Hindawi Publishing Corporation
International Journal of Antennas and Propagation
Volume 2013, Article ID 961042, 5 pages
http://dx.doi.org/10.1155/2013/961042

Research Article

A Compact RFID Reader Antenna for UHF Near-Field and Far-Field Operations

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Received 17 February 2013; Revised 8 July 2013; Accepted 9 July 2013

Academic Editor: Yuan Yao

A compact loop antenna is presented for mobile ultrahigh frequency (UHF) radio frequency identification (RFID) application. This antenna, printed on a 0.8 mm thick FR4 substrate with a small size of 31 mm × 31 mm, achieves good impedance bandwidth from 897 to 928 MHz, which covers USA RFID Band (902–928 MHz). The proposed loop configuration, with a split-ring resonator (SRR) coupled inside it, demonstrates strong and uniform magnetic field distribution in the near-field antenna region. Its linearly polarized radiation pattern provides available far-field gain. Finally, the reading capabilities of antenna are up to 56 mm for near-field and 1.05 m for far-field UHF RFID operations, respectively.

1. Introduction

Radio frequency identification (RFID) technology has been rapidly developed for automated identification and tracking of objects in warehouse, supply chain, industry, and commerce [1]. Currently, mobile UHF RFID technology has received much attention owing to its advantages in cost, portability, and item-level applications. Mobile UHF RFID service is defined as a compact UHF RFID reader into a mobile phone. Anyone with it can directly identify the RFID tag attached product and access mobile internet by wireless communication for searching, verifying, and managing product information [2].

The challenge of mobile UHF RFID reader is that the reader antenna must be miniaturized into the mobile phone and have both near-field and far-field operation for various objects and applications [3]. Electromagnetically far-field operation is commonly used to achieve long reading range, and typical UHF RFID reader antenna works with a pure far-field characteristic [4]. Inductively near-field operation is usually used for objects surrounded by metals or liquids [5]. Recently, a group of loop-type antennas have been considered with a pure near-field characteristic [6–13]. Few papers about UHF reader antenna for both near-field and far-field operations are presented, but they have too large size to integrate in the mobile phone: one has a dimension of $184 \times 174\ \text{mm}^2$ [14], and another smaller antenna is $72.3 \times 72.3\ \text{mm}^2$ [15].

In order to address the size constraint problem, we have designed a loop antenna with both near-field and far-field characteristics. But it has too narrow bandwidth of 13.5 MHz (915.5–929 MHz) [16]. The United States Federal Communications Commission (FCC) designates 902–928 MHz as the special frequency allocation for UHF RFID band. Most of the countries approve a part of USA band for RFID operation, for example, China band (920–925 MHz), Korea band (917–924 MHz), Australia band (918–926 MHz), and so on [17].

Therefore, we present a novel folded-dipole loop antenna with split-ring resonator (SRR) structure in this paper. An SRR element is coupled inside the folded-dipole loop and formed by a concentric metal ring with a split. The antenna prototype is fabricated and achieves a measured matching bandwidth of 31 MHz (897–928 MHz), which covers the USA RFID band (902–928 MHz). Simulation and measurement show that the proposed antenna has strong surface current distribution, uniform magnetic near-field distribution, and

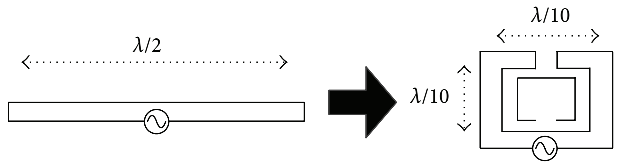


FIGURE 1: Size comparison of folded-dipole loop with SRR loading.

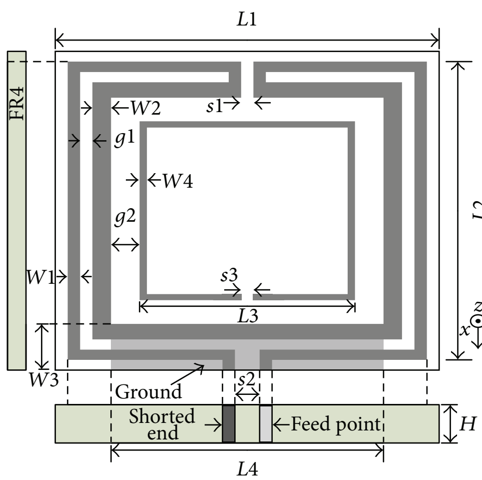


FIGURE 2: Geometry of the proposed antenna.

