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A Multi-beam Reflectarray Antenna with the Genetic Algorithm Optimizing Beams

Chulou Yang, Wenting Li*, Yejun He, Long Zhang, Sai-Wai Wong
Guangdong Engineering Research Center of Base Station Antennas and Propagation
Shenzhen Key Laboratory of Antennas and Propagation
College of Electronics and Information Engineering, Shenzhen University, 518060, China
Email: w.li@szu.edu.cn*.

***Abstract*- In this paper, a multi-beam reflectarray antenna with three beams is proposed. The reflectarray is composed of 25×25 units, and each unit can provide a 0 to 370° phase-shift range by changing the size of the patches. The distribution of the phase on the reflectarray is obtained with the genetic algorithm (GA) which is applied to generate the desired beams. To verify the design, a reflectarray with three fixed feeds is simulated in High Frequency Structure Simulator (HFSS). The simulated results agree well with the calculated results. The simulated first sidelobe level (SLL) of each beam is less than -13 dB, and the simulated beam directions are -7°, 0°, and 7°, respectively.**

I. Introduction

Multi-beam reflectarray antennas are usually used in satellite communications. High gain and beam-switching capability are required in designing these antennas. To obtain the desired beams, the phase compensation of the unit in the reflectarray is required. The shapes of the beams in large switching angles are distorted and their first SLLs are high with the beam switching in a single-focus reflectarray [1]. In [2], a bifocal reflectarray is designed to improve the sidelobes, and further optimization in beam-switching performance is proposed. A three-dimensional bifocal technique is introduced in [3] to design a reflectarray antenna with a main reflectarray and a sub-reflectarray, which can obtain better first SLLs of the beams in large switching angles. In [4], a multi-beam phase match method is used to minimize the phase error of the unit and improve the performance of beam switching. Another method to minimize the phase error is to adjust the weighting factor of the feed, which is introduced in [5]. A folded reflectarray antenna is proposed in [6] to generate 19 beams with low first SLLs.

In this paper, a three-beam reflectarray antenna is proposed. In designing the phase compensation of the unit in the reflectarray, the GA is applied. Two objectives, the directions and the first SLLs of the beams, are optimized at the same time. To verify the proposed method, the reflectarray antenna with three beams is simulated in HFSS. The beam can switch at –7°, 0°, and 7°, while the first SLLs are –13 dB, –15.5 dB, and –13.5 dB, respectively.

II. Design of Antenna

In this section, the structure of the unit, and the details of the GA are described. The configuration of the reflectarray is shown as well.

A. Unit Cell

The unit is a multi-layer structure with the dimension L_w×L_w, which is shown in Fig.1. It consists of two Rogers4003C substrates, an FR4 substrate, and two air layers, with the thickness of L_r, L_f, and L_a, respectively. The top patch and the bottom patch are printed on Rogers4003C substrates respectively. The size of the top patch is L_b×L_u, while that of the bottom patch is L_b×L_d. The specific values of the parameters of the unit are listed in Table I.

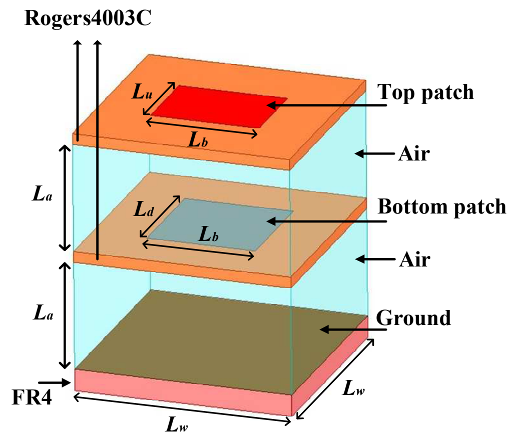

Figure 1. Unit structure.

TABLE I
PARAMETERS OF THE UNIT

Parameter	L_a	L_b	L_f	L_r	L_u	L_w
Value(mm)	2	5	1	0.508	0.75L_d	10

Different reflection phases at 10 GHz can be obtained by changing L_d, which is shown in Fig. 2. The unit can provide a phase-shift range from 0 to 370°.

