Combined RFID Tag Antenna for Recipients Containing Liquids

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In UHF RFID (radio frequency identification), passive tag antennas can be fixed on boxes or recipients where the nature and contents might vary. These variations strongly affect the antenna performance. A combined antenna is proposed to ensure an effective read-range for a plastic recipient containing water or not. Two separate antennas are first designed for the filled and unfilled cases, respectively, then combined for a correct working in both configurations.

Introduction: The close environment of UHF RFID tags, i.e. the medium on which the inlay is fixed (plastic, metal, cardboard) and its contents (liquids, highly dielectric, metallised,…), degrades the radiation pattern, the antenna matching to the integrated circuit and the overall tag efficiency. This, added to the obstructions and multipath effects in indoor environments, can dramatically reduce the read-range between the reader and the tag.

In this Letter, the objective is to design a tag antenna attached to a plastic recipient that may be empty or filled with a liquid. The originality of the structure relies on a small-loop based module which is used to excite two dipole antennas through inductive coupling. Each antenna is designed to work either for the filled or unfilled case at 868 MHz (UHF band).

Module description: The MuTRAK640 module manufactured by Tagsys [1] is essentially the series connection of a small loop antenna with a UHF RFID chip, the Impinj Monza 4 [2]. The measured chip read sensitivity and input impedance are −14.7 dBm and 1100Ω// 2.11pF, respectively [3]. Let $Z_c = R_c + jX_c$ be the series equivalent impedance of the chip load ($Z_c = 6.8\Omega$ –j86 Ω at 868 MHz). The circuit is encapsulated in a rectangular housing made of FR4 epoxy. A key point is that the small loop dimensions yield a radiation resistance smaller than 1Ω. Therefore, the loop only allows short-range reading distances (few centimetres) restricted to the reactive near-field region.

A useful feature of the module is that it can be used as a primary excitation for larger tag antennas. The idea is that a small device basically developed for short reading distances because of its low radiation resistance also performs well at distances up to 10 m when coupled to a dipole-like antenna. Typically, the magnetic field normal to the loop surface turns around the dipole located at a close proximity of the module and generates a current in the dipole. The dipole boosts the module radiation by increasing its radiation efficiency.

Inductive coupling and antenna matching: The excitation of a dipole by an inductively-coupled loop yields the following impedance seen from the chip terminals [4]:

$$Z_{\text{antenna}} = Z_{\text{loop}} + \frac{(M\omega)^2}{Z_{\text{dipole}}} \qquad (1)$$

The above expression includes the mutual coupling factor M caused by the proximity between the dipole and the small loop, and the dipole impedance Z_{dipole} besides the loop impedance Z_{loop}. From (1), it can be observed that the series resonance of a half-wavelength dipole is transformed into a parallel resonance at the loop terminals. Equation (2) gives the power wave reflection coefficient of the antenna normalised to the antenna resistance [5]:

$$\Gamma = \frac{Z_c - Z^*_{\text{antenna}}}{Z_c + Z_{\text{antenna}}} \qquad (2)$$

Antenna design: The maximum power transfer between the antenna and the chip will occur for $Z_{antenna} = Z_c{}^*$. Apart from the compensation of the chip capacitance by the antenna inductance, it is also necessary to keep a low antenna resistance. A dipole with spiral inductors at its ends is coupled to the encapsulated circuit MuTRAK as shown in Fig. 1. Spiral dipoles are compact and more efficient than zig-zag or meandered dipoles as large gaps between the parallel segments are introduced. The dipole was made of a thin copper wire which is fixed on a piece of paper to keep the antenna shape and rigidity. The dimensions of the dipole are given in Fig. 1. The distance between the module edge and segment L1 is 2mm.

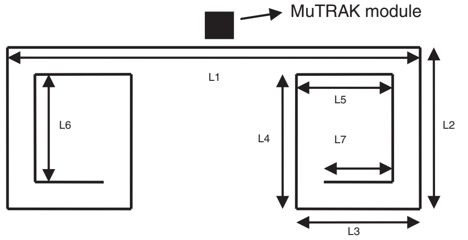

Fig. 1 *Spiral dipole coupled to MuTRAK module (loop + chip)*

Initial dimensions spiral dipole working in free-space: L1 = 40mm, L2 = 20mm, L3 = 13.5mm, L4 = 16.5mm, L5 = 10mm, L6 = 13.5mm, L7 = 3.5mm, wire radius = 0.15mm. Total length: 181 mm

The loop-coupled spiral dipole antenna is designed to resonate at 868 MHz. All simulations are performed with the 4NEC2 code based on the method of moments. The simulated impedance is $Z_{antenna} = (5.1 + j62)\ \Omega$ for the required frequency (Fig. 2). The estimated gain is 0dBi. Coupling the dipole to the module introduces a parallel resonant at the chip terminals at 868 MHz as observed in Fig. 2. As a result, the antenna impedance shows a higher radiation resistance and a flatter reactance around 868 GHz compared to the loop impedance. However, the reactance mean value is essentially the loop reactance which is too low at 868 MHz to exactly compensate for the −86Ω reactance of the chip. Therefore, even though the comparable antenna and chip resistances result in a Γ minimum, the total reactance (approximately −24Ω) is large compared to the total resistance (approximately 12Ω) which leads to Γ = 0.89. It means that the read-range which would be obtained for a perfect match is divided by $1/\sqrt{1-|\Gamma|^2} \simeq 2.2$. This mismatch is inherent to the module resonance centred at 915 MHz, not to the design procedure. The following tag resonance is due to the cancellation of the total reactance and occurs above 1000 MHz, i.e. much higher than the module resonance as the dipole coupling reduces the reactance of the isolated loop.

