Research on Jamming to RF Screening Radar Based on Signal Reconstruction

Yuanjiang Zhu
The 723 Institute of CSIC, Yangzhou 225001, Jiangsu Province, China
Email: 13815845416@139.com

Abstract. Aiming at the problem that the jamming effect to RF screening radar by active jammer is not satisfactory, this paper provides one jamming method based on signal reconstruction. That jamming method conducts signal reconstruction based on estimation to radar signal parameters, which can achieve effective jamming to RF screening radar. The method at first, establishes jamming theory model based on signal reconstruction, and conducts simulation research accordingly. This paper makes simulation to that method. The results indicate that the relative intensity of main peak after pulse compression decreases with increase of frequency deviation or relative FM slope deviation, the decrease distribution caused by positive/negative deviation is symmetric, if frequency or FM slope of reconstructed jamming signal is closer to radar signal, the gain is higher after pulse compression. So overall consideration should be conducted during jamming design to select proper frequency deviation and FM slope according to jamming power. The method provided in this paper has important reference value for engineering research.

1. Introduction
As an important sensor for target detection and situation awareness, the radar plays an important role in environment monitoring and firepower guidance etc., whose combat performance can directly influence the information dominance of modern warfare. In recent years, with the development of radar signal processing technology, radar has the capacity of acquisition of target subtle characteristics. Besides, in order to adapt to the increasingly complex E.M. environment, radar employs certain ECCM measures so as to decrease or eliminate jamming effect in different aspects. RF screening [1-4] is one of those ECCM techniques. In one pulse interval, radar transmits the signal of different frequency from effective signal frequency at pulse front-edge, so as to counter active jamming of front-edge duplication.

According to literature, RF screening technique is widely employed in radar ECCM techniques. After radar employs RF screening, the jamming effect to radar by active jammer is universally decreased. RF screening technique is simple in technical execution and satisfactory in ECCM performance. There is not much research on jamming to RF screening technique until now. Zhou Wei-Jiang [5] etc. provide several jamming methods to RF screening signal without validation by simulation. Hou Xiao-Lin [6] etc. conduct simulation validation to reconnaissance of RF screening signal without research on jamming method. Aiming at the inadequacy of above research, this paper provides a jamming method to RF screening technique based on signal reconstruction, introduces the basic principle of RF screening at first, establishes jamming theory model based on signal reconstruction, and conducts simulation research accordingly.
2. Basic Principle of RF Screening

Due to simple execution and high ECCM performance, RF screening technique is widely employed in conventional radars. As an ECCM measure in frequency domain, the same point as frequency agility of RF screening is that the transmitted signals are at different frequency points. The difference is that in RF screening, radar only makes processing to echo signal at the screened frequency point and omits the echo signal at screening frequency point, and the screening pulse and screened pulse are transmitted in one same PRI as figure 1.

![Figure 1. Sketch map of RF screening.](image)

In RF screening mode, radar transmits the signal at screening frequency at first, then transmits the signal at screened frequency point. The screening pulse can be at single frequency point or multiple frequency points. In order to avoid echo signal at screening frequency mixed into receiving channel, following condition must be satisfied.

\[ F' > F + B \quad \text{or} \quad F' < F - B \quad (1) \]

where \( F \) is screened frequency point, \( F' \) is screening frequency point and \( B \) is the signal bandwidth.

The selection rules of RF screening pulse are as follows [7].

1) Pulse width: \( T \geq 300 \) ns usually. Based on the precondition that it can make hostile IFM device achieve stable frequency measurement, the pulse width should be short as possible, otherwise it may occupy more radar resources.

2) Available signal width \( T \): It should be decided as per radar detection capacity. But it also should not be too much wide otherwise it may lead to 2nd-time capture and tracking of hostile frequency measurement device and make the screening pulse ineffective.

3) Consideration for solving-ambiguity and avoidance of obstruction effect: The selection of PRF should consider the avoidance solving-ambiguity in velocity and range, and avoidance of influence to radar task due to obstruction, duplication and superpose interference caused by screening pulse.

In order to counter frequency measurement capacity of ESM effectively, the peak power of screening pulse should be higher than real radar signal.

