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Research Article

Dual-Sense Circular Polarization Antenna Based on Reconfigurable Orthogonal Network

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A novel circular polarization (CP) reconfigurable microstrip antenna is presented. The CP reconfigurable antenna is divided into three layers, composed of an annular radiating patch, ring slot, and reconfigurable orthogonal network (RON). The designed antenna is fed by dual vertical branches at the output port of the RON. By adjusting the bias voltage of the PIN switch loaded on the reconfigurable orthogonal network, the output phase can be changed, which means that the polarization direction of CP antenna is switchable. Simulation results show that the proposed feeding network provides constant phase difference and lower insertion loss for both states in the operating frequency band, thereby achieving good match and axial ratio characteristics either LHCP or RHCP state. Measured results show that the proposed antenna exhibits operational bandwidth of 1.2% with axial ratio below 3 dB and return loss above 10 dB in both polarized states. Good agreement between simulated and measured results is obtained.

1. Introduction

Satellite communication systems play an increasingly important role in the modern communication system. Satellite communication has many advantages, such as wide coverage, large communication capacity, high transmission quality, and rapid networking. With the widespread use of satellite communications, higher requirements have also been placed on antenna design in satellite communication systems. A circularly polarized antenna can be less affected by the multipath interferences and it is also immune to the Faraday rotation effect. Furthermore, there is no strict direction requirement for the transmitting and receiving antenna compared to the linearly polarized antenna [1]. Therefore, circularly polarized antennas are widely used in navigation systems and satellite communication.

Circularly polarized radiation can be realized by exciting two orthogonal modes with equal amplitude and 90° phase difference. In the current research, the feeding method of the circularly polarized antenna can be mainly divided into single-feed technique [2–4] and multifeed technique [5–8]. Ring-slot structure with stubs can be fed with single feeding line to excite CP polarization [2]. The two orthogonal modes can also be excited by symmetrical ring patch and a slot with L-shaped coupling strip [5, 6] or dual coupling branches [7, 8]. Generally, multifeed form needs to be realized by the corresponding orthogonal feeding network design [9].

A reconfigurable antenna is a type of antenna that has emerged in the past decade. It provides an effective and feasible approach for aperture-sharing technology. LHCP/RHCP reconfigurable antenna is useful in T/R sharing design for the satellite communication system. The polarization direction of the antenna can be mechanically reconfigured between LHCP and RHCP by rotating the MS in [10]. Compared to mechanical reconfiguration, electrical reconfiguration with PIN diodes [11] or varactor diodes [12] has better operability. In [13], an E-shaped patch antenna with dual RF switches was loaded on the radiation patch gap and surface current distribution was reversed by adjusting opposite state of the switches, which brings about different circular polarization modes. A circular polarization reconfigurable loop antenna was used in [14]. PIN diodes were integrated into the circular loop radiator, and two opposite polarization states were obtained by reverse current direction on the loop. In [15], switches were set on the symmetrical arrow-shaped coupling strip and the antenna can be switched between linear polarization and circular polarization. The method of loading switches on the feed structure was also used in [16–18] to change the antenna operating states. Eight diodes were used for loading on the feeding network for LP/LHCP/RHCP reconfigurability in [17] and 13.1% impedance bandwidth was obtained for both linear polarization and circular polarization. In [18], the antenna can provide both LP/CP by adjusting the bias states of varactor diodes on the feeding network.

In this paper, a novel CP reconfigurable antenna is proposed. The antenna fed though coupling between ring slot on the ground plane and dual vertical feeding branches connected to the reconfigurable orthogonal network. The proposed feeding structure is composed of microstrip hybrid with two PIN diodes in opposite states. By adjusting the state of the PIN diodes loaded at input port of the hybrid, the proposed antenna can be switched electronically between LHCP/RHCP. This feeding network can be used in dual-feed circular polarization antenna to achieve CP reconfigurable.

2. Design and Analysis of Antenna Configuration

2.1. Antenna Configuration. The configuration of the proposed antenna is shown in Figure 1. The annular-ring patch is printed on the top layer of FR4 substrate ($\varepsilon_r = 4.4$ and $\tan\delta = 0.02$). The upper surface of the lower FR4 substrate is covered with ground plane. A ring slot is etched on the ground plane, and the reconfigurable orthogonal feeding network is etched on the opposite of the ground plane.

