Cause Analysis on Angular Error when Mono-pulse Radar is Tracking Noise Jammer and a Simulative Test

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Abstract: - When mono-pulse radar is disturbed by self-protecting noise jamming, angular tracking error signals can be extracted from noise jamming because jammer and echo from a target both come from the same direction. Based on the principle of angular tracking of mono-pulse radar and signal transmission characteristics when noise jamming passes a receiver, this paper makes analyses and points out the following causes leading to angular errors: finite frequency spectrum of intermediate frequency amplifier, the asymmetry between two receiver branches, frequency collimation error and the magnitude of transmitting power of noise jammer. A simulative test about angular error of active tracking and passive tracking are made on MATLAB platform under various matters. It is shown that angular error of passive tracking is greater than that of active tracking.

Key-Words: - Mono-pulse radar; angular tracking; noise jamming; angular error; simulation

1 Introduction

Mono-pulse radar is an advanced angular tracking system. While tracking a target, it is often interfered by self-protecting noise jamming from the target. Because mono-pulse radar can extract angular error from only one echo pulse in principle, so a lot of papers think that it is difficult to interfere and noise jamming can not destroy angular tracking stability of mono-pulse[1][2]. Under noise jamming, mono-pulse radar will lose distance information, but it will track the direction of the object continuously through tracking noise jamming even if noise jamming has covered the echo from the target because both noise jamming and the echo come from the same direction[3][4] [5][6]. Above study results show that the angular tracking system of mono-pulse radar has very high anti-jamming ability, but they are based on the assumption that the receiver of radar is ideal. In fact, it is difficult to make ideal receiver of mono-pulse radar. Besides, there exist some mismatching in circuit characteristics, which may lower anti-jamming ability. In this time orientation error will increase unavoidably.

By now, there have not been papers which deal with angular accuracy while mono-pulse radar is tracking noise jamming or relate to the difference in angular accuracy between active following and passive following. On the analysis of angular tracking principle of mono-pulse radar and signal transmission characteristics when noise jamming passes a receiver, this paper points out a few causes which induce angular error of mono-pulse radar while tracking noise jamming and builds models to simulate goniometric cases of active tracking and passive tracking. At last, the paper draws some helpful conclusions by comparing.

2 Angular Tracking Principle of Mono-pulse Radar

According to the way of angle discrimination， mono-pulse radar can be divided into amplitude-comparison system, phase discrimination system, and sum-and- difference system. Taking mono-pulse radar of amplitude-amplitude type for instance here. We will analyze the performance of tracking noise source of mono-pulse. The simplified block-diagram of the mono-pulse radar of amplitude-amplitude type for a plane orientation is shown in fig. 1.

Suppose only noise jamming signal is received under self-protecting noise jamming because noise jamming has covered the echo from the target. If noise FM jamming signal received by antenna systems is $J(t)=U_{\mathrm{j}}\cos[\omega_{\mathrm{j}}t+2\pi K_{\mathrm{FM}}\int_0^t u(\tau)d\tau]$ (where the modulation noise $u(t)$ is a zero mean, wide-sense stationary random process, U_{j} is the amplitude of noise FM signal, ω_{j} is the intermediate frequency of noise FM signal, K_{FM} is the frequency modulation slop. $U_{\mathrm{j}}=\sqrt{2P_{\mathrm{j}}}$, P_{j} is the power of the noise FM signal),

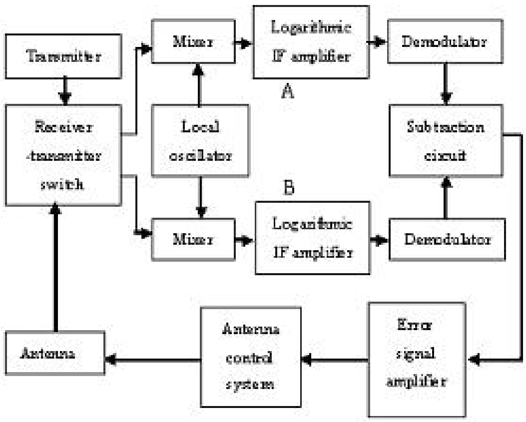


Fig.1. The simplified block-diagram of the mono-pulse radar of amplitude-amplitude type for a plane orientation

