Study on the technology of tracking noise jamming with monopulse radar and analysis on its tracking errors

YANHUA ZHANG, ZHONGJIE ZHANG, JIAN WANG
National Key Laboratory For Electronic Measurement Technology
College of Information and communication Engineering, North University of China
Taiyuan, Shanxi province
CHINA
tyzyhzyh@126.com http://www.nuc.edu.cn/

Abstract: - Under self-protecting noise jamming, mono-pulse radar can track the target by tracking noise jamming because noise jamming comes from the same direction as echo of target. In order to reduce angular tracking error, a method of introducing pulse modulation circuit and adjusting the bandwidth of intermediate frequency amplifier and video amplifier is proposed based on the main causes of angular error. Simulation studies verifies its effectiveness. In order to solve the problem of arranging stations in direction-finding cross-location technology, a method of station distribution arrangement is put forward based on the principle analysis of direction finding location with two stations. The receiving angle range to achieve higher location accuracy and the distance between two stations to meet the range of receiving angle are chosen. At last the easier calculation method of location accuracy in passive tracking is given. The studies show that the proposed methods can effectively improve tracking accuracy in tracking noise jamming with mono-pulse.

Key-Words: - Noise jamming; Mono-pulse radar; Angular error; Cross-location; Arrangement; Tracking error

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][3][4]. Under noise jamming, mono-pulse radar will lose distance information, but it will track the direction of the object continuously through tracking noise jamming because both noise jamming and the echo come from the same direction[5][6][7][8]. The slant range is gotten through triangle-relationship. 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 and orientation error will increase unavoidably[9][10][11][12]. In this case, how to reduce angular tracking error of monopulse radar and how to distribute radar stations to get higher location accuracy have great significance in ensuring its operational effectiveness and uninterrupted combat.

The technology of tracking noise jamming has been reported only in the Linear Scanning radar[13]. Using over-threshold cumulative technique to significantly improve signal-to-noise ratio in the differential channel of receiver to detect the noise jamming has been reported [14].By now, there have not been papers studying how to reduce angular error in tracking noise jamming. Besides, the study focus on technology of direction-finding cross-location is how to exclude the false location. However, the study on improving location accuracy by rationally arranging several passive sensors is relatively less, and more studies on cross-location are performed in the plane[15][16]. how to reduce angular error in tracking noise jamming and how to arrange radar stations to improve location accuracy of cross-location are studied in this paper and the location accuracy is calculated.

2 Tracking Principle

2.1 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 jamming with mono-pulse. The simplified block-diagram of the mono-pulse radar of amplitude- amplitude type for a plane orientation is shown in Fig. 1.

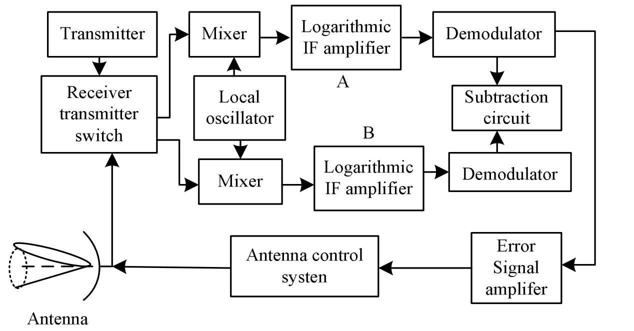

Fig.1. The simplified block-diagram of the mono-pulse radar of amplitude-amplitude type for a plane orientation

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 $J(t)=U_j\cos[\omega_j t+2\pi k_{FM}\int_0^t u(\tau)d\tau]$ (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. $U_j=\sqrt{2P_j}$, P_j is the power of the noise FM signal).

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

$$J_A(t,\theta)=U_jF(\theta_0-\theta)\cos[\omega_j t+2\pi k_{FM}\int_0^t u(\tau)d\tau]$$

$$J_A(t,\theta)=U_jF(\theta_0-\theta)\cos[\omega_j t+2\pi k_{FM}\int_0^t u(\tau)d\tau]$$

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:

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

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

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:

$$J_{jA}(t,\theta)=\ln\{k_AF(\theta_0-\theta]U'(t)\}$$

$$J_{jB}(t,\theta)=\ln\{k_BF(\theta_0+\theta]U'(t)\}$$

where $k_A=k_{jA}k_{HA}$ and $k_B=k_{jB}k_{HB}$, 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:

$$\Delta u(\theta)=\ln\frac{k_AF(\theta_0-\theta)}{k_BF(\theta_0+\theta)} \quad (1)$$

When two receivers are symmetrical and the angular error is very small, (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) it can be found 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.

2.2 The Principle of Passive Tracking Cross-location Between Two Stations

The principle of passive tracking cross-location between two stations is shown in Fig.2.

