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Improvement of Single-pulse angle measurement and tracking performance based on real-time calibration system for amplitude and phase

Zhonghua Zhang
Ordnance military school of Wuhan
Wuhan, China

Huidong Qiao
Luoyang Electronic Equipment Testing Center,
Luoyang, China

Manxi Wang
State key laboratory of complex electromagnetic environment effects on electronic and information system,
Luoyang, China

***Abstract*—The radar using Single-pulse system is widely used in the field of electronic reconnaissance system for its superiority in angle measurement and tracking. But the system's angle measurement and tracking performance are affected by the angle error which is resulted by the inconsistency of the characteristics of amplitude and phase in the differential channel. Due to the use of real-time automatic adjusting system for amplitude and phase in the receiver, the consistency of amplitude and phase is improved obviously, so that the error of angle measurement is greatly reduced.**

Keywords—Single-pulse system; inconsistency; angle measurement; real-time automatic adjusting;

I.INTRODUCTION

The radar used in the reconnaissance system must provide accurate numerical value of a single target coordinate (distance, azimuth) and track the target.

The linear and the directivity of the radar antenna is the physical basis of radar angle measurement[1]. The method of automatic angle measurement is adopted in order to provide the accurate value of the target quickly. An error voltage can be generated when the target direction is deviated from the antenna axis. The magnitude of the error voltage is proportional to the error angle ε, and the polarity of the voltage varies with the direction of deviation. After the error voltage is transformed, amplified and processed by the tracking system, the direction of the antenna is reduced to the direction of the error angle, so that the axis of the antenna is aligned with the target.

The angle measurement of Single-pulse is that all the information necessary to determine the angle of the error should be acquired on the basis of a single-pulse. The signal of Σ and Δ are formed in branch of Σ and Δ echo by the signal received from the single-pulse antenna after passing multimode feed. Radar beam of Σ

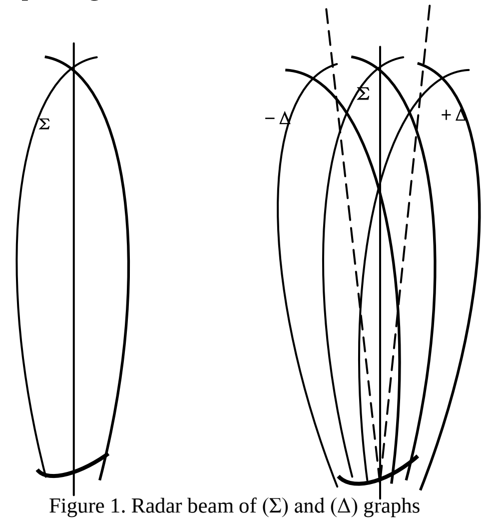

Figure 1. Radar beam of (Σ) and (Δ) graphs

and Δ graphs are shown in Figure 1.

And the Σ beam echo signal is mainly used as a phase reference to determine positive and negative of signals, and the Δ beam echo signal is mainly used for the angle measurement. When the target in the center of Σ beam, the echo signal received by the feed are same，The Σ signal is maximum and the Δ signal is zero after passing multimode feed[2]. When the target deviates from the and the center of the Σ beam, the size and polarity of echo signal received by the single-pulse antenna represent the deviation degree and direction of the target from the beam center. Then the value of the azimuth error is calculated by the radar computer software，which is sent to the servo system to control the antenna for azimuth movement, and the azimuth angle error signal is to zero.

II. ANGLE ERROR ANALYSIS

The system's angle measurement is affected by the angle error which is resulted by the inconsistency of the characteristics of amplitude and phase in the differential channel[3].

A. Effect of phase imbalance on Performance

The phase imbalance of single-pulse system mainly refers to the asymmetry of feed structure and microwave circuit and the phase inconsistency of mixer, amplifier of intermediate frequency. The additional phase shift before the comparator for Σ and Δ is referred to as the high frequency phase shift. The additional phase shift of if part is called if phase shift. High frequency phase shifts is indicated as φ, intermediate frequency phase shifts is indicated as θ.

