Study on Interrupted-Sampling Repeater Jamming Performance Based on Intra-pulse Frequency Coded Signal

Rui Shen*, Zhen Liu, Jinping Sui, Xizhang Wei
School of Electronic Science and Engineering, National University of Defense Technology, Changsha, 410073, China, sr_neu@163.com

ABSTRACT

Intra-pulse frequency coded (IPFC) signal, with its large time-bandwidth and low probability of interception characteristics, is widely applied to anti-jamming radar system. This paper focuses on the efficiency of interrupted sampling repeater jamming (ISRJ) under IPFC signal, and the influence on jamming effect with different signal forms and waveform parameters is mainly analyzed. The simulation results show that the ISRJ of step frequency coded signal and liner modulated frequency signal have similar jamming performance. The ISRJ of random frequency coded signal can only form a single false target at direct forwarding mode. Furthermore, with the increasing of the sub-pulse number, the ISRJ performance of random frequency coded signal will be reduced.

Keywords: Intra-pulse frequency coded signal; interrupted sampling; signal form; waveform parameter

1. INTRODUCTION

With the development of modern radar electronic warfare, the jamming efficiency and the response speed of jammer are significantly important. The traditional barrage jamming and deceptive jamming are difficult to achieve an effective jamming performance due to the low jamming efficiency, slow response and the need to receive all signal [1, 2]. The interrupted sampling repeater jamming (ISRJ) is proposed to break through the jamming bottleneck, which can form a series of realistic coherent false target groups by low-rate interrupted sampling and forwarding the intercepted radar signal. The mode of ISRJ improves the response speed and the efficiency of jamming greatly [3].

In order to enhance radar detection ability and anti-jamming performance and reduce the probability of radar signal interception, the intra-pulse modulated signal is widely used currently, which mainly includes two kinds of forms: intra-pulse frequency modulated signal and intra-pulse phase modulated signal. So, it is necessary to study on the ISRJ of intra-pulse modulated signal. Presently, the main research object of ISRJ is liner modulated frequency (LMF) signal and a small amount of research literature appearing focuses on the ISRJ of phase coded signal, which expands the radar signal types of ISRJ. The result shows that the jamming effect is not sensitive to the phase encoding methods, and the ISRJ of phase coded signal can form the group false target jamming at the cost of power under the repeated forwarding method [4, 5].

Compared with intra-pulse modulated frequency signal, the phase coded signal has a small resolution and is lack of bandwidth relatively. This paper focuses on the ISRJ performance of intra-pulse frequency coded signal. The jamming effects at the different signal forms and waveform parameters are analyzed emphatically. The structure of the article is as follows: Section II carries on the mathematical model of ISRJ. Section III describes the mathematical model of the intra-pulse frequency coded signal and its ISRJ signal, and analyzes the influence on ISRJ performance at different waveform parameters through the ambiguity function theory. In the section IV, the validity of the research is verified by simulation. Section V is the concluding remarks.

2. ISRJ MODELING

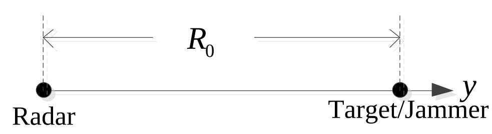


Figure 1. Geometric relationship of radar and target/jammer.

*sr_neu@163.com; phone 86 0731-84575713

Ninth International Conference on Digital Image Processing (ICDIP 2017), edited by Charles M. Falco, Xudong Jiang
Proc. of SPIE Vol. 10420, 104204N · © 2017 SPIE · CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2281779

We assume that the radar transmitting signal is $x(t)$. The distance between the target/jammer and radar is R, and their geometric relationship is shown in Figure 1.

The target echo signal can be expressed as

$$x_T(t) = A_T x\left(t - \frac{2R}{c}\right) \tag{1}$$

where the A_T denotes the backscattering coefficient. The radar signal intercepted by the jammer will be interrupted sampled, amplitude modulated and forwarded. Then, the ISRJ will be generated at the radar receiver on the purpose of deception and suppression. The principle picture of ISRJ formation is shown in Figure 2.

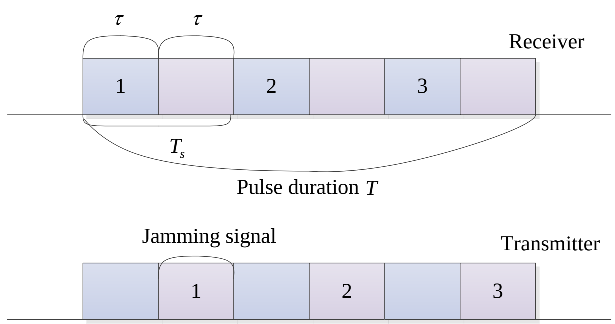


Figure 2. Principle diagram of the ISRJ.

