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A Method of Remote Support Jamming Based on the Chaff Clouds Scattering

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Abstract. Electronic Jamming is an important means to cover the penetration formation and improve survival probability of penetration aircraft when Air force performs ground penetrating mission. A compound interference method of jamming surface-to-air missile guidance radar by scattering long –range jamming signals though chaff clouds is proposed, which uses jammer to irradiate chaff clouds scattered on the penetration route, and injects jamming energy into the main lobe of surface-to-air missile guidance radar by scattering chaff clouds to make better interference effect.

1. Introduction

Aviation in the process of penetration task execution, often need to use the electronic jamming equipment such as machine of long distance support jamming enemy air defense missile guidance radar should be jammed, can to a certain extent, reduce the risk of penetration formation was found and shot down, effectively ensure the safety of the flight crew and mission success.

For chaff interference problem existing relevant personnel of different levels of study. The research and application of chaff jamming in foreign countries has been started since the Second World War. Foreign researchers have done a lot of research on the separation characteristics of chaff, chaff cloud diffusion model, descent model, RCS rule, etc. [1-3], which has been applied in many wars and achieved good results. Domestic researchers have also done a lot of work. H. Zheng [4], J. Li etc. [5] make the thorough analysis of the chaff cloud polarization and energy characteristics, chaff interference principle and application development; H.Q. Hu etc. [6] of airborne chaff bomb is given under different conditions the optimal timing of using calculation method; W.Y. Cai et al. [7] established chaff motion model in atmospheric environment; Y. Li et al. [8] proposed a new compound jamming method to solve the problem of chaff jamming's decreasing jamming ability and effectiveness to the new radar system; J.H. Zhou et al. [9] studied the influence of chaff as an important way of passive jamming on radar detection.

This paper proposes a method of Compound Jamming using chaff cloud scattering to support jamming signal in long distance. A front projection is established. The multitime spraying model of antitime chaff bomb can quickly and effectively determine the location of each spraying chaff bomb in penetration formation. In order to verify the validity of the model, simulation verification is carried out with an example.

2. A method for the implementation of remote jamming signal scattered by chaff clouds

The jammer's strong interference and strong scattering of chaff clouds, which can transfer interference

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energy from radar antenna's main lobe into the receiver. Reached a good interference effect, at the same time, avoid the radar echo caused by low velocity of chaff have been radar filter with dynamic target display technology, thus greatly expand the application range. In jammer screen penetration formation process, when penetration formation reaches the boundary of enemy air defense fire circle. Spreading Chaff Clouds on the Line of Guidance Radar and Our Penetration Formation.

According to Radar Principle [10], the scattered echo power of penetration formation received by radar receiver is as follows:

$$P_r = \frac{P_t G_z^2 \lambda^2 \sigma}{(4\pi)^3 R^4} \tag{1}$$

The interference signal power of chaff cloud scattering jammer injecting strong interference energy into radar antenna main lobe is:

$$P_{rg} = \frac{P_g G_g \sigma_b A_r}{(4\pi)^2 D^2 C^2} = \frac{P_g G_g G_z \lambda^2 \sigma_b}{(4\pi)^3 D^2 C^2} \tag{2}$$

Among them, P_t is radar transmitting power, G_z is antenna main lobe gain, λ is radar operating wavelength, A_r is effective area for current radar antenna, σ is equivalent scattering area of penetration formation, R is the maximum detection distance of radar, σ_b is equivalent scattering area of chaff cloud, D is the distance between chaff cloud and radar, C is the distance between jammer and chaff cloud.

Assuming that the radar receiver can detect the target signal successfully when the signal-to-interference ratio is greater than 10, the main lobe gain of the radar antenna is equal to the main lobe gain of the jamming antenna, i.e. $G_z = G_g$, and there is no other noise source except the jamming energy, then the signal-to-interference ratio can be expressed as:

$$\frac{P_r}{P_{rg}} = \frac{10 D^2 C^2 P_t \sigma}{R^4 P_g \sigma_b} \geq 10 \tag{3}$$

Then the maximum detection range of radar can be expressed as:

$$R = \sqrt[4]{\frac{D^2 C^2 P_t \sigma}{P_g \sigma_b}} \tag{4}$$

In the process of penetration of enemy ground-to-air missile guidance radar, the position of jammer in airspace and ground-to-air missile guidance radar is relatively fixed, the position distance between jammer and enemy ground-to-air missile guidance radar is L, and the interference angle between jammer and ground-to-air missile guidance radar and penetration route is θ. The maximum detection range of radar can be expressed as:

$$R \leq \sqrt[4]{\frac{D^2 P_t \sigma}{P_g \sigma_b}(D^2 + L^2 - 2DL\cos\theta)} \tag{5}$$

