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Planar omnidirectional tag antenna for UHF RFID system

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A novel design of planar omnidirectional tag antenna for ultra high frequency (UHF) radio frequency identification (RFID) is proposed. With the use of a square loop accompanying dual dipole strips, the measured half-power bandwidth of the proposed broadband tag antenna can reach 143 MHz (857–1000 MHz), which includes the entire operating bandwidth for worldwide UHF RFID system. Meanwhile, with omnidirectional reading pattern, the measured reading distance is about 11.0 m as it is mounted on the carton. Good tag sensitivity was obtained across the desired frequency band.

1. Introduction

Ultra high frequency (UHF) (860–960 MHz) band radio frequency identification (RFID) system had gained much interest 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 dimensio,[4–6] dual resonant modal of impedance,[7] F-shaped dipole antenna,[8] loop antenna with a pair of rectangular parasitic patches,[9] and dual-branch dipole antenna with the shorting pin.[10] Since the above presented tag antennas are only linearly vertical or linearly horizontal polarized with high orientation sensitivity and mostly designed with narrow bandwidth accompanying directional reading problem, broadband dual-polarized antennas become the most popular candidates to receive the radio frequency (RF) signal that emanates from arbitrarily oriented reader antennas for improving the reliability of communications between readers and tags. Moreover, dual-polarized antennas with polarization diversity can reduce the loss caused by the multipath effects due to the presence of environmental reflections between the reader and the tag antenna. However, the UHF frequencies authorized for RFID 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. The related broadband tag antenna with dual-polarized operation has been presented.[11] However, there is the disadvantage of being

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bulky antenna size for the above antenna. In this article, we present a novel compact design of UHF RFID tag antenna with omnidirectional reading pattern. By introducing a square loop instead of the shorting stub in the linear-polarized tag antenna [1–8,10] resulting in providing more input impedance of the tag antenna, a novel dual-polarized tag antenna is proposed by using the meander strips to obtain compact operation.[12] The measured half-power bandwidth of the proposed broadband tag antenna can reach 143 MHz (857–1000 MHz), which includes the entire operating bandwidth for worldwide UHF RFID system. Moreover, with omnidirectional reading pattern, maximum reading distance is about 11.0 m as the proposed tag antenna is attached on the carton. Details of the proposed 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 both linearly polarized antennas. Figure 1 shows the geometry of the proposed omnidirectional tag antenna. This tag antenna with the antenna size of $60 \times 60\,mm^2$ is printed on an FR4 substrate ($\varepsilon_r = 4.4$, thickness = 0.4 mm, and loss tangent = 0.0245). The novel square loop with the dimension of L1 × L1 is introduced to connect with the proposed dual meander dipole strips for lowering the input impedance of this proposed tag antenna. These inner and outer dipole strips are identical in size and shape, so that the transmitted signal from these two dipole radiators are in-phase and uncorrelated. Dual inner meander lines (section AC and BD) orthogonally arranged inside the square loop are introduced to increase the inductive reactance for better impedance matching. Moreover, by mounting the outer vertical (Y-direction) meander line with the total length (E→A and C→G) to be 215 mm (about 0.63 λ_0 at 887 MHz) and the outer horizontal (X-direction) meander line with the total length (F→B and D→H) as 205 mm (about 0.65 λ_0 at 956 MHz) for this proposed tag antenna, dual resonant modes near 887 and 956 MHz bands can be excited to enhance the operating bandwidth for UHF RFID system. The impedance of the microchip (Alien Higgs-2 used in this study [13] with EPC global Gen2 certification), which is