when the noise jamming deviates from the equi-signal direction at an angle of θ, two outputs of the antenna systems are given by:

$$J_{\mathrm{A}}(t,\theta)=U_{\mathrm{j}}F(\theta_0-\theta)\cos[\omega_{\mathrm{j}}t+2\pi k_{\mathrm{FM}}\int_0^t u(\tau)d\tau]$$

$$J_{\mathrm{A}}(t,\theta)=U_{\mathrm{j}}F(\theta_0+\theta)\cos[\omega_{\mathrm{j}}t+2\pi k_{\mathrm{FM}}\int_0^t u(\tau)d\tau]$$

Where $F(\theta_0-\theta)$ and $F(\theta_0+\theta)$ are the gain of two antennas respectively when the target deviates from the equi-signal direction at an angle of θ.

After HF amplifier, mixer and logarithmic IF amplifier, two input signals of demodulator are:

$$J_{\mathrm{MA}}(t,\theta)=\ln\{k_{\mathrm{HA}}F(\theta_0-\theta)U'(t)\cos[\omega_{\mathrm{j0}}t+\varphi(t)]\}$$

$$J_{\mathrm{MB}}(t,\theta)=\ln\{k_{\mathrm{HB}}F(\theta_0+\theta)U'(t)\cos[\omega_{\mathrm{j0}}t+\varphi(t)]\}$$

Where k_{HA} and k_{HB} are the transmission coefficient of HF amplifier and mixer of two branch circuits of A and B respectively , $U'(t)$ is the envelope function of sampling function, ω_{j0} is the center frequency of IF amplifier, $\varphi(t)$ is the phase function of sampling function.

After linear envelope detection and video frequency amplifier, two input signals of the subtraction circuit are:

$$J_{\mathrm{jA}}(t,\theta)=\ln\{k_{\mathrm{A}}F(\theta_0-\theta]U'(t)\}$$

$$J_{\mathrm{jB}}(t,\theta)=\ln\{k_{\mathrm{B}}F(\theta_0+\theta]U'(t)\}$$

where $k_{\mathrm{A}}=k_{\mathrm{jA}}k_{\mathrm{HA}}$ and $k_{\mathrm{B}}=k_{\mathrm{jB}}k_{\mathrm{HB}}$, k_{jA} and k_{jB} are the transmission coefficient of linear envelope detection and video frequency amplifier of two branch circuits of A and B respectively .

The output of the subtraction circuit can be given by:

$$\Delta u(\theta)=\ln\frac{k_{\mathrm{A}}F(\theta_0-\theta)}{k_{\mathrm{B}}F(\theta_0+\theta)} \quad (1)$$

When two receivers are symmetrical and the angular error is very small, Eq.(1) can be written as follows:

$$\Delta u(\theta)=\ln\frac{F(\theta_0-\theta)}{F(\theta_0+\theta)}\approx 2\mu\theta \quad (2)$$

Where μ is the slope coefficient of antenna directional diagram at work.

From (2) we can find out that subtraction circuit output $\Delta u(\theta)$ reflects the deflection angle θ proportionally. When the noise jamming deviates from the equi-signal direction, error signal $\Delta u(\theta)$ is first amplified and processed, and then drives the antenna to rotate. The antenna ceases to rotate until the error signal is zero, now it is aiming at the noise jamming and angular tracking is realized.

3 The Causes of Angular Error in Noise Jamming

From angular tracking principle of mono-pulse radar, we can know that the mono-pulse radar has two assumptions in design:

1) Two receivers are symmetrical absolutely;
2) IF amplifier has a wide enough bandwidth.

