Target Angular Scintillation Measurement of Wide-band Range Comparison Monopulse Radar in Anechoic Chamber

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Abstract— The range comparison monopulse radar measures angles by comparing the range of the difference-channel signals with the range of the sum-channel signal. Practically, It has been generally accepted that what the radar measures is not the directions of the target, but angular glint errors. In order to realize this characteristic of radar target, a wide-band radar simulate system based on CATR (Compact Antenna Test Range) was used in this researching. By making use of high-frequency phase shift correcting algorithm, the effect of test errors caused by the difference-sum channels' non-equilibrium was weakened. With paying close attention to the complex dimension expend radar target, an algorithm including HRRP (high resolution range profile) method was used to extract and describe the nicety of angular scintillation. At last, the scintillation measurement results of double balls union and airplane model have been laid out.

1. INTRODUCTION

Angular scintillation, or angle glint, in the tracking loop of a radar missile seeker arises from warps in phase front of the scattered wave produced by interference between the individual centers of scattering on a complex target. Because the seeker attempts to orient itself at right angles to the phase front, these warps can produce a substantial displacement between the apparent radar center and the physical center of target. It will cause the angle test error that induces an inaccurate result. Because the glint is a type of connatural character of radar target, getting the angular scintillation to a nicety will accelerate the advancement of radar system and target identity research.

Generally, the methods of measuring angle glint can be distinguished into three classes: outdoor static testing, indoor static testing and dynamic testing. As an admitted fact, the targets scattering characters test result that obtained in CATR (Compact Antenna Test Range) Anechoic Chamber are exact. In order to realize this characteristic, a wide-band radar simulate system based on CATR was designed in this researching. The theory of Monopulse Radar Antenna angle testing and a new kind of calculating formula and angle glint analyze method based on HRRP (High Resolution Range Profile) have been expounded in the following disquisition. At last, a test result on angle glint of double-ball union and airplane model have been laid out.

2. THE METHOD OF ANGLE TEST BY MONOPULSE RADAR ANTENNA

2.1. Angle Test Elements

The range comparison monopulse radar measures angles by comparing the range of the difference-channel (Δ) signals with the range of the sum-channel (Σ) signal. Considering the solution in polar coordinate, the single (Σ-Δ) antenna pattern can be shown as Fig. 1, the pattern function is $F(\theta)$, the beam angle is θ_0, the target angle is $\Delta\theta$, then the ranges of receiving singles A_1 and A_2 are,

$$\begin{cases} A_1 = kF(\Delta\theta - \theta_0) \\ A_2 = kF(\Delta\theta + \theta_0) \end{cases} \tag{1}$$

k is a const decided by radar equation. Because the $\Delta\theta$ is very small, the ranges of Σ signal and Δ signal are,

$$A_\Sigma = A_1 + A_2 = kF_\Sigma(\theta) \approx K \tag{2}$$

$$A_\Delta = A_1 - A_2 = kF_\Delta(\theta) \approx K\eta\varepsilon \tag{3}$$

where: $\eta = \frac{F'_\Delta(0)}{F_\Sigma(0)}$ and $K = kF_\Sigma(0)$, the ε is the angle error which gained by ratio A_Δ and A_Σ.

2.2. Acquirement of the Angle Error

Commonly the acquirement of the angle test result is based on range comparison between the signals of difference-channel and sum-channel directly. If the input signal of the IQ receiver are

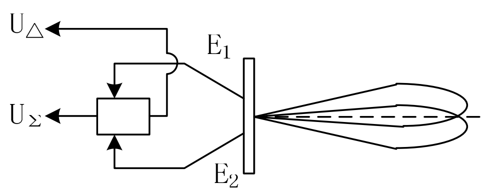

Figure 1: Monopulse radar antenna beam in one angular test plane.

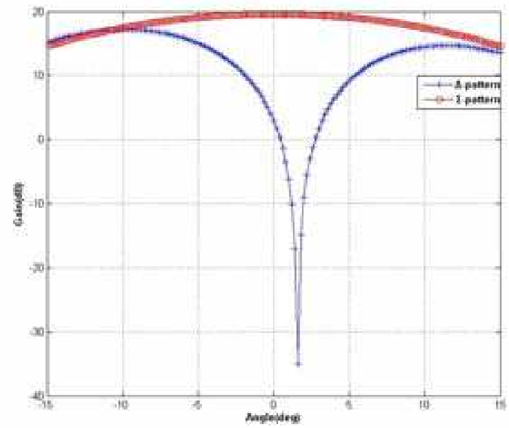

Figure 2: $(\Sigma\text{-}\Delta)$ antenna pattern with the differ-gain.

