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Anti-Jamming Efficiency Evaluation of Field Air Defense Early Warning Radar

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Abstract: With the rapid development of radar, the role of enemy jammers in actual combat is becoming more and more prominent, and they play a very critical role in combat, jamming the "clairvoyance" (early warning radar) of our field air defense position, weakening the ability of our early warning radar to find targets, so it becomes very important to evaluate the anti-jamming effectiveness of early warning radar. In this paper, the effectiveness function is used to evaluate the jamming effectiveness of the early warning radar after the jamming. Finally, an example is given to verify the effectiveness of the evaluation method.

1. Introduction

Because the early warning radar has the longest detection range and is the "clairvoyant eye" of the air defense group, the early warning radar is often the primary target of the enemy's jamming air attack in field air defense operations. The early warning radar has its own anti-jamming system. In the field air defense operation, the first thing that the enemy jammer wants to jam is the early warning radar, and its jamming effect directly reflects the influence of the enemy jammer on the working ability of the early warning radar.

Table 1: Jamming mode and jamming effect on frequency agile radar

Interference pattern	Interference effect
Wideband blocking jamming	1. When the blocking bandwidth is greater than or equal to the agile bandwidth, a blanket jamming effect is produced 2. Low utilization rate of interference power
Deception adaptive jamming	The jammer actively guides and deceives the adaptive frequency-agile radar spectrum into the "notch", and then the jammer aims at the narrow-band clutter jamming, and the jamming effect is better.

At present, the field air defense force is equipped with the latest early warning radar a low and medium altitude radar and B high and medium altitude radar, both of which are frequency agile radar. The carrier frequency of the signal transmitted by the frequency agile radar is not a fixed value, but jumps rapidly within a certain frequency band, which increases the difficulty of frequency alignment of the jammer. And the anti-jamming capability of the radar is effectively improved.

Based on this characteristic of this type of radar, under the existing technology, the main methods to jam this type of radar are broadband barrage jamming and deception adaptive jamming, and their jamming effects are shown in Table 1.

2. Anti-interference evaluation criteria

2.1 Jamming effect evaluation steps

Evaluating the anti-jamming capability of early warning radar is essentially to analyze the extent of threat reduction under a specific standard. In most cases, the process steps are usually as follows:

(1) Reasonably formulate the criteria for judging the anti-interference capability;

(2) after the standard is selected, the evaluation scheme is selected;

And (3) further calculating an anti-interference effect value on the basis of the obtained weight value.

2.2 Evaluation criteria

The efficiency criterion means that in the course of combat, the enemy jammer interferes with our early warning radar, and our early warning radar interferes with it, so as to achieve the effect of reducing its threat [1]. The efficiency criterion is directly oriented to the combat task, which relies on a large number of statistical data and can intuitively reflect the impact of the implementation of anti-jamming on the combat process. Another special case is that the index declines to the same extent, but the actual anti-interference ability is different. The following is a simple example: The probability of our early warning radar detecting the target after anti-jamming is shown in Table 2.

Table 2: Target detection probability of early warning radar after anti-jamming

	Before interference	After anti-interference
A	0.9	0.45
B	0.45	0.225

From the analysis of the Table 2, it can be seen that the probability of target detection is reduced by half before and after anti-jamming[2]. However, in actual combat, only when the detection probability of early warning radar reaches a certain value, can it detect the target normally. Therefore, the anti-interference effect of A is better than that of B.

3. Evaluation of anti-jamming effect based on efficiency criterion

In decision theory, the actual value of the outcome to the decision-maker, that is, the preference order of the decision-maker to the outcome, is described by utility, which is the quantification of preference[3]. In the evaluation of anti-jamming effect, utility refers to the extent to which the early warning radar can continue to combat after anti-jamming in actual combat. Anti-jamming utility value refers to the quantification of the damage degree of early warning radar to the enemy's electronic jamming intention.

From the analysis of radar attributes, it is assumed that the radar is looking for a target during detection, and the probability that it can accurately find the target before anti-jamming work is carried out on the radar is p_0, and the probability of accurately capturing the target after the anti-jamming work is p'. What the enemy needs to pay attention to is the relevant data parameters before and after the anti-jamming work[4].

In this paper, the expression of radar anti-jamming effect is in the plural form. If the enemy jammer disturbs our radar equipment, the utility value is U_0, the utility value after jamming is U', the utility value of our early warning radar after anti-jamming is U_R. Define the anti-jamming effectiveness of our early warning radar. U It can be expressed as:

$$U = (U_0 - U') + j(U_R - U') \quad (1)$$

The result obtained from the above formula and the analysis results of the example is that after the enemy interferes with our radar equipment, the working performance of the radar in searching for the target is affected; $(U_0 - U') > 0$ It shows that the combat effectiveness of the early warning radar is improved after the implementation of anti-jamming[5].

