A Miniaturized 2.45 GHz RFID Tag Antenna Using Planar Impedance Transformer

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Abstract— We proposed a miniaturized 2.45 GHz RFID tag antenna consisting of a dipole radiator and a planar impedance transformer formed on a copper foil layer cladding on 0.5 mm thick FR4 substrate. The impedance transformer comprises two inductively coupled spiral inductor to realize both resistance boosting and inductive compensation for the short dipole radiator to be conjugate-matched to the microchip. The length of the dipole radiator and the side length of the spiral inductor can be easily adjusted to tune the input resistance and inductance of the tag antenna. Finite Difference Time Domain (FDTD) 3D electromagnetic simulation method is utilized to simulate and optimize the tag antenna design. The final design occupies only an area of 33.55 mm × 8.54 mm. The omnidirectional radiation pattern, the peak gain value of −0.2 dBi and the radiation efficiency of 0.56 are also achieved, which demonstrate acceptable electrical performance for miniaturized tag design.

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1. INTRODUCTION

Passive Ultra High Frequency (UHF) Radio Frequency Identification (RFID) technology has become increasingly popular in various areas of automatic identification of objects such as access control, animal tracking, inventory management, asset identification and manufacturing industry [1, 2]. A basic passive UHF RFID system consists of a passive tag with stored information that is attached to an object and a reader that transmits commands and energy to active tag by electromagnetic wave. Communication from tag to reader is based on electromagnetic wave backscattering modulation by the data stored on tag [3]. Generally, a RFID tag consists of an Application Specific Integrated Circuit (ASIC) microchip connected to an antenna. There is no internal source of energy in a passive tag just like the meaning of “passive”. Compared with active one, passive tag is characteristic of simpler circuits, lower cost and smaller size, which enhance its usability in commercial applications of large scale. Particularly, small tag size is often strongly desired for being easily attached to an article with limited volume. A tag antenna typically has a size comparable to a wavelength of working frequency, which is generally much larger than the tag microchip’s. Therefore, an important consideration in miniaturized tag design is to adopt those antenna designs with both low profile and compact size. Some reported RFID tag antennas such as half-wavelength dipole antenna, planar inverted F-antenna [4], folded dipole antenna [5], etc., apparently can not meet the above requirements adequately. Meander Line Antenna (MLA), as an attractive choice for electrically small antennas, has been proposed and designed for RFID tag applications by means of genetic algorithms (GA) in [6]. However, since GA is kind of optimisation method based on conditional random searching, its method is inherently computationally intensive and hardly provides intuitive design information.

Another important consideration for tag design is the impedance matching between tag microchip and antenna. Under the condition of conjugate matching, the power transfer from a tag antenna to its terminated microchip is maximized and consequently the reading distance is optimized. A dipole-like small antenna has low input resistance and high input capacitance, which makes it severely mismatch with tag microchip which is generally of high input resistance and high input capacitance. However, due to high fabrication cost, it is usually prohibitive to add an external matching network with discrete elements including inductors and capacitors in tag design. Therefore, an ideal tag antenna must be capable of self-tuning to specified impedance in order to directly match with tag microchip.
In this paper, we proposed a miniaturized 2.45 GHz RFID tag antenna that consists of a dipole radiator and a planar impedance transformer formed on a copper foil layer cladding on 0.5 mm thick FR4 (\(\varepsilon_r = 4.4, \tan \delta = 0.02\)) substrate. The impedance transformer comprises two inductively coupled spiral inductor to realize both resistance boosting and inductive compensation for the short dipole radiator to be conjugate-matched to the microchip. Two dimension parameters, i.e., the length of the dipole radiator and the side length of the spiral inductor can be easily adjusted to tune the input resistance and inductance of the tag antenna. Finite Difference Time Domain (FDTD) 3D electromagnetic simulation method is utilized to simulate and optimize the tag antenna design. The final design occupies only an area of 33.55 mm × 8.54 mm. The omnidirectional radiation pattern, the peak gain value of −0.2 dBi and the radiation efficiency of 0.56 are also achieved, which demonstrate acceptable electrical performance for miniaturized tag design.

