Design of Cylindrical Conformal Array Antenna based on Microstrip Patch Unit

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Abstract **─** Based on microstrip patch antenna, a cylindrical conformal 8×8 array antenna is designed, which uses a T-shaped power divider to realize 64 feed channels. The simulation results show that the peak gain of planar array antenna can reach 24.8dB, while the peak gain of cylindrical conformal antenna decreases by 1.2dB and 1.7dB in phi=0° and phi=90° respectively. And the main beam direction deflects by 0° and 4° respectively. The measurement results show that the performance of the processed object is close to the simulation. After conformal with cylinder, the peak gain is 23.5dB, and the beam deflection is 4°, which verifies the feasibility of the designed cylindrical conformal array antenna.

Index Terms **─** Array antenna, conformal, microstrip patch.

I. INTRODUCTION

With the development of electronic information technology, the requirements for the antenna are developing towards miniaturization and integration. And the demands for the beam scanning range and gain of the antenna are also higher and higher. The emergence of planar array antenna solves the problems of limited gain and difficult wave scanning of single antenna to a certain extent [1-2]. However, with the expansion of application scope of antenna, planar array antenna is gradually difficult to adapt to the needs of complex occasions.

Conformal array antenna can keep consistent with its bearing surface, that is, it fits the surface of the carrier completely. If it is attached to the cylindrical surface, it is called cylindrical array. The beam direction of the array element can basically achieve complete coverage along the curved surface [3-4], which can save space and avoid the fast change of the inherent beam scanning performance of planar array with the increase of scanning angle. It can be applied in satellite, airborne, missile and other complex occasions [5-7].

Compared with the planar array antenna, conformal array antenna has some unique advantages in practical applications. It is suitable for highly integrated electronic design, and the conformal array antenna can effectively reduce the weight of integrated electronic system. Using conformal array antenna can reduce the air resistance of the aircraft in flight, improve its aerodynamic performance, and effectively reduce the radar cross section (RCS) of the aircraft and improve its stealth performance.

In [8], a cylindrical conformal circularly polarized (CP) series-fed microstrip array design for broadside radiation is presented. They primarily focusing of the CP major lobe of the conformal array by proper dimensioning of the aperture spacings. And the direction-of-arrival (DOA) estimation of a conformal antenna array with directive elements is studied in [9]. The simulation results prove that this conformal array achieves better DOA estimation performance than that of the planar array antenna. In addition, a cylindrical conformal transmission array has been developed [10], which has a peak measured gain of 19.6 dB and an aperture efficiency of 25.1%. In the aspect of beam scanning, [11] designed a dual-layer multibeam conformal slot array antenna, which has a scanning range of ±46°. And [12] proposed a conformal phased array antenna for unmanned aerial vehicle (UAV) radar, which can scan ±60° in E-plane. It shows a wide range of common antenna application scenario. Conformal array antenna is naturally suitable for wide-angle beam scanning and integrated design. It can provide more comprehensive field of view, better aerodynamic performance and reduce the volume and weight of aircraft as much as possible. Conformal array antenna is an important branch of antenna development in military and civil fields in the future.

Compared with other common microwave antennas, microstrip patch antenna has the characteristics of small size, light weight, easy integration, easy processing, and easy carrier conformal [13-15], etc. It has been widely apply in electronic information, wireless communication and other fields [16-18]. In this paper, a conformal array antenna is designed based on microstrip patch antenna unit.

Ku-band has low ground interference, low resistance to electromagnetic interference of other frequencies, and low receiving environment. The antenna of this frequency band is small in diameter and easy to integrate.

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The design of the Ku-band antenna can effectively alleviate the shortage of spectrum resources and improve the utilization rate of spectrum. There have been many studies on Ku band patch antennas. In [19], a S-shape microstrip patch antenna that works from 15.35 GHz to 19.65 GHz is designed. In [20], a single-layer multi-band reflectarray antenna in X bands (10.8 GHz to 12.8 GHz), Ku bands (15.3 GHz to 17.3 GHz) K bands (24 GHz to 26 GHz) bands is proposed. In [21], a Ku-band patch antenna with Enhanced bandwidth is designed (14.58 GHz to 16.33 GHz).

II. UNIT DESIGN

In this paper, the array element is designed based on the microstrip rectangular patch antenna, the substrate is Rogers 5880, and the designed center frequency is 15GHz. The initial size of the patch is calculated by the theoretical formula. The width of the rectangular patch can be calculated by equation (1):

$$W = \frac{c_0}{2 f_0}\sqrt{\frac{2}{\varepsilon_r + 1}}, \tag{1}$$

where c_0 is the speed of light in free space, f_0 is the center frequency, and ε_r is the dielectric constant of the substrate.

