Progress In Electromagnetics Research Letters, Vol. 102, 145–149, 2022

A Low-Profile Cylindrical Conformal Transmitarray Antenna

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Abstract—In this paper, we present the design of a cylindrical conformal transmitarray antenna for generating high-gain beam. A low-profile transmitted element with 3-bit quantization is designed. It can cover 360° transmission phase shift range with transmission magnitude below −2 dB. A prototype of the cylindrical conformal transmitarray antenna is fabricated and measured. The measured gain is 21.75 dBi with aperture efficiency of 42.7%, and the thickness of the transmitarray is only 0.1 wavelengths at operating frequency.

1. INTRODUCTION

Transmitarray antenna has the advantages of high gain, high efficiency, low profile, light weight, and easy fabrication [1, 2]. Hence, it has become one of the research hotspots. Transmitarray is composed of transmitted elements with independent phase adjustability [3], and usually a horn antenna is placed behind the transmitarray as a feed. Under the illumination of the feed, the transmitarray antenna can form a required phase distribution on the aperture. In contrast to reflectarray antennas, transmitarray antennas avoid feed blockage [4, 5].

Transmitarray element not only needs enough transmission phase shift range to meet the aperture distribution requirements, but also needs a good transmission magnitude to meet energy transmission requirements. Compared with reflectarray, these requirements greatly increase the design difficulty of a transmitarray element. According to working principles, the design of a transmitarray element can be divided into three categories: multilayer frequency selective surfaces (M-FSS) [6, 7], receive/transmit elements [8], and metamaterial transformation approach [1, 9].

Recently, researches of transmitarray antenna have gradually extended from planar to conformal [10]. Conformal transmitarray antenna can fit the shape of various installation platforms. The advantages of conformal transmitarray antennas, they have attracted great attentions. In this paper, a highly efficient cylindrical conformal transmitarray antenna is presented. We use eight elements with varied dimensions to cover 3-bit quantized 360° of transmission phase shift range with transmission magnitude below −2 dB. The proposed conformal transmitarray antenna is fabricated, and the measured aperture efficiency is 42.7%.

2. CONFORMAL TRANSMITARRAY DESIGN

Figure 1 shows the configuration of a low-profile transmitting unit cell. The length of upper and lower square patches is S, and that of the middle square patch is $L = 9\,\text{mm}$. There are five slots in the middle metallic layer: a symmetrical cross-shaped slot is in central position, and the other four small square slots are evenly distributed around centrality. The length of the cross-shaped slot is Wx, and its width is Wy. The length of the small square slot is $S1 = S/4$. The thickness of supporting substrate is

Received 21 December 2021, Accepted 7 February 2022, Scheduled 9 February 2022

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$h = 1.5$ mm, and the total thickness of the unit cell is 3 mm. The substrate is Wangling F4B teflon woven glass fabric copper-clad laminates with dielectric constant $\varepsilon_r = 3.55$ and dissipation factor $\tan\delta = 0.002$.

A low-profile transmitting element was designed, covering 3-bit quantized 360° phase shift range with transmission magnitude below −2 dB. By changing the dimensions of S, Wx, and Wy, we can obtain necessary phase shift with good transmission magnitude, as shown in Table 1.

Table 1. Properties of the Unit cell at 10 GHz.

Element No.	S (mm)	Wx (mm)	Wy (mm)	$\|S_{21}\|$/dB	$\angle S_{21}$
1	1.5	7	1	−1.93	−3.78
2	2.7	7	1	−0.09	−43.4
3	3.9	7	1.5	−1.99	−84
4	5.8	7	1	−1.05	−136.2
5	6.4	7	1	−0.37	−180
6	6.55	9	0.1	−0.07	−224.8
7	7.16	9	0.1	−0.64	−270.5
8	7.62	9	0.1	−0.11	−314.4

