Characteristics and experimental study of radar scattering foil

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Abstract. Aiming at the current situation that Doppler radar can use the echo frequency difference to avoid the interference of chaff and chaff clouds, by studying the average radar scattering cross section, bandwidth characteristics, horizontal drift speed, polarization characteristics of the foil. The performance of the Paller effect, etc., examined the foil's ability to counter Doppler radar. The static test is used to test the performance of the foil. Experimental research shows that the composite foils of multiple sizes can increase the reflection loss of the composite foil and improve the interference efficiency. Uses round foil as the base material, and foil with mixed side length of 10mm can enhance the loss performance under various polarization conditions.

1. Introduction

Chaff is an important jamming device in passive electronic countermeasures. It is also one of the cheapest and most effective means of jamming missiles or other aircraft. Chaff interference is generally a space that uses a large number of randomly distributed interference clouds or interference corridors formed by half-wavelength foils to disrupt, confuse, divert, or detonate missiles and other aircraft. Among them, saturated suppression interference is usually used to disrupt the enemy. A missile or other aircraft attacks its own target; confusion is when it is found that an enemy missile or other aircraft has entered the front of the theater but has not yet launched an attack, launching chaff bombs in different directions to form multiple chaff [1] clouds identical to the target to confuse the enemy. The attack on the real target by the party; the transfer is that your own target has been tracked by enemy missiles or other aircraft. At this time, you can use the nearby chaff cloud and active interference to conduct distance dragging to make it track the false target; the lure is your own target, immediately attacked by enemy missiles or other aircraft. At this time, a target-shaped chaff can be quickly dropped over the front of the target (or flying), so that the chaff cloud of countless false targets spreads over target, and the real target Leave quickly. As a foil [2] and foil cloud for passive electronic countermeasures, if you want to maintain a long empty time in the air, you must move slowly, and the
frequency of the echo returning from it is close to the frequency of the transmitted wave; and missiles and other aircraft. The speed is very fast, and the echo reflected from it varies greatly. Therefore, Doppler radar can use the frequency difference of echo between them to avoid the interference of chaff and chaff [3] cloud, which is the main method for Doppler radar to combat passive interference. However, according to the working principle of radar tracking target signals, strong reflection of chaff clouds, and uneven distribution of sparse cloud clusters, a large frequency shift will be generated in Doppler radar. In order to understand the ability of chaff and chaff clouds to resist Doppler radar, the effectiveness of passive electronic countermeasures was more effectively exerted. It is necessary to study the radar's average scattering cross section, maximum scattering cross section, bandwidth characteristics, polarization characteristics, vertical descent and horizontal drift speed, and the Doppler effect on radar for single foil and foil clouds.

2. Performance characteristics of foil

Foil is a piece of aluminum with a thickness of 18-20μm, which is cut into round, quadrangular or elongated quadrilaterals with smooth surfaces. Each small part of the foil is an independent reflection source and has similar reflection characteristics. For a millimeter wave radar, it is a large conductive size body and has a strong reflection effect on incident waves. Therefore it is mainly used for reflection and interference millimeter wave radar. Among them, the United States first used a round aluminum sheet with a diameter of about 3 cm in the Gulf War. The "8mm flake foil bullet" used in our country contains four elongated rectangular aluminum pieces with unequal side lengths. The sizes of the two diagonal lines are between 2-10cm, which guarantees that they can be leveled in the air Motion and fast rotation.

2.1. Radar scattering cross section of foil

According to the principle of electromagnetic field, the maximum cross-sectional area of radar scattering of any shape of metal foil is

\[
\sigma_m = 4\pi\frac{\lambda^2}{\lambda^2}
\] (1)

For a circular flat foil, radius is \( r \) and surface area is \( A = \pi r^2 \), the maximum radar cross-sectional area of a single foil is

\[
\sigma_m = 4\pi\frac{r^2}{\lambda^2}
\] (2)

For rectangular flat foils, length is \( a \) and width is \( b \), and the surface area is \( A = a \times b \), the maximum radar cross-sectional area of a single foil is
\[ \sigma_s = 4\pi\pi^2 b^2 \lambda^{-2} \]  

(3)

If the foil has an arbitrary attitude in space and has an equal probability distribution, the average radar cross-sectional area of the foil should average its entire solid angle in space. After pushing to obtain, the average radar cross-sectional area of the two-dimensional space of a foil is

\[ \bar{\sigma} = 0.2\sigma_s \]  

(4)

It can be seen from the above formula that for the same foil, as the frequency increases, the cross-sectional area of radar scattering increases.

