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Planar circularly polarized tag antenna with compact operation for UHF RFID application

Jui-Han Lu* and Bo-Shen Chang

Department of Electronic Communication Engineering, National Kaohsiung Marine University, Kaohsiung 811, Taiwan, R.O.C.

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A novel compact design of planar circularly polarized (CP) tag antenna for UHF RFID system is proposed. By introducing the Y-shaped slit as the feed structure, the measured half-power bandwidth of the proposed CP tag antenna can be more than 135 MHz (860–1000 MHz), which includes the entire operating bandwidth for world-wide UHF RFID system. The obtained 3 dB axial-ratio (AR) bandwidth can be about 10 MHz suitable for Taiwan UHF RFID applications. The proposed tag antenna reduces the antenna size by at least 30% since the antenna size is only $40 \times 40 \times \pi\,\mathrm{mm}^2$. The simulated peak gain and antenna efficiency are approximately 0.4 dBic and 91% for Taiwan UHF RFID band. Meanwhile, with omnidirectional reading pattern, the measured reading distance is about 7.2 m. Good tag sensitivity was obtained across the desired frequency band.

Keywords: omnidirectional; circularly polarized; UHF RFID tag

1. Introduction

UHF (860–960 MHz) band Radio frequency identification (RFID) system had recently attracted in supply chain, tracking and inventory management because it can provide longer reading distance, fast reading speed and large information storage capability. Tag antenna is the pivotal role for UHF RFID system to transmit/receive the modulated information. The detection range and accuracy are directly dependent on the performance of reader/tag antennas. Several tag antennas for UHF RFID system have been presented by using symmetrical dipole antenna to enhance wide bandwidth,[1–3] meander antenna to reduce the geometry dimension,[4–6] dual resonant modal of impedance,[7] F-shaped dipole antenna,[8] loop antenna with a pair of rectangular parasitic patches,[9] dual-branch dipole antenna with the shorting pin [10] and dual meander-dipole antenna with a square loop [11]. Since the above presented tag antennas are linearly polarized [1–10] or dual-polarized [11] with high orientation sensitivity and mostly designed with narrow bandwidth accompanying directional reading problem, circularly-polarized (CP) antennas become the most popular candidates to receive the RF signal that emanates from arbitrarily oriented reader antennas for improving the reliability of communications between readers and tags. Moreover, CP antennas with polarization diversity can reduce the loss caused by the multi-path effects due to the presence of environmental reflections between the reader and the tag. However, the UHF frequencies authorized for RFID

*Corresponding author. Email: jhlu@webmail.nkmu.edu.tw

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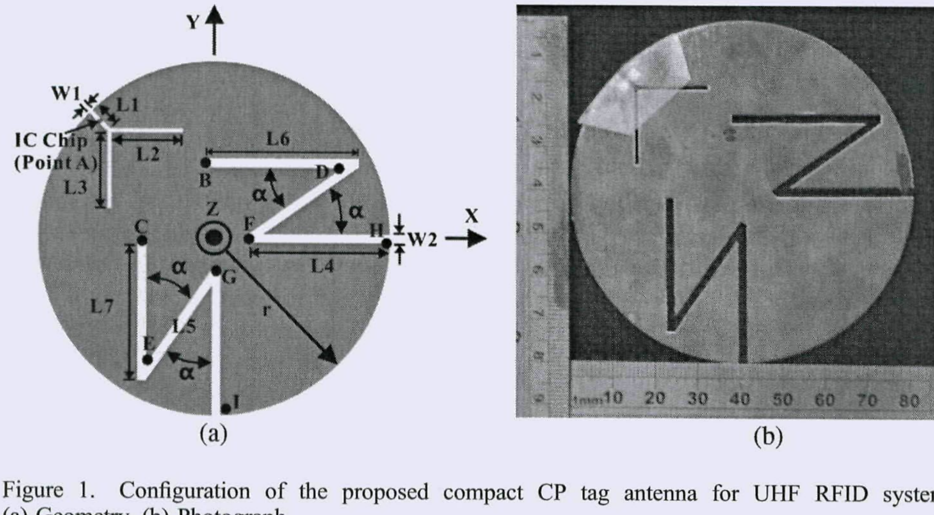
applications are varied in different countries and regions. Hence, a universal tag antenna with desired performance across the entire UHF RFID band operated at 860–960 MHz (a fractional bandwidth of 11.1%) would be beneficial for the RFID system configuration and implementation to overcome the operating frequency shift and impedance variations due to the manufacturing process errors. Circular polarization can be obtained by exciting the two orthogonal linearly polarized modes with a 90° phase offset. Several CP tag antennas for UHF RFID system have been presented [12–18] for various applications. However, there is the disadvantage of being bulky antenna size for the above tag antennas. In this article, we present a novel compact CP design of UHF RFID tag antenna with omnidirectional reading pattern. By introducing the Y-shaped slit embedded into the planar circular tag to provide more input impedance, a novel CP tag antenna is proposed by embedding a pair of orthogonal N-shaped slits to obtain compact operation. The proposed CP tag antenna can provide more than 135 MHz (865–1000 MHz) of the measured half-power bandwidth, which includes the entire operating bandwidth for worldwide UHF RFID system. The 3 dB axial-ratio (AR) bandwidth of 10 MHz (920–930 MHz) is obtained and suitable for Taiwan UHF RFID applications. Moreover, with omnidirectional reading pattern, the maximum reading distance is about 7.2 m. Furthermore, in the aspect of considering overall antenna dimension, our designed antenna with a small size of $40 \times 40 \times \pi\,\text{mm}^2$ has more than 30% antenna size reduction than that of the smallest CP tag antenna with the dimension of $85 \times 85\,\text{mm}^2$ [12] for UHF RFID application. Details of the proposed compact tag antenna design are described in this study, and the related results for the obtained performance operated across the UHF bands are presented and discussed.

