A BIDIRECTIONAL WAVEGUIDE ANTENNA WITH POLARIZATION RECONFIGURABLE CAPABILITY

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ABSTRACT: *A bidirectional metallic waveguide antenna with polarization reconfigurable capability is presented in this study. The polarization states of the proposed design can be flexibly reconfigured among two orthogonal circular polarizations (CP) and linear polarization (LP) simply by selecting four different combinations of microstrip feeding branches with switches. Two identical rectangular metal sheets perpendicular to each other were inserted into the diagonal directions of a waveguide aperture. They were excited with the same amplitude, but with 0°, 180°, 90°, or 270° phase difference by choosing two of four microstrip feeding segments each time, and left-band CP, right-hand CP, and LP could be generated, respectively. Meanwhile, the sense of CP in two opposite radiating directions was also the same for either sense of CP. The proposed reconfigurable antenna can provide link reliability and polarization diversity for mobile wireless communications in a multipath propagation environment. In addition, it alone can realize multifunctional operations and thus reduce system complexity and cost. Details of antenna design are shown, and measured results for the constructed prototype are exhibited and discussed.* © 2014 Wiley Periodicals, Inc. Microwave Opt Technol Lett 56:422–427, 2014; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.28089

Key words: *reconfigurable polarization; bidirectional radiation; circular polarization; waveguide antenna*

1. INTRODUCTION

Antenna polarization refers to the orientation of electrical fields in a plane perpendicular to the propagating direction, which can be divided into linear polarization (LP) (vertical or horizontal) and circular polarization (CP) (left hand or right band). A polarization-reconfigurable antenna is a type of antenna whose polarization can be flexibly switched among the above-mentioned four states. Polarization reconfigurability can be used to combat multipath fading effect in modern mobile wireless communications by providing the available channels with uncorrelated signals, and thus enhance link reliability, realize diversity performances, and improve channel capacity. Experimental analysis of antenna polarization diversity on system capacity has been conducted by researchers [1, 2], and measured results showed that transmit/receive antennas radiating different polarizations are able to increase system diversity level and the received signal power significantly compared to antennas with the same polarization. Therefore, designs of antennas with polarization diversity are gaining increasing importance in mobile wireless applications. Microstrip patch antennas with polarization reconfigurable capability are extensively studied owing to their attractive features such as low profile, light weight, and easy fabrication [3–6]. But these proposed patch antennas with switchable polarizations usually have limited operating bandwidth, and their radiation patterns are unidirectional, which is not suitable for bidirectional antenna designs.

Antennas with bidirectional radiation are needed in various mobile wireless systems, such as a microcellular base station, a high-speed indoor WLAN, a radio frequency identification system, a coal mine channel, a bridge, tunnel or railway communication, and so forth. Bidirectional circular polarization (Bi-CP) with diversity performance is further preferred for link stability and channel capacity enhancement. Slot antennas that can radiate bidirectional beams are good candidates for the design of Bi-CP with polarization switchable ability [7–10]. Reconfigurable slot antennas with perturbations switched on or off by PIN diodes were proposed in Refs. [7–9], and polarizations switching between LP and CP or between left-hand CP (LHCP) and right-hand CP (RHCP) were realized, respectively. An annular slot antenna with switchable polarizations developed from a feeding mechanism was demonstrated in Ref. [10], and one LP and two orthogonal CPs were provided. The common feature for all the available designs using circularly polarized slot radiators is that they will provide CP of reversed senses in two contrasting radiating directions. This means that if a LHCP is produced at one end, RHCP would unavoidably be generated at the opposite end. No information can be exchanged if the polarizations are mismatched in that opposite direction.

