

Broadband Reflective Linear Polarization to Circular Polarization Unit Cells and the Application in Array Design

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Abstract—This paper presents a new set of linear polarization to circular polarization (LP-CP) unit cells (UCs) for broadband reflective polarization conversion, and the application in designing broadband CP reflectarray (RA). The LP-CP UCs are composed of different combinations of rectangular loops for different reflective phases. By controlling the ratio of width to length of the rectangular loop, the LP-CP conversion can be realized. By further adjusting the coupling between two rectangular loops, broadband LP-CP conversion can be achieved accordingly. Four phase states of 0°, -90°, -180°, and 90° are obtained for the elaborately designed UCs for application in designing CP RA. The measured results show that the final fabricated RA can achieve a wide CP bandwidth of 53% for high gain radiation.

Index Terms—Broadband, linear polarization to circular polarization, reflectarray.

I. INTRODUCTION

Because of the advantages of planar array aperture, low fabrication cost, and same high gain radiation compared to the traditional parabolic reflectors [1], planar reflectarray (RA) antennas have drawn researchers great interest in different application backgrounds, such as satellites, radars, base stations, etc. For long-distance communication or remote sensing scenarios, circularly polarized (CP) wave propagation is especially welcomed benefiting from its innate polarization immunity to the polarization angle between the transmitting antenna and the receiving antenna [2]. Therefore, versatile CP RA antennas are designed and implemented for long-distance communication and sensing.

An easy way to realize a CP RA antenna is using a CP antenna as the feed source to illuminate an aperture consisting of multiple symmetrical size-scalable reflective elements, just as the design of linearly polarized (LP) array apertures [3]–[5]. Because the reflection phase is always focused on a single frequency while designing unit cells, the gain and CP bandwidth are normally limited and difficult for broadband design. Another method is using the CP feed source to illuminate the array aperture for CP radiation, which is named as the element rotation technique [6]–[7]. In this technique, elements are not scaled but rotated for different reflection phases, so that the impedance characteristics of elements on the whole aperture are not different but consistent with each other, and broad CP reflection bandwidth for the array can be therefore achieved. In [6], it is theoretically derived that when an element is rotated

by an angle of φ , a two-time (2φ) phase delay can be achieved for the reflected CP wave. In addition, one can introduce the linear polarization to circular polarization (LP-CP) polarizers, so that CP RAs can be realized [8]–[10]. In [9], by regulating the lengths of the narrow slots along two orthogonal directions, a broadband low-cost metal only RA antenna is realized for CP radiation with CP bandwidth up to 39%.

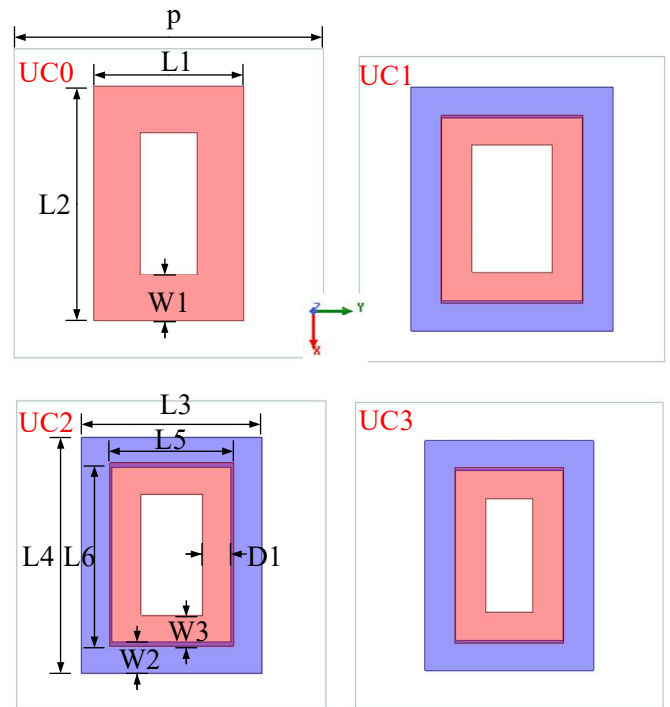


Fig. 1. Configurations of the proposed LP-CP UCs. (Detailed parameters: $p=$ mm, $W1=1.6$ mm, $W2=1$ mm, $W3=1$ mm, $D1=1.6$ mm, $L1=4.9$ mm, $L2=7.5$ mm, $L3=6.5$ mm, $L4=7.4$ mm, $L5=4.5$ mm, $L6=6$ mm)

In this paper, a new set of reflective unit cells (UCs) are presented for broadband LP-CP conversion. The UCs are composed of different combinations of rectangular loops. By elaborately adjusting the length and width ratio of the rectangular loops and the coupling between the rectangular loops, broadband quadrature reflective LP-CP conversion can be achieved for the reflected wave. This new combination of LP-CP UCs is formed by four different cells. UC0 is the baseline cell with single rectangular loop for reference 0° reflective phase, while the remaining UCs are broadband design with coupled rectangular loops for -90°, -180°, and 90° reflective phases respectively. A CP RA is developed by using the proposed UCs, and then fabricated for performance verification.

