Novel Compact Circularly Polarized Patch Antenna for UHF RFID Handheld Reader

M. J. Chang[1], H. M. Chen[1], Y. F. Lin[1], Wilson W. C. Chiu[2]
[1]Institute of Photonics and Communications, National Kaohsiung University of Applied Sciences, Kaohsiung 807, Taiwan
[2]Wirop Industrial CO., LTD., Kaohsiung 806, Taiwan
Email: hmchen@kuas.edu.tw

Abstract- **A compact X-shaped slotted square-patch antenna is proposed for circularly polarized (CP) radiation. A cross-strip is embedded along the X-shaped slot for a novel proximity-fed technique to generate CP radiation in the UHF band. In the proposed design, two pairs of T-shaped slots are etched orthogonally on the square patch, connected to the center of the X-shaped slot for CP radiation and antenna size reduction. Proper adjustment of the length and coupling gap of the cross-strip will excite two orthogonal modes with 90^0 phase difference for good CP radiation. Simulated and measured results indicate that the proposed structure can achieve circular polarization. A measured impedance bandwidth (VSWR$\leq$2) of about 3.0% (909-937 MHz) and a 3-dB axial-ratio (AR) bandwidth of about 1.3% (917-929 MHz) were obtained.**

I. INTRODUCTION

Radio frequency identification (RFID) system in the ultra-high frequency (UHF) band has gained much interest in several service industries, manufacturing companies and goods flow systems [1]. An RFID system generally consists of a reader and a tag. In North America and Taiwan, these UHF RFID systems operate between 920-928 MHz, and between 865-867 MHz in Europe. A reader with an antenna sends a radio frequency signal to a tag and receives a backscattered signal from the tag. The RFID reader antenna is one of the important components in RFID systems and has been designed with CP operation in mind, because circularly polarized antennas can reduce the loss caused by the multi-path effects between the reader and the tag antenna. RFID handheld readers require a light-weight CP antenna with a low profile and small size.

A typical technique for the generation of CP radiation is to produce two orthogonal linearly polarized modes on the radiating element, with a 90^0 phase difference. Single-fed circularly polarized annular-ring, square and circular patch antennas with symmetrical or asymmetrical perturbation elements have been reported [2]. Using perturbation cuts or strips to differentiate suitably the two orthogonal modes at resonant frequency enables the antenna to radiate easily CP waveforms.

In recent years, small CP patch antennas attracted a lot of research interest, since they are extensively used in UHF RFID systems. Different methods for the single-feed patch antenna have been published in the literature [3-7]. In [3], the antenna demonstrated an arrow-shaped slot-coupled CP technique using different lengths of the cross-strip embedded at the center of the patch for RFID handheld reader application. The overall antenna volume is $0.46\lambda_0 \times 0.31\lambda_0 \times 0.005\lambda_0$ at 925 MHz. Coaxial-fed cross-shaped slotted patch antenna was also proposed for CP radiation and size reduction, while the overall antenna volume is $0.27\lambda_0 \times 0.27\lambda_0 \times 0.013\lambda_0$ at 910 MHz [4]. A single-layer square-ring patch antenna with a dual-feed Wilkinson power divider for CP radiation in UHF band is presented, but it provided a relatively larger CP bandwidth, and has an overall antenna volume of $0.29\lambda_0 \times 0.29\lambda_0 \times 0.005\lambda_0$ at 925 MHz [5]. As is well known, using high dielectric substrate is another effective method for achieving size reduction, but this antenna still operates at its half wavelength mode [6]. A small, single-layer, crossed-dipole antenna for CP radiation with antenna volume of $0.19\lambda_0 \times 0.19\lambda_0 \times 0.005\lambda_0$ at 925 MHz is proposed in [7]. To our knowledge, this antenna has the smallest volume for handheld RFID reader application.

In this letter, a novel and compact square patch antenna with an X-shaped slot has been proposed for achieving CP radiation. The excitation mechanism of the proposed antenna is the radiating patches along the perimeter of an X-shaped slot, which was proximity fed from the cross-strip embedded in the X-shaped slot. However, studies on the single-layer proximity-fed square patch antenna with circular polarization have been scarce. The antenna operates at its fundamental orthogonal modes for the UHF band (902-928 MHz). The two near-degenerated resonant modes for circular polarization are generated by etching unequal cross-strips on the diagonal of the patch.