For better utilization of spatial resources and improvement of communication quality, a back-to-back configuration was introduced in Refs. [11–14] to realize the CP of the same sense in two opposite directions. Slot-coupling [11] and coplanar waveguide feeding techniques [12–14] were used to excite two identical patches for radiations of Bi-CP with the same rotating sense. However, bidirectional circularly polarized beams of the same sense obtained in these proposed designs are just replication and superposition of unidirectional CP elements located at the front and back sides of a common feeding scheme, and they have narrow axial ratio bandwidth and beamwidth. In Ref. [15], we designed a waveguide antenna with natural ability of producing Bi-CP of the same sense, and this feature was realized by two rectangular metal strips orthogonally inserted into a waveguide. However, only one sense of Bi-CP was available in this design and these two metal strips needed to be rotated by 90° to generate the other sense of Bi-CP.

In this study, we propose a bidirectional waveguide antenna with polarization reconfigurable capability, and polarizations switchable among LHCP, RHCP, and LP are realized by selecting different feeding mechanisms, eliminating the need of structural rotation compared to the design in Ref. [15]. The proposed polarization-reconfigurable antenna alone can achieve multifunctional operations instead of using multiple antennas with different polarizations. It can satisfy the different requirements of several systems and thus greatly reduce system size, weight, and cost.

2. ANTENNA DESIGN

2.1. Antenna Structure

Figure 1(a) shows the geometry of the proposed bidirectional waveguide antenna with switchable polarization, and the whole antenna consists of three main parts including a square-aperture metallic waveguide with two open ends, two identical rectangular metal sheets, and a microstrip line feeding network. The aperture width and height of the waveguide is W_A and H_W, respectively. A 1-mm-thick dielectric substrate ($\varepsilon_r = 2.65$, tan $\delta = 0.005$) is screwed inside the square waveguide for the construction of microstrip feeding structure. As shown in Figures 1(b) and 1(d), the two metal sheets Sheet 1 and Sheet 2 of width W_S and length L_S are soldered on the microstrip feeding line with an inclination angle of 45°. They are horizontally orthogonal to each other and vertically separated by a distance of D_S, which is about a quarter of the guided wavelength at the desired working frequency.

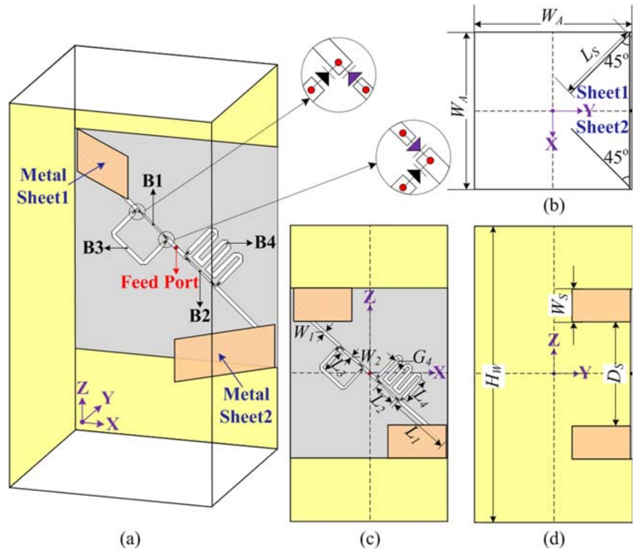

Figure 1 Geometry of the proposed antenna with reconfigurable polarization: (a) Three dimensional view and planar views; (b) *xoy* plane; (c) *zox* plane; and (d) *zox* plane. Parameter values are $W_A = 76.0$, $H_W = 143.0$, $W_S = 16.0$, $L_S = 40.0$, $D_S = 50.0$, $W_1 = 1.6$, $L_1 = 30.7$, $W_2 = 0.9$, $L_2 = 13.9$, $L_3 = 12.2$, $L_4 = 12.6$, and $G_4 = 1.5$ (unit: mm). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