3. Jamming Theory Model Based on Signal Reconstruction

The sketch map of jamming to RF screening radar based on signal reconfiguration see figure 2. The signal of RF screening radar is amplified by receiving antenna and down converted to IF signal. IF signal is converted to digital signal by digital receiver. Through the popular Fractional Fourier Transform algorithm, identification/separation and parameters estimation are conducted to the screening signal and screened signal. After parameters estimation, DDS conducts reconstruction to jamming signal and achieve jamming to RF screening radar.
3.1. Parameters Estimation

Fractional Fourier Transform (FrFT) is also called the Angle Fourier Transform (AFT). FrFT of Function $x(t)$ is defined as follows \cite{8,9}.

$$X_a(u) = F^a[x(t)] = \int_{-\infty}^{\infty} x(t) K_a(t,u)dt$$ \hspace{1cm} (2)

Suppose $A_\phi = \sqrt{1-j \cot \phi}$, $n = 1, 2, \ldots$, then the core function is

$$K_a(t,u) = \begin{cases} A_\phi \exp(j \pi t^2 + u^2) \cot \phi - j 2 \pi u t \csc \phi & \phi \neq n \pi \\ \delta(t-u) & \phi = 2n \pi \\ \delta(t+u) & \phi = (2n+1) \pi \end{cases}$$ \hspace{1cm} (3)

where $\phi = a \frac{\pi}{2}$, which is the rotary angle of time-frequency plane. $a$ is the order of FrFT. $F^a$ is the FrFT operator and $\delta(t)$ is unit pulse function. We can see that period of FrFT is 4. If and only of $a = 4n$ (i.e. $\phi = 2n \pi$), result of FrFT is $x(t)$. If $a = 4n + 1$ (i.e., $\phi = 2n \pi + \frac{\pi}{2}$), FrFT becomes Fourier Transform. If $a = 4n + 2$ (i.e. $\phi = 2n \pi + \pi$), result of FrFT is $x(-t)$. If $a = 4n + 3$ (i.e., $\phi = 2n \pi + \frac{3\pi}{2}$), result of FrFT is negative Fourier Transform. FrFT only needs to be conducted for $a \in (0, 2)$.

According to formula (2) and (3), definition formula of FrFT becomes

$$X_a(u) = A_\phi \int_{-\infty}^{\infty} x(t) \exp[j \pi (u^2 + t^2) \cot \phi - j 2 \pi u t \csc \phi]dt, \quad \phi \neq n \pi$$ \hspace{1cm} (4)

For the signal consisting of screening pulse and screened pulse, its expression can be as follows

$$x(t) = s(t) + w(t)$$ \hspace{1cm} (5)

where $s(t)$ is the screened LFM signal, whose expression is

$$s(t) = \exp[j \pi (2 f_0 t + k t^2)]$$ \hspace{1cm} (6)

where $f_0$ and $k$ are initial frequency and frequency modulation slope of LFM signal.

$w(t)$ is the screening pulse whose expression is

$$w(t) = \exp[j \pi (2 f_s t)]$$ \hspace{1cm} (7)

The detection procedure of LFM signal can be expressed by following formula.

$$\{a_0, u_0\} = \arg \max \left| X_a(u) \right|^2$$ \hspace{1cm} (8)

Specific estimation results are as follows.
If the rotary angle $\alpha$ is employed as detection variable, FrFT can greatly decrease the calculation amount. For processing of multi-component LFM signal, FrFT can avoid the complex transform procedure which WVD transform must conduct. Besides, as a linear transform, FrFT can also avoid the interference by cross-terms. In addition, FrFT can reserve the phase information of LFM signal during estimation to LFM signal parameters.

