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Research on Radar Burn-Through Range Under Noise Jamming Based on Radar Equation

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Abstract. Based on the characteristics of radar noise jamming and radar equation, the maximum operating range formula of radar under jamming condition is analyzed by using the logarithmic method, and the burn-through distance of radar under shield jamming and self-defense jamming is solved by taking examples, and the jamming effect is compared and analyzed.

Keywords. Electronic countermeasure, Noise interference, Burn-through distance

1. Introduction

Local wars and conflicts in recent years show that electronic jamming plays an increasingly important role with the development of information equipment technology applications. As an important part of the air defense system, the detection range of radar under disturbed conditions is an important parameter to measure its working efficiency. Therefore, it is of positive significance to analyze the maximum operating range of radar under noise jamming and determine the Burn-through range of radar under noise jamming.

2. Characteristics of noise interference

Radar jamming is mainly divided into suppression jamming and deception jamming, of which suppression jamming is the most widely used. Because radar detects the echo signal of the target to find the target and measure its parameter information, the main purpose of jamming is to reduce the radar's ability to find and track the target.

The mode of suppression jamming is mainly continuous and incoherent noise jamming. The best noise jamming signal should have the characteristics of receiver noise. According to information theory, Gaussian white noise (uniform spectral density) is the best noise jamming signal. When the average power is fixed, the Gaussian white noise has the maximum entropy value of any random waveform, that is, the maximum uncertainty. The main advantage of noise jamming is that it is not necessary to know the signal characteristics and signal processing links of the radar in detail, but only need to know the operating frequency of the radar. Therefore, noise

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jamming equipment is relatively simple. As long as the jamming frequency is consistent with the operating frequency of the radar and the power is large enough, the jamming effect on the radar receiving system will be good.

The noise jamming system is an ECM device designed to generate disturbance in the radar receiver so that it cannot detect the target. In order to make jamming effective, in the radar receiver, the jamming signal J generated by the jammer must have the strength that can cover the radar echo signal S. This strength can be calculated by using the radar equation, that is, the interference signal ratio must be high enough [1].

3. Calculation of the Maximum Operating Range of Radar under Noise Jamming

3.1. Electromagnetic propagation loss and atmospheric attenuation

When electromagnetic wave propagates in the air, it is subject to atmospheric attenuation and propagation loss. The attenuation loss is different for different propagation distances and different operating frequencies. If we take 10 logarithms on both sides of the radar equation, we can get the electromagnetic wave propagation loss formula as follows [2]

$$L_S = 32.4 + 20\lg D + 20\lg F \qquad (1)$$

In the Formula (1): Ls is electromagnetic wave propagation loss, in dB; D is the propagation distance of electromagnetic wave, in km; F is the frequency of electromagnetic wave, in MHz.

3.2. Radar echo power and jamming signal power

The echo power received by the radar is [3]

$$S = P_T + 2G_{T/R} - 103 - 20\lg F - 40\lg D_T + 10\lg S \qquad (2)$$

In the formula: P_T is radar transmission power (dB); $G_{T/R}$ is the gain of transmitting and receiving antennas (dB); F is the radar operating frequency (MHz); D_T is the target distance (km); S is the effective radar cross section of the target.

The jamming signal received by the radar is the electromagnetic wave directly sent by the jammer, and its propagation path is one-way. However, under the condition of supporting jamming, the direction of jamming signal arriving at the radar may be different from the direction of radar echo, so the gain of radar to jamming signal is different from that to echo. At this time, the jamming signal power received by the radar is

$$J = P_J + G_J - 32 - 20\lg F - 20\lg D_J + G_{RJ} \qquad (3)$$

In the formula, P_J is the transmitting power of radar jammer (dB); G_J is the interference transmitting antenna gain (dB); F Is the interference operating frequency (MHz); D_J is the target distance (km); G_{RJ} is the antenna gain of the radar in the jamming direction.

3.3. Interference signal ratio of radar receiver

The jamming effect of the jammer against the enemy radar is not measured by the absolute jamming power value of the jammer, but by the interference signal ratio at the

radar receiving end, that is, the ratio of the jamming signal power value to the radar echo signal power value, which is called interference signal ratio for short. In case of noise jamming, the operating frequency of the jammer is consistent with that of the radar. After the jamming signal power value (Formula 3) and the echo signal power value (Formula 2) at the radar receiving end are obtained, the interference signal ratio at the radar receiving end can be obtained as follows, which can be seen from the formula

$$J/S = P_J + G_J - 32 - 20\lg F - 20\lg D_J + G_{RJ} - (P_T + 2G_{T/R} - 103 - 20\lg F - 40\lg D_T + 10\lg S)$$
$$= 71 + P_J - P_T + G_J - 2G_{T/R} + G_{RJ} - 20\lg D_J + 40\lg D_T - 10\lg S \qquad (4)$$

Formula (4) shows that the jamming effect of the radar receiver is mainly related to the interference-to-signal ratio. The higher the interference-to-signal ratio, the better the jamming effect. The jamming effect is mainly related to the parameters such as the transmitter power and antenna gain of the jammer, the radar transmission power and antenna gain, the target distance, and the radar effective scattering area of the target. Therefore, the interference-to-signal ratio under specific parameters can be calculated by using this formula.