Suppose the jammer jamming power is P_g=100 kw, the radar transmitting power P_t=100 kw, the equivalent scattering area of chaff cloud formed by a single spraying of n chaff bullets is σ_b=40n m^2, the equivalent scattering area of penetration formation σ=10 m^2, L=220 km. When the angle of interference is equal to 45 degrees, the jammer penetrates the ground-to-air missile guidance radar frontally, then the maximum detection range of the radar is the distance from the chaff cloud radar. The relationship between the equivalent scattering area of chaff cloud and chaff cloud is shown in Figure 1.

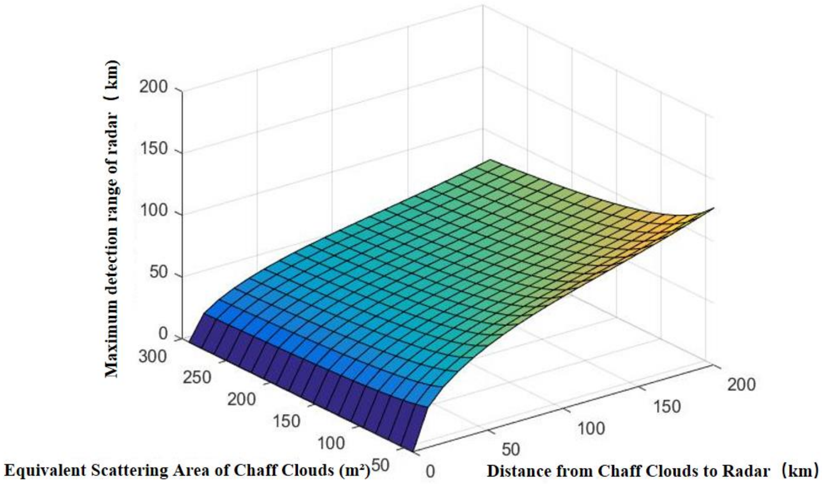

Figure 1. The relation between R and D and σ_b

If a long-range jamming aircraft injects jamming directly into the radar side-lobe from the distance radar antenna L, and G_p is the gain of the radar antenna side lobe, then the effective area of the radar antenna becomes A_f, and the definition of the remaining variables remains unchanged, the jamming power entering the radar receiver can be written as follows:

$$P_z = \frac{P_g G_g A_f}{4\pi L^2} = \frac{P_g G_g G_p \lambda^2}{(4\pi)^2 L^2} \tag{6}$$

The SIR can be expressed as:

$$\frac{P_r}{P_z} = \frac{P_t G_z^2 \lambda^2 \sigma}{(4\pi)^3 R^4} / \frac{P_g G_g G_p \lambda^2}{(4\pi)^2 L^2} = \frac{L^2 P_t G_z \sigma}{4\pi R^4 P_g G_p} \geq 10 \tag{7}$$

At this time, the maximum detection range of radar is expressed as:

$$R \leq \sqrt[4]{\frac{L^2 P_t G_z \sigma}{40\pi P_g G_p}} \tag{8}$$

Assuming that the average side-lobe level of radar with side-lobe cancellation technology is G_p/G_z=-40dB, the distance of long-range support jamming aircraft is L=220 km, and the transmitting power of radar is P_t=100 kw, in which the scattering area of penetration formation is σ=10 m^2, the side-lobe cancellation technology can provide about 10dB cancellation ratio, thus further reducing the side-lobe level, the relationship between the maximum detection range of radar and the jamming power is shown in Figure 2.