The annular-ring patch feed though the ring slot on the middle layer. Different from L-shaped microstrip line in [6], the proposed antenna is excited by dual vertical open feeding branches with 90° phase difference. Compared to the L-shaped microstrip line, the advantage of dual feeding branches is that it is easy to adjust the phase difference between the two coupling positions on the ring slot, which is the theoretical basis of polarization reconfigurability. The dual vertical feeding branches are powered by microstrip hybrid, in which the design frequency is 1.74 GHz.

Two PIN diodes are, respectively, arranged at two input ports of the microstrip hybrid. In order to control the state of PIN diodes, two DC bias lines are introduced at both ends of the diodes. To guarantee AC/DC isolation, 68 nH chokes are soldered on the DC bias line. Meanwhile, a 220 pF capacitor is used to block DC signal on RF input port.

2.2. Reconfigurable Feeding Network Design. The schematic diagram of the proposed reconfigurable orthogonal feeding network is shown in Figure 2. The feeding network consists of the microstrip hybrid and two PIN diodes, and the diodes are connected in series. One side of the bias voltage is loaded between the two diodes, and the other side is loaded on the outside of the two diodes. The characteristic impedances of these transmission lines are Z_0 and Z_{01}; Z_{01} was defined as 0.707 Z_0. Based on the scattering-parameter matrix of microstrip hybrid, ±90° phase difference between two output ports can be achieved by feeding from one of the two input ports. By adjusting the width of transmission lines, 90° phase difference between port2 and port3 can be obtained. In the state of D1 turned on and D2 turned off, the phase transmitted to port2 is 90° behind the phase transmitted to port3. Besides, in the state of D1 off with D2 on, the phase transmitted to port2 is 90° ahead of the phase transmitted to port3.

The simulated results of S parameter are shown in Figure 3. As shown in the figure, return loss is less than −25 dB, while phase difference between port2 and port3 is ±90° in the operating band; meanwhile, the input signal is equally divided into two outputs, the insertion loss of each port is nearly 4 dB.

2.3. Polarization Reconfigurable Antenna Design. The two orthogonal modes with equal amplitude for CP operation were excited by dual vertical feeding branches. The feeding network designs contribute to achieve equal amplitude of the two resonant modes; the reconfigurable feeding network can be used to generate 90° phase-shift with the two resonant modes. As shown in Figure 4, connecting DC bias voltage at the hybrid and the feeding port, respectively, PIN diode D1 and D2 remained in opposite states.

The annular patch is fed through a ring slot on the middle layer. Aperture coupling is an indirect feeding method. The open feeding lines at the bottom of the antenna feed for the annular radiation patch through the ring slot on the ground plane. The middle ground plane can be used to suppress spurious radiation which may be caused by the feeding structure; meanwhile, the presence of air layer helps to optimize impedance matching of the antenna. According to the discussions above, the direction of CP radiation was determined by current direction on the radiating surface, which can be changed by different output phases of the vertical feeding branches. Reconfigurable orthogonal feeding network is used to feed for the proposed antenna. Changing phase relationship of the two output ports by controlling PIN diodes loaded on the feeding network in different output states, two pairs of orthogonal modes are switched. LHCP/RHCP reconfigurable function is realized. Dual C-shaped rings are introduced on the feeding structure. As shown in Figure 1(a), it is set on inside of the output port of microstrip hybrid; distances from the feeding network are CD1 and CD2. The design size of the C-Shaped ring is around 0.5 λ_p, where λ_p is the free-space wavelength at resonance frequency. As can be seen from Figure 5, C-shaped ring is used as a filter to improve in-band characteristics.