Interference is mainly performed for radars with the wavelengths of 3cm. The corresponding frequency is 10GHz. And the size of the foil is required to be greater than the square of the wavelength, that is, the foil area is larger than 9cm\(^2\). The circular and square foils have small sliding angles. Therefore, for circular foils, the radius is 1.7cm. And for square foils, the side length is 3cm. In order to expand the effective working frequency of the foil, it can be filled with a mixture of various sizes of foils. Round foils has 0.3cm, 0.8cm, 1.7cm, 2.3cm, 3cm, 7cm and the square foils of 0.5cm, 1cm, 2cm, 4cm, 5cm can be used to cover the interference bands. Millimeter, centimeter and decimeter waves

2.2. Doppler effect during foil translation

When the foil [4] is close to the reflection direction, the direction of the reflected wave at point A in figure 1 is exactly the receiving direction due to the unequal length of each side; subsequently, due to the vibration deformation of the foil, point B reflects exactly the receiving direction. The two reflected waves are not only very strong, but their characteristics are very close, which makes it difficult for the radar to recognize them. In addition, the vibration speed is very fast, which causes the radar to mistake the B signal for the A signal processing. At present, the interval between two pulses emitted by the radar is 10\(^{-6}\)s. Even a supersonic aircraft flies only 0.01m. At this time, the foil echo has moved 1mm, and it will be mistaken for the same speed as the aircraft. Because the surface of the foil is smooth and the conductive size is large, the reflection characteristics of the adjacent area are obviously close. Even if the moving distance is small or even vibrates in place, the radar will mistakenly think that it has moved a great distance. The Doppler frequency shift of the reflected wave is:

\[ \Delta \bar{\omega} = 2\bar{\nu} \cdot \left( -\frac{\omega}{\omega} \right) \cdot 2\pi \cdot \lambda^{-1} \]  

(5)

Where is the relative speed of the reflector to the observation point; \( \lambda \) is the incident wavelength and \( \Delta \bar{\sigma} \) is the Doppler frequency shift (frequency change).
In figure 1, \( A'B' \) shows the position of the foil's translation (the incident and scattered waves are translated) after two points \( AB \) have passed through a pulse. Because the reflected wave characteristics of the point A and the point B are very close, the radar will mistake \( \Gamma(S_A, S_A') \) as \( \Gamma(S_A, S_B') \). \( AA' \) has a small median value in \( 10^{-6} \)s. \( AB' \) is 2 to 3 orders of magnitude larger than \( AA' \), resulting in a great correlation distance and frequency shift. Over the entire area of the receiving room between \( AB' \) on the radar antenna, the amount of Doppler frequency shift produced by each point is:

\[
\begin{aligned}
\left\{ E_{S_A}(t_1) &\approx E_{SB}(t_1) \\
E_{S_A}(t_2) &\approx E_{SB}(t_2)
\right. \\
\end{aligned}
\]

(6)

At this time, the differential radar scattering cross section to be processed in the airborne computer will be

\[
\sigma_d(\sigma, \bar{r}, \tau) = \lim_{R \to \infty} \left[ R^2 \langle E_{SA}(t_1) E_{SB}^*(t_2) \rangle \right]
\]

(7)

Be mistaken for

\[
\sigma_d(\sigma, \bar{r}, \tau) = \lim_{R \to \infty} \left[ R^2 \langle E_{SA}(t_1) E_{SA}^*(t_2) \rangle \right]
\]

(8)

Even if there is no fluctuation in the movement of a single piece of foil, only a uniform-speed translational body can generate a spectrum broadening. The widening width of its maximum bandwidth is the frequency shift of \( AB' \), and a false frequency shift can be generated at its point AB. The distribution range of the speed (V) displayed on the radar is:

\[
V \in \left[ 0, \left| \frac{A-B'}{A-A'} \right| \cdot V_0 \right]
\]

(9)
The distribution of uniform velocity \( V \) is

\[
P(V) = \frac{|A - A'|}{|A - B'|} V_0
\]  

(10)

In summary, a foil with a dual characteristic of a uniform smooth surface and a large conductive size will generate a considerable Doppler shift when it is translated in the atmosphere and Frequency shift is proportional to the translation speed of the foil. Misunderstood as a high-speed moving target, it can effectively interfere with Doppler radar and moving target detection radar.

