A Transmitarray Antenna with Double Conformal Rings as the Cell Elements

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Abstract **─** In this paper, we mainly study the electromagnetic transmission characteristics of transmission array antennas and transmission units. Based on array antenna theory and geometric theory, we construct a transmission array antenna for a double conformal rings (DCR). It works in a 10GHz two-layer transmission array. A double resonant conformal rings are used as the unit element. By changing the physical dimensions of the double conformal unit, phase coverage of up to 600° can be achieved. And the 1d B gain bandwidth is has by 7% compared to the previous transmission array. The simulated and measured peak gain is 27.59 dB and 25.91dB, respectively.

Index Terms **─** Compensation phase, double conformal rings, transmitarray antenna.

I. INTRODUCTION

The use of micro strip transmitarrays (TAs) and reflectarrays (RAs) is essential in long-range communication systems because of their high-gain radiations, narrow beam widths, simple configurations, and easy fabrication.

A four-layer transmitarray operating at 30 GHz is designed using a dual-resonant double square rings as the unit cell element. The two resonances of the double rings are used to increase the per-layer phase variation while maintaining a wide transmission magnitude bandwidth of the unit cell [1]. A novel antenna system that combines the functionalities of TAs and RAs is proposed. The antenna system consists of a specially designed bifunctional meta-lens and a self-made Vivaldi antenna (feed source). The meta-lens can focus the y-polarized incident wave at the transmission side and focus the x-polarized wave at the reflection side with the same focal length. By launching the meta-lens with differently polarized Vivaldi antennas, and it was able to obtain a TA and RA [2]. Based on the electrical characteristics of grapheme and using graphene-based 4-layer transmitarray unit cells, a 1024-element transmitarray antenna at 260GHz is designed. Simulation results show that these millimeter-wave antennas using graphene patches show good radiation performance. And die whole transmitarray plane and reflectarray plane are both transparent [3]. The impact of the phase compensation method on transmitarray (TA) performance is studied here in terms of directivity, gain, aperture efficiency, and beam scanning capability. The numerical results show that TTD compensation allows increasing the TA bandwidth and reducing beam squint as compared to constant phase-shift compensation [4]. The matching condition and the theoretical results are discussed, and the theory shows that an element with non-identical layers can realize similar phase range as the identical-layer design but with a much lower profile [5]. There is introduce two kinds of rectangular slots in the design to control the magnitude and phase range of transmission coefficients in the two designed frequency bands through changing the slot length [6].

In this letter, a broadband planar transmitarray antennas based on DCR structure is proposed. This element has a wide transmission band with only two metallic layers, which is 2 and 3 layers less than the TAs proposed in [10] and [11], respectively. The total thickness of substrate layers is only 3 mm (0.1λ_0), which is 30% and 23% thinner than the TAs proposed in [8] and [9], which makes the structure very compact at 10GHz. Therefore, a large array of this cell is low-profile and easy to fabricate. Also, the provided phase shift by the physical dimensions of this element is continuous and up to 600°.

The rest of the letter is organized as follows. In Section II, we introduce the design of a DRCL structure unit cell. In Sections III and IV, the simulation and measured results of the TA composed of the proposed cell are discussed, respectively. Finally, the results show the proposed TA with only two metallic layers can achieve a higer gain performance, and conclusions are

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drawn in Section V.

II. UNIT CELL DESIGN AND SIMULATION

To collimate the incident wave from the feed horn, a transmitarray uses the antenna elements on its surface to re-phase the incoming spherical wave and then retransmit the signal as a plane wave. The amount of phase adjustment needed at each antenna element depends on the phase delay an incident ray has accumulated travelling between the feed horn and the transmitarray surface. Figure 1 (b) denotesas r_f the vector to the ith element from the feed's phase center, and r_i as the position vector to the ith element from the transmitarray centre; k_0 is the propagation constant, and $\hat{u}_0$ is thedirection of the transmitted main beam.