The influence of intermediate frequency phase shift：If the characteristics of phase shift between the Σ and Δ channel is not consistent because of θ which is intermediate frequency phase shift, the difference of phase between the input end of the phase detector and the difference signal will be no longer 0° or 180° ,but become 0° or 180° +θ, then the output error voltage of the phase detector is changed into：

$$U = \pm 2K_d U_\Delta \cos\theta \tag{1}$$

K_d is the transmission coefficient of the phase detector.

U_Δ is the amplitude of the Δ signal.

Obviously, the sensitivity of the angle measurement is cut down by the value of the error voltage reducing due to the impact of θ.If θ>90° ，the polarity of error voltage will turn around, then the tracking system will become a positive feedback, and the error will be more and more big.

The effect of high frequency phase shift：If the high frequency phase shift φ is generated in the microwave system before the comparator for Σ and Δ, there is a phase shift φ between the two signals added on the 1 and 2 arms of the comparator. At this time, even if the target is located on the axis of the antenna, the signal is not 0.In fact, the difference of phase between the Σ and Δ signal is 90° . In case of no if phase shift θ , the phase detector has no output, therefore, the tracking error will not be generated. If there is if phase shift θ, the phase shift between the signal of Σ and Δ will be no longer 90° , then the phase detector has output of voltage, which forces the antenna to deviate from the target, until the useful error voltage is offset the voltage of the phase unbalance, the antenna shaft is stopped at the new balance position, thus the antenna deviates from the target angle, which causes the error of the angle measurement.

B. Effect of unbalanced voltage gain on system performance

In Single-pulse radar, the feed should have the same axis of the antenna beam shape, symmetry，and the amplitude of the gain should be the same exactly, two lobed at the intersection with the same slope. However, the amplitude of two signal is out of balance because the size of attenuation before the Σ and Δ comparator is not equal，by which the deviation of the aiming axis is caused and which is caused the error of angle measurement[4].

III.IMPROVEMENT METHOD

In view of the above problems, many aspects of the specific improvement method have been used：

The automatic tracking of moving target is realized by using horizontal plane single-pulse technique. The block diagram of the radar receiving system is shown in Figure 2.

