The influence analysis of Active Distributed Jamming on radar detection probability

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Abstract. In this paper, we studied the influence of active distributed suppression jamming on radar detection probability. Firstly, the radar detection probability models of three kinds of target echo signals, namely, deterministic signal, Swerling type I and II signal, Swerling type III and IV signal, are established under the condition of active distribution; Then, the influence of distributed jamming on the detection probability of three kinds of target echo signals is simulated and analyzed in two kinds of scenarios of distributed support jamming and long-distance distributed support jamming. The simulation results show that the noise power entering the main lobe has the greatest influence on the radar detection probability, but when the noise power in the main lobe increases to a certain extent, the influence on the radar detection probability is not obvious.

1. Introduction
Previous war cases show that EW combat forces are usually used first to paralyze or suppress the opponent's early warning detection system. Driven by the actual operational requirements, the research of electronic warfare equipment and electronic warfare operation mode has become a hot spot of military power research, and the electronic countermeasure means and operation mode are constantly innovated. With the gradual maturity of UAV technology, due to its low cost, strong endurance and small target characteristics, it is being used in various electronic countermeasures scenarios. The research of electronic warfare UAV has made a lot of achievements, and has the trend of gradually equipping [1-5]. Compared with the large electronic jammer, it is more flexible in operation, and can accompany the penetration aircraft to the position closer to the target. At the same time, aiming at the problem of insufficient jamming power caused by its volume limitation, the UAV cluster can be used to solve this problem with the advantage of quantity superposition. In extreme cases, the UAV cluster can be sacrificed in exchange for the consumption of the enemy's air defense force. In this paper, the influence of active distributed suppression jamming on radar detection probability is studied, in order to provide guidance for mission planning of UAV jamming cluster.

2. Radar detection probability model under active distributed jamming condition
For radar, the acting principle of compressed jamming on radar is that the jamming noise signals drown out the target echo signals, making the target echo signals cannot be detected by the back-end devices of the receiver. In this case, the intuitive representation is that the power of the jamming noise signal is greater than the power of the target signal. The jamming degree of radar can be reflected by the ratio of target signal power and jamming noise power.
2.1 Target echo power
Define the transmitting power of the radar be $P_t$, the antenna gain of the radar $G_t$, the radar wavelength $\lambda$, the radar effective reflecting area of the target $\sigma$, the distance from the radar $R$, and the transmission loss $L_r$, then the echo power of the target can be:

$$P_r = \frac{PG_t^2\lambda^2\sigma}{(4\pi)^2LR^2} \quad (1)$$

2.2 Radar jamming signal power under active distributed jamming condition
Assuming that there are $n$ unmanned jammers simultaneously jamming the radar, $i$ is ($i = 1, 2, ..., N$) the Angle of the connection between part jammer and radar from the main lobe of radar, and the value range is $-180^0 \sim 180^0$, then the total power of jamming signals received by radar cluster of unmanned jammer is [1]:

$$P_j = \sum_{i=1}^{n} \frac{PG_iG(\theta)\lambda^2\gamma_iB_n}{(4\pi)^2R_iL_i \Delta f_i} \quad (2)$$

Where, $P_i$ is the transmitting power of the $i$-th UAV; $G_i$ is the antenna main lobe gain of the $i$-th UAV; $G(\theta)$ is the gain of radar antenna in the direction of the $i$-th UCAV; $\theta_i$ is the angle between the connection direction from the radar to the $i$-th jammer and the main lobe direction of the radar; $\lambda$ is the wave length of radar jamming; $\gamma_i$ is the polarization mismatch loss of unmanned jamming signal; $R_i$ is the distance from the $i$-th UCAV to the radar; $L_i$ is the transmission loss of the $i$-th UAV; $B_n$ is the bandwidth of radar receiver; $\Delta f_i$ is the interference bandwidth of the $i$-th jammer.

In the direction of UAV, the gain of radar antenna can be obtained by the following empirical formula [2]:

$$G(\theta) = \begin{cases} G_i & |\theta| \leq \frac{\theta_{0.5}}{2} \\ K(\frac{\theta_{0.5}}{\theta})^2G_i & \frac{\theta_{0.5}}{2} < \theta \leq 90^0 \\ K(\frac{\theta_{0.5}}{90})^2G_i & 90^0 < \theta \leq 180^0 \end{cases} \quad (3)$$

Where, $\theta_{0.5}$ is the main lobe width of radar; $\theta$ is the angle between the main lobe direction of radar and the connecting direction from radar to UAV; $K$ is a constant related to the characteristics of radar antenna, which is generally taken as 0.04-0.1. In this paper, it is taken as 0.1.