It is noticed that the two assumptions are satisfied only under given conditions. In fact, two receivers can not be symmetrical absolutely even if they would be well designed and enough bandwidth assumption is not untenable for noise jamming, which cause more error for tracking noise jamming. In addition, there are some other reasons causing the error increasing. A detailed analysis about them is as follows:

3.1 The Dissymmetry of Two Receiver Branches

The differences between noise jamming and thermal noise lie two aspects: First, the spectral width of the thermal noise is very wide, and that of the noise jamming is relatively narrow. But because the bandwidth of the receiver is limited, two kinds of noises have the same spectral width while entering the receiver; Thermal noises in two receivers are irrelevant because they come from different receivers and noise jamming are relevant because they come from the same noise source. In fact two receivers can not be totally symmetrical, so the external noises become irrelevant any more when the noises reach the subtraction circuit. We may say that though there are differences between noise jamming and thermal noise, their impact on angular accuracy of a radar can be regarded as similar when two receivers are not totally symmetrical. Under thermal noise, the smaller signal-to-noise ratio is, the greater the angular error of thermal noise is and the lower the tracking precision will be. Because signal-to-noise ratio decreases generally under noise jamming, so the angular accuracy will fall according to the analogy between thermal noise and noise jamming.

3.2 The Limited Bandwidth of IF Amplifiers

Because bandwidth of IF amplifiers is the narrowest of all grades of circuits in a receiver, the bandwidth of IF amplifiers can be regarded as that of the receiver approximately. Main received signal is echo from the target by active tracking whereas main received signal is noise jamming by passive tracking. The two kinds of signals have different spectral bandwidth, the frequency spectrum of echo is relatively narrow and is within the bandwidth of IF amplifiers whereas the frequency spectrum of noise jamming is even wider than bandwidth of IF amplifier, so when the frequency spectrum of two IF amplifiers are inconsistent, especially when fading characteristics of IF amplifiers are inconsistent, tracking noise jamming will cause greater angular error.

3.3 Frequency Collimation Error

There is frequency collimation error in collimation system, so operating frequency of jammer can not be same as that of radar and the center frequency of received noise jamming after frequency mixer is not in conformity with that of IF amplifiers, which may introduce another angular error of tracking noise jamming.

3.4 Transmitting Power of the Noise Jammer

When two receiver branches are totally symmetrical, the magnitude of transmitting power of noise jammer can not affect angular error of tracking noise jamming because normalization effect of logarithmic amplifier. But when they are not totally symmetrical, it is different.

4 Simulations and Analyses

4.1 Models

4.1.1 The model of Echo signal

The peak power of transmitter is P_t and mathematic model of transmitting signal is:

$$s(t) = Au_1(t)\sin(\omega_c t)$$

Where $A=\sqrt{P_t R_A}$, R_A is the receiver characteristic resistance; $u_1(t)$ is the pulse modulation signal; $\sin(\omega_c t)$ is carrier wave signal and ω_c is the work frequency of the radar transmitter.

According to the radar equation, the model of target echo signal received by antenna is:

$$R(t) = \sqrt{\frac{G_t G_r \sigma \lambda^2}{(4\pi)^3 R_t^{\,4} L_r}} \cdot s(t)$$

Where G_t is the gain of radar transmitter; G_r is the gain of the receiver antenna; σ is the dispersion section of target; λ is the transmitting wave-length; R_t is the distance from the radar to the target; L_r is the loss of radar.

4.1.2 The model of noise FM jamming signal

The model of noise FM jamming signal is:

$$J(t) = U_j \cos[\omega_j t + 2\pi K_{FM} \int_0^t u(\tau)\mathrm{d}\tau + \varphi]$$

The noise FM signal jamming bandwidth is:

$$\Delta f_j = 2\sqrt{2\ln 2} K_{FM} \sigma_n$$

Where σ_n is variance of modulation noise.

According to the detecting equation, the self-defense noise FM signal received by antenna is:

$$J_r(t) = \sqrt{\frac{G_j G_r \lambda^2}{(4\pi)^2 R_t^{\,2} L_j}} \cdot J(t)$$

Where G_j is the power of the noise transmitter, L_j is comprehensive loss of noise transmitter.

