Research on Jamming to Coherent FA Radar Based on Intermittent Sampling Repeater

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Abstract. Due to integration of the frequency agility (FA) technology and coherent technology, Coherent FA radar has natural advantage in ECCM performance and represents one of important development trends of new radar types. Aiming at the technical characteristics of coherent FA radar, this paper proposed a jamming method to coherent FA radar based on intermittent sampling repeater. Theory models of coherent FA radar and intermittent sampling repeater jamming are established at first and the jamming effect is analyzed. The proposed jamming method is validated to be able to achieve the expected jamming effect to coherent FA radar by simulation at last.

Keywords. Coherent FA radar; intermittent sampling repeater; simulation research.

1. Introduction
In recent years, with development of military technology, the conflict between jamming to radar and ECCM of radar becomes increasingly intense. Faced with the E.M. environment of increasing complexity and advanced jamming based on DRFM technique, modern radars have to be provided with strong ECCM capacity so as to achieve threat detection in complex E.M. countermeasure environment [1-5]. As an important ECCM method, frequency agility (FA) has gained much attention in recent years. But coherent accumulation in FA has been a challenge in radar application. Rapid developments of computer technology and digital signal processing technology enable coherent accumulation in FA. The carrier frequency of adjacent pulses transmitted by coherent FA radar can change randomly and radar detection range, clutter suppression performance and ECCM performance can be increased by coherent processing [6-10].

The researches on jamming to FA radar till now mainly focus on jamming to non-coherent FA radar. For example, Zhang [11] provided one jamming method to FA radar based on frequency scan technology to improve the jamming capacity of EW system to wide range FA radar. Yang et al. [12] made research on jamming capacity to random FA radar by wideband suppression jamming, narrow-band frequency-sweep jamming and narrow-band spot jamming. Feng et al. [13] conducted research on influence factors of different jamming methods to FA radar and analyzed the advantages/disadvantages of each method. Song et al. [14] made research on jamming methods to FA radar based on the problems existing in ECCM of FA radar.

Those methods may achieve jamming effect to FA radar in certain degree, but all of those researches are aiming at jamming to non-coherent FA radar. Coherent FA radar is greatly different from non-coherent FA radar in processing, which has better ECCM capacity. There is little research about relevant jamming method. Aiming at that situation, this paper proposes a jamming method to coherent FA radar based on intermittent sampling repeater and conducts analysis to jamming performance through simulation.
2. Model of Coherent FA Radar Signal

The coherent FA radar transmits one set of pulse train whose carrier frequencies changes randomly and conducts coherent processing to pulses of different carrier frequencies so as to achieve extremely high range resolution and velocity resolution.

Supposing the carrier frequency of first pulse transmitted by coherent FA radar is $f_c$, and then carrier frequency of pulse “$n$” is as follows.

$$f_n = f_c + d_n \Delta f, \quad n=0,1,...,N-1$$  \hspace{1cm} (1)

where $n$ is pulse serial number, $N$ is pulse quantity in one coherent processing interval (CPI). $\Delta f$ is the minimum frequency interval and $d_n$ is random integer $[11-16]$.

Supposing the radar transmits signal of single carrier frequency $f_n$, whose pulse width is $\tau$ and repetition interval is $T$, then the waveform of transmitted signal “$n$” can be expressed as follows.

$$S(t) = \sum_{n=0}^{N-1} \text{Re} \left[ \frac{t-nT}{\tau} \right] \exp(-j2\pi f_n t)$$ \hspace{1cm} (2)

After mixing, the target echo signal is output as follows.

$$y(t) = A_n \exp(-j2\pi f_n \left( \frac{2(R_0 - v(nT + 2R/c))}{c} \right))$$ \hspace{1cm} (3)

where $R_0$ is the initial range and $v$ is the radial velocity.

So the echo generated at range unit “$l$” can be obtained as follows.

$$X_l = \sum_{n=0}^{N-1} A_n e^{-j\omega_d n} e^{-j2\pi f_n \left( \frac{2(R_0 + l\Delta R)}{c} \right) T}$$ \hspace{1cm} (4)

where $\Delta R$ is the width of range unit. Coherent processing can be achieved by compensation processing to above formula.

3. Signal Model of Intermittent Sampling Repeater Jamming

The core concept of intermittent sampling repeater jamming is based on time-sharing of jammer antenna, which can generate vivid coherent false targets train. The most common types of intermittent sampling repeater jamming include intermittent sampling direct repeater and intermittent sampling duplication repeater. The previous one is equivalent to transpond the sampled signal after delay of one sampling time duration, so it can only generate one false target cannot achieve the jamming effect of dense false targets. So intermittent sampling duplication repeater is employed in this paper.

Supposing the signal of transmitted by radar is LFM signal.

$$S(t) = A_s \text{rect} \left( \frac{t}{T} \right) \exp[j(\omega_s t + \pi Kt^2) + \varphi_0]$$ \hspace{1cm} (5)

where $A_s$ is signal amplitude, $T$ is pulse width, $\omega_s$ is carrier frequency, $K = \frac{B}{T}$ is frequency modulation slope, $B$ frequency modulation bandwidth and $\varphi_0$ is the initial phase.

