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Novel CPW-fed slot antenna for UHF RFID metal tag applications

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Abstract: A novel planar CPW-fed passive tag antenna that may be mounted on a metallic object is presented to meet UHF radio frequency identification (RFID) applications. It comes with a slot radiator and an inverted-C shaped coupling structure, which is fabricated on a 0.4 mm-thick FR4 substrate to be attached on a 3 mm-thick polypropylene (PP) substrate. No additional matching circuit is required with our design, so a compact tag size of 93(L)×20(W)×3.4(H) mm^3 can be obtained. With a proper operating bandwidth from 915 to 929 MHz, the proposed tag can achieve maximum reading ranges of 7.4 m and 4.7 m when used with and without a metallic plate for 4W *EIRP*.

Keywords: RFID, metal tag, tag antenna, maximum reading range

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

Recently, radio frequency identification (RFID) techniques with automatic wireless data access have rapidly earned high attention for various commercial purposes, such as tracking goods, supply chain managements and retail store applications. Compared with the lower frequency tags (LF and HF bands) already suffering from limited reading range, the UHF RFID tags can have farther reading range and higher data transfer rate [1]. These tags need not only good impedance matching between the antenna and tag chip to attain efficient power transfer, but also a small size to be easily attached on an object. Generally, tag antennas using half-wavelength dipole form were studied to provide an omnidirectional coverage [2, 3], but they were not suitable for practical applications due to their large sizes. Some planar antennas based on a loop-type structure to reduce tag size have been reported in [4, 5]. However, these tag designs work inefficiently when placed near a metallic object. To this end, several metal tags using inverted-F antenna (IFA), planar inverted-F antenna (PIFA) and patch antenna are thus developed in [6, 7, 8, 9]. Owing to lower radiation performance, all these metal tags operate with a shorter reading range for practical applications.

In this paper, we propose a printed CPW-fed slot antenna to construct a metal tag for UHF RFID applications. This design with a size of $93(L)\times 20(W)\times 3.4(H)\,mm^3$ is consisted of a slot radiator and an inverted-C shaped coupling structure. By using such configuration, the effects caused by an object with high conductivity can be reduced significantly, so that the tag performance can be enhanced as well. Comparing to those studies shown in [6, 7, 8, 9], the proposed tag can work with a farther reading range when mounted on a metal plate. Also note that the operating bandwidth of the antenna can be flexibly tuned by employing various slot gaps. Details of the antenna design are then presented in Section 2, and a prototype of the proposed tag has been constructed and experimentally investigated in Section 3. Finally, this paper is concluded with a brief summary in Section 4.

2 Antenna design

The whole geometry with detailed design parameters of the proposed metal tag antenna is depicted in Fig. 1 (a). This tag antenna, consisting of a slot

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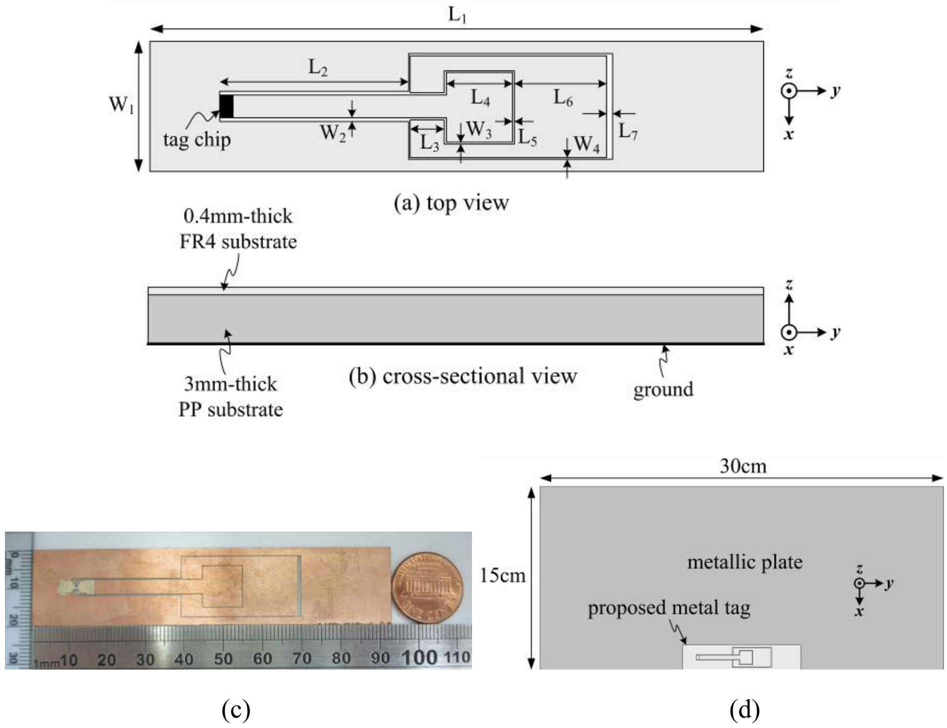