4.1.3 The model of thermal noise in a receiver

Thermal noise in a receiver can be simulated as white noise. Only the signals in the bandwidth scope of receiver can enter the receiver. So the paper firstly produces an ideal white noise signal with expectation of 0 and variance of 1, then changes it to band-limited white noise with medium frequency bandwidth of the receiver by means of filtering to simulate thermal noise of receiver. Thermal noise power (σ^2) of receiver should be got as:

$$\sigma^2 = kT_0 B_r F$$

Where k is the Boltzmann constant; T_0 is equivalent noise temperature; B_r is the receiver bandwidth (Hz); F is noise coefficient.

4.1.4 The models of angular tracking system

Models of circuits in the angular tracking system as fig.1 are set up On MATLAB platform too. Servo system is taken no account of temporarily. Main simulation parameters are shown in table 1.

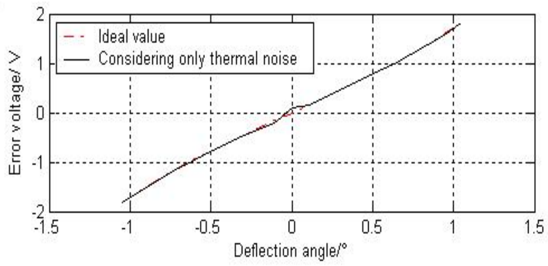
Following assumptions are used in simulations: the goniometric value when only echo signal is received and two receiver branches are totally symmetrical is regarded as ideal one; echo signal is received and thermal noise of receiver is considered in active tracking; noise jamming is received and thermal noise of receiver is considered in passive tracking. Difference of amplitude and phase between two receiver branches is ±1dB and 5° . A few cases are simulated as follows:

Table 1. Main simulation parameters

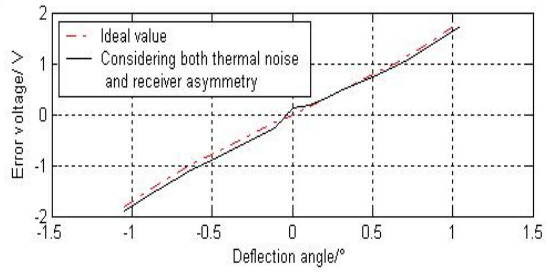
peak power of radar transmitter P_t/kW	200	bandwidth of noise jammer Δf_j / MHz	10
radar transmitting(receiving) antenna gain G_t / dB	40	transmitting power of the noise jammer P_j / W	1
loss of radar system L_r / dB	-10	antenna gain of the noise jammer G_j / dB	13
radar working frequency f_c / GHz	10	synthesizes loss of noise jammer L_j / dB	-7
effective reflecting area of target σ / m^2	3	power gain of high frequency amplifier G_h / dB	40
tracking distance R_t / km	20	mixers power loss L_m / dB	10
pulse repetition frequency f_{rep} / kHz	1	gain of IF amplifier G_m / dB	0
pulse width τ / μs	1	logarithm IF bandwidth f_{ifa} / MHz	2
equivalent noise temperature T_0 / K	290	video frequency amplifier bandwidth f_{va} /MHz	1
noise figure of receiver F / dB	3	video frequency amplifier gain G_{va} /dB	50

4.2 Angular Error of Active Tracking at Several Situations

Two kinds of situations in which only thermal noise is considered and both thermal noise and receiver asymmetry are considered are simulated. Direction detecting sensitivity curves of active tracking in the two kinds of situations are shown as fig. 2 (a) and (b) respectively. The calculated angular errors in the two situations are 0.0145° and 0.0536° respectively. It can be find out that thermal noise will cause angular error in active following and asymmetry of two receiver branches will cause greater angular error.