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The measured results confirm the effectiveness of proposed LP-CP UCs and excellent CP performance of the fabricated CP RA prototype.

II. UNIT CELL DESIGN

A new set of four LP-CP UCs are proposed in this section, which are used to convert the incident LP wave into reflected CP wave. The detailed UC configurations are shown in Fig. 1. As can be seen, three of these UCs (U1, U2, U3) are composed of dual rectangular loops. By properly adjusting the widths of two different sizes of the rectangular loops, polarization conversion from LP to CP is realized. By further properly adjusting the coupling between the internal rectangular loop and the external rectangular loop, broadband LP-CP conversion can be realized. In this work, UC1 is developed for -90° reflective phase, UC2 is developed for 180° reflective phase, and UC3 is developed for 90° reflective phase.

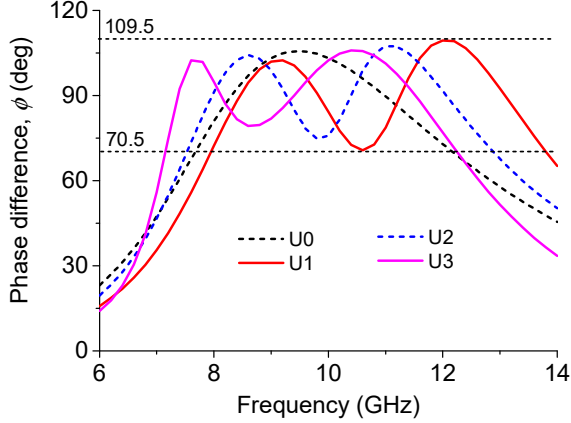


Fig. 2. Conversion bandwidth of the designed UCs.

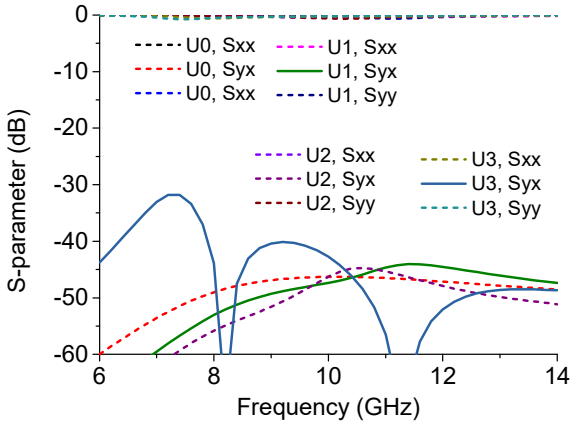


Fig. 3. S-parameters of the designed UCs.

The first UC0 is the baseline design, which is only composed of one rectangular loop, and realized for 0 reflective phase. In the UCs' design, the patch shown in pink is printed on the top layer of the substrate, while the patch shown in blue is printed on the bottom layer of the substrate. Note that below the substrate, there is an additional air layer that is inserted

with the thickness of 3 mm. Commercially available substrate of Rogers 4003C with the relative dielectric permittivity of 3.55 and thickness of 0.508 mm is used to print both top and bottom layers of UCs.

Fig. 2 shows the simulated conversion bandwidth of four UCs. As can be seen in the figure, the conversion bandwidth is defined by the cell reflection phase range of 70.5° - 109.5° . The baseline cell UC0 has the narrowest conversion bandwidth covering from 7.53 GHz to 12.9 GHz due to the single rectangular loop configuration. In good contrast, cells of UC1 to UC3 have much wide conversion bandwidth, which varies around the curve of UC0 and UC2. It can also be found that UC0 only has one peak, while cells of UC1 to UC3 have two peaks. This is why that cells with two coupled rectangular loops can have wider conversion bandwidth than the single rectangular loop. The overlapped conversion bandwidth is 7.95-12.18 GHz for the developed UCs.

Fig. 3 shows the S-parameters of the designed UCs. As can be seen, all the UCs have near full reflection over the co-polarized linear wave, which is close to 0 dB. The UCs have near zero conversion to the cross-polarized linear wave, and the conversion coefficient of S_{yx} is well below -30 dB. This means that the incident LP wave can be well reflected and then fully converted into good CP wave by the proposed four LP-CP UCs.

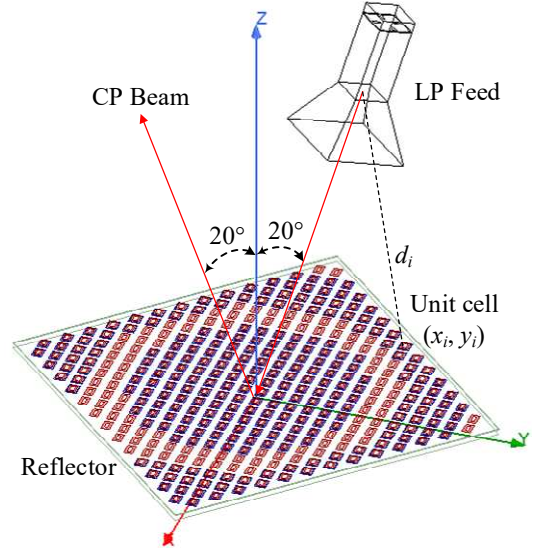


Fig. 4. Configuration of the designed CP RA.

