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A Simulation Study of Chaff Echo Signal Based on LFM

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Abstract

In order to verify the chaff jamming performance, according to the time-frequency distribution and statistical characteristics of chaff echo, this paper presents a modeling and simulation method of chaff echo based on its mechanism of generation, Also it presents a simulation study of chaff echo signal based on LFM signals. The simulation results indicate that the generated chaff echo of this method has the same distributions of the actual chaff echo. Similarly, the chaff cloud echo based on LFM signal verifies the effectiveness of chaff jamming, and provides help for the next step of anti chaff jamming research.

Keywords: *chaff jamming, echo analysis, time-frequency distribution, LFM simulation*

1. Introduction

With the advantages of all day long and ultra-distance viewing, radar is becoming one of the most important sensors on the battlefield, which plays a vital role in the modern high-tech war and a large part of modern warfare depends on the attack and defense of the radar[1-2]. Therefore, the chaff jamming emerges as the times require. Chaff jamming as one kind of important passive jamming measure, with the characteristics of low cost, convenient use and good jamming effect, have been widely used in modern battlefield. IEEE (American Institute of Electrical and Electronics Engineers) defined chaff jamming as: a light reflecting air cloud and it is usually made of aluminum foil or coated metal fiber, which can produce interference echoes in a certain space range[3-4]. With the development of modern electronic warfare, chaff jamming plays an important role in modern anti-ship missile combat, which has become the conventional electronic warfare equipment of all national navy ships. Based on the spatial geometry relationship of chaff jamming, the paper established chaff cloud echo modeling and simulation of LFM signals, which provides supports for anti-ship missiles against chaff jamming.

2. Different Forms of Interference

Chaff cloud has three different forms of interference, as repeater jamming, dilution jamming, and centroid jamming[5]

2.1 Repeater Jamming

Repeater jamming is the chaff, launched to a certain height of the air, forming a chaff cloud, and then the ship radiates electromagnetic wave to chaff cloud, using the characteristics of front and side scatterings of electromagnetic wave, the chaff cloud indirectly radiates interference to the coming missile, which reduced the guidance control of the missle. To improve the interference effect, repeater jamming can be combined with active interference, and the incoming missile will receive both chaff cloud scattering power and active interference power which will make the missile lose its target. The jamming principle is shown in Figure 1.

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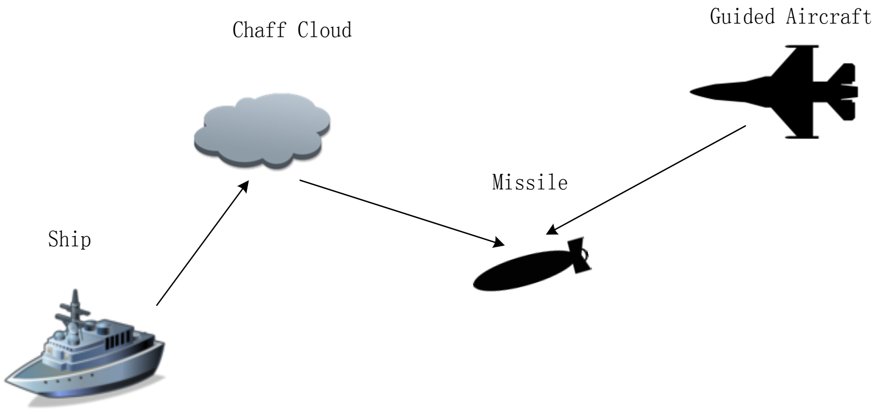

Figure 1. Repeater Jamming

2.2 Dilution Jamming

Dilution jamming is one kind of interference that the ship launched several chaff bombs to the surrounding airspace before the missile enters the search stage and generally explodes in 1000 meters from the ship to form a number of false targets. When the incoming missile terminal guidance radar searches for the target, it will receive multiple reflected false echoes, so that the search and capture probability of the target is reduced. The dilution jamming principle is shown in Figure 2.

