Design of Novel RFID Tag Antennas for Metallic Objects

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I. INTRODUCTION

Recently, radio frequency identification (RFID) in the UHF band has gained popularity in many applications, since it provides a broad readable range, fast reading speed, and large information storage capability. In RFID, tags are usually attached to various objects for which the surface materials are unknown. However, the reading performances of tags, such as readable range and reading stability, change depending on the characteristics of the surface materials that the tags are attached to. For example, if the surfaces are made of dielectric materials, then the readable range is decreased due to the frequency shift of the resonant frequency. The radiation efficiency also decreases based on the electrical property of the surface materials. Moreover, if the objects have high conductivities, as is the case for metallic objects, then this degradation of the reading performance becomes significant since the tangential electrical currents on the metal surface cancel out.

To overcome these problems, some researchers have proposed a tag antenna using a planar inverted-F structure [1, 2]. These antennas can operate well on high conductivity materials, since they already have large ground planes, as well as their antenna bodies. Nevertheless, these structures have some shortcomings, such as high cost and difficulty in fabrication because they require multiple shorting pins and a large ground plane, as well as thick dielectric substrates.

In this paper, we propose a novel tag antenna; it has a very simple structure that does not require a ground plane or shorting pins. The proposed tag antenna has significant advantages over other types of tag antennas for metallic objects, such as low cost, light weight, and ease of fabrication. The body of the antenna is printed as a single planar strip line on a thin PET substrate (polyethylene, ε_r=3.9, tanδ=0.003) and it is mounted on foam substrate (ε_r=1.0). The detail design parameters of the proposed antenna were optimized using the Pareto genetic algorithm (GA) [3] in conjunction with the IE3D EM simulator and the resulting tag antenna has readable ranges of about 2.8 m when mounted in the air and 1.8 m when mounted on a metallic surface.

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II. DESIGN METHODOLOGY AND RESULTS

The geometry of the proposed antenna is shown in Fig. 1. The conducting antenna body is printed on a 50-μm-thick PET substrate, which is in turn mounted on a 3-mm-thick foam substrate. The antenna body consists of the inner spiral dipole, outer bent dipole, and matching network. The outer bent dipole is placed on the exterior of the spiral dipole with lengths L_1 and L_2. The spiral dipole is printed a distance of G_3 from the outer bent dipole and G_4 from the double T-matching network. The spiral shape of the inner dipole performs well when the tag is placed in free space and is adopted to reduce the size of the antenna [4]. The outer bent dipole is added to the inner dipole for broaden bandwidth when the tag is in free space and for better operation when the tag is mounted on high conductivity materials. The modified double T-matching network with lengths of D_1, D_2, and D_3 is to match a commercial tag chip with a large capacitance to the antenna body. Especially, this matching network is also designed to boot up the small input resistance of the tag antenna when the tag is on high conductivity material. To determine the detailed design parameters of the antenna body and the matching network, we used the Pareto GA conjunction with the numerical EM simulator IE3D of Zeland software. The antenna is optimized to work at a frequency of around 914 MHz both for air and on metallic surfaces. The size of the antenna is 30 mm x 90 mm.

Figure 2 shows the return loss of the optimized tag antenna when it is placed on free space. The return loss is computed using the conjugate impedance of the commercial tag chip (All-9238, 9250 [6]). The measured and simulated results are plotted as dashed and solid lines, respectively, and they show fairly good agreement. The measured half power bandwidth (S_{11} < -3dB) is from 904.5 to 974 MHz, which includes the required bandwidths in Korea and Japan, and from 856.5 to 872 MHz, which includes the required bandwidth in Europe. The readable zone using the designed tag antenna with a commercial tag chip and reader were measured. This result is plotted with the simulation obtained using a radar equation on the right side of Fig. 3. The maximum broadside readable range is about 2.8 m and the measurement is very close to the simulated results. The measured readable range of the tag antenna, when the antenna is attached on low dielectric materials such as FR4 or wood, is over 1.5 m.

Figure 4 shows the return loss of the tag antenna on metallic surfaces. The measured half power bandwidth is 7.5 MHz, from 909 to 916.5 MHz, and it agrees well with the simulation. The readable zone with the metallic surface is represented on the left side of Fig. 3. The simulation and measurement results disagree slightly because the simulation is calculated using an infinite conducting plate as the metallic surface, while a finite one is used for the measurement. The proposed tag antenna has a 1.8 m broadside readable range, while that of a dipole-type commercial tag antenna is 0.5 m under the same measurement conditions (3 mm gap from metallic surface). This result verifies that the proposed antenna operates well on metallic objects, as well as in free space.

Figures 5(a) and 5(b) show the distribution of electric currents at 870 MHz and 970 MHz, respectively, when the tag is in air. At 870 MHz, the electric currents are flowing through the inner spiral dipole as well as the outer bent dipole, but at 970 MHz, the currents are dominantly flowing on the outer bent dipole. These two resonances are closely spaced in frequency and this results the broad bandwidth operation of this tag antenna when it is in air. Figure 6 represents the electric currents when the tag is on a metallic surface. The electric currents strongly flow on the outer dipole since the resonance of the outer dipole shifts down by the extra capacitance between the antenna body and metallic surfaces. The double T-matching network was also designed for matching this changed antenna impedance to the tag chip. Therefore, the proposed tag antenna radiates well on various surface materials, including conducting objects.