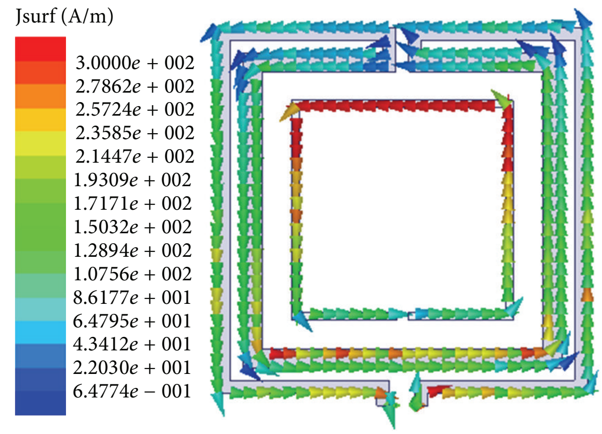


FIGURE 3: Antenna surface current distribution.

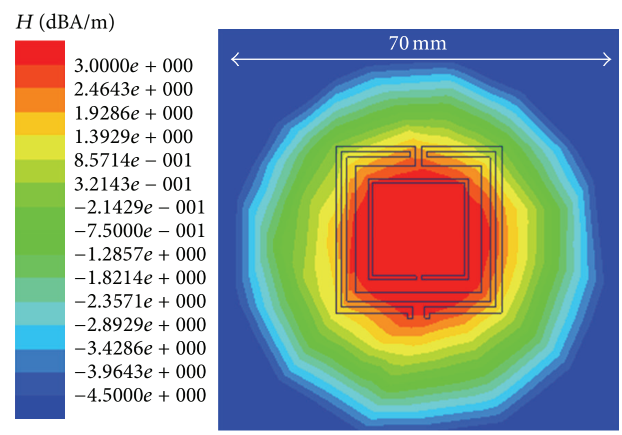


FIGURE 4: Near-field magnetic distribution (xy-plane, $z = 10$ mm).

available far-field gain. The reading capability of prototype is up to 56 mm with near-field RFID tag and up to 1.05 m with conventional far-field RFID tag.

2. Antenna Design

Loop antennas are commonly used for communication and RFID systems [18–22]. At LF and HF bands, a physically large loop is still a very small electrical fraction compared to the operating wavelength. So, the conventional RFID antenna design at LF and HF bands is to use a multiturn loop. However, it is not suggested at UHF band because the multiturn loop or spiral inductor has poor far-field gain. The other way is to use folded-dipole loop [23]. The folded-dipole loop antenna has good size reduction and exhibits better far-field gain than multiturn loop.

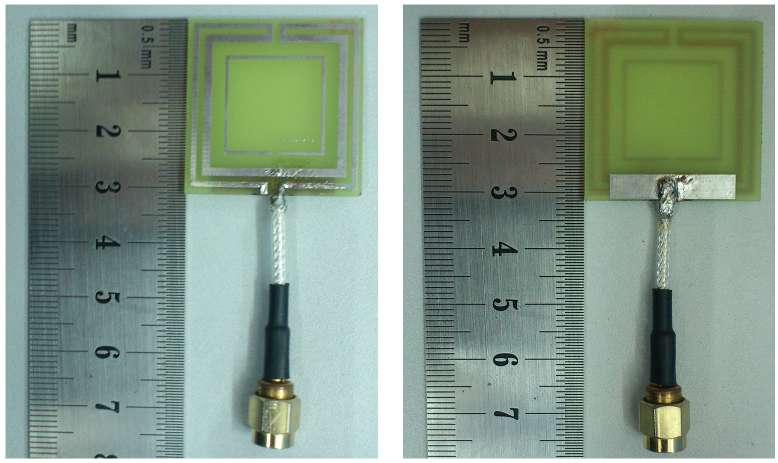
In this paper, a novel folded-dipole antenna with parasitic element is proposed, as shown in Figure 1. The bent folded dipole forms a large outer loop with a split, and a single spilt ring combines a small inner loop. The inductive loading is created by the ring, while the capacitive effect is determined by the split of the ring. Both inductive and capacitive loadings act as an LC tank circuit, which can enhance the magnetic resonance, and realize antenna size reduction. As shown in Figure 1, the total length of proposed antenna is miniaturized as the same resonance condition as the conventional folded-dipole antenna of half wavelength.