III. ARRAY APPLICATION AND RESULTS

Utilizing the developed LP-CP UCs, a CP RA is developed and shown in Fig. 4. The entire RA is composed of a tilted horn antenna with linear polarization as the illumination source, and the bottom reflective aperture full of proposed LP-CP UCs. The LP feed horn is placed with an incline angle of 20° to avoid the possible blockage of the reflective CP beam, and the beam direction is designed to the symmetrical -20° for CP radiation.

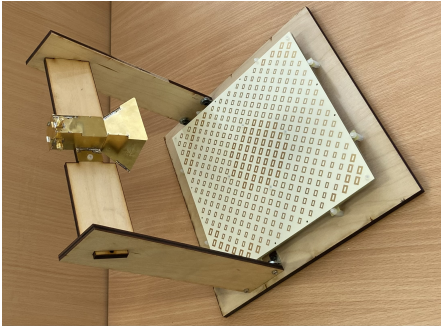


Fig. 5. Photographs of the fabricated CP RA.

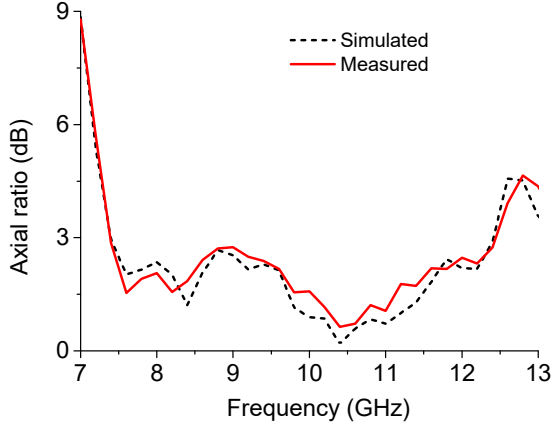


Fig. 6. Measured and simulated AR of the developed CP RA.

This developed CP RA was then fabricated for performance verification. Fig. 5 shows the photo of the fabricated prototype, and the measured AR is shown in Fig. 6 with the simulated AR added for comparison. As can be seen, the measured AR shows reasonable agreement with the simulated AR, and the measured CP bandwidth for AR less than 3 dB is 7.3-12.5 GHz. Radiation patterns were also measured and shown in Fig. 7. In the figure, the co-polarization means the RHCP, while cross-polarization means the LHCP. The patterns working at 10 GHz are given in the figure. It can be seen that the beam direction is at -20° just as designed in xz-plane. A low cross-polarization level is measured, which means an excellent CP radiation is achieved for the developed prototype.

IV. CONCLUSION

A new set of four LP-CP UCs and the application in realizing a broadband CP RA have been presented in this paper. The LP-CP UCs feature broadband polarization conversion from LP to CP, which are evaluated by the S-parameters and reflective phase bandwidth. The broadband LP-CP conversion is achieved by adjusting the width to length ration and the coupling between two rectangular loops. This characteristic of broadband LP-CP conversion is successful applied in design CP RA, which was fabricated and measured for performance verification. The excellent agreement between the simulated and measured results shows the effectiveness of proposed UCs in application of CP RA.

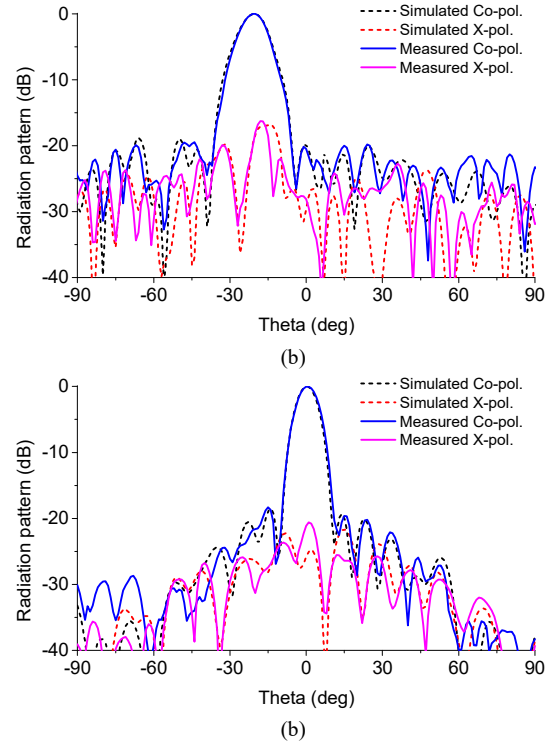


Fig. 7. Radiation patterns of the fabricated CP RA in (a) xz-plane and (b) yz-plane.

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