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# A Reflectarray With Small Focal Diameter Ratio

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*Abstract-* **In this paper, a novel method to design a reflectarray antenna with a small focal diameter ratio (F/D) is proposed. In the traditional designing approach, the reflecting phase of the element in the reflecting surface is achieved by placing the element in the periodic boundary. However, in this paper, the reflecting phase is obtained by a 7×7 array illuminated by the plane waves. For the reflectarray with a small focal diameter ratio, the gain can be improved by the proposed method compared with the traditional method. To verify the method, two 16×16 reflectarrays designed by the traditional and proposed methods are simulated, respectively. In the working band from 9.6 GHz to 10.8 GHz, the gain of the reflectarray is improved by 1.39 dB at most. And the first sidelobe level (SLL1) of the reflectarray is less than -10 dB in the operating band.**

## I. INTRODUCTION

Reflectarray antennas have been used in many fields nowadays. Compared with parabolic reflector antennas, reflectarrays are easier to make and have a compact size.

The reflecting phase of the element is often controlled by the geometric parameters of the element, such as patch size [1], stub length [2], or patch rotation angle [3]. In [1], the stacked patches with different sizes are applied to design the reflectarray. In [2], a tightly coupled reflectarray is designed by changing the length of the delay line of the element.

In the traditional reflectarray designing approach, the reflecting phase of the element is often obtained from the simulation in which the element is placed in the periodic boundary. Then, the reflectarray could generate the beam in the far field by controlling the reflecting phase of the unit cell.

In this paper, a novel method for acquiring the reflecting phase of the element is proposed. In the method, a 7×7 array is illuminated by a plane wave. The reflecting phase can be calculated by the incident field and scattering field of the element in the array. A double-layer patch reflectarray is designed to verify this method. The reflectarray designed by the proposed method has a higher gain than the reflectarray designed by the traditional method.

## II. ANTENNA THEORY AND DESIGN

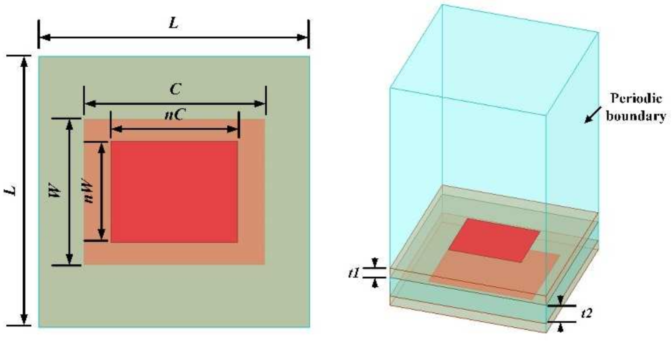
In this section, the element of the reflectarray is shown. The proposed method of obtaining the reflecting phase of the element is introduced in detail.

### A. Reflectarray Element

The reflecting element is shown in Fig.1. The reflecting element consists of a top patch and a low patch. Two patches are printed at the top of two substrates (FR4) [4], of which the thickness is *t1*. The size of the top patch is 0.7 times as long as that of the low patch. The two substrates are separated by an air layer of which the thickness is 2 mm. The dimension of the unit cell is 15 mm×15 mm. The parameters of the unit cell are shown in Table I. The working frequency of the element is 10GHz.

TABLE I
PARAMETERS OF THE REFLECTARRAY ELEMENT

| Parameter | *L* | *t1* | *t2* | *n* | *C* | *W* |
|---|---|---|---|---|---|---|
| Value(mm) | 15 | 1 | 2 | 0.7 | 10 | 8 |



(a) (b)

Figure 1. Model of the reflectarray unit cell. (a) Top view. (b)Side view.

### B. Obtaining the Reflecting Phase of the Unit Cell

In the traditional method, the element is placed in the periodic boundary for simulation [5], as shown in Fig.1. However, in this paper, a 7×7 array is illuminated by a plane wave. The 7×7 array is shown in Fig.2. The structure of the unit cell in the 7×7 array is the same as the structure of the element in the periodic boundary. The unit cells of the 7×7 array are of the same dimensions.

