Ship-borne Warning Helicopter Fire Control Radar Antenna Pattern Design and Simulation

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Abstract—The design and realization of radar antenna direction chart is important in the simulation of radar system. The good design of radar antenna direction chart can improve the rate and reality of radar system simulation. Firstly this paper introduces the traditional antenna direction chart which has two bugs which are normalization and pitch angle. Because of these bugs, this paper introduces antenna direction chart function which is improved and added. This paper simulates the direction chart function. The simulation indicates that through the improved antenna direction, chart is better in pitching and direction and also approaches real radar antenna direction chart.

Keywords-radar; antenna; simulate; direction chart

I. INTRODUCTION

In simulation of radar and electronic warfare effectiveness evaluation and simulation, the design of the radar antenna is an important part is the foundational, the design of the traditional radar antenna diagram more focus on theoretical level, for the simulation design has certain insufficiency, the improvement is carried on while maintaining the original theory principle, on the basis of closer simulation application, which lays a foundation for the realization of the subsequent simulation.

II. THE TRADITIONAL ANTENNA PATTERN DESIGN

In the usual day chart, only the azimuth of the simulation is involved. The orientation of the antenna diagram function using singh function is described as below :

$$f(\theta)=\frac{1+\cos\theta}{2}\times\frac{\sin(k\sin\theta)}{k\sin\theta} \quad (1)$$

In this type, θ_b is One-way half power lobe width. And usually achieve good lord sidelobe ratio, the simulation side lobe weighted is given. A requirement for the sidelobe level is SdB (S <50db), the main lobe weighted sidelobe is zero outside parts:

$$f(\theta)=a\times\frac{|\sin(k\sin\theta)|}{|k\sin\theta|} \quad (2)$$

Figure 1 draws the sidelobe level of 20 db antenna pattern (horizontal angle value, the unit is degree, ordinate said singh function values).

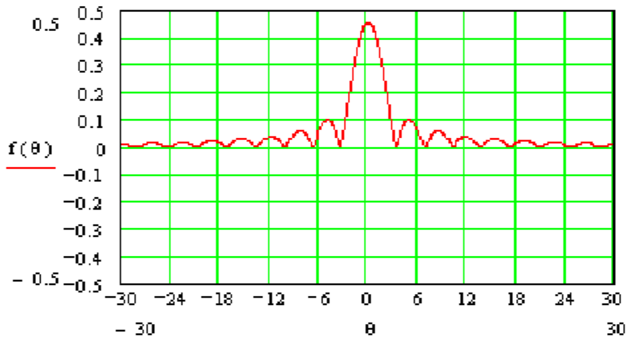

Figure 1 singh function antenna pattern

When $y(\theta)=20\log(f(\theta))$, Antenna pattern is shown in Figure 2 (horizontal angle value, the unit is degree, ordinate said amplitude values) :

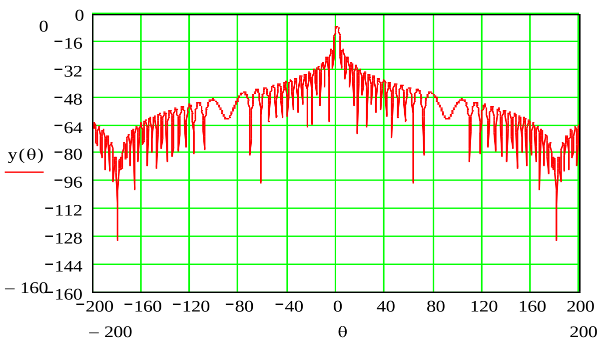

Figure 2 normalized antenna pattern

III. THE MODIFIED DESIGN OF THE ANTENNA PATTERN

Because of the type used in antenna pattern model in normalization, and the shortcomings of the pitching Angle and so on, according to the practical characteristics of modern airborne fire control radar antenna and technical parameters, the antenna orientation graph model is improved. This system adopts the single pulse radar system and adopts the four small antenna for receiving and transmitting. Total antenna mouth is evenly divided into four parts, named A, B, C, D, as shown in Figure 3 (in the antenna coordinate system, left A negative right is, is on the negative.)