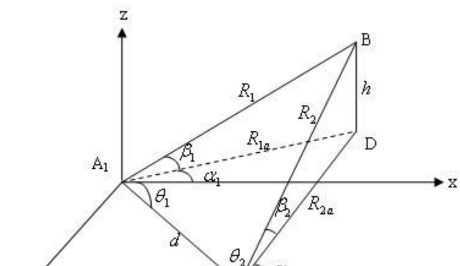

Fig.2 Cross-location between two stations

In Fig.2, A_1 and A_2 are positions of passive tracking radar, B is position of target, D is projection point of B, R_1 is the distance from A_1 to B, R_{1a} is projection distance of R_1, R_2 is the distance from A_2 to B, R_{2a} is projection distance of R_2, h is the height of target, α_1 and β_1 are azimuth angle and pitch angle measured by station A_1, α_2 and β_2 are azimuth angle and pitch angle measured by station A_2, d is distance from A_1 to A_2, θ_1 and θ_2 are angles that the line A_1 A_2 meets x axis at point A_1 and point A_2. Suppose the angles that line A_1A_2 meets A_1D and A_2D are θ_a and θ_b respectively, therefore

$$\theta_a = \theta_1 + \alpha_1 \quad (3)$$

$$\theta_b = \theta_2 - \alpha_2 \quad (4)$$

According to the triangle relationship in Fig.2

$$\cos\beta_1 = \frac{R_{1a}}{R_1} \quad (5)$$

$$\cos\beta_2 = \frac{R_{2a}}{R_2} \quad (6)$$

$$\frac{\sin\theta_b}{R_{1a}} = \frac{\sin\theta_a}{R_{2a}} = \frac{\sin[180^\circ - (\theta_a + \theta_b)]}{d} \quad (7)$$

Solutions to simultaneous equations 3-7 are

$$R_1 = \frac{d\sin(\theta_2 - \theta_1)}{\cos\beta_1 \sin[\theta_1 + \theta_2 - (\alpha_2 - \alpha_1)]} \quad (8)$$

$$R_2 = \frac{d\sin(\theta_1 + \alpha_1)}{\cos\beta_2 \sin[\theta_1 + \theta_2 - (\alpha_2 - \alpha_1)]} \quad (9)$$

The distance h between two stations and angle θ_1 and θ_2 can be measured when the two stations are located. Azimuth angle α_1, α_2 and pith angle β_1, β_2 can be given timely after radar tracks target passively. Distance R_1 and R_2 can be got by equation 8 and 9. The 3-dimensional coordinates of target can timely got by passive cross-location with two radars.

3 Reducing Angular Error in Tracking Noise Jammer

3.1 The Causes of Angular Error in Tracking Noise Jamming

From angular tracking principle of mono-pulse radar, it is can be known 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:

3.1.1 The Dissymmetry of Two Receiver Branches and Cumulative Effect

Noise jamming has a certain similarity with thermal noise in radar receivers because noise jamming has a strong random. 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 after entering the receiver; Thermal noises in two receivers are irrelevant because they come from different receivers but 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.

The error equation of thermal noise impacting on mono-pulse radar can be expressed as

$$\sigma_t = \frac{\theta_{0.5}}{k_m\sqrt{B\tau(S/N)f_r/B_n}} \qquad (S/N > 4) \qquad (10)$$

$$\sigma_t = \frac{\theta_{0.5}}{k_m\sqrt{B\tau(S/N)f_r/B_n}} \cdot \sqrt{\frac{(S/N)+1}{(S/N)}} \qquad (S/N \le 4) \quad (11)$$

Where σ_t is thermal noise error, $\theta_{0.5}$ is the antenna beam width of radar, k_m is a coefficient, for mo-no pulse radar it is 1.57, $B\tau$ is the product of receiver bandwidth and pulse width, S/N is the ratio of signal to noise, f_r is pulse repetition frequency of radar, B_n is the bandwidth of dadar servo system. From (10) and (11) it can be found out that under thermal noise, the smaller signal-to-noise ratio S/N is and the smaller f_r/B_n is, the greater the normalized error of thermal noise is and the lower angular accuracy is.

Because signal-to-noise ratio decreases generally under noise jamming and the accumulation effect of noise jamming is worse, so the angular accuracy will lower according to the analogy between thermal noise and noise jamming.

3.1.2 The Limited Bandwidth of IF Amplifiers

Because the 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 in active tracking whereas main received signal is noise jamming in 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.

According to angular information transmission process in noise jamming tracking with amplitude-amplitude type mono-pulse radar, angular information passes in the form of signal envelope. the signal after the detector has a certain fluctuation because noise jamming is a strong random signal. the bandwidth of IF amplifiers has a great impact on signal fluctuation. When noise FM jamming passes IF amplifiers of narrower frequency bandwidth, the output fluctuation after IF amplifiers will increase, error signal will increase too, which would give rise to greater angular tracking error.Namely, when noise jamming passes the original receiver, matched filter receiver is no longer functional, receiver bandwidth is too narrow for noise jamming, which would lower angular tracking accuracy.

3.1.3 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.