The effective permittivity of microstrip patch antenna is obtained by equation (2):

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-\frac{1}{2}}. \tag{2}$$

Because of the edge shortening effect of rectangular radiation patch, ΔL is the length of equivalent radiation gap, which can be obtained from equation (3):

$$\Delta L = 0.412h\frac{(\varepsilon_e + 0.3)(W/h + 0.264)}{(\varepsilon_e - 0.258)(W/h + 0.8)}. \tag{3}$$

The actual length of the radiation patch should be:

$$L = \frac{c}{2 f_0\sqrt{\varepsilon_e}} - 2\Delta L. \tag{4}$$

After getting the initial size, the central embedded structure is used for unit feeding and the structure is shown in Fig. 1. The radiation impedance of traditional microstrip antenna usually adds an impedance converter between the antenna and the feeder to achieve smaller reflection. However, this kind of patch antenna loaded with impedance converter has complicated structure and needs to provide loading space for impedance converter, which means it is difficult to achieve miniaturization. Based on the principle of impedance loading, the central embedded feed patch antenna can realize impedance matching in a small space by opening two slots between the feeder and the antenna and loading a reactance on the feeder of the antenna.

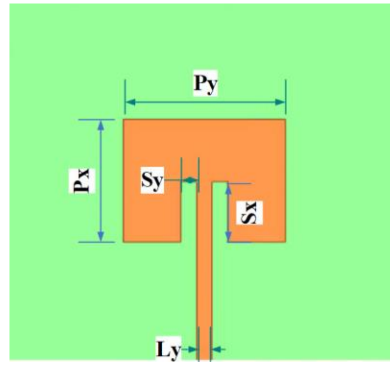


Fig. 1. Microstrip patch antenna unit.

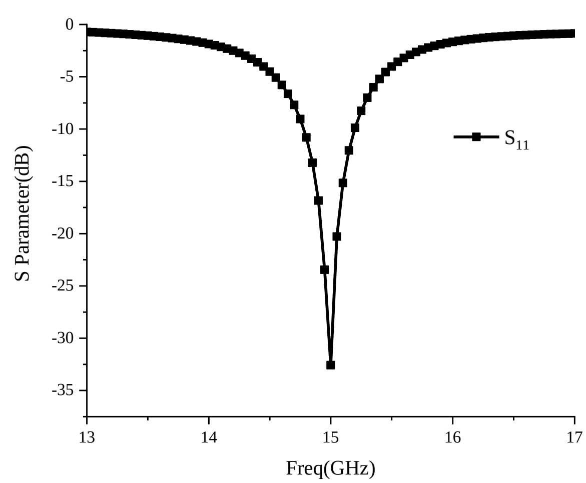
The optimized parameters are shown in Table 1, and the simulation results of S parameters and gain are shown in Fig. 2. At the center frequency of 15GHz, S_{11} is less than -30dB and the peak gain is 6.7dB.

Table 1: Design parameters and their values

Parameters	Value (mm)
Px	6.4
Py	8
Sx	1.5
Sy	0.9
Lx	6.5
Ly	0.4
h	0.508

III. ARRAY SIMULATION

In order to reduce the mutual coupling between array elements, the array spacing is 0.7λ= 14mm. The structure model of power divider is shown in Fig. 3. The designed planar array antenna is 8×8 uniform array, and the improved T-type power divider structure is still used to realize 64 channels feeding.



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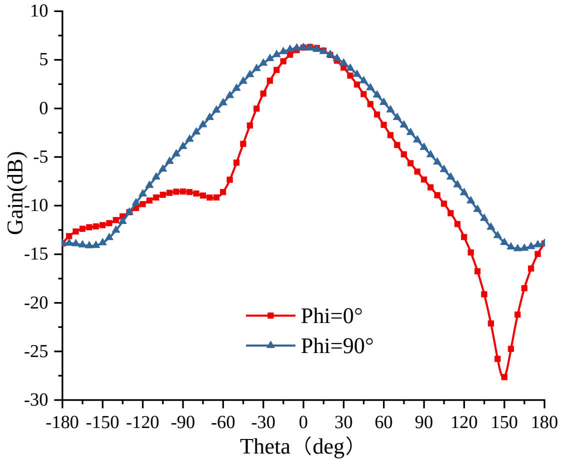


(b)

Fig. 2. Unit simulation results: (a) S_{11} and (b) gain.

