Quasi-coherent Noise Jamming Based on Interrupted-sampling and Pseudo-random Serials Phase-modulation

Ning Tai, Yu-Jian Pan, Deping Zhang, Chao Wang, and Naichang Yuan
College of Electronic Science and Engineering
National University of Defense Technology, Changsha, China

Abstract— Using the idea of pseudo-random serials phase modulation for reference, an active jamming method of quasi-coherent noise suppression is proposed for countering wideband radar of pulse compression system. The basic idea is that the jammer processes interrupted-sampling in range direction and modulates phases on sampled radar signal according the values of pseudo-random serials, and then sends the jamming signal to victim radar. This method will form large amounts of noise around the pulse compression output of target echo. Simulation results shows that jammer based on this technology needs less jamming power than other non-coherent ones.

1. INTRODUCTION

Coherent radars, for example, pulse compression radar and pulse Doppler radar, can achieve high coherent processing gain by making use of the characteristics of intra pulse and inter pulse [1]. This coherent processing obviously depresses the efficiency of non-coherent electronic jamming and puts forward a great challenge for radar jammer. With the development of high-speed large scale integrated circuits and signal processing method in the electronic counter field, technologies such as digital radio frequency memory (DRFM) and direct digital synthesizer (DDS) have become popular measures to counter coherent radars [2]. After detecting radar signal, jammer with two receive-transmit antennas which work asynchronously should receive and transmit the sampled signal. But in many occasions, the high isolation between two antennas is difficulty or even unable to be implemented. To solve this problem, [3] proposes a method based on interrupted-sampling. The jammer samples a segment of radar signal and then transmits the sampled signal. A train of false targets will be achieved after the sampled signal passing through the matched filter of pulse compression radars. [4] introduces a kind of smart noise jamming technology: convolution modulation noise jamming method. This type of jamming could acquire radar processing gain but its real-time is not good and can't be applied in the jammer with only one antenna. This paper proposes a quasi-coherent jamming signal. Section 2 describes the time domain characteristic and the frequency domain characteristic of pseudo-random serials phase-modulation signal. Section 3 deals with the interrupted-sampling theory. Section 4 shows the output of pulse compression radar when the jamming signal feeds the matched filter. Section 5 gives the simulation results of jamming effect and conclusions.

2. THEORY OF PSEUDO-RANDOM SERIALS PHASE-MODULATION

Pseudo-random serials are usually applied in spread-spectrum communication and the serials can be created by a shift register under the control of oscillator. The expression of the serials in time domain is as below:

$$u(t)=\sum_{l=-\infty}^{+\infty}\sum_{i=0}^{N-1}\mathrm{rect}\left(\frac{t-\frac{T_c}{2}-iT_c-lPT_c}{T_c}\right)a(i) \tag{1}$$

where $\mathrm{rect}(\frac{t}{T_c})=\begin{cases}1 & |t|\le\frac{T_c}{2}\\ 0 & \text{else}\end{cases}$, $a(i)=\pm1$, T_c is the code width and P is the period of pseudo-random serials, For the pseudo-random serials created by a N bit shift register, P equals to 2^N-1. From expression (1) we can get the power spectral density [5].

$$G(f)=\frac{P+1}{P^2}\left(\frac{\sin(\pi fT_c)}{\pi fT_c}\right)^2\sum_{\substack{k=-\infty\\k\neq0}}^{+\infty}\delta\left(f-\frac{k}{PT}\right)+\frac{1}{P^2}\delta(f) \tag{2}$$

Figure 1 illuminates the power spectral density of pseudo-random serials, of which T_c is set as 0.5 µs. The result shows that the main power of pseudo-random serials is concentrated in

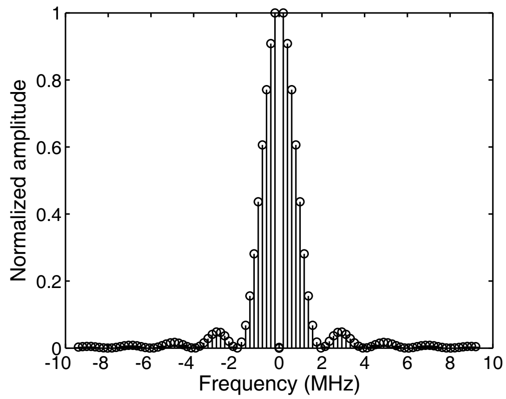

Figure 1: Power spectral density.

