

A Compact Microstrip Patch Antenna with Reconfigurable Feed Network for Polarization Diversity

Chunxia Cheng*, Fushun Zhang, and Yali Yao

Abstract—A compact reconfigurable four-feeding microstrip antenna with polarization diversity is presented in this paper. With four triangle-shaped elements as the radiation patch, the proposed antenna can achieve good impedance match for linear polarization (LP), left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP). A four-way power divider made by three Wilkinson power dividers and interconnected with PIN diodes is designed to feed the four elements. By controlling the states of the diodes, the antenna can produce LP, LHCP and RHCP. By using T-shaped slots on the patch and back to back geometry, a compact size of $0.6\lambda_0 \times 0.6\lambda_0 \times 0.02\lambda_0$ is achieved. The impedance bandwidth of LP is about 80 MHz (3.3%), while the usable bandwidths (overlap of impedance bandwidth and AR bandwidth) of LHCP and RHCP are about 370 MHz (15%) and 250 MHz (10%). The average gain for LP is -2.1 dB, and that for CP is -3.3 dB. This reconfigurable patch antenna with switchable polarization has good performance and simple structure, which can be used for 2.4 GHz wireless communication systems.

1. INTRODUCTION

Recently, reconfigurable antennas have drawn lots of attention due to their ability to improve the performance of the wireless communication systems. For example, the switchable polarization antenna can be used to mitigate signal fading loss caused by multipath effects in wireless local area networks (WLANs) [1]. Moreover, it can be applied to realize frequency reuse to expand the capability in satellite communication systems [2] and used in multiple-input-multiple-output (MIMO) systems [3]. If the antenna can be switched between linear and circular polarization, it will make the antenna more versatile. But, it is difficult to simultaneously realize a good impedance match for circular and linear polarization. The reason is that CP radiation is generated by two degenerate orthogonal linear modes, the input impedance of which is different from that of one resonant mode used to generate LP radiation. Several designs have been proposed to solve this problem [4–6]. In [4], X shaped slot is cut at the center of a rectangular cross-shaped patch and the polarization can be switched by controlling the bias voltage of the two PIN diodes that are inserted into the center of the slot. In [5], two orthogonal notches are cut near opposite angles of the square patch and the polarization can be switched by controlling the bias voltage of the two PIN diodes that are placed on the notches. In [6], the polarization sense can be controlled by the two diodes loaded on two square loop slots in the ground plane. However, both the LP bandwidth and the usable CP bandwidth (overlap of impedance bandwidth and AR bandwidth) of the antennas in the above references are less than 2.5%. In [7], by cutting stair-slots on the ground the impedance bandwidth is increased to 6.1% but the 3-dB AR bandwidth is only 1.5%. A polarization recognizable spiral slot antenna with wide LP and usable CP bandwidth is proposed in [8], but its radiation pattern is bi-directional with a slight angle shifting in its main direction. Another method of designing the reconfigurable antenna is using a switchable feed network [9, 10]. However, the CP

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bandwidth is only 1.4% and the LP bandwidth is 2.5% in [9]. The usable CP bandwidth of the antenna in [10] is wider, but the LP bandwidth is only 2.5%.

A compact four-feeding polarization reconfigurable patch antenna combining with a switchable feed network for 2.4 GHz wireless communication system is proposed in this study. The proposed antenna using four triangle-shaped elements to simultaneously achieve good impedance match for circular and linear polarization. A four-way power divider made by three Wilkinson power dividers and interconnected with sixteen PIN diodes is designed to feed this antenna to realize the polarization diversity property. One set of connections provides a feed network of four sources with equal amplitude and contrast phase between the opposite sources, which results in linear polarization. The second and third set of connections result in left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP) when the four sources with equal amplitude but 90° phase increase in clockwise or counter-clockwise. By using T-shaped slots on the patch and back to back geometry, the overall volume of the proposed antenna is $0.6\lambda_0 \times 0.6\lambda_0 \times 0.02\lambda_0$, which is more compact than the antenna in [10] ($0.7\lambda_0 \times 0.7\lambda_0 \times 0.03\lambda_0$). The antenna can cover the 2.4 GHz WLAN frequency band (2.4–2.48 GHz) with good impedance bandwidths for both LP and CP modes and 3 dB axial ratio bandwidth for CP mode. Four-feeding structure improves the AR bandwidth and symmetrical performances of the pattern.