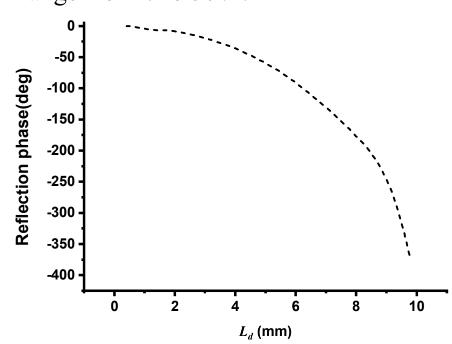

Figure 2. Relationship between L_d and the reflection phases of the unit.

B. Genetic Algorithm

In the multi-beam reflectarray, the GA is employed to design the phase compensation of the unit which can generate the desired beams. As the directions and the first SLLs of the beams generated by the multi-beam reflectarray antenna are significant, they are the objectives of the proposed GA. The implementation of the GA used to optimize the beams is introduced below.

With the position of the i^{th} feed, and the beam angle (θ_i,φ_i) generated by the i^{th} feed, the phase compensation Φ_{mn}^{i} corresponding to the unit in row m, column n on the reflecting surface can be calculated by (1) [7],

$$\Phi_{mn}^{i} = k_0(d_{mn}^{i} - (x_{mn}cos\varphi_i + y_{mn}sin\varphi_i)sin\theta_i) + \varphi_{i0}, \quad (1)$$

where k_0 is the propagation constant in the vacuum. d_{mn}^{i} is the distance from the unit to the phase center of the i^{th} feed. (x_{mn},y_{mn}) is the coordinates of the unit. And φ_{i0} is a constant.

By changing (θ_i,φ_i) and the weight of Φ_{mn}^{i}, a synthesized phase compensation Φ_{mn}^{s} can be obtained by (2),

$$\Phi_{mn}^{s} = \sum_{i=1}^{N} w_i \Phi_{mn}^{i}, \sum_{i=1}^{N} w_i = 1, \quad (2)$$

where w_i is the weight of Φ_{mn}^{i}, and N is the number of the feeds. The radiation patterns of the reflectarray can be calculated from the superposition of the electric field at the far field with Φ_{mn}^{s}. And the first SLL V_{slli} and the beam direction $(\theta_{ai},\varphi_{ai})$ of the i^{th} radiation pattern can be obtained, which are the objectives to be optimized.

For the i^{th} beam generated by the i^{th} feed, its cost function F_i can be expressed as (3),

$$F_i = a_i F_{ani} + (1-a_i)F_{slli}, \quad (3)$$

where a_i is the weight of F_{ani}. F_{ani} is the cost function of the beam direction, and F_{slli} is the cost function of the first SLL.

In this paper, φ_i and φ_{ai} are both 0. F_{ani} is given by (4),

$$F_{ani} = \begin{cases} (\theta_{ai}-\theta_{ui})^2, \theta_{ai} > \theta_{ui} \\ (\theta_{ai}-\theta_{li})^2, \theta_{ai} < \theta_{li} \\ 0, \theta_{li} \le \theta_{ai} \le \theta_{ui} \end{cases}, \quad (4)$$

where θ_{ui} and θ_{li} is the upper bound and the lower bound of the desired beam direction respectively.

F_{slli} is given by (5),

$$F_{slli} = \begin{cases} (V_{slli}-V_{di})^2, V_{slli} > V_{di} \\ 0, V_{slli} \le V_{di} \end{cases}, \quad (5)$$

where V_{di} is the desired first SLL of the i^{th} beam.

Therefore, the total cost function F can be expressed as (6),

$$F = \sum_{i=1}^{N} b_i F_i, \sum_{i=1}^{N} b_i = 1, \quad (6)$$

where b_i is the weight of F_i.

To summarize, w_i and θ_i are the variables in the proposed GA. N, a_i, b_i, θ_{ui}, θ_{li}, and V_{di} are the super parameters. Cost function F should be as small as possible to meet the convergence conditions. The flow chart of the GA which can make F converge is shown in Fig. 3.

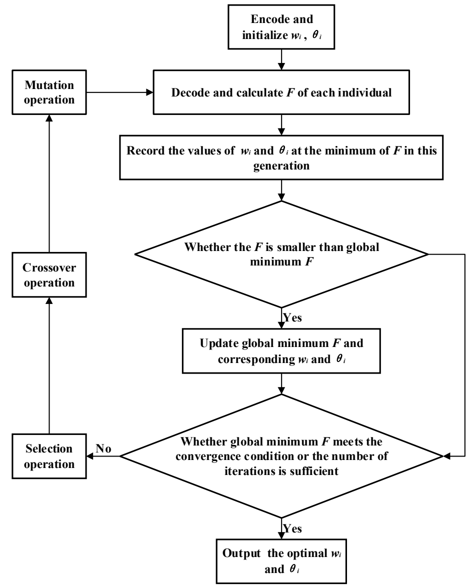

Figure 3. Flow chart of the GA.

