Radome Boresight Error Optimization by Array Pointing

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Abstract: ***Aiming at the boresight error control problem in the radome design, based on the analysis of the space radiation characteristics of the masked array antenna, a method for controlling the boresight error of the radome through the iterative optimization of array pointing is proposed. By optimizing a 16-element array antenna with a 4-phase shifter and a tangent oval radome system, it is verified that the method can effectively complete the design of the antenna system with a cover.***

Keywords: radome, boresight error, optimization

1. Introduction

Boresight error affects the tracking accuracy of the antenna and is a key indicator in the design of the radome [1]. Most of the current low boresight error radomes are designed with variable thickness [2][3]. In order to accurately determine the thickness of each station site, evolutionary algorithms are usually used to optimize [4][5]. The evolutionary algorithm directly uses the far-field parameters as the design basis to make it possible to effectively suppress the boresight error. However, in the optimization process, it requires calculating the radiation far-field of the covered antenna for each sample to be evaluated, which brings huge Calculation amount [6].

This article establishes a rapid design method for radome multi-angle boresight error optimization, and realizes it through the state adjustment of the low-bit digital phase shifter. In this paper, a rapid correction method of boresight error based on array pointing iteration is proposed, and a tangent oval radome containing 16-element linear array is optimized by this method, and satisfactory calculation results are obtained.

2. Analytical Method

In the two-dimensional model shown in Figure 1, the phased array antenna is a set of infinitely long line current excitation sources parallel to the z axis.

$$I_n = A_n e^{j\phi_n}, \qquad n = 1,2,\cdots,N \tag{1}$$

Here, n is the number of the array element, and A and ϕ represent the amplitude and phase of the current respectively.

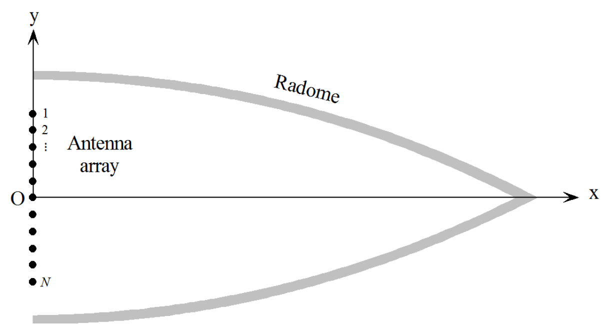


Figure 1: Antenna array with a radome

The radiated electric field of the antenna array only has a z-direction component, and the incident electric field at the p split unit on the inner surface of the radome is

$$E_{z,p} = -\sum_{n=1}^{N} \frac{\omega\mu_0}{4} H_0^{(2)}(k\rho_{pn}) I_n, \qquad p = 1,2,\cdots,P \tag{2}$$

Among them, ω is the electromagnetic wave angular frequency, k is the free space wave number, μ_0 is the free space permeability, ρ is the distance between the source point and the field point, and $H_0^{(2)}$ is the second kind of zero-order Hankel function. The tangential electric field and tangential magnetic field on the outer surface of the radome are respectively [7]

$$\boldsymbol{E}_t = [(\boldsymbol{b}\cdot\boldsymbol{E}_i)\boldsymbol{b}]T_\perp + [(\boldsymbol{t}\cdot\boldsymbol{E}_i)\boldsymbol{t}]T_{//} \tag{3}$$

$$\boldsymbol{H}_t = [(\boldsymbol{b}\cdot\boldsymbol{H}_i)\boldsymbol{b}]T_{//} + [(\boldsymbol{t}\cdot\boldsymbol{H}_i)\boldsymbol{t}]T_\perp \tag{4}$$

In the formula, $T_{//}$ is the parallel polarization transmission coefficient, $T_\perp$ is the vertical polarization transmission coefficient, $\boldsymbol{b}$ is the unit vector of the vertical polarization direction of the incident surface, and $\boldsymbol{t}$ is the unit vector of the parallel polarization direction. The equivalent electromagnetic current on the outer surface of the cover can be expressed as

$$\boldsymbol{J} = \boldsymbol{n}\times\boldsymbol{H}_t, \qquad \boldsymbol{M} = \boldsymbol{E}_t\times\boldsymbol{n} \tag{5}$$