Fig. 1. (a) Top view ($L_1 = 93$ mm, $L_2 = 28.5$ mm, $L_3 = 5.3$ mm, $L_4 = 10.1$ mm, $L_5 = 0.2$ mm, $L_6 = 14$ mm, $L_7 = 1$ mm, $W_1 = 20$ mm, $W_2 = 0.5$ mm, $W_3 = 0.2$ mm, and $W_4 = 0.2$ mm), (b) Cross-sectional view, (c) Fabricated prototype, (d) The proposed metal tag mounted on a metallic plate.

radiator and an inverted-C shaped coupling structure, is excited by a coplanar waveguide (CPW) structure. The overall dimensions of the antenna are about 93(L)×20(W)×3.4(H) mm^3. It is fabricated on a 0.4 mm-thick FR4 substrate and then attached on a 3 mm-thick polypropylene (PP) substrate, where the FR4 substrate has a relative permittivity $\varepsilon_r = 4.4$ and a loss tangent $\tan\delta = 0.02$, and also the PP substrate has $\varepsilon_r = 2.3$ and $\tan\delta = 0.006$. Here we utilize a low loss PP substrate placed below the FR4 substrate to enhance the radiation efficiency for the tag antenna. To further reduce the effects from a metallic object, on the other hand, a copper ground plane is printed behind the PP substrate, as shown in Fig. 1 (b). By properly designing the coupling gaps L_5 and W_3, the proposed antenna can resonate at a frequency of 925 MHz. Using a double-layer structure, the tag can radiate with good performance when mounted on a metal object. This is because the resonant currents flow along the slot edge for our design. Note that reduction of the slot radiator is possible but may degrade the tag performance without re-tuning the antenna structure.

Here an Impinj Monza Gen2 chip was used for the prototype antenna, whose input impedance was $(33 - j112)\,\Omega$ equal to that of a RC series circuit with $R = 33\,\Omega$ and $C = 1.58$ pF at 925 MHz. The sensitivity of the chip was −12 dBm. The input impedance of the antenna, therefore, needs to be $(33 + j112)\,\Omega$ at 925 MHz in order to get maximum power transfer

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between the antenna and the chip. The proposed antenna has been modeled and simulated by utilizing Ansoft HFSS software, whose electrical characteristics and radiation performance are analyzed as well. The parameters optimized for the proposed tag antenna are determined with $L_1 = 93$ mm, $L_2 = 28.5$ mm, $L_3 = 5.3$ mm, $L_4 = 10.1$ mm, $L_5 = 0.2$ mm, $L_6 = 14$ mm, $L_7 = 1$ mm, $W_1 = 20$ mm, $W_2 = 0.5$ mm, $W_3 = 0.2$ mm, and $W_4 = 0.2$ mm. A photograph as shown in Fig. 1 (c) is the implemented metal tag with the chip. Its performance will be carefully examined with a $30(L){\times}15(W)\,cm^2$ metallic plate, as shown in Fig. 1 (d).