In Figure 2, the geometry of antenna was designed on an FR-4 substrate (dielectric constant $\varepsilon_r = 4.4$, loss tangent $\delta = 0.02$, and thickness $H = 1.6$ mm), and the whole antenna size is $L1$ (31 mm) $\times L1$ (31 mm). On the top view of substrate, the dimensions of folded-dipole loop are $L2 = 29$ mm, $s1 = 1.0$ mm, $s2 = 2.0$ mm, $W1 = 1.0$ mm, $W2 = 1.5$ mm, and $g1 = 1.0$ mm. The dimensions of SRR are $g2 = 3.3$ mm, $s3 = 0.9$ mm, and $W4 = 1.2$ mm. On the bottom view, the dimensions of the ground are $L3 = 22$ mm and $W3 = 4.5$ mm.

The antenna was simulated at the centre frequency of interesting band (915 MHz), by using Ansoft High Frequency Structure Simulator (HFSS) software. The simulation result of antenna surface current distribution is shown in Figure 3. It can be seen that the current remains in-phase at both the outer loop and inner SRR and the current along SRR is larger in amplitude relative to that along the outside folded-dipole loop. The in-phase current presented a uniform and strong magnetic field distribution at xy-plane and $z = 10$ mm, as shown in Figure 4. Thus, the tags with inductive coupling can be interrogated in the near-field antenna region.

3. Results and Discussion

A prototype of the proposed antenna was fabricated, as shown in Figure 5. The entire area of prototype is just 31 ×



(a) (b)

Figure 5: Photograph of antenna prototype. (a) Top view, (b) bottom view.

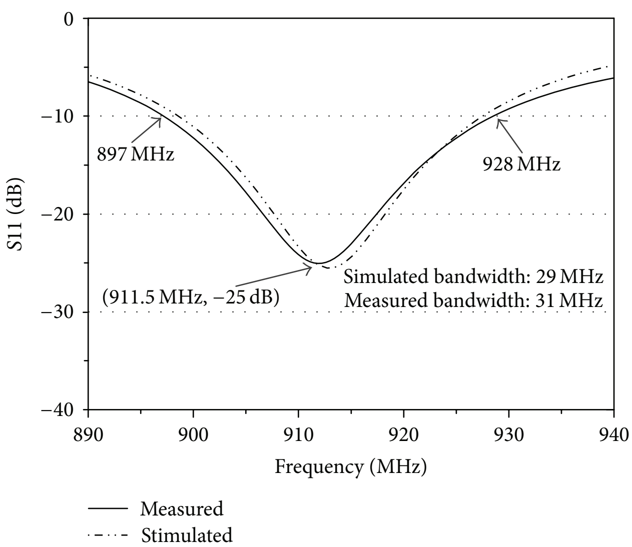


Figure 6: Reflection coefficient for proposed antenna.

Table 1: Comparison of near-field read-range.

Environment	Transmission power at 10 dBm	Transmission power at 20 dBm
Air	30 mm	48 mm
Water container	42 mm	56 mm
Paper	33 mm	36 mm
Plant surface (corn)	37 mm	38 mm
Hand skin (human)	24 mm	29 mm

31 mm^2, as a coin of one CNY. The simulated and measured matching bandwidth of the proposed antenna is shown in Figure 6. There is good agreement between simulation and measurement. The measured bandwidth of the prototype is 31 MHz (897–928 MHz), under the condition of reflection coefficient less than −10 dB. It completely covers the USA RFID band (902–928 MHz).

The schematic view of near-field reading test is presented in Figure 7(a). As shown in Figure 7(c), the proposed antenna prototype is fabricated on the test stand, and the near-field button tag, attached to polyfoam, is parallel to the surface of antenna. The read range between antenna and tag is achieved along the positive Z-axis. As shown in Figure 7(d), the Impinj UHF button of $13*10$ mm^2 dimension was taken as the reference tag, and the Impinj Technology Speedway R420 reader was used for measurement [24].