3.1.4 Different receiving Power of Noise Jamming

If two receiver branches are totally symmetrical, the magnitude of receving power of noise jamming can not affect angular error of tracking noise jamming because normalization effect of logarithmic amplifier. But If they are not totally symmetrical, the magnitude of receving power will affect angular error.

Therefore, passive tracking will cause greater angular error because of above causes, which 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.

3.2 Reducing Angular Error in Tracking Noise Jamming

From above reasons causing angular error in tracking noise jammer, we can know that the dissymmetry of two receiver branches and the limited bandwidth of IF amplifiers are main considering factors in improving mono-pulse radar receiver. Morever, reducing the disturbance magnitude of error voltage signal is the key problems. Because there are many effective methods of reducing the dissymmetry degree of two receiver branches, so the study in this paper does not focus on it. This study focus in the paper is how to use other means to reduce the angluar error of the noise jamming tracking in the case of constant dissymmetry degree of two receiver branches.

The overall thought of improving receiver is adding a tracking noise jamming circuit on the existing tracking receiver. When radar is not jammed, the original tracking receiver is used, and when radar is jammed, the added tracking receiver is used. By this method, a higher angular tracking accuracy is assured whether self-protecting noise jamming is received.

In tracking noise jamming, receiver should have the ability to work normally at any frequency within jamming frequency spectrum. Usually the bandwidth of antenna system is very wide, and the bandwidth of HF amplifier and that of mixer are also very wide, so after them noise jamming signal will not be distorted. That means the envelope fluctuation of noise jamming signal will not be changed. The transmission of noise jamming envelope with no distortion can not be assured because of the quite narrow bandwidth of IF amplifier. When noise FM jamming signal passes a IF amplifier with narrow bandwidth, great distortion and noise fluctuation will be output because of the great frequency partial. That is to say the original IF amplifier is the best detector for target echo, but for noise jamming detecting function will become worse because the statistic characteristic of signal changes. Therefore the bandwidth of IF amplifier is one of the important parameters which should be emphatically considered in improving receiver design.

Moreover, mono-pulse radar receives pulse echo signal when not jammed, but receives continuous wave noise signal when jammed by noise jamming. In order to reduce average power of noise jamming, increase the effective accumulated pulse number of noise jamming signal and strengthen the suitability among improved circuit, following processing circuit and servo system, impulse modulation circuit is added after logarithmic IF amplifier to change the continuous noise signal into pulse noise. Certainly, pulse modulation circuit can also be placed before the logarithmic IF amplifier. But in the case the bandwidth choice of logarithmic IF amplifier must consider the bandwidth of added pulse, which will be some complicated.

After adopting the pulse modulating circuit, the top of pulse signal of demodulation circuit still has fluctuation, and the output pulse waveform passing video frequency amplifier and the subtraction circuit also has fluctuation, the fluctuation may be the main factor causing servo system fluctuate. Therefore, diminishing fluctuation through reducing the bandwidth of video frequency amplifier can improve the angular tracking accuracy in tracking noise jammer.

The block-diagram of original angular tracking receiver and added tracking circuit is shown as Fig.3.

