Radar target echo cancellation using interrupted-sampling repeater

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Abstract: A method of using Interrupted-Sampling Repeater Jamming (ISRJ) to cancel radar target echo is proposed. After the principles of ISRJ are expounded, three conditions that should be met for radar echo cancellation are proposed, including range synchronization, phase coherent and amplitude match. Then, the restriction for key parameters of ISRJ, i.e. the repeater power, the delay time and frequency of repeater are deduced in theory. At last, the influences of those parameters on radar echo cancellation are discussed in detail. Some numerical results are presented to verify the effectiveness of this method. This work is beneficial to the jamming design and use of ISRJ.

Keywords: interrupted-sampling, repeater jamming, linear frequency modulated signal, coherent cancelling

Classification: Microwave and millimeter wave devices, circuits, and systems

References

[1] X. S. Wang, J. C. Liu, W. M. Zhang and Z. Liu: Sci. China Ser. F: Info. Sci. **50** (2007) 113. DOI:10.1007/s11432-007-2017-y

[2] D. J. Feng, H. M. Tao, Y. Yang and Z. Liu: Sci. China Ser. F: Info. Sci. **54** (2011) 2138. DOI:10.1007/s11432-011-4431-4

[3] Y. J. Wang, G. Q. Zhao and H. W. Wang: J. Xidian Univ. **35** [6] (2008) 1031.

[4] D. C. Scheler: *Electronic Warfare in the Information Age* (Artech House, London, 1999) 1st ed. 38.

[5] J. C. Liu, Z. Liu, X. S. Wang and X. P. Xiao: Prog. Nat. Sci. **17** [1] (2007) 99. DOI:10.3321/j.issn:1002-008X.2007.01.015

1 Introduction

Interrupted-Sampling Repeater Jamming (ISRJ) is a novel jamming, whose core idea lies in the utilization of interrupted under-sampling of radar signals [1, 2]. By sampling and repeating radar signal with a low rate, ISRJ can produces a train of false targets in radar after the jamming signal feed the matched filter. The technique do not only improve the speed of jammer evidently, but also can it be used in jammer with a receive-transmit time-sharing antenna, which implies that it is no longer necessary to implement high isolation between two receive-transmit antennas. In addition, because of the use of under-sampling, rigorous radio frequency sampling rate is not requested by this jamming technique, that reduces the demand of high-speed sampling for wideband radar. So ISRJ is an important progress in the electronic jamming of coherent radars.

For the case of LFM pulse compression radars, ISRJ can formed many false targets which differ with each other on amplitude but keep coherent when the interrupted sampling frequency is smaller than the bandwidth of the radar signal. In this paper, a method, which cancel radar target echo using ISRJ false target, is proposed. Space and phase characteristics of false targets are adapted conveniently for echo cancellation by modulating jamming parameter. This new method can serve as a significant reference tool for the design of correlative jammer.

2 The output of the radar matched filter for ISRJ signal

Assume that the interrupted sampling function noted as $p(t)$ is a rectangular envelope pulse train with pulse duration τ and pulse repeat interval T_s, as Fig. 1 illustrates, is defined as

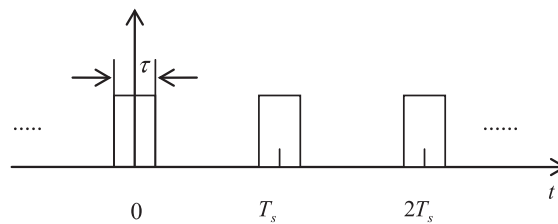$$p(t) = rect\left(\frac{t}{\tau}\right) * \sum_{-\infty}^{+\infty} \delta(t - nT_s) \tag{1}$$

Fig. 1. The interrupted sampling function.

Using the Fourier transform $\sum_{-\infty}^{+\infty} \delta(t - nT_s) \leftrightarrow \frac{1}{T_s} \sum_{-\infty}^{+\infty} \delta(f - nf_s)$, $rect(\frac{t}{\tau}) \leftrightarrow \tau sa(\pi f \tau)$, where $f_s = 1/T_s$ is sampling frequency, $sa(x) = \sin(x)/x$, the frequency spectrum of $p(t)$ is given as

$$P(f) = \sum_{-\infty}^{+\infty} \tau f_s sa(\pi n f_s) \delta(f - nf_s) = \sum_{-\infty}^{+\infty} a_n \delta(f - nf_s) \tag{2}$$

where $a_n = \tau f_s sa(\pi n f_s \tau)$. Assume radar signal $x(t)$ is a LFM signal, with pulse duration is T, band width B, and frequency spectrum $X(f)$. It can be expressed

$$x(t) = \frac{1}{\sqrt{T}} rect\left(\frac{t}{T}\right) e^{j\pi k t^2} \qquad (3)$$