3 Results and discussions

A prototype for the proposed tag antenna with the chip was constructed and tested. The measured results regarding the input impedances of the fabricated tag were performed using a vector network analyzer (Agilent PNA 8362B). Figures 2 (a) and (b) respectively exhibit the simulated and measured input resistances and reactances against the frequency for the antenna, where good agreements between the simulations and measurements have been received. We can observe that the simulated and measured impedances are respectively equal to $(39 + j104)\,\Omega$ and $(41 + j115)\,\Omega$ at 925 MHz. These re-

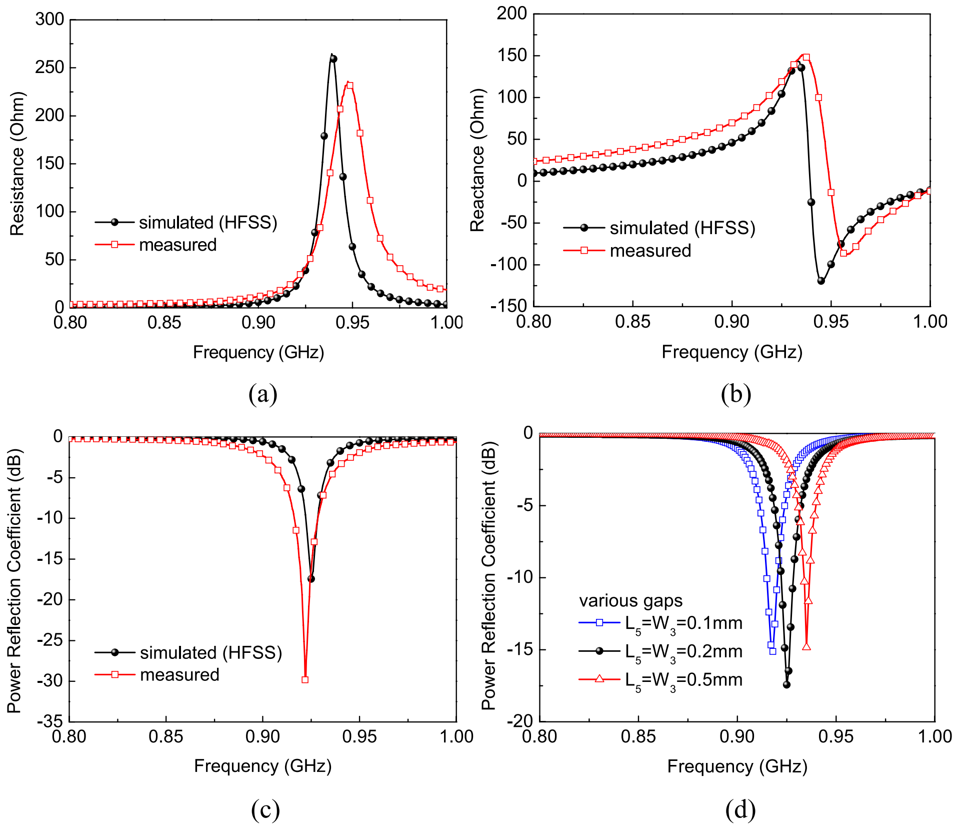

Fig. 2. (a) Simulated and measured input resistance, (b) Simulated and measured input reactance, (c) Calculated power reflection coefficients, (d) Simulated power reflection coefficient with various coupling gaps.

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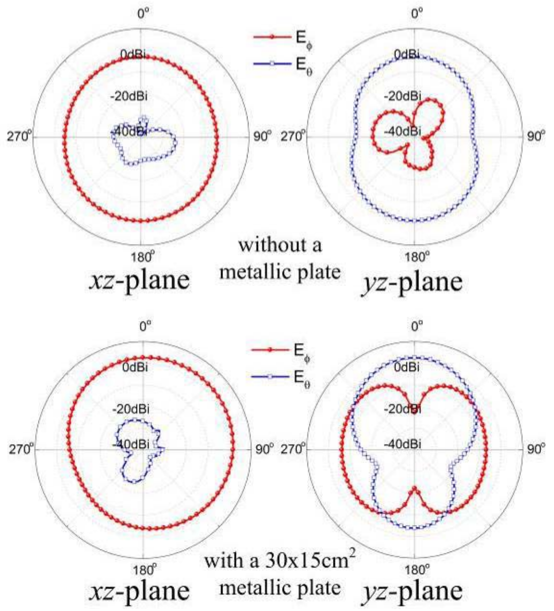
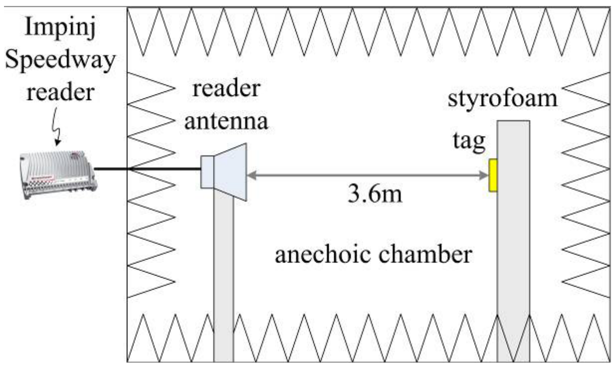
veal that the chip can be well matched with our antenna design. The power reflection coefficient (PRC) curves of the tag antenna are then calculated in Fig. 2 (c). With −10 dB PRC, the simulated and measured impedance bandwidths have been determined to be about 921–929 MHz and 915–929 MHz, which also cover the RFID UHF band. Figure 2 (d) also simulates with various coupling gaps L_5 and W_3 to investigate the performance variation of the antenna. As seen, lower resonant frequency may be obtained by employing a thinner gap, whereas a wider gap can produce higher resonant frequency. Using such tunable property, the proposed tag design can work flexibly with a metallic object.

