A Polarization Reconfigurable Patch Antenna With Loop Slots on the Ground Plane

Xue-Xia Yang, *Member, IEEE*, Bing-Cheng Shao, Fan Yang, *Senior Member, IEEE*, Atef Z. Elsherbeni, *Fellow, IEEE*, and Bo Gong

***Abstract*—This letter proposes a reconfigurable microstrip patch antenna with polarization states being switched among linear polarization (LP), left-hand (LH) and right-hand (RH) circular polarizations (CP). The CP waves are excited by two perturbation elements of loop slots in the ground plane. A p-i-n diode is placed on every slot to alter the current direction, which determines the polarization state. The influences of the slots and p-i-n diodes on antenna performance are minimized because the slots and diodes are not on the patch. The simulated and measured results verified the effectiveness of the proposed antenna configuration. The experimental bandwidths of the −10-dB reflection coefficient for LHCP and RHCP are about 60 MHz, while for LP is about 30 MHz. The bandwidths of the 3-dB axial ratio for both CP states are 20 MHz with best value of 0.5 dB at the center frequency on the broadside direction. Gains for two CP operations are 6.4 dB, and that for the LP one is 5.83 dB. This reconfigurable patch antenna with agile polarization has good performance and concise structure, which can be used for 2.4-GHz wireless communication systems.**

***Index Terms*—Microstrip antenna, polarization agility, reconfigurable antenna, slotted ground plane.**

I. Introduction

RECONFIGURABLE antennas play an important role in modern wireless communication systems, such as personal communications service (PCS) and wireless local area network (WLAN). Reconfigurable antennas with polarization diversity can realize frequency reuse, which expands the capability of communication systems, and are useful when the operating frequency band is limited. Polarization diversity antennas can also alleviate the harmful influence caused by multipath effects.

It is easy for a single-fed patch antenna to activate circular polarization (CP) wave by a perturbing the path of the current on the antenna element in many ways. The common method for perturbation is by cutting or adding a small part on a square, a circular, or a triangle patch; for reconfigurability, this part can be connected to the patch through a p-i-n diode, which acts as a switch [1]–[5]. To activate such a diode, a dc bias circuit and an isolated area are on the same side of the patch with the via being holed from the patch to the ground. Patch antennas with controlled slots can also reach the aim of polarization reconfiguration. Different lengths of U-slot on the center of patch can excite two CP waves or one linear polarization (LP) and one CP [6]. A proximity-fed patch with cross slots can switch polarization states among two orthogonal LPs and right-hand CP (RHCP) [7]. A square ring slot with the center part being perturbed is capable of switching between left-hand CP (LHCP) and RHCP [8]. A square slot antenna fed by coplanar waveguide has wider operation bandwidth and low gain [9]. Since diodes and capacitors on patches influence the antenna's performances in some degree, to minimize their influence, perturbations were realized by slots on the ground [10]. However, eight diodes and four capacitors are required to obtain LHCP and RHCP. This design motivates our current investigation.

In this letter, a novel reconfigurable patch antenna with polarization agility is suggested. The design of the antenna consists of a traditional square patch, ground plane with two square slots, and two p-i-n diodes. The advantages of slotted ground plane are to omit the dc area and to minimize the effect of diodes on the radiation performances of the antenna. Simulation, fabrication, and experiments are carried out, and detailed data are presented. The antenna is relatively concise, exhibits low fabrication cost, and hence is suitable for the rapidly developing modern wireless communication systems.

II. Antenna Design

The geometry of the proposed antenna is shown in Fig. 1. The top layer is a square patch, and the bottom one is ground plane for both RF and dc operations. Two little square patches on the ground plane are isolated out by a loop slot. Both the patch and the ground plane are made of perfectly conducting material. According to the cavity theory, the operating frequency is determined by the side length L of the square patch, and a feed point with 50 Ω input impedance is located on the symmetric axial of the y-axis and about 1/3 L away from the lower edge, which is denoted as H. A small square loop slot in the ground is cut underneath the area of the upper left corner of the patch. The square slot with side length w and slot width s is located at an offset of l distance from the patch side. The slot width on the right-hand side is expanded to d in order to allow for the placement of the diode across this side of the slot.