Reconfigurable feeding network including four segmental branches of microstrip line $B1$, $B2$, $B3$, and $B4$, as indicated in Figures 1(a) and 1(c), is developed along the diagonal line of the two metal sheets. The connection or disconnection of each microstrip feeding branch is controlled by the states of switches that are installed at the two ends of each branch, and thus four different selectable signal paths can be obtained. In addition, the width for the entire microstrip feeding structure is W_1 except for the branches $B1$ and $B2$, whose width W_2 is designed to be narrower than the others for better impedance matching. The total length of branch $B3$ with bent length L_3 is a quarter wavelength longer than the direct connecting length L_2 of branch $B1$ for 90° phase shift, and branch $B4$ with bent length L_4 and gap distance G_4 is three-quarter wavelength longer than branch $B2$ for 270° phase delay. In this way, the two metal sheets can be excited with different phases through selecting a certain signal path with switches, and the polarization of the proposed bidirectional waveguide antenna can be changed dynamically among CPs and LPs.

2.2. Operation Principle

By choosing two of the four segmental microstrip branches with switches each time, four different signal paths can be achieved, and the two inclined metal sheets are then fed with four sets of phase differences for the realization of switchable polarization. A detailed description of the four different combinations of microstrip feeding branches is given in Figure 2. For case 1 shown in Figure 2(a), branches $B1$ and $B2$ are selected simultaneously, and the two rectangular metal sheets are then excited with the same amplitude and phase. Another 90° phase shift is introduced by the quarter-wavelength distance between the two metal sheets, and therefore, bidirectional LHCP can be realized by this configuration. When branches $B3$ and $B4$ are chosen, as in case 2 in Figure 2(b), the two metal sheets are then excited with the same magnitude but with a 180° phase difference. Bidirectional RHCP is obtained this time with the incorporation of that spatial 90° phase shift.

For either sense of the generated Bi-CP, an important feature is that they naturally share the same sense in two opposite radiating directions. The reason for this phenomenon is that a fixed 90° phase difference caused by the quarter-wavelength spatial separation is always existed between the two metal sheets, no matter they are fed in phase or out of phase. For case 1 where the two metal sheets are fed with the same phase, Sheet 2 phase lags behind that of Sheet 1 by 90° when the antenna radiates upward, and Sheet 1 phase lags behind that of Sheet 2 by 90° when the antenna radiates downward. Therefore, bidirectional LHCP can be obtained simultaneously. Likewise, for case 2 where the two metal sheets are fed with antiphase, the phase of