II. ANTENNA DESIGN

The configuration of the proposed antenna is shown in Fig. 1, in which a square patch with the same side length of 60 mm is printed on the upper side of single FR4 substrate, with thickness of 0.8 mm and relative permittivity of 4.4. A same FR4 substrate is chosen as the ground plane, and the height of the air substrate is selected as 13.4 mm. An X-shaped slot of 57.9×7.5 mm^2 is etched along the diagonal of the patch radiator. A cross-strip with width of 1.5 mm is embedded in the X-shaped slot as a feeding line, and has tuning stubs of different lengths (L_a = 17.5 mm and L_b = 22.5 mm). The single coaxial probe is located at the center of the patch and connected to the cross-strip. The tuning stubs can also improve the phase difference of the proposed antenna. The slotted patch is electromagnetically coupled from the cross-strip through a gap distance of 0.75 mm. At the same time, the cross-strip feed line is employed to excite directly the patch along the perimeter of the X-shaped slot. Therefore, CP radiation from the patch can be enabled. In addition, a pair of T-shaped slots of unequal length are etched on the square patch and connected to the X-shaped slot at an angle of 45^0. With the T-shaped slots of unequal length (S_a and S_b), the fundamental resonant modes of the slotted square patch can be split into two orthogonal resonant modes with equal amplitudes and a 90^0 phase difference for CP radiation requirements, as well as for good impedance matching.

To illustrate the radiation mechanism of the proposed antenna, two resonant paths of surface current on the slotted patch are depicted in Fig. 2. As clearly seen, the two current paths are inherently formed to be orthogonal. Varying the length of each T-shaped slot provides an adjustable resonant mode of the proposed antenna. In this study, S_x and S_y are selected to be 17.9 and 18.9 mm, respectively. For Fig. 2(a), the resonant length of the radiating square patch is about 154.8 mm, which operates at its first mode and corresponds to about 0.473 λ_0 of 916 MHz. Similarly, the resonant length of the second mode in Fig. 2(b) is about 152.8 mm, corresponding to about 0.473 λ_0 at 930 MHz. The proposed antenna with optimal dimensions given in Figure 1 is fabricated and tested. Note that the antenna configuration will radiate a left-hand CP (LHCP) wave.

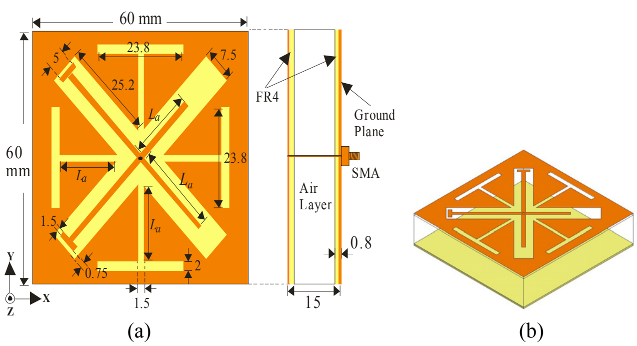


Figure 1. Geometry of the circularly polarized X-shaped slotted patch antenna. (a) top and side view; (b) 3D structure.