Where the slope of the frequency modulation is $k = \dfrac{B}{T}$, which generally satisfy $BT \gg 1$. The interrupted samples of the radar signal is equivalent to $x(t)$ multiplying with $p(t)$, so the sampled signal $x_s(t)$ is

$$x_s(t) = p(t)x(t) \qquad (4)$$

and its frequency spectrum is $X_s(f) = P(f) * X(f)$. When the radar matched filter $h(t)$ is fed by the interrupted-sampling repeater jamming $x_s(t)$, the output $y_s(t)$ is

$$y_s(t) = x_s(t) * h(t) \qquad (5)$$

From [1], the output of the radar matched filter is given as

$$y_s(t) = \sum_{n=-\infty}^{+\infty} a_n y_{sn}(t) \qquad (6)$$

Where $y_{sn}(t)$ is given as

$$y_{sn}(t) = sa[\pi(nf_s + kt)(T - |t|)]\left(1 - \frac{|t|}{T}\right)\exp(j\pi n f_s t), \quad |t| < T \qquad (7)$$

Based on (6) and (7), it is clear that the out of matched filter is formed by lots of false target $y_{sn}(t)$ with the doppler shift $f_d = nf_s$. The peak point of false target lie in $t_{\max} = -\dfrac{nf_s}{k}$ and the distance of two neighboring peaks is $\Delta t_{\max} = \dfrac{f_s}{B} T$.

Considering self-defense jamming, obviously, the peak point of false target can precede or overlap with radar target echo only when $n \le -1$, otherwise they will lag behind. In view of the rapid decrease of the scaled coefficient a_n when the absolute value of n increases, this paper uses the -1 order false target to cancel radar target echo.

3 Radar target echo cancellation

According to literature [3], three conditions should be met for cancellation radar target echo. The first is the peak point of false target should synchronize with the target echo in time domain; the second is the two should be opposite phase for coherent cancellation; the third is the amplitude of the two should be equal for cancellation to the full extent. In the following, we will analyze those conditions separately. From (7), the -1 order false target precedes the zero order false target and the distance between them is $\Delta t_{\max} = f_s/k$. On the other hand, the distance where radar target precede the zero order false, is repeater delay τ_d. So, if peak point of the -1 order false target synchronize with radar target, the repeater delay τ_d should satisfy the formula

$$\tau_d = f_s/k \tag{8}$$

The phase of radar target echo is make up of two parts. The one is the signature of radar target itself, and another is the space phase brought by distance. For self-defense jamming, target and jammer have the same distance to radar, that shows it is unnecessary to compensate space phase. As a matter of convenience, we assume radar the signature phase of radar target is known and equal to zero. According formula (7), the peak point of $y_{sn}(t)$ lie in $t = -f_s/k$, where

$$y_{sn}(t)|_{t=-f_s/k} \approx sa[\pi(f_s + kt)(T - |t|)](T - |t|)\cdot$$
$$\exp\{-j\pi[(f_s + kt)(T + t) - kt^2]\} \tag{9}$$

From formula (9), when $t = -f_s/k$, the phase of $y_{sn}(t)$ is

$$\varphi = \pi f_s^2/k \tag{10}$$

If f_s^2/k is a odd integer, $y_{sn}(t)$ and target echo will be opposite phase and target echo will be weakened because of coherent cancellation. So the request for sampling frequency is

$$f_s = \sqrt{nk} \quad n = 1, 3, 5, \cdots \tag{11}$$

Lastly, we analyze the demand for repeater power. From (6), we know that scaled amplitude of false targets of nth order is a_n. If the amplitude of false targets of n order is equal to the amplitude of the radar target, the amplitude ratio of the false targets to the true target, namely the amplitude modulation coefficient, should be

$$A_J = \frac{1}{a_n} = \frac{1}{\tau f_s Sa(\pi n f_s \tau)} \tag{12}$$

The relationship between the effective radiant power of jammer and radar parameters, amplitude modulated coefficient can be expressed by [4, 5]

$$ERP_J = \frac{PG_t\sigma}{4\pi R^2} A_J^2 \tag{13}$$

Where P is the peak power of radar, G_t is the receiving antenna gain, σ is the target RCS, and R is the distance between jammer and radar. The power of the repeater required is illustrated by Fig. 2, where the radar antenna gain is
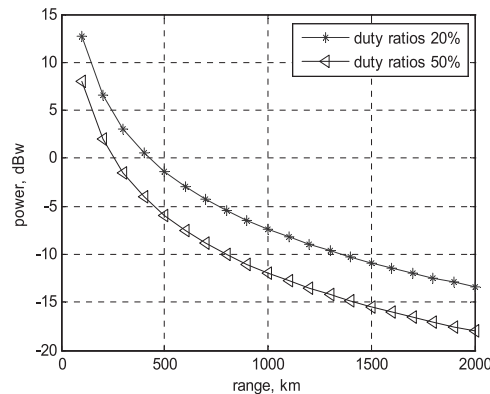

Fig. 2. The power requirement for jammer.