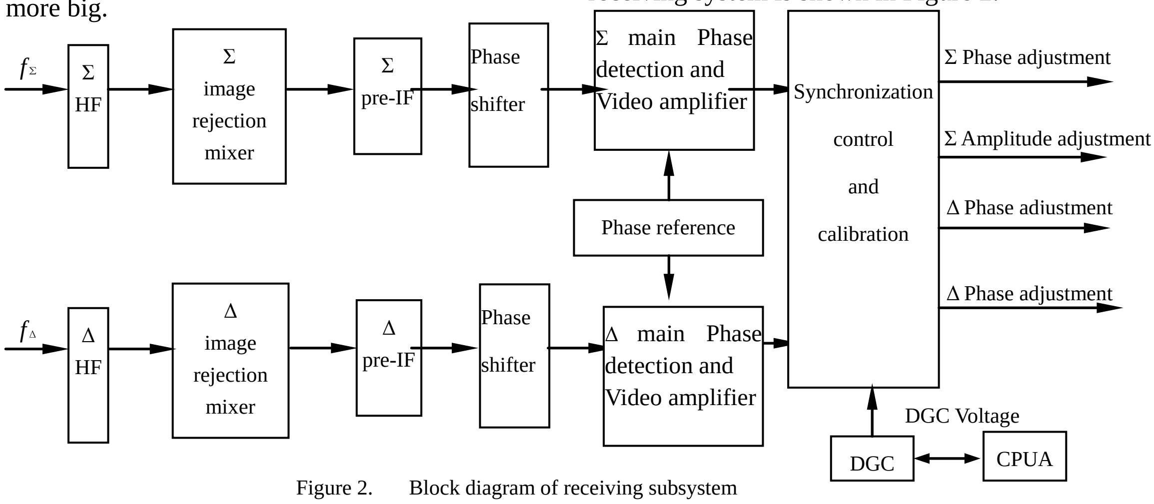

Figure 2. Block diagram of receiving subsystem

The system has a real-time automatic adjusting system for amplitude and phase, which makes the precision of amplitude consistency in receiver of high and intermediate frequency of Σ and Δ<1dB, delta two, the consistency precision of phase <3°. The receiving subsystem adopts the overlapping layout, and the parts are connected with the semi-rigid cable, which can ensure the signal transmission is reliable and the difference between the two phases is consistent. The mixer for image rejection is used to eliminate the interference of image frequency and reduce the noise figure of the receiver，and improve the sensitivity of receiver. The parameters, structure and electrical properties in tow roads of the devices are the same basically in order to ensure the consistency of amplitude and phase of Σ and Δ.

The sine signal of 500kHz of Σ and Δ are output by the main receiver in two channel. Σ signal is sent to calibration level adjustment, amplitude automatic adjustment, automatic phase adjustment circuit after the first stage amplifier and the gate selected. Δ signal is sent to amplitude automatic adjustment, automatic phase adjustment circuit after the first stage amplifier and the gate selected.

In the circuit of calibration level adjustment，the Σ signal is integrated as a DC level U_Σ to reflect the magnitude，which a reference level，and will be sent to the attenuator for voltage controlled after the control gate. U_Σ is also sent to the self-checking circuit, and compares with reference voltage U. When $U_\Sigma>U$, the output is high，the circuit can work properly. When $U_\Sigma<U$, the output is low，the circuit cannot work properly.

In the circuit of amplitude automatic adjustment，the difference of amplitude in two roads is extracted by the DC level which are integrated from the two signals of Σ and Δ separately after passing the comparator:

Gain control signal U_{DGC} to adjust the amplitude of the control signal These two signals were sent to the front in place (Δ), the combination of voltage controlled attenuator，To adjust the amplitude of Δ signal in order to keep consistent. ΔU is sent to the self-checking circuit and compares with reference voltage U by a comparator， When $-U<\Delta U<U$, self-amplitude output is high, which indicates the amplitude is normal；When $\Delta U>U$ or $\Delta U<-U$, self-amplitude output level is low，which indicates the amplitude is not normal.

In the circuit of phase automatic adjustment，an amount of phase difference of Σ and Δ signal is extracted by the phase detector:

$$\Delta\Phi = \Phi_\Sigma - \Phi_\Delta \tag{2}$$

Then the quantity of ΔΦ is turn into a pulse with a certain width which is amplified and integrated to a DC level as the control level $U_0\Phi$. The electrical modulation of the phase shifter of Σ should be tweaked when the phase of Σ advances of phase of Δ. As the same principle, the electrical modulation of the phase shifter of Δ should be tweaked when the phase of Δ advances of phase of Σ. At last, the consistency of phase in two roads can be maintained. $U_0\Phi$ which reflects the amount of phase difference is sent to circuit of phase self-checking， compares with a reference level .When $-U<U_0\Phi<U$, self-phase output is high, which indicates the phase adjustment is normal；When $U_0\Phi<-U$ or $U_0\Phi>U$, self-phase output level is low, which indicates the phase adjustment is not normal. The accuracy of the phase consistency of two signals is $\Delta\Phi\leqslant\pm5^\circ$ in this circuit.

IV. CONCLUSION

The angle measurement of Single-pulse is that all the information necessary to determine the angle of the error should be acquired on the basis of a single-pulse. Therefore, it has certain advantages in the aspect of angle measurement and tracking. The signal of Σ and Δ are formed in branch of Σ and Δ echo by the signal received from the single-pulse antenna after passing multimode feed. The system's angle measurement is affected by the angle error which is resulted by the inconsistency of the characteristics of amplitude and phase in the differential channel. It is obvious that the amplitude and phase consistency can be improved greatly, so that the error of angle measurement is greatly reduced, and the tracking performance of radar is improved after the real-time automatic adjusting system of amplitude and phase has been adopted.

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