2. Antenna design

In the presence of environmental reflections which results in the multi-path effect, the transmitted and received plane waves undergo polarization direction changes. This will cause the tag antenna not to be read by the reader. Therefore, polarization diversity has to be utilized, requiring the use of CP antennas. Figure 1 shows the geometry of the proposed compact CP tag antenna. This tag antenna is fabricated by the copper plate



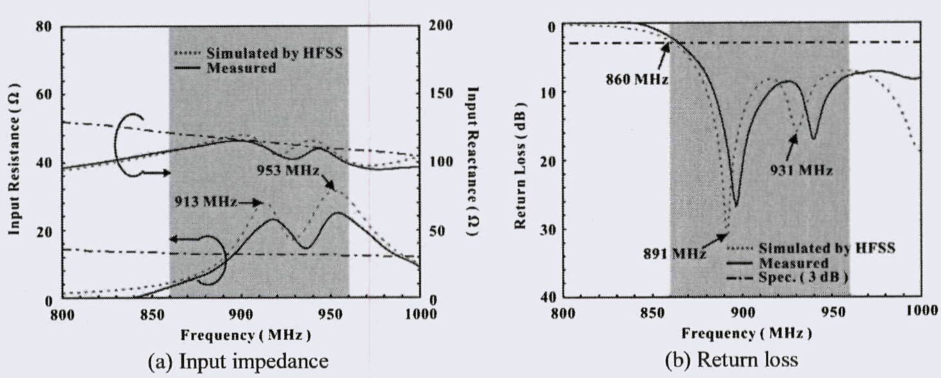
(a) (b)

Figure 1. Configuration of the proposed compact CP tag antenna for UHF RFID system. (a) Geometry. (b) Photograph.

(thickness = 0.2 mm) with the size of $\pi \times 40 \times 40\,\text{mm}^2$. The feeding Y-shaped slit comprises the conventional rectangular slit of L1 × W1 and an L-shaped slot with unequal lengths of L2 and L3 to increase the input impedance of this proposed tag antenna. The proposed orthogonal N-shaped slits are identical in shape with various length, so that the transmitted signal from this proposed tag antenna are in quadrature-phase. Moreover, the orthogonal N-shaped slits embedded into the circular copper plate are employing to extend the distributed surface currents to decrease the operating frequency for compact operation. By embedding the vertical (Y-direction) slit with the excited length (A→C→E→G→I) to be 111 mm (about 0.35 λ_0 at 953 MHz) and the horizontal (X-direction) slit with the excited length (A→B→D→F→H) as 114 mm (about 0.35 λ_0 at 913 MHz) for this proposed tag antenna, dual resonant modes near 913 and 953 MHz bands can be orthogonally excited to enhance the operating bandwidth for UHF RFID system. The impedance of the microchip (Alien Higgs-2 used in this study [19] with EPC global Gen2 certification), which is connected along the slit at point A, is (13 − j140) Ω at the operating frequency of 925 MHz band, and its threshold power sensitivity is about −14 dBm at 910 MHz band. To demonstrate the above deduction and guarantee the correctness of simulated results, the electromagnetic simulator HFSS based on the finite element method [20] has been applied for the proposed tag antenna design. The input impedance of the proposed tag antenna is measured on an Agilent Vector Network Analyzer E5071C, connected to a single-ended probe equipped with a balun transform, and calibrated with two-port calibration kit N1020A. As a result, Figure 1 shows the calculated values of design parameters throughout the presented strategy above. Particularly, from those results we are simultaneously optimizing them by using Ansoft HFSS as we set $r = 40$ mm, L1 = 5 mm, L2 = 17 mm, L3 = 18 mm, L4 = 32 mm, L5 = 30 mm, L6 = 35 mm, L7 = 31 mm, W1 = 1 mm, W2 = 2 mm, α = 35°.