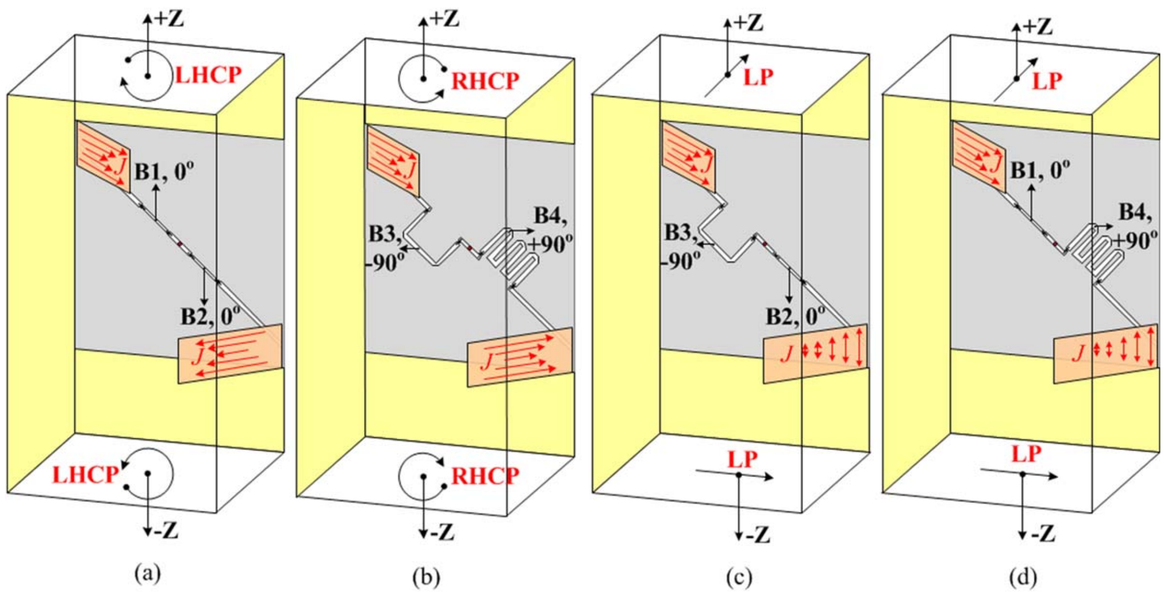

Figure 2 Polarization reconfigurability by four different combinations of microstrip feeding line: (a) case 1, bidirectional LHCP; (b) case 2, bidirectional RHCP; (c) case 3, bidirectional LP; and (d) case 4, bidirectional LP. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

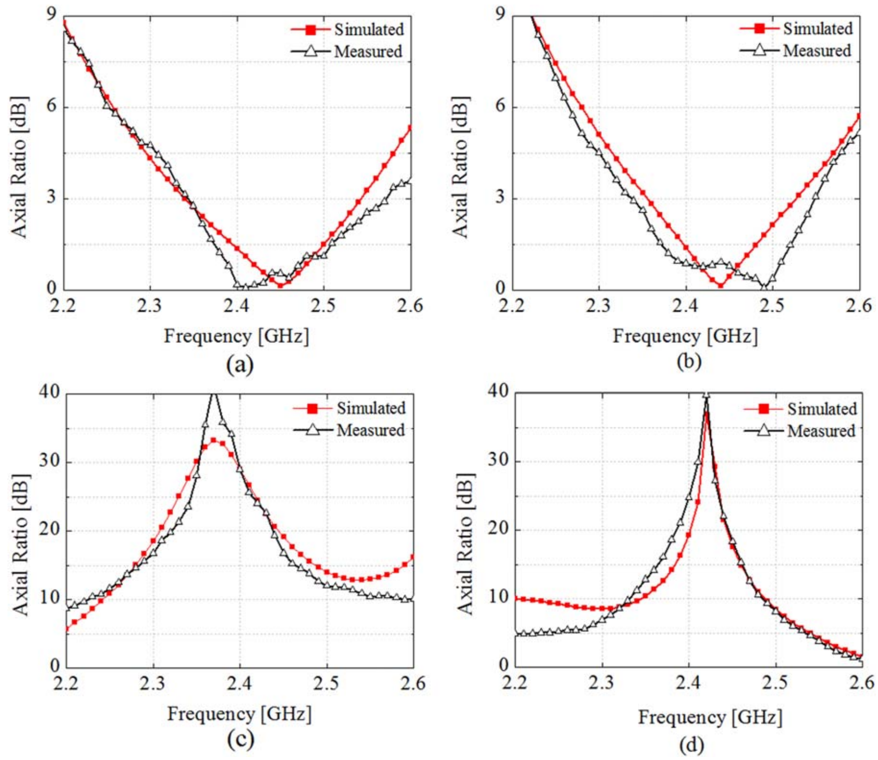

Figure 3 Simulated and measured axial ratio of the proposed antenna for (a) case 1, LHCP; (b) case 2, RHCP; (c) case 3, LP; and (d) case 4, LP. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

Sheet 2 will lead ahead that of Sheet 1 by 90° for upward radiation, and the phase of Sheet 1 will lead ahead that of Sheet 2 by 90° for downward radiation. As a result, bidirectional RHCP is produced automatically.

To realize bidirectional radiations of LP, the two rectangular metal sheets need to be excited with the same or reversed phase by taking the feeding phase difference and the spatial phase shift into account together. If an additional 90° feeding phase difference is introduced to compensate the spatial 90° phase shift between the two metal sheets, two orthogonal vectors of the excited electrical fields can be superposed to radiate linearly polarized waves. For case 3 in Figure 2(c), branches *B*2 and *B*3 are connected to the main microstrip line to feed the two metal sheets with 90° phase difference, and bidirectional LP is generated successfully. Meanwhile, the LPs in the two opposite radiating directions are orthogonal to each other, which could also be used for spatial polarization diversity. The generated LP in the case 4 of Figure 2(d) is the same as that in case 3, as the 90° phase delay along the upper signal path is equivalent to the 270° phase shift along the lower signal path.