$[-1/T_c, +1/T_c]$. The envelope of power spectral density is determined by the code width T_c, that's to say, T_c determines the frequency spectrum width of pseudo-random serials. The shorter T_c is, the wider the frequency width will be, and the main amplitude will descend.

3. THE THEORY OF INTERRUPTED-SAMPLING AND DIRECT TRANSMITTING

This section briefly introduces the theory of interrupted-sampling and direct transmitting jamming. The basic procedure is: A serial of rectangle pulse is used for sampling the large band-time product radar signal and meanwhile the transmitting process takes place at the interval between two sampling processes. Assuming the interrupted-sampling signal noted as $p(t)$ is a rectangular envelope pulse train with pulse repeat interval T_s and pulse duration τ.

$$p(t) = \mathrm{rec}\left(\frac{t}{\tau}\right) * \sum_{n=-\infty}^{+\infty} \delta(t - nT_s) \tag{3}$$

The corresponding frequency spectrum is given as:

$$P(f) = \sum_{-\infty}^{+\infty} \tau f_s \cdot sa(\pi n f_s \tau) \cdot \delta(f - nf_s) \tag{4}$$

where $sa(x) = \sin(x)/x$ and $f_s = 1/T_s$ means the sampling frequency of interrupted-sampling signal. A special occasion in (4) is $T_s = 2\tau$, i.e., $p(t)$ is a square pulse train, and (4) becomes

$$P(f) = \sum_{-\infty}^{+\infty} \frac{1}{2} \cdot sa\left(\frac{n\pi}{2}\right) \cdot \delta(f - nf_s) \tag{5}$$

It is obvious that when n is even except for zero, the amplitude of (5) is zero and it decreases when n increases. Assume that the radar signal intercepted by jammer is $x(t)$, so that the sampled radar signal is

$$x_s(t) = p(t)x(t) \tag{6}$$

and its frequency spectrum is

$$X_s(f) = P(f) * X(f) \tag{7}$$

Substituting (4) into (7), the expression becomes:

$$X_s(f) = \sum_{n=-\infty}^{+\infty} \tau f_s \cdot sa(\pi n f_s \tau) \cdot X(f - nf_s) \tag{8}$$

From (8) we can see that $X_s(f)$ is a weighted superposition of the shifted replicas of $X(f)$. The weighting coefficient is $\tau f_s \cdot sa(\pi n f_s \tau)$. In the situation $T_s = 2\tau$, (8) becomes

$$X_s(f) = \sum_{n=-\infty}^{+\infty} \frac{1}{2} \cdot sa\left(\frac{n\pi}{2}\right) \cdot X(f - nf_s) \tag{9}$$

When $n = 0$, $X_s(f)$ equals to the spectrum of real target echo wave. Thus this portion could form a primary false target after matched filter as same as the real target. The other parts $X(f - nf_s)$ shifting $\pm nf_s$ in frequency can be seen as jamming signals adding $\pm nf_s$ to f. For a linear frequency modulated (LFM) signal pulse compression radar, this jamming signal after pulse compression will form multiple false targets with different amplitude in the range direction. The amplitude is determined by $\tau f_s \cdot sa(\pi n f_s \tau)$. These false targets are located symmetrically around the primary false target. With the increasing of n, the mismatch after matched filter in $X(f - nf_s)$ is getting worse, and the amplitude of false target debases heavily. Thus this jamming method of interrupted-sampling and direct transmitting usually forms 3 to 5 effective false targets. The simulation parameters are set as below: The radar signal bandwidth is 10 MHz, pulse width is 48 µs, and the sample signal period T_s is 4 or 2 µs. As is shown in Fig. 2, multiple false are achieved after pulse compression and the distance between two neighboring false targets are determined by T_s. An especial instance is that is larger than the bandwidth of radar signal so that $X(f \pm nf_s)$ $n \neq 0$ is located outside the bandwidth of match filter. The jamming signal in above occasion generates only one primary false target and this is the limitation of this type of jamming.