3. Experimental Results and Discussion

For better explanation of the measured results of the proposed antenna, the fabricated CP reconfigurable antenna prototype with PIN diodes and biasing circuit is shown in

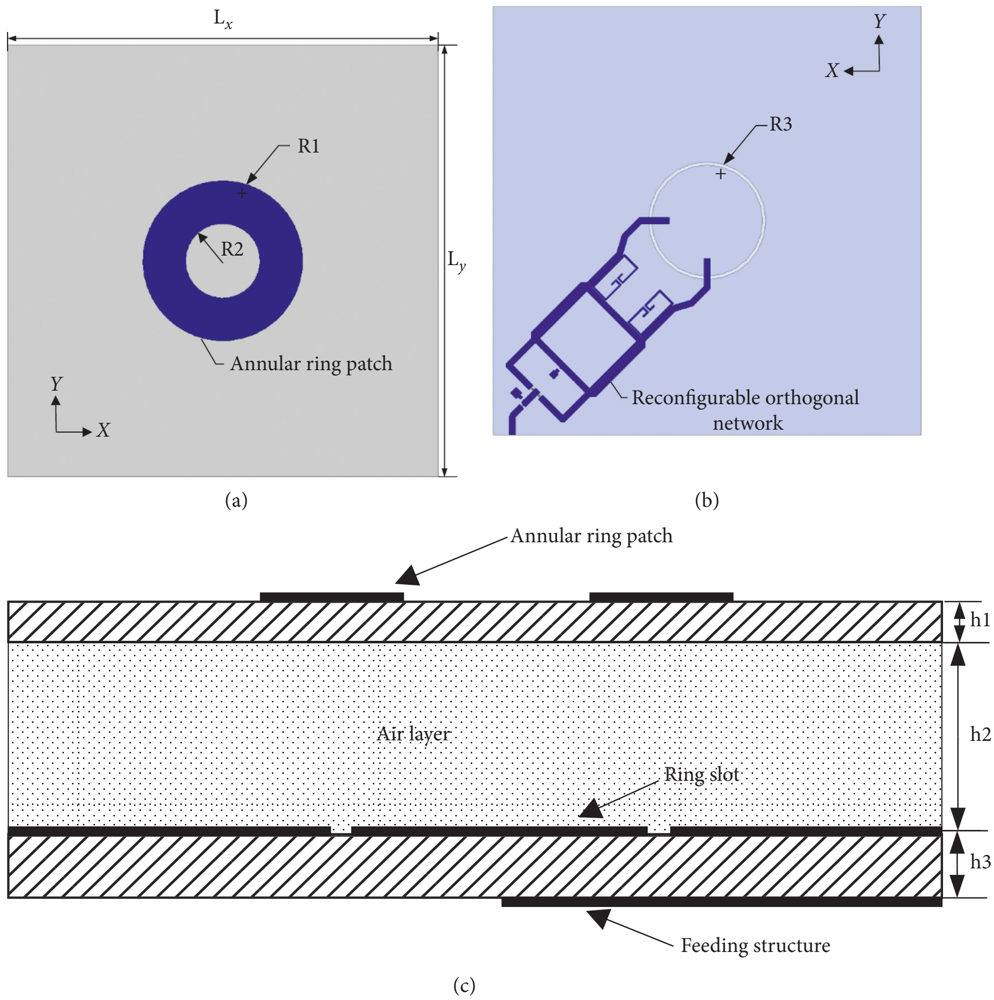


FIGURE 1: Geometry of the proposed antenna: (a) top view, (b) bottom view, and (c) sectional view.

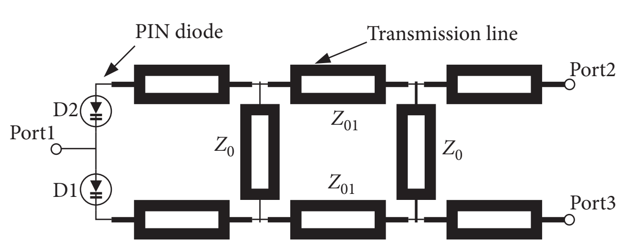


FIGURE 2: Schematic diagram of the reconfigurable feeding network.