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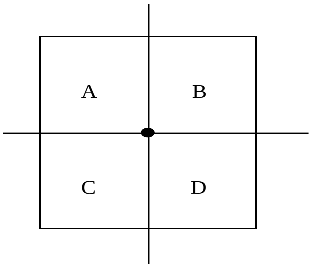

Figure 3 days radar chart

A, B, C, D are four separated points and exactly the same antenna performance. The four common points are the antenna, which is the center of the radar antenna axis and is not only the mechanical shaft radar antenna, but also the radar antenna electrical axis.

Target echo from A, B, C, D four antenna into and poor. After dealing with the addition subtraction and difference (CCM), in the outlet and road:

$$\Sigma = A + B + C + D \tag{3}$$

In the poor road:

$$\Delta A = (B + D) - (A + C) \tag{4}$$

$$\Delta H = (A + B) - (C + D) \tag{5}$$

Corresponding to the antenna pattern functions are:

$$f\Sigma(\sigma,\phi) = fA(\sigma,\phi) + fB(\sigma,\phi) + fC(\sigma,\phi) + fD(\sigma,\phi) \tag{6}$$

$$f\Delta A(\sigma,\phi) = fB(\sigma,\phi) + fD(\sigma,\phi) - fA(\sigma,\phi) - fC(\sigma,\phi) \tag{7}$$

$$f\Delta H(\sigma,\phi) = fA(\sigma,\phi) + fB(\sigma,\phi) - fC(\sigma,\phi) - fD(\sigma,\phi) \tag{8}$$

Four antenna patterns are:

$$fA(\sigma,\phi) = G \times a_1(t\times\sigma_A)\frac{1+\cos(t\times\sigma_A)}{2}\times\frac{|\sin(k_1\times\sin(t\times\sigma_A))|}{|k_1\times\sin(t\times\sigma_A)|} \times a_2(t\times\phi_A)\frac{1+\cos(t\times\phi_A)}{2}\times\frac{|\sin(k_2\times\sin(t\times\phi_A))|}{|k_2\times\sin(t\times\phi_A)|} \tag{9}$$

$$fB(\sigma,\phi) = G \times a_1(t\times\sigma_B)\frac{1+\cos(t\times\sigma_B)}{2}\times\frac{|\sin(k_1\times\sin(t\times\sigma_B))|}{|k_1\times\sin(t\times\sigma_B)|}\times a_2(t\times\phi_B)\frac{1+\cos(t\times\phi_B)}{2}\times\frac{|\sin(k_2\times\sin(t\times\phi_B))|}{|k_2\times\sin(t\times\phi_B)|} \tag{10}$$

$$fC(\sigma,\phi) = G \times a_1(t\times\sigma_C)\frac{1+\cos(t\times\sigma_C)}{2}\times\frac{|\sin(k_1\times\sin(t\times\sigma_C))|}{|k_1\times\sin(t\times\sigma_C)|} \times a_2(t\times\phi_C)\frac{1+\cos(t\times\phi_C)}{2}\times\frac{|\sin(k_2\times\sin(t\times\phi_C))|}{|k_2\times\sin(t\times\phi_C)|} \tag{11}$$

$$fD(\sigma,\phi) = G \times a_1(t\times\sigma_D)\frac{1+\cos(t\times\sigma_D)}{2}\times\frac{|\sin(k_1\times\sin(t\times\sigma_D))|}{|k_1\times\sin(t\times\sigma_D)|} \times a_2(t\times\phi_D)\frac{1+\cos(t\times\phi_D)}{2}\times\frac{|\sin(k_2\times\sin(t\times\phi_D))|}{|k_2\times\sin(t\times\phi_D)|} \tag{12}$$

Respectively to mark on the type of parameter:

(1) G is four beam amplitude weighting for the synthesis of a beam.

