Compact Circularly Polarized RFID Tag Antenna with an Embedded U-shaped Feedline for Metallic Surfaces

Te Pan[1], **Shuai Zhang**[2], **Zhibin He**[1], **Hui Liu**[1], **and Sailing He**[1,2]

[1]Centre for Optical and Electromagnetic Research
Academy of Advanced Optoelectronics, South China Normal University, Guangzhou, China
[2]The Royal Institute of Technology, Stockholm, Sweden

Abstract— A passive radio frequency identification (RFID) tag antenna with circular polarization (CP) radiation is proposed to operate at 902–928 MHz and mount on metallic surfaces. A U-shaped terminal short-circuited feedline welded to a tag-chip is embedded in a rectangular slot to achieve a coupled feeding and a good impedance matching. By employing two truncated corners and two L-shaped slots with unequal length on the patch, a good left-hand circular polarization (LHCP) and compact size are obtained. The measured impedance bandwidth of the antenna is 85 MHz (875–960 MHz), while the simulated 3-dB CP bandwidth is 6 MHz (912–918 MHz). The proposed tag antenna shows reasonable read ranges when mounted on the metal plate in the following experiment.

1. INTRODUCTION

In commercial applications of UHF band RFID, most reader antennas are design as circular polarization (CP) for increasing the diversity of orientation, while the majority of tag antennas are designed as linear polarization (LP) [1, 2]. Under this circumstance, the mismatch of polarization will happen and cause unwanted loss of power transmission between reader and tag. Owing to the tag-chip is designed with capacitive input impedance, the conjugate impedance matching should be acquired between the chip and tag antenna to achieve the maximum read range of the tag. Nowadays, lots of commercial sectors also demand the tag antenna with the ability to mount on metallic surface [3]. In general, it is a challenge to design a metal-mountable tag antenna with CP, in the meanwhile, has a simple method to fulfill the complex impedance matching.

Up to now, some works [4–6] are proposed to overcome the mentioned challenges. In [4–6], they all introduce a good technique to attain the CP, impedance matching and an excellent performance when the tag antenna is mounted on metallic plates. But their feedlines occupy some redundant area outside the radiator and cause asymmetries in these antenna structures. This will bring an increase of the overall size (the size of antenna top layer metallization) and a reduction of the antenna gain in the boresight direction.

To reduce the overall size and achieve a good impedance matching, we propose a compact CP RFID tag antenna with a U-shaped terminal grounded feedline embedded in a rectangular slot for application of metal-mountable. The 3-dB CP bandwidth of 6 MHz is accomplished by etching on the patch with two truncated corners and two L-shaped slots of unequal lengths. By tuning the diagonal truncations and the two L-shaped slots, a good CP is realized. The rectangular slot and the L-shaped slot also help to obtain a compact patch size. The tag shows a good performance of read range when it is mounted on metals.

2. ANTENNA STRUCTURE AND DESIGN

The geometry is shown in Fig. 1. The substrate we used is FR4 (relative permittivity of 4.4, loss tangent of 0.02) with a thickness of $h = 1.6$ mm. The two L-shaped slotswith the same width of 1.5 mm, length of S_1, S_2 respectively and the truncated corners are etched on the $60 \times 60\,\text{mm}^2$ radiating patch to produce CP. The ground plane size is $85 \times 85\,\text{mm}^2$ and the operating frequency band is set to 902–928 MHz. A terminal grounded U-shaped feedine, with a width equal to 1.7 mm and a coupling distance of $D = 1$ mm, is embedded in the rectangular slot ($S_W = 30$ mm, $S_L = 15$ mm) to capacitively excite the patch. The impedance of the welded Monza4 tag chip ($11 + j143$ K at 915 MHz, threshold power $Pth = -17.4$ dBm) is also matched by the feedine. In the view of the theory of short-circuited transmission line from [7], the total length of the feedline should be set to 27.9 mm to get reactance of 143 jΩ by applying the following formula (1):

$$143 = Z_0 \tan\left[\frac{2\pi}{\lambda}(L_1 + L_2)\right] \tag{1}$$

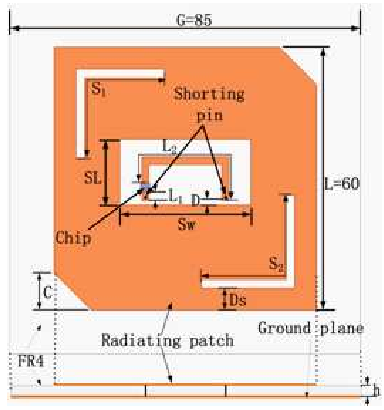

Figure 1: The geometry of the proposed circularly polarized patch tag antenna (unit: mm).