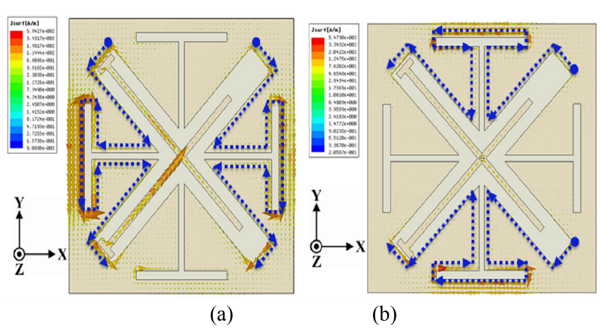


Figure 2. Simulated path of the surface current on the slotted patch. (a) at 916 MHz, (b) at 930 MHz.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The proposed CP antenna is designed to operate at the center frequency of about 923 MHz in the UHF band for RFID readers. The return loss is measured using an Agilent N5230A vector network analyzer, and axial ratio and radiation patterns are evaluated in an anechoic chamber with an NSI-AMS2000 antenna measurement system. Fig. 3 shows the simulated and measured return loss of the proposed antenna. The measured impedance bandwidth for 10 dB return loss is 3.03%, ranging from 917 to 929 MHz, and agrees well with the HFSS-simulated results (917-929 MHz). In addition, the operational principle of this CP antenna is derived from the fact that the generated mode can be separated into two orthogonal modes (916 and 930 MHz) of equal amplitude and 90^0 phase difference. The two resonant modes, 916 and 930 MHz, are also observed in Fig. 2. The measured and simulated axial ratio in the boresight direction, versus frequency, is presented in Fig. 4. The measured 3-dB axial-ratio CP bandwidth is about 12 MHz, from 917 to 929 MHz or 1.3% around the center frequency of 923 MHz, and 6 MHz from 922 to 928 MHz or approximately 0.65%, with respect to the center frequency of 925 MHz for simulation. Note that the measured minimum axial-ratio is about 0.3 dB at 923MHz, indicating that the circular polarization generated is very pure. Fig. 5 presents the simulated amplitude ratio and phase difference in the broesight direction. As seen in these results, the amplitude ratio (E_θ/E_ϕ) and phase difference for the 3-dB AR bandwidth are close to -1~0 dB and 70^0~110^0, respectively, for producing a good LHCP radiation. The measured and simulated radiation pattern at 923 MHz is plotted in Fig. 6. The measured and simulated 3-dB beamwidths are about 60^0 (-30^0~30^0) in both x-z and y-z planes. The measured gain was obtained using the gain transfer method with the standard gain horn antenna used as a reference. The obtained peak gain is from 3.5 to 4 dBic and the efficiency is about 40% over the UHF band (920-928 MHz), and the gain is similar to those in previous studies [3-7].

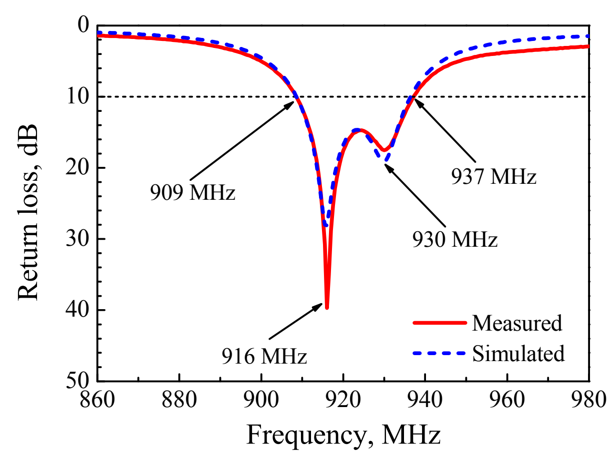


Figure 3. Measured and simulated return loss of the proposed antenna.

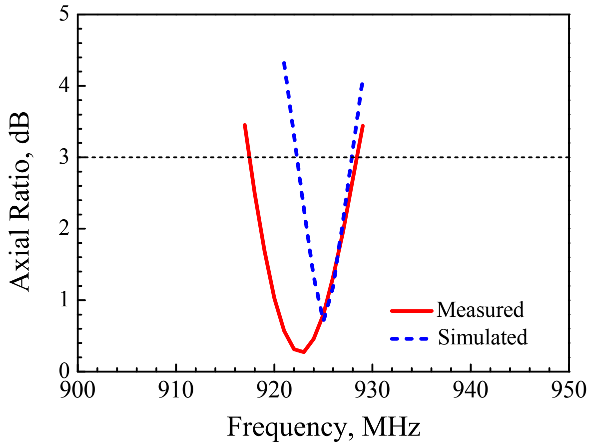


Figure 4. Measured and simulated axial ratio of the proposed antenna.