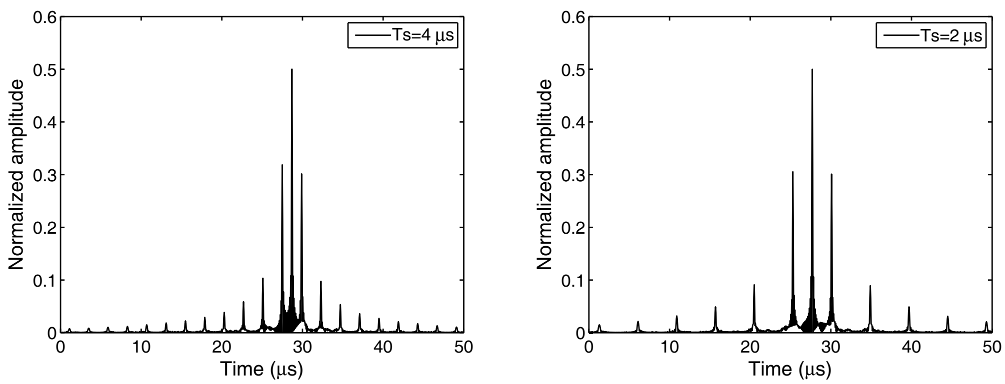

Figure 2: Pulse compression results of interrupted-sampling and direct transmitting.

4. INTERRUPTED-SAMPLING AND PSEUDO-SERIALS PHASE-MODULATION JAMMING METHOD

The pseudo-random serials phase-modulation process on sampled signal is the product of (1) and (6).

$$x_p(t) = u(t)x_s(t) \tag{10}$$

Of which the frequency spectrum is:

$$X_p(f) = U(f) * X_s(f) \tag{11}$$

From the analysis in Section 2 we know that the pseudo-random serials phase-modulation will expand the spectrum of modulated signal. Section 3 shows that interrupted-sampling jamming can form many false targets. (11) means that $X_p(f)$ is the superposition of each expanded false target. We know that phase-modulation by pseudo-random serials further wrecks the coherence between interrupted-sampling signal and radar signal, but this jamming method can still get some processing gain. Thus this jamming effect is similar to noise jamming but the frequency of jamming signal is around that of radar signal. (10) shows that when the value of pseudo-random serials changes, a 180° phase change happens in the jamming signal. This discontinuity caused by phase conversion will expand the spectrum of signal. Fig. 3 shows pulse compression outputs of target echo, Gauss noise and jamming signal. In the simulation, the interrupted-sampling period is 4 µs with a duty ratio 50%. The code width of pseudo-random serials is 0.5 µs and the length of serials is 511. The parameter of LFM signal is set as: bandwidth is 10 MHz and pulse width is 48 µs. From the results we know that jamming signal forms large amount of noise around the radar echo and Gauss noise distributes evenly in time domain. The coherence between jamming signal and original radar signal declines after phase-modulation and thus the processing gain of jamming signal will of course debase.