If the effective anti-jamming utility value is expressed in the coordinate system U, as shown in Figure 1.

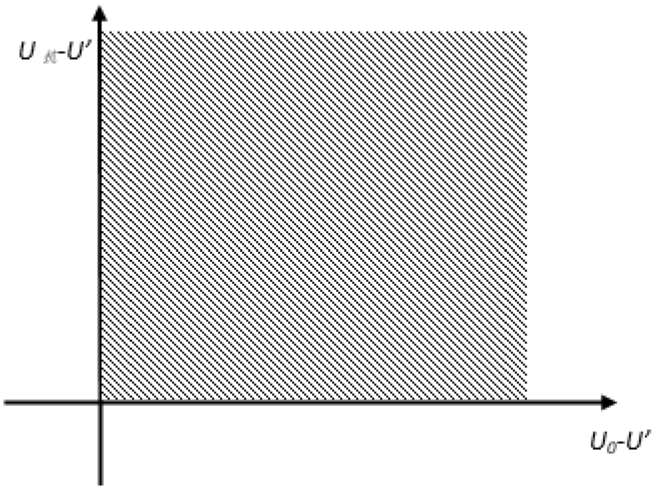

Figure 1: Effective region of anti-jamming utility value

The utility criterion has strong intuition, and can reflect the influence degree of our early warning radar on its own performance after the implementation of anti-jamming, which is of great significance in the implementation of operational command.

3.1 Evaluation index of anti-interference effect

In the air defense operation, according to the threat degree of the target radar to our side, the radar working ability can be divided into search ability and tracking ability. The search capability includes target detection probability, target detection probability, target recognition capability, multi-target detection accuracy, false alarm rate, tracking capability, etc. This paper mainly selects the probability of finding the target. P_d ? Maximum detectable target range. R_d ? Probability of correct target identification P_t ? Multi-target detection accuracy. δ And continuous detection times T_d. As the evaluation index of jamming effect, these five indexes basically reflect the working ability of radar. In which that probability of fin the target P_d. Target detection distance R_d. Probability of correctly identifying the target P_t .It belongs to the benefit index, and the larger the value, the better; Multi-target detection accuracy δ. Continuous detection time T_d .It is a cost-based indicator, and the smaller the value, the better.

The measurement and calculation of these five index values, especially the change of these index values after the implementation of anti-jamming, are the basis of anti-jamming evaluation. The specific calculation method is not the focus of radar jamming assistant decision, so it will not be introduced in detail in this paper.

3.2 Utility function of evaluation index

The work of radar requires specific analysis of anti-jamming data, so that the anti-jamming effect is more reliable, otherwise there will be deviations. Therefore, it is necessary to analyze the early warning radar (A, B) with a large number of examples, so that a complete function model can be constructed in an accurate way, and such a function model can be convincing. The matters needing attention for anti-jamming must be strictly controlled in every detail, and no error can occur even in a small data.

1) Incremental utility function

It means that the utility value of an index is proportional to the attribute value, and the greater the attribute value, the greater the utility value[6]. Therefore, the discovery target probability P_d. Target detection distance R_d. Probability of correctly identifying the target P_t Applicable to the growth utility function, the specific form that can be selected is as follows:

$$U(x)=\begin{cases}(x/x_0)^{\alpha_1},0\le x\le x_0\\ (x/x_0)^{\alpha_2},x\end{cases} \tag{2}$$

$\alpha_1 \ge 1$, $0 \le \alpha_2 \le 1$. x It means the attribute value of a certain indicator. x_0 It means that the attribute value of anti-interference needs to be satisfied. Once this value is reached, it can be determined that the utility value of the index corresponds to u_0 (When the utility value is less than u_0 The early warning radar cannot meet the operational requirements).

The graph is shown in Figure 2.

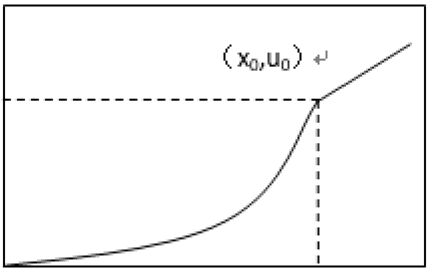

Figure 2: Incremental Utility Function

2) Weakening utility function

It means that the utility value of an index is inversely proportional to the attribute value. So there is the multi-target detection accuracy. δ. Continuous detection time T_d. For a weakening utility function, the feasibility measure can be calculated as

$0 \le \beta_1 \le 1$, $\beta_2 < 0$. In the calculation formula, because of the multi-target detection accuracy of the early warning radar in actual combat $\delta = 1$ When, the corresponding $u(\delta) = 0$, so the positive constant is introduced c.