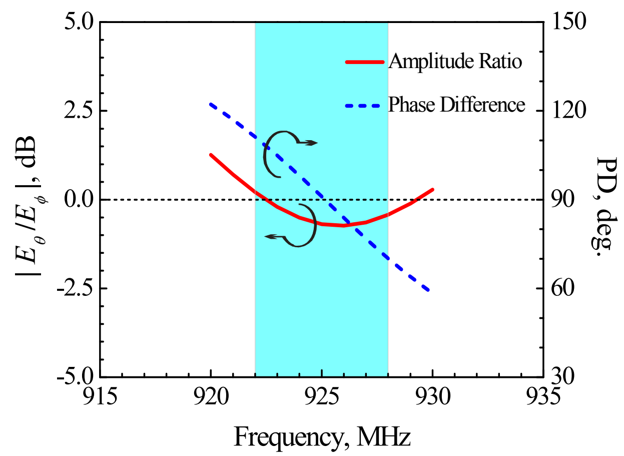
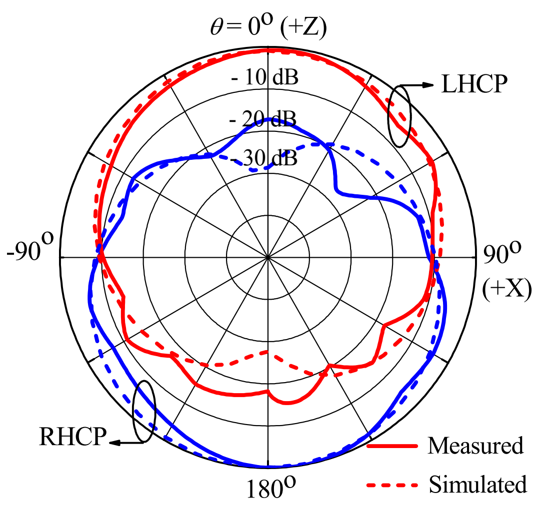
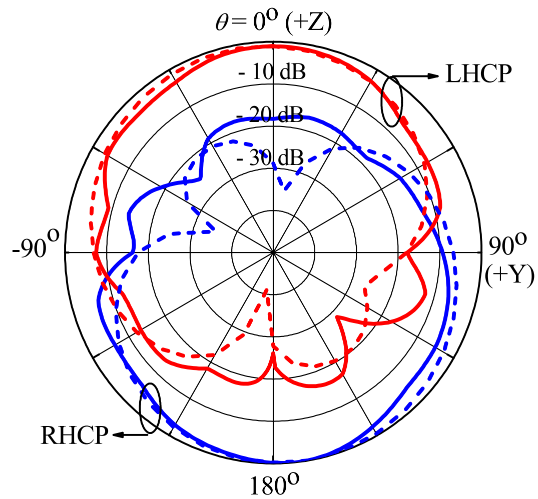


Figure 5. Simulated amplitude ratio and phase difference.



(a)



(b)

Figure 6. Measured and simulated normalized CP radiation patterns at 923 MHz. (a) x-z plane; (b) y-z plane.

IV. Conclusion

A new feed coupling mechanism of circularly polarized slotted patch antenna with cross-strips of unequal length for RFID readers is designed and evaluated. By applying the proximity-fed technique to this square patch, good CP bandwidth and impedance matching can be obtained. The overall antenna volume is $0.19\lambda_0 \times 0.19\lambda_0 \times 0.046\lambda_0$ at 923 MHz. Since the proposed antenna uses a simple design, with lower weight, smaller volume and lower cost, it can thus serve as the transmitting antenna in handheld RFID readers. However, this is the first study on the CP patch antenna with a proximity-fed at the same layer, which merits further exploration.

Acknowledgment

This work was supported by the National Science Council of Taiwan under Contract NSC100-2221-E-151-054-MY3.

References

1. K. Finkenzeller, *RFID Handbook*, 2nd Ed, New York: Wiley, 2004.
2. K. L. Wong, *Compact and Broadband Microstrip Antennas,* Chapter 5, New York: Wiley, 2002
3. Y. F. Lin, H. M. Chen, S. C. Pan, Y. C. Kao, and C. Y. Lin, "Adjustable axial ratio of single-layer circularly polarized patch antenna for portable RFID reader, " *Electron. Lett.*, vol. 45, pp. 290-291, 2009.
4. Nasimuddin, Z. N. Chen, and Z. Qind, "A compact circularly polarized cross-shaped slotted microstrip antenna," *IEEE Trans. Antennas and Propagat.*, vol. 60, pp. 1584-1588, 2011.
5. Y. F. Lin, H. M. Chen, F. H. Chu, and S. C. Pan, "Bidirectional radiated circularly polarized square-ring antenna for portable RFID reader," *Electron. Lett.*, vol. 44, pp. 1383-1384, 2008.
6. X. Tang, H. Wang, Y. Long, Q. Xue, and K. L. Lau,"Circularly polarized shorted patch antenna on high permittivity substrate with wideband," *IEEE Trans. Antennas and Propagat.*, vol. 66, pp. 1588-1592, 2011.
7. Y. F. Lin, Y. K. Wang, H. M. Chen, and Z. Z. Yang, "Circularly polarized crossed dipole antenna with phase delay lines for RFID handheld reader," *IEEE Trans. Antennas and Propagat.*, vol. 66, pp. 1221-1227, 2011.