Broadband RFID tag antenna with quasi-isotropic radiation pattern

C. Cho, H. Choo and I. Park

A passive RFID tag antenna in the UHF band using two bent dipoles and a modified double T-matching network is proposed. The antenna was fabricated with a thin copper layer printed on a 50 µm-thick PET substrate for low-cost production. The proposed antenna provided a quasi-isotropic radiation pattern and a fairly broad bandwidth $S_{11} < -10$ dB, 8.5%) for conjugate-matching with a commercial tag chip. The efficiency of the antenna was about 90% in the operating frequency band. The measured readable range was between 170 –240 cm for an arbitrary rotation angle of the tag.

Introduction: Radio frequency identification (RFID) is an emerging technology for the identification of target objects and is regarded as one of most important methods for the realisation of ubiquitous computing networks. To maximise the system performance and comply with the ISO-8000 regulations, RFID requires a tag antenna that can provide adequate readability with restricted system power. One of the challenges of the tag antenna design is that the readable range of the tag should not vary significantly with changes in the rotation angle so that consistent readability is achieved. This requires the tag to have a radiation pattern close to an isotropic pattern. A small and planar profile is also very desirable to allow for easy attachment to an object. Additionally, high radiation efficiency is needed to extend the readable range with restricted system power. The antenna must also have a broad bandwidth to compensate for the frequency shift due to the presence of unknown dielectric materials nearby the tag.

In this Letter, a novel structure is proposed for a tag antenna consisting of two closely spaced bent dipoles for a quasi-isotropic radiation pattern and a double T-matching network for broadband matching with a capacitively loaded tag chip. The proposed antenna had a measured bandwidth from 848 to 926 MHz ($S_{11} < -10$ dB, 8.5%) for conjugate-matching with a commercial tag chip and an efficiency of about 90% within the frequency range of operation. Additionally, the proposed antenna exhibited a quasi-isotropic radiation pattern of which the gain deviation for an arbitrary angle is less than 6 dB from 880 to 960 MHz. The measured maximum readable range was between 170 and 240 cm for an arbitrary rotation angle of the tag.

Antenna structure and characteristics: Fig. 1 shows the structure of the proposed tag antenna. The thin copper layer of the tag antenna is printed on a PET substrate ($\varepsilon_r = 3.9$ tan $\delta = 0.003$) with a thickness of 50 µm. This metallic layer is composed of two bent dipoles with a double T-matching network. A bent dipole with lengths of L_3 and L_4 was placed inside of another bent dipole with lengths L_1 and L_2. The bent sections of the dipole strips, L_1 and L_3, were closely spaced with a distance D. A numerical simulation found that the phase of the current at the bent section, L_1, of one dipole is about 180° out of phase from the bent section, L_3, of the other dipole. Therefore, at the end of each bent section of the dipoles, strong electric fields occurred from one to the other and a magnetic current was produced between the two bent sections flowing in the y-direction. This strong magnetic current, along with the dominant electric current flowing on the L_2 section, compensates the radiation nulls of each other and provides a quasi-isotropic radiation pattern. Generally, the input impedance of a commercial passive tag chip has a large capacitive component owing to the rectifying DC circuit; therefore, the input impedance of the tag antenna should be matched with the conjugate input impedance of the tag chip for maximum power transmission [1]. The double T-matching network with distances of M_1, M_2 and M_3 boosts the inductance of each dipole [2] to match with the tag chip and it also broadens the bandwidth through a high-order tuning effect.

To determine detailed design parameters for the given structure, a Pareto genetic algorithm (GA) was used in conjunction with the numerical EM simulator IE3D of Zealand software. The tag antenna was optimised to work at the frequency of 914 MHz, and the three design goals considered were: a small and planar profile, a high EB (efficiency and bandwidth product), and a quasi-isotropic radiation pattern. After a convergence of the Pareto GA process, optimised design parameters were found with the following dimensions: $L_1 = 53.1$ mm, $L_2 = 79.2$ mm, $L_3 = 37$ mm, $L_4 = 57.8$ mm, $W_1 = 0.5$ mm, $W_2 = 4$ mm, $W_3 = 12.5$ mm, $W_4 = 4$ mm, $M_1 = 5.8$ mm, $M_2 = 18.6$ mm, $M_3 = 30.7$ mm, $W_{M1} = 1$ mm, $W_{M2} = 1.5$ mm and $D = 10.2$ mm. Fig. 2 shows the simulated and measured return loss of the optimised design when the antenna is conjugate-matched with the commercial tag chip (ALL-9238, 9250 [3]). The measured bandwidth is 8.5% ($S_{11} < -10$ dB) from 848 to 926 MHz, a 78 MHz bandwidth. This agreed well with the simulation bandwidth of 65 MHz found using IE3D. This encompasses almost the entire bandwidth for worldwide RFID in the UHF band.