The graph is shown in Figure 3.

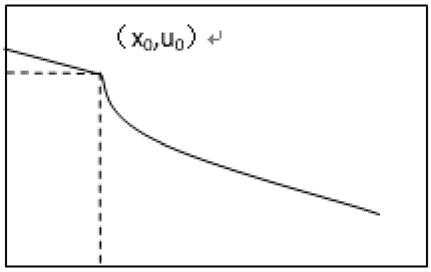

Figure 3: Graph of that attenuate utility function

3.3 Evaluation of anti-interference effect

1) Determination of index weight

The following is a simple example for analysis:

When the enemy's jammer is in the jamming state, if the enemy's air attack target is far away from our position and cannot reach our firepower range, the target detection probability of our early warning radar P_d. Target detection distance R_d It belongs to the first-level indicators, and other indicators belong to the second-level indicators. If the enemy's air attack target is close to our position and close to the firepower range of our position, the probability of finding the target P_d. Probability of correctly identifying the target P_t. Multi-target detection accuracy δ It belongs to the first-level indicator; Then the other two indicators belong to the category of secondary indicators[7].

If the ratio of the importance of the primary and secondary indicators is m_d, then the indicator weight is:

$$\omega_{s_1} = \frac{m_d}{n_1 m_d + n_2} \qquad (3)$$

$$\omega_{s_2} = \frac{1}{n_1 m_d + n_2} \qquad (4)$$

ω_{s_1}, ω_{s_2} It refers to the weight of the first and second level indicators. n_1, n_2 It refers to the number of primary and secondary indicators.

2) Anti-interference effect calculation

Presumed target discovery probability P_d ? Maximum detectable target range. R_d ? Probability of correct target identification P_t ? Multi-target detection accuracy. δ And continuous detection times T_d The utility functions of the $u_1(x)$, $u_2(x)$, $u_3(x)$, $u_4(x)$, $u_5(x)$, $(u_{0i} - u_i) + j(u_{(\text{resist})i} - u_i)$, $i = 1,2,3,4,5$. Then the anti-jamming effect of each index can be evaluated and estimated:

$$u_i = \begin{cases} (u_{0i} - u_i^{'}) + j\omega_{s_1}(u_{(\text{resist})i} - u_i^{'}), & u_i \text{ is a primary indicator} \\ \dfrac{1}{m_d}(u_{0i} - u_i^{'}) + j\omega_{s_2}(u_{(\text{resist})i} - u_i^{'}), & u_i \text{ is Secondary indicators} \end{cases} \qquad (5)$$

After the overall evaluation and estimation of the anti-jamming effect, the results are as follows:

$$u = \sum_{i=1}^{5} u_i, i = 1, 2, 3, 4, 5 \quad (6)$$

4. Evaluation process

Step 1: Quantification of anti-jamming purpose. In actual combat, various attributes of our radar signals will be captured by enemy jammers, so that the enemy will make purposeful and targeted arrangements for its operational policy and strategic deployment in advance, and generally judge our strategic intentions from the captured information. We need to make rational use of the resources in our hands and bring them into full play in order to achieve anti-jamming and reasonably target the enemy's jammers. Make careful arrangements for all matters of combat, correctly distinguish and grasp the importance of various indicators; The correlation functions of all indicators are listed in detail.

Step 2: Calculate the index weight. Put what has been made clear m_d Apply to formula (4).

Step 3: Calculate the indicator attribute value. The acquired data, distribution, performance and attributes of enemy air units are analyzed in detail. All information of radar and jammer needs to be evaluated and judged comprehensively. The ultimate goal is to obtain the evaluation index attribute values of enemy radar before and after jamming.

Step 4: Calculate the anti-jamming utility. The data calculated in the second step is reversely brought into the first step, so that the result is the utility function of each index. Through the obtained utility function, whether the utility value of the evaluation index before and after interference has changed to a certain extent can be obtained. The detailed steps can be referred to according to formula (1).

Step 5: Calculate the anti-interference effect. The utility value of each index is inserted into the formulas (5) and (6), m_d , ω_{s_1} , ω_{s_2} And then the anti-interference effect value can be obtained through the corresponding calculation program.