2. RECONFIGURABLE ANTENNA

The configuration of the proposed reconfigurable antenna is shown in Fig. 1. As shown in Fig. 1(b), the proposed structure consists of two FR4 substrates ($h_1 = h_2 = 1$ mm, $\epsilon_{r1} = \epsilon_{r2} = 4.5$) with the same size of $L_{sub} = 70$ mm. A four-feeding radiation patch containing four T-shaped slots cut from the four triangle-shaped elements is printed on the top side of the upper layer substrate. The radiation patch has a dimension of $L_{patch} = 55$ mm and the width of the slots between each radiation element is $W_3 = 1.6$ mm. And other parameters are $L_1 = 10$ mm, $W_1 = 1.5$ mm, $L_2 = 30.2$ mm, and $W_2 = 1$ mm. The ground plane is printed on the bottom side of the upper layer substrate. Four probes pass through the ground plane and soldered to the feeding network underneath the ground plane. In order to prevent the probes from touching the ground plane, four holes are milled on the copper of the ground plane; the holes have a radius of 2 mm and coincide with the probe position. The polarization is controlled by the phase shift between each adjacent element.

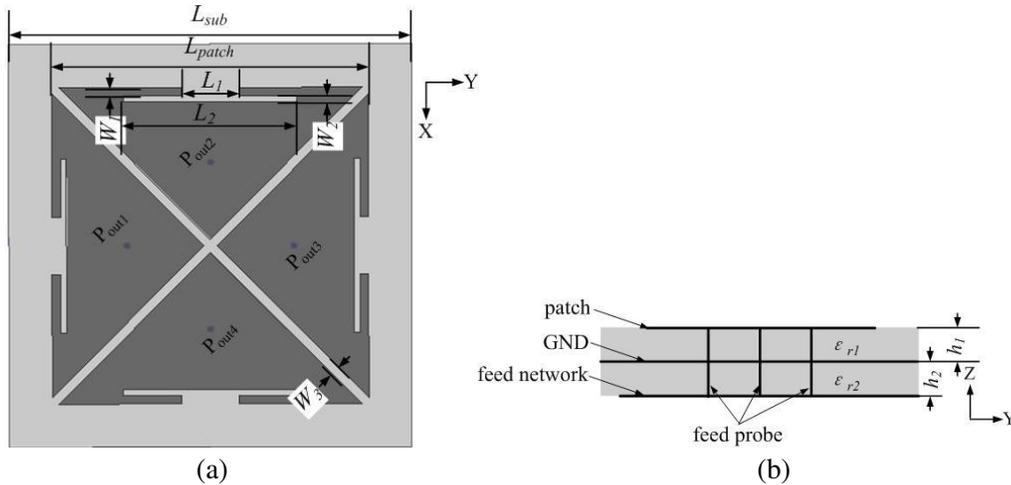


Figure 1. Geometry of the proposed antenna (a) top view and (b) side view.

As shown in Fig. 2, in order to achieve polarization reconfiguration, a feed network made by three Wilkinson power dividers is printed on the bottom side of the lower layer substrate. Sixteen PIN diodes are interconnected in the feed line to control the phase of the four output of the feed network. The PIN diode in this paper is Infineon BAR89-02LRH PIN diode, with a package dimension about

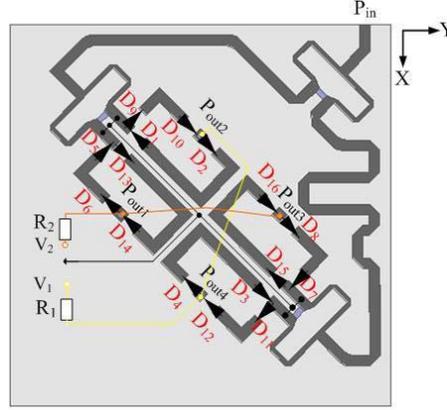


Figure 2. Feeding network and the associated dc biased network.

1.0 mm × 0.6 mm. The dc bias voltage V_1 or V_2 is either 3 V or −3 V, which can be provided by a dc source. The current-limited resistor R_1 or R_2 is 134 Ω. The forward current of the diode I_F is given by

$$I_F = \frac{V_1(\text{or } V_2) - 2 \times V}{R_1(\text{or } R_2)} = 10 \text{ mA} \quad (1)$$