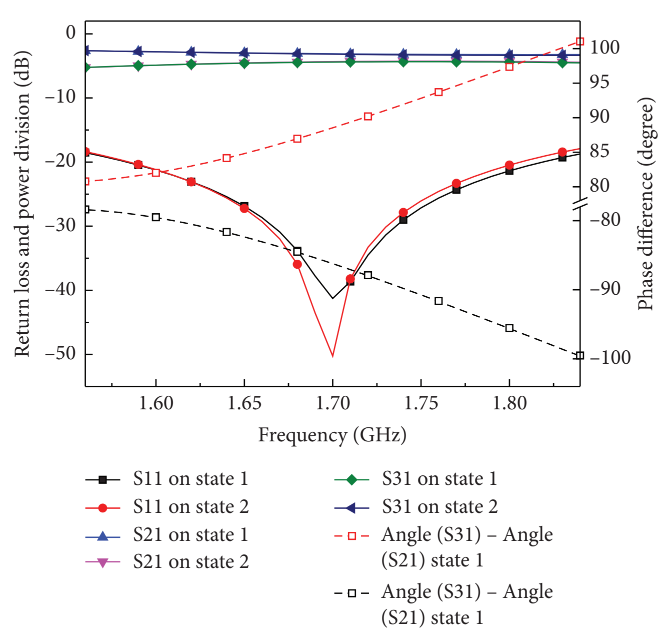


FIGURE 3: Simulated S parameter of the reconfigurable feeding structure.

Figure 6. The optimized antenna parameters are shown in Table 1.

To switch the state of the PIN diodes, ±0.8 V DC voltages were applied on the DC biasing line. The additional wires in Figure 6 are used to provide bias for the diodes. In order to reduce the influence of the diode bias circuit on the radiation performance of the antenna, the bias line is placed away from the antenna radiation direction. Meanwhile, an inductor with 68 nH is used as RF choke to reduce the influence of DC component on the antenna. Changing the DC voltage controls the diodes to

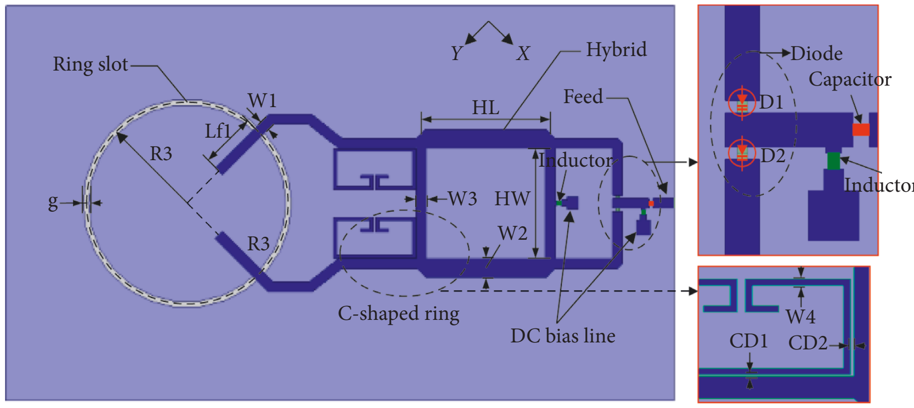


Figure 4: Reconfigurable orthogonal feeding network for CP antenna.