The read capability of near-field antenna includes read width and read-range. With Impinj UHF button parallel to the prototype, the maximum read width of xy-plane is 70 mm at $z = 10$ mm, as shown in Figure 7(b). It agrees well with the simulated results of magnetic field distribution in Figure 4.

Furthermore, the near-field read-range of test scene in Figure 7(a) is measured under a different transmission power and different environment. As shown in Table 1, we can see the measured results with Impinj UHF button tag attached on different objects, including air, liquids, paper, plant, and human body. The maximum read-range of near-field test can reach 56 mm with the tag attached to water container, along the positive Z-axis under the transmission power level of 20 dBm. The read-range in the other environment is similar to that in the air. This is a major advantage of the near-field RFID operation.

The simulated and measured radiation patterns of the proposed antenna are presented in Figure 8. The measured radiation patterns were obtained by the anechoic chamber. Figures 8(a) and 8(b) show the radiation patterns at 915 MHz in the two orthogonal planes (E-plane and H-plane). The far-field gain of proposed antenna achieves −2.0 dBi at the bidirectional X-axis and negative Z-axis, which shows that the proposed antenna can be acceptable for far-field RFID operation.

To examine the far-field performance, the experiment of far-field reading distance has been performed by using Impinj

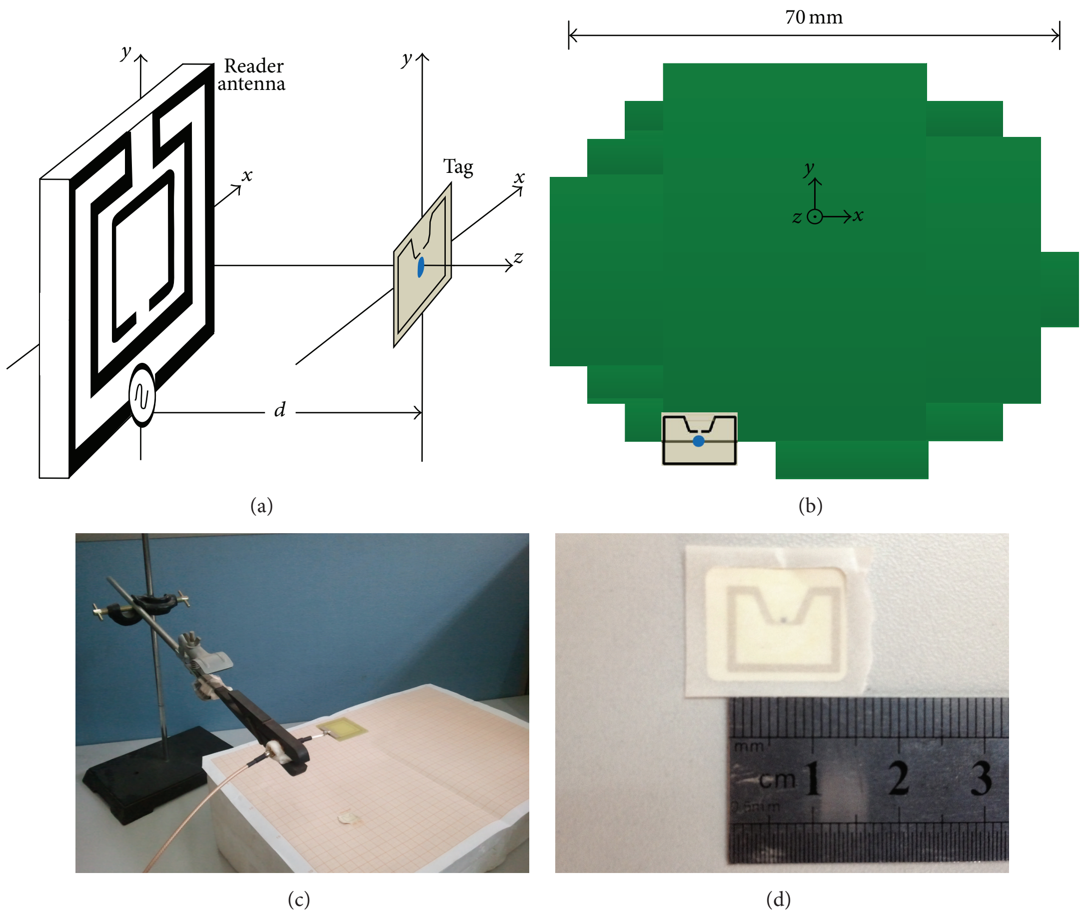
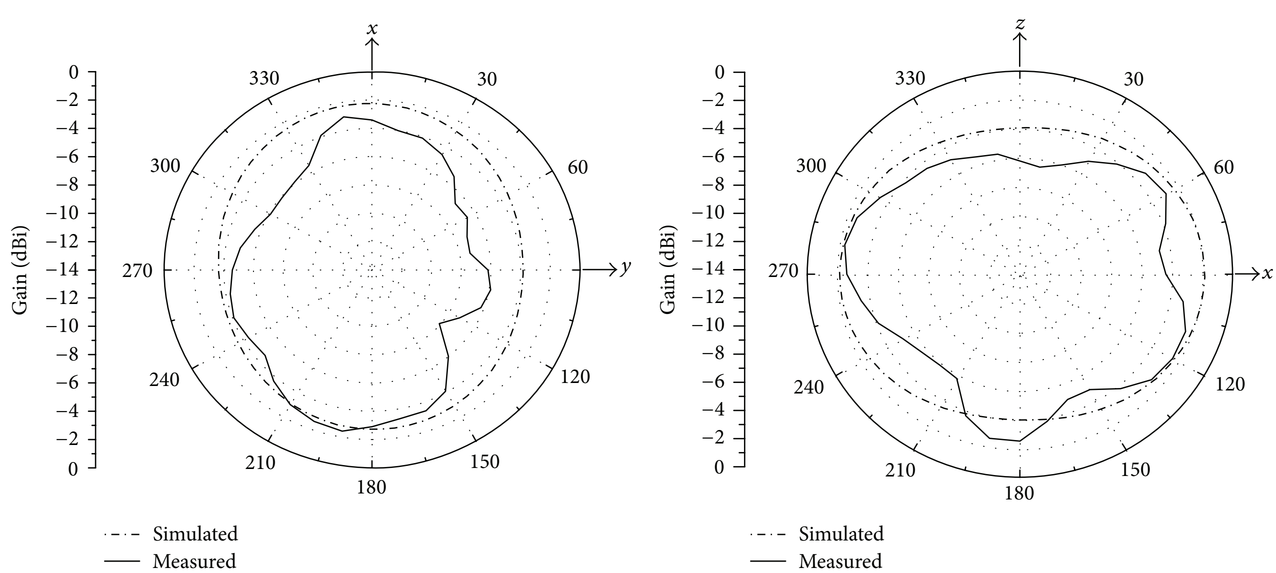