Among them, $\boldsymbol{n}$ is the unit external normal vector of the equivalent surface. The radiation field of the equivalent electromagnetic current in two-dimensional space is

$$\boldsymbol{E}_{\mathrm{far}} = \frac{1}{4j}\int_l \left[kH_1^{(2)}(k\rho)(\boldsymbol{M}\times\boldsymbol{\rho}) - j\omega\mu_0 H_0^{(2)}(k\rho)\boldsymbol{J}\right]dl \qquad (6)$$

When the antenna scanning angle is ν, the theoretical phase value of the array element should be

$$\phi_n = \frac{2\pi}{\lambda} nd\sin\nu \qquad (7)$$

Where λ is the wavelength and d is the distance between the array elements. Substituting $\phi_n(\nu)$ into equation (1), after calculation, the actual direction $\mathrm{R}(\nu)$ of the antenna system with cover can be obtained.

Aiming at the axisymmetric radome with uniform structure and continuous profile, this paper designs an iterative optimization process to adjust ν, so that $\mathrm{R}(\nu)$ is close to the target pointing angle θ, as follows

$$\nu_0 = \theta \qquad (8)$$

$$\nu_{i+1} = \nu_i - \psi_i \ , \quad i = 0,1,2,\cdots \qquad (9)$$

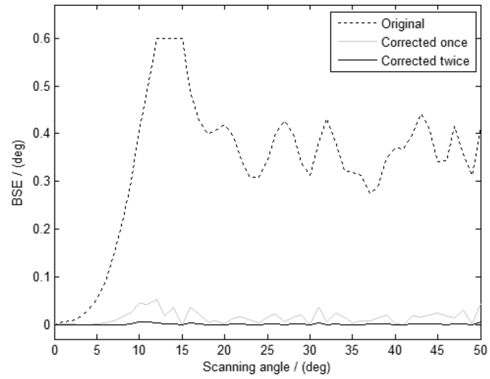
$$\psi_i = \mathrm{R}(\nu_i) - \theta \qquad (10)$$

Because the radome profile is continuously gradual in space, and there is no sudden change in the material distribution, according to the local convergence theorem of fixed point iteration [8], it can be proved that the iterative scheme locally converges, and the iteration can be effectively realized.

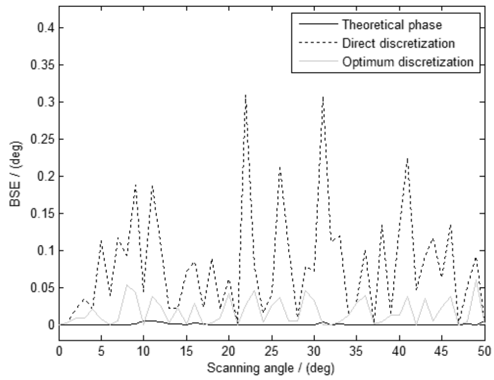
3. Calculation and Analysis

Optimize the boresight error of a tangent oval radome containing a linear array. The 16-element constant-amplitude linear array has a spacing of 0.5λ and a frequency of 13GHz. The number of bits of the digital phase shifter is set to 4. The length of the radome is 24λ, the bottom diameter is 12λ, the cover thickness is 0.2823λ, the relative dielectric constant is 4, and the loss tangent is 0.015.