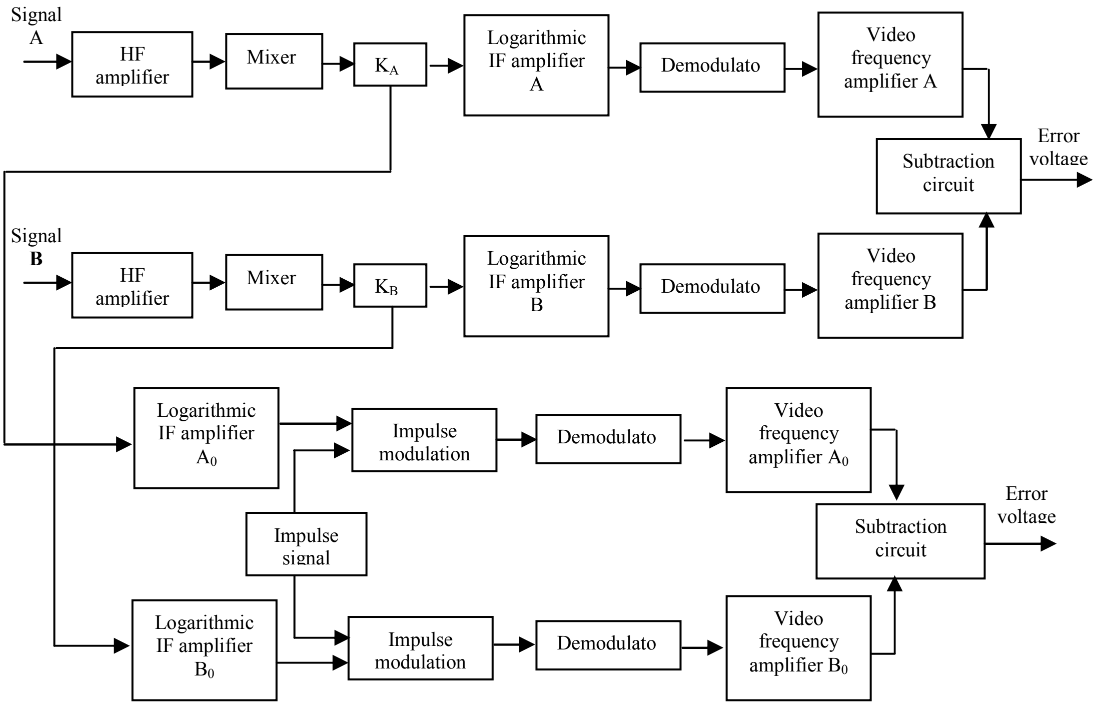

Fig.3 the block-diagram of Original Angular Tracking Receiver and Added Tracking Circuit

As shown in the gridline of Fig.3, added tracking receiver has different bandwidth in IF amplifier and video frequency amplifier with the original tracking receiver, added tracking receiver has pulse modulation circuit but original tracking receiver circuit has not, K_A and K_B are the single-pole double-throw microwave switches.

3.3 Simulation Study on Above Improving Method

Mathematic models of echo signal, noise Fm jamming signal, thermal noise signal as well as various circuits in angle tracking system of mono-pulse radar are set up.Main simulation parameters are shown as Table1.

Under self-defence noise jamming, useful signal power P_{in} and interference power P_{jin} entering the receiver within pass band are respectively

$$P_{\text{in}} = \frac{P_{\text{t}} G_{\text{t}} G_{\text{r}} \sigma \lambda^2 L_{\text{r}}}{(4\pi)^3 R_{\text{t}}^4} \quad (12)$$

$$P_{\text{jin}} \approx \frac{P_{\text{j}} G_{\text{j}} G_{\text{r}} \lambda^2 L_{\text{j}} r_{\text{j}}}{(4\pi)^2 R_{\text{t}}^2} \cdot \frac{B_{\text{r}}}{B_{\text{j}}} \quad (13)$$

From (12) and (13), interference-to-signal ratio is

$$\frac{J}{S} = \frac{P_{\text{jin}}}{P_{\text{in}}} = \frac{4\pi P_{\text{j}} G_{\text{j}} R_{\text{t}}^2 L_{\text{j}} r_{\text{j}} B_{\text{r}}}{P_{\text{t}} G_{\text{t}} \sigma L_{\text{r}} B_{\text{j}}} \quad (14)$$

From (14)and the corresponding parameters of Table 1 , interference-to-signal ratio at 15km is 27.8dB.

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; Simulation case when noise jamming, thermal noise of receiver are received and two receivers are dissymmetrical is regarded as angle-measuring situation in passive tracking.The angular error rms value of original passive tracking in angle-measuring range by simulation is 0.42° . The improved effect has Significant ralations to IF amplifier bandwidth, video frequency amplifier bandwidth, pulse width and dissymmetry degree of amplitude and phase characteristics of two receiver branches.

Table 1. Main simulation parameters

parameters	value	parameters	value
peak power of radar transmitter P_t/kW	100	synthesizes loss of noise jammer L_j / dB	-7
radar transmitting(receiving) antenna gain G_t / dB	40	polarization Loss r_j / dB	-3
loss of radar system L_r / dB	-10	noise figure of receiver F / dB	10
radar working frequency f_c / GHz	10	bandwidth of noise jammer Δf_j / MHz	10
effective reflecting area of target σ / m^2	3	power gain of high frequency amplifier G_h / dB	40
tracking distance R_t / km	15	mixers power loss L_m / dB	10
pulse repetition frequency f_{rep} / kHz	1	gain of Linear part of IF amplifier G_m / dB	60
pulse width τ / μs	1	logarithm IF bandwidth B_r / MHz	2
equivalent noise temperature T_0 / K	290	video frequency amplifier bandwidth B_v /MHz	1
transmitting power of the noise jammer P_j / W	50	video frequency amplifier gain G_v /dB	30
antenna gain of the noise jammer G_j / dB	13	amplitude difference of two receiver branches/dB	1

3.3.1 The Choice of Main Parameters

(1) Bandwidth choice of IF amplifier

In the passive angular tracking of noise jammer, how to design IF amplifier as the best filter is extremely important problem. Generally, bandwidth choice of IF amplifier is mainly considered from reducing wave form distortion and improving signal-to-noise ratio of receiver output.

The bandwidth of IF amplifier must cover the noise jamming spectrum to diminish the distortion of envelop signal. Because the bandwidth of noise FM jamming as Table 1 is 10 MHz, the bandwidth of IF amplifier of receiver should be wider than10 MHz.