3. Results and discussions

Figure 2 shows the related simulated and experimental results of the input impedance and return loss for the proposed tag antenna of Figure 1. The related results are listed in Table 1 as comparison where f_L and f_H, respectively, represents the lower and higher cutoff frequency (RL = 3 dB). Results show the satisfactory agreement for the proposed tag antenna operating at UHF band. It is easily seen that dual resonant modes near 913



(a) Input impedance (b) Return loss

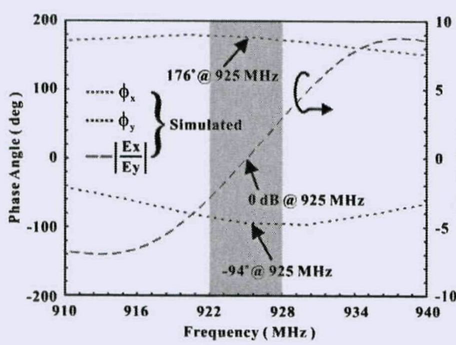
Figure 2. Simulated and measured input impedance and return loss against frequency for the proposed CP tag antenna.

Table 1. Simulated and measured return loss against frequency for the proposed CP tag antenna.

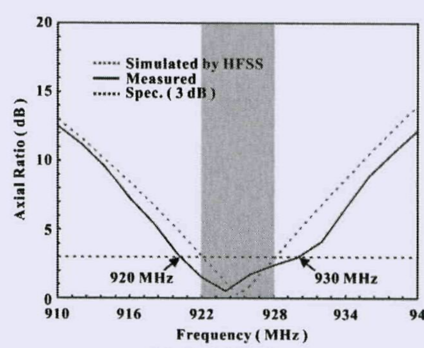
The proposed tag antenna	f_L–f_H (MHz)	BW (MHz/%)
Measured	865–1000	135/12.1
Simulated	862–1000	158/12.2

and 953 MHz bands can be easily excited with good matching to the input impedance of the IC microchip. For the realization of impedance matching between the tag antenna and IC chip, the half-power (3 dB return loss) bandwidth specification had been adopted in the proposed designs.[7–11] From the experimental results shown in Figure 2(b), the measured bandwidth (RL ≧ 3 dB) can be more than 135 MHz (865–1000 MHz) for UHF band, which totally covers the worldwide RFID UHF band. Figure 3 shows the related simulated and experimental results of the phase diagram and AR (in the boresight direction) for the proposed CP antenna of Figure 1. It can be seen that these two orthogonal modes (913 and 953 MHz) are excited in 90° phase difference to result in good CP radiation. In Figure 3(b), this CP antenna also provides a 3-dB AR over the Taiwan UHF band of 922–928 MHz.

To fully comprehend the excitation of UHF RFID bands, the surface current distributions at 913 and 953 MHz are illustrated Figure 4, along with an additional blue arrow sign showing the path lengths of dual resonant modes. In Figure 4(a), it can be seen that the excited surface current operating at 913 MHz is distributed along the horizontal N-shaped slit (A→B→D→F→H). For 953 MHz resonant mode, a relatively stronger excited surface current path of 0.35 wavelength distributed along the vertical slit (A→C→E→G→I) is illustrated in Figure 4(b). To realize the CP operation at 925 MHz, the surface current distributions on the tag antenna are shown in Figure 5 including the interpretation of CP radiation. We observe that the surface current distributions are around the N-shaped slits for four phase angles of 0°, 90°, 180° and 270°, respectively. Every instantaneous phase displayed at every 90 intervals demonstrates a very strong right-handed circularly polarized (RHCP) wave; that is, the surface current flows from the x-axis into the y-axis, becoming as a RHCP. Notice that the left-handed circularly polarized (LHCP) radiation can be obtained by exchanging the vertical and horizontal N-shaped slits each other.