In the formula, the feedline width of 1.7 mm determines the characteristic impedance Z_0, and λ means the guided wavelength at 915 MHz. Considering the electromagnetic coupling effect [8], the feed line length should be slightly tuned to 37.7 mm to ensure the antenna impedance be close to $11 + 143j\Omega$ at 915 MHz. Table 1 shows the detailed dimensions of the designed antenna.

Table 1: Optimized design parameters of the antenna (Unit: mm).

D_s	L_1	L_2
15.1	18	3
C	S_1	S_2
8.5	33.6	35.6

3. RESULTS AND DISCUSSIONS

In this paper, the ANSYS HFSS is applied to accomplish the work of simulation and optimization. The impedance bandwidth of our RFID tag antenna is defined by the power reflection coefficient (PRC) $\Gamma < -3$ dB [9]. The input impedances are successfully measured by using the method of [10], with a four-port VNA (Agilent N5247A) and a test fixture. Fig. 2 shows the input impedances from measuring and simulating and the corresponding PRC chart respectively. As the condition of impedance matching is mainly decided by the reactance matching, so the measured results are actually fitting well with the simulated ones. In fact, as compared with the simulation, the measured 3 dB PRC shows a better bandwidth of 85 MHz (from 875 to 960 MHz), which completely cover the 902–928 MHz band. The difference between the measurement and the simulation may be caused by the test fixture placed above the antenna and the deviation of the antenna fabrication process.

In the following, the analysis of realizing a good CP by adding the truncated corners and the two unequal L-shaped slots is discussed. Firstly, the satisfactory CP is not able to realize only with the truncated corners under the current feeding condition. So we introduce the two L-shaped slots with unequal length to further enhance the CP performance. As the simulated amplitude ($|E_x|$, $|E_y|$),

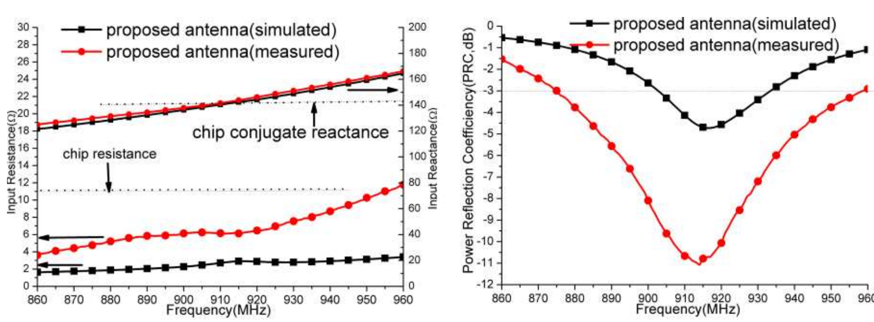

Figure 2: Measured and simulated input impedances, power reflection coefficient of the proposed tag antenna.

the relevant phase difference $(\Phi_y - \Phi_x)$, and the corresponding AR bandwidth diagram exhibited in Fig. 3, we can see that the amplitude will be equal around 91 5MHz regardless of the L-shaped slots, but the phase difference will move to the lower frequency when the L slots are added. So the L-shaped slots can be uesed to tune the phase difference to achieve a good and pure CP radiation and reduce radiator size at the same time.

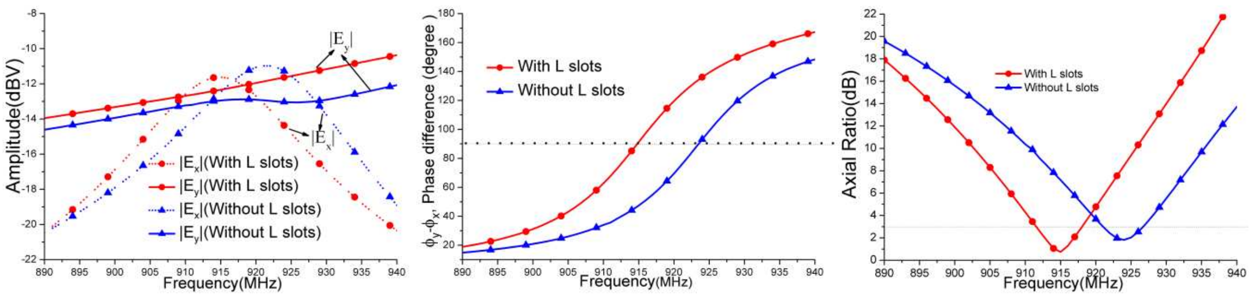

Figure 3: Simulated amplitude and phase difference diagrams of E_x and E_y, axial ratio in the boresight direction.

