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# Integration Multi-Objective Optimization Method of Airborne Radome System

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**Abstract:** ***To improve the characteristics of boresight error (BSE) and power transmission coefficient in a phased array antenna-radome system, an integration optimization method, adjusting radome structure and antenna excitation successively, is studied. A multi-objective fitness function is designed for the particle swarm optimization (PSO), which obtain the performance parameters by Aperture Integration-Surface Integration (AI-SI) method. The results obtained are compared with those achieved by pure radome optimization, showing the effectiveness of the proposed method.***

**Keywords:** Radome, Antenna array, Boresight error, Power transmission coefficient.

## 1. Introduction

Radome is an essential part of airborne radar system, to protect the antenna from the effects of harsh external environment. Since radome is installed very close to antenna, radome can cause refraction and reflection of antenna radiation wave, and thus affect the performance of antenna. The purpose of radome optimization design is to reduce the adverse impact of radome on antenna.

Variable thickness radome, being widely used in recent years, can be designed on the ray incident angle of local radome wall [1]. But more precise radome designs often need the help of evolutionary algorithms. Hsu optimized the BSE of single-layered radome with simulated annealing technique [2]. After that, genetic algorithm [3], immune clone algorithm [4], and particle swarm algorithm [5] were applied to the optimization design of radome. These studies focused on radome structural design, while ignoring the potential role of antenna in the optimization of antenna-radome system.

In this paper, an integrated optimization method combining radome structure parameters and antenna radiation parameters is employed to simultaneously optimize the boresight error (BSE) and power transmission coefficient. The proposed method is used for the optimization of 25 elements antenna array- A-sandwich radome system. The following sections present the applied technique and results.

## 2. Optimization Method

### 2.1 Radiation calculation

In order to obtain the performance parameters of design optimization, Aperture Integration-Surface Integration (AI-SI) method [6] is employed to calculate the far radiation field of antenna-radome system. As shown in Fig. 1, a set of infinite long current source is used to represent a phased array antenna inside a radome, and the current of array element is,

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

where $A$ and $\phi$ represent the amplitude and phase of $I$, and will be adjusted in the integration optimization. $n$ is the array element index.

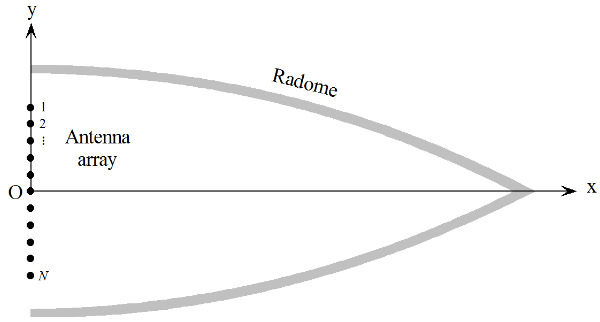


**Figure 1:** Antenna array with a radome

By analyzing the dielectric material distribution of local wall structure, we can get local transmission coefficient of radome wall [7]. When the array antenna radiation field of inner radome surface is calculated, the field of outer surface can be solved by local transmission coefficient. Then far field will be calculated on the basis of Huygens's principle,

$$\psi(\boldsymbol{\rho}) = \int_{\Gamma}\left[\psi(\boldsymbol{\rho}')\frac{\partial G_0(\boldsymbol{\rho},\boldsymbol{\rho}')}{\partial \boldsymbol{n}'} - G_0(\boldsymbol{\rho},\boldsymbol{\rho}')\frac{\partial \psi(\boldsymbol{\rho}')}{\partial \boldsymbol{n}'}\right]d\Gamma' \tag{2}$$

where $\psi$ represent the field to be calculate, $\boldsymbol{\rho}'$ and $\boldsymbol{\rho}$ are points location of radome outer surface and far field, $G_0$ is the scalar Green's function, $\Gamma$ is the contour of radome outer surface, $\boldsymbol{n}'$ is the unit vector normal to $\Gamma$.

### 2.2 Integration optimization

Assuming that $G_m$ represents a certain kind of performance parameters of antenna array with a radome, $\mathbf{X}_r$ is structural parameters of the radome, $\mathbf{X}_a$ is excitation parameters of the antenna array, the antenna-radome system optimization problem can be summarized as [8],

