Design of planar RFID tag antenna for metallic objects

C. Cho, H. Choo and I. Park

Proposed is a novel RFID tag antenna consisting of an inner spiral dipole, an outer bent dipole and a double T-matching network that is suitable for attaching to metallic objects. For low-cost fabrication, the antenna is printed on a single-layer substrate without a ground plane or shorting pins. The detailed design parameters of the antenna were optimised using the Pareto genetic algorithm so that the antenna would operate adequately both in free space and on metallic objects. The antenna was fabricated, based on the optimised design, and the performance in free space and on a metallic surface were measured. The half-power matching bandwidth (VSWR < 5.8) and the reading range of the antenna in free space were 7.6% and 2.8 m, while on a metallic surface the corresponding values were 0.8% and 1.8 m. For non-metallic surfaces (i.e. low dielectric targets, $2 < \varepsilon_r < 4$), the antenna exhibited the reading range of 2–3 m.

Introduction: Radio frequency identification (RFID) in the UHF band is gaining popularity in many applications since it provides a long reading range, fast reading speed and large information storage capability. In RFID applications, tags are usually attached to objects, the surface material of which is not known in advance in many instances. It is well-known that surface material characteristics strongly affect the reading range and reading stability. In particular, the maximum reading range is drastically reduced owing to the impedance mismatch between the antenna and the tag chip when the tag is close to a surface material with high conductivity. The mismatch is mainly attributed to the parasitic capacitance between the antenna and the metallic surface, which results in large variation in the antenna's input reactance.

Some studies have proposed tag antennas using a planar inverted-F structure for metallic objects [1, 2]. These antennas operate well on high-conductivity materials, since they already include large-area ground planes as part of the antenna body. These structures, however, have certain shortcomings, such as high cost and difficulty of fabrication, because they require shorting pins and a large ground plane.

In this Letter, we propose a simple low-cost planar tag antenna that reduces the influence of a metallic object by incorporating two different antenna structures; wherein the reactances of the two structures change in opposite directions in the presence of high-conductivity surface materials. The half-power matching bandwidth (VSWR < 5.8) of the antenna in free space was measured to be in the frequency range 856.5–872 and 904.5–974 MHz. On a metallic surface, the bandwidth is in the range 909–916.5 MHz. The measured reading ranges in free space and on a metallic surface are 2.8 and 1.8 m, respectively. The antenna exhibits a 2–3 m reading range when attached to low dielectric targets ($2 < \varepsilon_r < 4$).

Antenna structure and characteristics: Generally, a tag antenna using a dipole structure has a large variation in input reactance, especially near materials with high conductivity. The resulting change in input impedance leads to a large impedance mismatch between the antenna and the tag chip. In this Letter, we propose a novel structure based on the combination of two different types of dipoles to suppress the variation in the antenna's reactance.

Fig. 1 shows the proposed antenna printed on a low-cost PET substrate (ε_r: 3.9, $\tan\delta$: 0.003) that is 50 µm thick. A 3 mm-thick foam substrate ($\varepsilon_r \cong 1.0$) on the back of the PET substrate mitigates the reduction in antenna efficiency when the tag is attached to a metallic object. The printed tag antenna consists of an outer bent dipole (L_1 and L_2), an inner spiral dipole (L_3, L_4 and L_5) and a double T-matching network (D_1, D_2 and D_3). In free space, the two dipoles exhibit double resonances near the operating frequency, resulting in broadband impedance matching. When the tag is attached to high-conductivity materials, the reactance of the two dipole antennas is modified in an opposite manner; the inner dipole becomes capacitive and the outer dipole becomes inductive. Thus, the total impedance at the input terminal of the proposed antenna changes very little in the presence of the conductor and maintains input reactance similar to the free space value. Consequently the reading range does not decrease drastically when the tag is used near high-conductivity materials. The double T-matching network is used for conjugate matching between the dipoles and the commercial tag chip, wherein the input reactance of the latter is typically highly capacitive.

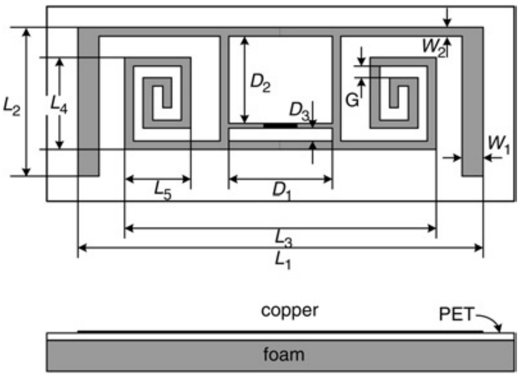

Fig. 1 *Proposed RFID tag antenna structure*

To optimise the design parameters for the proposed antenna, we applied the Pareto genetic algorithm [3] in conjunction with the IE3D EM simulator (Zeland software). The optimisation process yielded the following design parameters: $L_1 = 83.4$ mm, $L_2 = 29.9$ mm, $L_3 = 64.2$ mm, $L_4 = 17.8$ mm, $L_5 = 13.1$ mm, $D_1 = 19.6$ mm, $D_2 = 19.1$ mm, $D_3 = 2.4$ mm, $G_1 = 3.3$ mm, $W_1 = 3$ mm and $W_2 = 0.9$ mm. Fig. 2 shows the VSWR of the proposed antenna in free space as well as on a metallic object (copper plate of 150 mm^2, $\sigma = 5.8 \times 10^7$). The VSWR was obtained by calculating the mismatch between the antenna impedance and the impedance of a commonly-used commercial tag chip (All-9338 [4]). In free space, the measured and simulated results are plotted as dotted and dash-dotted lines, respectively, which exhibit fairly good agreement. The measured half-power matching bandwidth (VSWR < 5.8) spans the frequency range of 904.5–974 and 856.6–872 MHz, which include the bandwidths designated for RFID usage in Korea, Japan, North America and Europe. The radiation antenna efficiency measured using the Wheeler cap method [5] is greater than 75% in the operating frequency bands. The measured maximum reading range of the tag antenna using a commercial reader system [4] is about 2.8 m compared to the value of 3 m for the commercial dipole-type tag under the same circumstances.