(2)Perspective transformation for arc factor is $t = \dfrac{\pi}{180}$ (because of using the pitching Angle and azimuth angle).

(3) σ is Antenna azimuth. σ_A is $\sigma_A = \sigma + \sigma_0$, σ_B is $\sigma_B = \sigma - \sigma_0$, σ_C is $\sigma_C = \sigma + \sigma_0$, σ_D is $\sigma_D = \sigma - \sigma_0$,Antenna mechanical axis and space target azimuth is σ;

The biggest gain of the antenna pattern axis direction and the antenna azimuth is σ_0;

(4) ϕ is Antenna pitching angle. For the antenna ϕ_A,a pitching angle is $\phi_A = \phi + \phi_0$; for the antenna ϕ_B, a pitching angle is $\phi_B = \phi - \phi_0$; for the antenna ϕ_C, a pitching angle is $\phi_C = \phi + \phi_0$; for the antenna ϕ_D, a pitching angle is $\phi_D = \phi - \phi_0$;

Antenna mechanical axis of the pitch angle and space target is ϕ;

The biggest gain of the antenna pattern direction of the pitch angle and antenna axis is ϕ_0;

(5) A single figure in the direction of the beam singh function coefficient is $k_1 = \dfrac{1.3916}{\sin(t\times\frac{\theta_b}{2})}$, a single beam bearing beam width is θ_b;

(6) A single figure in the direction of the beam singh function coefficient is $k_2 = \dfrac{1.3916}{\sin(t\times\frac{\theta_a}{2})}$, a single beam longitudinal beam width is θ_a;

(7) Sidelobe antenna beam azimuth weighting factor is $a_1(\sigma)$.

$$a_1(\sigma) = \begin{cases} 10^{-0.05(S-13.26)} & |\sigma| \geq \dfrac{\pi}{k_1} \\ 1 & |\sigma| < \dfrac{\pi}{k_1} \end{cases} \tag{13}$$

(8) Antenna beam pitch sidelobe weighted factor is $a_2(\sigma)$.

$$a_2(\sigma) = \begin{cases} 10^{-0.05(S-13.26)} & |\sigma| \geq \dfrac{\pi}{k_2} \\ 1 & |\sigma| < \dfrac{\pi}{k_2} \end{cases} \tag{14}$$

This radar simulation sets the main pay disc as S = 20 db, which is a single small antenna beam azimuth with beam width of $\theta_b = 1.6^\circ$, a single small pitch beam with the width of $\theta_a = 4.2^\circ$, composite beam antenna and azimuth half power beam with the width of $2\sigma = 1.6^\circ$, composite beam antenna and pitch half power beam with the width of $2\phi = 4.2^\circ$. According to the normalized gain for one and a half, and the relationship between power point will be more parameters in the normalized antenna and the direction map function $f\Sigma(\sigma,\phi) = fA(\sigma,\phi) + fB(\sigma,\phi) + fC(\sigma,\phi) + fD(\sigma,\phi)$, namely:

$$f\Sigma(0,0) = 4\cdot G\cdot\frac{1+\cos(t\sigma_0)}{2}\cdot\frac{|\sin(k_1\sin(t\sigma_0))|}{|k_1\sin(t\sigma_0)|}\cdot\frac{1+\cos(t\phi_0)}{2}\cdot\frac{|\sin(k_2\cdot\sin(t\phi_0))|}{|k_2\cdot\sin(t\phi_0)|} = 1 \tag{15}$$

$$f\Sigma(\sigma,0) = G\cdot\left(\frac{1+\cos(t\phi_0)}{2}\cdot\frac{|\sin(k_2\cdot\sin(t\phi_0))|}{|k_2\sin(t\phi_0)|}\right)\cdot$$
$$[a_1(t(\sigma-\sigma_0))\cdot 1+\cos[t(\sigma-\sigma_0)]\cdot\frac{|\sin[k_1\cdot\sin(t(\sigma-\sigma_0)]|}{|k_1\sin(t(\sigma-\sigma_0))|}$$
$$+a_1(t(\sigma+\sigma_0))\cdot 1+\cos[t(\sigma+\sigma_0)]\cdot\frac{|\sin[k_1\cdot\sin(t(\sigma+\sigma_0)]|}{|k_1\sin(t(\sigma+\sigma_0))|}]$$