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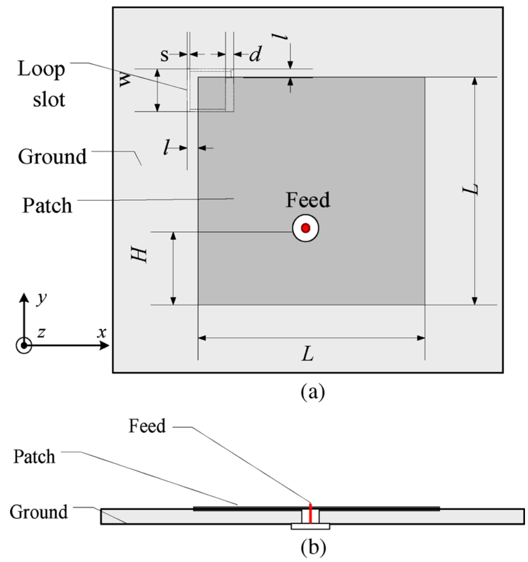

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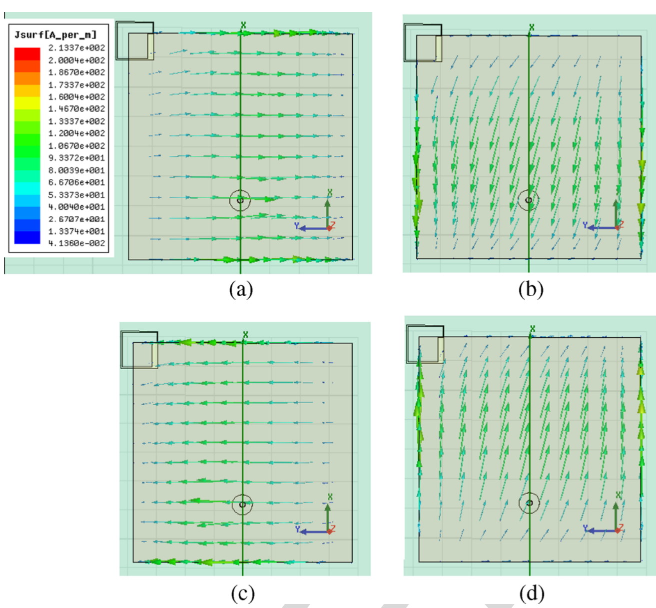

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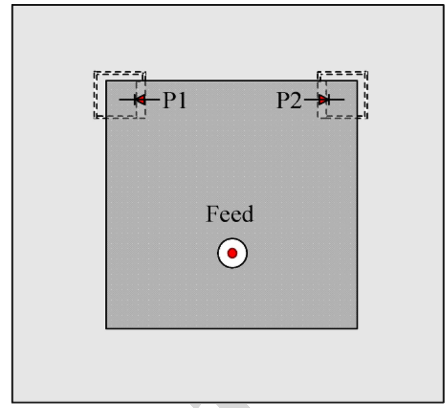
This small loop slot acts as a perturbation to the square patch antenna. The slot sizes and position influence the circular polarization and impedance characteristics, which will be analyzed in detail in Section III. Two modes of operation, TM_{01} and TM_{10} with a 90° phase difference at a designed frequency, can be excited. The current on the patch rotates along the clockwise direction as shown in Fig. 2, thus an LHCP wave is radiated. Correspondingly, RHCP can be radiated when the loop slot is cut on the ground plane under the area of the upper right corner of the patch. The patch will operate on linear polarization state if there is no slot on the ground plane or the two slots are effectively shorted out.

The proposed polarization reconfigurable patch antenna with loop slots on the ground is shown in Fig. 3. The p-i-n diodes P1 and P2 are loading the two loop slots. When one of the diodes is on, it acts as a small resistance that can be regarded as a short circuit. When the diode is off, it acts as a small capacitance and can be regard as open circuit. When the two diodes are in the "OFF" status, the two perturbation effects cancel each other and LP performance appears.