3. RESULTS AND DISCUSSION

The design procedure and parameter impacts of the proposed antenna with Bi-CP of the same sense can be found in Ref. [15]. The parameters that have a great influence on the bidirectional axial ratio include the aperture W_A and height H_W of the waveguide, the width W_S of each metal sheet and the separation D_S between the two metal sheets. The impedance matching characteristic of the proposed antenna is significantly influenced by the length L_S of each metal sheet, the width W_1 and W_2 of

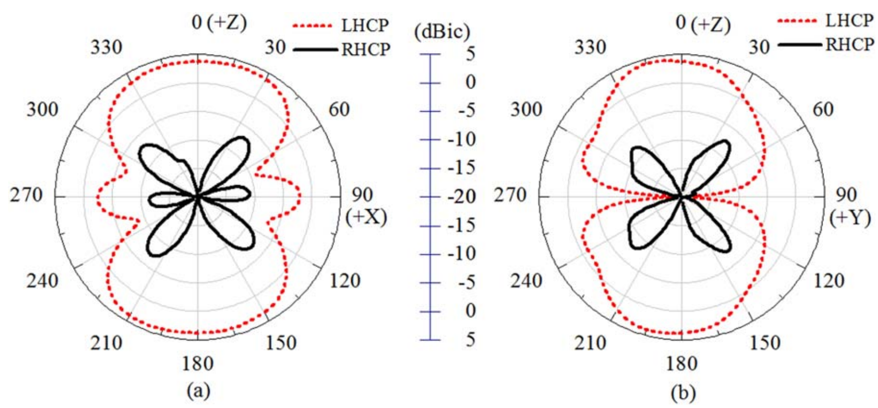

Figure 4 Simulated bidirectional gain patterns of LHCP for case 1: (a) *zox* plane and (b) *zoy* plane. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

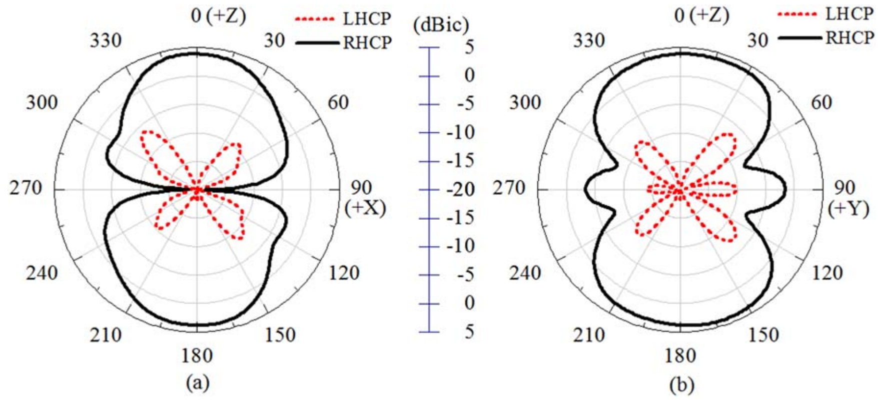

Figure 5 Simulated bidirectional gain patterns of RHCP for case 2: (a) *zox* plane and (b) *zoy* plane. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

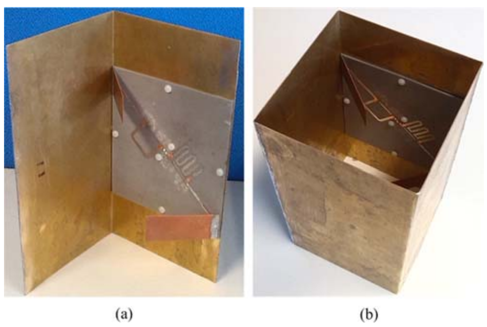

Figure 6 Fabricated prototype: (a) feeding network and the two orthogonal metal sheets and (b) the composite waveguide antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

the feeding microstrip branches. Copper strips with the same width as the feeding microstrip line in place of diode switches are used in this study for proof of concept. The turning on or off of the switches is realized by adding or removing the corresponding copper strips at the ends of each microstrip branch.