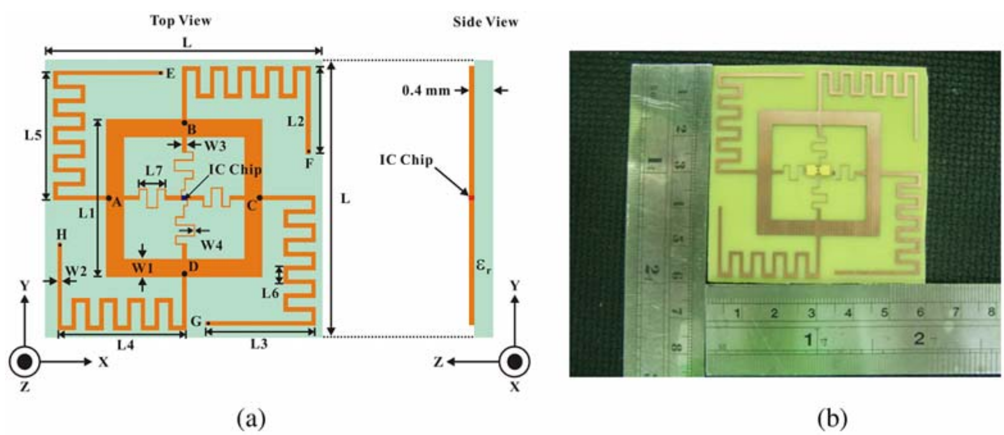


Figure 1. Configuration of the proposed omnidirectional tag antenna with bandwidth enhancement for UHF RFID system. (a) Geometry. (b) Photograph.

connected between two feed points of dual inner meander lines, 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 [14] 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 L = 60 mm, L1 = 34 mm, L2 = 19 mm, L3 = 24 mm, L4 = 28 mm, L5 = 28 mm, L6 = 4 mm, L7 = 6 mm, W1 = 4 mm, W2 = 1 mm, W3 = 1 mm, and W4 = 0.3 mm.

3. Results and discussion

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. Due to the dielectric constant and loss tangent of FR4 substrate varied with the operating frequency [15–16]; the measured resonant frequency and input impedance for this antenna are less different from the related simulated results by setting the constant substrate parameters such as the relative permittivity of 4.4 and loss tangent of 0.0245 across the operating bands. In Figure 2(a), it is seen that dual resonant modes near 887 and 956 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.[7–10] From the experimental results shown in Figure 2(b), the measured bandwidth (RL ≧ 3 dB) can reach about 143 MHz (857–1000 MHz) for UHF band, which totally covers the worldwide RFID UHF band.

To fully comprehend the excitation of UHF RFID bands, Figure 3 shows the simulated surface current distributions at 887 and 956 MHz bands. In Figure 3(a), it can be seen that the excited surface current operating at 887 MHz is distributed along the vertical meander line

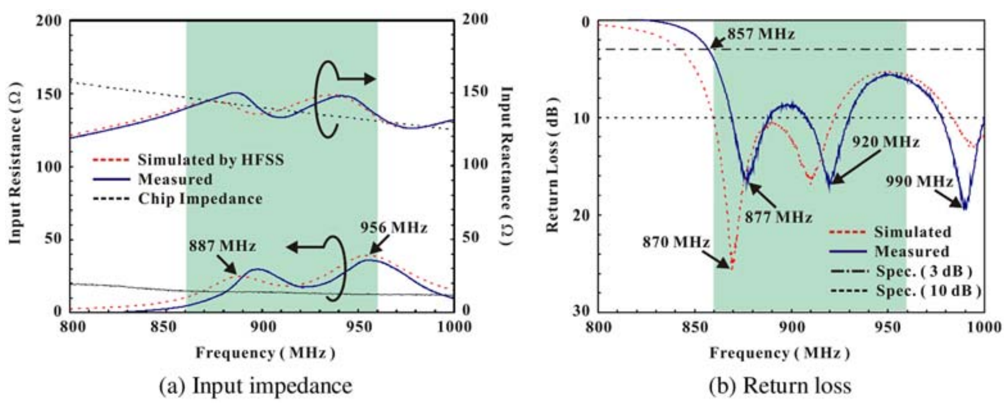


Figure 2. Simulated and measured input impedance and return loss against frequency for the proposed tag antenna.