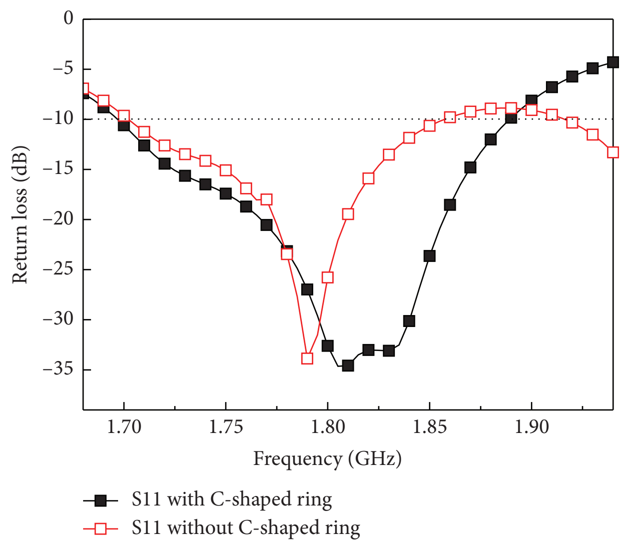
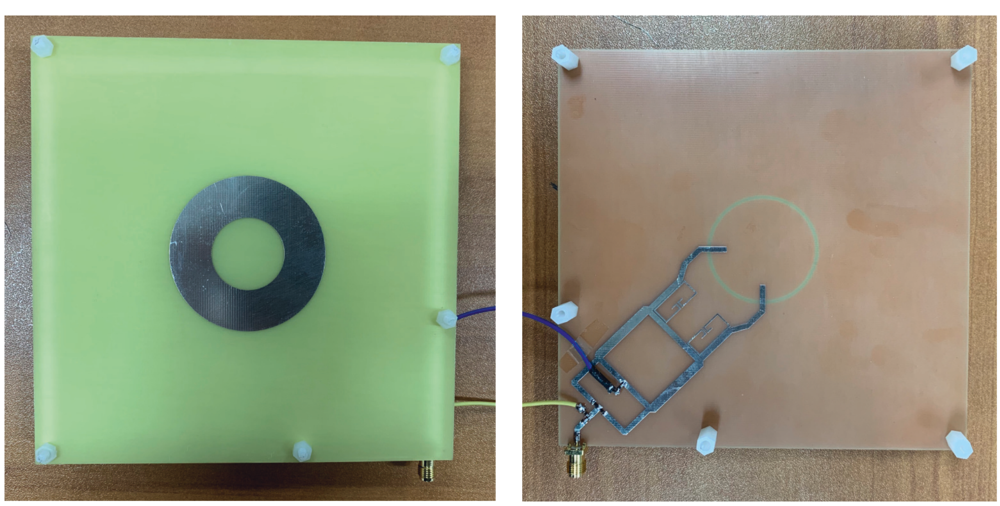
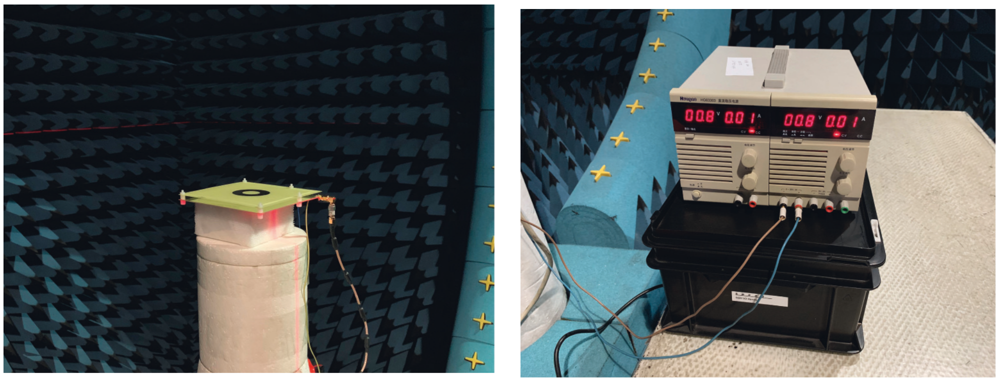


Figure 5: Simulated results with C-shaped ring.



(a) (b)

Figure 6: Continued.



(c) (d)

Figure 6: Fabricated prototype of the propose antenna: (a) top view of the CP antenna, (b) bottom view of the CP antenna, (c) antenna in the chamber, and (d) DC source.

Table 1: Dimensions of the optimized antenna design.

Parameters	(mm)
Lx	135
R2	11.7
Lf1	8
CD1	0.1
W2	3.2
h1	0.5
Ly	135
R3	18
HL	21.4
CD2	0.2
W3	1.7
h2	6
R1	25
g	1
HW	22.9
W1	1.7
W4	0.5
h3	1

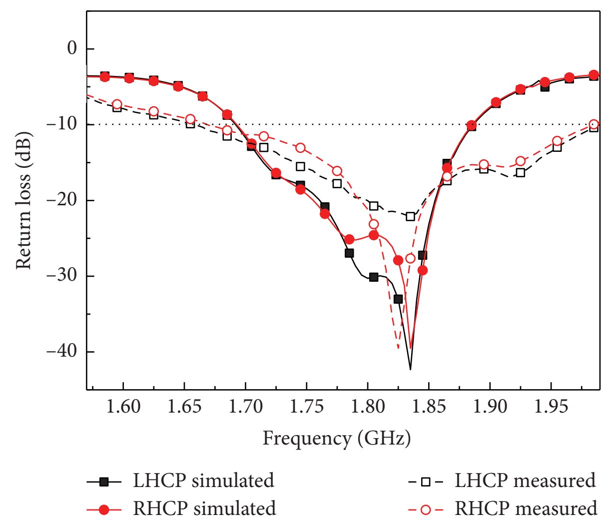


Figure 7: Simulated and measured S11.