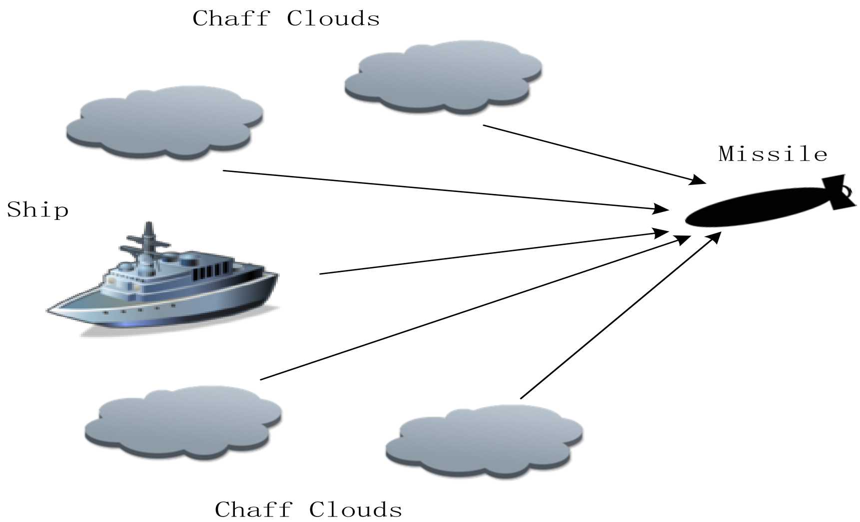

Figure 2. Dilution Jamming

2.3 Centroid Jamming

Centroid jamming is the main interference for shipborne chaff to the end of the incoming missile. When the guidance radar enters to the tracking section, the chaff transmitter launches chaff bombs in hundreds of meters around the ship within the ship radar's resolution cell which take advantage of chaff clouds to simulate radar decoys and the RCS of the chaff cloud is larger than the ship radar to decoy radar tracking points off the ship. At the same time, according to the direction of the missile, heading, speed and wind speed, wind direction and other factors, the ship rapidly pulls out of the radar resolution cell, in order to avoid the guidance radar track again. The centroid jamming principle is shown in Figure 3.

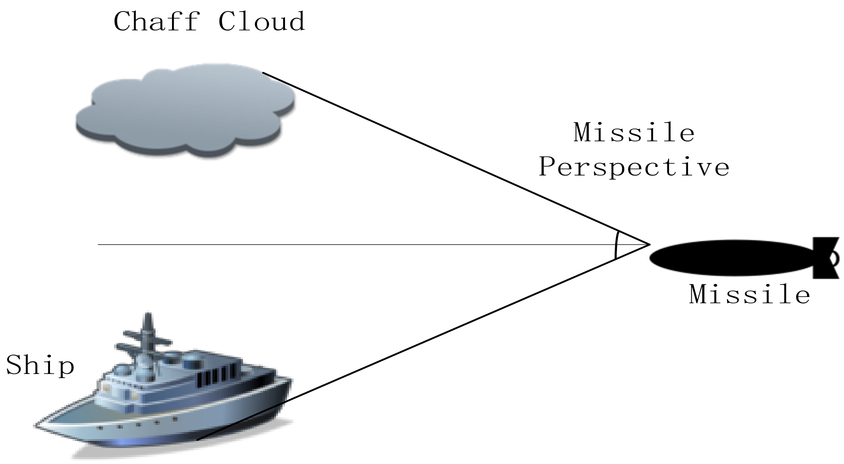

Figure 3. Centroid Jamming

3. The Time Domain Characteristics of Chaff Clouds

Chaff is affected by many factors, such as atmospheric density, wind speed, air flow, and so on. Therefore, strictly speaking, the statistical characteristics of chaff jamming are non-stationary, but consider the following conditions:

(1) Chaff fully dispersed in the air and the number of the chaff into the antenna beam and out the antenna beam approximately equal in the process of slow decline.

(2) The interval between the chaff dipole is at least two wavelengths above.

(3) The amplitude and phase of the scattered signal are not correlated with each other, and dipoles are randomly oriented, so that we can put the scattering signal of the chaff cloud as a stationary signal and it is determined by the combination of each dipole echo. Synthetic echo signal[6-7] is

$$S = Ue^{j\theta} = \sum_{k=1}^{N} A_k e^{j\varphi_k} \tag{1}$$

In the formula: U is the amplitude of the synthetic interference signal; θ is the phase of the synthetic interference signal; A_k is the amplitude of the k chaff echo signal; φ_k is the phase of the k chaff echo signal; N is the number of chaff.

When N is large, we can conclude that the amplitude of chaff cloud echo, namely U is Rayleigh distribution, and the phase θ is uniform distribution.