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

The proposed tag antenna	f_L–f_H (MHz)	BW (MHz/%)
Measured	857–1000	143/12.1
Simulated	840–1000	160/12.2

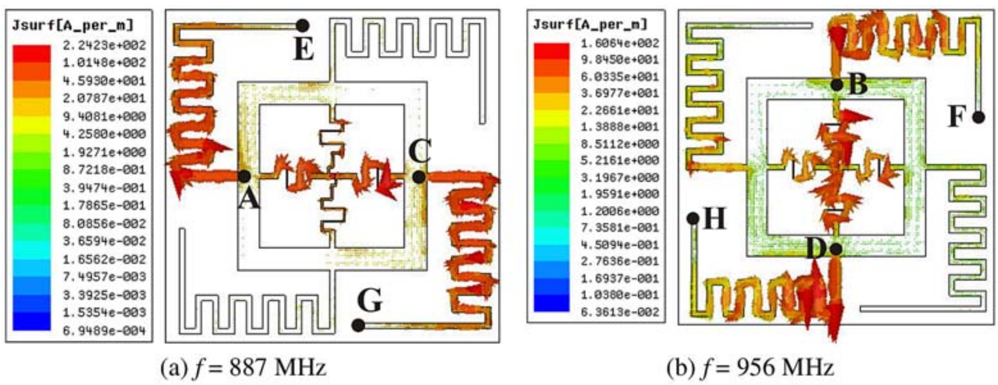


Figure 3. Simulated surface current distributions for the proposed tag antenna shown in Figure 1.

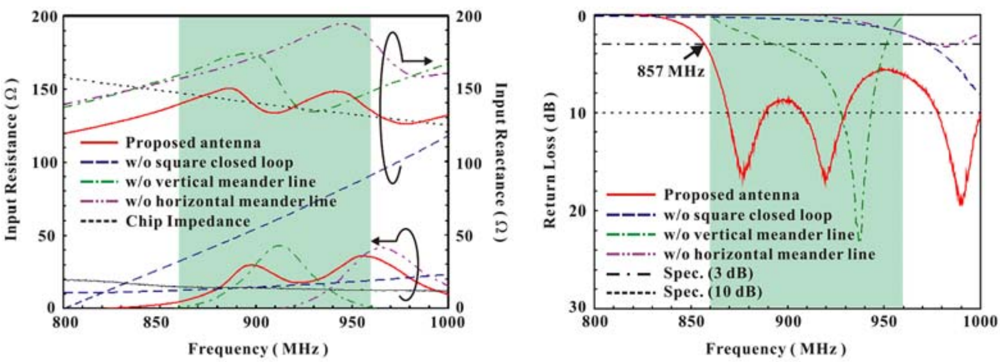
(E→A→C→G) with that along the horizontal meander line (F→B→D→H) at 956 MHz band. The surface current length (E→A and C→G) is about 215 mm and correspondingly equal to approximate 0.63 wavelength of the operating mode at 887 MHz band which is longer than half-wavelength due to the cancellation of opposite polarity currents between two adjacent meandered sections.[12] For 935 MHz resonant mode, a relatively stronger excited surface current path of 0.65 wavelength distributed along the horizontal strip (F→B and D→H) is illustrated in Figure 3(b). This characteristic indicates that dual resonant modes can be excited with dual linear polarization.

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 broadband operation is generated. Return loss and input impedance are mainly affected by the dimensions of the square loop, the inner or outer meander lines and the carton.

