Progress In Electromagnetics Research, PIER 81, 279–289, 2008

INDOOR ACCURATE RCS MEASUREMENT TECHNIQUE ON UHF BAND

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Abstract—Based on the step-frequency RCS measurement system, high performance absorbers and low scattering supports, employing two log-periodic dipole antennas to carry out the quasi-monostatic measurement and many DSP techniques to reduce the error, the indoor accurate RCS measurement can be completed on UHF band. Experimental results show that the valid data waved less than 1 dB can be obtained over 70% of whole band.

1. INTRODUCTION

The way of research on radar cross section (RCS) includes calculation and measurement [1–6]. Though the theory of electromagnetism is integrated which can analyze many typical targets scattering mechanism, it's hard to calculate the targets which have complex structure and compound materials. Therefore, the measurement is the most effective and quickest method. A lot of characteristic data can be obtained by measuring all kinds of targets, and the data base of target's characteristics will be founded. Moreover, the calculation is able to be proved by the measurement. It's good for understanding more information with regard to the basic phenomenon of scatter. All in all, the RCS of target is determined by the measurement.

RCS measurement can be divided into outdoor and indoor according to the different field. The outdoor measurement is easily influenced by weather. It is difficult to get high resolution and accurate results. On contraries, the indoor measurement can provide a controlled electromagnetic circumstance, and researchers can work in a comfortable place. Moreover, more accurate results can be gained with less cost. It also save one third of time in comparison of the indoor measurement.

Compact antenna test range (CATR) is mainly used for RCS measurement at present [7]. The advantage of CATR is that it can transform sphere microwave front into planar microwave one working as a space filter, then the far-field condition [8] can be met at a short distance, and the distortion of return wave front caused by sufficient distance due to incidence of sphere microwave can be avoided. However, when the frequency of measurement is low [9–11], there is diffraction [12, 13] at the margin of CATR, and the precision will be greatly affected by this phenomenon. How to obtain the accurate RCS value at low frequency band is a difficult problem. In this paper, a remarkable system and many techniques are presented to solve this issue. The system first transmits step-frequency signal which has broad bandwidth for achieving high range resolution, then good performance of hardware and kinds of DSP techniques are used [14]. The experiment on UHF band shows that accurate RCS data can by obtained by this method.

2. MEASUREMENT SYSTEM

2.1. Step-frequency Signal

A step-frequency signal is transmitted and received by network analyzer in the system [15–17]. As shown in Figure 1, it is a ultra-bandwidth radar signal whose frequency is changed step by step, and the increment of frequency is a constant. Therefore, it has high resolution on range. The signal can be regarded as a serial of pulses in time-domain, and the frequency of each pulse are different.

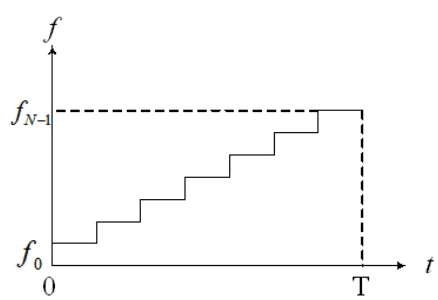

Figure 1. Step-frequency signal.

2.2. Absorber

The performance of anechoic chamber greatly depends on the quality of absorber [18–20]. After comparing some kinds of absorbers with measurement and analysis, a sort of cone absorber is chosen for the system. As shown in Figure 2, the height of absorber is 1.5 m, and the reflection at 0.3 GHz$\sim$1 GHz is lower than -35 dB.

Figure 2. Absorber.

2.3. Antenna

In order to cover the entire UHF band, log-periodic dipole antenna (LPDA) [21] is used as shown in Figure 3. It consists of many symmetric dipoles which have different size, and they are arranged with intervals on two transmission lines generated by a source. A

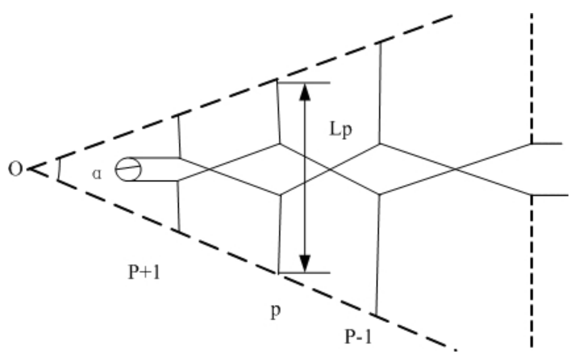

Figure 3. Configuration of LPDA.

short section is fixed at the end of transmission lines for regulating the match of current.

When the current is fed in antenna, the electromagnetic energy provided by source transmits along the lines to drive dipoles. Only the dipole whose size is close to the resonance length creates large current, and radiates microwave to space. The current on the other dipoles are too little to contribute the far-field radiation pattern. Although resonance point moves when changing frequency, the geometry of antenna guarantees that the characteristics of aerial will not be altered. The frequency span of antenna in the system is from 200 MHz to 1 GHz, and the gain is about 8 dB at whole band.