In (1), V is the voltage across one diode for $I_F = 10 \text{ mA}$, which is approximate 0.83 V according to the datasheet [11]. As shown in Table 1, when the dc bias voltage V_1 and V_2 are 3 V, the diodes $D_1 \sim D_8$ are in the ON state and the phase shift of adjacent port ($P_{out1} - P_{out2}$, $P_{out2} - P_{out3}$, $P_{out3} - P_{out4}$) is 90° , so left hand circularly polarization (LHCP) is achieved. When the dc bias voltage V_1 and V_2 are −3 V, the diodes $D_9 \sim D_{16}$ are in the ON state and the phase shift of adjacent port ($P_{out2} - P_{out1}$, $P_{out1} - P_{out4}$, $P_{out4} - P_{out3}$) is 90° , so right hand circularly polarization (RHCP) is achieved. When the dc bias voltage V_1 is −3 V and V_2 is 3 V, the diodes $D_5 \sim D_{12}$ are in the ON state and the phase shift of port are $P_{out1} - P_{out2} = P_{out3} - P_{out4} = 0^\circ$, $P_{out2} - P_{out3} = P_{out1} - P_{out4} = 180^\circ$, so +45° linear polarization is achieved.

Table 1. Bias conditions and polarization states for reconfigurability.

Polarization states	V_1	V_2	D_1, D_2	D_3, D_4	D_5, D_6	D_7, D_8	D_9, D_{10}	D_{11}, D_{12}	D_{13}, D_{14}	D_{15}, D_{16}
LHCP	3 V	3 V	ON	ON	ON	ON	OFF	OFF	OFF	OFF
RHCP	−3 V	−3 V	OFF	OFF	OFF	OFF	ON	ON	ON	ON
LP	−3 V	3 V	OFF	OFF	ON	ON	ON	ON	OFF	OFF

3. EXPERIMENTAL RESULTS AND DISCUSSION

The structure is simulated using the software Ansoft HFSS13. A proposed antenna prototype is fabricated. The top and bottom views are displayed in Figs. 3(a) and (b). In the measurement, a dc block capacitor must be attached to the SMA connector to block the dc current. Fig. 4 shows the reflection coefficients of the proposed antenna operating in the three polarization states. For the LP state, the antenna has a 10 dB return loss bandwidth of 80 MHz from 2.4 GHz to 2.48 GHz (3.3%). When the antenna operates in LHCP or RHCP states, the 10 dB return loss bandwidth is wider than 2.4 GHz WLAN band (2.4–2.48 GHz). As can be seen from the graph, good agreement between the simulation and experiment results is achieved.

As shown in Fig. 5(a), simulated and measured ARs are described. The 3dB axial ratio (AR) bandwidths of LHCP and RHCP are 15% and 10%, respectively. Four-feeding structure contributes

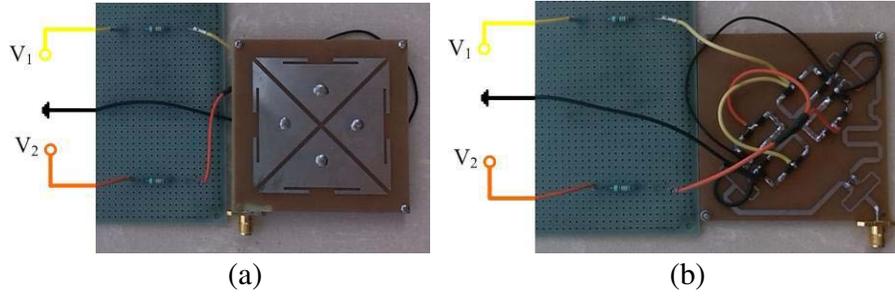


Figure 3. Antenna prototype: (a) top view; (b) bottom view.

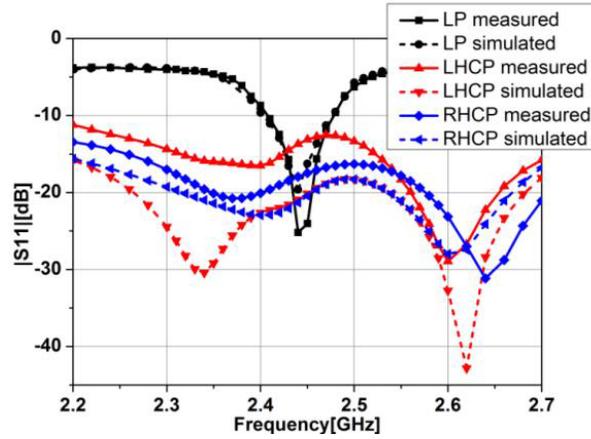


Figure 4. Reflection coefficients.