To optimize the boresight error of the difference pattern, the scan angle range of the cover antenna system is selected from 0 to 50° with an interval of 1°. Figure 2(a) shows the iterative correction process of boresight error for adjusting the theoretical pointing of the antenna. It can be seen that after two iterative corrections, the boresight error of the system has been lower than 0.006°, because the phase digital dispersion will also introduce a larger error, so there is no The need to continue iterating. In addition, it can be noted that when the scanning angle is 12 to 15°, the boresight error value before correction is 0.6°. This is because the calculation accuracy is lower when the boresight error is large. In order to improve the calculation efficiency, when calculating the far field, first calculate the system pointing error according to the calculation interval of 0.1°. If the pointing error is within the range of ±0.5°, it is solved in detail at the calculation interval of 0.001°. The digital discrete effect of the theoretical phase is shown in Figure 2(b). The boresight error of the 4-phase shifter system does not exceed 0.061°.



(a) Theoretical pointing correction



(b) Digital phase realization

Figure 2: Boresight error optimization of difference pattern

The boresight error optimization result for the sum pattern is shown in Figure 3. After iterative pointing correction and phase discretization, the maximum boresight error of the system is 0.065°. Figure 4 and Figure 5 respectively show the difference pattern and the sum pattern before and after the system optimization when the scanning angle is 20 degrees. It can be seen that although the fitness function in the optimization process only reflects the boresight error, the optimization does not change the distribution of the pattern, and the main lobe width and side lobe electrical average are not significantly affected.

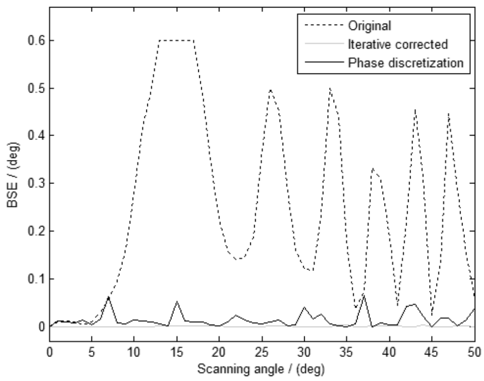


Figure 3: Boresight error optimization of sum pattern

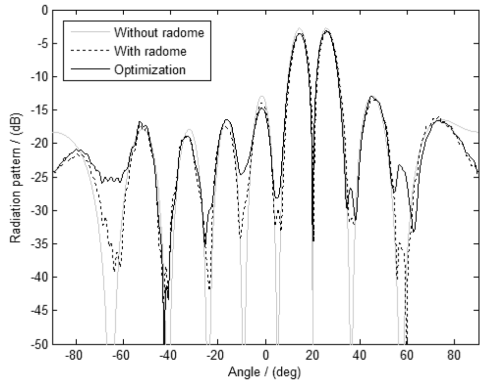


Figure 4: Difference pattern before and after optimization

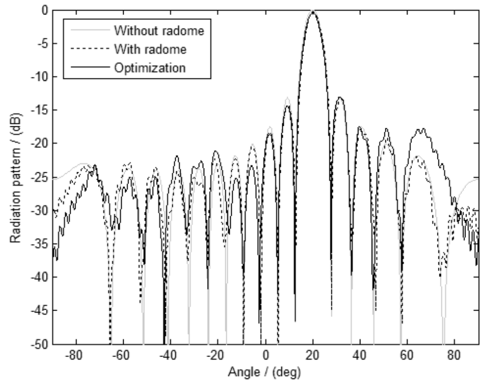


Figure 5: Sum pattern before and after optimization

4. Conclusion

This paper proposes a radome multi-angle boresight error optimization technology. Through the establishment of a fast iterative algorithm, the correction of the pointing angle of the radome can be achieved, which can significantly improve the calculation efficiency during the optimization design process, and facilitate the realization of a large number of optimizations for the complete range of scan angle.

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Author Profile

WANG Wei received the B.E. degree in electronics and information technology, the Master's degree in aerospace propulsion theory and engineering and the Ph.D. degree in electronic science and technology from the Northwestern Polytechnical University, Xi'an, China. Since 2015, he has been a lecturer in Xi'an Aeronautics University. His current research interests include antenna and radome design, electromagnetic scattering analysis and intelligent optimization algorithm.