(a) Phase diagram



(b) Axial Ratio

Figure 3. Simulated and measured phase diagram and AR against frequency for the proposed CP tag antenna.

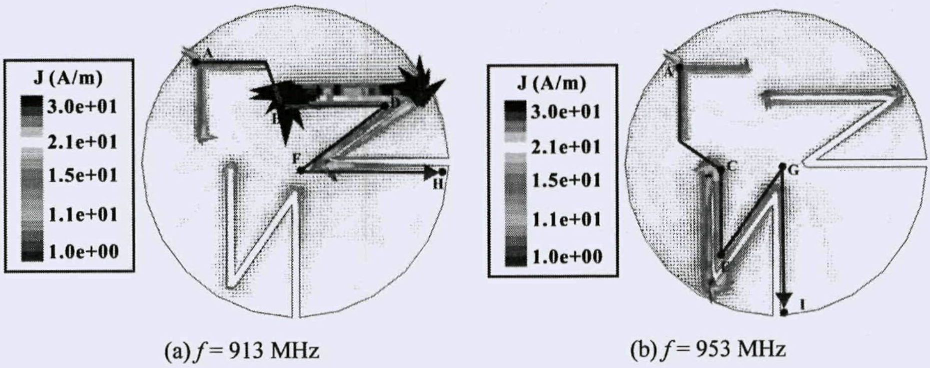


Figure 4. Simulated surface current distributions for the proposed CP tag antenna shown in Figure 1.

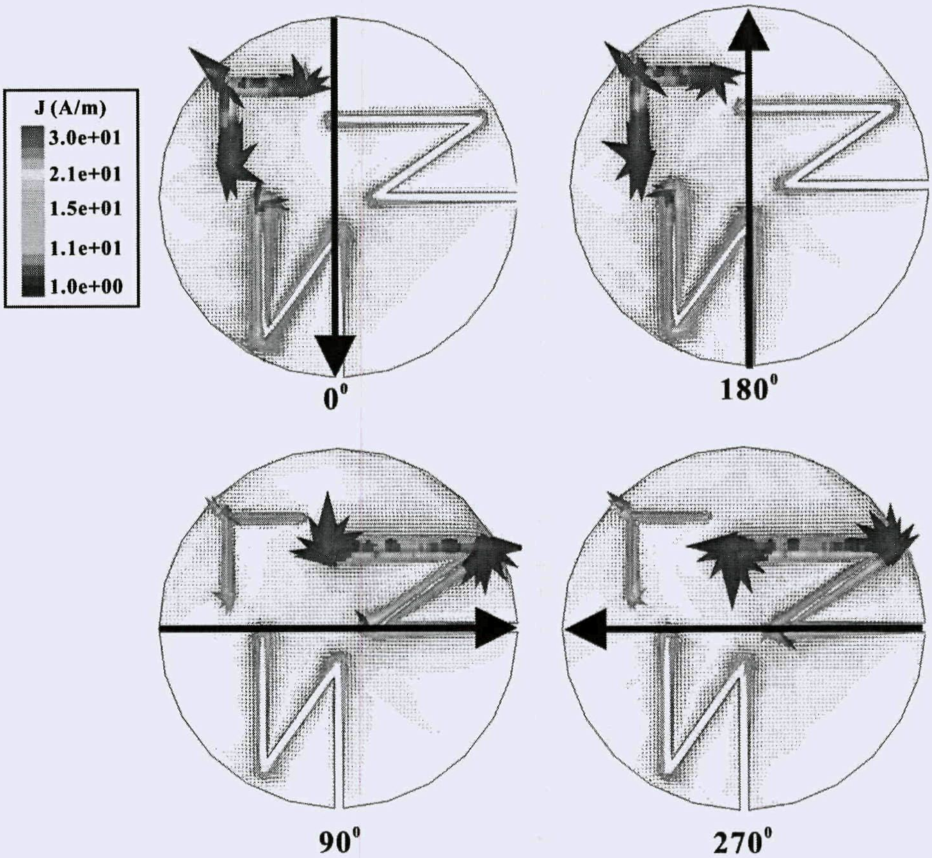


Figure 5. Simulated surface current distributions for the proposed RHCP tag antenna operating at 925 MHz with four phase angles: (a) 0°, (b) 90°, (c) 180°, (d) 270°.