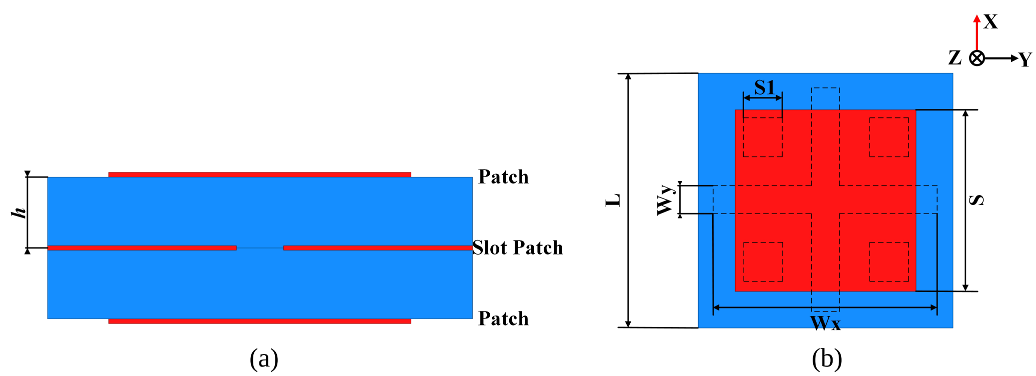

Figure 1. Geometry of the transmit unit cell: (a) side view and (b) top view.

Figure 2 shows the performances of the proposed 3-bit elements for different oblique incidence angles with different polarizations. Parameter θ is the elevation angle of the incident wave. In the illumination of transverse magnetic (TM) polarized incident wave, the magnitude loss and phase-shift range of the 3-bit elements varies slightly while oblique incident angle varies from 0° to 45°. Under the illumination of transverse electric (TE) polarized incident wave, the magnitude loss of the 3-bit elements varies to below −4.5 dB while oblique incident angle varies from 0° to 45°, except for oblique incidence angle $\theta = 45°$ of element No. 8, and the maximum phase decrease of the 3-bit elements is 51.9°.

To verify the feasibility of the designed low-profile transmitting element, a cylindrically conformal transmitarray is constructed with $19 \times 19 = 361$ elements, as shown in Figure 3. The cross section size of the cylindrical conformal transmitarray is 151.2 mm × 171 mm. The distance between the feed horn and cylindrical conformal transmitarray centre is 100.36 mm.

3. EXPERIMENTAL VERIFICATION

In order to verify the effectiveness of the above 19×19 cylindrical conformal transmitarray, a prototype is fabricated and measured. Photographs of the cylinder conformal transmitarray prototype are shown

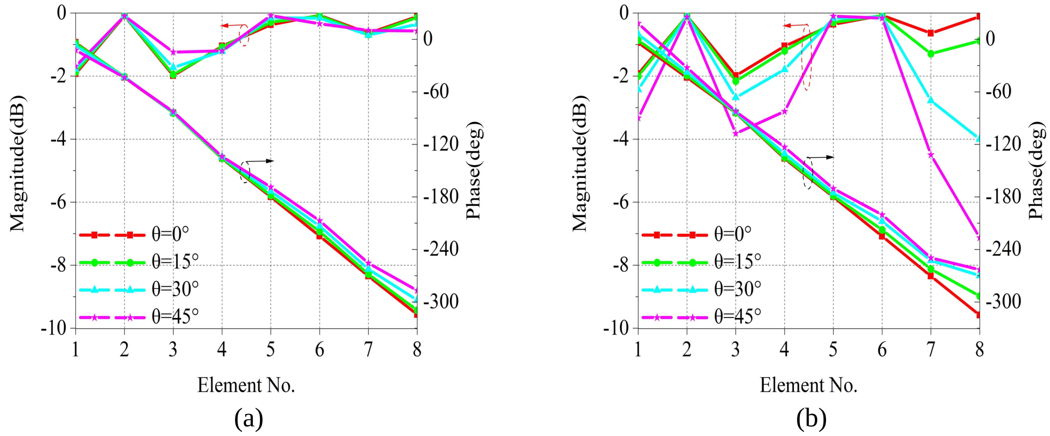

Figure 2. Magnitude and phase distribution of 3-bit transmit elements, (a) TM-polarization, (b) TE-polarization.