As is shown in Fig. 3, the ideal amplitude output of LFM signal after pulse compression is normalized to 1.00. The jamming signal output descends obviously to the value of 0.14. Meanwhile the amplitude of Gauss noise is nearly 0.02. Compared with the non-coherent Gauss noise, this jamming signal can achieve more processing gain, which means that this method saves jamming power. Provided that the power of jammer is large enough, victim radar can't distinguish the right position of target from the jammed situation. A jammer based on this theory requires lower jamming power than other non-coherent jammers and it depresses a long distance for the covered target. Fig. 3 shows that the jamming signal covers 20 μs in time domain and depresses 6 kilometers in range direction. If code width is narrow, the cover distance is relative wide. But the processing gain decreases when code width becomes narrow, which means that the wider cover distance needs more jamming power. The simulation result indicates that with the selection of different code widths and sampling periods we can acquire different depressing distance and different pulse compression gain. To achieve a long depressing distance we need a narrow code width and large jamming power.

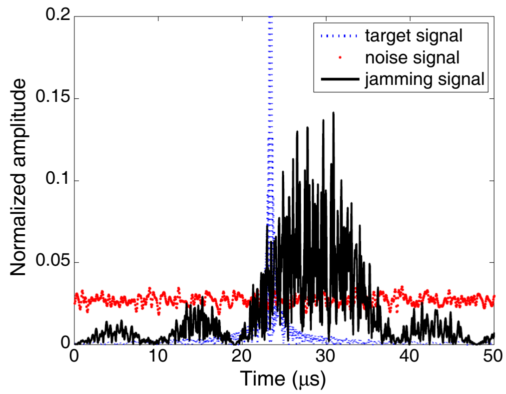

Figure 3: Pulse compression results of target echo, Gauss noise and jamming signal.

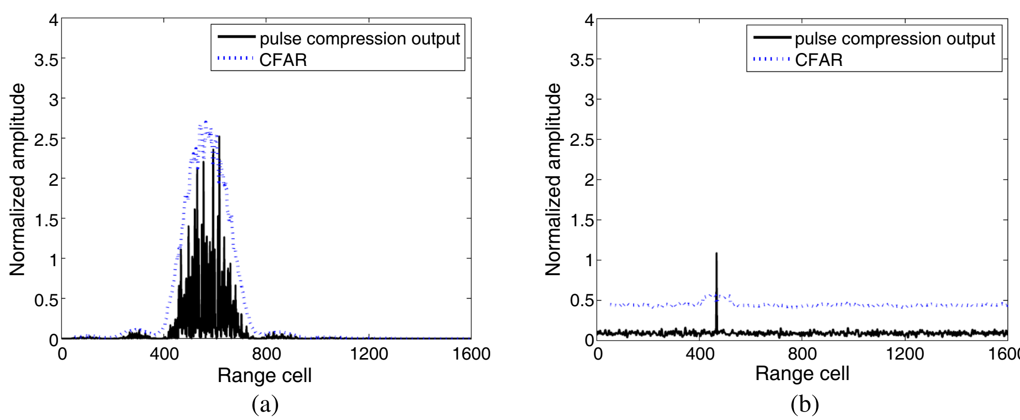

Figure 4: CFAR threshold results. (a) Jamming condition. (b) Gauss condition.

5. SIMULATION AND CONCLUSION

To validate the effect of this jamming method, we analyze the CFAR threshold of a pulse compression radar. The simulation parameters are set as: The pulse width of LFM signal is 48 μs, bandwidth is 10 MHz, pseudo-random serials code width is 0.5 μs. The period of interrupted-sampling signal is 4 μs with the duty ratio of 50%. The power of jamming signal and Gauss noise is 11.5 dB. The real target is located at the 467th range cell and the jammer is at the 534th range cell. The CFAR threshold results for quasi-coherent jamming signal and Gauss noise is shown in Fig. 4. In the simulation, the pulse compression amplitudes of jamming signal and Gauss noise are normalized to the amplitude of target. From the results we can see that Gauss noise enhances the CFAR threshold evenly but the target can be still distinguished. The quasi-coherent jamming signal forms large amount of noise around the real target and the CFAR threshold is too high for the real target so it can't be found out.

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