Under the current technical constrain, the radiation patterns of the RFID tag antenna is difficult to measure, so Fig. 4 only presents the simulated CP radiation patterns at 915 MHz. In Fig. 4, the 3-dB beamwidth is about 75° and a good front-to-back radiation ratio of 50 dB in both the x-z and y-z planes is revealed. This indicates an excellent and pure left hand circular polarization (LHCP) radiation of our antenna when it is placed in free space. Fig. 4 also shows the simulated gains of our tag antenna in different placement environments (free space, as well as mounted on metal plates of various sizes) and the corresponding AR diagram. In fact, the antenna gain will be about −8.5 dBi and the minimum point of AR will stay around 915 MHz when size of the mounted metal is more than $100 \times 100\,\text{mm}^2$. The antenna gain will promote about 1 dB when installed on the metal rather than in free space. As the figure presents, the proposed antenna will maintain a reliable gain and a good CP whether it is in free space or mounted on metals.

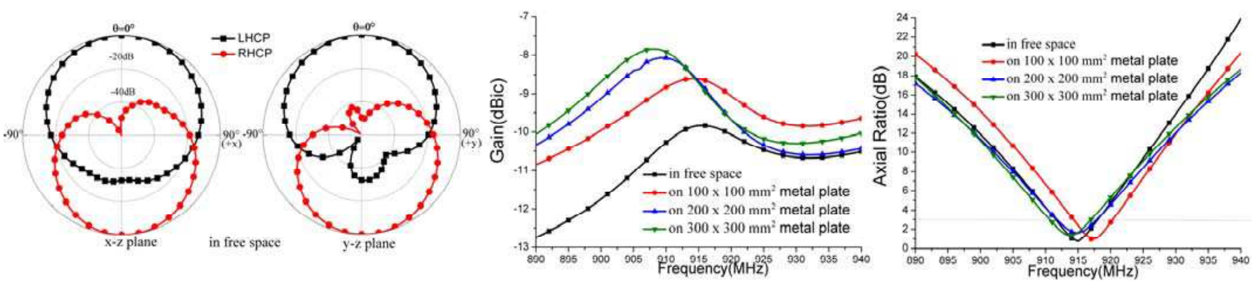

Figure 4: Simulated normalized CP gain radiation patterns at 915 MHz, antenna gains and axial ratio.

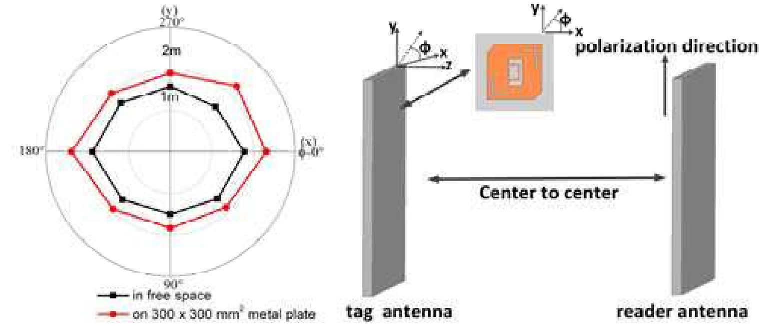

Figure 5: Measured reading distances when the tag antenna is rotated along the φ direction with a fixed reader antenna.

Table 2: Comparison between measured and calculated maximum reading distances of the proposed CP tag using LP reader antenna and CP reader antenna with the same output power (3.98 W) at the operating frequency.