An antenna prototype for 2.4-GHz WLAN communications was designed, fabricated, and measured to verify our design concept, and the specific values of designed parameters are listed in the caption of Figure 1. The simulation and analysis were accomplished by Ansoft HFSS based upon the finite element method. The simulated and measured axial ratio of the proposed reconfigurable antenna in +Z direction for the four different cases is compared in Figure 3, and overall they agree well with each other. A good 3-dB axial ratio bandwidth was obtained for the former two cases radiating circularly polarized waves. However, the axial ratio was greater than 10 dB over a

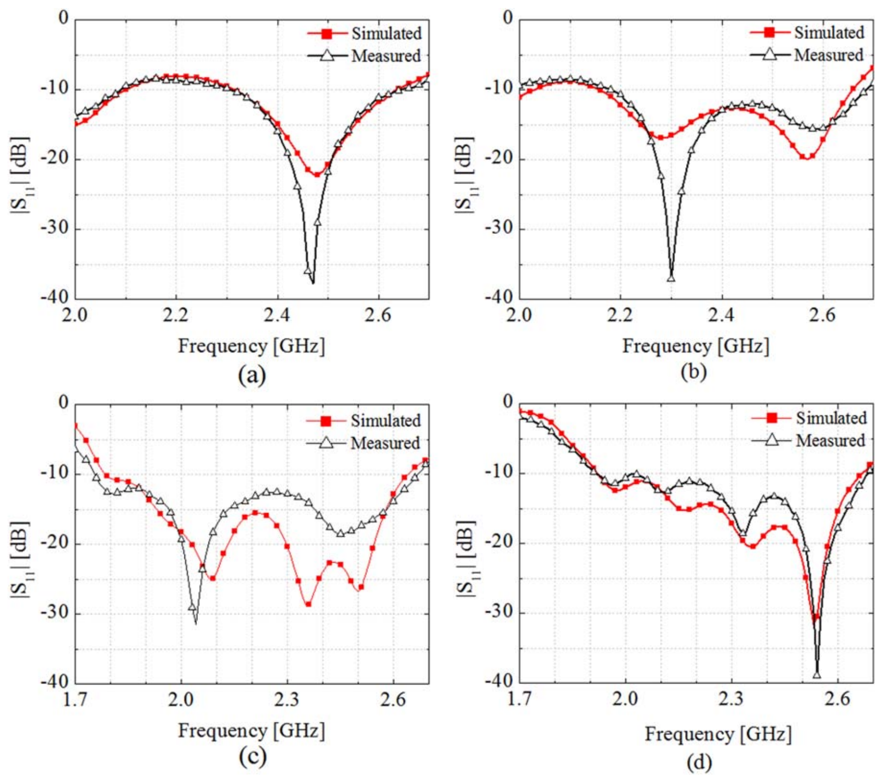

Figure 7 Simulated and measured reflection coefficient of the proposed antenna for (a) case 1, LHCP; (b) case 2, RHCP; (c) case 3, LP; and (d) case 4, LP. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