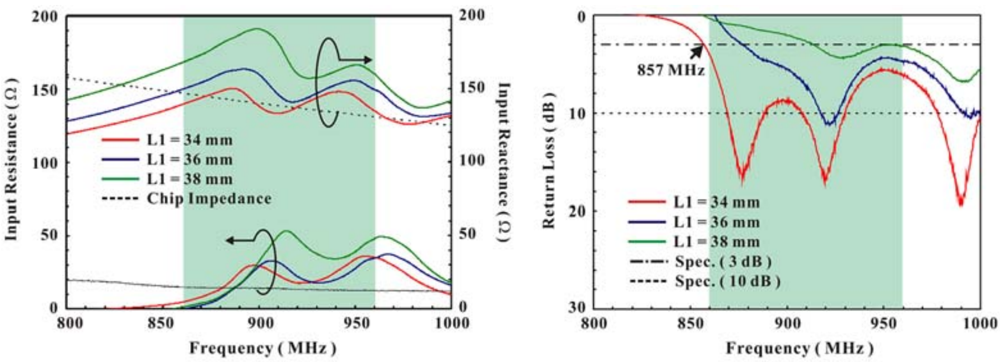
4.1. Effects of the square loop

Figure 4 shows the experimental results of input impedance and return loss against frequency for the proposed dual-polarized tag antenna with the square loop, vertical and horizontal meander line or not. By introducing the square loop connected with the inner meander line, 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. In addition, lower and higher resonant modes can be individually excited by the vertical and horizontal outer meander lines with more input impedance. Figure 5 shows the measured input impedance and return loss against frequency for the proposed tag antenna with various side lengths (L1) of



(a) Input impedance (b) Return loss

Figure 4. Measured input impedance and return loss against frequency for the proposed tag antenna with the square closed loop, vertical and horizontal path or not.



(a) Input impedance (b) Return Loss

Figure 5. Measured input impedance and return loss against frequency for the proposed tag antenna with various side lengths (L1) of the square closed loop.

the square loop. It can be found that as L1 increases from 34 to 38 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]

4.2. Effects of the inner and outer meander line

Figure 6 shows simulated input impedance and return loss against frequency for the proposed tag antenna with the inner meander line or not. It is clearly seen that the inner meander lines near the IC chip can generate the inductive effect to increase the input reactance to obtain better impedance matching. By introducing the inner meander line instead of the regular strip (Ref 1), the input reactance is significantly increased to improve the operating bandwidth as shown in Figure 6(b). Moreover, miniaturization is an important issue for the tag antenna with compact operation. Due to less surface current distribution in the terminal of the half-wavelength dipole antenna, the meander strip design can not only provide compact operation but also make little impedance change. Meanwhile, Figure 7 shows the measured input