Then target echo signal is as follows.

$$S_{RF}(t) = A_R \text{rect} \left( \frac{t}{T} \right) e^{j[(\omega_s + \omega_d) t + \pi Kt^2] + \varphi_0}$$ \hspace{1cm} (6)

where $A_R$ is echo signal amplitude and $\omega_d$ Doppler frequency shift caused by target velocity.

The principle of intermittent sampling repeater jamming [15-17] (figure 1). The sampled signal is transponded after increasing delay of $k\tau$, $k=1,2,...,M$, where $M = [T_s/\tau] - 1$ is the quantity of
sampling which can be transponded in one single sampling period $T_s$. $\lfloor x \rfloor$ means to employ the nearest integer downwards.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{Principle of duplication repeater.}
\end{figure}

Supposing the intermittent sampling signal is rectangle envelop pulse train whose pulse width is $\tau$ and repetition interval is $T_s$, then the sampling signal is as follows.

$$X_s(t) = \sum_{n=1}^{N} A_s \text{rect} \left[ \frac{t-(n-1)T_s}{\tau} \right] \exp[j(\omega_s t + \pi K t^2) + \varphi_0]$$ (7)

where $\text{rect} \left( \frac{t}{\tau} \right) = \begin{cases} 1, & 0 \leq t \leq \tau \\ 0, & \text{else} \end{cases}$

So the signal of intermittent sampling repeater jamming can be expressed as follows.

$$X(t) = \sum_{i=1}^{M} X_s(t - i\tau)$$ (8)

Figure 2 is the time-frequency characteristics of LFM radar signal. Figure 3 are the results of radar signal and jamming signal after pulse compression processing. From the figures we can see that radar signal generates one single peak value at the target location while the jamming signal generates several peak values after pulse compression.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig2.png}
\caption{Time and frequency characteristics of LFM signal.}
\end{figure}
4. Simulation of Jamming to Coherent FA Radar Based on Intermittent Sampling Repeater
The simulation parameters are as follows. Signal bandwidth is 100MHz and agility range is 3GHz±0.5GHz. Inter-pulse random agility is employed and pulse quantity of coherent processing is 128. Pulse width of radar signal is 60μs and repetition interval is 1000Hz. Target range is 10km and velocity is 80m/s. The jamming employs 3μs sampling and 9μs jamming.

When there is no jamming, the results before and after coherent processing are shown in figures 4 and 5.
From figures 6 and 7, we can see that after coherent processing, coherent FA radar can extract target range and velocity information with high accuracy from range dimension and velocity dimension.

From figures 6 and 7, we can see that when there is noise jamming whose jamming/signal ratio is 40dB, the target is completely covered by noise before coherent processing. But after coherent processing, the target appears and target information can be extracted satisfactorily from range dimension and velocity dimension. So it is very difficult to achieve effective jamming to coherent FA radar by noise jamming.

When the proposed intermittent sampling repeater jamming is employed, the results before and after coherent accumulation is as follows when jamming/signal ratio is 0dB.

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**Figure 5.** Range-Doppler indication after coherent processing (without jamming).

**Figure 6.** Range-Doppler indication before coherent processing (under Gauss white noise jamming).
Figure 7. Range-Doppler indication after coherent processing (under Gauss white noise jamming).

Figure 8. Range-Doppler indication before coherent processing (under intermittent sampling repeater jamming).

Figure 9. Range-Doppler indication after coherent processing (under intermittent sampling repeater jamming).
From figures 8 and 9, we can see that the top value is the true target and there are several false targets behind it. But due to inadequate jamming power, the power of false targets is lower than true target after coherent processing. With increase of jamming power, when jamming/signal ratio is 10dB, the processing results before and after coherent accumulation are as follows.

**Figure 10.** Range-Doppler indication before coherent processing (under intermittent sampling repeater jamming).

**Figure 11.** Range-Doppler indication after coherent processing (under intermittent sampling repeater jamming).

We can see that when the jamming/signal ratio is 10dB, there are several false targets whose power are similar to true target after coherent processing, that is to say several effective false targets are received by radar. Thus effective jamming can be conducted to coherent FA radar. But compared with real target, the generated false targets are behind it in range. The radar can easily eliminate the false targets by front-edge tracking. In order to achieve effective deception jamming, frequency-shift processing can be conducted to above generated jamming signal so as to achieve moving forward of false targets in range finally through range-Doppler coupling of LFM signal.
From the figures 10-12, we can see that after employment of proper frequency-shift modulation, the location of false targets is moved forward and the real target is covered by false targets finally. The target and jamming can not be distinguished by front-edge tracking and other methods.

5. Conclusion
This paper conducts theory analysis and simulation research to jamming to coherent FA radar based on intermittent sampling repeater. The basic principle of coherent FA radar is analyzed at first and theory model of intermittent sampling repeater jamming is established for research. Simulation research is conducted at last. Research conducted in this paper can provide certain reference for jamming to coherent FA radar.

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