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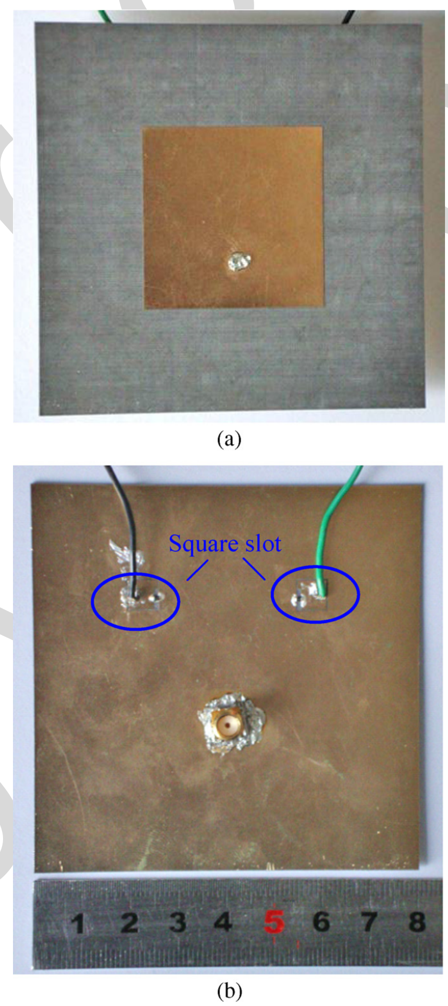

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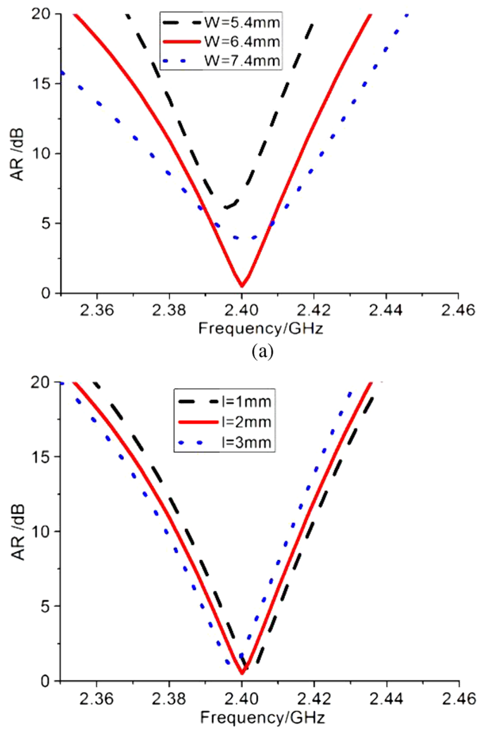


Fig. 5. Axial ratio versus frequency for different perturbation sizes. (a) Different w. (b) Different l.

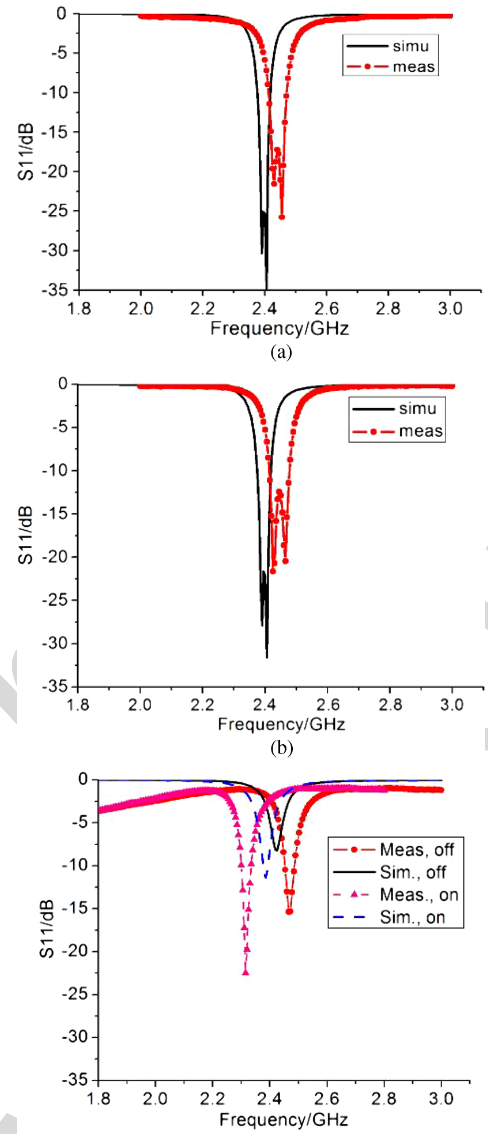


Fig. 6. Simulated and measured S_{11} of the reconfigurable patch antenna. (a) LHCP. (b) RHCP. (c) LP.

a 2.1-Ω resistor in the "ON" status, and a 0.17-pF capacitor in the "OFF" status. When the diode P1 is off and P2 is on, the upper left loop slot does work, whereas the upper right loop slot has little effect on the patch's current distribution, resulting in an LHCP wave. Similarly, an RHCP wave can be excited when the diode P1 is on and P2 is off. The antenna radiates linearly polarized wave when both diodes are switched on or off.