III. CONCLUSION

In this paper, we proposed a novel RFID tag antenna for attaching to metallic objects. The proposed tag antenna has a simple-structure, light-weight, and low-cost, since it does not require a ground plate or shorting pins and is printed on a cheap substrate. For detail design parameters, we used the Pareto GA with a full-wave EM simulator to obtain a tag antenna that can work in the air as well as on a metallic object. The resulting tag antenna has measured half power bandwidths of 15.5 MHz, from 856.5 to 872 MHz, and 69.5 MHz, from 904.5 to 974 MHz, when it is placed in free-space. In addition, it has a 7.5 MHz bandwidth from 909 to 916.5 MHz when placed on a metallic object. The maximum readable range in air is about 2.8 m and it is over 1.5 m on a low dielectric material. When the tag is placed on a metallic object, it has a readable range of about 1.8 m**.** To explain the operating principle of the proposed tag antenna, we plotted the electric currents when the antenna is placed in air and on a metallic object.

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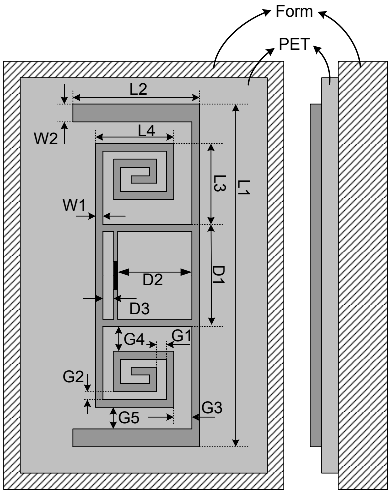


Fig. 1. Configuration of the proposed antenna.

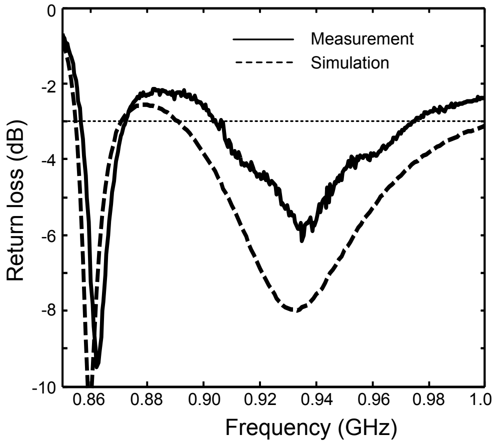


Fig. 2. The return loss of the antenna in air.

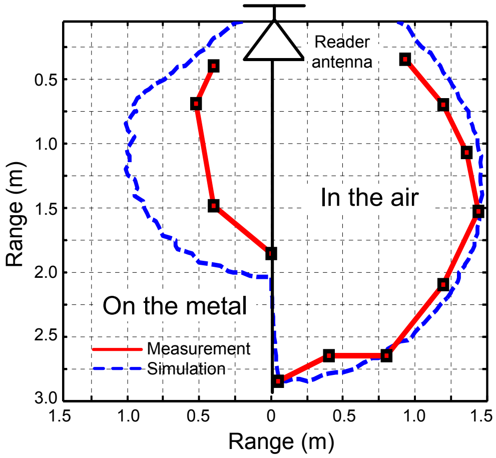


Fig. 3. The readable zone.

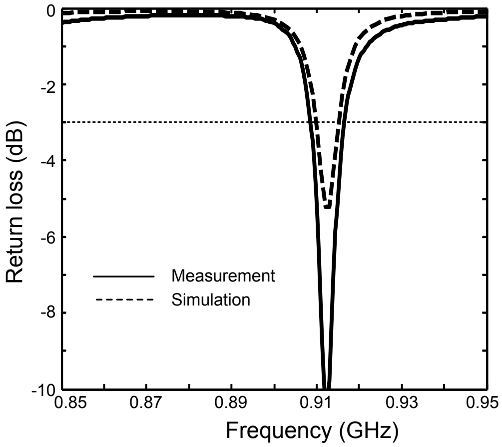
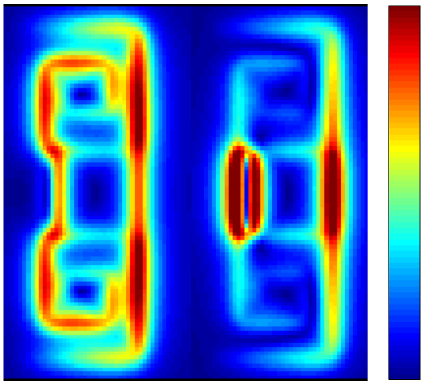


Fig. 4. The return loss on a metallic object.



(a) (b)

Fig. 5. Electric current when the tag is in the air: (a) 870 MHz, (b) 970 MHz.

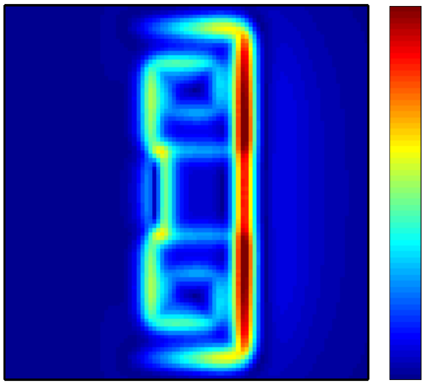


Fig. 6. Electric current at 914 MHz when the tag is on a metallic object.