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Optimal Waveform Design for Smart Jamming Focused on CA-CFAR

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***Abstract*—Focused on CA-CFAR anti-jamming mechanism, the method of optimal waveform design is studied to increase detection threshold for reducing true target detection, which can also improve the detection rate of false targets. Based on the relationship of signal to interference (ISR) and reference distance, the amplitude of jamming waveform is designed to follow Rayleigh distribution and finite interval random, and the interval is designed as random interval based on minimum interval. In addition, the interference region is designed as dense false targets region and sparse false targets region. Through modeling and simulation of CA-CFAR and smart jamming, the method of designing optimal waveform is explored, which will provide reference for other related waveform design.**

Keywords-CA-CFAR; Smart jamming; Waveform design; False alarm probability

I. PREFACE

CFAR is designed to suppress false alarms caused by different noise, clutter, or ECM, which can be used to enhance the performance of a threshold or gain control device. CFAR detection performance is directly related to the background clutter distribution type. When the CFAR detector and the clutter distribution type match it can ensure good detection performance, otherwise it will lead to a serious loss of CFAR or high false alarm probability. When the background clutter follows the Rayleigh distribution, the mean class, OS class and adaptive CFAR detection method can get better detection performance[1-2].

II. CA-CFAR MECHANISM

When χ^2 is used to testify the clutter distribution type, it is necessary to know the distribution function of the clutter. First, the parameters of the clutter distribution should be estimated with the samples. The probability density of the Rayleigh distribution is:

$$f(x)=\frac{x}{\sigma^2}\exp(-\frac{x^2}{2\sigma^2}), x\ge 0 \tag{1}$$

where σ^2 is average power of the clutter. The parameter σ of the distribution is estimated from the observation sequence x using the moment estimation method. The estimated value is

$$\sigma=(\frac{2}{\pi})^{\frac{1}{2}}\frac{1}{N}\sum_{i=1}^{N}x_i \tag{2}$$

A. CA-CFAR Constant False Alarm Mechanism

The clutter interference environment assumed by the CA-CFAR detector is that the probability density function of clutter amplitude after detection follows the Rayleigh distribution.

The specific method is to use a digital shift register tapped delay line to obtain output x of the detection cell and output x_i of *N* reference cells simultaneously. The output x_i of reference cells averaged to obtain estimates of the average, with the output x of the detected cell is divided by the valuation of the average value, to complete the normalization. The result is independent of the clutter amplitude, so we can get constant false alarm processing effect[3-5]. The schematic diagram is shown as Fig .1.

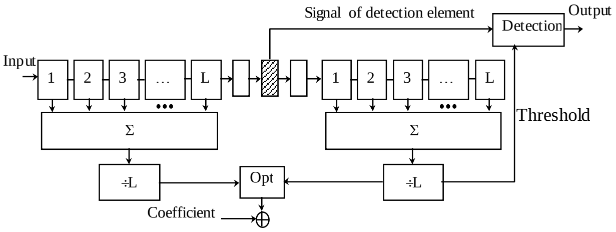

Figure 1. Example of a ONE-COLUMN figure caption.

The maximum likelihood estimate is the average of the known samples which is obtained by derivation, see (3). The expression of the final detection threshold is (4).

$$\hat{\beta}^2=\frac{1}{N}\sum_{i=1}^{N}x_i \tag{3}$$

$$\hat{T} = \frac{\alpha}{N}\sum_{i=1}^{N} x_i \tag{4}$$

We can get the false alarm probability as (5) and the product factor as the (6) after derivation.

$$\bar{P}_{fa} = \int_{-\infty}^{\infty} e^{-\frac{\hat{T}}{\beta^2}} p_{\hat{T}}\left(\hat{T}\right) \mathrm{d}\hat{T} = \left(1+\frac{\alpha}{N}\right)^{-N} \tag{5}$$

The required threshold product factor to a given expected mean false alarm probability is

$$\alpha = N\left(\bar{P}_{fa}^{-\frac{1}{N}} - 1\right) \tag{6}$$

The average false alarm probability $\bar{P}_{fa}$ does not depend on the actual jamming noise power, but only on the average number N of nearby neighbor samples and the threshold product factor α. Therefore, CA-CFAR technology shows the characteristics of constant false alarm probability.