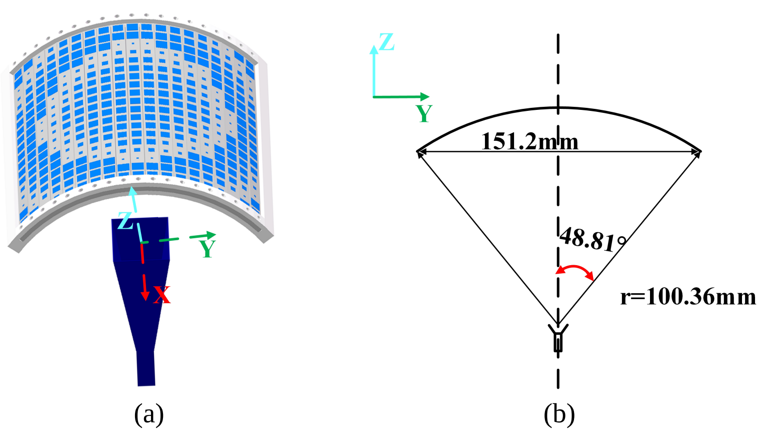

Figure 3. Conformal Transmitarray Antenna, (a) 3D structure, (b) sketch of front view.

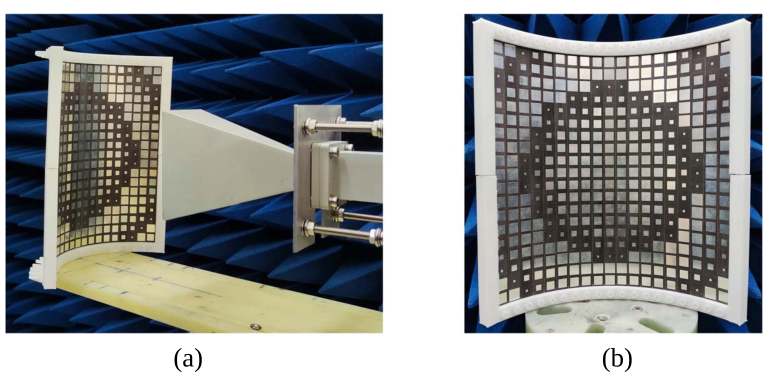

Figure 4. (a) The overall structure and (b) the conformal transmitarray prototype.

in Figure 4. The measurement of far-field pattern is performed. The comparison of simulated and measured realized gains is shown in Figure 5. In the simulation, the peak gain appears at 10 GHz with 22.83 dBi, with aperture efficiency of 52.9%. For the measurement, the maximum gain is at 9.85 GHz with the value of 21.75 dBi, achieving 42.7% aperture efficiency. Additionally, the measured 1-dB gain bandwidth is 2.4% (9.71 GHz–9.95 GHz), and the measured 3-dB gain bandwidth is 5.4%

(9.51 GHz–10.04 GHz). The frequency deviation between simulation and measurement is mainly caused by permittivity error of dielectric substrates and fabrication tolerances.

Furthermore, the simulated and measured E-plane and H-plane radiation patterns at 9.85 GHz are shown in Figure 6. From Figure 6, it can be seen that the simulated and measured cross-polarization levels are both below 30 dB. These results indicate that the cylindrical conformal transmitarray antenna can effectively generate high-gain beam with good performances. However, the measured beam-widths in E-plane and H-plane are both wider than the simulated ones, which can be ascribed to the inevitable installation error and supporting frame effect. In addition, the measured sidelobe levels are higher than

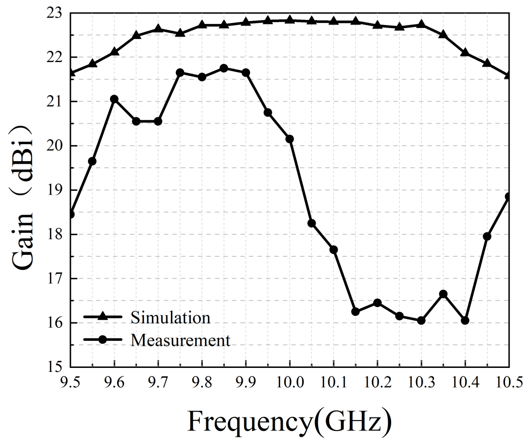

Figure 5. The results of simulated and measured gains.