$$f\Sigma(0,\phi) = G\cdot\left(\frac{1+\cos(t\sigma_0)}{2}\cdot\frac{|\sin(k_2\cdot\sin(t\sigma_0))|}{|k_2\sin(t\sigma_0)|}\right)\cdot$$
$$[a_2(t(\phi-\phi_0))\cdot 1+\cos[t(\phi-\phi_0)]\cdot\frac{|\sin[k_1\cdot\sin(t(\phi-\phi_0)]|}{|k_1\sin(t(\phi-\phi_0))|}$$
$$+a_1(t(\phi+\phi_0))\cdot 1+\cos[t(\phi+\phi_0)]\cdot\frac{|\sin[k_1\cdot\sin(t(\phi+\phi_0)]|}{|k_1\sin(t(\phi+\phi_0))|}]$$

Available, amplitude weighting factor G = 0.475366, azimuth = 0.610689, pitching angle = 1.63548.

IV. ADVANCED ANTENNA PATTERN SIMULATION IMPLEMENTATION

The parameters obtain above generation into four small antenna antenna pattern, the available antennas and beam:

$$f\Sigma(\sigma,\phi) = fA(\sigma,\phi) + fB(\sigma,\phi) + fC(\sigma,\phi) + fD(\sigma,\phi) \tag{16}$$

Antenna azimuth difference beam:

$$f\Delta A(\sigma,\phi) = fB(\sigma,\phi) + fD(\sigma,\phi) - fA(\sigma,\phi) - fC(\sigma,\phi) \tag{17}$$

Figures available and direction (angle of 60 degree to 60 degree, the pitching angle of 0 degree) are shown in Figure 4 below (and the solid line shows the antenna beam and dotted line antenna azimuth difference beam with the horizontal angle respectively of 60 degree to 60 degree and the vertical said normalized values) :

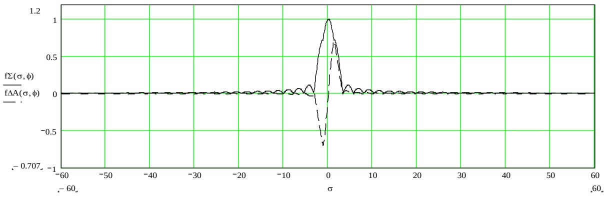

Figure 4 the antenna beam and azimuth difference beam

Available antennas and beam:

$$f\Sigma(\sigma,\phi) = fA(\sigma,\phi) + fB(\sigma,\phi) + fC(\sigma,\phi) + fD(\sigma,\phi) \tag{20}$$

The antenna elevation difference beam:

$$f\Delta H(\sigma,\phi) = fA(\sigma,\phi) + fB(\sigma,\phi) - fC(\sigma,\phi) - fD(\sigma,\phi) \tag{21}$$

Available and direction graphs (pitching angle of 60 degree to 60 degree, the azimuth angle of 0 degree) are shown in Figure 5 below (and the solid line shows the antenna beam and dotted line antenna elevation difference beam with horizontal angle of respectively 60 degree to 60 degree, the vertical said normalized values) :

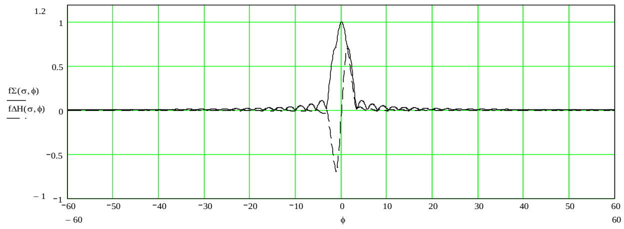

Figure 5 the antenna beam and elevation difference beam

In order to analyze the problem definition, it is convenient to do the following:

Definition 1: meteorological visibility R_0 weather conditions at the time, the airborne radar maximum detection range.