$S_\Sigma(t) = K\cos(\omega t + \varphi_0)$ and $S_\Delta(t) = K\eta\varepsilon\cos(\omega t + \varphi_0)$, the response by Σ and Δ can be described as,

$$\Sigma_I = K\cos\varphi_0, \quad \Sigma_Q = K\sin\varphi_0 \tag{4}$$

$$\Delta_I = K\eta\varepsilon\cos\varphi_0, \quad \Delta_Q = K\eta\varepsilon\sin\varphi_0 \tag{5}$$

According to the angle test elements, the angle error calculate expression is,

$$\varepsilon = \frac{\Delta}{\Sigma}\cos\varphi = \operatorname{sgn}\left(\Sigma_I\Delta_I + \Sigma_Q\Delta_Q\right)\frac{|\Delta_I + j\Delta_Q|}{\eta\,|\Sigma_I + j\Sigma_Q|} \tag{6}$$

sgn$(*)$ is a function to get the sign of $\Sigma_I\Delta_I + \Sigma_Q\Delta_Q$ and describes the direction of the angle deflexion.

However, every independent receive channel couldn't be symmetric with another absolutely, these independence often represent as differ gain or differ phase. It will cause the $(\Sigma\text{-}\Delta)$ antenna pattern and angle testing curve to face a differ-error, as it shows in Fig. 2 and Fig. 3. When the differ gain and differ phase is subsistent in the same time, the 0° angle will leap on the angle testing curve. It is a serious balk that radar cannot estimate where is the 0° angle spot, see Fig. 4 the blue line with '+' in green circle. In order to avoid the 0° angle spot error, the angle error calculate expression has to be improved.

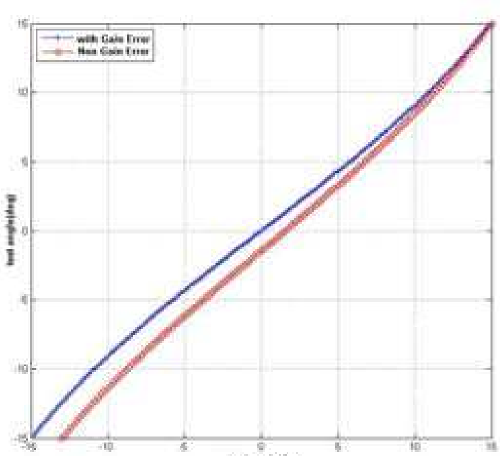

Figure 3: Angle testing curve with differ-phase.

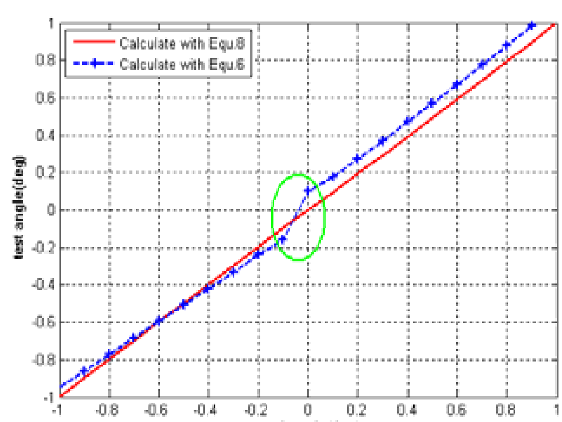

Figure 4: The angle testing curve with different angle error calculate expressions.

From Equation (6),

$$\Sigma_I \Delta_I + \Sigma_Q \Delta_Q = \frac{1}{4}|\Sigma|\,|\Delta| \cos(\varphi_\Delta - \varphi_\Sigma) = \frac{1}{4}|\Sigma|\,|\Delta| \cos(\varphi) \tag{7}$$

Improve the angle error calculate expression to following result from Equations (6) and (7),

$$\varepsilon = \frac{\Sigma_I \Delta_I + \Sigma_Q \Delta_Q}{\eta\,|\Sigma_I + j\Sigma_Q|} = \frac{A_\Delta}{\eta \mathrm{A}_\Sigma} \cos\phi_\varphi \tag{8}$$

Calculating with the Equation (8), the $\cos\phi_\varphi$ will be always 0, so the angle error is 0 at the 0° angle spot, even if the channel is not symmetric. As it is shown by the red line in Fig. 4.