We assume that the interrupted sampling signal $p(t)$ is a pulse train with a rectangular envelope and the pulse duration of τ and the sampling period is T_s, which can be expressed as

$$p(t) = \mathrm{rect}\left(\frac{t}{\tau}\right) * \sum_{-\infty}^{+\infty} \delta(t - nT_s) \tag{2}$$

The radar signal will be interrupted sampled after the jammer intercepts the radar signal. The sampled signal $x_s(t)$ can be got by multiplying radar signal and sampling signal, which can be expressed as

$$x_s(t) = p(t) x\left(t - \frac{R}{c}\right) \tag{3}$$

The ISRJ can be generated at radar receiver after the sampled signal is modulated and forwarded.

$$x_J(t) = A_J p(t) x\left(t - \frac{2R}{c} - \tau\right) \tag{4}$$

The impulse response of match filter is expressed as $h(t)$. The response of the real target echo signal through the matched filter can be described as

$$y_T(t) = h(t) * x_T(t) = A_T x\left(t - \frac{2R}{c}\right) * h(t) \tag{5}$$

The interrupted sampling signal can be expanded by using Fourier expansion

$$p(t) = \frac{\tau}{T_s} + \frac{2\tau}{T_s} \sum_{n=1}^{\infty} \frac{\sin n\pi f_s \tau}{n\pi f_s \tau} \cos 2\pi n f_s t \tag{6}$$

Substituting (6) into (4), the jamming echo signal can be derived as

$$x_J(t) = A_J x\left(t - \frac{2R}{c} - \tau\right)\left(\frac{\tau}{T_s} + \frac{2\tau}{T_s}\sum_{n=1}^{\infty}\frac{\sin n\pi f_s \tau}{n\pi f_s \tau}\cos 2\pi n f_s t\right)$$
$$= A_J \frac{\tau}{T_s} x\left(t - \frac{2R}{c} - \tau\right) + 2A_J \sum_{n=1}^{\infty} a_n \cos 2\pi n f_s t \cdot x\left(t - \frac{2R}{c} - \tau\right) \tag{7}$$

where $a_n = \tau/T_s \,\mathrm{sa}\left(n\pi f_s \tau\right)$. The direct forward method is used, and the jamming signal ratio (JSR) is set to 1. The output of the ISRJ through the matched filter can be expressed as

$$y_J(t) = x_J(t) * h(t) = A_T \frac{\tau}{T_s} x\left(t - \frac{2R}{c} - \tau\right) * h(t) + 2A_T \sum_{n=1}^{\infty} a_n \cos 2\pi n f_s t \cdot \left(x\left(t - \frac{2R}{c} - \tau\right) * h(t)\right)$$
$$= \frac{\tau}{T_s} y_T(t-\tau) + 2\sum_{n=1}^{\infty} a_n \cos 2\pi n f_s t \cdot y_T(t-\tau) \tag{8}$$
$$= y_{J0}(t) + y_{Jn}(t)$$

According to (8), the ISRJ can be divided into two parts. The first part $y_{J0}(t)$ is the main false target, and the part of summation $y_{Jn}(t)$ is the sidelobe as the secondary false target.

3. THE ISRJ FOR INTRA-PULSE FREQUENCY CODED SIGNAL

3.1 The characteristic of intra-pulse frequency coded signal

The complex envelope of an intra-pulse frequency coded signal is given by [6]

$$x(t) = \frac{1}{\sqrt{Mt_b}} \sum_{m=1}^{M} u_m\left[t - (m-1)t_b\right] \tag{9}$$

where M denotes the total number of the sub-pulse, m denotes the number of the sub-pulse, the bandwidth and pulse duration are set to B and t_p respectively and the sub-pulse repetition period is t_b. The envelope of the m-th sub-pulse $u_m(t)$ can be described as

$$u_m(t) = \begin{cases} \exp(j2\pi f_m t), & 0 \le \mathrm{t} \le \mathrm{t}_b \\ 0 & \text{elsewhere} \end{cases} \tag{10}$$

where

$$f_m = a_m \Delta f \tag{11}$$

and

$$a = \left\{a_1, a_2, \ldots, a_M\right\} \tag{12}$$

Using (10) and (11) in (9) yields

$$x(t) = \frac{1}{\sqrt{Mt_b}} \sum_{m=1}^{M} \exp\left\{j2\pi a_m \Delta f\left[t - (m-1)t_b\right]\right\} \tag{13}$$

where f_m denotes the frequency of the m-th sub-pulse, Δf is the unit step frequency and a represents the different frequency codes.