From [7], he necessary phase compensation value φ_c at each element is given by (1):

$$\varphi_c = -k_0(r_f + r_i\hat{u}_0) + 2n\pi, n = 1, 2, 3, \cdots. \quad (1)$$

This chapter proposes a new broadband planar transmission array unit structure, namely a DCR structure, as shown in Figs. 1 and 2, which has a large phase coverage and good polarization and angular stability. The cell structure diagram are given in Fig. 1. The lower layer of the dielectric substrate is a metal ground, and the upper layer etches a double conformal metal rings, and the circumference of the rings are about half the wavelength of the free space. The thickness of the dielectric substrate is generally much smaller than the wavelength, usually less than 0. 1λ (λ is the wavelength in the medium). By selecting an appropriate cell structure and size, the antenna cell period can be effectively reduced. The unit model is simulated using the master slave boundary conditions, and the simulation model is shown in Fig. 2.

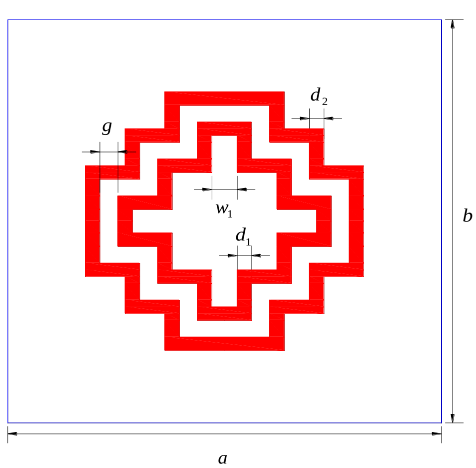

Fig. 1. DCR element the parameters of cell element d_1=d_2=0.4mm, a=b=12mm, g=0.5mm, w_1=0.7mm.

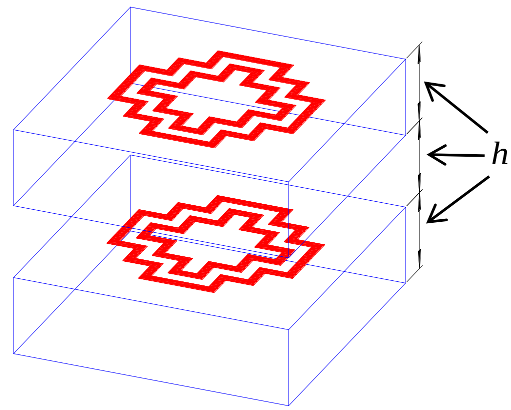

Fig. 2. DCR element's three-dimensional structure, h=3mm.

In order to improve the linearity of the phase curve, the transmission array unit must be optimized. The transmission phase curves of a single inner rings, a single outer rings and the DCR unit are shown in Fig. 3. As can be seen from Fig. 3, the phase shift curves of a single inner rings and a single outer rings are approximately 300° and are both smaller than the phase shift range of the DCR proposed herein. The main reason for the large phase coverage of the DCR unit is that the unit has dual resonance characteristics, as shown in Fig. 4, When the unit length is L=7.7mm. From the characteristic relationship between the transmission curve and the frequency, the double resonance frequencies appear at 4.4 GHz and 13.5 GHz, respectively.

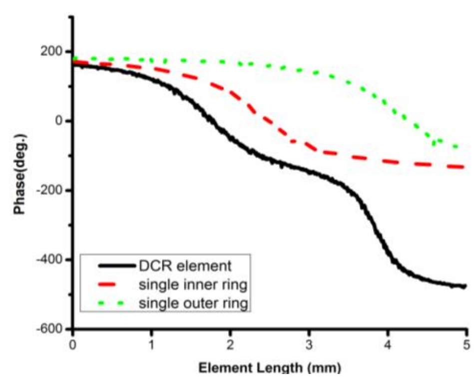

Fig. 3. Phase characteristics of the unit transmission coefficients.