2.3. Doppler effect caused by foil rotation

Due to the uneven size and weight of the foil itself, it must rotate while panning in the air and because the surface of the foil is smooth and conductive, the reflection of radio waves is similar to geometric optics. Figure 2 shows the reflection of radio waves when the foil is far away from the radar and the sharp decrease of the reflected energy when it is slightly deviated from the normal angle of incidence, making it difficult for the radar to detect, and then returning echoes after rotating \( 180^\circ \) and this period of time is about \( 10^{-2} \)s. The radar has already transmitted \( 10^4 \) pulses. The Doppler radar calculates the frequency from multiple pulse echoes and is limited to a maximum of 100 pulses by the memory speed limit. At this time, the radar has lost its original target. Therefore, the foil only rotates without generating Doppler frequency shift.

3. Performance characteristics of foil clouds

The foil cloud has both the full Doppler characteristics of a single foil and the group's Doppler effect. The values of speed, orientation, and rotation speed are all distributed according to certain characteristics, and the fluctuation distribution of the motion velocity will cause the spectrum spread of the echo among them. And the Gaussian normal distribution of velocity fluctuations is
\[ P(V_r) = \left( \frac{2\pi\sigma_v}{2}\right)^{1/2} \cdot e^{-\left(\frac{v^2\sigma_v}{2}\right)} \]  

(11)

Compared with chaff [5] cloud, foil cloud has larger volume, sparse cloud clusters, and unstable distribution of reflected wave intensity and direction. It is precisely because of this unstable scattering center that a larger Doppler effect is generated. Therefore, the backscattering coefficient of the foil cloud with reflection as the main interference mechanism is 2 to 3 orders of magnitude larger than that in other directions, and the number of foils in the entire cloud is not large. The change of the centre is very fast, which causes the Doppler radar to misjudge the foil cloud as a high-speed moving target, and its distribution of direction, velocity, and frequency shift is very wide.

4. Performance testing

In view of the fact that it is difficult to measure the microwave interference performance of foils and foils during dynamic diffusion under air explosion conditions, the project team selected the diffused product to perform a static test to check its interference efficiency.

A rectangular cardboard frame with an inner diameter of 25cm × 25cm and a side length of 5cm wide was formed into a rectangular frame. Scotch tape was applied to the hollow area to ensure that one side had adhesive and the substrate was a metal plate. The collected diffusion foil strip product was evenly spread on one side of the adhesive, and the mass before and after the diffusion product was distributed was measured with an electronic balance, and the amount of diffusion product per unit area was calculated. The free space method was used to measure the reflectance of the rectangular frame in which the diffusion product were dispersed in the microwave band. The model of the device is AV3630, and the test frequency range is 1GHz-20GHz.

The test results are shown in figure 3 and figure 4 below. Among them, sample No. 1 is a uniform mixture of 4 kinds of round foils (diameter = 16, 34, 46, 76mm) at 0.3g each, which is equivalent to an areal density of 19.2g-\text{m}^{-2}. When 0.3g round foil with a diameter of 16mm is added to the surface of No. 1 sample, the loss of its reflection increases; after adding the same number of similar foils, its reflection loss continues to increase. Sample No. 5 in figure 4 is 5 kinds of square foils (side length = 5, 10, 20, 30, 45mm) 0.3g each uniform mixture. When 0.3g square foil with side length 10mm is added on the surface, its reflection loss also increases.
5. Conclusion

In this paper, a comprehensive and in-depth theoretical analysis of the performance characteristics of foils and foil clouds is conducted, and the performance of the samples is tested through static tests. The following conclusions were reached:

1) A round foil with a diameter of 16, 34, 46, and 76mm and a 0.3g each of the homogeneous mixture are used to compound 0.3g of a round foil with a diameter of 16mm, which has significant loss performance.

2) 0.3g each of five square foils with side lengths of 5, 10, 20, 30, and 45mm was mixed uniformly with 0.6g of 10mm side rectangular foils, which had good loss performance.

3) The mixing of multiple sizes of foils can improve the interference efficiency of the composite foils and more effectively exert the effectiveness of passive electronic countermeasures.

4) In order to enhance the loss performance under a variety of polarization conditions, a round foil can be used as the substrate, and a square foil with a composite edge length of 10mm can be used to make a foil spring.

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