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A Reconfigurable Dual-Broadband Circularly Polarized Antenna by Orthogonal Slot Technique for RFID Reader

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Abstract—A dual-broadband circularly polarized (CP) antenna with compact structure $97 \times 97 \times 0.8\,\mathrm{mm}^3$ is proposed. The measured $-10\,\mathrm{dB}$ return loss bandwidth is 0.38 GHz (0.75–1.13 GHz) for UHF band and 0.81 GHz (2.32–3.13 GHz) for ISM 2.4 GHz band. The measured 3 dB axial ratio bandwidth is about 0.235 GHz (0.83–1.065 GHz) for UHF band and 0.34 GHz (2.36–2.7 GHz) for ISM band. The antenna consists of a feedline, patch, Stepped slot-1 and -2, a pair of orthogonal rectangular slots (H/V slot), and an L-slot. There are two advantages for the proposed antenna: broadband and independent adjusting for UHF and ISM 2.4 GHz bands. The proposed antenna is a good candidate for worldwide RFID reader antenna.

1. INTRODUCTION

In recent years, RFID technology has been developed rapidly and appeared in many applications such as warehouse and retail item management. Circularly polarized radiation is necessary for a reader antenna since tags are arbitrarily oriented with linear polarization (LP). The UHF (ultra-high frequency) 0.9 GHz and ISM (Industrial Scientific Medical) 2.4 GHz bands become more and more popular in RFID application. However, the UHF frequencies are different in different countries [1], e.g., 902–928 MHz in the North and South of America, 866–869 MHz in Europe, 952–955 MHz in Japan, 840.5–844.5 MHz and 920.5–924.5 MHz in China. Hence, a CP reader antenna covering both universal UHF (0.84–0.96 GHz) and ISM (2.4–2.48 GHz) bands is requested.

Up to now, various CP reader antennas have been presented [2–14]. Utilizing asymmetric slots and truncated corner on a patch antenna can only excite single CP band with a narrow CP bandwidth no more than 5% [2–4]. Therefore, many wideband CP antennas have been proposed to cover global UHF band, such as a stacked coin-shaped patch CP antenna fed by a Ring-Shaped Strip [6], a slits loaded square patch antenna with an L-shaped ground plane [7], four IFA (inverted-F) elements fed by a four-feed network [8], a square-slot-loaded antenna fed by an L-shaped metal strip [9]. The above mentioned antennas have drawbacks of large size [6, 7] or complex structure [8]. A few of dual-band CP reader antennas are studied to operate in UHF and ISM bands [10–14]. A stacked antenna with a small size $60 \times 60 \times 7\,\mathrm{mm}^3$ composed of two radiators is presented in [10]. However, the operating bands are narrow and excited by independent ports which makes it inconvenient in application. In [11] and [12], a stacked patch antenna fed by complex feeding network exciting two CP bands has been presented. However, the UHF CP bandwidth of these dual-band antennas is too narrow to cover the entire UHF band.

In this paper, a wideband CP antenna is obtained by several orthogonal polarization slots and proper feed. Frequency reconfigurability is controlled by three PIN diodes. The proposed antenna can cover both entire UHF and ISM 2.4 GHz bands. The paper is organized as follows. Section 2 shows antenna design. Section 3 provides the simulated and measured results for the proposed antenna, and the conclusion is in section 4.

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2. DESIGN OF THE ANTENNA

2.1. Antenna Configuration

The antenna is made on an FR4 substrate with size $97 \times 97\,\text{mm}^2$, thickness 0.8 mm, relative permittivity 4.4, and loss tangent 0.02. Fig. 1 shows the geometry of the proposed antenna, and the prototype is shown in Fig. 2. The antenna consists of a feedline, patch, Stepped slot-1 and -2, a pair of orthogonal rectangular slots (H/V slot), and an L-slot, which are marked in Figs. 1 and 2. The feedline is in the bottom side of the substrate, and the others are in the top side. There are two advantages for the proposed antenna: broadband and independent adjustment for UHF and 2.4 GHz bands. (1) Broadband. The broadband CP is made by several orthogonal polarization slots in the top side (Stepped slot-1 and -2, a pair of H/V-slots and an L-slot). Suitable places A and B are used to feed for UHF and 2.4 GHz bands, respectively (for introducing 90° phase difference between orthogonal polarizations). (2) Independent adjustment. The Stepped slot-1 and -2 are responsible for CP operation at UHF and 2.4 GHz band, respectively. Frequency reconfigurability is obtained by three PIN diodes with ON state for UHF band and OFF state for 2.4 GHz band, and then the performance for the UHF and 2.4 GHz bands can be independently adjusted. All the constituent parts are marked in Figs. 1 and 2. The lengths for V(H)-slot