Figure 5 shows the amplitude distribution of the scattered electric field on the surface of the element. The aperture efficiency of the unit can be better observed, and the electric field distribution on the cell aperture is relatively uniform, which also explains the high gain array phenomenon.

In order to effectively analyze and design the transmission array, it is important to accurately analyze the phase shift characteristics of the transmission unit when TE (Transverse Electric, TE) and TM (Transverse Magnetic, TM) polarized waves are incident. Since each unit is about half the length of the medium, each unit is in a resonant state when electromagnetic waves emitted by the feed source are incident on a transmissive surface composed of a large number of cells.

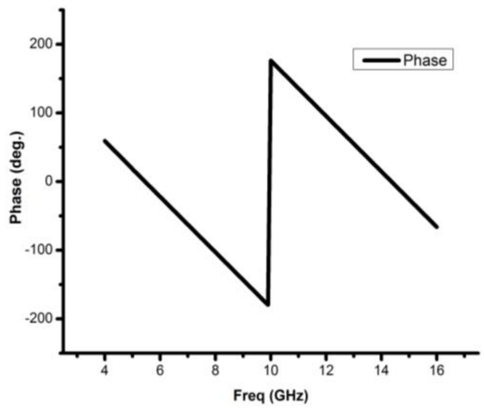

Fig. 4. Resonance characteristics of the unit transmission coefficients.

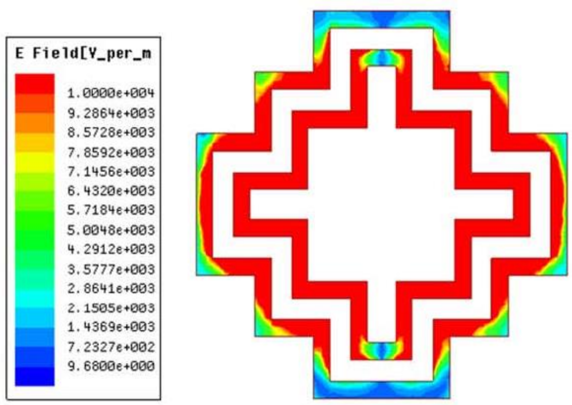

Fig. 5. Scattering E-field magnitude distribution on the DCR element in the normal incidence at 10 GHz.

In order to simplify the analysis and design, and also to increase the polarization stability of the unit structure, a symmetrical structure is adopted in the *x* direction and the *y* direction, and the unit period is $a=b=12$ mm. The double conformal rings element proposed in this chapter has more degrees of freedom, such as the inner rings line width d_1, the outer rings line width seedling d_2, the inner rings and the outer rings spacing *g*, and the inner rings line spacing w_1. So many degrees of freedom are an important reason for the degree of linearity of the curve to improve the phase shift.

III. TA CONFIGURATION

The simulation array model is shown in Fig. 6. The array consists of two layers with a substrate thickness of 3 mm, which is 35% and 25% thinner than the TAs proposed in [8] and [9], with a 3 mm gap between the two layers, and each layer consists of 30x30 cells. It should be noted that for each unit, the arm length in the *x* direction and the arm length in the *y* direction are the same, so the unit is symmetrical in the *x* and *y* directions. The plate was selected as F4BMX-2, the thickness of the substrate was sheet, the dielectric constant was 2.2, and the loss tangent at the center frequency of 10 GHz was 0.001. In order to obtain the desired phase shift curve, in the process of designing the transmission array, each unit size or rotation angle in the array must be adjusted. This compensated phase shift curve can be obtained by full-wave simulation of infinite period boundary conditions.