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$$\begin{cases} \max(\text{or}\min)F(\mathbf{X}_{\mathrm{a}}) = \int_{\Lambda} u(f)\int_{\Theta} v(\theta)\sum_{m=1}^{M}\left[w_m G_m(\mathbf{X}_{\mathrm{r}},\mathbf{X}_{\mathrm{a}},\theta,f)\right]\mathrm{d}\theta\mathrm{d}f \\ L_m \le G_m(\mathbf{X}_{\mathrm{r}},\mathbf{X}_{\mathrm{a}},\theta,f) \le U_m, m=1,2,\cdots,M \\ \mathbf{X}_{\mathrm{r}}\in\mathbf{D}_{\mathrm{r}}, \mathbf{X}_{\mathrm{a}}\in\mathbf{D}_{\mathrm{a}}, \theta\in\mathbf{\Theta}, f\in\mathbf{\Lambda} \end{cases} \qquad (3)$$

where $u(f)$ and $v(\theta)$ are the weight functions corresponding to different frequency $f$ and different scanning angle $\theta$, $w_m$ represent the weight functions of $G_m$, $\mathbf{D}_{\mathrm{r}}$ and $\mathbf{D}_{\mathrm{a}}$ are value space of $\mathbf{X}_{\mathrm{r}}$ and $\mathbf{X}_{\mathrm{a}}$, $\mathbf{\Theta}$ and $\mathbf{\Lambda}$ represent value space of $\theta$ and $f$.

In evolutionary algorithm optimization, excessive variable parameters mean enormous burden of calculation, and will make it difficult to find the optimal solution. Therefore, we have adopted a two-step optimization strategy. Firstly, traditional radome thickness optimization is performed, to optimize $\mathbf{X}_{\mathrm{r}}$ and keep $\mathbf{X}_{\mathrm{a}}$ constant. Then, based on the optimal radome parameters obtained in the previous step, the antenna parameters $\mathbf{X}_{\mathrm{a}}$ is optimized.

As an efficient global optimization algorithm, particle swarm optimization (PSO) is used for this optimization problem. A review of this method applied to electromagnetic problem is depicted in [9].

### 2.3 Fitness function

For a fixed frequency point, suppose the antenna scanning angle $\theta$ can be varied. Before optimization, the maximum BSE of all scanning angles is $B^{\max}$, the maximum and minimum power transmission coefficient are $P^{\max}$ and $P^{\min}$. In order to simultaneously optimize the BSE and power transmission coefficient, the optimization fitness function can be taken as follow,

$$\mathrm{fitness}(\boldsymbol{X}) = 1 + w_1\frac{\max[B(\boldsymbol{X},\theta)]}{B^{\max}} - w_2\frac{\min[P(\boldsymbol{X},\theta)] - P^{\min}}{P^{\max} - P^{\min}} \qquad (4)$$

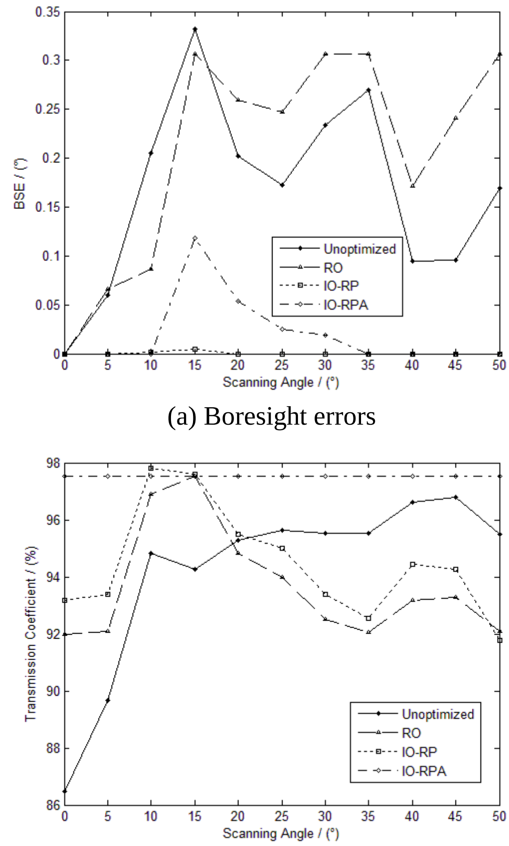
where, $w_1$ and $w_2$ are weight coefficients and to determine which one is the key optimal object.

## 3. Numerical Results

Consider a tangent ogive radome with A-sandwich wall construction enclosing a linear array of 25 elements. The radome has the length of 40λ and the base diameter of 20λ. Here, λ is the wavelength in free space. The two skin layers of the A-sandwich wall have the dielectric with relative permittivity of $\varepsilon_{\mathrm{r}}=3.0$ and loss tangent of $\tan\delta=0.005$. The core layer is made of foam with $\varepsilon_{\mathrm{r}}=1.1$ and $\tan\delta=0.001$. In the optimization process, the thickness of two skin layers keep invariant at 0.8mm and the thicknesses of the core layer at the 5 selected points are changed from 7mm to 12mm.

On the basis of radome core layer thickness optimization (RO), two types of integration optimization were performed. In the first case, excitation current phase would be adjusted, and the integration optimization would be expressed as IO-RP, where each antenna element has been given a compensation phase between -10° to 10°. As for the second case, both phase and amplitude of array element current would be regulated, the corresponding integration optimization process would be called IO-RPA, where compensation phase is disposed between -5° to 5°, and the amplitude could be changed between 4-6mA.