2.4. Support

Support is the most important source of background noise, which is difficult to separate it from target. So the low scattering support must be chosen for the system. There are several methods to support target at present, such as low density foam, intensity non-metallic thread, metal chop covered with absorber, hollow solid plastic pipe and so on.

The scattering of non-metallic thread is low, but it's hard to turn in azimuth. The price of metal chop is expensive, and target will be injured at the fixed point. Plastic pipe only can be used in a narrow band. So the low density foam is applied here [22] as shown in Figure 4.

Figure 4. Low density foam support.

The support is composed of two parts. The bottom one is a 3 m high cylinder whose diameter is 2 m. This part is to enhance the stability of support. The upper one is a 3 m high frustum of a cone with top size of 1 m in diameter, it can reduce the returns caused by specula reflection. The connection of two parts is filled with absorber to decrease the angular reflection.

The system is shown in Figure 5.

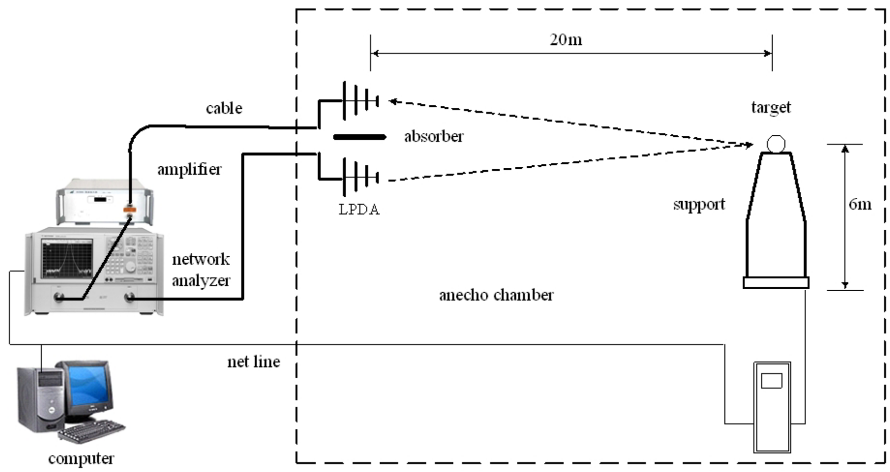

Figure 5. Measurement system.

Step-frequency signal is created by network analyzer, after passing a power amplifier, the signal is transmitted by a LPDA, quasi-monostation model is used in the measurement, so another LPDA closed to the transmitting antenna receives returns. The velocity of support rotation and the interval of sample are controlled through net lines by a computer. As the revolving stage rotating, a trigger signal is sent to network analyzer, and then the network analyzer begins to measure. Comparing the echo value of scaling with the target and the RCS of the target can be determined.

3. CALIBRATION TECHNIQUES

The main problem of RCS measurement is how to remove clutters from the test signal. Therefore, the measurement is usually completed in an anechoic chamber which can absorb the energy incident to the walls and floor. However, even the most thoughtful design anechoic chamber also retains some residual reflections and the mutual coupling between two antennas. The accuracy of measurement will be limited by these clutters, especially for the test on UHF band. If some calibration techniques are used, they can be greatly eliminated.

3.1. Fourier Transform

Either in general scientific research or in application of engineering technology, Fourier transform is a important mathematical tool [23, 24]. Step-frequency system can measure the response of each discrete frequency, and the response of time-domain [25] can be displayed by inverse fast Fourier transform (IFFT). It shows the reflection as whole chamber at different time (or range). So the reason why the reflection appears will be analyzed at a certain range, then through reducing the strong scattering points near target, the accuracy of measurement is substantially improved.

3.2. Time-domain Cancellation

The echo of low scattering target is often mixed with background noise. In order to extract the useful signal, a hardware system is applied to reduce the effect of noise by traditional method. It separates the transmitted signal, then adjusts the phase and amplitude of sampled signal by phase shifter and attenuator, finally eliminates the echo of whole chamber. But the hardware system is only suitable for continue wave (CW) measurement system. The time-domain cancellation can be adopted in step-frequency measurement system. Way presented here is that first the time-domain response will be got by applying IFFT to the frequency-domain response of returns, and stored in a memory of network analyzer, then vector subtraction is used between the current measurement data and the response stored before in memory. It can eliminate the coupling of antennas, as well as the reflection from the walls of chamber. The background noise will be decreased by 30 dB. It's effective for static measurement at a certain angle.

3.3. Frequency-domain Cancellation

With the rotation of revolving stage, the support and the nearby surroundings will be changed, and the time-domain response is different at each angles. So the frequency-domain cancellation [26] must be used for the whole angles RCS measurement. The method is that the echo of chamber at each frequency point is recorded over the whole rotation angles of the revolving stage firstly, and the frequency-domain data of target are measured with no change of background at the same angle, then the vector subtraction is applied to the data of chamber and target at corresponding angle. It can reduce the harmful effect of support by 20 dB, and it's important to the measurement of low scattering target.

3.4. Range Gate

After obtaining the time-domain response of whole chamber, the distribution of reflection will be observed at different position by transforming time to range. The echo energy of target can be chosen by an appropriate range gate, and the background noises (such as the coupling between antennas) are removed effectively. It can improve the accuracy of measurement.