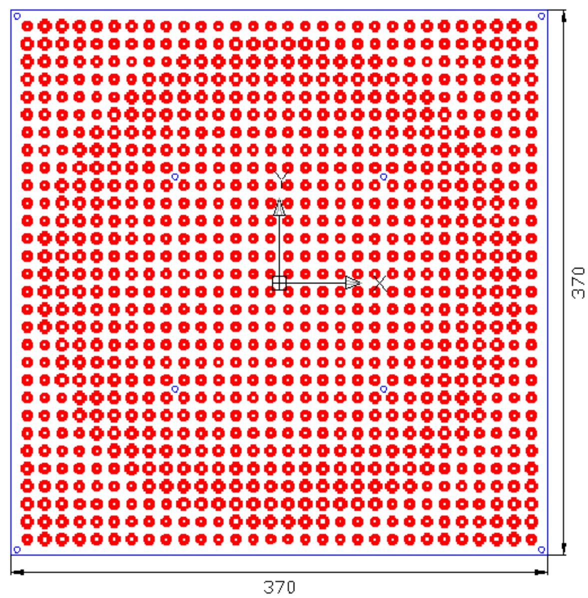

Fig. 6. 30x30 DCR transmission array simulation model.

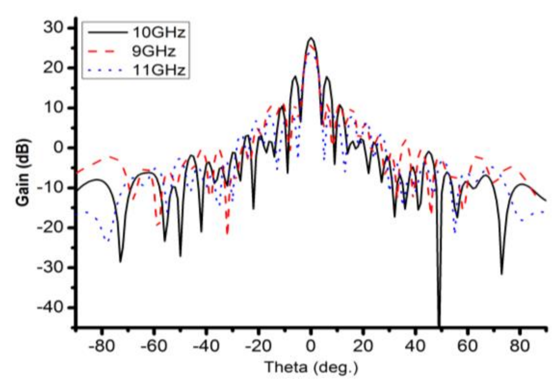

Fig. 7. The simulated transmitarray radiation gains at 9 GHz, 10 GHz, and 11 GHz.

In the design of this chapter, in order to reduce the unit size and the coupling between the units, we use the unit size of the more linear region in the phase length curve as much as possible. Figure 7 shows the simulation pattern of the three frequencies of 9 GHz, 10 GHz and 11 GHz in the *xoy* flat. There is a certain offset in the direction of the main beam throughout the operating band. The main reason for generating the main beam offset is that each cell has a certain phase difference at different frequency points. The peak gain of the simulation at a center frequency of 10 GHz is 27.59 dB. To demonstrate its gain bandwidth, Fig. 8 shows the relationship of gain as a function of frequency. The 1dB relative bandwidth of the center operating frequency of 10 GHz is 7%, and the absolute operating bandwidth is from 9.3 GHz to 11.3 GHz.

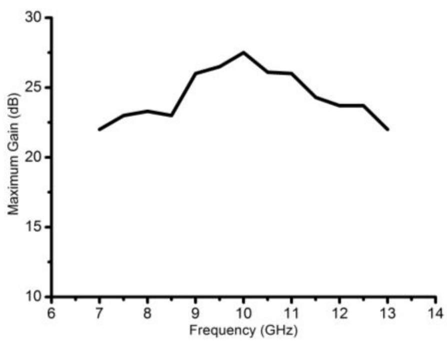

Fig. 8. The maximum gain versus frequency within the operational frequency band.

IV. MEASURED RESULTS AND DISCUSSION

Based on the above simulation and design, the transmitarray with 30x30 elements was fabricated and measured. The processing array is shown in Fig. 9, the array and cell prototype of this sample correspond to Fig. 6. The measured system is shown in Fig. 10. TA represents the fabricated array. Tx and Rx represent the transmitting horn and the receiving horn, respectively, and during the measurement that the polarizations of RX and TX horn antennas are vertical the same as TM polarization. The measurement of the radiation pattern was performed in an anechoic chamber at Xidian University, China. The distance from TX to TA is 0.45 m and from RX to TA 3m.The height of TX to the ground is 1.5 m. The heights of RX and TA to the ground are 3 m.

Figure 11 shows the normalized radiation pattern of the measurements. It can be seen that there is a certain decrease in the main beam gain of other frequency points in the main beam direction of the operating frequency band of 10 GHz with respect to the center frequency. The peak gain of the measurement at a center frequency of 10 GHz is 25.91dB. It is generally consistent with the simulation. Figure 12 shows the comparison of the normalized radiation pattern for the center frequency 10 GHz simulation and measurement. Although there is a deviation in the direction of the main beam, the overall agreement is good. The processing error and the instability of the plate during the experiment are the main causes of measurement deviation.