B. *CA-CFAR Simulation in Clustering*

Condition setting: clutter signal follows the Rayleigh distribution, the number of reference cells is 20, the number of protection cell is 3, the detection cell is 1, the false alarm probability is 10^{-3}. The detection threshold variation is obtained by the constant false alarm processing to the collection data, as shown in Fig .2. The suppression effect of CA-CFAR on clutter is obvious.

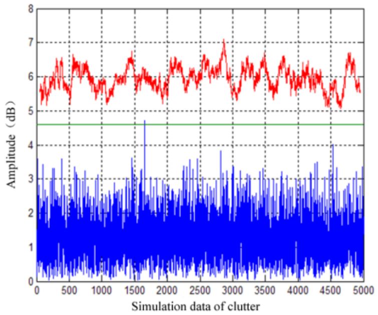

Figure 2. CA-CFAR Simulation in Clustering.

III. SMART JAMMING WAVEFORM DESIGN AND SIMULATION OF CA-CFAR COUNTERMEASURE EFFECT

Smart jamming, a new type of jamming besides barrage jamming and deception jamming, can get bigger radar processing gain due to its consistency with radar signal, which has been widely concerned and studied, and has been developed and progressed rapidly[9-10]. This paper focuses on the study of smart multiple false-targets jamming and waveform optimization. For the traditional or existing jamming mode, how to go beyond their defects and drawbacks in countering CFAR, bringing the new processing methods into the smart jamming and improving the performance of smart jamming is the goal of this study.

A. *Smart Jamming Waveform Design*

The false target group is generated dynamically, amplitude of which is follow the Rayleigh distribution.The false target group is divided into sparse region, dense region, sparse region three parts and designed respectively. The dense false target region is mainly used to enhance the threshold suppression target. The sparse false target regions mainly provide the multiple false targets threshold. The false target Interval is set to more than 8 times the length of the radar distance resolution, and frequency shift range is set to megahertz level. Waveform model is shown as (7).

$$F(T,S,P) = \begin{cases} S_i >= S_0 \,\&\, P_i >= P_0, \forall T_i < T_{m-j} \\ S_i <= S_0 \,\&\, P >= n * P_0, n > 2, \forall T_{m-j} < T_m < T_{m+j} \\ S_i >= S_0 \,\&\, P_i >= P_0, \forall T_i > T_{m-j} \\ P_i \sim raylrnd \,\&\, \sum_{i=1}^{N} P_i = P_{jam} \end{cases} \tag{7}$$

where S is the false target interval; P is the false target power; P_0 is the radar detection sensitivity; S_0 is the equivalent of the radar distance unit; T_m is the target position; N is the false target quantity; n is the power product factor.

B. *Influence of Random Properties on Waveform Design*

Condition setting: The radar signal is LFM signal; the smart jamming waveform on time domain after pulse compression is shown in Fig .3; there are 20 reference units, 3 protection units and 1 detecting unit; the false alarm probability is 10^{-3}. The target's echo signal and the jamming signal is dynamically generated. The number of fake targets is around 100 while the real target is in the middle of the fake targets.

The influence of interval stochastic on waveform design: The interval of fixed interval false targets varies from 80 to 200 with successive increments. By contrast, the interval of random interval false targets is the minimum interval plus a random increment, and the smallest interval also changes from 80 to 200 with successive increments. When the interval is 100, the effect of random false targets with fixed intervals and the ones with minimum interval on CFAR is illustrated in Fig .3. We can see that the false targets with fixed interval will raise the detecting threshold and the false target cannot be detected. While the false targets with stochastic characteristic can not only raise the threshold of detecting, but also disturb radar's detecting for some false targets can pass the detection threshold.

As the interval increases until reaching up to 170m, the random characteristics of smart jamming false targets are more obvious than ones of fixed interval. However, when the interval is larger than a certain distance, the validity of the fixed interval and the random interval will be similar to the same.

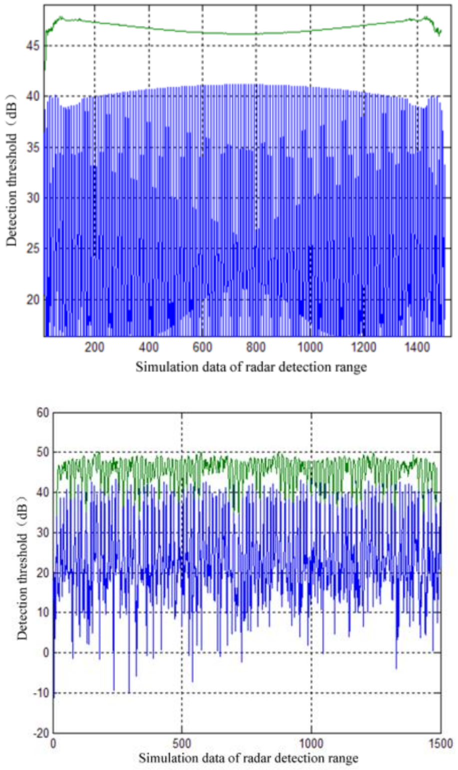

Figure 3. Simulation of the effect of fixed and random interval false targets on CFAR.