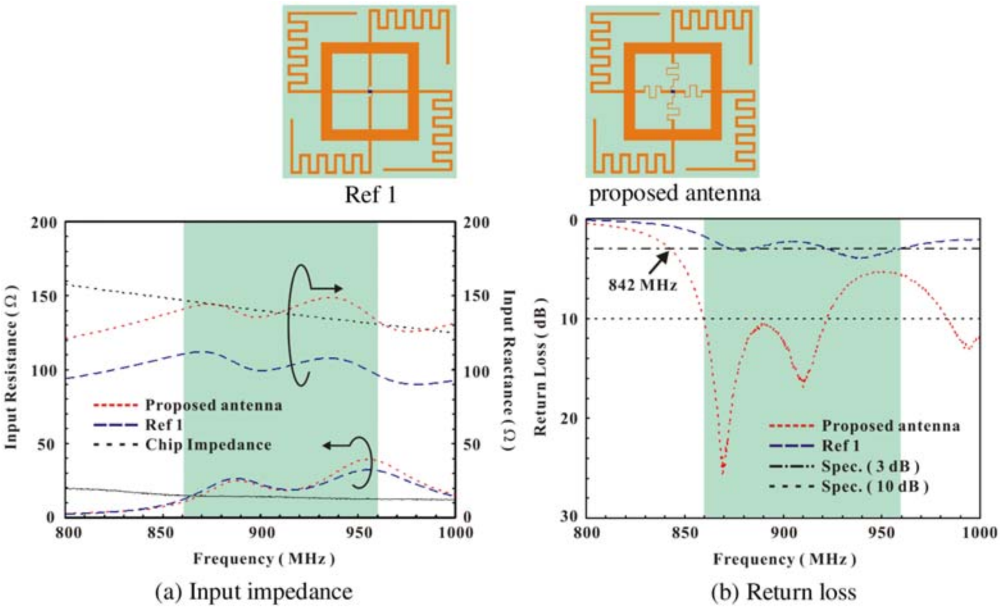


Figure 6. Simulated input impedance and return loss against frequency for the proposed tag antenna with the inner meander or regular line.

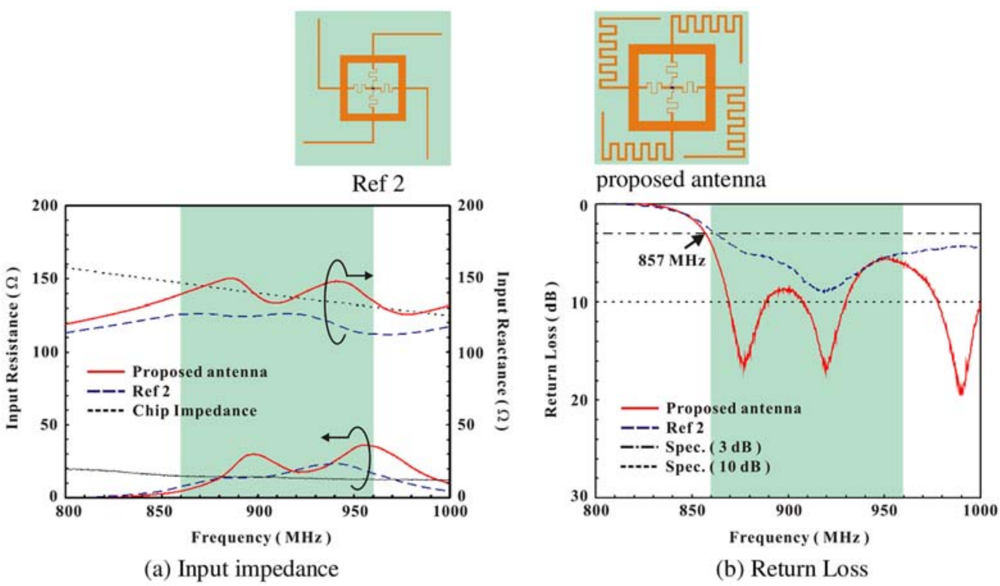


Figure 7. Measured input impedance and return loss against frequency for the proposed tag antenna with the outer meander line or not.

impedance and return loss against frequency for the proposed dual-polarized tag antenna with the outer meander line or not. Due to the inductive effect caused by the outer meander line, the input reactance is significantly increased to obtain bandwidth enhancement as shown in Figure 7(b). In addition, this proposed broadband tag antenna with the dimension of

$60 \times 60\,mm^2$ can obtain more than 69% antenna size reduction than the tag antenna composed of the regular dipole (Ref 2) using the same FR4 substrate with the dimension of $103 \times 113\,mm^2$.

4.3. Effects of the carton

Figure 8 shows the comparison of the measured input impedance and return loss for the proposed tag antenna attached on the cartons with different sizes. It is found that the operating frequency is decreased as the carton's size increases to affect the radiation characteristics of this proposed tag antenna. As the carton's dimension is more than $150 \times 150\,mm^2$, the input impedance is insensitive of the carton's sizes to make this proposed tag antenna have more applications. Meanwhile, only need to decrease the length of the outer meander line, the operating frequency shifting can be overcome and easily meet the bandwidth specification of UHF RFID system. In addition, by decreasing the dimension of the square loop, the input impedance of this proposed tag antenna attached on the cartons decreases as the results shown in Figure 5 to obtain the optimal impedance matching.