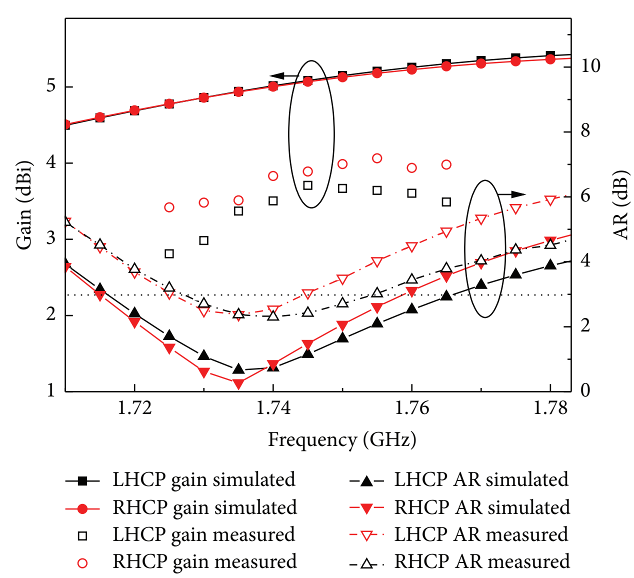


Figure 8: Simulated and measured AR and gain.

switch between the two states. Two Skyworks SMP1345-079LF PIN diodes are used in the proposed antenna. 1.5 Ω equivalent resistance with serial inductance of 0.7 nH and 5000 Ω equivalent resistance with serial inductance of 0.7 nH are used as equivalent parameters of PIN diode switch in on and off. When loading forward bias 0.8 V, D1 turned on with D2 turned off. In contrast, when loading bias −0.8 V, D2 turned on with D1 turned off. The insertion loss and isolation of the PIN diode at 1.74 GHz are −0.1 dB and −35 dB. The chamber test environment is shown in Figure 6(c). Return loss, axial ratio, and gain and radiation pattern of the prototype antenna have been measured for verification. Both simulated and measured results of return loss and axial ratio are shown in Figures 7 and 8. Approximate results can be obtained for both polarized states due to symmetry of the antenna.

The proposed CP reconfigurable antenna has achieved measured 10 dB impedance bandwidth of 14.1% for both LHCP and RHCP states. Figure 7 shows a good agreement