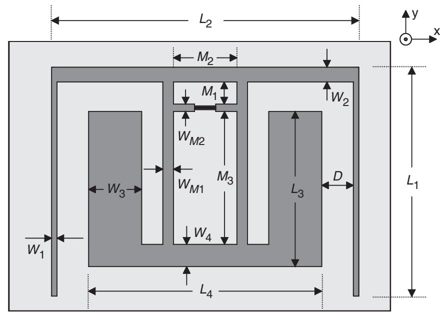

Fig. 1 *Proposed passive RFID tag antenna structure*

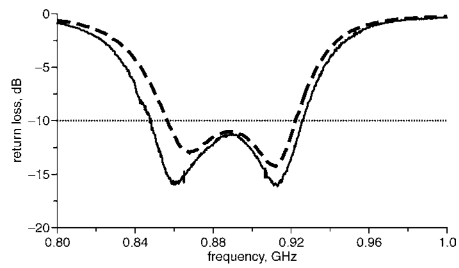

Fig. 2 *Frequency against measured and simulated return loss*

– – – – simulation
——— measurement

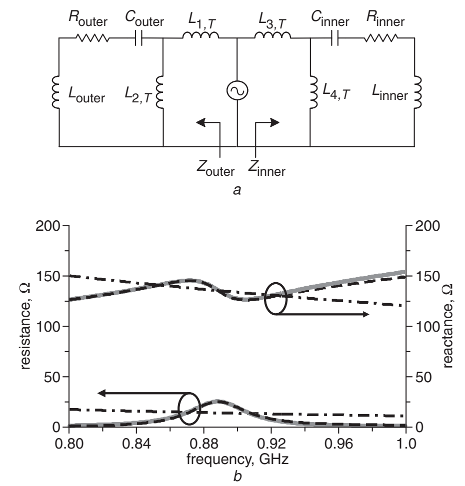

Fig. 3 *Equivalent circuit model and input impedance*

a Equivalent circuit model
b Input impedance
– – – – circuit model
——— measurement
- · - · - · tag chip*

To explain the operating principle of the reactive matching of the tag antenna, the input impedance characteristic of the antenna was modelled using a lumped elements circuit, shown in Fig. 3*a*. The $L_{1,T}$, $L_{2,T}$, $L_{3,T}$ and $L_{4,T}$ represent the inductances in the double T-matching network, while R_{outer}, L_{outer}, C_{outer}, R_{inner}, L_{inner} and C_{inner} are the modelled lumped elements for the impedance of the two bent dipoles. To obtain the lumped element values, each part of the antenna was simulated separately using the IE3D simulator and the data were fitted to the circuit model to arrive at each element value. The simulated impedance using the circuit model and the measured impedance are shown in Fig. 3*b*. The result using the circuit model matches fairly well with the measured result. The conjugate impedance of a commercial tag chip is also shown in Fig. 3*b*. The resistance of the tag antenna has a similar value to the tag chip in the frequency range of 871 to 909 MHz. The reactance caused by the double T-matching network is able to efficiently cancel out the capacitance of the tag chip. Additionally, the reactance of the antenna crosses the conjugate impedance of the tag chip in the operating frequency band at values of 854, 889 and 925 MHz. This high-order tuning effect of a double T-matching network serves to broaden the matching bandwidth of the proposed tag antenna.

The readable range is proportional to the square root of the antenna gains [4]. To maintain a deviation of the maximum readable range of less than 1/2 for an arbitrary rotation of the tag antenna, the tag antenna should be designed to have a total gain deviation of less than 6 dB. Fig. 4 represents the measured and simulated gain deviation of the tag antenna for arbitrary rotation angles in terms of frequency. Both the measured and simulated results showed less than a 6 dB gain deviation from 880 to 940 MHz. Fig. 4 also shows the measured efficiency using the Wheeler cap and the simulated efficiency with IE3D, respectively. The measured efficiency was above 90% for the entire frequency range of operation. The maximum readable range of the tag was measured using a commercial RFID system (BHNPR001 [3]). The measured readable range of the tag antenna was 170–240 cm for any rotation angle of the tag. This confirms that the proposed antenna offers very consistent readability.

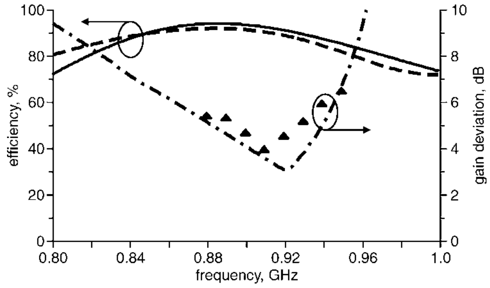

Fig. 4 *Frequency against the efficiency and gain deviation*

– – – – efficiency simulation
——— efficiency measurement
- · - · - simulation gain deviation
▲ ▲ ▲ measurement gain deviation

Conclusion: A passive RFID tag antenna in UHF band is proposed. The antenna is composed of two bent dipoles and a modified double T-matching network. The measured conjugate-matching bandwidth with a commercial tag chip is 8.5% and the efficiency is about 90% in the operating frequency band. The gain deviation is under 6 dB from 880 to 940 MHz and the readable range is 170–240 cm for an arbitrary rotation of the tag.

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