Pattern Synthesis of Focal-Plane Array Fed Antenna with Particle Swarm Optimization

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***Abstract* - A particle swarm optimization (PSO) algorithm is used to synthesis the pattern of the focal-plane array fed parabolic reflector antenna for deep-space exploration. Physical optics is used to compute the far field pattern of the antenna excited by the individual array elements of focal-plane array. Compared with the conventional conjugate field matching (CFM) method, this PSO synthesis algorithm can effectively control the pattern parameters such as side-lobe level, and the desired direction.**

***Index Terms* — Pattern synthesis, particle swarm optimization (PSO) algorithm, deep-space exploration, focal-plane array, conjugate field matching(CFM).**

I. INTRODUCTION

Deep-space exploration is one of the three space activities in the 21th century, in which the huge path loss could be compensated by large aperture antennas operating at high frequency [1]. At the same time, the required antenna performance in term of side level and point accuracy is challenging.

Conjugate field matching(CFM) method is commonly used in pattern synthesis of array-plane fed reflector antenna. It weights the feed signals to synthesis the pattern at desired direction and improve the antenna's field of view. However, the parameter such as side-lobe level is difficult to control [2].

Particle swarm optimization (PSO) algorithm is a swarm intelligence based evolutionary computation technique, which was first proposed by Dr. Kennedy and Dr. Eberhart in 1995[3]. It has been used in the pattern synthesis of the array antenna, including synthesis of low side lobe, design of null-forming, beam forming and so on [4-5].

Because of coma effect, the secondary far field pattern illuminated by each feed of focal array is different, the principle of pattern multiplication could not be used on the focal-plane array fed reflector antenna directly. So, the secondary pattern should be calculated individually in each pattern synthesis, which would make the calculation load quite heavy.

In this paper, physical optics is used to compute and store the far-field pattern of the antenna excited by each of the individual array elements. With an appropriate fitness function the PSO algorithm is used to optimize the weights to obtain the desired pattern with accurate direction and low side lobe. Weighting the stored pattern could greatly reduce the amount of computation. Compared with the conventional CFM method, this PSO algorithm could effectively control the parameters such as side-lobe level, and synthesize the pattern of desired direction.

II. FOCAL ARRAY FEED REFLECTOR ANTENNA

The rotating parabolic reflector antenna shown in Fig.1 has been commonly used in deep-space exploration ground station, which is fed by a hexagonal plane array with inter-element spacing ΔS located on the focal plane of the reflector.

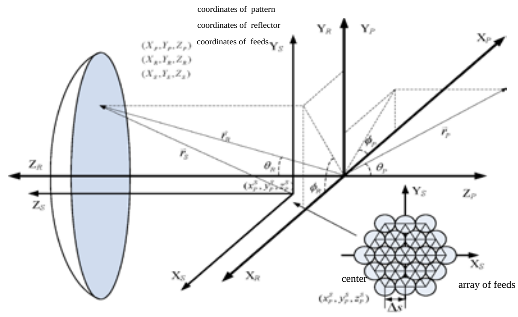

Fig.1. Focal array fed reflector antenna

The surface currents parabolic reflector calculated by physical optics is:

$$\bar{J}^{PO} = 2\hat{n} \times \bar{H}_i \tag{1}$$

Where, $\hat{n}$ is the normal vector pointed to feed and vertical to the parabolic reflector, $\bar{H}_i$ is the incident magnetic field from the i_{st} feed to the parabolic reflector.

The secondary far field pattern could be expressed as:

$$\bar{E}(r_P) = -jk\eta_0 g(r_P)(I - \hat{r}_P\hat{r}_P)T(\theta_P, \phi_P) \tag{2}$$

Where, $g(r_P) = e^{-jkr_P}/r_P$ is the space Green's function, $T(\theta_P, \phi_P) = \int_\Sigma \bar{J}_S^{PO} \exp(jk\bar{r}_R\hat{r}_P)d_S$ is the integration of the total surface current.

According to array signal processing theory, the desired pattern could be synthesized to improve the performance of the reflector antenna by weighting N secondary beams illuminated by N elements in the focal feed array.

III. ANTENNA SYNTHESIS BASED ON PARTICLE SWARM OPTIMIZATION ALGORITHM

Because of the off-axis coma effect, the secondary far field pattern illuminated by each feed of focal array is different.