In the angular tracking of noise jamming, the chosen signal put into the angular tracking system from the range gate includes noise jamming signal and thermal noise signal. For the angular measuring, the noise jamming signal includes not only "angular measuring signal" but also"noise". The voltage of "angular measuring signal" is the mean(expectation) of noise jamming, and the power of "noise" is variance of noise jamming, therefore, the signal-to-noise can be expressed as:

$$\frac{S}{N}=\frac{\{E[u_j(t)+u_n(t)]\}^2}{D[u_j(t)+u_n(t)]}$$

In the formula, $u_j(t)$ is the noise jamming signal, $u_n(t)$ is the thermal noise signal. In tracking noise FM jamming, the calculated signal-to-noise ratio of demodulation circuit under different bandwidth of logarithm IF amplifiers are shown as table 2 by simulating.

Table 2 Signal-to-noise ratio of demodulation Circuit

bandwidth of IF amplifiers/MHz	1	2	5	10	12	15	20
the ratio of signal-to-noise	6.0	6.1	10.4	17.1	18.0	18.3	22.4

From table 2 we can find out that wider bandwidth of logarithmic IF amplifier can improve signal-to-noise ratio within a certain range of bandwidth. But the bandwidth can not be chosen too widely, because the wider the bandwidth is, the greater thermal noise power is and the smaller sensitivity is. Smaller sensitivity has disadvantage in detecting target. Moreover, in order to reduce processing capacity of following A/D converter, the bandwidth of receiver should be narrowest within the allowed signal-to-noise ratio according to signal form of the system.

If above influence factors are considered comprehensively, the bandwidth of logarithmic IF amplifier can be chosen as the bandwidth of noise jamming 10 MHz.

(2) Matching the bandwidth of video frequency amplifier with logarithmic IF amplifier and pulse width

Mono-pulse radar receives pulse echo signal when not jammed. In this situation, the bandwidth of video frequency amplifier is chosen following the principle that pulse signal will not reduce because of waveform distortion when passes through it, the bandwidth in video frequency amplifier B_v is generally chosen as $B_v=\frac{1}{\tau}$ (τ is pulse width).

Mono-pulse radar receives continuous noise signal when jammed by noise jamming. If the bandwidth of logarithmic IF amplifier in added tracking circuit is $B_r^{'}$, the width of modulated pulse is τ', similar to the echo signal, the bandwidth of video amplifier $B_v^{'}$ should assure that the signal waveform will not decrease because of distortion, then the following equation should be satisfied

$$B_{\mathrm{v}}^{'} \geq \frac{1}{\tau'} \tag{15}$$

In the meantime, the bandwidth of video amplifier $B_v^{'}$ is not necessarily wider than that of IF amplifier, so the following equation should be satisfied

$$B_{\mathrm{v}}^{'} \leq B_{\mathrm{r}}^{'} \tag{16}$$

From (15) and (16), a new equation is achieved

$$\tau' \geq \frac{1}{B_{\mathrm{r}}^{'}} \tag{17}$$

1) The Influnce of video amplifier bandwidth on angular error

If $B_r^{'} = 10\mathrm{MHz}$, $\tau' = 1\mu\mathrm{s}$, angular measuring error data with different bandwidths of video frequency amplifier in the linear tracking range by simulating are shown as table 3. From table 3, it is can be known that if $\frac{1}{\tau'} \leq B_v^{'} \leq B_r^{'}$ $(1 \leq B_{\mathrm{v}}^{'} \leq 10\,\mathrm{MHz})$, the narrower the bandwidth of video frequency amplifier is and the smaller angular measuring error is. The smallest angular measuring error is achieved at $B_{\mathrm{v}}^{'} = \frac{1}{\tau'}$, so the bandwidth of video frequency amplifier $B_{\mathrm{v}}^{'}$ can be chosen according to pulse width τ', namely $B_{\mathrm{v}}^{'} = \frac{1}{\tau'}$ should be met.

Table 3 Angular Measuring Error Data with Different Bandwidths of Video frequency Amplifier

bandwidth of video frequency amplifier / MHz	0.1	0.2	0.5	1	2	5	10	12
angular Measuring Error/°	0.480	0.379	0.312	0.357	0.454	0.449	0.490	0.502

2) The Influnce of pulse width on angular error

According to (17), if $B_{\mathrm{r}}^{'} = 10\mathrm{MHz}$, then $\tau' \geq 0.1\mu\mathrm{s}$ .Suppose $B_{\mathrm{r}}^{'} = 10\mathrm{MHz}$ and $B_v^{'} = 10\mathrm{MHz}$, angular measuring error data with different pulse widths achieved by simulating are shown as table 4. From table 4, it is found out that when the bandwidth of video frequency amplifier is certain, cancellation performance in narrower pulse width is better,so angular error is smaller. But pulse width can not be chosen too narrow because too narrow pulse is not easily realized, so the choice of the added pulse width should also be matched with the bandwidth of video amplifier.