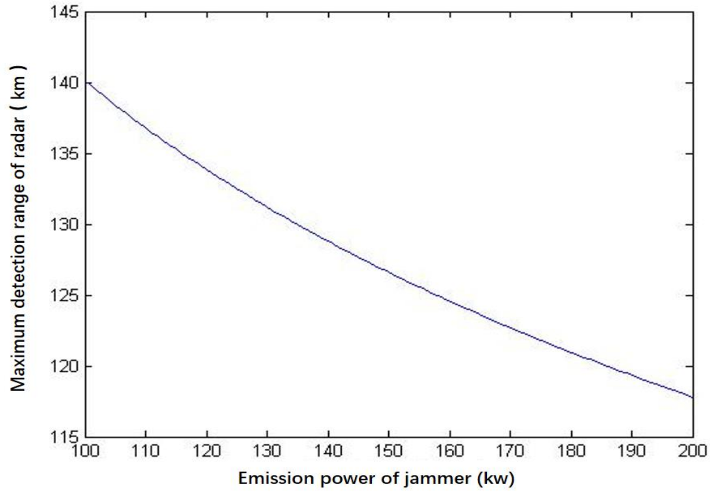

Figure 2. Relationship between P_g and R under average side lobe level

Comparing the jamming effect of two different methods of Figure 1 and Figure 2, it can be found that the detection distance of radar to penetration formation can be greatly reduced by using chaff cloud to transmit long-range jamming signal, and the jamming effect is better. The jamming effect of chaff cloud transmitting remote support jamming signal is affected by the distance D from chaff cloud to radar and the equivalent scattering area σ_b of chaff cloud. The closer the chaff cloud is to radar, the larger the equivalent scattering area, the better the jamming effect. However, it is more effective to shorten the distance between chaff cloud and radar.

3. Multiple spraying model of chaff bomb based on compound interference method

In front penetration, when the penetration formation flies to the detection range boundary of the enemy ground-to-air missile guidance radar, the penetration formation throws some chaff bombs. The rear long-distance support jammer begins to illuminate the chaff cloud formed by the chaff bomb explosion, jamming the enemy ground-to-air missile guidance radar, suppressing the maximum detection range of the enemy ground-to-air missile guidance radar, making it unable to detect the penetration formation. When the penetration formation flew to the edge of the maximum detection range of the enemy surface-to-air missile guidance radar after jamming suppression, a number of chaff bombs were thrown again to shorten the maximum detection range of the enemy surface-to-air missile guidance radar, repeating the above process until the maximum detection range of the enemy surface-to-air missile guidance radar was suppressed to the required range. The spraying process is shown in Figure 3.

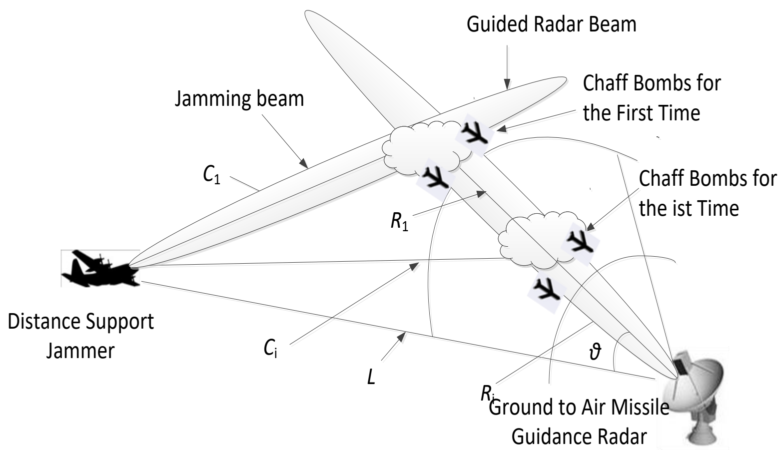

Figure 3. Chaff cartridge throwing timing diagram

The maximum detection range of the enemy ground-to-air missile guidance radar after each spraying of chaff bomb is:

$$R_{i+1} \le \sqrt[4]{\frac{R_i^2 C_i^2 P_t \sigma}{P_g \sigma_b}} \tag{9}$$

R_{i+1}(i=1~n) is the maximum detection range of a certain surface-to-air missile guidance radar after the ith chaff bomb throwing. C_i(i=1~n) is the distance between the jammer and the chaff cloud after the (i-1)th chaff bomb throwing. It is required to suppress the maximum detection range of the enemy surface-to-air missile guidance radar to *K*.

Then the maximum detection range of the enemy ground-to-air missile guidance radar after each spraying of chaff bomb can be expressed as follows:

$$R_{i+1} \le \sqrt[4]{\frac{R_i^2 P_t \sigma}{P_g \sigma_b}(R_i^2 + L^2 - 2R_i L\cos\theta)} \tag{10}$$

The first time to throw chaff bombs is when the penetration formation first flies to the edge of the unjammed detection range of the enemy surface-to-air missile guidance radar.

$$X = R_1 \tag{11}$$

X is the distance between penetration formation and enemy ground-to-air missile guidance radar.