2.3 Inherent noise power of radar receiver
Whether or not there is external noise interference, there is always a certain degree of inherent noise in the radar receiver. Suppose that the noise figure of radar receiver is $F_n$, the standard room temperature is $T_n$, generally 290k, and the Boltzmann constant $k$ is $1.38 \times 10^{-23}$J/K, When the bandwidth of the radar receiver is $B_n$, the inherent noise power of the radar receiver $N_0$ is:

$$N_0 = kT_nB_nF_n \quad (4)$$

2.4 Radar detection probability
If the radar detects the target based on monopulse, the radar detection probability is the probability that the signal envelope of the synthesized waveform of the target echo signal and the noise signal exceeds the detection threshold voltage, including three kinds: the detection probability of the deterministic target echo signal, the detection probability of the Swerling I and II target echo signal, and the detection probability of the Swerling III and IV target echo signal.
(1) The detection probability of the target echo signal $P_d$ is [2]:

$$P_d = \frac{1}{2}[1 + \text{erf}(\sqrt{\frac{1}{2} + S_n} - \sqrt{\ln(\frac{1}{P_{fa}})})]$$  \hspace{1cm} (5)

Where, $P_{fa}$ is the false alarm probability of radar, and the general value is $10^{-6}$. $S_n$ is the ratio of target echo signal power to noise power:

$$S_n = \begin{cases} \frac{P_r}{N_0} & \text{when no jammers} \\ \frac{P_r}{N_0 + P_r} & \text{when jammers exist} \end{cases}$$  \hspace{1cm} (6)

$\text{erf}(x)$ is a complementary error function:

$$\text{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-u^2} du$$  \hspace{1cm} (7)

(2) The detection probability of Swerling I and II target echo signal is [3]:

$$P_{di} = (P_{fa})^\frac{1}{1+S_n}$$  \hspace{1cm} (8)

Where, $P_{fa}$ is the false alarm probability of radar, and the general value is $10^{-6}$. $S_n$ is the ratio of target echo signal power to noise power, and the calculation formula is the same as above.

(3) Detection probability of Swerling III and IV target echo signal [3]:

$$P_{dv} = \frac{S_n}{2+S_n}(1+\frac{2}{S_n} - \frac{\ln P_{fa}}{1+S_n / 2})\exp(\frac{\ln P_{fa}}{1+S_n / 2})$$  \hspace{1cm} (9)

Where, $P_{fa}$ is the false alarm probability of radar, and the general value is $10^{-6}$. $S_n$ is the ratio of target echo signal power to noise power, and the calculation formula is the same as above.

3. Simulation analysis
In the simulation experiment, the simulation analysis is carried out in two scenarios: distributed support jamming of the team and the remote distributed support jamming. In the scene of distributed support interference with the team, the electronic warfare aircraft cluster and the penetration aircraft group fly; In the long-distance distributed support jamming scene, the electronic warfare aircraft cluster interferes with the radar outside a certain distance, and the penetration aircraft can penetrate separately.

3.1 Parameter setting
The specific parameters of radar are shown in Table 1.

| Radar parameter               | Value | Unit | Radar parameter               | Value | Unit |
|-------------------------------|-------|------|-------------------------------|-------|------|
| Transmitting power           | 100   | kW   | Receiver bandwidth           | 1     | kHz  |
| Antenna gain                 | 25    | dB   | Noise figure                 | 3     | dB   |
| Boltzmann constant           | $1.38 \times 10^{-23}$ | J/K  | System loss                  | 12    | dB   |
| Standard room temperature    | 290   | K    | False alarm probability      | $10^{-6}$ | -    |

The specific parameter setting of jammers is shown in Table 2.
Table 2. Jammer parameter setting

| Jammer parameter       | Value | Unit | Jammer parameter       | Value | Unit |
|------------------------|-------|------|------------------------|-------|------|
| Transmitting power     | 20    | W    | Polarization loss      | 0.5   | -    |
| Antenna gain           | 0     | dB   | Total interference loss| 3     | dB   |
| Interference bandwidth | 4     | MHz  |                        |       |      |

3.2 distributed support jamming

In this case, the RCS of penetration aircraft is set as 10 dBsm. Compared with penetration aircraft, the RCS of UAV can be ignored, and the distance between UAV and radar is consistent with that between penetration aircraft and radar.

Figure 1 shows the change curve of the probability of penetration aircraft detected by radar with the radar distance under the cover of the group of UAV jammers when there are no jammers in the main lobe of radar.

![Figure 1](image1.png)

(a) deterministic signal  
(b) Swerlling type I and II signal  
(c) Swerlling type III and IV signal

Figure 1 Relationship between radar detection probability and distance between penetrating aircraft and radar when there is no jammer in radar main lobe

As can be seen from Figure 1:

1. The more the number of jammers, the more obvious the suppression effect of jammer cluster on radar.
2. With the approaching of penetration aircraft, the probability of penetration aircraft being detected by radar increases gradually, and increases rapidly in a certain range. When there are 15 jammers, if the distance from the penetration aircraft to the radar changes from 30km to 20km, the probability of detection increases sharply from 0.1 to nearly 0.8.

Figure 2 shows the change curve of the probability of penetration aircraft detected by radar with the radar distance under the cover of UAV jammer cluster when there is only one jammer in the main lobe of radar.