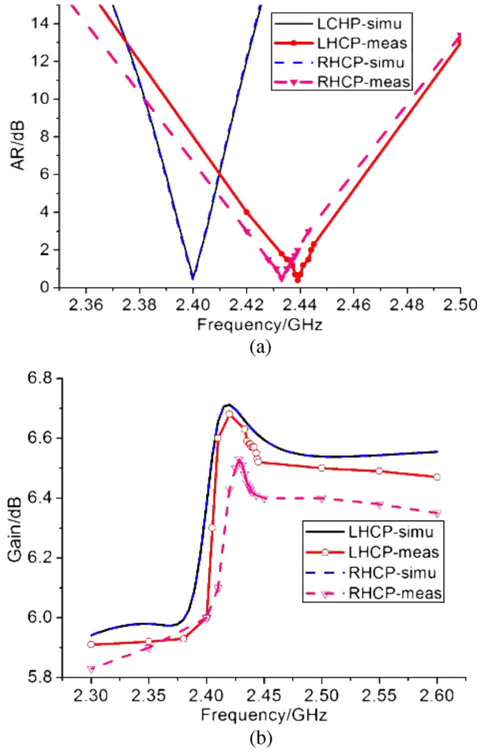
The ground plane is divided into three portions by the two loop slots. The dc bias voltage on the two diodes can be supplied directly without extra biasing elements such as capacitors. This reconfigurable microstrip antenna design avoids the need for the isolation of the dc area from the vias, which not only simplifies the antenna structure, but also reduces the influences on the antenna radiation performances.

III. Simulation and Experiment Results

The proposed antenna was fabricated on a substrate with a dielectric constant of 2.65 and a thickness of 0.8 mm. The reconfigurable antenna operates at 2.4 GHz. All of the geometrical parameters are $L = 38.0$ mm, $H = 10.0$ mm, $w = 6.4$ mm, $s = 0.2$ mm, $d = 1.0$ mm, and $l = 2.0$ mm. Fig. 4 shows the front and the back pictures of the fabricated antenna. The anodes of the two diodes are connected to the ground, and the cathodes are connected to the corresponding little square patches with two leads being soldered on each one. The diode is on when a negative voltage is applied, and is off when a positive voltage is applied.

The geometrical sizes of the perturbation elements on the CP characteristics are investigated. The effects of the square slot side length w and the position l on the axial ratio are sketched in Fig. 5. The side length w of the square slot influences the axial ratio, as shown in Fig. 5(a). It is found that the size of the perturbation element is greatly influencing the CP characteristic similar to the truncation effects on a square patch [1]–[3]. The slot position l has a little effect on the axial ratio as shown in Fig. 5(b). However, the operation frequency of the lowest axial ratio (AR) increases slightly with the decreasing of l. A narrower slot width s would exhibit a better CP characteristic from the simulation, but it should meet the fabrication tolerance.

Simulated and measured frequency responses of the reflection coefficient for the LHCP, RHCP, and LP are shown in Fig. 6. From Fig. 6(a) and (b), it can be found that two degenerated modes of TM_{01} and TM_{10} with close resonant frequencies were generated. The measured -10-dB bandwidths of S_{11} for LHCP and RHCP were about 60 MHz. Good impedance match was obtained. Fig. 7 shows the axial ratio and gain curves of two CP operations. The measured AR is about 0.5 around 2.438 GHz,



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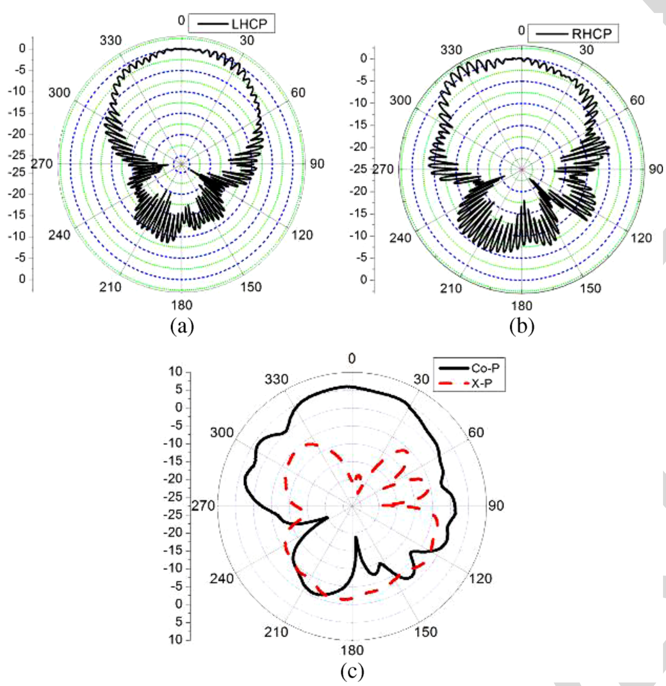