4. Parametric studies and optimization

In order to achieve the desired impedance matching, we need to slightly modify corresponding parameters in cooperating with the antennas modification from which the circular polarization operation is generated. Return loss and input impedance are mainly affected by the dimensions of the Y-shaped slit and the attached carton.

4.1. Effects of the square loop

Figure 6 shows the simulated results of input impedance and AR against frequency for the proposed CP tag antenna with the Y-shaped slit or rectangular slit. By introducing the L-shaped slot of unequal length connected with the short rectangular slit to be as the proposed Y-shaped slit, the input impedance significantly increases to be easily matching with that of the IC chip for the enhancement of the operating bandwidth for UHF RFID band. However, the 3 dB AR bandwidth with various feed structures is slightly varied. Figure 7 shows the simulated input impedance and AR against frequency for the proposed tag antenna with various lengths (L3) of the L-shaped slot. It can be found that as L3 increases from 16 to 18 mm, the input impedance is significantly increased to reduce the operating bandwidth caused by the input reactance more increased, which is similar to the effect of a shorting stub in the general linear polarized tag antenna.[1–8,10] In addition, lower and higher resonant modes can be individually excited by the vertical and horizontal N-shaped slit. Meanwhile, miniaturization is an important issue for the tag antenna with compact operation. Due to less surface current distribution in the terminal of the embedded slit, the N-shaped slit design can not only provide compact operation but also make little impedance change. In addition, this proposed CP tag antenna with the dimension of $\pi \times 40$ (40 mm^2 can obtain more than 75% antenna size reduction than

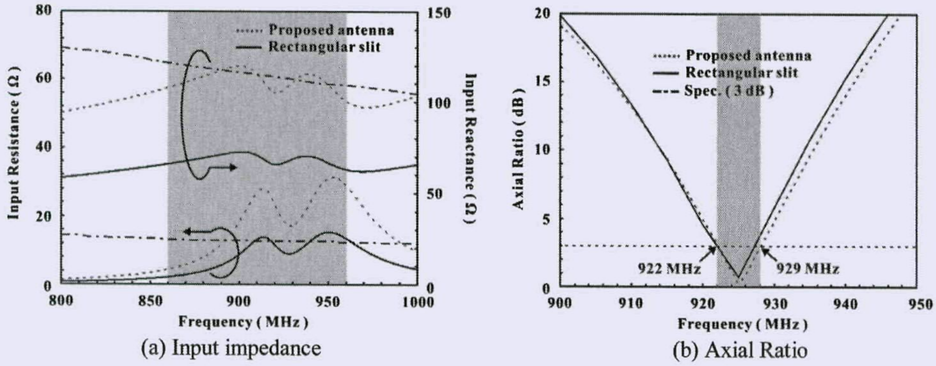
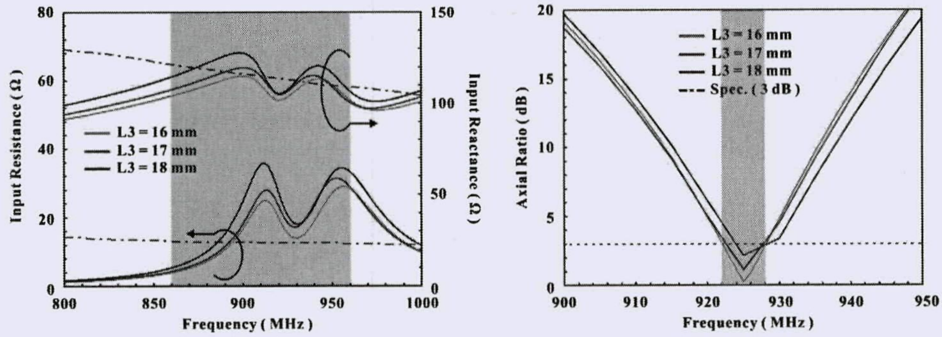


Figure 6. Simulated input impedance and AR loss against frequency for the proposed tag antenna with various slits as the feed structure.



(a) Input impedance (b) Axial Ratio

Figure 7. Simulated input impedance and AR against frequency for the proposed tag antenna with various lengths (L3) of the Y-shaped slit.

the tag antenna composed of the regular circular copper patch with the dimension of $\pi \times 80 \times 80\,\mathrm{mm}^2$ as operating at the same frequency.

