respectively. However, the electromagnetic energy emitted from the one of the antennas propagates to different directions with different magnitudes, such as the E_{s} to free space, E_{d}, E_{SUT}, and E_{PEC} to receiving horn antenna coupled from the emission antenna, reflected from the SUT and metal plate, respectively, as shown in Fig. 1. Obviously, the electromagnetic energy of E_{SUT} and E_{PEC} are combined with those of E_{d}, and E_{m} which is the multiple-reflections between the SUT (or metal plate) and the horn antennas. This is the reason that it is not very accurate by using (2) directly for the calculation of SUT's reflectivity, and why the window functions are necessary in time domain.

III. WINDOW FUNCTIONS INVESTIGATIONS

The various window functions have different characteristics which may influence the results of calculated reflectivity significantly. This work aims to compare some of the traditional window functions based on the simulated results from the designed model with a pair of horn antennas operated at 4-6 GHz in Microwave Studio CST, as shown in Fig. 2. First, set the bottom boundary as PML (Perfectly Matched Layer). Then, record the simulated transmission coefficient S_{21} between two antennas as Γ_{Empty}, Γ_{PEC}, and Γ_{SUT} by switching the platform material as PML, PEC, and SUT, respectively.

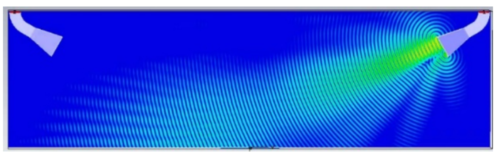

Fig. 2 Simulation model in CST

Based on those recorded Γ_{Empty}, Γ_{PEC}, and Γ_{SUT}, which includes the influence of spurious coupling energy E_d, self-coupling energy and the multiple reflection energy E_m, we can add a "Time Gate" in time domain for the accurate results, as the data processing flow shown in Fig. 3. Moreover, the influence of the scattered signal E_s can be eliminated[5] according to the final step shown in Fig. 3.

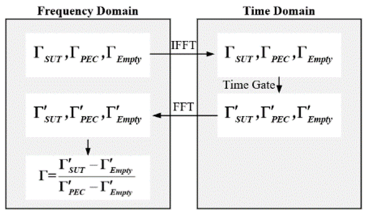

Fig. 3 Data processing flow of arch method

The horn antennas shown in Fig. 2 operated at the frequency of 4-6 GHz, the permittivity of SUT is set as ε_r=10+j0.8, and the distance between the antenna and SUT is 3 meters. After the simulation based on aforementioned process, the Γ_{Empty}, Γ_{PEC}, and Γ_{SUT} are record and shown in Fig. 4. Based on those raw data and equation (2), we can estimate the reflection performance of SUT roughly.

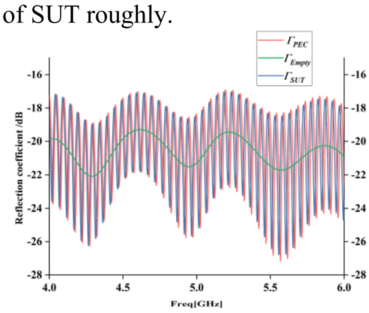

Fig. 4 Three sets of frequency domain data obtained by simulation

Fig.5 shows the measured Γ_{Empty}, Γ_{PEC}, and Γ_{SUT} in time domain transformed from frequency domain with the information of both amplitudes shown in Fig. 4 and the phase, by using the fast Fourier transform (FFT) algorism. From Fig.5, we can see that the self-coupling energy and spurious coupling energy between the antennas are very large. Regarding the received energy, they are overlapped in the time domain with different amplitudes, and the multiple-reflection energy is observed after a period.

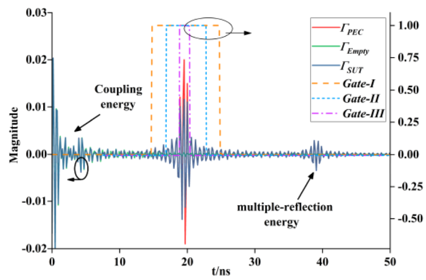

Fig. 5 Simulation data after Fourier transform and three kinds of rectangle window function

From Fig.5 we can see that the Γ_{PEC} is the largest, Γ_{SUT} is the second, and Γ_{Empty} is the smallest, which is in line with the common sense. Therefore, the reflected electromagnetic wave is received by the antenna for the first time, and needed be intercepted. In Fig.6, the rectangle window function based on different widths are used and compared, and the results are shown in Fig. 6. We can see that the results in frequency domain are influenced by the windows' width in time domain significantly, which needs be considered carefully during experiment.