Figure 7: Near-field measurement. (a) Schematic view. (b) Read width at xy-plane and $z = 10$ mm. (c) Test scene. (d) Impinj UHF button.



(a) E-plane (xy-plane) (b) H-plane (xz-plane)

Figure 8: Simulated and measured far-field radiation patterns.

R420 reader. It is shown that the proposed antenna, with conventional dipole tag in the air, has a maximum reading distance of 1.05 m, at the transmission power level of 20 dBm (0.1 W). But the different environment seriously affects the far-field reading performance. When the tag is attached to water container or conducting plate (human body), the far-field reading distance reduces rapidly.

4. Conclusions

In this paper, a folded-dipole loop antenna with SRR has been investigated for mobile UHF RFID applications. The coupled SRR element miniaturizes this antenna to a compact size of 31 mm × 31 mm. Simulation and measurement of antenna implemented sufficient impedance bandwidth (897–928 MHz), uniform magnetic near-field distribution, and suitable far-field gain. Experiments by proposed antenna have shown good capability of both near-field and far-field tag reading. Such a compact antenna is suitable for both near-field and far-field UHF RFID operations.

Acknowledgments

This paper is supported by the National High Technology Research and Development Program (863 program) of China (2008AA04A103), Science and Technology Planning Project of Guangdong Province (2011B080701068), and National Natural Science Foundation of China (61101015 & 60971052).

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