C. Configuration of the Multi-beam Reflectarray Antenna

The configuration of the multi-beam reflectarray antenna is shown in Fig. 4. It is composed of 25×25 units and N feeds along the x-axis. The dimension of the reflectarray is 250 mm×250 mm. The rectangular waveguides BJ120 are used as the feeds, which are placed at a height of 120 mm from the reflecting surface. One feed is directly above the center of the reflectarray. The distance between adjacent feeds is 20 mm.

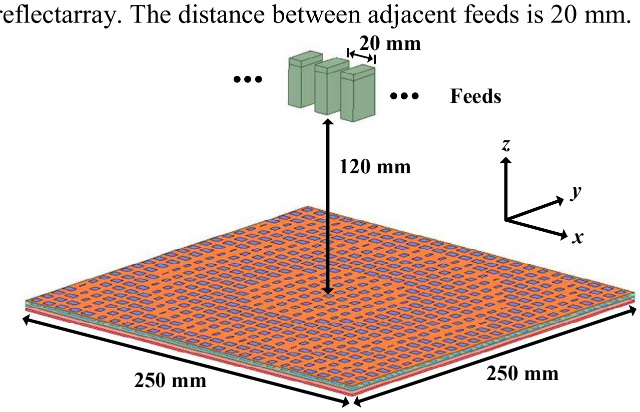

Figure 4. Simulation model.

III. CALCULATED AND SIMULATED RESULTS

In the GA, taking the values of the super parameters listed in Table II, the radiation patterns can be optimized and the calculated results can be obtained. To compare, a three-beam reflectarray antenna is also simulated in HFSS and the simulated results are obtained as well.

TABLE II
SUPER PARAMETERS OF THE GA

Super parameter	N	a_1	a_2	a_3	b_1	b_2	b_3
Value	3	0.2	0.2	0.2	0.45	0.1	0.45
Super parameter	θ_{u1}	θ_{u2}	θ_{u3}	θ_{l1}	θ_{l2}	θ_{l3}	
Value(degree)	–7	1	10	–10	–1	7	
Super parameter	V_{sll1}	V_{sll2}	V_{sll3}				
Value(dB)	–14	–14	–14				

The simulated and calculated radiation patterns at 10 GHz are shown in Fig. 5. The simulated directions of the beams are the same as the calculated ones, which are ﹣7°, 0°, and 7° respectively. The first SLLs of the calculated results are ﹣14 dB, ﹣19 dB, and ﹣14 dB, while those of the simulated results are ﹣13 dB, ﹣15.5 dB, and ﹣13.5 dB. Compared with the gain of the simulated Beam 2, those of the simulated Beam 1 and the simulated Beam 3 deteriorate by 0.9 dB and 0.7 dB, respectively.

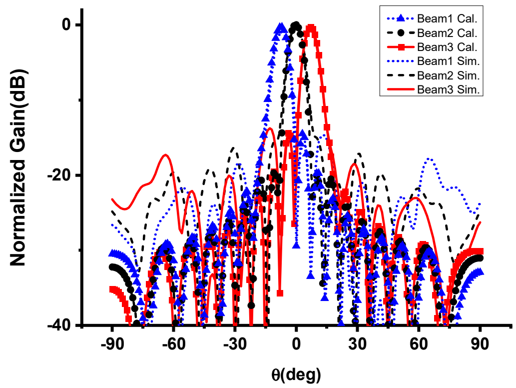

Figure 5. Calculated and simulated radiation patterns at 10 GHz.

IV. Conclusion

In this paper, a three-beam reflectarray antenna is proposed. It consists of 25×25 units and three rectangular waveguides used as feeds. The beams of the reflectarray are optimized by the proposed GA with variables, super parameters, and multi-objective cost functions. The simulated results make good agreements with the calculated results. The directions of the simulated and calculated beams are the same. And the first SLLs of the simulated beams are worse than the calculated results, but the differences are within 3.5 dB. The results prove that designing a multi-beam reflectarray antenna with the proposed method is feasible.

Acknowledgment

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