4.4. Comparison between the proposed tag and the commercial product

To verify the tag performance, based on the backscattering method,[17] 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 9, 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 10 shows the comparison of the measured tag sensitivity and reading range for the proposed tag and the commercial (Impinj H47 with Monza 4D chip) tag attached on the cartons. This Monza 4D chip has the threshold power sensitivity about −17.4 dBm at 910 MHz band, which is less than that (−14 dBm) of Alien Higgs-2 for this proposed tag. It is easily found that the performances for reading range and tag sensitivity of the proposed tag is almost the same as that for the commercial tag (Impinj H47). Meanwhile, the reading range of this proposed tag is observed with the maximum reading distance of

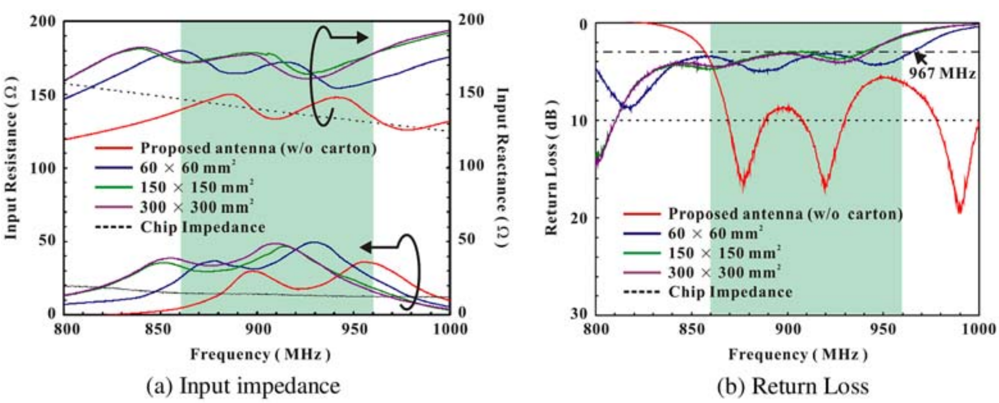


Figure 8. Measured input impedance and return loss against frequency for the proposed tag antenna attached on the cartons with different sizes.

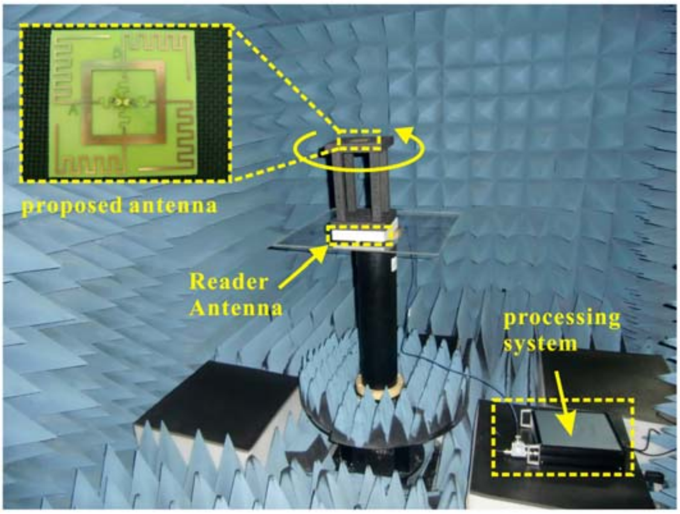


Figure 9. Measured environment with Tagformance lite Measurement System from Voyantic Company.