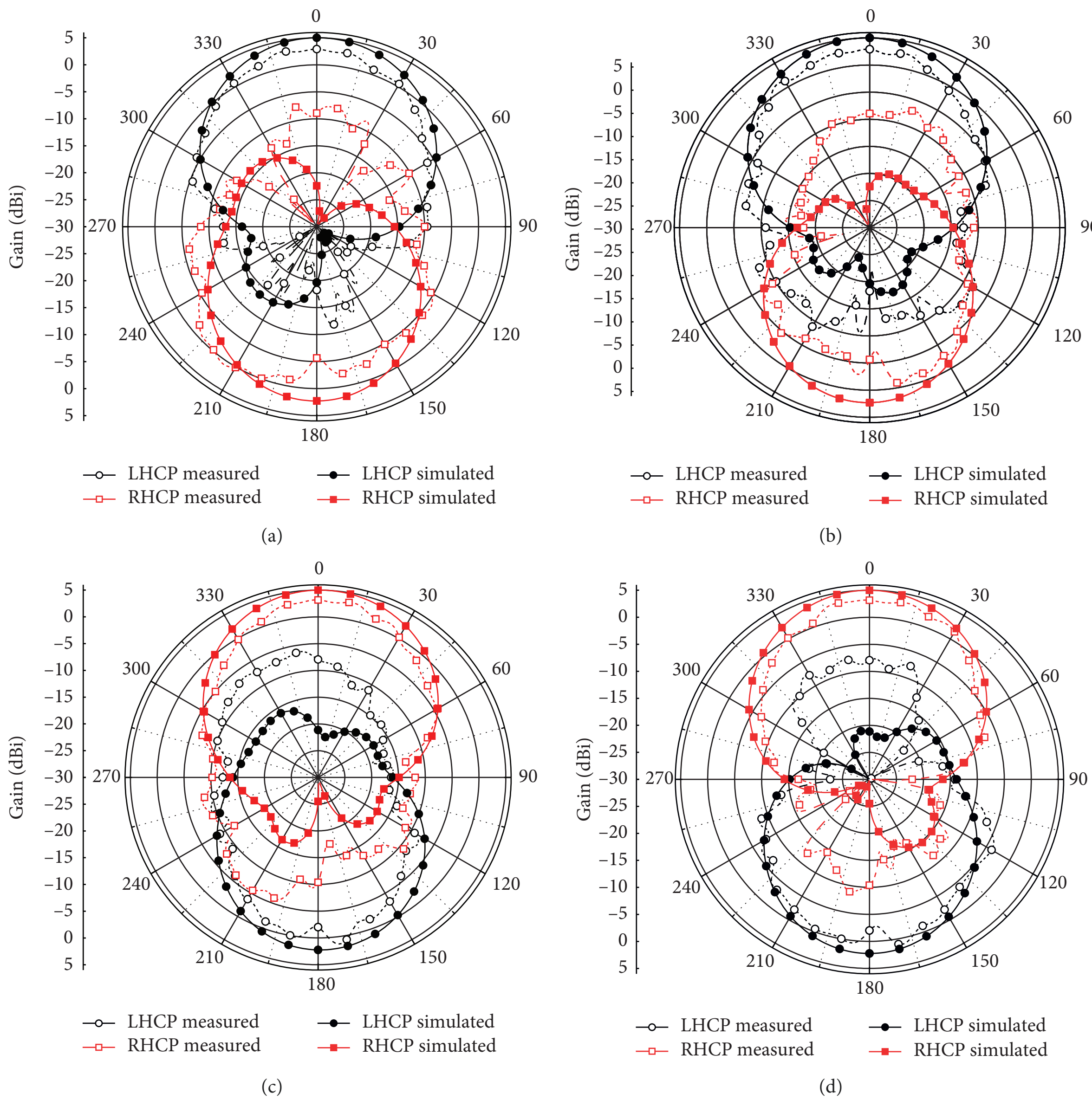


Figure 9: Simulated and measured radiation pattern at 1.74 GHz: (a) state 1 with $\varphi = 0^{\circ}$, (b) state 1 with $\varphi = 90^{\circ}$, (c) state 2 with $\varphi = 0^{\circ}$, and (d) state 2 with $\varphi = 90^{\circ}$.

on measured and simulated results. The results of axial ratio and gain are shown in Figure 8. It can be found that the simulated 3 dB axial ratio bandwidth is nearly 3.2% for both the polarized states while the measured axial ratio bandwidth is 1.2%, and the minimum 3 dB axial ratio is about 0.79 at 1.74 GHz. The simulated gain is 5 dBi for both states while the measured gain is 3.7 dBi for LHCP and 3.9 dBi for RHCP. The simulated and measured radiation patterns at 1.74 GHz for the two polarization states are plotted in Figure 9. Moreover, the measured antenna efficiency is about 50% within the operating range; it may be influenced due to the presence of internal resistance of the PIN diodes.

4. Conclusions

A circular polarization reconfigurable antenna based on reconfigurable orthogonal network has been investigated in this paper. The proposed antenna can be electronically switched between LHCP and RHCP by changing the states of PIN diodes loaded at the reconfigurable orthogonal network. The experimental results show good agreement with the simulation results. The circular polarization reconfigurable technology can be used in antenna aperture sharing designs. The proposed antenna has realized good impedance matching and 1.2% axial ratio bandwidth for the both states.

Data Availability

The simulated and measured data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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