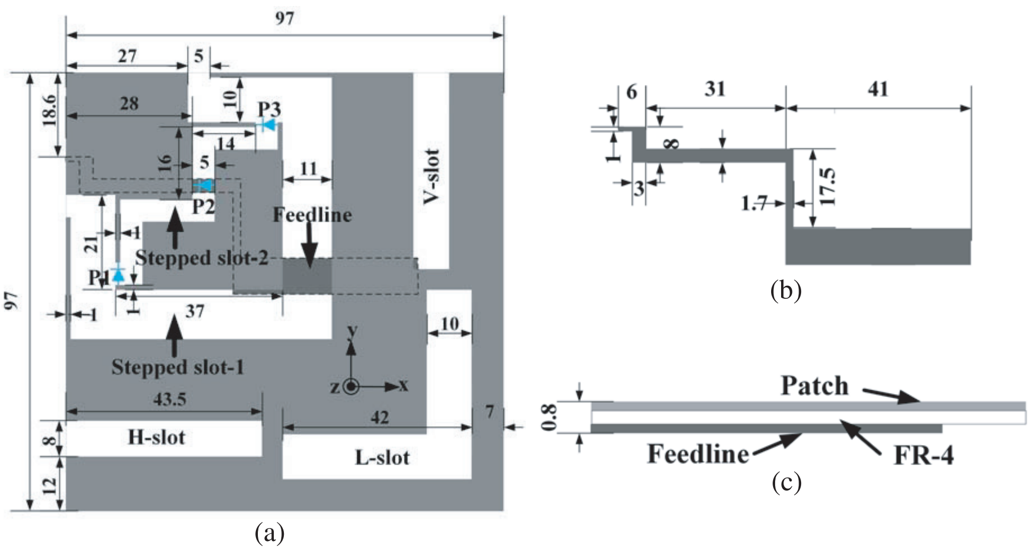

Figure 1. Geometry of the proposed antenna (units: mm). (a) Top view, (b) feedline, (c) side view.

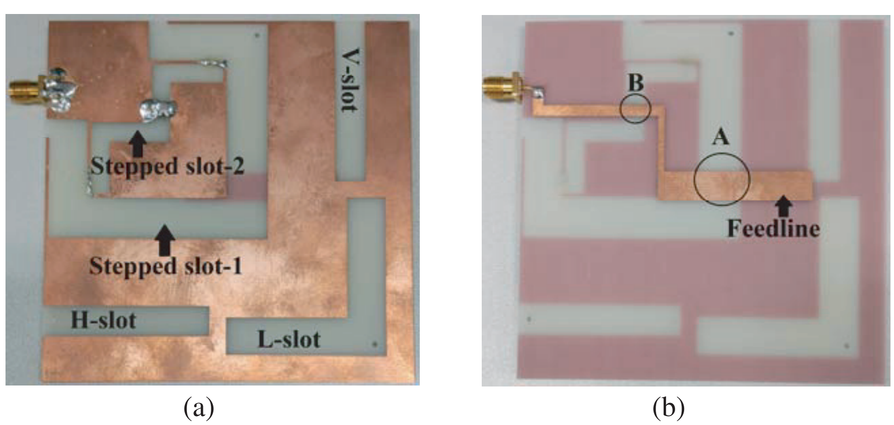

Figure 2. Prototype of the proposed antenna. (a) Top view (Stepped slot-1 and -2, V/H slot and L-slot), (b) bottom view (feedline and point A/B).

and L-slot are about $\lambda_g/4$ of 1 GHz and $\lambda_g/2$ of 1 GHz, respectively. The widths for all slots and the bandwidth of the operation band are adjusted by Ansoft HFSS.