4. The Frequency Characteristics of Chaff Echo Signal

In general, the spectrum of the dipole cloud reflection signal and the radiation signal is not the same. This difference is due to the average Doppler shift caused by wind, gravity, air and other effects.

Assume that each direction movement of the chaff dipole is possible, and the autocorrelation function of chaff echo voltage can be expressed as followed[6]:

$$g(\tau) = \exp\left[-\left(\frac{2\pi}{a\lambda}\right)^2 \tau^2\right] \quad (2)$$

In the formula, λ is the radar wavelength, and a is the relevant constant about chaff dipole quality, Boltzmann constant and absolute temperature. Then the covariance function of chaff echo power[8] is:

$$I(\tau) = g(\tau)^2 \exp\left[-\left(\frac{2\sqrt{2}\pi}{a\lambda}\right)^2 \tau^2\right] \quad (3)$$

And the Fourier[9] is:

$$S(f) = \frac{a\lambda}{2\sqrt{2}\pi} \exp\left[-\left(\frac{a\lambda f}{2\sqrt{2}}\right)^2\right] \quad (4)$$

Can be seen, the spectrum density of chaff echo power is Gauss function.

5. Modeling of Chaff Cloud Echo Signal

According to the principle that the echo signal of chaff cloud is the sum of each single chaff echo signal, our model of chaff cloud echo is as followed [10]:

(1) The Doppler frequency shift caused by the horizontal movement of the chaff cloud is:

$$f_{dr} = \frac{2v_r \bullet \cos\theta}{\lambda} \quad (5)$$

v_r is the average speed of the chaff cloud, θ is the angle between v_r and the radial direction of radar, and λ is the wavelength of the radar incident wave.

(2) The Doppler frequency shift caused by up-and-down speed of chaff cloud movement, namely v_c obeys the normal distribution.

$$P(v_c) = \left(1 \big/ \sqrt{2\pi}\sigma_c\right) \exp\left(-v_c^2 \big/ 2\sigma_c^2\right) \quad (6)$$

And $\sigma_c = 1 \big/ \left(\sqrt{2}a\right)$, a is the relevant constant about chaff dipole quality, Boltzmann constant and absolute temperature.

In general, the commonly used radar signal is a narrow band signal, which is far less than the central frequency, and its emission signal can be expressed as

$$s(t) = \mathrm{Re}\left[u(t)\exp(j2\pi f_0 t)\right] \quad (7)$$

In the formula, Re represents the real part; $u(t)$ is a complex envelope of modulated signal; f_0 is the center frequency of the incident wave.

When the radar is in a working state, $u(t)$ of a simple pulse waveform can be written as

$$u(t) = \sum_{-\infty}^{+\infty} rect((t - nT_r)/\tau) \tag{8}$$

$rect$ is expressed as a rectangular function, and the pulse width is τ, the pulse repetition period is T_r. We can find that the role of $u(t)$ is to make the incident wave work in the pulse state. So, the model of the radar incident wave can be simplified without considering the pulse state of the radar. Assuming the radar transmitting signal is

$$s(t) = \mathrm{Re}(\exp(j2\pi f_0 t)) \tag{9}$$

According to the above model, the simulation of chaff cloud echo can be expressed as:

(1) Assuming that the v_c is a group of normal distribution of random vector, mean 0, variance σ_c, which contains M elements of v_{ci} (M is the number of chaff in the radar resolution unit), $i = 1,2,\cdots,M$. For the chaff i, the Doppler frequency shift caused by the speed fluctuation is

$$f_{dli} = {2v_{ci}}/{\lambda} \tag{10}$$

(2) The Doppler frequency shift of chaff i is

$$f_{di} = f_{dr} + f_{dli} \tag{11}$$

f_{dr} is the Doppler frequency shift caused by the horizontal movement of the chaff cloud.

(3) The echo signal of chaff i is (Since the fixed delay of complex envelope of the chaff echo signal has no effect on the distribution and the statistical properties of chaff echo, we do not consider the delay factor and simplify the echo model)

$$sl_i(t) = \mathrm{Re}\left[\exp(j2\pi(f_0 + f_{di})t)\right] \tag{12}$$

(4) The signal of chaff cloud echo is

$$sl(t) = \sum_{i=1}^{M} sl_i(t) \tag{13}$$

6. Simulation and Analysis

(1) Assume that the chaff cloud has been fully dispersed; the distance between chaff is greater than 2 times the wavelength; ignore the mutual coupling effect and all chaff has been fallen within the radar beam.