The principle of pattern multiplication could not be used on the focal-plane array fed reflector antenna directly. The CFM method is usually used to determine the weights, but hard to control the side-lobe level[2].

A. Particle swarm optimization algorithm

The PSO algorithm has the advantages of simple ideas and easy programming, and it could be parallel processed, with some robustness, and could find the global optimal solution with greater probability compared with the traditional genetic algorithms(GA).

In this paper, the PSO algorithm is used to optimize the weights of elements, and the desired pattern could be gained by choosing appropriate fitness function to do the constraint.

B. Fitness Function

The far field pattern of the array feed reflector antenna is :

$$F(\theta,\phi)=\sum_{i=1}^{N} w_i \bar{E}_i(\theta,\phi) \qquad (3)$$

$w_i = a_i * \exp(j\theta_i)$, a_i and θ_i represent the weights of amplitude and phase of the i_{st} element respectively. Our goal is to define the cost function to synthesis the accurate direction with low side lobe. The fitness function could be defined as:

$$Fit(w_1,\cdots,w_N)=\min(a*(\bar{F}(\theta_0,\phi_0)-1)+\beta*\max_{\theta,\phi\in s}(\bar{F}(\theta,\phi))) \qquad (4)$$

Where $\bar{F}(\theta,\phi)=F(\theta,\phi)/[\max F(\theta,\phi))]$ is the normalized far field pattern, s is the side-lobe region. α is the weights of pointing error at desired direction and β is the weights of the side-lobe level in the fitness function.

IV. SIMULATION AND RESULTS ANALYSIS

A 5-m aperture reflector antenna operating at 32.05GHz has been illustrated as an example, whose F/D is 0.8. The horn feed array with 61 elements is placed in the focal-plane of the parabolic, arranged with the hexagon structure as shown in Fig. 1. The element spacing ΔS is 0.75 λ. Patterns synthesized with CFM method and PSO algorithm pointing at 0°and 0.2°are shown in Fig. 2.

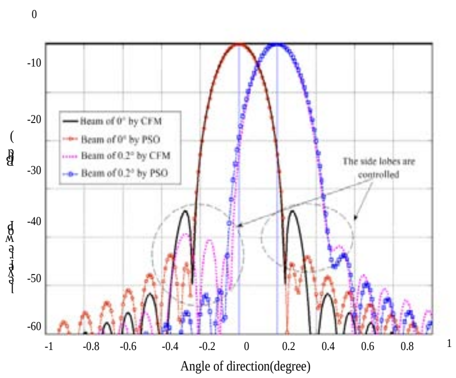

Fig. 2. Patterns synthesized by CFM method and PSO algorithm

In Fig.2, it is shown that both CFM method and PSO algorithm could synthesize beams pointing at 0°and 0.2° accurately. Compared with the CFM method, the pattern synthesized by PSO algorithm exhibits lower side-lobe level.

Fig. 3 shows the simulated results of the patterns aiming to point at 0.25° with CFM method and PSO algorithm.

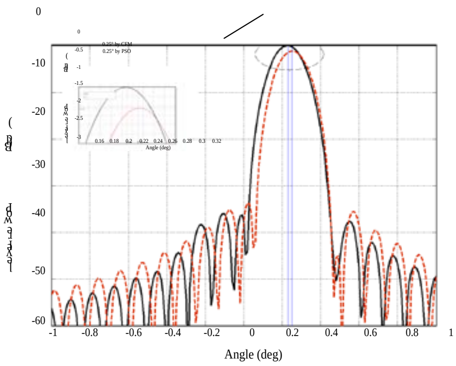

Fig. 3. Pattern comparison between CFM method and PSO algorithm

Fig. 3 shows that the pattern synthesized with PSO algorithm points at 0.25° accurately, while the pattern with CFM method actually points at 0.23°. It should be noticed that, compared with the CFM method, the gain of the array-feed reflector pattern synthesized by PSO algorithm drops about 1.1dB. This is because that parts of the energy of the beam has been inhibited to maintain the desired pointing.

V. CONCLUSION

A PSO algorithm is used to synthesize the pattern of the focal-plane array fed parabolic reflector antenna for deep-space exploration. Physical optics is used to compute the far-field pattern of the antenna illuminated by each of the individual array elements in focal-plane array. The simulated results show that the proposed pattern with PSO points more accurate compared to the traditional CFM method, at the same time, the side-lobe level could be controlled. This method show practical values in deep-space exploration as well as space relay satellite antenna.

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