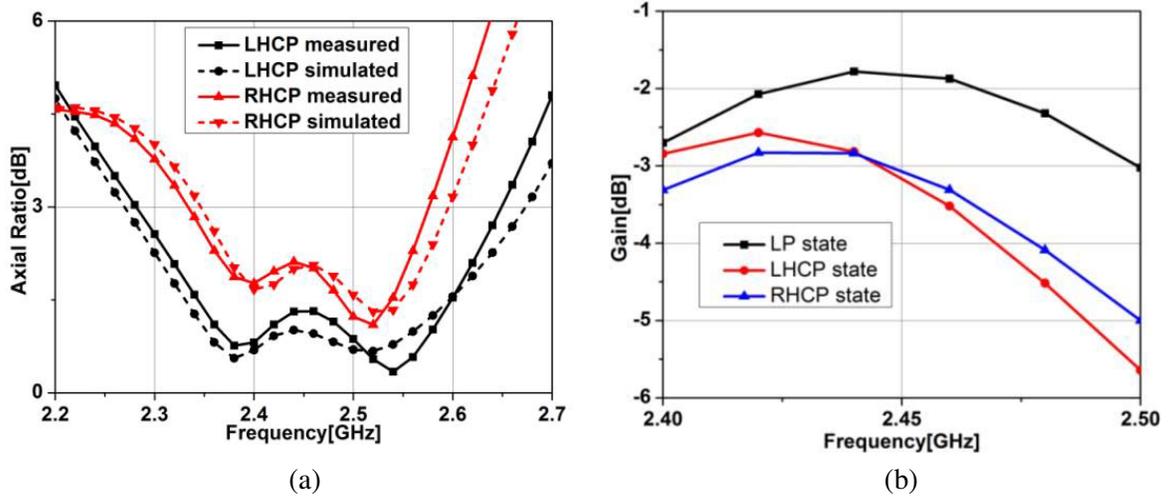


Figure 5. Comparison of axial ratio and gain: (a) simulated and measured axial ratio; (b) measured gain.

to the wider AR bandwidths feature. The measured antenna gains for the three polarization states from 2.4 GHz to 2.5 GHz are shown in Fig. 5(b). The gains are about $-2.7 \sim -1.8$ dB for LP state, $-4.5 \sim -2.6$ dB for LHCP state, and $-4.1 \sim -2.8$ dB for RHCP state. The gains of the LHCP and RHCP are lower than that of the LP state. These differences of antenna gains can be attributed to the effects of polarization loss.

