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Design and Simulation of Conformal Phased Array Antenna

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Abstract. A method of arbitrary conformal antenna pattern transformation from global coordinates to local coordinates is given firstly. Then a conical conformal array with configuration of equal angle is modeled. At last the performance of beam with the configuration is analyzed, simulation result shows the beam width is 3.6° and the sidelobe level is lower than -12dB.

Keywords: a conical conformal array, beam, arbitrary conformal antenna pattern, modeled.

1. Introduction

Antenna is the main energy converter of radar seeker. It converts the transmitted signal into space radiation field, and converts the echo signal reflected by the target into guided wave field and sends it to the receiver. Therefore, antenna design plays an important role in the design of radar seeker. The development of radar seeker antenna mainly includes cone-scan antenna, monopulse parabolic antenna and waveguide slot array antenna. Although this kind of antenna can search and track the target, its scanning mode is mechanical scanning, which needs precise servo system to complete. Therefore, its angle scanning range is small, tracking speed is slow and volume is large.

Phased array antenna has the advantages of fast beam scanning speed, flexible control and strong anti-jamming performance because it uses electronic scanning instead of mechanical scanning. At present, the phased array antenna is mainly planar array antenna. Its design technology is relatively mature, but there are some shortcomings. Its beam scanning range is narrow, beam width and sidelobe level will increase with the increase of scanning angle, and array gain will decrease with the increase of scanning angle. In order to fully satisfy the design requirements of the moving platform, the radiation units of the phased array antenna are installed on the surface of the moving platform to make it coincide with the surface of the moving platform. A conformal phased array antenna can be formed, where the moving platform can be a carrier of aircraft, missiles, ships and so on. Conformal phased array antenna is the combination of conformal array and phased array, so it can overcome the shortcomings of planar antenna, realize beam scanning with wide angle and wide range, and keep the antenna gain and beam shape unchanged during scanning. It can also improve the aerodynamic performance of carrier and reduce the cross-section area of radar. Therefore, conformal phased array antenna has become a new important development direction of radar antenna technology.

2. Pattern of Arbitrary Directed Array Element

Let array elements be mounted on any surface, the number is N, as shown in Figure 1. Assuming the position of the element is (x_n, y_n, z_n), its corresponding position vector is:

$$\vec{r}_n = x_n\vec{u}_x + y_n\vec{u}_y + z_n\vec{u}_z \tag{1}$$

Assuming that the elevation angle and azimuth angle of the target direction is θ and ϕ, the unit vector of the target direction is:

$$\vec{u}_R = \sin\theta\cos\phi\vec{u}_x + \sin\theta\sin\phi\vec{u}_y + \cos\theta\vec{u}_z \tag{2}$$

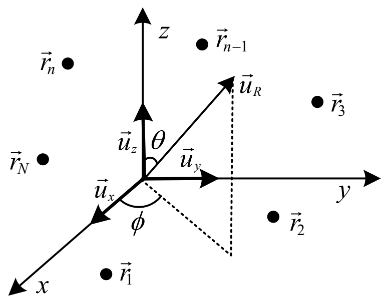

Figure 1. Pattern of arbitrary directed array

When the coordinate origin is selected as the phase reference point O, the phase difference corresponding to the element n is as follows:

$$\beta_n = -k(\vec{r}_n \cdot \vec{u}_R),\, k = 2\pi/\lambda \tag{3}$$

Assume that the orientation function of the element n in the global coordinate system is $f_n(\theta,\phi)$, the guiding vector of the conical conformal phased array antenna is:

$$V(\theta,\phi) = \left[f_1(\theta,\phi)e^{-j\beta_1}, f_2(\theta,\phi)e^{-j\beta_2}, ..., f_N(\theta,\phi)e^{-j\beta_N}\right]^T \tag{4}$$

Assume the unit vector in the (θ_T,ϕ_T) direction of the desired signal be:

$$\vec{u}_T = \sin\theta_T \cos\phi_T \vec{u}_x + \sin\theta_T \sin\phi_T \vec{u}_y + \cos\theta_T \vec{u}_z \tag{5}$$

The phase difference in the desired direction is:

$$\beta_T = -k(\vec{r}_n \cdot \vec{u}_T) \tag{6}$$

Suppose that the complex weighted vector of the element n is:

$$w_n = A_n e^{j\alpha_n} e^{-j\beta_T} \tag{7}$$

Weighted amplitude is A_n, and weighted phase is α_n. The far field pattern (θ,ϕ) of the conical conformal phased array antenna is as follows:

$$E(\theta,\phi) = \sum_{n=1}^{N} w_n^* f_n(\theta,\phi)e^{-j\beta_n} = W^H V \tag{8}$$

$$W = \left[w_1, w_2, ..., w_N\right]^T \tag{9}$$

From the formula (9) we can see that beam scanning can be achieved by changing the weighted phase of each element. However, the sidelobe level of uniformly weighted element is higher. Therefore, the weighted amplitude and weighted phase must be optimized simultaneously in order to obtain the desired pattern, i.e. pattern synthesis. In conformal phased array antenna, the radiation pattern of each element is different because its location is not on the same plane. Even if the direction pattern of each element is the same in its local coordinate system, the radiation pattern of each element varies greatly in the global coordinate system of the conformal array because of the different relative rotation angles. Therefore, the derivation of conformal array is solved. When vectoring, the pattern of each antenna element needs to be transformed from local coordinate system to global coordinate system.

3. Conical Conformal Phased Array Configuration

Conformal phased array antenna arrays are arranged in concentric circles with equal angles as shown in Figure 2 and Figure 3. the projection of antenna arrays in xy plane is shown in Figure 2, and Figure 3 is the geometric structure of the whole antenna array.