For example, for a radar transmitter with a peak power of 200kW, its antenna gain is 30dB. It detects a target 100km away, and the effective radar cross section of the target is 800m^2. Suppose that a radar jammer adopts the support jamming mode, transmits 200W jamming signal with 20dB antenna gain at a distance of 20km from the radar, and enters from 0dB radar antenna side-lobe to cover the target. Then according to formula (4), the interference-to-signal ratio when jamming is supported is

$$J/S = 71 + 53 - 83 + 20 - 2*30 + 0 - 20\lg(20) + 40\lg(100) - 10\lg(800) = 26$$

If the radar jammer adopts self-defense jamming, the $D_T = D_J$, $G_{T/R} = G_{RJ}$, and Formula (4) can be simplified as

$$J/S = 71 + P_J - P_T + G_J - G_{T/R} + 20\lg D_J - 10\lg S \qquad (5)$$

Formula (5) is the interference equation for self-defense jamming.

Under the same target, radar and jammer parameters above, the interference signal ratio during self-defense is

$$J/S = 71 + 53 - 83 + 20 - 30 + 20\lg(100) - 10\lg(800) = 42$$

Comparing the two results, it can be seen that the interference ratio of self-defense jamming is much larger under the same circumstances.

3.4. Maximum operating range of radar under noise jamming

When the radar operator can identify the real target signal and the jammer noise signal on his display, the maximum operating range of the radar in this case is called the radar "Burn-through range", that is, the maximum operating range of the radar under jamming conditions. It reflects the working ability of radar under jamming conditions, and this ability is reflected in the interference signal ratio of radar receiver.

In general, $J/S = 10$dB is taken as the dividing point between normal and abnormal radar operation. If the interference signal ratio is greater than 10dB, the radar cannot work normally. If the interference signal ratio is less than 10dB, the radar can work normally. Similarly, for the jamming party, if the interference signal ratio to the radar is greater than 10dB, it indicates that the radar jamming is effective at this time; if the interference signal ratio to the radar is less than 10dB; it indicates that the radar jamming is invalid at this time.

Therefore, the formula (4) can be rewritten as

$$40\lg D_T = -71 - P_J + P_T - G_J + 2G_{T/R} - G_{RJ} + 20\lg D_J + 10\lg S + J/S \quad (6)$$

In formula (6), D_T is the maximum operating range of the radar under the condition of supporting jamming.

In the case of the supporting jamming in the above example, using the formula (6), it can be obtained that the radar Burn-through distance is

$$40\lg D_T = -71 - 53 + 83 - 20 + 60 - 0 + 20\lg(20) + 10\lg(800) + 10 = 62$$

So, $D_T = 10^{62/40} = 35.48$ (km)

It shows that under the condition of supporting jamming, the radar can normally find and track the target when the target is close to the mine within 35.48 km.

When the radar detects the target with self-defense jammer, in the formula (6), D_T=D_J, $G_{T/R}$=G_{RJ}, the formula of radar Burn-through distance is:

$$20\lg D_T = -71 - P_J + P_T - G_J + G_{T/R} + 10\lg S + J/S \quad (7)$$

In the above example (Formula 7), if the jammer is configured to implement on the target, the maximum operating range of the radar is

$$20\lg D_T = -71 - 53 + 83 - 10 + 30 + 10\lg(800) + 10 = 18$$

So, $D_T = 10^{18/20} = 7.94$ (km)

It can be seen that under the same noise jamming conditions, the radar's detection distance to targets with self-defense jammers is far less than the detection distance when they are under cover. At this time, the self-defense jamming effect is much better than the support jamming effect.

4. Conclusion

With the continuous development of radar and jamming technology, the struggle in the electromagnetic field will be more and more intense. While the radar is breaking through the traditional system, it is also constantly pursuing new progress in theory and technology, that is, to find and track targets as much as possible under the condition of jamming. This paper studies the calculation method of Burn-through distance under the condition of noise jamming through the radar equation, compares and analyzes the jamming effect, and draws the conclusion that self-defense jamming is much better than support jamming under the same noise jamming condition. Therefore, radar countermeasure should focus on the anti-jamming research of self-defense jamming.

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