Fig. 8. Measured radiation patterns of the reconfigurable patch antenna: (a) LHCP at 2.439 GHz; (b) RHCP at 2.433 GHz; (c) LP at 2.42 GHz.

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From Figs. 6 and 7(a), it can be seen that the measured center frequency is higher than the simulated one except for the LP state while two diodes have "ON" status. The frequency shift is mainly due to the uncertainty of the dielectric constant because, according to the simulation, the center frequency will move about 40 MHz when the dielectric constant changes from 2.60 to 2.65. The measured center frequency shift of LP could be due to the lengthened current path caused by slot and diodes.

The measured patterns of the reconfigurable patch for LHCP at 2.439 GHz, RHCP at 2.433 GHz, and LP of E-plane at 2.42 GHz are shown in Fig. 8. Good radiation performances are achieved for every polarization status. For the LP, the cross polarization in the broadside direction is about −30 dB, and the measured gain is 5.83 dBi.

IV. Conclusion

A novel reconfigurable patch antenna with polarization agility for LHCP, RHCP, and LP is proposed. The polarization sense is controlled by only two diodes, which are loaded on two square loop slots in the ground plane. This design simplifies the biasing circuits for the dc voltage and keeps the square patch unperturbed. Good reconfigurable polarization function and radiation performance are obtained from simulations and experiments. This proposed antenna has the merits of concise structure and low cost and supports wide applications in wireless communication systems.

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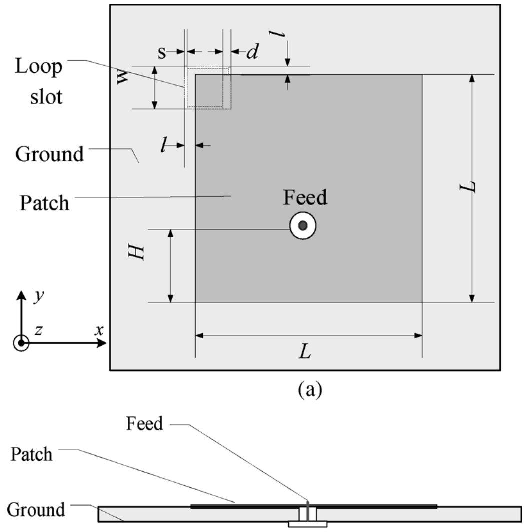

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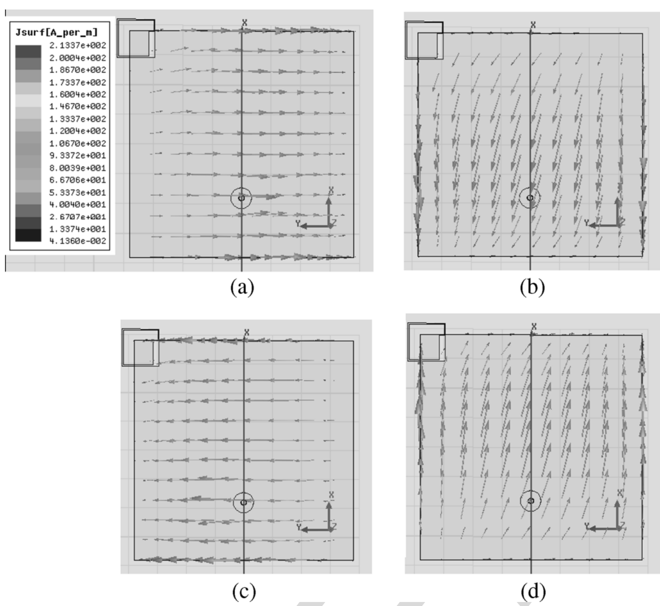