4.2. Effects of the carton

To verify the tag performance, based on the backscattering method,[21] the measurement about the maximum distance for the proposed tag antenna with the microchip is carried out in anechoic chamber by introducing Tagformance Lite Measurement System from Voyantic Company as shown in Figure 8, which is comprised of a computer, a reader controller, a reader CP antenna and an oriented fabricated tag attached on a rotary Styrofoam. The measured system can provide a variable transmitted power with a cable loss calibration. A reader with the output power of EIRP 3.28 W was connected to the CP antenna with peak gain of 8 dBi. Figure 9(a) shows the comparison of the

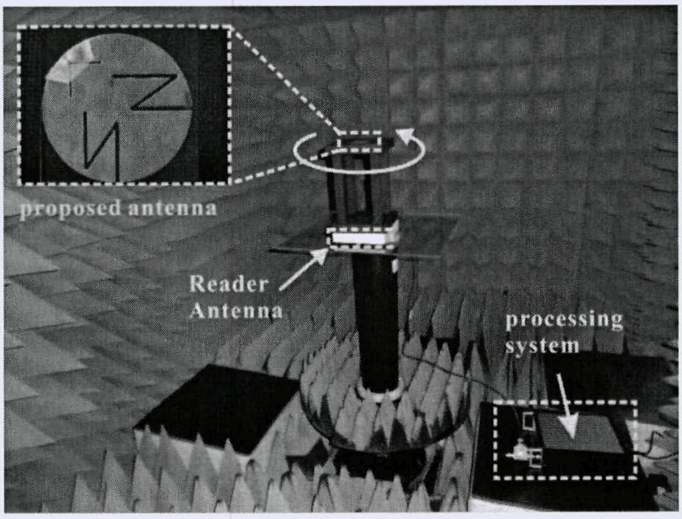
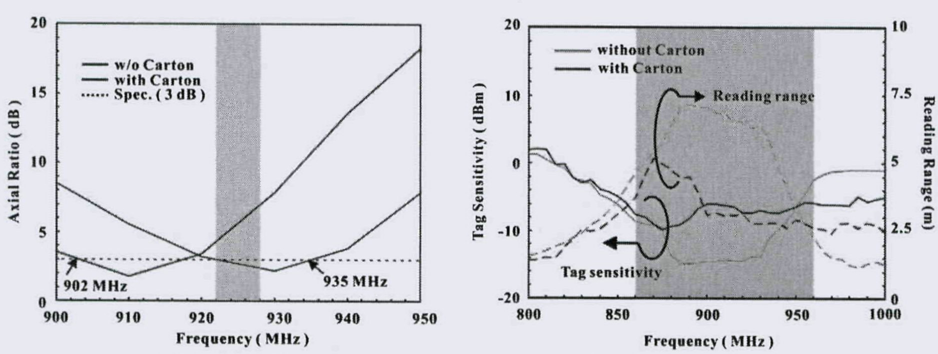


Figure 8. Measured environment with Tagformance lite Measurement System from Voyantic Company.

measured AR for the proposed tag antenna attached on the carton or not. It is clearly found that the operating frequency is decreased as the proposed tag attached on the carton to affect the radiation characteristics of this proposed tag antenna. However, only need to decrease the length of the N-shaped slit, the operating frequency shifting can be overcome and easily meet the bandwidth specification of UHF RFID system. Figure 9(b) shows the comparison of the measured tag sensitivity and reading range for the proposed tag attached on the carton or not. It is easily found that, due to the loading effect of the carton, the performances for reading range and tag sensitivity of the proposed tag attached on the carton is less than that for the proposed tag without the carton. Moreover, as the proposed compact CP tag is not attached on the carton, the maximum reading distance is about 7.2 m at the operating frequency of 890 MHz having optimal impedance.