3.5. Zero Insertion

IFFT is often carried out in accordance with the stepped points, parts of information may not be displayed in time-domain because of no sufficient points, and it's hard to choose the right range gate. So some returns of target may be lost, which causes the leakage of spectrum. The points of IFFT can be increased by zero insertion in frequency-domain. Though the information of frequency-domain is not changed, the response resolution will be improved. It's important to choose the region of target exactly.

3.6. Window Function

According to the theory of convolution, some parts of time-domain information chosen by range gate are equivalent to the convolution of original signal spectrum and gate function. It may cause the fluctuation of retrieved spectrum. The narrower range gated, the less accurate data gained. If a suitable window function is added to the original signal spectrum, the impact caused by cutting off data will be reduced [27]. Generally speaking, it's better to select a low-sidelobe window function that may improve the spectrum obviously. However, the width of main valve will be expanded, which may reduce the resolution. Therefore, we must consider it comprehensively, and normally the hamming window is taken.

4. PARAMETERS AND STEPS OF MEASUREMENT

Setting the appropriate parameters is essential to step-frequency RCS measurement system. According to the different requirements of measurement, the parameters need to be intercalated as follows:

1) *The span of frequency.* The signal provided by network analyzer is equivalent to a serial pulse in time-domain. The width of pulse τ is $1/BW$, where BW is the span of frequency, so the resolution of range Δd is $c/2BW$. We can see that is a wide frequency span

and narrow pulse signal which introduces a very good resolution of range. Therefore, the span of frequency must be chosen according to the desired resolution.

2) *Number of points.* According to the measurement distance R, the maximal interval of frequency $\Delta f_{\max}$ is $c/2R$, and the least points is $BW/\Delta f_{\max}$.
3) *IF bandwidth.* It's helpful to improve the signal to noise ratio (SNR) by setting appropriate IF bandwidth. In theory, the narrower IF bandwidth we set, the better results we get. However, if the IF bandwidth is too little, the sweep time will be increased greatly, and the time of measurement must be unbearable.
4) *Power.* Due to the effect of cable loss and attenuation on space, the received energy of signal will be reduced. So it's necessary to increase the transmitted power to improve the SNR. However, the stability of power can not be assured beyond a limited scope. Therefore, we add a power amplifier to keep the source unchanged.

The steps of measurement are as follows:

Step 1: The whole chamber is measured, and then the time-cancellation is done to reduce the impact of clutters.

Step 2: The target is measured. The region where energy from target tested is higher than that from background will be chosen by a range gate, and returned to frequency-domain.

Step 3: The scaling is measured. The frequency-domain data are recorded in the same range gate.

The RCS of target is calculated by the following formula:

$$\sigma_{dBsm} = S_{21} - S'_{21} + \sigma'_{dBsm}$$

where, σ_{dBsm} is the RCS of target, σ'_{dBsm} is the RCS of scaling, S_{21}, S'_{21} are the measured value of target and scaling.

5. RESULT OF EXPERIMENT

The span of frequency is 300 MHz to 1000 MHz, the number of points is 176, the resolution of range is 20 cm, the power is 10 dBm, the IF bandwidth is 10 KHz, the target is a metal sphere whose diameter is 40 cm, the scaling is a metal plate whose area is 50 cm×50 cm. The accurate RCS of target over 70% (its error is less than 1 dB) can be obtained. The results of 400 MHz to 900 MHz (ka ranges from 1.7 to 3.9) are shown in Figure 6.

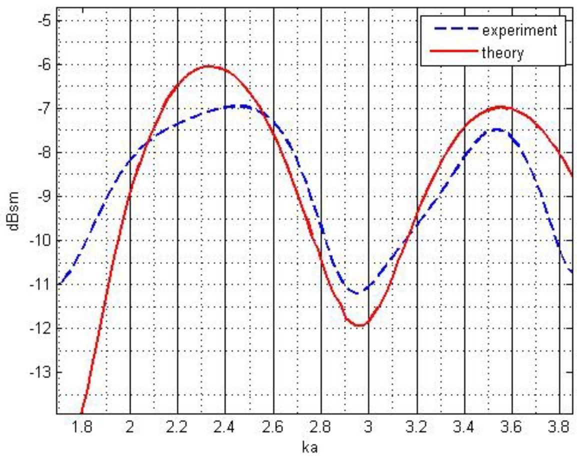

Figure 6. Results of 400 MHz to 900 MHz.

6. CONCLUSION

Step-frequency system is a kind of high resolution RCS measurement system. The dynamic scope of system can be expanded by improving background, power is amplified to increase the SNR of system, and many DSP techniques are applied to calibrate the measurement error. The accurate RCS measurement on UHF band will be gained by the system and techniques. Moreover, if the antenna is changed, they can also be applied to the higher frequent band.

ACKNOWLEDGMENT

I am grateful to Prof. W. L. Wang, UAV Specialty Technique Key Laboratory of National Defense Technology, Northwestern Polytechnic University, for his helpful advice. Any errors are of course my responsibility.

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