Impact analysis of DRFM-based active jamming to radar detection efficiency

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Abstract: The influence of DRFM active jamming technology on pulse compression coherent radar is studied here. By establishing radar signal detection model and introducing radar equation, the influence of signal produced by DRFM on the detection performance of radar receiver is analysed, and the relationship between radar detection probability and interference power is obtained. Finally, the effective index for judging the jamming effect is summarised, and the range of effective jamming signal power is determined.

1 Introduction

The pulse compression coherent radar has the ability to detect farther distance as well as better range resolution. Then, the traditional interference will be resisted by it at the same time. Therefore, it is wildly used in the field of high detection precision, and meanwhile it will face threats from all aspects.

Generally, the jamming methods of pulse compression coherent radar can be divided into two types: covering and jamming. The suppression interference is to use the noise signal or other signals to interfere the target echo signal in the way of covering or blocking, in order to interfere with the radar detection of target information. Its basic principle is to reduce the signal-to-noise ratio (SNR) of radar monitoring target. Under the given false alarm probability, the detection probability will decrease with the reduction of SNR, which will bring difficulty of radar detection target. The interference mainly includes broadband noise interference and narrowband blocking interference. The deception jamming mode is designed to build false. The target includes three ways: distance deception, speed deception, and angle deception. The purpose of this paper is to analyse the energy of the jamming signal and use the suppression jamming method based on DRFM technology [1, 2]. In the condition that the radar target detection probability is lower than the minimum detection probability, the minimum energy consumed is obtained, and the suppression efficiency is evaluated by the evaluation index of the radar anti-jamming capability.

2 Detection model of radar signal

2.1 Radar signal

In order to reflect the characteristics of pulse compression technology, the radar signal of this paper selects LFM pulse signal which is widely used [3]. LFM signal decouples energy and range resolution. It is a large time width and bandwidth product signal, and the pulse compression technology is used to obtain high amplitude pulse signal [4].

In order to analyse the interference signal more intuitively, it can be defaulted that the SCR (Signal-Clutter Ratio) is far greater than the SNR and satisfies the ‘10 dB criterion’ [5]. Therefore, the influence of the sea clutter can be ignored. Assuming that the bandwidth of the LFM signal transmitted by the radar is B, the duration of the pulse is T, the definition of the frequency modulation slope is K = B/T, and the basic waveform of the radar transmitting signal is shown as follows.

$$s(t, T) = \text{rect}\left(\frac{t}{T}\right) \times \exp(j\pi K T^2)$$  (1)

$$\text{rect}\left(\frac{t}{T}\right) = \begin{cases} 1, & t \in \left[\frac{T}{2}, \frac{T}{2}\right] \\ 0, & t \notin \left[\frac{T}{2}, \frac{T}{2}\right] \end{cases} \quad (2)$$

After the radar receives the echo signal, in order to obtain the SNR, the signal will be pulse compressed through a matched filter, in which the pulse response of the matched filter is as a result.

$$h(t) = s(t - t, T)$$  (3)

The envelope of output signal after pulse compression is shown in Fig. 1.

As the matching filter and the non-target signal are mismatched, the peak power of the target signal will be increase by BT times. The SNR will also be increased by BT times after the noise interference signal, and the target signal are matched by the matched filter.

2.2 CA-CFAR

Constant false alarm ratio (CFAR) is adopted when radar determines whether the target is detected [6]. In order to detect errors probability in the case of unknown target detection, the Neyman–Pearson criterion is often used. In this paper, the
Fig. 2 Schematic diagram of CFAR unit distribution

detection method called CA-CFAR is adopted. The SNR can be calculated as follows.

$$\text{SNR} = \frac{P_s}{P_n + P_j}$$  \hspace{1cm} (4)

Those symbols denote the power of target echo, the power of noise, and the power of interference signal, respectively.

As shown in Fig. 2, the mean value of the base noise is calculated by the \(N\) reference units. When there is no interference signal, the output signal of intermediate is Gauss noise. So, the probability density function of the unit which is checked as follows:

$$f_y(y) = \frac{1}{\sigma}e^{-(y^{2}/2\sigma^{2})}$$  \hspace{1cm} (5)

By removing one front protection unit and one back protection unit, the \(N\) adjacent reference units are used to estimate the value of \(\sigma^{2}\), and the joint probability density function is as follows.

$$f_y(y) = \frac{1}{\sigma^{N}}e^{-(\sum_{i=1}^{N}y_i^{2}/2\sigma^{2})}$$  \hspace{1cm} (6)

The value of maximum likelihood of \(\sigma^{2}\) is as follows.

$$\sigma^{2} = \frac{1}{N} \sum_{i=1}^{N}y_i$$  \hspace{1cm} (7)

So, the level of threshold power required by CA-CFAR is as follows.

$$T = \alpha \sigma^{2} = \alpha \frac{N}{N} \sum_{i=1}^{N}y_i$$  \hspace{1cm} (8)

Among them, the proportionality coefficient \(\alpha\) satisfies the following function.

$$\frac{\text{Prob}}{\text{False Alarm}} = \left(1 + \frac{\alpha}{N(1 + \varepsilon)}\right)^{-N}$$  \hspace{1cm} (9)

Under the condition of given threshold \(T\), the expected value of the detection probability of the unit is as follows.

$$P_{\text{D}} = \left(1 + \frac{\alpha}{N(1 + \varepsilon)}\right)^{-N} \left(1 + \frac{\text{Prob}_{\text{FA}}(\alpha)}{1 + \varepsilon} \right)^N$$  \hspace{1cm} (10)

Among them, \(\varepsilon\) is the SNR. If the probability of detection is <0.1, it is considered that the target cannot be detected by the radar.