3.2 The effects of ISRJ performance with different waveform parameters

According (8), we can draw a conclusion that the output of the radar signal through the matched filter affects the ISRJ performance directly. So, we analyzed the ambiguity function of intra-pulse frequency coded signal to figure out the effect on ISRJ performance with different waveform parameters.

The ambiguity function of intra-pulse frequency coded signal can be expressed as referred to [6, 7].

$$\chi(\tau,v)=\frac{1}{Mt_b}\sum_{m=1}^{M}\exp\left[j2\pi(m-1)vt_b\right]\cdot\Phi_{mm}(\tau,v)+\frac{1}{Mt_b}\sum_{m=1}^{M}\exp\left[j2\pi(m-1)vt_b\right]\cdot\sum_{\substack{n=1\\m\neq n}}^{M}\Phi_{mn}\left[\tau-(m-n)t_b,v\right]$$
$$=\chi^{(1)}(\tau,v)+\chi^{(2)}(\tau,v) \tag{14}$$

where

$$\Phi_{mn}(\tau,v)=\left(1-\frac{|\tau|}{t_b}\right)\mathrm{sa}\left[\pi\alpha\left(t_b-|\tau|\right)\right]\cdot\exp\left(-j\pi\alpha\left(t_b+\tau\right)-j2\pi a_n\Delta f\,\tau\right),\ |\tau|\le t_b \tag{15}$$

represents the cross correlation function among the sub-pulse, $\alpha=\left(a_m-a_n\right)\cdot\Delta f-v$. In equation (14), $\chi^{(1)}(\tau,v)$ denotes the center of the ambiguity function and $\chi^{(2)}(\tau,v)$ represents the sidelobe of the ambiguity function. Considering the range dimension, we use the absolute values of $\chi^{(1)}(\tau,v)$ and $\chi^{(2)}(\tau,v)$. The cross correlation function of central ambiguity and its sidelobe are obtained by setting $v=0$, yielding

$$\left|\chi^{(1)}(\tau,0)\right|=\frac{1}{Mt_b}\left(1-\frac{|\tau|}{t_b}\right)\cdot\left|\frac{\sin(\pi M\Delta f\,\tau)}{\sin(\pi\Delta f\,\tau)}\right| \tag{16}$$

$$\left|\chi^{(2)}(\tau,0)\right|=\frac{1}{Mt_b}\left|\sum_{m=1}^{M}\sum_{n=1,m\neq n}^{M}\Phi_{mn}\left[\tau-(m-n)t_b,0\right]\right| \tag{17}$$

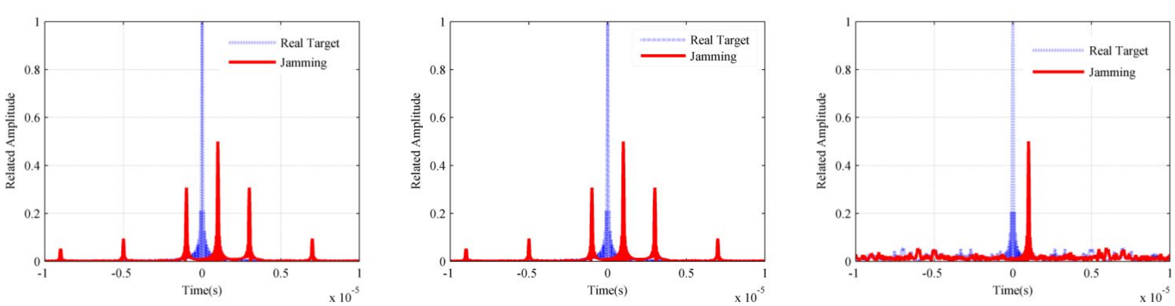
The cross correlation function of the sidelobe ambiguity function is overlapped of different sub-pulses' after translating $(m-n)t_b$. The superposition mode determines the form of the radar signal's range cross correlation.

4. SIMULATION

4.1 The effects of ISRJ performance with different signal forms

The effects of ISRJ performance with different signal forms are analyzed. We adopt the LFM signal, step frequency coded signal and random frequency coded signal. The parameters of simulation are as follows: the signal duration and bandwidth are 64us and 16MHz. The number of sub-pulse is 32 and sub-pulse duration is 2us. The period of interrupted sampling is 2us. The duty cycle of sampling is 0.5 and we use the direct forwarding method. The results are plotted in Figure 3.

According to Figure 3, we can draw a conclusion that the ISRJ performance of the LMF signal and step frequency coded signal are similar under the direct forwarding method. But, the ISRJ of random frequency coded signal only forms a single false target compared with them.