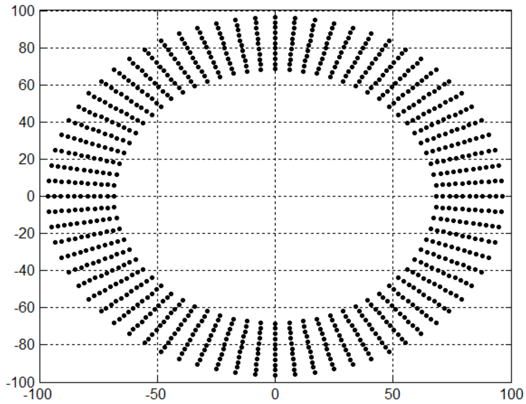

Figure 2. Projection in xy plane

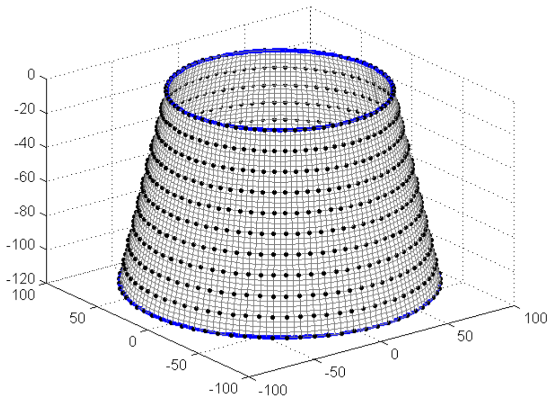

Figure 3. Geometric structure

From the z-axis direction, the array elements are aligned along the cone generatrix direction. From the xy plane view, the array can be seen as composed of several circular subarrays with the same number of elements, each of which is evenly spaced on the ring with the starting angle 0°. In the z-axis direction, there is a circular ring array of M with equal spacing. The vertical spacing between the ring and the ring is d_z, and the angular spacing between the elements on each ring is $\Delta\phi$, the number of elements is:

$$N = ceil(2\pi / \Delta\phi) \tag{10}$$

$ceil$ is the integral function, circle radius of m is:

$$R_m = R_0 + (m-1) \times d_z \times \tan(\theta_0) \tag{11}$$

therefore, the element position of n in circle m is:

$$\begin{aligned} x_{mn} &= R_m \cos[(n-1)\Delta\phi] \\ y_{mn} &= R_m \sin[(n-1)\Delta\phi] \\ z_{mn} &= h-(m-1)\times d_z \end{aligned} \tag{12}$$

4. Simulation Results

Assume cone height is $h=13\lambda$, the top radius is $R_0=8.5\lambda$, the cone angle is $\theta_0=14^\circ$, the center frequency is 35GHz, array elements are arranged in concentric circle and equal angle, and it is composed of $M=21$ circular array. The vertical distance between the ring and the ring is $d_z=0.65\lambda$, the angular spacing between elements on each ring is $\Delta\phi=3.5^\circ$.

The antenna element is conformal to the cone surface, and the whole conformal phased array antenna array is divided into several sub-arrays. In order to achieve wide-angle and wide-range beam scanning, sub-array switching mode can be used in azimuth plane to achieve beam scanning, and phased scanning mode can be used in elevation plane. Assuming that the azimuth angle covered by each subarray is 90 degrees, the number of elements contained in the subarray is 525.

Assuming that the beam is directed in the normal direction of the cone $(76^\circ,0^\circ)$, the beam patterns on the azimuth and elevation planes are shown in Figures 4 and Figures 5. Figure 4 shows that the main lobe width is -14dB and the side lobe level is -14dB. Figure 5 shows that the width of the main lobe in the elevation plane is also the same, and the sidelobe level is -12dB.

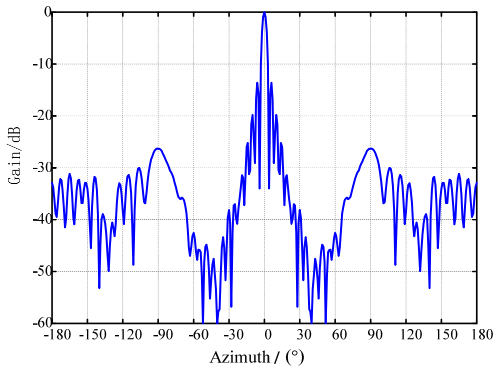

Figure 4. Azimuth plane

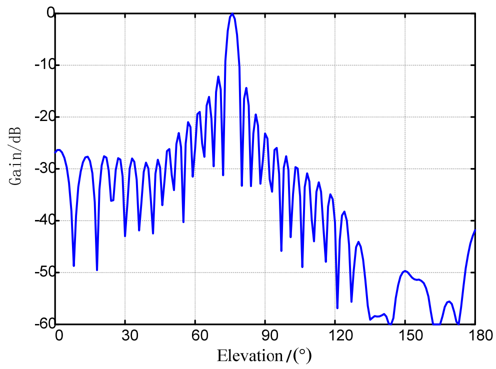

Figure 5. Elevation plane

5. Conclusion

Conformal phased array antenna has become an important direction of radar antenna technology development. In this paper, based on the application background of compound guidance radar seeker, the directional pattern function of arbitrary directional array is deduced firstly, then the conical conformal phased array antenna model is established by concentric circle configuration with equal angle, and the directional pattern function of the antenna array is obtained under this configuration.

Finally, the beam characteristics of the conformal phased array antenna are analyzed under this configuration. The simulation results show that the beam width of the conformal phased array antenna is both in azimuth and elevation, and the sidelobe level is below -12dB.

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