The resulting boresight errors and power transmissivity are shown in Fig. 2. Compared with the uniform wall radome, the maximum BSE was reduced from 0.332° to 0.306° by variable thickness radome optimization. By the integration optimization of compensation phase, the maximum BSE was further reduced to 0.005°. In the case of the current amplitude has been optimized along with phase, the maximum BSE was 0.118°. Considering IO-RP, with greater adjustable range of compensation phase, accessed to a smaller BSE, we can say that the optimization of phase parameter is crucial for low BSE antenna-radome system design.




(a) Boresight errors

(b) Power transmission coefficient

**Figure 2:** Results comparison of radome multi-objective optimization

After optimization of the radome wall thickness, the minimum power transmission coefficient was improved from 86.5% to 92.0%. With the further optimization of compensation phase, the power transmissivity have been improved in most of scanning angles, while the minimum transmission coefficient decreased to 91.8%. For the case of joint optimization current amplitude and compensation phase, in each scanning angle, it has gained nearly 97.5% of transmission coefficient. So the optimization of amplitude parameter plays an important role in the design of high transmissivity antenna-radome system.

Fig. 3 shows the optimized core layer thickness profile of radome wall. Since we need to make the appropriate array element optimization for each scanning angle, two sets of compensation phase for pointing 10° and 30° obtained in IO-RP are shown in Fig. 4. In Fig.5, the current amplitude and compensation phase for same scanning angle in IO-RPA are presented.

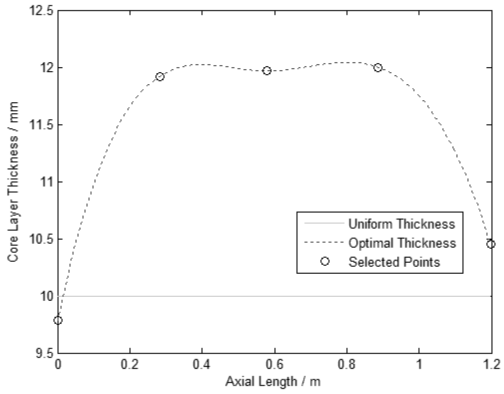



**Figure 3:** Optimized core layer thickness profile of A-sandwich radome

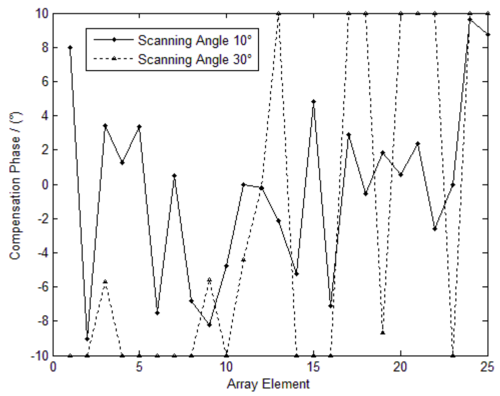



**Figure 4:** Compensation phase of pointing 10° and 30° obtained in IO-RP

## 4. Conclusion

An integration optimization method is proposed to optimize the BSE and power transmission coefficient of antenna array-radome system. The method comprises two steps of multi-objective PSO with specially designed fitness function, respectively, to adjust the radome thickness and antenna excitation current. Numerical simulations show that the integration optimization can significantly compensate for the lack of pure radome thickness optimization. In addition to improving the performance of antenna-radome system, this research also helps to relax the design requirements of radome electrical characteristics, reduce the design difficulty of radome.

## 5. Acknowledgements

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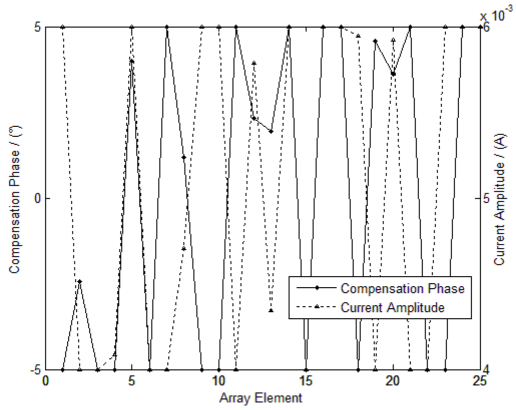
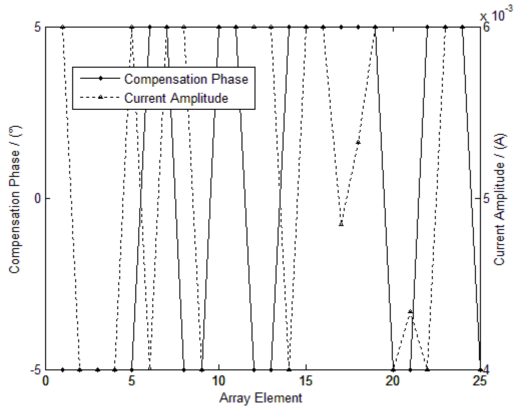



(a) Pointing 10°




(b) Pointing 30°

**Figure 5:** Compensation phase and current amplitude obtained in IO-RPA

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