Conditions	Simulated Gain (G_r)	Reading Distance by LP Reader Antenna (m)		Reading Distance by CP Reader Antenna (m)	
		Meas.	Cal.	Meas.	Cal.
Free Space	-9.8 dBic	1.88	2.26	2.74	3.2
$300 \times 300\,\text{mm}^2$ metal plate	-8.7 dBic	2.38	2.56	3.27	3.62

The read range measurement of our tag antenna is shown in Fig. 5 and Table 2. An RFID reader module (IPJ R420) with operating frequencies of 902–928 MHz, a LP reader antenna (Laird-E9012PLNF, gain of 12 dBi) and a CP reader antenna (Laird A9028, gain of 8 dBi) are applied to do the read range measurement. The overall output power of the read antenna system is set to 3.98 W in each case. As shown in Fig. 5, the tag antenna is rotated along the φ direction and the LP reader antenna is fixed to measure the maximal reading distances, under the conditions of in free space and on metal plates with two different areas ($100 \times 100\,\text{mm}^2$, $300 \times 300\,\text{mm}^2$). In free-space, the read range presents similar distances around 1.7 m at all angles of φ. In addition, when mounted on $300 \times 300\,\text{mm}^2$ metal plates, it shows a stable read range changes between 1.9 to 2.4 m with φ varying. Therefore, it means a good performance of CP radiation and a reliable and practical on-metal reading distance of the proposed antenna. Within the local equivalent isotropic radiated power (EIRP) [11], all the measured and simulated reading distances are given in Table 2. The Friis transmission formula [6] is utilized to calculate the theoretical reading distance.

4. CONCLUSIONS

A compact RFID CP tag antenna has been designed and tested. An AR bandwidth of 6 MHz and compact radiator size of $60 \times 60\,\text{mm}^2$ are obtained by employing the slot-embedded feeding network with good impedance matching. Thanks to the compact and symmetrical radiator, our antenna exhibits a good performance in practice. Later simulations and experiments indicate a good performance of our antenna when mounted on metallic surfaces. Therefore, when it comes to the application of mounting on metallic surfaces, the proposed UHF RFID tag antenna can be a good candidate. The next step of research is to achieve a better impedance matching condition and a broader AR bandwidth.

ACKNOWLEDGMENT

The partial support of Guangdong Innovative Research Team Program (No. 201001D0104799318), the National High Technology Research and Development Program (863 Program) of China (No. 201 2AA030402), the Swedish VR grant (# 621-2011-4620) is also gratefully acknowledged.

REFERENCES

1. Marrocco, G., "The art of UHF RFID antenna design impedance-matching and size-reduction techniques," *IEEE Antennas Propag. Mag.*, Vol. 50, No. 1, 66–79, Feb. 2008.
2. Yang, P. H., Y. Li, L. Jiang, W. C. Chew, and T. T. Ye, "Compact metallic RFID tag antennas with a loop-fed method," *IEEE Trans. Antennas Propag.*, Vol. 59, No. 12, 4454–4462, Dec. 2011.
3. Lin, K. H., S. L. Chen, and R. Mittra, "A looped-bowtie RFID tag antenna design for metallic objects," *IEEE Trans. Antennas Propag.*, Vol. 61, No. 2, 499–505, Feb. 2013.
4. Tseng, Y. M., S. H. Kuo, H. D. Chen, and C. Y. D. Sim, "Circularly polarized circular microstrip RFID tag antenna," *2012 Proceedings of APMC*, 1142–1144, Kaohsiung, Taiwan, Dec. 2012.
5. Chen, H. D., S. H. Kuo, and J. L. Jheng, "Design of compact circularly polarized radio frequency identification tag antenna for metallic object application," *Microw. Opt. Technol. Lett.*, Vol. 55, No. 7, 1481–1485, Jul. 2013.
6. Chen, H. D., S. H. Kuo, C. Y. D. Sim, and C. H. Tsai, "Coupling-feed circularly polarized RFID tag antenna mountable on metallic surface," *IEEE Trans. Antennas Propag.*, Vol. 60, No. 5, 2166–2174, May 2012.

7. Pozar, D. M., *Microwave Engineering*, 3rd Edition, Wiley, New York, 2005.
8. Son, H. W. and C. S. Pyo, "Design of RFID tag antennas using an inductively coupled feed," *Electron. Lett.,* Vol. 41, No. 18, 994–996, Sep. 2005.
9. Nikitin, P. V., K. V. S. Rao, S. F. Lam, V. Pillai, R. Martinez, and H. Heinrich, "Power reflection coefficient analysis for complex impedances in RFID tag design," *IEEE Trans. Microw. Theory Tech.*, Vol. 53, No. 9, 2721–2725, Sep. 2005.
10. Qing, X., C. K. Goh, and Z. N. Chen, "Impedance characterization of RFID tag antennas and application in tag co-design," *IEEE Trans. Microw. Theory Tech.*, Vol. 57, No. 5, 1268–1274, May 2009.
11. "Regulatory status for using RFID in the UHF spectrum," Jan. 20, 2008 Available: www.epcglobalinc.org.