2.2. Structure Analysis

An L-shaped open slot with length of $\lambda_g/4$ for vertical and horizontal pieces, properly fed by a microstrip line can excite CP mode [15]. In our design, the L-shaped open slot has been evolved into Stepped slot-1 and -2, which reduces the total size drastically and remains good CP performance in the meantime. The antenna design process can be described by three steps from Ant-1 to Ant-3 as in Fig. 3. (1) For Ant-1. Etching Stepped slot-1 in a complete copper plane in the top side → feeding in a specific location (point A in Fig. 2(b)) generating CP in UHF band. (2) For Ant-2. A pair of H/V-slots and an L-slot etched from the patch → introducing another resonance near 1 GHz → producing broadband CP and improving impedance match for UHF band. (3) For Ant-3. The Stepped slot-2 with three PINs is introduced for 2.4 GHz CP radiation. → Frequency reconfigurability is obtained → When the PINs are on, the stepped slot-2 becomes two short closed slots, and only Stepped slot-1 radiates UHF CP mode. When the PINs are off, the Stepped slot-2 generates CP modes in 2.4 GHz band.

The return losses and axial ratios from Ant-1 to -3 are shown in Fig. 4. For Ant-1, a CP mode near 0.9 GHz is preliminarily excited. For Ant-2, both impedance and AR bandwidths in UHF band are greatly improved. For Ant-3, a wideband CP radiation in 2.4 GHz band is formed when PINs are in OFF state, and frequency reconfigurability is achieved. As shown in Fig. 4, the UHF and 2.4 GHz bands are mainly excited by Stepped slot-1 and -2, respectively, and the performance of UHF band

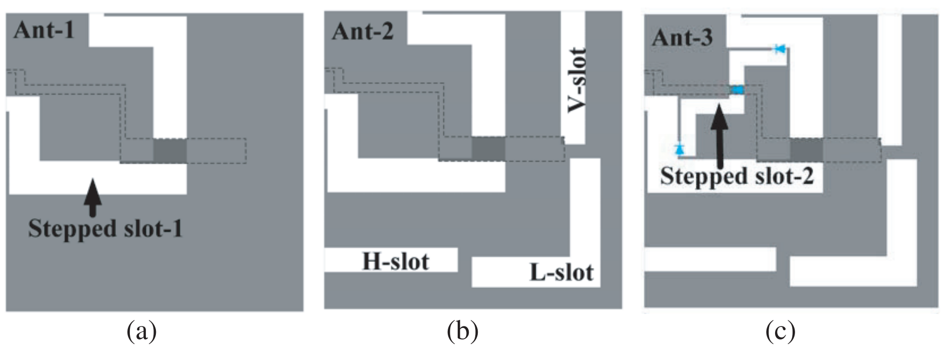

Figure 3. Antenna design process from (a) Ant-1 to (c) Ant-3. Ant-3 is the proposed antenna.

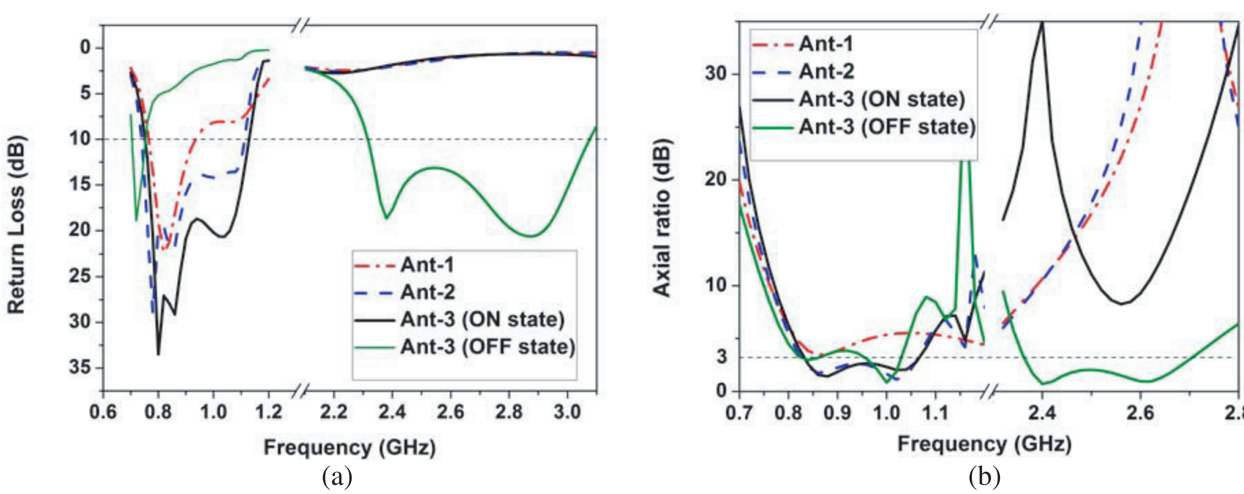

Figure 4. Simulated (a) return loss, (b) axial ratio for Ant-1, 2 and 3.

keeps unchanged when CP mode in 2.4 GHz band is introduced, so independent adjustment for the dual bands is obtained.