Table 4 Angular Measuring Error Data with Different Pulse Widths

pulse Width/ μs	0.1	0.2	0.5	1	2	5	10	15
angular Measuring Error/°	0.262	0.316	0.388	0.479	0.573	2.135	2.135	1.919

3)Matching choice of the bandwidth of video frequency amplifier with pulse width

When $B_{\mathrm{r}}^{'} = 10\mathrm{MHz}$ is chosen and $B_{\mathrm{v}}^{'} = \frac{1}{\tau'}$ is met, angular measuring error data with different pulse widths achieved by simulating are shown as table 5.

Table 5 the Angular Measuring Errors with Different Pulse Widths

pulse Width/ μs	0.1	0.2	0.5	1	2	5	10	15
angular Measuring Error/°	0.248	0.224	0.310	0.357	0.289	0.273	0.269	0.294

From table 5 it can be known that in the above-mentioned conditions, the largest angular measuring error is achieved at $\tau' = 1\,\mu s$, If $\tau' < 1\,\mu s$ or $\tau' > 1\,\mu s$, angular measuring error both decreases. The smallest angular error achieved is at $\tau' = 10\,\mu s$, so pulse width τ' can be chosen as $10\,\mu s$, correspondingly the bandwidth of video frequency amplifier $B_v^{'}$ can be chosen as 0.1MHz accoding to their matching ralation $B_v^{'} = \frac{1}{\tau'}$.

3.3.2 Comparing of Angular Measuring Accuracy
According the chosen parameters listed above, the angular measuring error in tracking noise FM jamming is 0.269º. Compared with angular measuring error in tracking noise FM jamming with original tracking receiver(0.42°) , we can find out that the improved angular measuring error decreases, Which show the effect of the above method.

4 Station Distribution
Location fuzzy region is the main problem in direction-finding cross-location technology because of direction-finding error. For 3-dimensional coordinates cross-location, the fuzzy region is a cube, the analysis of this question is very complex. The smaller the volume of cubic, the higher location accuracy is. From this point of view, it has advantage that station is higher and more near away from the target. In general, suffering limitation of practical topography, the height choice of station is difficult, so study on station distribution of three coordinates cross-location is induced to the plane.

4.1 The Range of Receiving Angle to Achieve Higher Location Accuracy
Fig.4 shows cross-location in the plane corresponding with Fig.2.

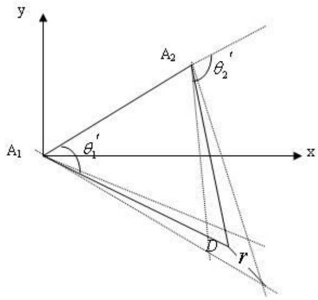

Fig.4 Cross-location between station A_1 and A_2

In Fig.4, $\theta_1' = \alpha_1 + \theta_1$, $\theta_2' = \alpha_2 + \theta_1$, $\sigma_{\alpha 1}$ is azimuth angle accuracy of station A_1, $\sigma_{\alpha 2}$ is azimuth angle accuracy of station A_2, $\sigma_{\alpha 1} = \sigma_{\alpha 2} = \sigma_\theta$, $\sigma_{\alpha 1}$ and $\sigma_{\alpha 2}$ are independent each other. It is can be obtained by the cosine theorem and triangle operation [16]:

$$\sigma_r = \sigma_\theta d \cdot \sqrt{\frac{\sin^2\theta_2' + \sin^2\theta_1'}{\sin^4(\theta_2' - \theta_1')}} \qquad (18)$$

It can be known from (18) that acceptance angle θ_1' , θ_2' , direction finding accuracy σ_θ and distance d are three factors influencing location accuracy. There are three methods to improve location accuracy, they are as follows:

1) Improving the direction finding accuracy of stations.

2) Reasonably assigning the position of stations to get the optimal acceptance angle.

3) Stations should be as close as possible to the target.

The influences of station position on accuracy of cross-location are studied. Fig.5 and Fig.6 show the influence of the changes of acceptance angle on location accuracy when $\sigma_\theta = 0.20^\circ$ or $\sigma_\theta = 0.42^\circ$ respectively.

From Fig.5 and Fig.6, the optimal range of θ_1' and θ_2' are 20°-60°and 120°-170° respectively. Fig.7 shows the optimal region of noise jammer under the investigation of two radars. When the noise jammer is in the optimal region of shaded parts, higher location accuracy can be got with two stations to locate the noise jamming.

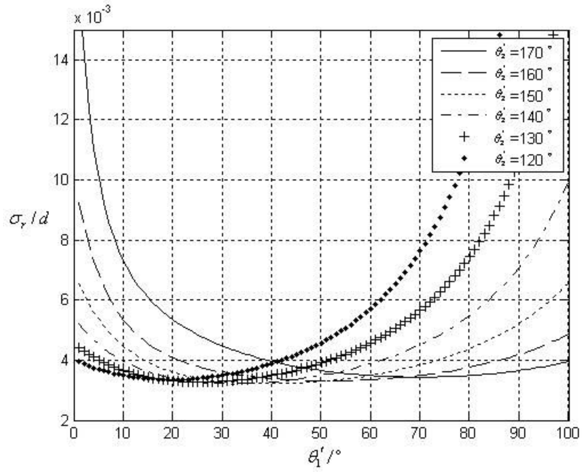

Fig.5 Influence of acceptance angle θ_1' and θ_2' on location accuracy when $\sigma_\theta = 0.20^\circ$