(a)



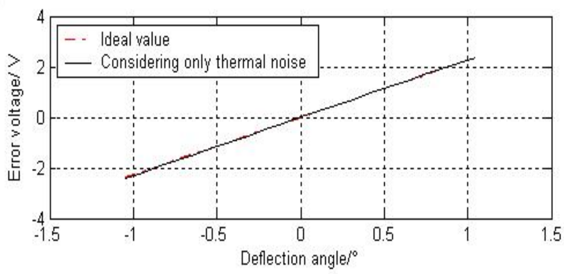
(b)

(a) Considering only thermal noise
(b) Considering both thermal noise and receiver asymmetry

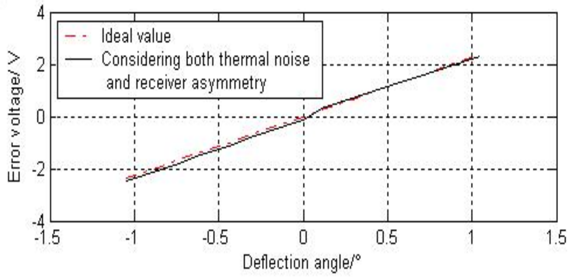
Fig.2. Angular error of active tracking at two kinds of situations

4.3 Angular Error of Passive Tracking at Several Situations

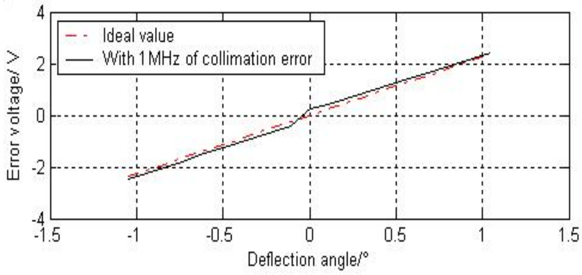
Four kinds of situations are simulated in which: (a) only thermal noise is considered, (b) both thermal noise and receiver asymmetry are considered, (c) thermal noise, receiver asymmetry and 1MHz of frequency collimation error are considered, (d) change the magnitude of transmitting power of noise jammer in the third situation. Direction detection sensitivity curves of passive tracking in the first there situations are shown as fig. 3(a), (b) and (c) respectively. Angular errors under different magnitude of transmitting power of noise jammer are shown as fig. 3(d).



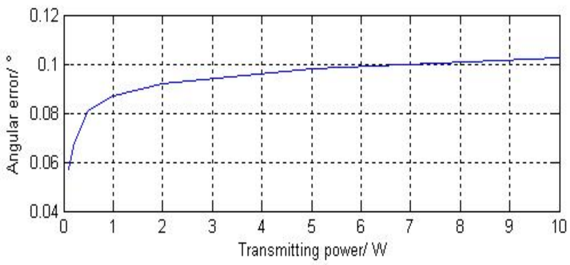
(a)



(b)



(c)



(d)

(a) Considering only thermal noise
(b) Considering both thermal noise and receiver asymmetry
(c) With 1MHz of frequency collimation error
(d) Different magnitude of transmitting power of noise jammer

Fig. 3. Angular error of passive tracking at several kinds of situations

The calculated angular errors in the three situations are 0.0169°, 0.0600° and 0.0869° respectively. Comparing fig.3 (a) with fig. 2 (a), we can find out that even if two receiver branches are identical, greater angular error is caused in passive tracking because of the limited bandwidth receiver under noise jamming, but the enhancement is rather unremarkable because of the function of the logarithm amplifier. Comparing fig .3 (b) with fig. 2 (b) we may find out that passive tracking causes greater angular error under the same degree of asymmetry of two receiver branches. Comparing fig.3 (c) with fig.3 (b) we may find out that passive tracking with 1MHz of frequency collimation error causes greater angular error as compared with that without frequency collimation error. From fig.3 (d), it is shown that when two receivers are not totally symmetrical, the greater power noise jammer transmits, the greater angular error of passive tracking is.

5 Conclusions

Passive tracking will cause greater angular error because of the limited bandwidth of receiver, asymmetry of two receiver branches, frequency collimation error and the magnitude of transmitting power of noise jammer. These will certainly cause tracking accuracy of object to decrease or cause tracking capacity to lose under noise jamming. Therefore, in order to maintain its original fighting efficiency, mono-pulse radar must be improved under self-protecting noise jamming

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