3. EXPERIMENTAL RESULTS

Simulated and measured return losses for the proposed antenna are shown in Fig. 5. The measured −10 dB return loss bandwidth is 0.38 GHz (0.75–1.13 GHz) at UHF band and 0.81 GHz (2.32–3.13 GHz) at 2.4 GHz band. The simulated and measured ARs are illustrated in Fig. 6. The measured 3 dB AR bandwidths are 0.235 GHz (0.83–1.065 GHz) and 0.34 GHz (2.36–2.7 GHz) at the UHF and 2.4 GHz bands, respectively. The measured results basically agree with the simulated ones.

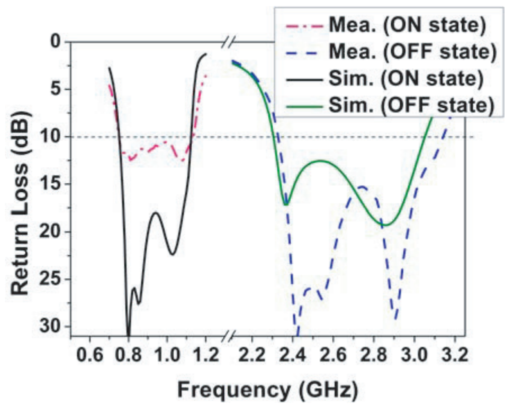

Figure 5. Simulated and measured results of return loss.

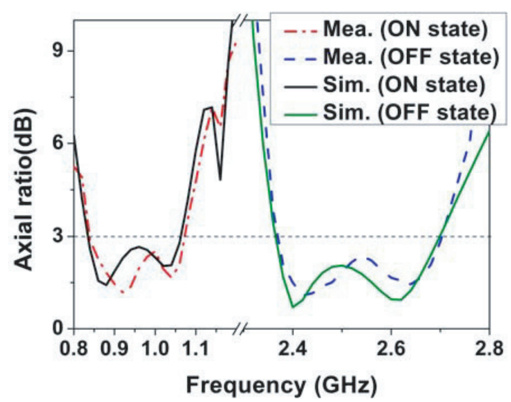

Figure 6. Simulated and measured results of axial ratio.

The simulated and measured gains are shown in Fig. 7. The gain is about 2.4 dBic for UHF band, and it is changed little for UHF band. The peak gain is 3.6 dBic for 2.4 GHz band. Figs. 8 and 9 show surface current distributions of the proposed antenna at 0.9 GHz (ON state) and 2.4 GHz (OFF state), respectively. The radiation pattern at 0.9 GHz and 2.4 GHz are in Fig. 10. Left- and right-hand CP radiations are in the $+z$ and $-z$ axis directions, respectively. Table 1 compares the proposed antenna with reported single and dual-band CP reader antennas, and IBW, ABW, and PG are −10 dB impedance bandwidth, 3 dB AR bandwidth, and peak gain, respectively. The reported reader antennas except for [9] have stacked patches, air layer or feeding network, leading to a complex structure and large volume. The proposed antenna has both a compact structure and wide CP operation bandwidth, covering both entire UHF band (0.84–0.96 GHz) and ISM (2.4–2.48 GHz) band.

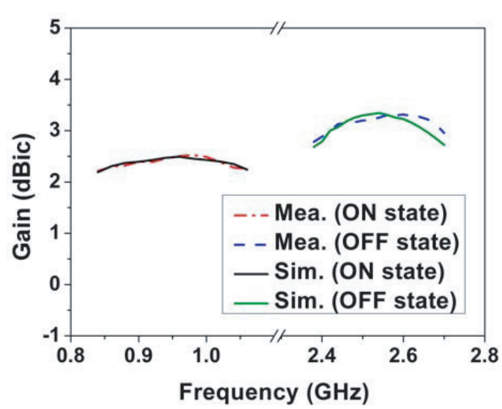

Figure 7. Simulated and measured results of gain in $+z$ direction.