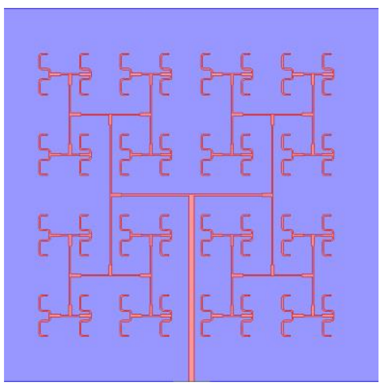


Fig. 3. 64 channels power divider.

After adding radiation patch, the structure of array antenna is shown in Fig. 4, which is 8×8 uniform array.

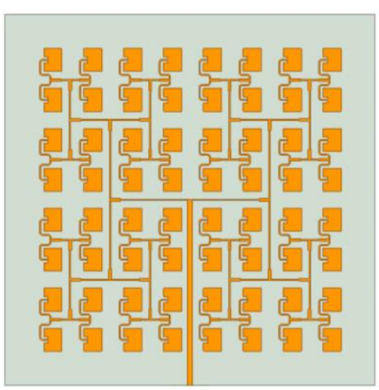
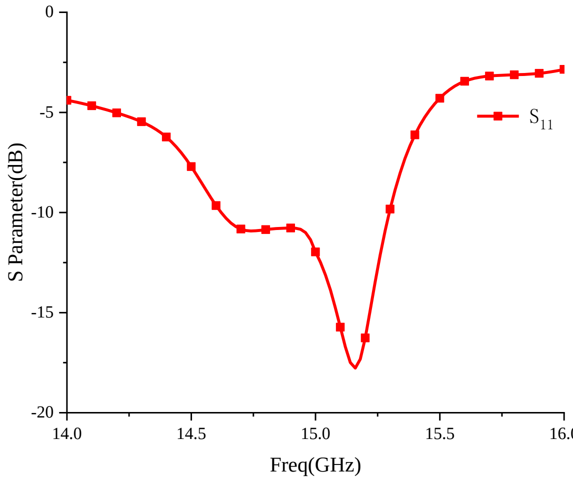


Fig. 4. Schematic diagram of planar array antenna model.

The simulation results of the array antenna gain are shown in Fig. 5. The S_{11} of the planar array antenna is -12.7dB at 15GHz, and the working bandwidth of -10dB is 640MHz. The peak gain of the planar array antenna can reach 24.8dB.



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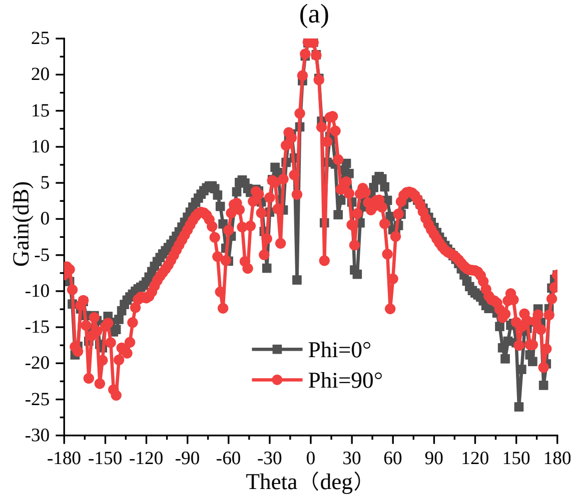

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Fig. 5. Simulation results of planar array antenna: (a) S_{11} and (b) gain.

The common array structure of cylinder based on the designed array antenna is shown in Fig. 6. According to the different radius of the conformal cylinder, the gain of the antenna will be attenuated and the beam direction will be deflected.

When the radius of the conformal cylinder is 600mm (30λ), the simulation results of the conformal array antenna pattern are shown in Fig. 7. The S_{11} of the planar array antenna is -12.3dB at 15GHz, and the working bandwidth of -10dB is 2GHz (14.2GHz-16.2GHz), which is nearly three times larger than before. The peak gain of phi=0° and phi=90° is reduced to 23.6dB and 23.1dB respectively, which is 1.2dB and 1.7dB lower than that of the planar array, and the main beam direction is deflected by 0° and 4° respectively.