The reflecting phase can be calculated by the incident field and the total field of the central element from (1),

$$\varphi_R(x_0,y_0)=angle\left(\frac{E_{scatter}(x_0,y_0)}{E_{in}(x_0,y_0)}\right) \qquad (1)$$

where $\varphi_R(x_0,y_0)$ is the reflecting phase of the central unit cell. The coordinate of the central unit cell is $(x_0,y_0)$. $E_{scatter}(x_0,y_0)$ and $E_{in}(x_0,y_0)$ are the scattering field and incident field of the central element. The scattering field is calculated by (2),

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$$E_{scatter}(x_0,y_0) = E_{total}(x_0,y_0) - E_{in}(x_0,y_0) \qquad (2)$$

where $E_{total}(x_0,y_0)$ is the total electric field of the central cell.

Fig.3 shows the relationship between the reflecting phase and the element size obtained from the traditional method and the proposed method. The reflecting phase of the element designed by the proposed method is lower than the reflecting phase of the element which is placed in the periodic boundary.

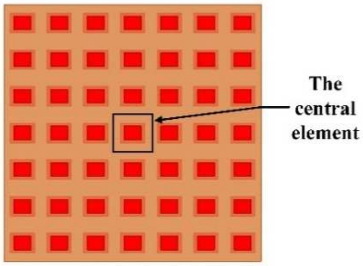


Figure 2. Model of the 7x7 array.

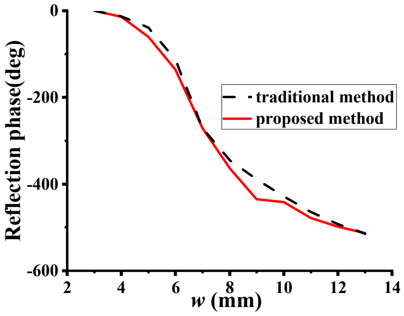


Figure 3. The reflecting phase of the two methods with phase at the y-coordinate and dimension at the x-coordinate.

### C. Reflection Phase

For the reflectarray, the reflecting phase is given by (3),

$$\varphi(x_i,y_i) = -k_0 sin\theta_b(x_i\cos\varphi_b + y_i\sin\varphi_b) - \varphi_0 + R_i k_0 \quad (3)$$

where $\varphi(x_i,y_i)$ is the required phase of the element [6]. The position of the unit cell on the reflecting surface is $(x_i,y_i)$. The required beam direction of the reflectarray is $(\theta_b,\varphi_b)$, and the distance from the phase center of the feed to the reference plane is $R_i$. $k_0$ is the wave number in the free space, and $\varphi_0$ is a phase constant which can be added to all unit cells of the reflectarray.

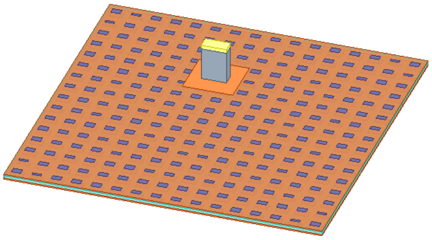


Figure 4. Model of the proposed reflectarray.

### D. Reflectarray Configuration

The configuration of the reflectarray antenna is shown in Fig.4. The reflectarray consists of the reflecting surface and a waveguide as the feed. The reflecting surface is composed of 16×16 elements. The dimension of the reflectarray surface is 240 mm×240 mm. The reflecting surface is fed by a standard waveguide [7]. The distance from the waveguide to the reflecting surface is 28 mm. *F/D* of the reflectarray is calculated from (4),