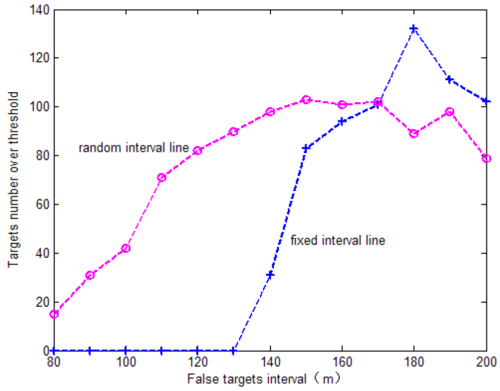

Figure 4. Comparison of the effect of fixed and random interval false targets on CFAR.

Influence of energy stochastic on waveform design: As is shown in Fig .5, the false targets of fixed interval and equal amplitude can restrain the CFAR as well as raise the threshold of detecting, but false targets cannot pass the detecting threshold. When the amplitude has stochastic characteristics, some false targets will pass the detecting threshold and achieve the effect of suppression. However, with the increase of false targets' interval, the amplitude stochastic characteristic is below equal interval, for the amplitude of the sharp signal decreases as the increase of interval, resulting in the reduction of the number of false targets which pass threshold.

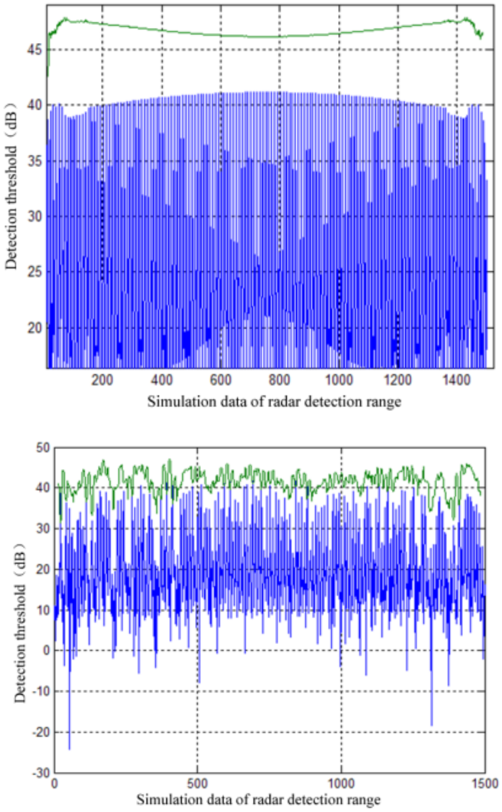

Figure 5. Parity and random amplitude false targets pass CFAR.

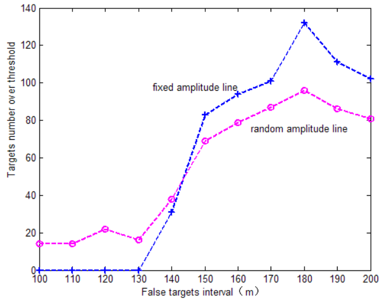

Figure 6. Comparison of CFAR performance between parity and random amplitude false targets.

C. *Modeling and effect analysis of confrontation CA-CFAR*

Simulation of sparse/dense partitioning settings and under different noise-signal ratio: When the noise-signal ratio is -40dB or 20dB, the sparse and dense false targets jamming area are set up and waveform are shown in Fig .7. The threshold after the CA-CFAR sliding window is shown in Fig .8.