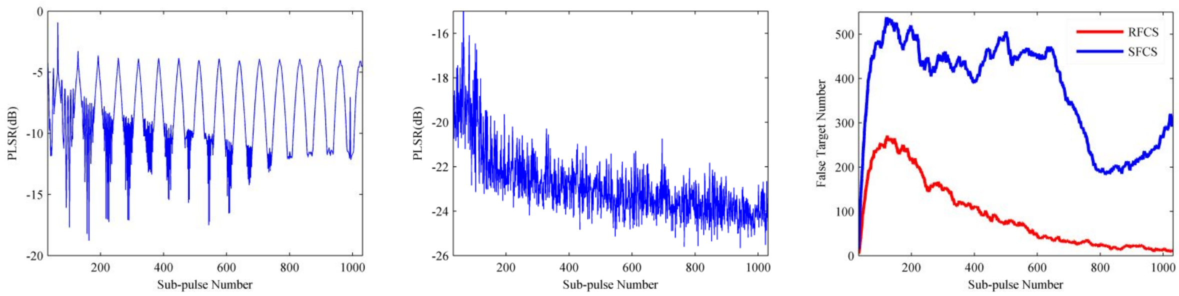


(a) (b) (c)

Figure 3. The ISRJ with different signal forms. (a) LMF signal. (b) Step frequency coded signal. (c) Random frequency coded signal.

4.2 The effects of ISRJ performance with different waveform parameters

We define two parameters which reflect the ISRJ performance, and they are Pulse-Sidelobe Ratio (PSLR) which is the amplitude ratio of maximum sidelobe to main lobe and the false target number under detective threshold.



(a) (b) (c)

Figure 4. ISRJ performance versus sub-pulse number. (a) PLSR versus sub-pulse number of SFCS. (b) PLSR versus sub-pulse number of RFCS. (c) Detected false target number versus sub-pulse number.

The working parameters of jammer are same with 4.1. We use the step frequency coded signal (SFCS) and random frequency coded signal (RFCS) respectively and their pulse duration and bandwidth are 64us and 16MHz. the detection threshold is one-tenth of the true target's amplitude. We calculate the PSLR and the false target number of two kinds of coded signals' ISRJ under the direct forwarding method. The results are shown in Figure 4.

According to Figure 4, we can see that the PSLR of the SFCS changes periodically with the increase of sub-pulse number. However, the PSLR of the RFCS decreases with the increase of the sub-pulse number due to the random characteristic of the frequency code. The detected false target number versus sub-pulse number is shown in Figure 4(c). We can draw a conclusion that the false target number of RFCS is smaller than the false target number of step SFCS when the sub-pulse number exceeds 100.

5. CONCLUSION

In this paper, we study the ISRJ of the intra-pulse frequency coded signal. Based on the comparison of different signal forms and waveform parameters, the performance of the corresponding ISRJ is mainly analyzed. The research results show that the step frequency coded signal has the similar ISRJ efficiency with the LMF signal. The random frequency coded signal only forms a single false target behind the real target at the direct forwarding method. Through the simulation, we calculate the PSLR and the number of the false target at a fixed threshold both of the step frequency coded signal and the random frequency coded signal. The random frequency coded signal has a low PSLR relatively, and with the increases of the sub-pulse number, the detective false target number decreases gradually.

REFERENCES

[1] D.C, Schleher, [Electronic warfare in the information age], Norwood: Artech House (1999).

[2] Shixian, Gong, Xizhang, Wei and Xiang, Li, "ECCM scheme against interrupted sampling repeater jammer in time-frequency analysis," Systems Engineering and Electronics, 6(25), 996-1003 (2014).

[3] Dejun, Feng, Huamin, Tao, Yong, Yang et al, "Jamming de-chirping radar using interrupted-sampling repeater," Science in China Information Sciences, 10(54), 2138-2146 (2011).

[4] Xuesong, Wang, Jiancheng, Liu, Wenming, Zhang et al, "Mathematic principles of interrupted-sampling repeater jamming," Science in China Series F Information Sciences, 1(50), 113-123 (2007).

[5] D.J, Fouts, P.E, Pace, Christopher, Karow, et al, "A single-chip false target radar image generator for countering wideband imaging radars," IEEE Journal of Solid-State Circuits, 6(37), 751-759 (2002).

[6] Nadav, Levanon, [Radar signals], Hoboken, New Jersey: John Wiley & Sons (2004).

[7] Ping, Liu, Qinglong, Bao and Zengping, Chen, "Design of false target deception jammer against PD radar," Modern Radar, 4(29), 9-11 (2007). (In Chinese)