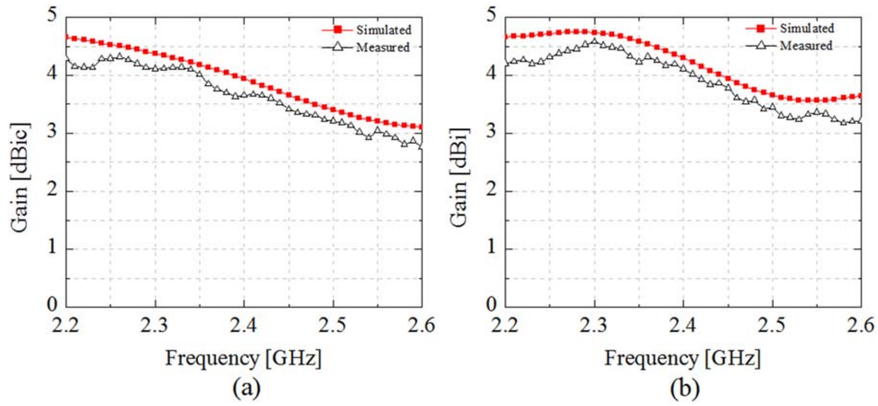

Figure 8 Simulated and measured gain of the proposed antenna for (a) case 1, LHCP and (b) case 3, LP. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

certain operating bandwidth for the latter two cases with bidirectional linearly polarized radiations. The comparison of axial ratio in –Z direction shows almost the same characteristics. The measured 3-dB axial ratio bandwidth for LHCP (case 1) and RHCP (case 2) were 220 MHz (8.9%, 2.35–2.57 GHz) and 210 MHz (8.6%, 2.34–2.55 GHz), respectively. The measured > 10 dB axial ratio bandwidth for LP of case 3 and case 4 were 350 MHz (14.6%, 2.22–2.57 GHz) and 160 MHz (6.6%, 2.33–2.49 GHz), respectively. Figures 4 and 5 plot the simulated radiation patterns for bidirectional LHCP (case 1) and RHCP (case 2) at 2.44 GHz, respectively, where we can see that an equal power division with an identical maximum realized gain of 3.8 dBic was realized at the upper and lower radiating ends, and a 3-dB axial ratio beamwidths of about 60° in the two opposite radiating directions were also obtained for the two principal planes. The gain variation was smaller than 3 dB within the angular range of the 3-dB axial ratio beamwidth.

The photograph of the constructed prototype is shown in Figure 6. In Figure 7, we compare the measured and simulated reflection coefficient by the four different sets of feeding structures. The measured impedance bandwidths with $|S_{11}| \leq -10$ dB were 350 MHz (14.1%, 2.30–2.65 GHz), 510 MHz (20.9%, 2.18–2.69 GHz), 900 MHz (40.7%, 1.76–2.66 GHz), and 760 MHz (33.0%, 1.92–2.68 GHz), respectively, for the four corresponding cases. The measured and simulated gain for CP (case 1) and LP (case 3) is given in Figure 8. The little loss in the measured gain may be caused by the feeding connector and the adopted dielectric material. The measured normalized radiation patterns for CP (case 1) and LP (case 3) at 2.44 GHz are drawn in Figures 9 and 10, respectively, and they both agree well with the simulated results. The radiation pattern for CP is measured with a spinning transmitting horn, and the zig zag at a specific angle represents the maximum and minimum values of the corresponding axial ratio. On the whole, the measured and the simulated results showed good agreement, and the little discrepancies could be attributed to the manufacturing error and measurement system set up.

4. CONCLUSION

A bidirectional waveguide antenna capable of reconfiguring polarization has been proposed, and its polarization state can be changed dynamically among LHCP, RHCP, and LP with the introduction of a switchable microstrip feeding network. By controlling the states of the switches that were installed at the two ends of the four microstrip branches, two of them were selected each time to connect with the main feeding line and four different feeding structures were obtained. The two orthogonal rectangular metal sheets were then excited with four different sets of phase differences, and thus switchable polarization was realized. Copper strips with the same width as the microstrip feeding line are used to function as switches for proof of concept, and implementation with switches by PIN diodes or microelectromechanical systems is under further consideration. Meanwhile, for either sense of the generated CP, the circularly polarized beams naturally share the same sense in the two opposite radiating directions, which is an inherent characteristic of the proposed