Then the penetration formation flies forward from S_i and sprays chaff bullets for the (i+1)th time, that is:

$$S_i = R_i - R_{i+1} \tag{12}$$

4. Case simulation analysis

Assuming that the detection range of a certain enemy surface-to-air missile guidance radar is R_1=200 km, the launch power P_t=100 kw, the equivalent scattering area of a certain fighter penetration formation σ=10 m^2, the equivalent scattering area σ_b =40 m^2 of each chaff bomb, the jammer is arranged on side of our side to the enemy surface-to-air missile guidance radar L=220 km, the jamming angle θ=45 degrees, and the jammer's jamming power P_g=100 kw. Assuming the maximum launching distance of air-to-ground weapons is 60 km, it is required that the maximum detection range of enemy-to-air missile guidance radar should be suppressed within 60 km by the number of chaff bombs thrown three times. Due to the restriction of weight and other factors, the interference resources that aircraft can carry are limited. Therefore, the method with the least number of chaff bombs and the best suppression effect should be preferred.

In the whole process of penetration, there are five methods to satisfy the requirement of three chaff bombs thrown by the penetration formation. As shown in Table 1, the total number of chaff bombs used at least is 8. The second method can suppress he smallest range of radar detection. Therefore, the second method is used to suppress the maximum range of radar detection to 56.8 km by using eight chaff bombs, as shown in Table 2.

Table 1. Three times chaff cartridge throwing

Method	Number of Dispersions in Position 1	Number of Dispersions in Position 2	Number of Dispersions in Position 3	Range of Radar Detection	Totals
First	1	1	6	58.1km	8
Second	1	2	5	56.8km	8
Third	1	3	4	57.7km	8
Fourth	2	2	4	58.4km	8
Fifth	2	1	5	59.9km	8

Table 2. the second method of chaff cartridge throwing

Data Type	Location 1 Data Size	Location 2 Data Size	Location 3 Data Size
The distance from the spraying position to the radar	200km	127.2km	84.33km
Number of chaff bombs thrown	1	2	5
Equivalent scattering area of chaff cloud cluster	40m²	80m²	200 m²
The maximum detection range of radar	127.2km	84.33km	56.8km

The interference process can be shown in Figure 4:

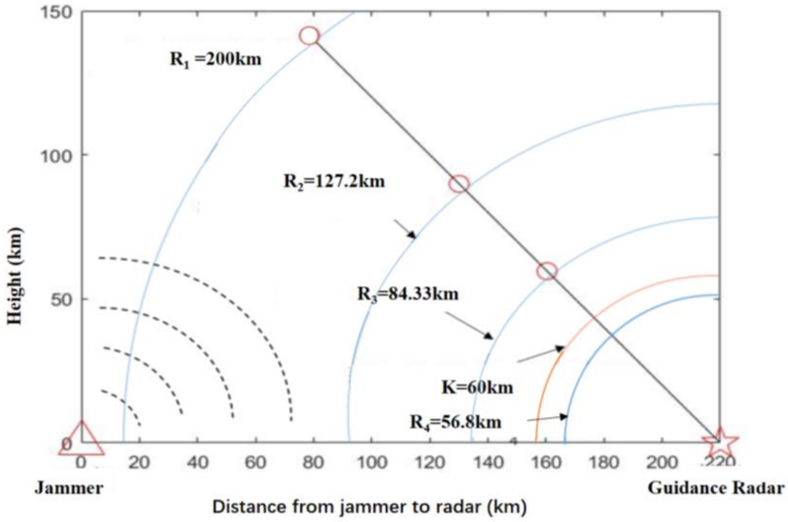

Figure 4. Schematic diagram of jam process

When the effective detection range of radar becomes 56.8 km, which is less than the required maximum detection range of radar 60 km. No longer continue to throw chaff bombs, penetration formations can start to implement ground penetration tasks. In actual combat, the number and position of chaff bombs are calculated according to the operational requirements and the number of chaff bombs that penetration formation can actually load, so as to achieve practical and anticipated interference effect.

5. Conclusion

(1) In this paper, a method of transmitting long-range jamming signals by chaff clouds is proposed. The method injects jamming energy from the main lobe of radar by scattering chaff clouds. Compared with the method of long-range side-lobe jamming of jammer, the method can achieve better jamming effect.

(2) A chaff bomb spraying model for frontal penetration is established. The results show that the model can suppress the maximum detection range of enemy ground-to-air missile guidance radar continuously and effectively during penetration, and provide effective protection for aircraft formation for penetration mission.

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