Since this tag antenna was with a complex impedance, it was unable to be measured by an ordinary 50 Ω far-field measurement system. Simulated patterns performed by HFSS were thus suitable to study the radiation performance for the proposed tag. Fig. 3 (a) plots the simulated far-field radiation



(a)



(b)

Fig. 3. (a) Simulated radiation patterns at 925 MHz for the proposed tag with and without a $30 \times 15\,\mathrm{cm}^2$ metallic plate, (b) Experiments of the maximum reading range for the fabricated tag.

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patterns in xz and yz planes at 925 MHz for the tag with and without a metallic plate. As can be found, for the tag standing alone, nearly omnidirectional patterns in the xz plane have been obtained and patterns in the yz plane are close to bidirectional. When the tag is mounted on a metallic plate having a size of 30(L)×15(W) cm^2, its directivity at $\theta = 0°$ in the yz plane has been enhanced significantly. Besides, pattern with an upper forward direction at $\theta = 45°$ in the xz plane is mainly due to the tag placed at the bottom on the metallic plate. It causes that the peak gain of the antenna increases from −1.13 to 2.93 dBi, and the reading range can be thus enhanced as desired.

To further verify the tag performance, the experiments regarding maximum reading range for the fabricated tag were performed in an anechoic chamber, as indicated in Fig. 3 (b). A commercial RFID reader (Impinj Speedway, IPJ-R1000) with an operating frequency range about 922–928 MHz and output power of 30 dBm was employed in these tests. A transmitting horn antenna with a gain G_t was fed by the reader via a connecting cable with loss L_c. The fabricated tag, attached on a Styrofoam with or without the metallic plate, was oriented to obtain the maximum power from the reader antenna at a fixed distance d. Consequently, the maximum reading range for a given *EIRP* can be determined by the following transmission formula [2].

$$r_{\max} = d\sqrt{\frac{EIRP}{P_{\min} G_t L_c}} \tag{1}$$

where $P_{\min}$ is the minimum power regarding the tag to be identified by the reader, $d = 3.6$ m, $G_t = 5.7$ dBi and $L_c = -1.5$ dB at 925 MHz for our chamber system. Since the measured $P_{\min}$'s with and without the metal plate are 25.5 dBm and 29.5 dBm for 4W *EIRP*, the maximum reading ranges of the tag are about 7.4 m and 4.7 m, respectively. Accordingly, these measured results are better than previous designs, so the proposed slot antenna is a promising solution for metal tag applications.

4 Conclusion

A planar CPW-fed slot antenna suitable for UHF RFID metal tag applications has been presented and analyzed in this paper. It mainly utilizes a slot coupling structure to resist the effects caused by a metallic object, so that better radiation performance can be reached. Also note that the antenna can be designed with different coupling gaps to tune the resonant frequency. This makes it flexible for the proposed tag to be used with various metallic objects. Compared with other studies, the proposed tag design having a higher directivity can behave a farther reading range when placed near a metallic plate. For these reasons, the proposed metal tag with good performance is well suitable for UHF RFID operations.

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