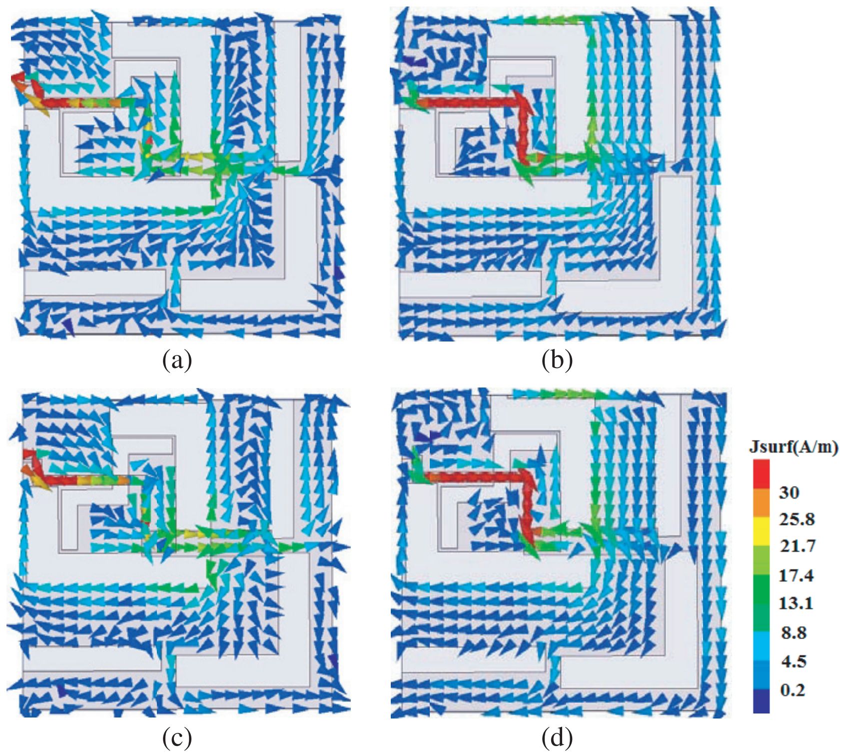

Figure 8. Simulated surface current distributions of the antenna at 0.9 GHz (ON state). (a) 0°, (b) 90°, (c) 180°, (d) 270°.

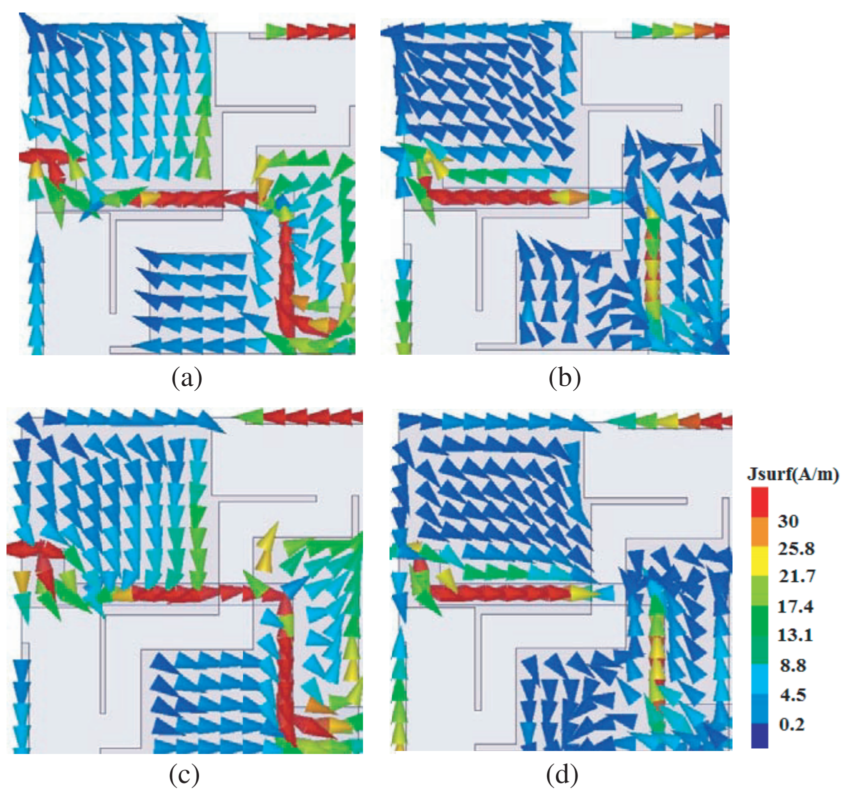

Figure 9. Simulated surface current distributions of the antenna at 2.4 GHz (OFF state). (a) 0°, (b) 90°, (c) 180°, (d) 270°.