Use Matlab to simulate and we can get the simulation results as follows:

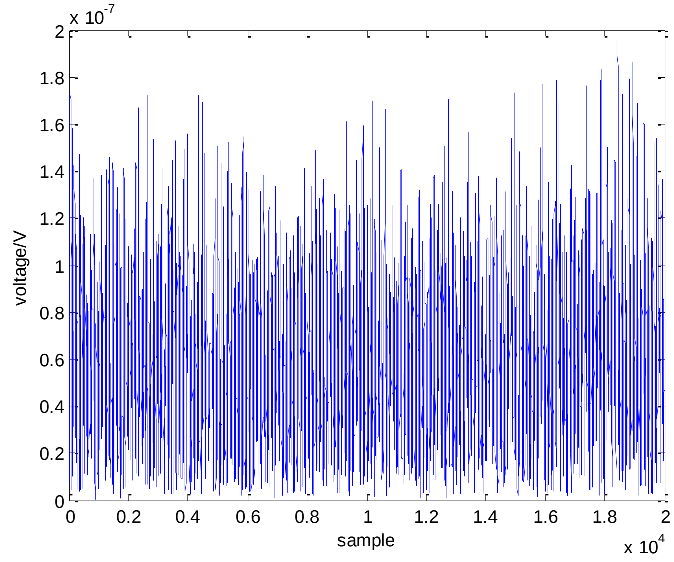

Figure 4. Chaff Echo Waveform in Time Domain

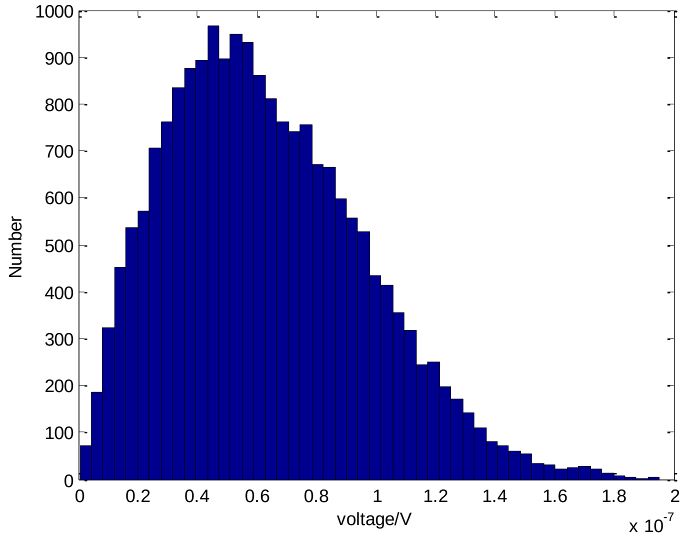

Figure 5. The Histogram of Chaff Echo Waveform in Time Domain

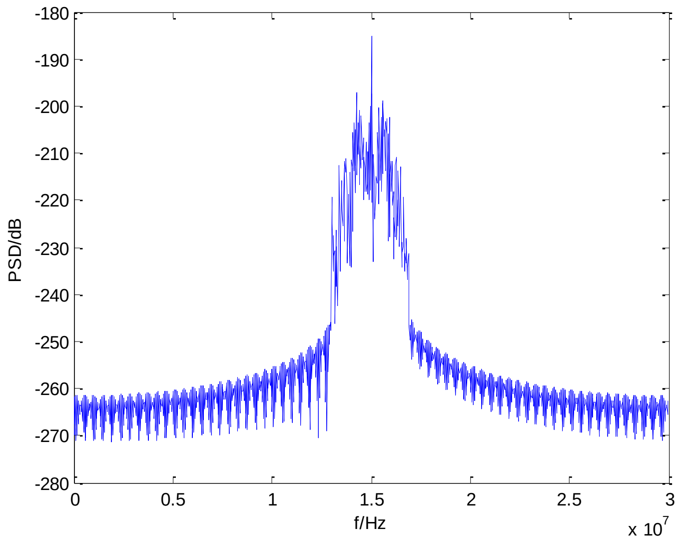

Figure 6. The Power Spectrum of Chaff Echo Signal

Simulation results indicate that the amplitude of chaff echo signal obeys the Rayleigh distribution and the power spectrum obeys Gaussian distribution. The simulation is the same as time-frequency distribution and the statistical characteristics of actual chaff echo.