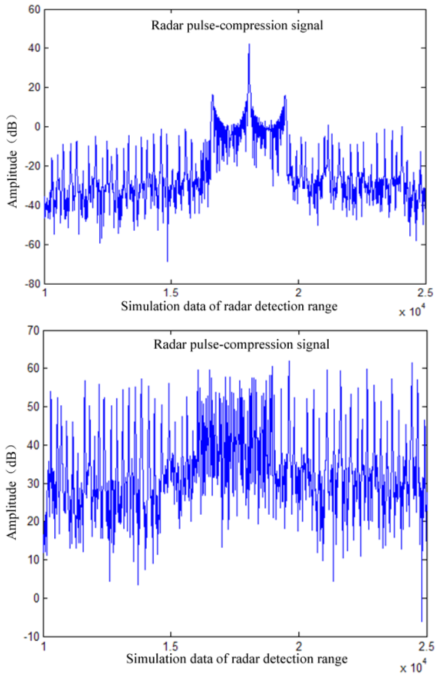

Figure 7. Waveform under the condition that noise-signal ratio is -40dB and 20dB respectively.

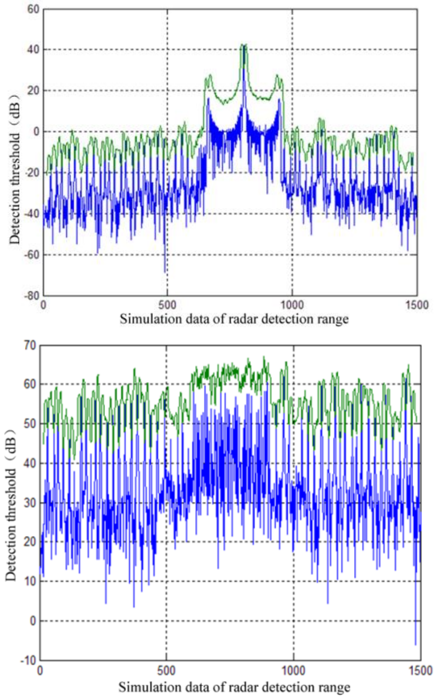

Figure 8. CFAR sliding window detection threshold under the condition that noise-signal ratio is -40dB and 20dB respectively.

Simulation results show that the dense area can elevate threshold after distinguishing dense and sparse false targets' setting, while the sparse area increases the false targets' number which pass the threshold and has the jamming effect.

Simulation of minimum interval under stochastic span condition: The minimum intervals of the dense zone false targets vary from 80m to 150m, while which of sparse zone vary from 150m to 200m. Noise-signal ratio changes from -40dB to 20dB. The number of false targets is illustrated in Fig. 9. We can see that in each definite interval, the number is basically maintained at a relatively stable order of magnitude. As the internal increases, the number presents an incremental trend.

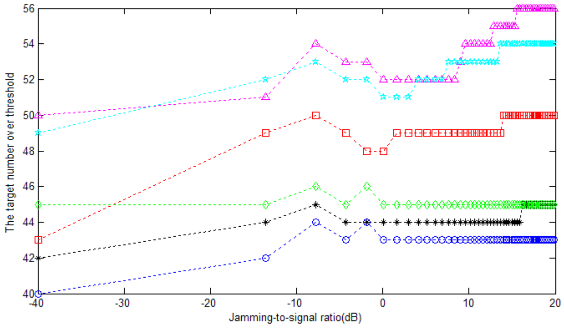

Figure 9. Simulation of the number of false targets passing threshold under the condition that false targets have a random span.

Through the above dense area and sparse area simulation we can see that dense false targets mainly have the effect of raising the threshold of detection, while sparse areas can make a large number of false targets pass the threshold, resulting in suppressing real targets.

Simulation of jamming effect under comprehensive condition: By using Monte-Carlo simulation, we can obtain statistical results of the number of real target passing CA-CFAR threshold. Then we can obtain its quantity in different noise-signal ratio under condition of sparse area and dense area false targets' interval, as shown in Figure 10. We can see that in order to achieve a better suppressing effect, the noise-signal ratio should be larger than 5dB. In the dense area, the false targets's interval should be about 8 times times the radar distance resolution, while in the sparse area it should not be less than 15 times.

IV. CONCLUSION

Based on the relationship of signal to interference (ISR) and reference distance, the amplitude of jamming waveform is designed to follow Rayleigh distribution and finite interval random. Then, the interval is designed as random interval based on minimum interval and the interference region is designed as dense false targets region and sparse false targets region. The jamming waveform design method can break through the uniformity of the false targets to resist the time trap technology, which will generate realistic interference effect. Meanwhile, this method can change fixed amplitude to random, which will not only cause the false targets through detection threshold to increase false alarm probability, but also raise the detection threshold to suppress real target.

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