![Figure 2](image2.png)

(a) deterministic signal  
(b) Swerlling type I and II signal  
(c) Swerlling type III and IV signal

Figure 2 Relationship between radar detection probability and distance between penetration aircraft and radar when there is one radar jammer in radar main lobe
As can be seen from Figure 2:
When there is only one jammer in the main lobe, the increase of the number of jammers has little effect on the detection probability of radar.

Comparing Figure 1 and Figure 2, it can be seen that:
When jammers exist in the main lobe of the radar, the detection range of radar decreases obviously.

Figure 3 shows the change curve of the probability of penetration aircraft detected by radar versus radar distance under the concomitant cover of UAV jammer cluster when there are 1, 2, 3, 4, 5 and 6 jammers in the main lobe of radar.

As can be seen from Figure 3:
When there are jammers in the main lobe of radar, the more the number of jammers, the better the suppression effect on radar. But when the number of jammers increases to a certain number, with the increase of the number of jammers, the suppression effect is not obvious.

Figure 4 shows the change curve of the probability of penetration aircraft detected by radar with the radar distance when there is no interference.

Comparing Figure 1-3 and Figure 4, it can be seen that when there is interference, the detection range of radar is obviously suppressed.

3.3 Long distance distributed support jamming
In this case, if the unmanned jamming cluster flies in a circle at a certain distance from the radar, the distance between the unmanned jamming cluster and the radar can be considered as a fixed value. In this paper, the distance between the unmanned jamming cluster and the radar is set as 100km by using the calculation results in Figure 4.
Figure 5 shows the change curve of the probability of penetration aircraft detected by radar with the radar distance under the cover of UAV jammer cluster when there are no jammers in the main lobe of radar.

![Figure 5](image)

(a) deterministic signal  
(b) Swerling type I and II signal  
(c) Swerling type III and IV signal

Figure 5 Relationship between radar detection probability and distance between penetrating aircraft and radar when there is no jammer in radar main lobe

Figure 6 shows the curve of the probability of penetration aircraft detected by radar versus radar distance under the cover of UAV jammer cluster long-distance support when there are 1, 2, 3, 4, 5 and 6 jammers in the main lobe of radar.

![Figure 6](image)

(a) deterministic signal  
(b) Swerling type I and II signal  
(c) Swerling type III and IV signal

Figure 6 Relationship between radar detection probability and distance between penetration aircraft and radar when there are 1 to 6 radar jammers in radar main lobe

Compared with figure 1 and figure 5, figure 3 and Figure 6, it can be seen that when the layout of UAV cluster is similar, the detection probability presents a similar change rule. At the same time, in the same situation, the effect of long-distance support jamming is not as good as that of team support jamming.

Figure 7 shows the change curve of the probability of penetration aircraft detected by radar with the radar distance when there is one jammer in the main lobe of radar and the RCS of penetration aircraft changes from 10dbsm to 20dbsm under the cover of UAV jammer cluster remote support.

![Figure 7](image)

(a) deterministic signal  
(b) Swerling type I and II signal  
(c) Swerling type III and IV signal

Figure 7 Relationship between radar detection probability and distance between penetrating aircraft and radar with different RCS when there is one radar jammer in radar main lobe
It can be seen from Figure 7 that when there is a radar jammer in the main lobe of the radar, for the same radar detection probability, when the RCS of the penetration aircraft decreases gradually, the penetration distance of the aircraft increases nonlinearly. After the RCS decreases to a certain extent, the gain in the penetration distance is not obvious.

Given the distance between the penetration aircraft and the radar, the RCS value of the target, Figure 8-10 show the variation of the probability of penetration aircraft detected by radar changes with the angle of unmanned jamming cluster deviating from radar main lobe under the long-range support cover of five UAV clusters, when the target echo signals are three types of target echo signals, namely, the known target echo signal, the swilling I and II target echo signal, and the swilling III and IV target echo signal.

From Figure 8-10, it can be seen that at the same distance, the detection probability of three kinds of target echo signals increases with the increase of target RCS value, that is, the smaller the RCS value of
the penetration aircraft covered by the unmanned interference cluster, the better the effect of suppression interference, and the stronger the penetration ability of the aircraft. For the RCS value of the same target and the same target, when the detection probability is not 0, and when the target is close to the radar, it is confirmed that the detection probability of the target echo signal is higher than that of the Swerlling I and II target echo signal and the Swerlling III and IV target echo signal; The detection probability of Swerlling III and IV target echo signal is higher than that of Swerlling I and II targets.

4. conclusion
In this paper, the influence of Active Distributed Jamming on the detection probability of radar is simulated and analyzed in detail in two typical scenarios, i.e. distributed support jamming and long-distance distributed support jamming. The simulation results can be used to guide the operational use of UAV. Later, we will further analyze the influence of jamming power of UAV on the suppression effect of UAV cluster.

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