(2) Assuming that the radar transmits a LFM signal and the target location is 10500, 11000, 12000, 12008, 13000 and 13002. In the case of no chaff jamming, the radar can clearly distinguish the targets within its resolution. Simulation results are as follows

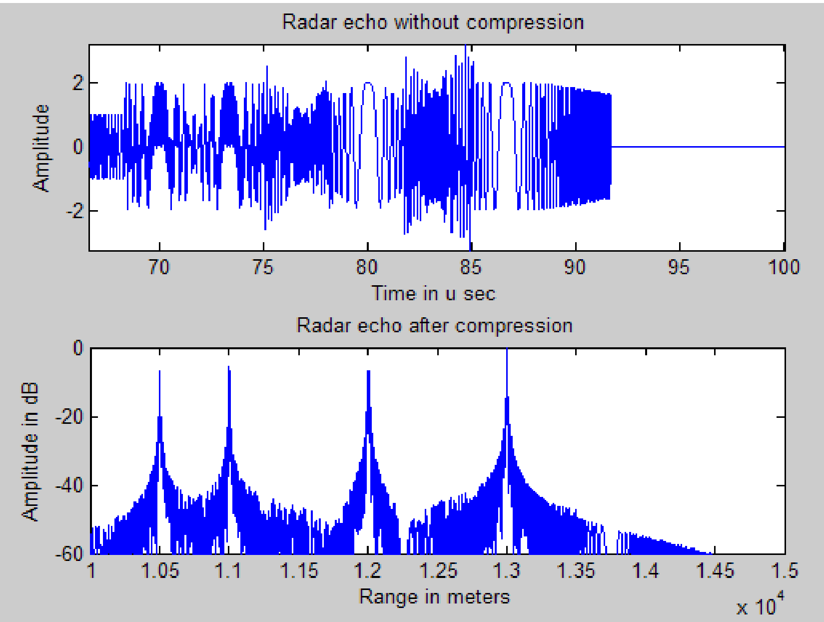

Figure 7. LFM Echo with no Chaff Jamming

(3) In the case of chaff jamming, the radar transmits a LFM signal. The target echo signal is submerged in the chaff echo; radar cannot detect the target and the chaff cloud has achieved the purpose of interference. Simulation results are as follows:

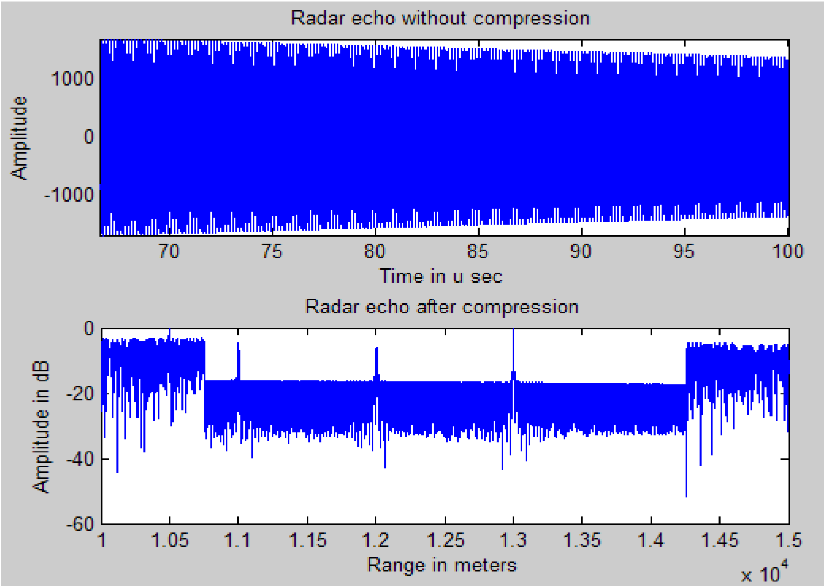

Figure 8. LFM Echo with Chaff Jamming

7. Conclusions

Through the analysis and Simulation of chaff jamming, it can be concluded that this model can be a very good simulation of chaff jamming. This is a simple model and there is a lot of following work to do. Also this has given a good basis for the follow-up research.

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