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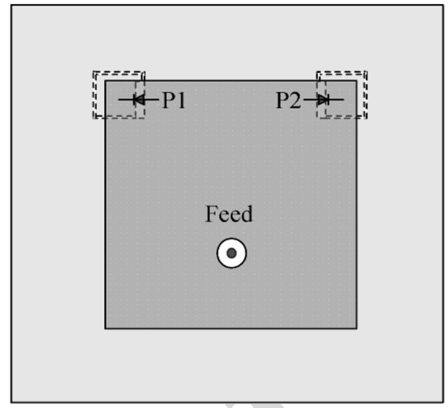

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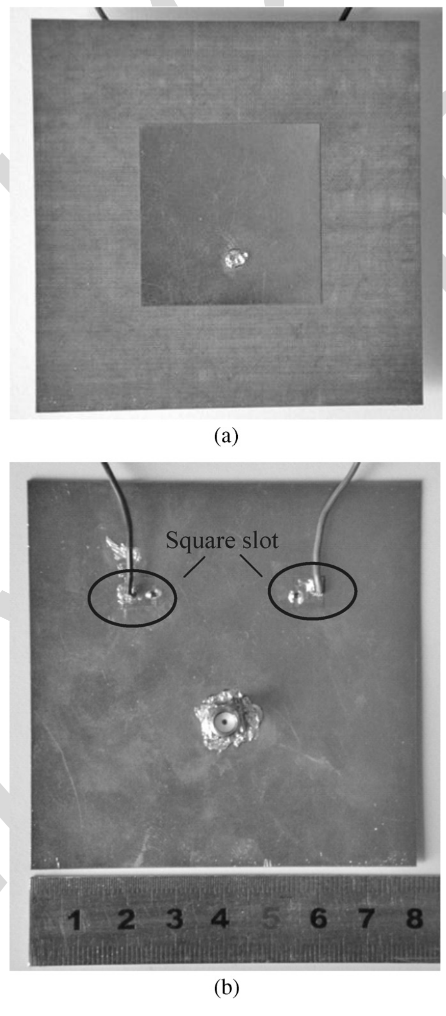

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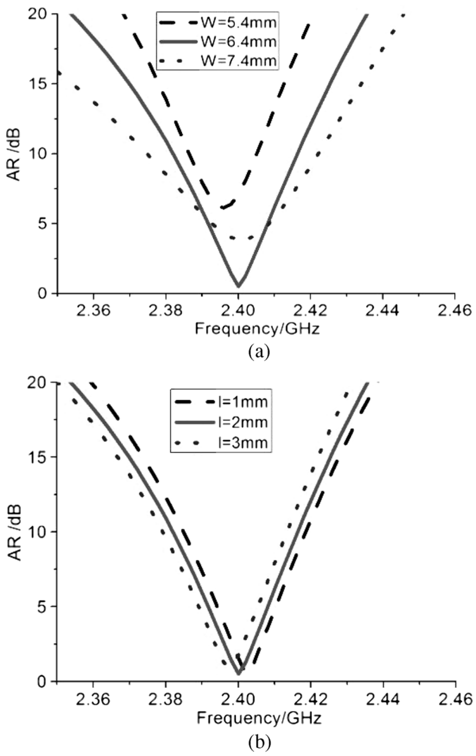

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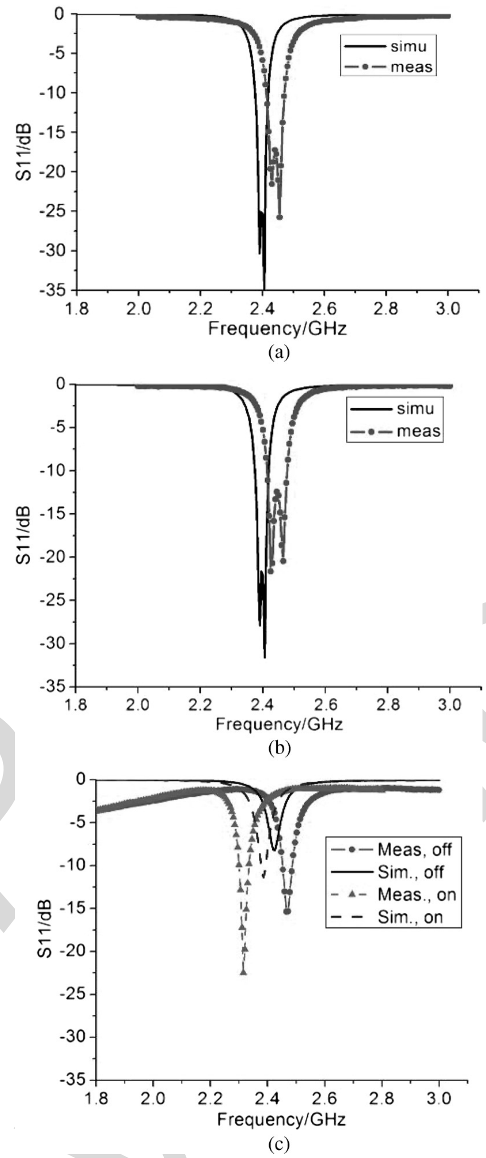