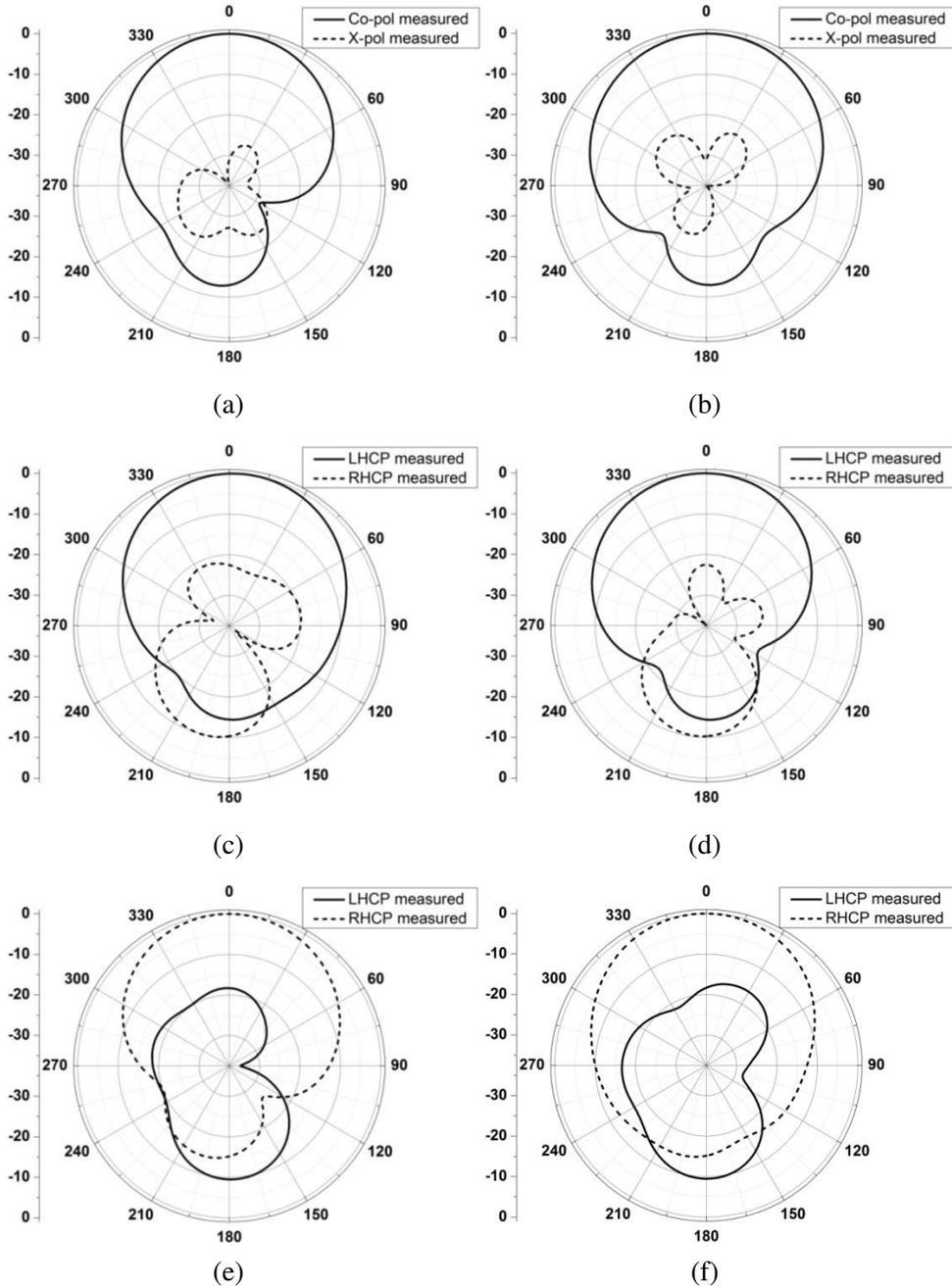


Figure 6. Radiation patterns on (a) $\varphi = 45^\circ$ plane and (b) $\varphi = -45^\circ$ plane for $+45^\circ$ LP; (c) xoz -plane and (d) $yo z$ -plane for LHCP; (e) xoz -plane and (f) $yo z$ -plane for RHCP.

The measured patterns of the reconfigurable patch for $+45^\circ$ LP, LHCP and RHCP at 2.44 GHz are shown in Fig. 6. Good radiation and symmetrical performances are obtained for the three polarization states. For the LP, LHCP and RHCP states, the cross polarization in the broadside direction is about -30 dB, -20 dB and -18 dB, respectively.

Table 2 shows the performance comparison of the proposed antenna with some published antennas. All the compared antennas can work in three polarization states. Although the gain of the proposed antenna is lower, its bandwidth especially circularly polarization bandwidth is wider than that of the reference antennas. The proposed antenna has lower profile than the antenna in reference [9].

Table 2. Comparison of similar reconfigurable antenna.

Ref.	Polarization states	Bandwidth	Peak gain	Size
[6]	LP	1.25%	5.83 dB	$0.6\lambda_0 \times 0.6\lambda_0 \times 0.01\lambda_0$
	LHCP	0.83%	6.4 dB	
	RHCP	0.83%	6.4 dB	
[7]	LP	6.1%	—	$0.4\lambda_0 \times 0.4\lambda_0 \times 0.01\lambda_0$
	LHCP	1.5%	2.9 dB	
	RHCP	1.5%	2.9 dB	
[9]	LP	2.5%	7.2 dB	$0.5\lambda_0 \times 0.5\lambda_0 \times 0.04\lambda_0$
	LHCP	1.4%	7 dB	
	RHCP	1.4%	7 dB	
This work	LP	3.3%	-1.8 dB	$0.6\lambda_0 \times 0.6\lambda_0 \times 0.02\lambda_0$
	LHCP	15%	-2.6 dB	
	RHCP	10%	-2.8 dB	

4. CONCLUSION

A compact reconfigurable four-feeding microstrip antenna with polarization diversity is presented. The proposed structure has four T-shaped slots cut from the four triangle-shaped elements and a feeding network containing three Wilkinson power dividers with sixteen PIN diodes, and the overall volume is only $0.6\lambda_0 \times 0.6\lambda_0 \times 0.02\lambda_0$. The radiating patch is fed by four probes passing through the ground plane and soldered to the feeding network underneath the ground plane. The antenna can produce linear polarization, left-hand circular polarization and right-hand circular polarization by controlling the diodes interconnected in the feed network. A good impedance matching performance for all polarization states is observed without any matching networks. The proposed design achieves a cross-polar level better than -30 dB in linear polarization and over 10% CP bandwidth in both the circular polarization states. Moreover, the prototype of the proposed antenna has symmetrical radiation patterns due to the four-feeding structure. The proposed design is simple and in low cost; therefore it can have some potential applications in the present wireless communications.

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