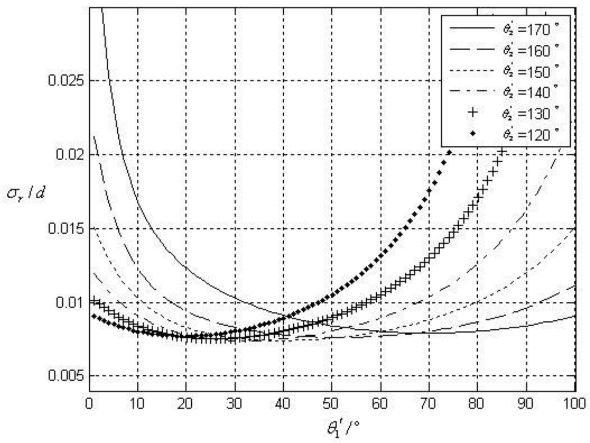

Fig.6 Influence of acceptance angle θ_1' and θ_2' on location accuracy when $\sigma_\theta = 0.42^\circ$

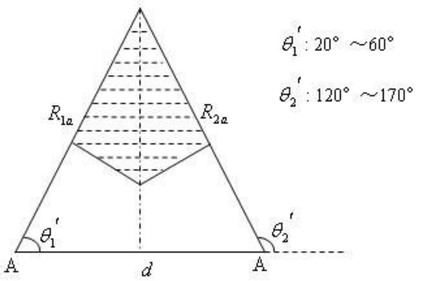

Fig.7 The optimal region of radar stations

Because the target studied in this paper is moving, the receiving angle measured by two stations must meet the less error range mentioned above. Otherwise, other eligible stations can be used to locate the target in order to realize the optimal selection in many stations and to improve location accuracy.

4.2 Choice of distance satisfying optimal receiving angle

Assumed that the tracking distance range of radar is 6km-21km, the flying height of target is about 5km, the target is flying from far on the vertical bisector of two radar stations, the range of $R_1(R_2)$ can be calculated as 3.3km-20.4km. From Fig.7

$$d = 2R_{1a}\cos\theta_1' \qquad (19)$$

If θ_1' meets the range of optimal receiving angle (20°-60°), then θ_2' also meets the range of optimal receiving angle (120°-160°) on the above assumption. As $\cos 60^\circ / \cos 20^\circ = 1.9$ and $20.4/3.3 = 6.2$, it is impossible that cross-location reaches the higher location accuracy only by two stations when the tracking range of radar is 3.3km-20.4km. It need three pairs of stations to reach higher location accuracy in 3.3km-20.4km. It can be respectively chosen the range to locate target position in 3.3km-6km, 6km-11.2km, 11.2km-20.4km.

In 3.3km-6km, if $d = 6\text{km}$, the receiving angle $\theta_1' = 24.6^\circ$ when $R_{1a} = 3.3\text{km}$, and the receiving angle $\theta_1' = 24.6^\circ$ when $R_{1a} = 6\text{km}$ by the equation 9, which all satisfy the optimal receiving angle.

In 6km-11.2km, if $d = 11.2\text{km}$, the receiving angle $\theta_1' = 21.0^\circ$ when $R_{1a} = 6\text{km}$, and the receiving angle $\theta_1' = 60.0^\circ$ when $R_{1a} = 11.2\text{km}$ by the equation 9, which all satisfy the optimal receiving angle.

In 11.2km-20.4km, if $d = 21\text{km}$, the receiving angle $\theta_1' = 20.4^\circ$ when $R_{1a} = 11.2$, and the receiving angle $\theta_1' = 59.0^\circ$ when $R_{1a} = 20.4$ by the equation 9, which all satisfy the optimal receiving angle.

4.3 Cross-location Accuracy of Three-coordinate

From Fig.2

$$h = R_{1a}\,\mathrm{tg}\beta_1 \qquad (20)$$

Total differential of the equation 20 is

$$dh = \mathrm{tg}\beta_1 dR_{1a} + R_{1a}\sec^2\beta_1 d\beta_1$$

Namely

$$\sigma_h = \mathrm{tg}\beta_1 \cdot \sigma_{R_{1a}} + R_{1a}\sec^2\beta_1 \cdot \sigma_{\beta_1} \qquad (21)$$

GDOP is often used as location accuracy to describe the 3- dimensional geometric distribution of location error. GDOP is usually expressed as following equation:

$$GDOP = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2} \qquad (22)$$

Based on what discussed above, it can be gained that:

$$GDOP = \sqrt{\sigma_r^2 + \sigma_h^2} \qquad (23)$$

If the passive location error is 0.42°, the location accuracy σ_r / d is within 0.013 according to Fig.6. σ_h and *GDOP* can be calculated by (21) and (23). Passive location accuracy at a few typical distances is shown in Table 6.