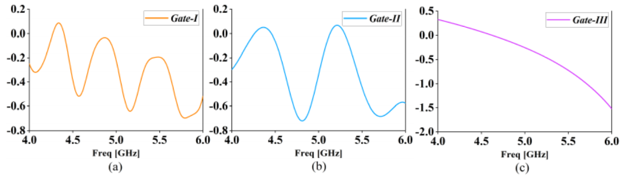

Fig. 6 The reflectivity after processed by (a)Gate-I, (b)Gate-II, and (c)Gate-III

Considering the results shown in Fig. 6, we think that Fig. 6(a) is the best one, because Gate-I intercepts all the reflected energy. However, there is ringing phenomenon in Fig. 6(a), which is not benefit for us to analysis the reflectivity of SUT. Fortunately, there are some other window function that can improve the above issues. In this article, five window functions are used to process the data, and they are Ideal Rectangular window functions, Butterworth window functions, Chebyshev window functions-I, Chebyshev window functions-II, and Elliptic window functions, respectively. There are some differences among these window functions, and their frequency response are shown in Fig. 7. Fig. 8 shows the filtered results and the results without filter.

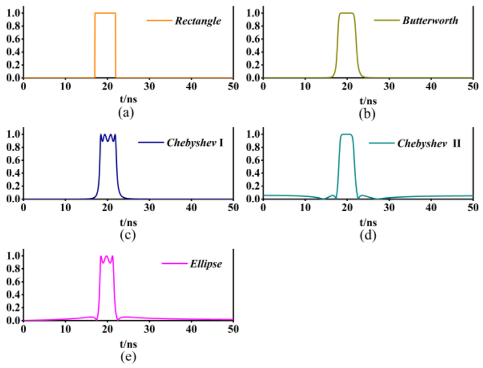

Fig. 7 Frequency response of the filters: (a) Rectangle (b) Butterworth (c) Chebyshev I (d) Chebyshev II and (e) Ellipse

From Fig. 8, we can see that the time domain gate can effectively eliminate the influence of interference on the reflected energy and restore the reflectivity of the absorber. Their trends obtained by the five filters are consistent, but the differences are obvious. The results of the ideal rectangular filter are accompanied by large fluctuations, while those of the Chebyshev filter-II and the Elliptical filter are accompanied by small ripples. The results of Butterworth filter and Chebyshev filter- I are smoother than others and recommended to be used in experiment.

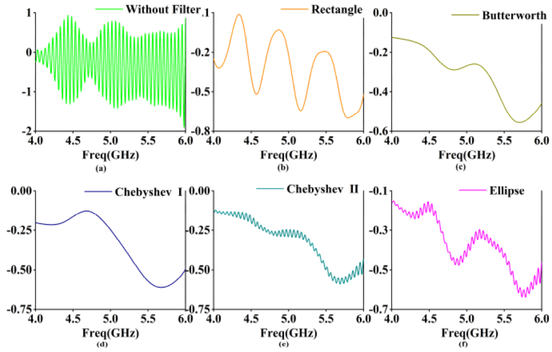

Fig. 8 Results (a)without filter and after filtering (b) Rectangle (c) Butterworth (d) Chebyshev I (e) Chebyshev II and (f) Ellipse

IV. Conclusion

In this paper, the basic principle of the arch method and the data processing method based on the data gating in time domain are reviewed. A variety of commonly used window functions are applied to process the simulated data for the influence investigation of different window functions. According to the processed results, we can see that the reflectivity of the measured sample cannot be obtained without a filter during data processing, and there are some differences in the results acquired by different window functions although the trends of obtained results are consistent. Thus, the window function need be well chosen in arch measurement system for high accuracy.

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