Figure 10 presents the simulated antenna gain and efficiency (mismatching loss included [22]) for the proposed compact tag antenna. For frequencies over the UHF band, the simulated antenna gain is approximately 0.28–0.4 dBic. Meanwhile, the simulated antenna efficiency is around 82–91% over Taiwan UHF RFID band. Finally, to determine the tag angular sensitivity patterns, the tag was rotated at 30-degree step from 0° to 360° for the *X–Z* (*H*-) and *X–Y* (*E*-) planes as shown in Figure 11. By introducing a CP reader antenna operated at 925 MHz band, the measured tag angular sensitivity pattern presents a fairly good omnidirectional pattern in the *X–Z* plane (H-plane), and the pattern in the *X–Y* plane (*E*-plane) is also quite close to omnidirectional as shown in Figure 11(a). And, the radiation pattern in the *X–Y* plane (*E*-plane) is observed with the maximum reading distance of 7.2 m. Hence, the proposed tag antenna can be employing to overcome the null-reading problem of conventional dipole-like tag antenna. In addition, to further realize the omnidirectional performance of the proposed tag, a linearly polarized reader antenna with a gain of 8 dBi is available. As the same measurement, Figure 11(b) shows the measured tag angular sensitivity patterns for the *E*/*H* planes at 925 MHz band. The principal-polarized patterns were similar to those of a typical dipole antenna. The bi-directional radiation pattern in the *X–Y* plane (*E*-plane) is observed with the maximum reading distance of 5.8 m, however, the measured pattern in the *X–Z* plane (*H*-plane) still presents a fairly good omnidirectional performance.



(a) Axial Ratio (b) Sensitivity and Reading range

Figure 9. Comparison of measured performance of the proposed tag attached on carton or not.

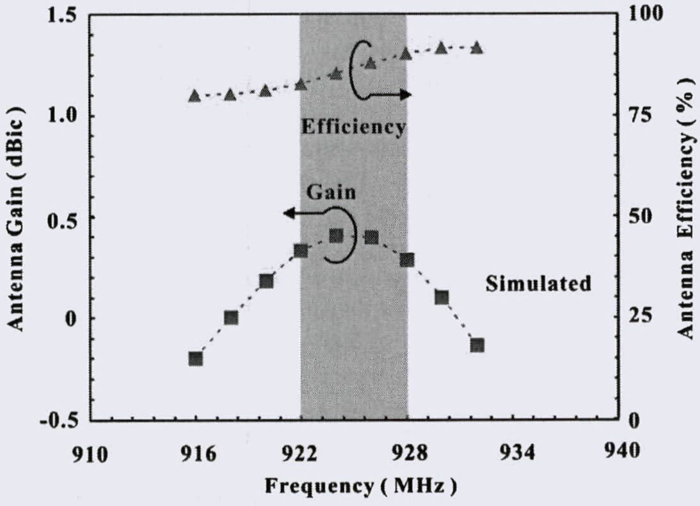


Figure 10. Simulated antenna gain and efficiency for the proposed compact tag antenna studied in Figure 2.

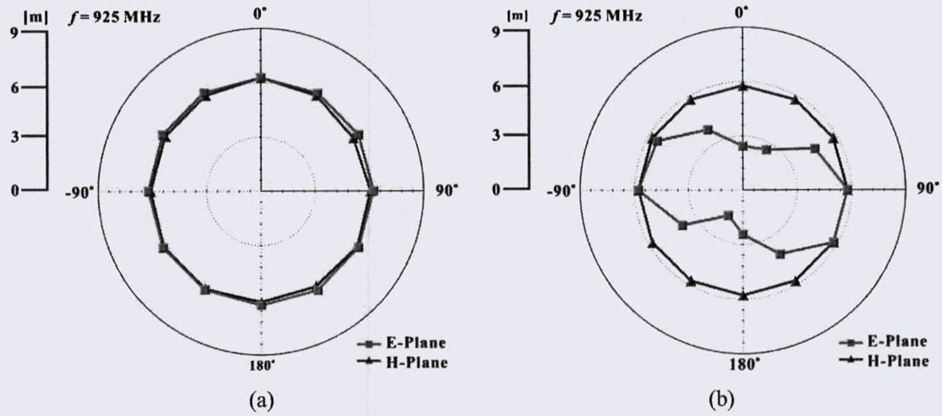


Figure 11. Measured reading range pattern for the proposed tag by using various reader antennas at 925 MHz band. (a) CP reader antenna. (b) LP reader antenna.

5. Conclusions

A novel compact design of planar omnidirectional tag antenna with circular polarization for UHF RFID system has been proposed. By employing the Y-shaped slit as the feed structure, the measured half-power bandwidth of the proposed broadband tag antenna can reach more than 135 MHz (865–1000 MHz), which meets the bandwidth specification of the UHF RFID system, and the 3 dB AR bandwidth of about 10 MHz for Taiwan UHF RFID applications. Since overall antenna dimension is only $40 \times 40 \times \pi\,\text{mm}^2$, the proposed tag antenna in this study can also operate with antenna size reduction of 30% than conventional CP tag antennas. The simulated peak gain and antenna efficiency are approximately 0.4 dBic and 91% for Taiwan UHF RFID band. Good tag sensitivity was obtained across the desired frequency band and the omnidirectional radiation pattern in the *X–Z* plane is observed with the maximum reading distance of 7.2 m.