3 DRFM active interference

Traditional jamming methods include directed noise amplify jamming, phase modulation jamming etc. Due to its strong randomness, it is effective in early radar jamming method. However, with the application of pulse compression and coherent accumulation in radar system, the contradiction between the detection distance and the resolution has been eliminated, and the effect of noise interference has been seriously weakened. As the radar signal introduced in the first section, the coherent signal of intra-pulse-modulation or inter-pulse-modulation is adopted by the pulse compression radar. The received signal can get the processing gain only if it is coherent with the transmitting signal of radar. Therefore, the effect of traditional jamming methods will be reduced.

Due to these situations, the typical noise jamming methods have been replaced by the technology of DRFM [7]. The information of radar signal will be received and stored. Then, it has better jamming effect on radar system. At present, there are many researches on jamming technology based on DRFM in the world, and the jamming mode of DRFM technology is adopted in the case of repeater intensive false target jamming and smart noise jamming [1, 5, 8–10]. By establishing the radar signal processing model, the effect of the jamming method based on DRFM is analysed in this paper. The evaluation method for the effect of the active jamming mode is established and the energy boundary value of the effective interference signal is obtained.

The power of target signal received by radar satisfies the radar equation [11].

$$P_r = \frac{P_s \lambda^{2} S}{(4\pi)^{2} R^{4}}$$  \hspace{1cm} (11)

Among them, \(P_r\) is the transmitting power of radar, \(G\) is the gain of antenna, \(\lambda\) is the wavelength of signal, \(S\) is the radar cross-section (RCS), and \(R\) is the object distance.

The jamming power is as follows:

$$P_j = \frac{P_s \lambda^{2} S \Delta f}{(4\pi)^{2} R_{j}^{4} \Delta f_{j}}$$  \hspace{1cm} (12)

Among them, \(P_j\) is the reflected power of jammer, \(G_j\) is the gain of jammer antenna, and \(R_j\) is the distance from jammer source to target, \(\Delta f\) is the bandwidth of radar receiver and \(\Delta f_j\) is the bandwidth of the jamming signal. When the jamming source is put together with the target, the result is \(R_j = R\). The range of radar under the jamming signal is as follows:

$$R_{j}^{2} = \frac{P_s \lambda^{2} S \Delta f}{(4\pi)^{2} R_{j}^{4} \Delta f_{j}}$$  \hspace{1cm} (13)

Meanwhile, the jamming signal based on DRFM will affect the detection threshold of CFAR. As shown in Fig. 2, if the jamming sign was saved in the memory of reference unit, the jamming power would be superimposed in the calculation. According to the method of CA-CFAR, the threshold value under jamming method based on DRFM can be obtained as follows.

$$T_j = \frac{\alpha}{N} \left( P_j + \sum_{i=1}^{N} y_i \right)$$  \hspace{1cm} (14)

Then, the product factor of the threshold is as follows:

$$\alpha_j = \alpha \left(1 + \frac{P_j}{N \sigma^{2}}\right) = \alpha \left(1 + \frac{\varepsilon}{N}\right)$$  \hspace{1cm} (15)

Among them, \(\varepsilon\) is the JNR. Then, the probability of detection can be obtained by the formula (12) and formula (13).

$$P_{\text{D}_{j}} = \left[1 + \left(\frac{P_{\text{FA}}(\alpha)}{1 + \varepsilon}\right)\right]^{-N}$$  \hspace{1cm} (16)

As shown in formula (16), when the false alarm rate is given, the detection probability is mainly determined by the JNR, SNR, and the number of the reference units.

4 Simulation and analysis

The purpose of the simulation is to analyse the effect of jamming method based on DRFM. In order to get the results, the simulation parameters are shown in Table 1.
As shown in Fig. 3, the relationship between the SNR and the detection distance of radar is reflected. Through the simulation results, when the detection distance is far away, the SNR will decrease correspondingly. It shows the expected effect of the jamming method based on DRFM on the detection of radar. Meanwhile, it shows that the detection distance of the radar can intuitively reflect the effect of the jamming method on the detection of radar.

As shown in Fig. 4, when the amount of reference units in CA-CFAR increases, the performance of the radar detection will be better. When the amount of reference unit is increased by 5, the power of jamming signal must be increased by about 10 dB to reach the same jamming effect. Meanwhile, according to the model proposed in this paper, the active power can be efficiently controlled to make the probability of detection lower than the lowest detection rate.

### 5 Conclusion

In this paper, the active jamming method based on DRFM is analysed. The influence of the DRFM-based jamming mode is analysed through the establishment of the radar signal model and the receiver signal detection model. The simulation results show that the detection distance of the radar can intuitively reflect the performance of the jamming method, and it can be used as an index to judge the jamming effect. Meanwhile, the relationship between the power of the jamming signal and the detection probability of target can be obtained through the establishment of the constant false alarm detection model, and the power of jamming signal can be controlled with the help of the model.

### 6 References

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### Table 1 Simulation parameters

| Parameters | Value |
|------------|-------|
| $P_t$      | 1 MW  |
| $P_r$      | 300 W |
| $G$        | 20 dB |
| $G_j$      | 15 dB |
| $n$        | 30    |
| $S$        | 10,000 m² |
| $P_{FA}$   | $10^{-6}$ |

![Fig. 3 SNR-object distance](image3.png)

![Fig. 4 Probability of detection JNR](image4.png)