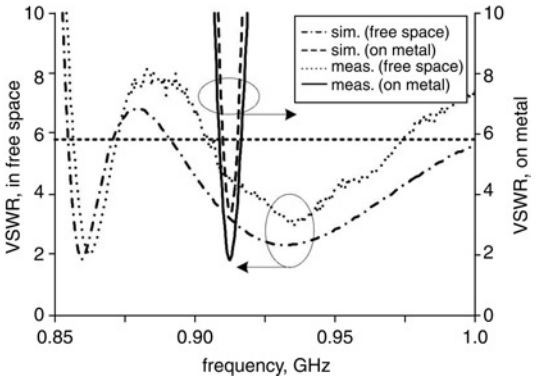

Fig. 2 *VSWR of proposed antenna*

The measured and simulated VSWR of the tag antenna when the tag is placed on a copper plate are represented as the solid and the dashed lines, respectively, and they show a good agreement. The measured half-power matching bandwidth is about 7.5 MHz in the range 909–916.5 MHz, and the measured radiation efficiency is greater than 20%. The measured reading range for our antenna is about 1.8 m compared to 0.5 m for the commercial dipole tag backed by the same thick foam. The antenna provides a 2–3 m reading range when it is attached to low-dielectric-constant targets ($2 < \varepsilon_r < 4$) such as FR-4 printed circuit board material and wood.

Operating principle of proposed antenna: To explain the operating principle of the proposed tag antenna, we developed a circuit model for the antenna as shown in the inset of Fig. 3. Both the outer and the inner dipoles are represented as series RLC circuits (R_o, L_o, C_o, R_i, L_i, C_i), and the double T-matching network is modelled as four inductors (L_{T1}, L_{T2}, L_{T3}, L_{T4}). The values of the lumped elements of the antenna are then found by trial-and-error: $L_{T1} = 10$ nH, $L_{T2} = 43.5$ nH, $L_{T3} = 13.5$ nH, $L_{T4} = 20.5$ nH, $R_i = 350\ \Omega$, $L_i = 3.6$ µH,

$C_i = 9.4$ fF, $R_o = 350\ \Omega$, $L_o = 400$ nH, and $C_o = 53.5$ fF. In Fig. 3, the impedance of the circuit model and the measured impedance in free space are represented with solid and dashed lines, respectively. The circuit model result agrees closely with the measured values.

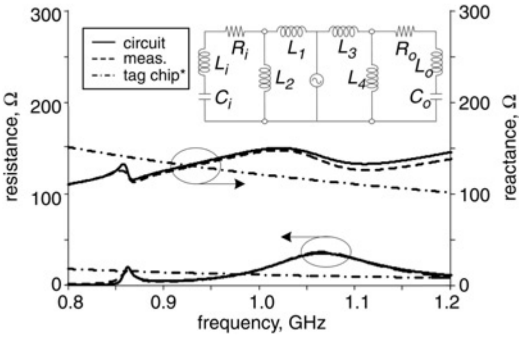

Fig. 3 *Equivalent circuit model and input impedance*

If the proposed tag is placed on a metallic surface, the inductance of the inner dipole decreases from $L_i = 3.6$ μH to $L_i = 0.22$ μH, while the outer dipole increases from $L_o = 400$ nH to $L_o = 510$ nH. Despite these changes, however, the antenna's input reactance more or less maintains the free space value. To investigate this point more clearly, we examined the near-field distribution of the antenna's magnetic field (H_x) by measuring it along direction of the dashed line as shown in the inset of Fig. 4. The magnetic fields are depicted with a solid line for the tag in free space, and with a dashed line for the case of the tag placed on the metallic surface. As expected, the magnetic field near the inner dipole (left side of Fig. 4) decreased, whereas the magnetic field in the vicinity of the outer dipole (right side of Fig. 4) increased. Since the reactances of the two dipoles change in opposite directions, the variation in the input impedance is drastically suppressed even when the antenna is positioned near surface materials with a high conductivity.

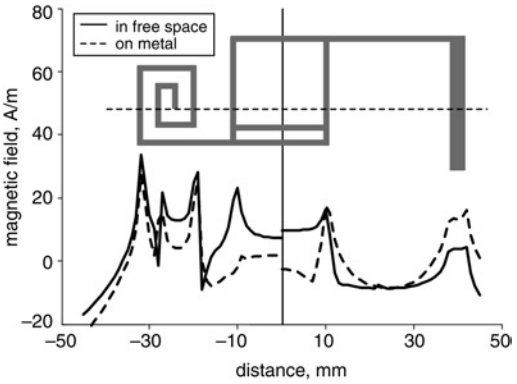

Fig. 4 *Near-field distribution of magnetic field of dipoles*

Conclusion: We propose a simple low-cost RFID tag antenna suitable for mounting on metallic objects. For low-cost fabrication, the antenna is printed on a thin PET substrate placed on top of a 3 mm-thick foam substrate with no shorting pins or ground plane. By adopting two different dipole structures with a double T-matching network, the proposed antenna achieves broad matching bandwidth in free space and effectively suppresses the influence of nearby metallic objects on the antenna's reactance. The measured reading ranges in free space and on a metallic surface were 2.8 and 1.8 m, respectively. For non-metallic surfaces (i.e. for low-dielectric-constant targets, $2 < \varepsilon_r < 4$), the antenna shows a reading range of about 2 to 3 m.

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