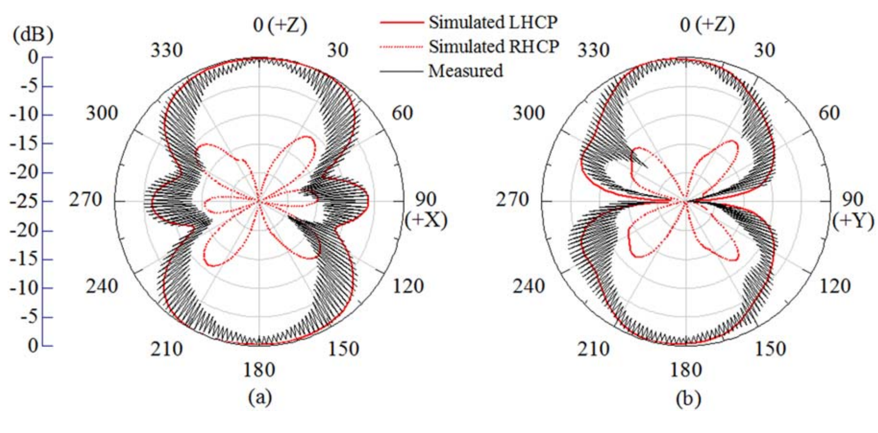

Figure 9 Simulated and measured CP radiation pattern for case 1, LHCP at 2.44 GHz (a) *zox* plane and (b) *zoy* plane. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

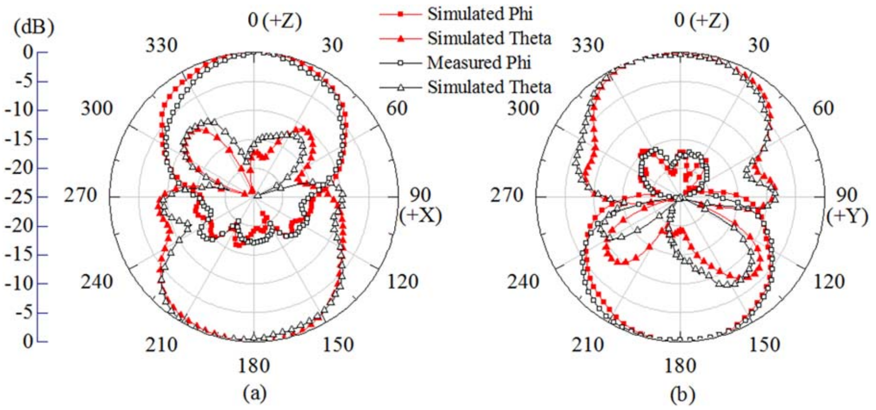

Figure 10 Simulated and measured LP radiation pattern for case 3, LP at 2.44 GHz: (a) *zox* plane; (b) *zoy* plane. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

structure. The polarization of the radiated bidirectional linearly polarized waves is orthogonal to each other at the two ends. The proposed reconfigurable antenna is able to realize polarization diversity performance, which is applicable for mobile wireless communication systems. In addition, it is simple in geometry, easy to fabricate, and can meet different requirements of several systems. A prototype for 2.4-GHz WLAN applications was designed and experimentally tested, and the measured and simulated results show good agreement.

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PRECISE MEASUREMENT OF FIBER DISPERSION BASED ON PHASE-MODULATED SIGNAL FADING

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ABSTRACT: *We propose a novel method for accurately measuring the chromatic dispersion based on the fading effect of the phase-modulated signal. The fiber dispersion, acting as an optical phase filter, causes the periodical fading of the phase-modulated signal, and the polynomial fitting of the fading curve enables the precise determination of the characteristic notch frequency and the fiber dispersion. Our method can be used for the chromatic dispersion measurement at different operating wavelengths and dispersive fibers by using a vector network analyzer.* © 2014 Wiley Periodicals, Inc. Microwave Opt Technol Lett 56:427–430, 2014; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.28088

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