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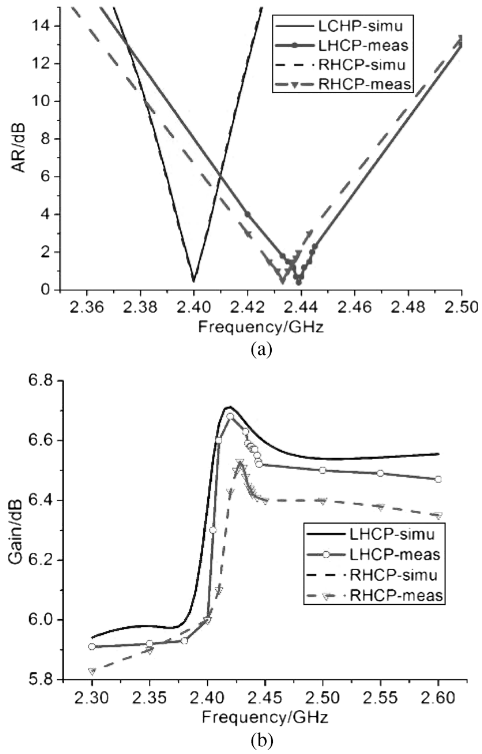

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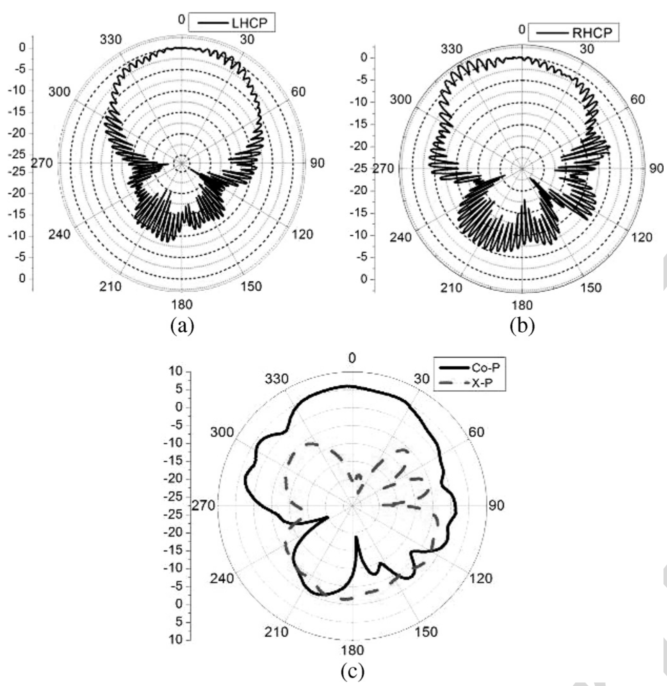

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The measured patterns of the reconfigurable patch for LHCP at 2.439 GHz, RHCP at 2.433 GHz, and LP of E-plane at 2.42 GHz are shown in Fig. 8. Good radiation performances are achieved for every polarization status. For the LP, the cross polarization in the broadside direction is about −30 dB, and the measured gain is 5.83 dBi.

IV. Conclusion

A novel reconfigurable patch antenna with polarization agility for LHCP, RHCP, and LP is proposed. The polarization sense is controlled by only two diodes, which are loaded on two square loop slots in the ground plane. This design simplifies the biasing circuits for the dc voltage and keeps the square patch unperturbed. Good reconfigurable polarization function and radiation performance are obtained from simulations and experiments. This proposed antenna has the merits of concise structure and low cost and supports wide applications in wireless communication systems.

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