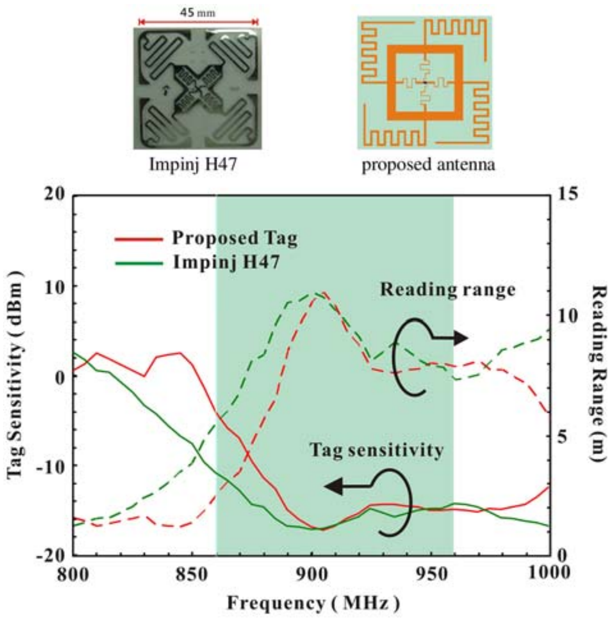


Figure 10. Measured tag sensitivity and reading distance of the proposed tag and Impinj H47 tag attached on carton.

11 m at about 905 MHz band. As this proposed tag operates below 900 MHz, the reading range is less than that of Impinj H47 due to various frequency responses between the used microchips.

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. For the practical application, i.e. the proposed broadband tag antenna is attached on the carton with

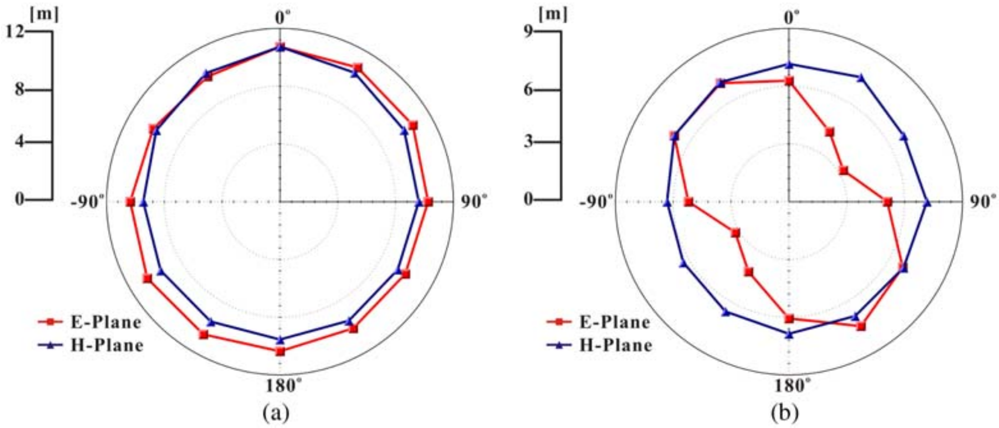


Figure 11. Measured reading range pattern for the proposed tag by using various reader antennas. (a) CP reader antenna. (b) LP reader antenna.

the dimension of $150 \times 150\,mm^2$. By introducing a circularly polarized reader antenna operated at 910 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). Due to the loading effect caused by the FR4 substrate, the measured reading distance for this proposed tag antenna is less different at the front (0°) and rear (180°) directions. And, the radiation pattern in the X–Y plane (E-plane) is observed with the maximum reading distance of 11 m. Hence, the proposed tag antenna can be employed 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 910 MHz band. The principal-polarized patterns were similar to those of a typical dipole antenna. The bidirectional radiation pattern in the X–Y plane (E-plane) is observed with the maximum reading distance of 7.5 m; however, the measured pattern in the X–Z plane (H-plane) still presents a fairly good omnidirectional performance.

5. Conclusions

A novel compact design of planar omnidirectional tag antenna with bandwidth enhancement for UHF RFID system has been proposed. By employing the square loop, the measured half-power bandwidth of the proposed broadband tag antenna can reach 143 MHz (857–1000 MHz), which meets the bandwidth specification of the UHF RFID system. 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 11 m.

Acknowledgment

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