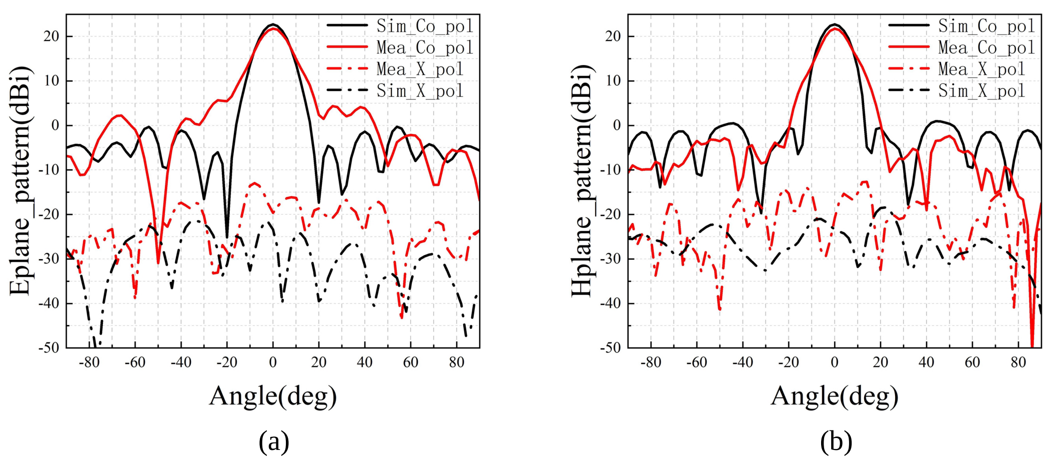

Figure 6. Simulated and measured patterns of (a) E plane and (b) H plane.

Table 2. Comparison of proposed design with referenced transmitarrays.

Ref.	Dielectric Constant	Number of layers	Electricalthickness	Array Contour	Aperture Efficiency
[2]	3.55	3	$0.07\lambda_0$	Plannar	37.9%
[7]	2.2	4	$0.73\lambda_0$	Plannar	38.4%
[10]	2.2	3	$0.04\lambda_0$	Cylindrical	25.1%
This work	**3.55**	**3**	$\mathbf{0.1\lambda_0}$	**Cylindrical**	**42.7%**

that in simulations. This is mainly affected by the testing environment.

We compare the proposed design with some latest publications on transmitarrays and conclude the performances in Table 2. References [2] and [7] achieve a good performance in aperture efficiency. However, they are both in planar form, and their aperture efficiencies are lower than this work. Although [10] is a cylindrical transmitarray, its aperture efficiency is approximately 60% of this work. From the compared result, we can summarize that our design has high aperture efficiency and low-profile features.

4. CONCLUSION

In this paper, we have designed, fabricated, and measured a cylindrical conformal transmitarray antenna with high-efficiency. The 3-bit low-profile transmitted element is designed, covering quantized 360° transmission phase shift range with transmission magnitude below -2 dB. Experimental results verify that the proposed cylindrical conformal transmitarray antenna has high aperture efficiency of 42.7% with the gain of 21.75 dBi.

ACKNOWLEDGMENT

The scientific contributions from other people or groups are acknowledged here. This work was supported by the National Natural Science Foundation of China under Grant No. 61961006 and the Science and Technology Foundation of Guizhou Province under Grant No. QKHJC [2020]1Y257.

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