2D FrFT distribution of LFM signal is as figure 3. According to the order corresponding to peak value, parameters of LFM signal can be estimated as per formula (9).

\[
\begin{align*}
\mu_0 &= -\cot \alpha_0 \\
\alpha_0 &= u \csc \alpha_0 \\
\phi_0 &= \arg \left[ \frac{|X_{\omega_0}(u_0)|}{A_{\omega_0} e^{\pi i u_0} \cot \alpha_0} \right] \\
\alpha_0 &= \frac{|X_{\omega_0}(u_0)|}{\Delta |A_{\omega_0}|}
\end{align*}
\]  

(9)

3.2. Signal Reconstruction

After parameters of LFM are obtained through the method in 3.1, the jamming signal can be configured as

\[s_j(t) = \exp[j\pi(2f_0t + k_jt^2)]\]  

(10)

Then the signal received by radar is

\[S_0(t) = s(t) + s_j(t)\]

\[= \exp[j\pi(2f_0(t - \tau) + k(t - \tau)^2)] + \exp[j\pi(2f_j(t - \tau) + k_j(t - \tau)^2)] + \exp[j\pi(2f_1(t - \tau))]\]  

(11)

After filtration processing by front-end, the screening pulse is eliminated by filter. The signal sent into radar receiver is

\[S_j(t) = s(t) + s_j(t)\]

\[= \exp[j\pi(2f_0(t - \tau) + k(t - \tau)^2)] + \exp[j\pi(2f_j(t - \tau) + k_j(t - \tau)^2)]\]  

(12)

4. Simulation to Jamming Based on Signal Reconstruction

Due to the limitation of parameter measurement accuracy of ESM receiver and accuracy of signal generation, it is very difficult to make the reconstructed jamming signal the same as radar signal. The
deviations mainly are in frequency and frequency modulation slope. The influence by those deviations will be analyzed as follows.

4.1. Influence of Frequency Deviation

The following diagram (figure 4) is pulse compression result when frequency deviation of reconstructed jamming signal from radar signal is 1MHz. We can see that the positive/negative frequency deviation of jamming signal influences the position of main peak after pulse compression. When frequency deviation is negative, the main peak after pulse compression is earlier than radar echo in time domain. When frequency deviation is positive, the main peak after pulse compression is later than radar echo in time domain. So position of false target can be controlled through change to frequency of reconstructed signal.

![Negativle deviation](image1.png)

(a) Negative deviation

![Positive deviation](image2.png)

(b) Positive deviation

**Figure 4.** Pulse compression result at frequency deviation=1MHz.

The following diagram (figure 5) is the ratio between relative intensity of main peak after pulse compression and frequency deviation of reconstructed jamming signal from radar signal. We can see that the relative intensity of main peak after pulse compression decreases with increase of frequency deviation and the decrease distribution caused by positive/negative deviation is symmetric, i.e. if frequency of reconstructed jamming signal is closer to radar signal frequency, the gain is higher after pulse compression. So overall consideration should be conducted during jamming design to select proper frequency deviation according to jamming power.

![Relative Intensity](image3.png)

**Figure 5.** Relation between relative intensity after pulse compression and frequency deviation of reconstructed jamming signal.
4.2. **Influence of FM Slope Deviation**

The following diagram (figure 6) is pulse compression result when deviation of FM slope is 10%. Either deviation of FM slope of reconstructed signal is negative or positive, the pulse compression results are the same and certain coverage is generated at the position of target echo, but the main peak power deceases about 6 dB. So jamming area coverage can be achieved through change to FM slope of reconstructed signal.

![Negative deviation](image1.png) ![Positive deviation](image2.png)

**Figure 6.** Pulse compression result when deviation of FM slope is 10%.

The following diagram (figure 7) is the ratio between relative intensity of main peak after pulse compression and relative FM slope deviation of reconstructed jamming signal. We can see that the relative intensity of main peak after pulse compression decreases with increase of relative FM slope deviation and the decrease distribution caused by positive/negative deviation is symmetric, i.e. if FM slope of reconstructed jamming signal is closer to that of radar signal, the gain is higher after pulse compression. So overall consideration should be conducted during jamming design to select proper FM slope according to jamming power.

![Relative intensity](image3.png)

**Figure 7.** Relation between relative intensity after pulse compression and relative FM slope deviation of reconstructed jamming signal.

5. **Conclusion**

RF screening signal is a popular radar ECCM technique. Aiming at the inadequacy of traditional jamming techniques to RF screening, this paper provides the jamming technique based on signal
reconstruction, and makes simulations to the influence to relative intensity of main peak after pulse compression by the deviation of frequency and frequency modulation slope between radar signal and reconstructed jamming signal. The simulation results indicate that the higher deviation leads to lower relative intensity of main peak after pulse compression. The method provided in this paper has important reference value for engineering research.

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