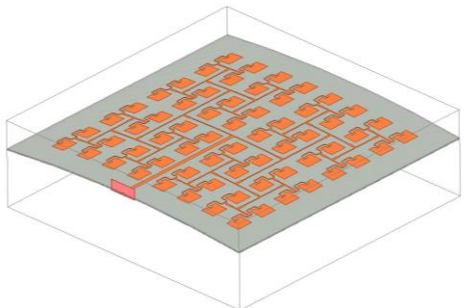
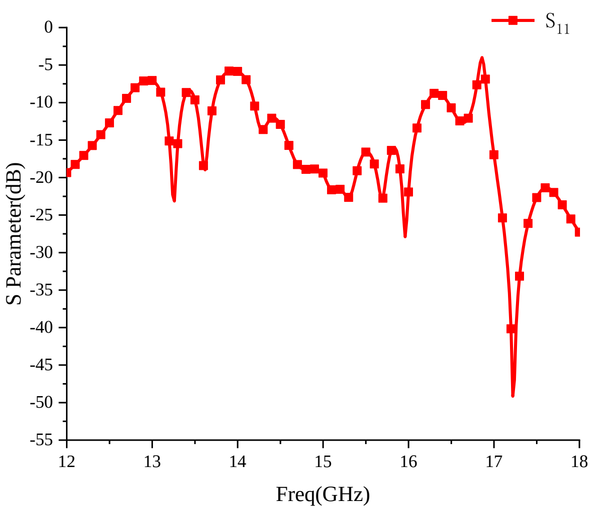


Fig. 6. Cylindrical conformal array antenna model.



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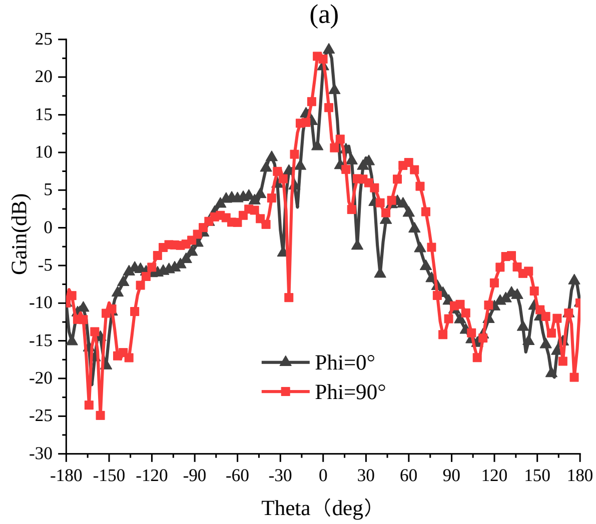


(b)

Fig. 7. Simulation results of cylindrical conformal array antenna: (a) S_{11} and (b) gain.

IV. ARRAY MEASUREMENT

Based on the designed antenna model, the prototype is fabricated. The prototype of the designed array antenna is shown in Fig. 8.

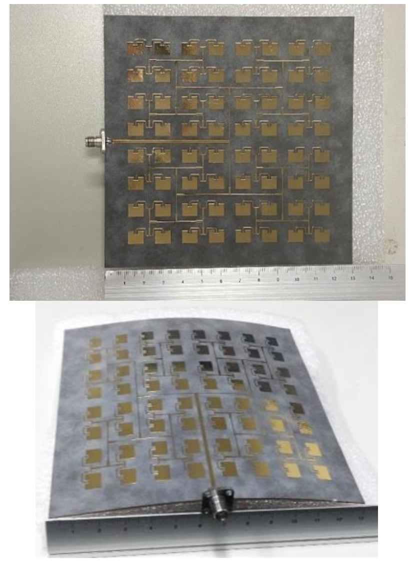
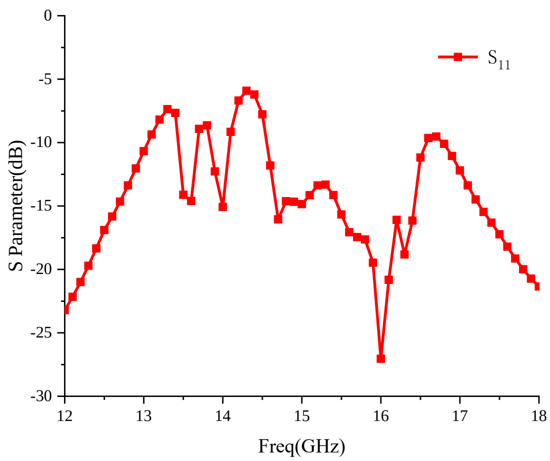


Fig. 8. Array antenna prototype.

Fig. 9. The measurement of designed antenna.