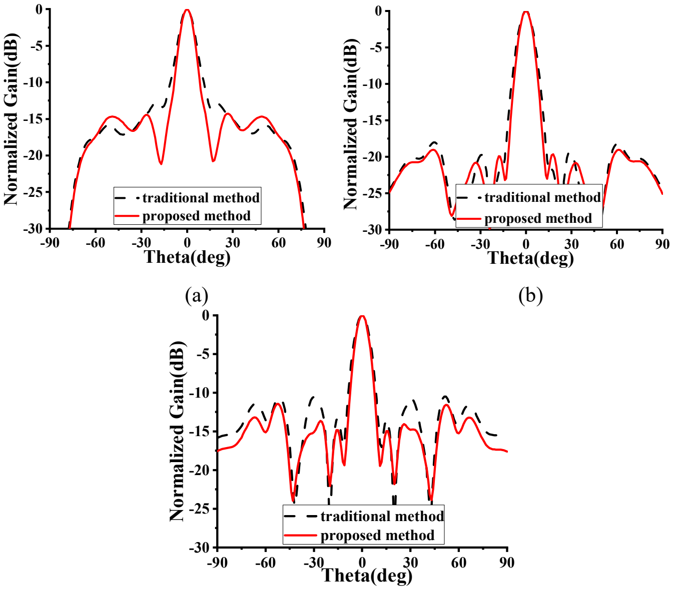
$$\frac{F}{D} = \frac{28}{240} = 0.117 \qquad (4)$$

where *F* is the distance between the surface of the feed and the reflecting surface. *D* is the diameter of the reflecting surface. The focal diameter ratio of the reflectarray is 0.117.

Two reflectarrays are designed by the traditional method and the proposed method respectively. Both reflectarrays have the same parameters except for the size distribution of the reflecting element.

## III. SIMULATION RESULTS

The two reflectarrays are simulated in High Frequency Structure Simulator (HFSS). The simulated results are shown in this section. Fig.5 shows the radiation pattern appearing at 9.6 GHz, 10 GHz and 10.8 GHz. The main beam is not distorted and the SLL1 is less than -10 dB. The SLL1 at 10 GHz decreases by 5 dB compared with 9.6 GHz. The radiation pattern keeps stable at the working band. The best SLL1 is about -18 dB appearing at 10 GHz.



(a)

(b)

(c)

Figure 5. Simulated radiation pattern at (a) 9.6 GHz, (b) 10 GHz and (c) 10.8 GHz.

Fig.6 shows the simulated gain of the two reflectarrays from 9.6 GHz to 10.8 GHz. The maximum difference of the gain is 1.39 dB appearing at 10.8 GHz and the minimum difference of the gain is 0.45 dB at 9.6 GHz. The simulated gain of the reflectarray designed by the proposed method varies from 18.81 to 21.11 dBi and the simulated gain of the reflectarray designed by the traditional method varies from 17.84 to 20.24 dBi. At 10

GHz, the gain difference between the two reflectarrays is 0.82 dB. The result of the simulation proves that the proposed method is superior to the conventional method in the operating band.

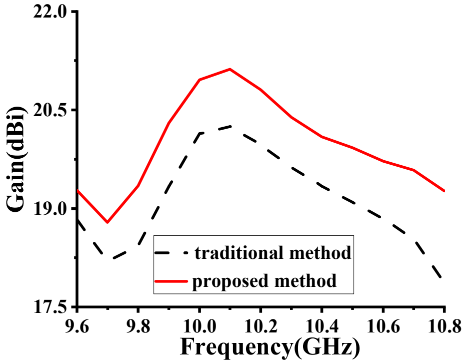


Figure 6. Simulated gains of the proposed reflectarray.

## IV. CONCLUSION

This paper proposes a novel method for designing and optimizing the reflectarray with a small focal diameter ratio, and the feasibility of this method is verified. Two 16×16 double-layer reflectarrays are designed to compare the difference between the novel method and the traditional method. A plane wave illuminates the 7×7 array to obtain the reflecting phase. The performance of reflectarray is improved only by changing the dimensions distribution of the reflecting element. It can be obtained from the simulation results that the gain of the reflectarray designed by the proposed method is 1.39 dB higher than the reflectarray designed by the traditional method at most, and the SLL1 can be less than -10 dB in the working band.

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