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Table 3: Quantized values for anti-jamming purpose

Indicator requirements	P_d	R_d	P_t	δ	T_d
	0.7	120km	0.5	1°	8s
Indicator level	Level 1	Level 1	Level 2	Level 2	Level 2
Utility function	$\alpha_1 = 1.4$ $\alpha_2 = 0.8$	$\alpha_1 = 1.6$ $\alpha_2 = 0.8$	$\alpha_1 = 1.6$ $\alpha_2 = 0.4$	$\beta_1 = -1$ $\beta_2 = -0.8$ $c = 0.05$	$\beta_1 = -1.2$ $\beta_2 = -0.5$ $c = 0.03$
Ratio of importance of indicator $m_d = 10$					

When the enemy jammer is detected to be in the jamming state, the following is the minimum operational standard for each category of evaluation index, and the probability that the target is observed P_d 0.7, the maximum observation distance from the target point R_d For 120km, the probability of accurate identification of the target P_t 0.5, the accuracy of detecting multiple targets δ Is 1 °, the probability of continuous observation of the target T_d Is 8 s. Table 3 shows the ratio of the importance levels of the indicators m_d Utility function parameters.

1) Index weight calculation

Will m_d Substitute formula (4) to obtain: $\omega_{s_1} = 0.4347$, $\omega_{s_2} = 0.0435$.

2) Indicator attribute value

Through field investigation and data collection in the army, the attribute values of the early warning radar under normal conditions, jamming and anti-jamming are obtained, as shown in Table 4.

Table 4: Anti-jamming Effect Evaluation Index Attribute Value of Early Warning Radar

Evaluation indicators	P_d	R_d	P_t	δ	T_d
Before interference	0.9	230km	0.9	0.5 °	6s
After interference	0.6	110km	0.3	1.5 °	10s
After anti-jamming	0.8	200km	0.6	0.9 °	7s

3) Calculation of the utility value of each index

The utility value of each index at each stage is calculated from formulas (2) and (3), as shown in Table 5.

Table 5: Utility value of each index in each stage

Evaluation indicators	P_d	R_d	P_t	δ	T_d
Interfered pre-effect value u_0	1.223	1.683	1.265	2.000	1.412
Post-interference utility value u'	0.806	0.870	0.442	0.673	0.864
Anti-jamming post-utility value $u_{抗}$	1.113	1.505	1.076	1.111	1.174

4) Calculation of evaluation value of anti-jamming effect

According to the weight values of the primary and secondary indexes obtained in Section (1), the evaluation value of the anti-jamming effect of each index is obtained from Formula (5), as shown in Table 6.

Table 6: Evaluation Value of Anti-jamming Effect of Each Index

Evaluation indicators	P_d	R_d	P_t	δ	T_d
u_i	$0.417+j0.133$	$0.813+j0.276$	$0.082+j0.028$	$0.133+j0.019$	$0.055+j0.013$

The comprehensive anti-jamming effect evaluation value obtained from formula (6) is: $u=\sum_{i=1}^{5}u_i=1.5+j0.469$

u The coordinates can be shown in Figure 4, and the value is in the effective area of the comprehensive evaluation value.

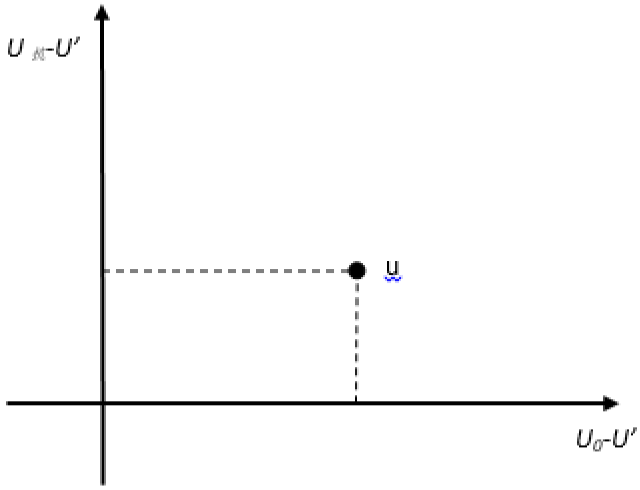

Figure 4: Coordinate position of comprehensive anti-jamming evaluation value

5. Conclusion

In this paper, the anti-jamming effectiveness evaluation based on utility criterion is proposed under the background of anti-jamming against the jamming of enemy air jammers. Calculate the discovery probability for the selected target P_d, maximum distance to detectable target R_d .The probability of making an accurate identification of the target P_t . Multi-target detection accuracy δ And continuous detection times T_d These five indexes define the overall efficiency calculation formula, quantify each index, and evaluate the anti-jamming effect through the changes of these indexes after the implementation of anti-jamming of our early warning radar, which more accurately reflects the improvement of the working ability of early warning radar after anti-jamming, provides a reference for decision makers to formulate operational plans, and assists decision makers to conduct battlefield command.

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