3. WIDE-BAND ANGULAR SCINTILLATION MEASUREMENT IN CATR ANECHOIC CHAMBER

3.1. Angle Glint Test in CATR Anechoic Chamber

As in Fig. 5, CATR in anechoic chamber is a common type of target scattering characters testing laboratory, which is made of reflecting antenna system that can take the spherical wave into plane wave to satisfy the far field test condition. As the above description, Angle Glint is a connatural identity of target which is not dependent with the range between radar and target in far field area, so the specialty of CATR is suitable for glint measurement. If the culmination of the reflecting face is spot O, the angle between center line of antenna beam and x axis is α, the points of intersection between center line of antenna beam and reflecting face is P_0, P_1, and P_2. According as the geometry, angle glint $\tilde{e} = \tilde{r}\varepsilon$, because the target's moving in the plant wave area (target area) will not cause the change of angle error test result.

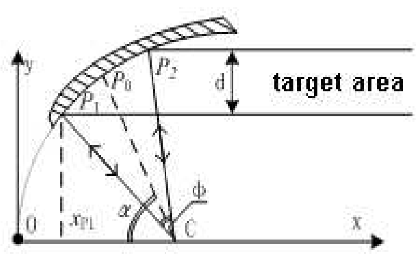

Figure 5: Configuration of CATR reflecting antenna system.

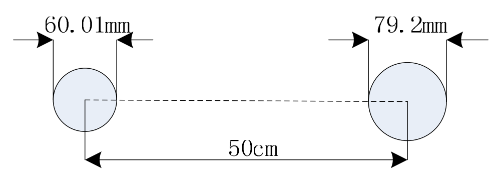

Figure 6: The double balls union with looking down.

From the angle glint calculation method, it is necessary to get $\tilde{r}$ only with geometry. For spot P_0,

$$\begin{cases} y_{P0} = (c + x_{P0})\sin(\alpha) \\ y_{P0}^2 = 4cx_{P0} \end{cases} \tag{9}$$

Then,

$$y_{P0} = 2c\left(\frac{1-\cos\alpha}{\sin\alpha}\right) = 2c \cdot \tan\left(\frac{\alpha}{2}\right) \tag{10}$$

So the angle glint calculation expression is,

$$\tilde{r} \approx |CP_0| = \sqrt{(x_{P0} - c)^2 + y_{P0}^2} = c\left(1 + \tan^2\frac{\alpha}{2}\right) \tag{11}$$

Then,

$$\tilde{e} \approx \varepsilon c\left(1 + \tan^2\frac{\alpha}{2}\right) \tag{12}$$

3.2. Excellences of Dealing with HRRP

As the above dissertate, by using Equation (12) the angle error in different distance cells can be achieved, the refined measurement of angle glint of complex target is capable. Every radar target can be regarded as a series of scattering spot in wide-band system perfectly. When the test result is deal with HRRP, the main parts that redound to increase the angular scintillation will be clearer than in narrow band system. To realize this particular can improve the research on mechanism about angle glint phenomenon and control technology of angular scintillation.

4. RESULTS AND DISCUSSIONS

In this section, the angle glint measurement results about double balls union and an airplane model have been laid out. When the test is actualizing, the range comparison monopulse radar system is working in Ka wave band and the frequency width is 500 MHz.

4.1. Double Balls Union

The double balls union is made of two aluminous balls with diameters 60.01 mm and 79.2 mm. In the experimentation, these balls was put in line and 50 cm away from each other, as Fig. 6. They were irradiated for 180° to get the angle glint in horizontal plane. The HRRP dealing result in angle changes is shown as Fig. 7. In this figure, it can be seen that both Δ-channel and Σ-channel are test the location distributing characters of the target, with Equation (8) and certain restrain arithmetic the angle glint in the distance cells where the double balls union is has been extracted. If the piece of the middle cells of angle glint is been take into rectangular coordinates, the traditional target angle glint will placed, and the comparison with theory calculate result in narrow band has been done in Fig. 8. There is the general identical movement between the test result and the calculate result, the differentia is resulted in noise of laboratory and the deference of frequency width.