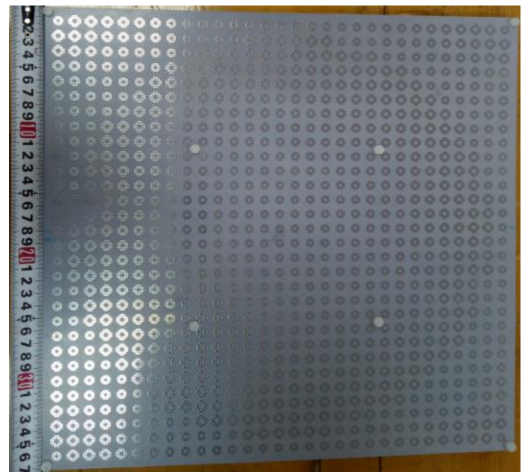

Fig. 9. Fabricated array antenna with 30x30 elements.

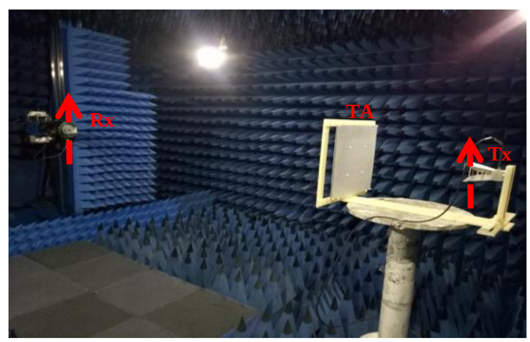

Fig. 10. Measurement system at Xidian University.

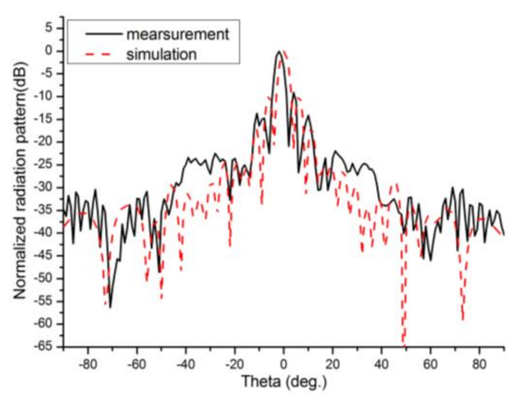

Fig. 11. Measured normalized radiation patterns of the transmitarray with 30x30 DCR elements.

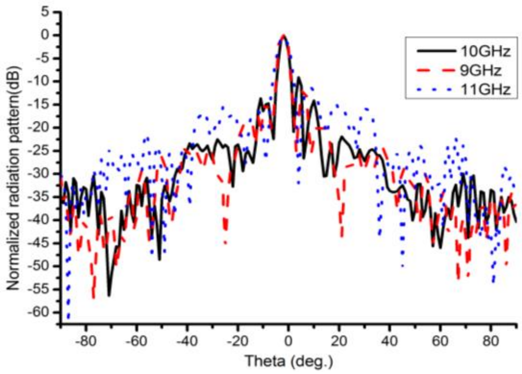

Fig. 12. Comparison between the simulated and measured results of the normalized radiation pattern at 10 GHz.

V. CONCLUSION

This work gives the design process and design ideas of a planar transmission array based on a DCR. This DCR unit has more degrees of freedom and can greatly improve the linearity of the phase curve. By changing the cell length of the DCR, not only can the phase shift range of up to 600° be obtained, but also the linearity is good. The 30x30 dual resonant rings unit double layer array was designed, processed and measured. The measured results show that the transmission array unit proposed in this chapter has 1dB bandwidth reaches 7%. The simulated and measured peak gain is 27.59 dB and 25.91 dB, respectively.

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