60 dB, peak power is 810 kW, target RCS is 0.1 m^2, sampling pulse duration is 2 μs, sampling frequency is 200 kHz, and duty ratios are 50% and 20% respectively. As can be seen, the required power of the interrupted-sampling repeater is not high enough to cover the low RCS target. For example, with the same scattering intensity as target, the required power is -7.4 dBw and -12 dBw respectively, when the distance between jammer and radar is 1000 km, and the duty ratios are 20% and 50% respectively. Obviously, the required power will increase when the duty ratio becomes lower. To sum up, if the repeater delay, the repeater frequency, the repeater power satisfy the formula (8), (11) and (13) respectively, radar target echo will be cancelled by the ISRJ false target.

4   Simulation result and analyse

Assume the simulation parameters meet the demand above, i.e. sampling frequency 200 kHz, the slope of the frequency modulation 4×10^{10} s^{-2}, repeater delay 5 μs, and the others parameters are invariable. The normalized pulse compression output is illuminated in Fig. 3.

As can be seen from Fig. 3, a train of false targets are produced by the interrupted-sampling repeater jamming which are symmetrically distributed in the radial distance and the power of the false targets decrease fast from the center to the edge. After target echo and jamming signal are fed to match filter at the same time, the 0 and 1 order false target don't vary, but the -1 order false target disappear because of the coherent cancellation with echo
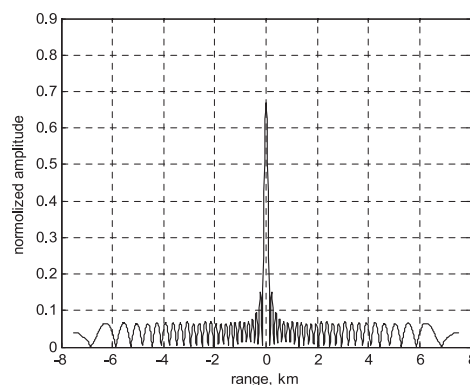
a. The amplitude of target echo after match filtering
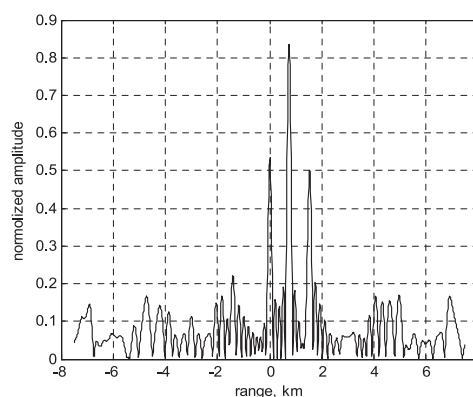
b. The amplitude of jamming signal after match filtering
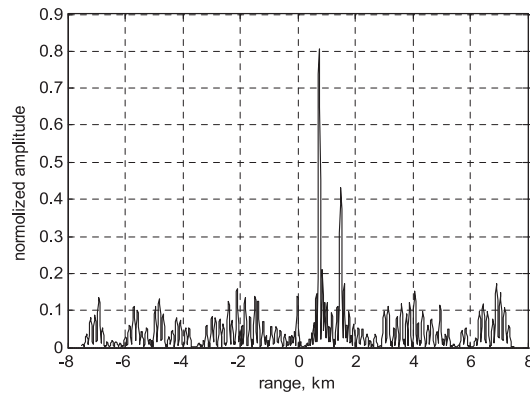
c. The output result after coherent cancelling

Fig. 3. Simulation result of cancelling target echo.

target. Numerical simulation results show that it is difficult to cancel target echo hundred-percent. According to (6), the out of matched filter is formed by lots of false target, and then its phase rest on the synthesis of many false targets. Although the -1 order false target is dominant in the target echo location, synthetic phase isn't equal to that of target echo nicely. However, from Fig. 3, we can see that the amplitude of target is even lower than sidelobe after cancellation, which means cancellation achieves similar effect of target stealth.

5　Conclusion

A method of using ISRJ to cancel radar target echo has been proposed. By modulating ISRJ repeater parameters, i.e. repeated time delay, repeated frequency, duty ratio of the repeated signal and jamming power, the proposed method achieves radar echo cancellation using ISRJ repeater. This method can arrive at a jamming effect analogous to active stealth but it has the advantage of simpleness and convenience. Theory analysis and simulation results demonstrate its effectiveness. Obviously, the jamming method proposed in this paper extends the interrupted-sampling repeater jamming and it contains a good promise for further jammer design.

Acknowledgments