Table 6. Passive location accuracy

R_1/km	6	9	2	15	18	21
R_{1a}/km	3.3	7.5	10.9	14.1	17.3	20.4
d /km	6	11.2	11.2	21	21	21
σ_r/km	0.045	0.084	0.084	0.158	0.158	0.158
σ_h/km	0.125	0.082	0.082	0.090	0.099	0.110
GDOP/km	0.133	0.117	0.117	0.182	0.187	0.193

From table6, by the arrangement discussed above, the location error *GDOP* is within 2.5 percent of slant range when angular error is 0.42°.

5 Conclusion

Under noise jamming, mono-pulse radar will lose distance information, but mono-pulse radar can track the target through tracking noise jamming because noise jamming comes from the same direction as echo of target. The cause analysis of angular error in tracking noise jamming and simulation studies show that passive tracking will cause greater angular error. In order to maintain its original fighting efficiency, a method of reducing angular error is put forward firstly. Simulation results verifies its availability.For the existing problem of of arranging stations in direction-finding cross-location technology, the proposed spatial location method in the paper improves location accuracy and the simple algorithm of location accuracy in passive tracking has a certain significance in practical application.

References:

[1] Arnold D Seifer, Monopulse-radar Angle Tracking in Noise or Noise Jamming, *IEEE on Aerospace and Electronic System,* Vol. 28, No.3, 1992, pp.662-638.

[2]Arnold D seifer, Monopulse-radar Angle Measurement in Noise, *IEEE on Aerospace and Electronic System*, Vol. 30, No.3, 1994, pp.950-957.

[3] K. RAJA RAJESWARI, M. UTTARA KUMARI, CH. SRINIVASU, B. LEELARAM PRAKASH, Filter Model For Reduced Sidelobes in Pulse Compression Radar, *WSEAS Transactions on Signal Processing*, vol.3, No.4,2007, pp.308-312

[4] HAYTHAM QASEM, LEONHARD REINDL, Nonlinear Indoor Tracking with Range only Measurements Based on High Frequency, *WSEAS Transactions on Signal Processing*, Vol.2, No.10, 2006, pp.1343-1350

[5] Li Fengshang, Anti-interference Ability Analysis of Monopulse Radar, *The Electronic Countermeasure of the Naval Vessel,* Vol. 26, No.1, 2003,pp.34-36.

[6] Wang Xinfu, The Interference Question to the Radar Angle Tracking System, *Electronic CountermeasureTechnology,* Vol. 14, No.3, 1999, pp.3-11.

[7] Sergei A Vakin, Lev N Shustov, Robert H Dunwell, *Fundamentals of Electronic Warfare*, Artech House, 2001.

[8] Wang Jun, Shang Guanjintai, Angle Tracking of Noise FM Jammers for a Passive Monopulse Seeker,*Radar and Countermeasure*, No.3, 2002, pp.7-11.

[9] Yanhua Zhang, Wei Zhang, Bo Zan, Jian Wang, Hong Chang, A Method of Angular Error in Tranking Noise Jammer with Mono-pulse Radar, *WSEAS Transactions on Communications*, Vol. 6, No.9, 2007, pp.804-810.

[10] Zhang Yanhua, Zanbo, Wang Jian, Chang Hong, Cause Analysis on Angular Error When Monopulse Radar is Tracking Noise Jammer and a Simulative Test, *6th WESEAS International Conference on Instrumentation, Measurement, Circuits &Systems,*Hangzhou, 2007, pp.99-103

[11] Zhang Yanhua, Zan Bo, Wang Jian, Chang Hong, Modeling and Simulation on Active Angle Measuring and Passive Angle Measuring with Monopulse Radar, *Journal of Projectiles, rockets, missiles, guidance*, Vol. 27, No.3, 2007, pp.338-341.

[12] Wang Jian, Zhang Yanhua, An Analysis of the Tracking Error of Single Pulse Radar Tracking Source of Noise, *Electronic Countermeasure Technology,* Vol. 20, No.5, 2005, pp.43-45.

[13] Kang Xizhang, L i Xiaoyi, The Improving of the Passive Direction Finding Precision of a Linear Scanning Radar, *Modern Radar*, Vol. 20, No.4, 1998, pp.11-17.

[14] Liu Haijun, Study on Detect ion and Processing Technique of noise jamming signal, *Master's Degree Thesis of Second Design Academy of Astronautical Industry Company of China*, 2000

[15] Xu Caihong, Zou Zhonghui, Study on Passive Location Technology,*Electronic countermeasure Vessels*, Vol. 20, No.5, 1996, pp. 1-12.

[16] Xiu Jianjuan, He You, Wang Guohong, Dong Yunlong, Study on Cut Angle of Direction Finding Location System, *Journal of Astronautics*, Vol.26, No.3, 2005, pp.282-286.