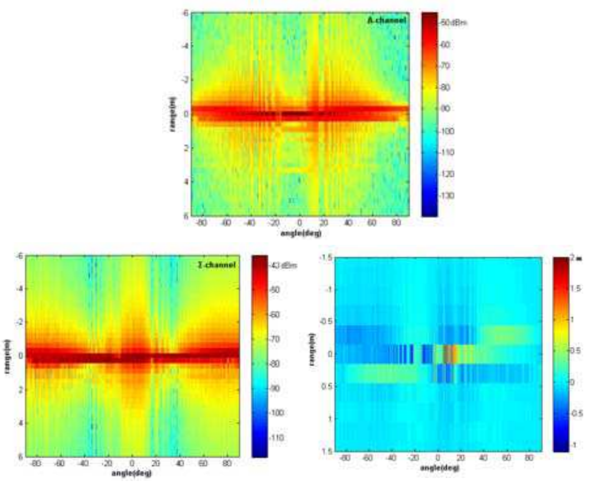

Figure 7: The test result of the double balls union, the HRRP with angle in Δ-channel (UP), the HRRP with angle in Σ-channel (Down-L), and the angle glint in different distance cells (Down-R).

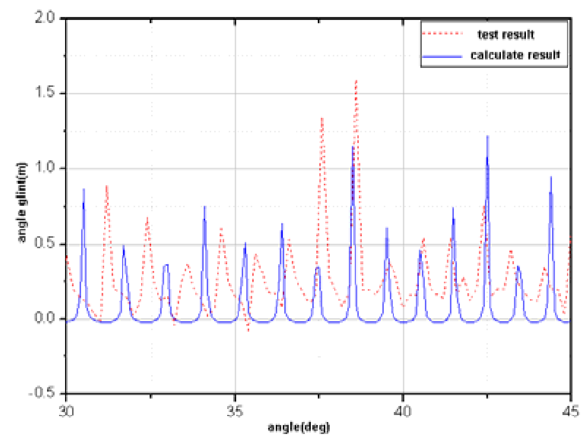

Figure 8: The angle glint curve of middle cell (red) and comparison with theory calculate result (blue) by double balls union test.

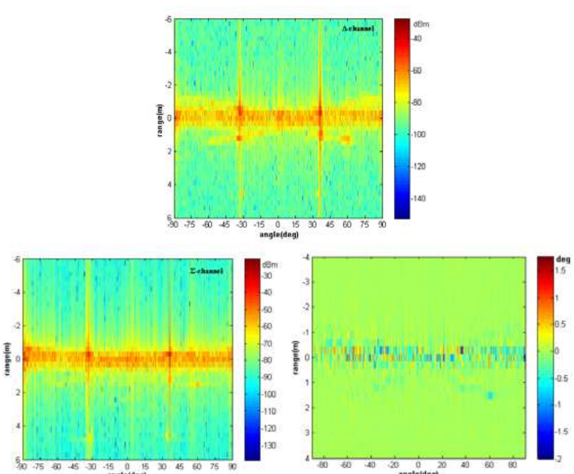

Figure 9: The test result of airplane model, the HRRP with angle in Δ-channel (UP), the HRRP with angle in Σ-channel (Down-L), and the angle glint in different distance cells (Down-R).

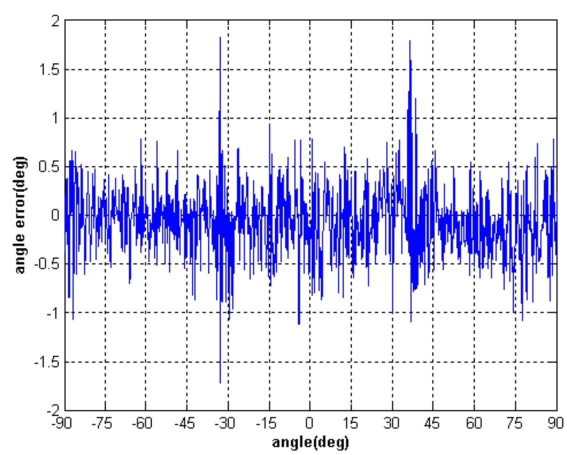

Figure 10: The angle error curve of middle cells by airplane model.

4.2. Airplane Model

In the same way, the angle glint measurement result of airplane model has been enumerated that are shown Fig. 9 and Fig. 10.

5. CONCLUSION

In this paper, author further discussed a type of new technique on target angular scintillation measurement, expatiated how to test target angle glint with wide-band range comparison monopulse radar in CATR anechoic chamber. A formulation about the excellences on dealing the angle error test result with HRRP has been given in the treatise also. At last, some measurement examples have been shown. Based on the comparison between the test result and the calculate result, it can be proved that the type of wide band test technique that this paper advanced is feasible.

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