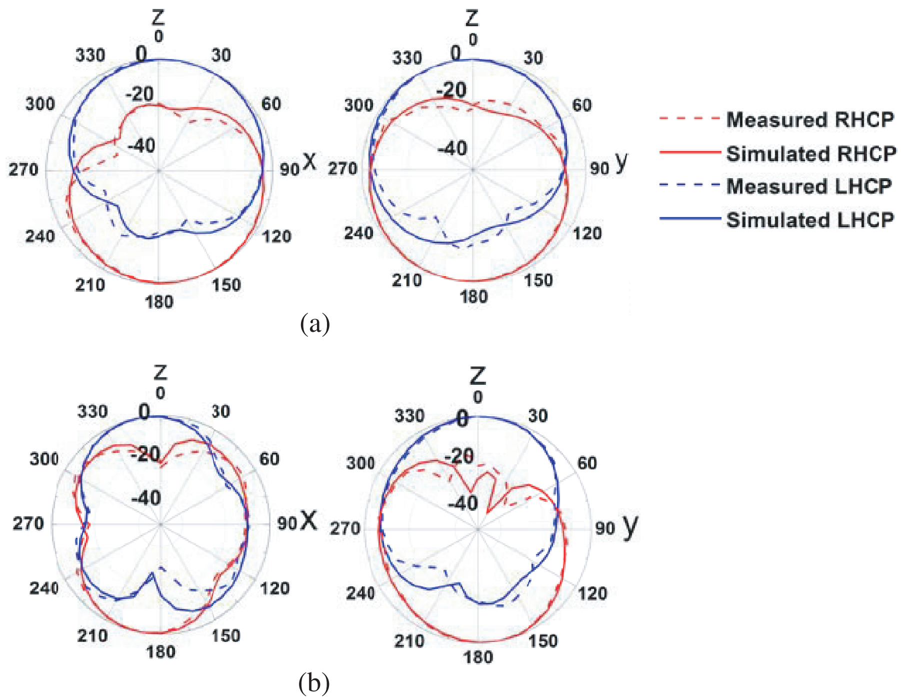

Figure 10. Simulated and measured radiation patterns in x-z plane and y-z plane at (a) 0.9 GHz, (b) 2.45 GHz.

Table 1. Performance comparisons with reported antennas.

Ref.	UHF Band			ISM Band			Size (mm^3)	Design technique
	IBW (%)	ABW (%)	PG (dBic)	IBW (%)	ABW (%)	PG (dBic)		
[6]	22.4 (20 dB)	15.9	9.8				250 × 250 × 39	2 layers stacked patches above ground
[7]	48.6	16.5	8.6				250 × 250 × 54	Single patch with air layer
[8]	36	18.6	3.1				100 × 95 × 13.6	Four-feed network with air layer
[9]	40.7	13.9	2.9				100 × 100 × 1.6	Single feed and single layer
[10]	10.5	3.1	−0.6	5.8	0.9	1.2	60 × 60 × 7	Dual-port and four-feed network
[11]	14.3	2.2	3.8	14.6	14.3	8.9	110 × 110 × 6.6	2 layers stacked patches and feed network
proposed	**40.5**	**25**	**2.7**	**29.7**	**13.4**	**3.6**	97 × 97 × 0.8	**Single feed and single layer**

4. CONCLUSION

In this paper, a wideband CP microstrip orthogonal polarization slot patch antenna fed by microstrip line is proposed. A broadband CP is made by several orthogonal polarization slots in the top side (Stepped slot-1 and -2, a pair of H/V slots and an L-slot) and specific location feed (for introducing 90° phase difference). Frequency reconfigurability is obtained by three PIN diodes with ON state for UHF band and OFF state for 2.4 GHz band. Two operating bands can be designed and adjusted independently. The proposed antenna can be a candidate for universal RFID reader at the UHF band and ISM 2.4 GHz band.

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