Definition 2: the earth curvature stadia R_D when considering the earth curvature effects of the chase depending on the distance.

As shown in Figure6, in order to target distribution center M as the center of the circle, respectively, to detect distance R_0, enemy anti-aircraft fire range d_{mk} for the radius, draw arc $d_{mk} \le R_0$ on the surface of the optical axis vertical.

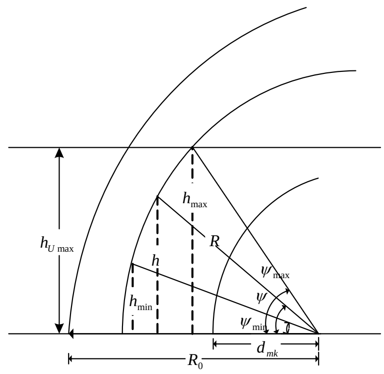

Figure 6. flying height limit range analysis diagram

Obviously, under a given detection range $R \le R_0$, the flight height is h, beam angle of depression is ψ which has the maximum and minimum values.

Decision ψ_{max} factors as follows:

(1) Ship-borne warning helicopter maximum height ceiling $h_{U\max}$

(2) Airborne radar beam load maximum depression angle limits.

Therefore, it can be determined under a given detection range $R \le R_0$, the maximum flying height of the ship-borne warning helicopter h_{max} and the maximum limits of beam angle of depression ψ_{max} are as follows:

$$\begin{cases} \psi_{\max} = \min\left(\psi_{U\max}, \arcsin\left(\frac{h_{U\max}}{R}\right)\right) \\ h_{\max} = R \cdot \sin(\psi_{\max}) \end{cases} \tag{18}$$

The key factors of the maximum h value are:

Ship-borne warning helicopter maximum height ceiling $h_{U\max}$ (in the case of only $h_{U\max} < R$ discuss).

The key factors of the minimum value h:

(1) Ship-borne warning helicopter minimum safe altitude $h_{U\min}$.

(2) The earth curvature sights $R_D = 4.12\left(\sqrt{h_{\min}} + \sqrt{h_m}\right)$.

(3) Carrying ship of ship-borne warning helicopter effective communication distance d_{TX}.

Obviously, given the detection distance $R \le R_0$, the ship-borne warning helicopter to effective detecting target, the minimum altitude should satisfy:

$$h_{\min} \ge h_1 = \left(\frac{R}{4.12} - \sqrt{h_m}\right)^2 \tag{19}$$

In formation against the distance d_{wm} between the ship and ship-borne, warning helicopter for effective communication, the minimum altitude ship-borne warning helicopter should satisfy:

$$h_{\min} \ge h_2 = \left(\frac{d_{wm}}{4.12} - \sqrt{h_w}\right)^2 \tag{20}$$

Among them:

$d_{wm} \le d_{TX}$, h_w carrier communication antenna height (/m).

Therefore, itcan be determined under a given detection range $R \le R_0$, minimum flying height of ship-borne warning helicopter $h_{\min}$ and minimum limits of beam Angle of depression $\psi_{\min}$ are as follows:

$$\begin{cases} h_{\min} = \max\left(h_{U\min},\ h_1,\ h_2,\ R\sin\psi\right) \\ \psi_{\min} = \arcsin\left(\frac{h_{\min}}{R}\right) \end{cases} \tag{21}$$

V. THE SIMULATION ANALYSIS

(1) set the simulation conditions

According to the actual combat of battlefield situation, set up the simulation conditions are as follows: $h_{U\max} = 3500m$, $d_{TX} = 150km \sim 80km$, $h_w = 25m$, $h_m = 16m$, $h_{U\min} = 500m$

Model detection of the simulation results of characterization in a given distance R, the distance between the enemy formation d_{wm}, the height of ship-borne warning helicopter detecting h, the scope of pitching Angle of the beam ψ. The calculation results are shown in Table 2.