As shown in Fig. 9, the fabricated antenna is tested to verify the effectiveness of the conformal array antenna design. The antenna test environment is shown in Fig. 9. The S_{11} and Gain measurement of the conformal antenna is shown in Fig. 10. The working bandwidth of -10dB is 1.9GHz(14.6GHz-16.5GHz), and the peak gain is 23.5dB, the beam direction is deflected by 4° in the measurement. The comparison results of measurement and simulation are shown in Fig. 11. The comparison of single antenna, planar antenna and conformal antenna is shown in Table 2. The comparison of proposed work with recent antennas is shown in Table 3. These results shows that the designed conformal array antenna has certain practical significance.



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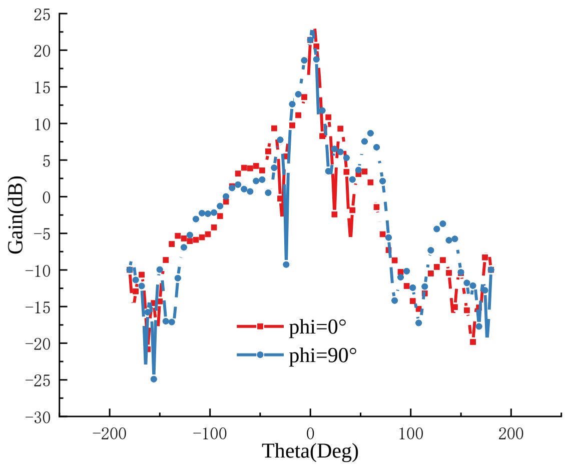
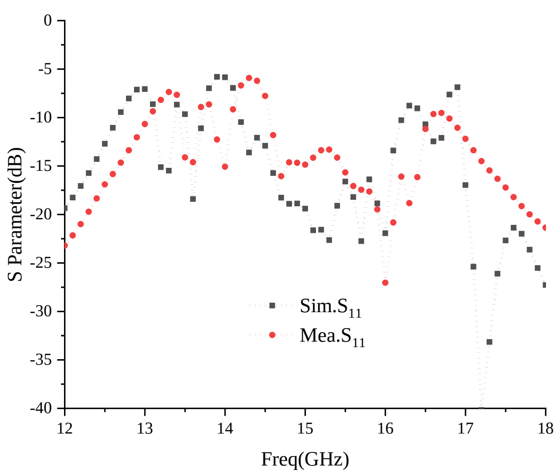


(b)

Fig. 10. Measurement results of designed antenna: (a) S_{11} and (b) gain.



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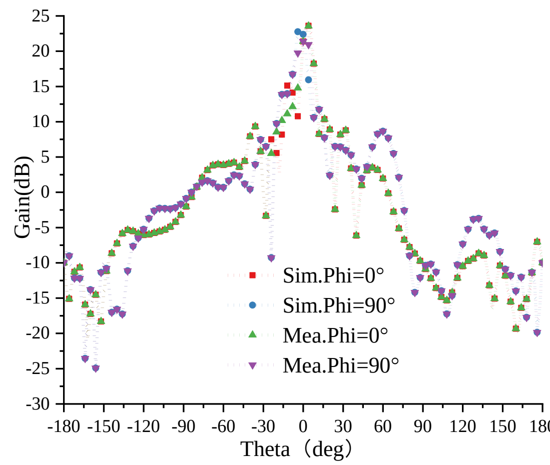

(b)

Fig. 11. Comparison of simulation and measurement results: (a) S_{11} and (b) gain.

Table 2: Comparison of single, planar and conformal antenna

Antenna	-10dB Bandwidth (GHz)	Peak Gain (dB)	Array Size
Single	0.4	6.7	-
Planar	0.7	24.8	8×8
Conformal	1.9	23.5	8×8

Table 3: Comparison of proposed work with recent antennas

Ref.	Bending Radius (mm)	-10dB Bandwidth (GHz)	Peak Gain (dB)	Array Size
[8]	50	＜0.5	10	1×10
[11]	90	0.6	19.3	10×10
[14]	-	0.25	4.5	1×4
[15]	304.8	0.6	15.36	4×4
This work	600	1.9	23.5	8×8

V. CONCLUSION

In this paper, a cylindrical conformal array antenna is designed based on microstrip patch antenna unit, which can achieve a gain of 24.8dB. Based on the model, a cylindrical conformal array antenna prototype is fabricated, and the measurement is carried out. The results show that the peak gain of the conformal antenna prototype is 23.5dB and the beam deflection is 4°. The feasibility of the designed cylindrical conformal array antenna is close to the simulation results, which can verify the rationality of the conformal antenna design.

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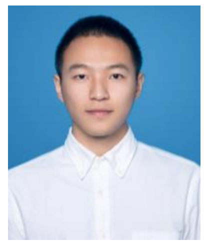

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