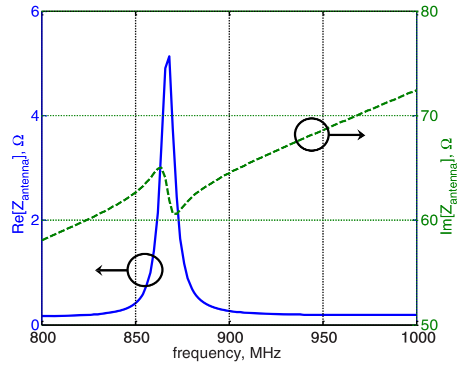

Fig. 2 *Impedance of loop-coupled spiral dipole*

Measurements of initial tag: Measurements of the dipole resonant frequency are performed with the King's shielded loop [6] used as a near-field sensor in the vicinity of the dipole. This particular probe avoids external sheet currents on the measurement cable. The dipole resonance is observed on a vector network analyser at the King's loop terminals. The dipole length is adjusted to resonate at 868 MHz, yielding the dimensions given in Fig. 1. Then, the MuTRAK module is implemented and read-range measurements are performed with the help of the Voyantic Tagformance Measurement System [7]. The tag read-range measured in the 800–900 MHz band (Fig. 3) shows a maximum of 3.8 m at 868 MHz. This is in agreement with the estimated read-range using the modified Friis formulation given in [5].

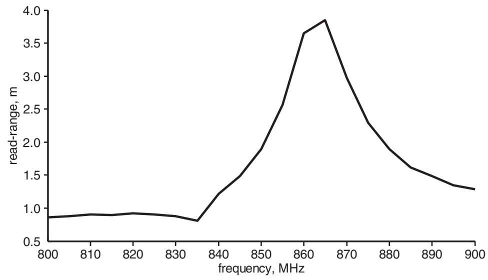

Fig. 3 *Read-range measurements with Voyantic setup*

Measurements with empty and filled plastic recipient: The spiral antenna described previously is placed on an empty plastic-polypropylene ($\varepsilon_r = 4$) recipient which has a size of 23 × 15.5 × 14.5 cm. Due to the plastic wall, a 60 MHz negative shift of the resonant frequency is measured. To adjust the resonance frequency the wire length is reduced, by gradually and symmetrically shortening the wire until the correct resonant frequency is obtained. A total length of 11.5 mm is finally removed from the dimensions given in Fig. 1 (L7 = 0, L6′ = 5.5mm). The maximum read-range drops to 3.7 m.

Once the recipient is filled with fresh water ($\varepsilon_r = 80$, $\sigma = 0.1$ S/m), tag detection is not possible even at a few centimetres from the reader. Using the King's shielded loop, a 550 MHz negative frequency shift of the dipole resonance is first determined. An additional 19 mm length reduction is necessary to resonate at 868 MHz (L7, L6 and L5 equal to zero and L4′ = 13mm). In the presence of water, the maximum read-range is 34 cm.

Combined antenna: The final tag combines both proposed antennas and the MuTRAK module as shown in Fig. 4. As the dipole resonant lengths are very different, no direct coupling between the dipoles is observed and each dipole behaves as if it were alone. Dipole 1 and dipole 2 resonate with the empty and filled recipient, respectively. Without water, the maximum read-range remains around 3.7 m. In presence of water, the read-range is reduced to 31 cm, i.e. 3cm shorter than for the single dipole. In any case, this is a strong improvement compared to the single antenna designed for the empty recipient where no detection is observed for any distance.

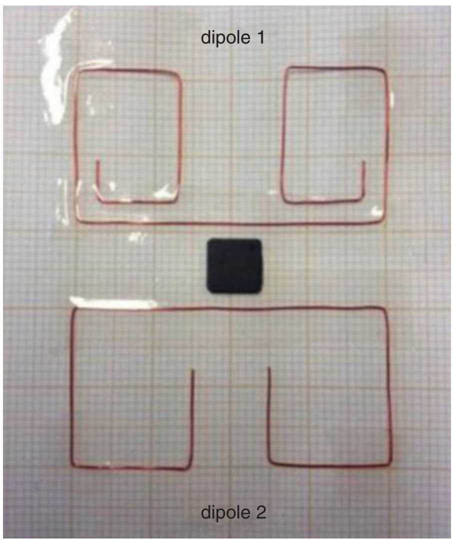

Fig. 4 *Combined antenna structure*

Conclusion: A combined antenna was designed in order to ensure the tag functionality when the tag is attached to recipients that may contain water or not. The proposed model enhances the read-range in the presence of water while keeping the performance in the empty case. The concept can be applied to other liquids or recipient materials as long as only two states (filled or unfilled) are considered. The tag read-range should be doubled with the new commercialised MuTRAK650 version of the module, based on a 3dB more sensitive chip (Monza 5) and optimised loop dimensions.

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One or more of the Figures in this Letter are available in colour online.

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