TABLE I SHIP-BORNE WARNING HELICOPTER SEARCH PARAMETERS

Search parameters range / Detection distance/km	D_1		D_2		D_3		D_4	
	$(h_{\min}/h_{\max})$	$(\psi_{\min}/\psi_{\max})$	$(h_{\min}/h_{\max})$	$(\psi_{\min}/\psi_{\max})$	$(h_{\min}/h_{\max})$	$(\psi_{\min}/\psi_{\max})$	$(h_{\min}/h_{\max})$	$(\psi_{\min}/\psi_{\max})$
d_1	(582.1/3500)	(0.83/5.02)	(500/3500)	(0.72/5.02)	(500/3500)	(0.72/5.02)	(500/3500)	(0.72/5.02)
d_2	(582.1/3500)	(0.67/4.01)	(500/3500)	(0.57/4.01)	(500/3500)	(0.57/4.01)	(500/3500)	(0.57/4.01)
d_3	(582.1/3500)	(0.56/3.34)	(500/3500)	(0.48/3.34)	(500/3500)	(0.48/3.34)	(500/3500)	(0.48/3.34)
d_4	(582.1/3500)	(0.48/2.87)	(500/3500)	(0.41/2.87)	(500/3500)	(0.41/2.87)	(500/3500)	(0.41/2.87)
d_5	(582.1/3500)	(0.42/2.51)	(500/3500)	(0.36/2.51)	(500/3500)	(0.36/2.51)	(500/3500)	(0.36/2.51)
d_6	(582/3500)	(0.37/2.23)	(500/3500)	(0.32/2.23)	(500/3500)	(0.32/2.23)	(500/3500)	(0.32/2.23)
d_7	(582/3500)	(0.33/2.00)	(500/3500)	(0.27/2.00)	(500/3500)	(0.27/2.00)	(500/3500)	(0.27/2.00)
d_8	(582/3500)	(0.30/1.82)	(515.2/3500)	(0.27/1.82)	(515.2/3500)	(0.27/1.82)	(515.2/3500)	(0.27/1.82)
d_9	(631/3500)	(0.30/1.67)	(631.3/3500)	(0.30/1.67)	(631.3/3500)	(0.30/1.67)	(631.3/3500)	(0.30/1.67)
d_{10}	(759/3500)	(0.33/1.54)	(759.1/3500)	(0.33/1.54)	(759.1/3500)	(0.33/1.54)	(759.1/3500)	(0.33/1.54)

(2) the use of Table 1

a. to determine the use of airborne radar beam pitching Angle.

b. according to the battlefield, situation is used to target detection distance.

c. To determine the ship-borne warning helicopter flew to the task area, the distance between the enemy formations.

(3) according to the combat mission against distance, to find that the distance required by the requirement of

ship-borne warning helicopter flight height and pitch range of the beam.

(4) the altitude in the table and the use of the visual axis bow angle range and control method.

If you want to always stay in determining the maximum effective detection range of target search, by choosing the corresponding maximum flying height in pitching angle of the beam. When it comes to lower altitude and wants to keep the maximum effective detection range, it should increase the pitching angle of the beam, the visual axis should be brought up. When raising altitude and the maximum effective detection range should be kept, pitching angle of the beam,should be reduced and the visual axis should be brought to the press.

VI. CONCLUSION

Ship-borne warning helicopter should determine its operational method of use in a fleet air defense combat, the design method can effectively calculate the airspace cumulative detection probability that the ship-borne warning helicopter detect on a particular incoming target a location, and it can provide the commander with no less than the one target probability search the target distance, so as to determine the scope of the flight altitude and pitching angle of the beam and provides reference for ship-borne warning helicopter fleet air defense combat use.

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