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References

[1] Choi Y, Kim U, Kim J, Choi J. Design of modified folded dipole antenna for UHF RFID tag. IET Electron. Lett. 2009;45:387–389.
[2] Fang Z, Jin R, Geng J, Sun J. A novel broadband antenna for passive UHF RFID transponders offering global functionality. Microwave Opt. Technol. Lett. 2007;49:2795–2798.
[3] Xu L, Hu BJ, Wang J. UHF RFID tag antenna with broadband characteristic. Electron. Lett. 2008;44:79–80.
[4] Bae SW, Lee W, Chang K, Kwon S, Yoon YJ. A small RFID tag antenna with bandwidth-enhanced characteristics and a simple feeding structure. Microwave Opt. Technol. Lett. 2007;50:2027–2031.
[5] Wu SJ, Ma TG. A passive UHF RFID meandered tag antenna with tuning stubs. Yokohama: Asia-Pacific Microwave Conference; 2006. p. 1486–1492.
[6] Rida AH, Yang L, Basat SS, Tentzeris MM. Design development and integration of novel antennas for miniaturized UHF RFID tags. IEEE Trans. Antennas Propag. 2009;57:3450–3457.
[7] Lu JH, Hung KT. Planar inverted-E antenna for UHF RFID tag on metallic objects with bandwidth enhancement. Electron. Lett. 2010;46:1182–1183.
[8] Lu JH, Wu JJ. Bandwidth enhancement design of planar F-shaped tag antenna with parasitic strips. Prog. Electromagn. Res. Lett. 2011;20:1–9.
[9] Lu JH, Su JY. Planar loop tag antenna with bandwidth enhancement for UHF RFID system. Microwave Opt. Technol. Lett. 2011;53:2711–2713.
[10] Lu JH, Zheng GT. Planar broadband tag antenna mounted on the metallic material for UHF RFID System. IEEE Antennas Wirel. Propag. Lett. 2011;10:1405–1408.
[11] Lu JH, Siao BF. Planar omnidirectional tag antenna for UHF RFID system. J Electromagn. Waves App. 2013;27:901–910.
[12] Deavours DD. A circularly polarized planar antenna modified for passive UHF RFID. Orlando (FL): IEEE International Conference on RFID; 2009. p. 265–269.
[13] Cho C, Park I, Choo H. Design of a circularly polarized tag antenna for increased reading range. IEEE Trans. Antennas Propag. 2009;57:3418–3422.
[14] Ghalibafan J. Circular polarized RFID tag antenna design based on human hand model. IEEE International Conference on RFID Technology and Application: Guangzhou; 2010. p. 16–18.
[15] Chen HD, Kuo SH, Sim CYD, Tasi CH. Coupling-feed circularly polarized RFID tag antenna mountable on metallic surface. IEEE Trans. Antennas Propag. 2012;60:2166–2174.
[16] Chen HD, Kuo SH, Sim CYD. Compact broadband dual coupling-feed circularly polarized RFID microstrip tag antenna mountable on metallic surface. IEEE Trans. Antennas Propag. 2012;60:5571–5577.
[17] Garcıa J, Arriola A, Casado F, Chen X, Sancho JI, Valderas D. Coverage and read range comparison of linearly and circularly polarised radio frequency identification ultra-high frequency tag antennas. IET Microwave Antennas Propag. 2012;6:1070–1078.
[18] Lin YF, Yeh SA, Chen HM, Chang SW. Design of an omnidirectional polarized RFID tag antenna for safety glass applications. IEEE Trans. Antennas. Propag. 2012;60:4530–4537.
[19] Alien Technology. Available from: http://www.alientechnology.com/ic/.
[20] Ansoft Corporation HFSS. Available from: http://www.ansoft.com/products/hf/hfss.
[21] Tag Performance Parameters and Test Methods EPCglobal Inc. [online]. Vol. 1.1.3; 2008 Jan. Available from: http://www.epcglobalinc.org/.
[22] Huang Y, Boyle K. Antennas from theory to practice. Singapore: John Wiley; 2008. p. 124.

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