2. TAG ANTENNA STRUCTURE

The proposed miniaturized 2.45 GHz RFID tag antenna is shown in Fig. 1. It consists of a dipole radiator and a planar spiral impedance transformer which both are formed by etching the copper foil cladding on FR4 dielectric substrate (\(\varepsilon_r = 4.4, \tan \delta = 0.02\)). The copper foil is 0.035 mm thick and the substrate is 0.5 mm thick. A tag microchip can be bonded to two square pads of 0.75 mm × 0.75 mm at the centre of the spirals. The dipole radiator has a length much less than half-wavelength of 2.45 GHz in free space. Thus, it has both a low input resistance and also a high input capacitive reactance as illustrated in Fig. 2, for example, 16.1–j181.0 \(\Omega\) at 2.45 GHz. In our application, the tag microchip has an input impedance of 80.0–j232.0 \(\Omega\). In order to make the dipole radiator to be conjugate-matched to the microchip, two inductively coupled spiral inductor are designed to compose an impedance transformer to realize both resistance boosting and inductive compensation. Both the line-width \(w\) and line-space \(s\) of the two spiral inductors are 0.25 mm. The single-arm length \(dl\) and width \(dw\) of the dipole radiator are 15.4 mm and 0.75 mm, respectively. The side length \(sl\) of the outer inductor is 9.29 mm, which is always 1.5 mm bigger than its side width \(sw\). The input impedance \(Z_T = R_T + jX_T\) of the tag antenna varies while \(sw\) and \(dl\) being tuned, as is illustrated in Fig. 3. It can be observed that the resistance \(R_T\) increases while \(dl\) increases and the reactance \(X_T\) decreases while \(sw\) decreases. Thus, we can make use of these two dimension parameters to tune the input resistance and reactance of the tag antenna.

3. RESULTS

Based on the design analyses in Section 2, we used Finite Difference Time Domain (FDTD) 3D electromagnetic simulation method to simulate and optimize the tag design. When \(dl\) is tuned to 15.4 mm and \(sw\) to 7.79 mm, the tag antenna impedance takes on 80.3–j228.9 \(\Omega\), which is approximately perfectly conjugate-matched to the tag microchip. The final tag design occupies a rectangular area of 33.55 mm × 8.54 mm. The diagonal dimension of the rectangular is 34.62 mm, which is far less than half-wavelength 61.22 mm at 2.45 GHz in free space.

Figures 4(a), (b) and (c) show the simulated tag antenna radiation patterns in \(xy\)-plane, \(yz\)-plane and \(xz\)-plane, respectively. As expected, its radiation patterns are similar to those of a classic dipole antenna. In \(yz\)-plane, it demonstrates the omnidirectional properties. In both \(xy\)-plane and
Figure 3: Input impedance of the miniaturized 2.45 GHz RFID tag antenna. (a) Real part, (b) Imaginary part.

$xz$-plane, the radiation nulls can be observed in the $x$-direction. The peak gain value of $-0.2 \, \text{dBi}$ and the radiation efficiency of 0.56 are achieved, which are good enough to be acceptable for a miniaturized UHF RFID tag design. Particularly, since FR4 material has very high dielectric loss at 2.45 GHz ($\tan \delta = 0.02$), it can be expected that the radiation efficiency and the gain would be improved much if other substrate of lower loss were used.

Figure 4: Radiation patterns of the miniaturized 2.45 GHz RFID tag antenna. (a) $xy$-plane, (b) $yz$-plane, (c) $xz$-plane.

4. CONCLUSIONS

In this paper, we proposed a miniaturized 2.45 GHz RFID tag antenna that consists of a dipole radiator and a planar impedance transformer formed on copper foil cladding FR4 substrate. We have used Finite Difference Time Domain (FDTD) 3D electromagnetic simulation method to simulate and optimize the tag design. The tag antenna was tuned to be approximately perfectly conjugate-matched to the tag microchip to maximize power transfer and consequently the reading range. This tag antenna achieves the omnidirectional radiation pattern, the peak gain value of $-0.2 \, \text{dBi}$ and the radiation efficiency of 0.56. The final design occupies a small area of 33.55 mm $\times$ 8.54 mm. All these properties make this tag design a good choice in compact UHF RFID applications.

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