Inkjet-printed UHF RFID Folded Dipole Antennas for Remote Sensing Applications

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***Abstract*—This paper presents an inkjet-printed tag antenna for RFID sensing applications. The antenna is designed to operate at the ultra high frequency (UHF) industrial, scientific, and medical (ISM) band and can be used for sensing applications where the parameter under sense can cause a shift in the antenna resonance frequency, which can be detected by the reader. The tag power-on threshold quantity, which is essential for associating the reader indication with the parameter under sense change, is predicted by exploiting simulation results and is verified experimentally with the implemented IC-loaded antenna.**

***Index Terms*—RFID, sensing, inkjet printed, antennas.**

I. Introduction

RFID technology is increasingly utilized for sensing applications that require low-cost and low-complexity sensors. Examples include environmental monitoring, biomedical applications, and others. Several RFID sensors have been introduced, whose operation principle is based on changing the antenna resonance frequency when a change at the sensed quantity occurs [1], [2]. This sensing scheme keeps the overall system design simple and is convenient for passive (i.e. batteryless) RFID tags. Passive RFIDs are needed, when the required computational ability is limited and thus, no complex sensor circuitry or analog-to-digital converters (ADCs) can be incorporated. Such a scheme needs an interrogation method which can detect the resonance frequency of the sensor tag and map it to a meaningful value (e.g. temperature). However, the measurement of the exact resonance frequency of an antenna would require wiring it to measuring equipment, which is non-convenient for an IC-loaded antenna. For that reason, a measurement has to be made at the wireless interrogator's (reader) side that indirectly gives information regarding the antenna's resonance. A quantity that is practical for such systems is the tag power-on threshold [2]

$$P_{\text{thr}} = \frac{P_{\text{min}}}{G_{\text{tag}}\ (1 - \text{RL})}, \tag{1}$$

where P_{min} is the minimum power required to wakeup the chip, G_{tag} is the tag antenna gain, and RL is the antenna return loss due to mismatches between the antenna and the chip. This quantity shows the minimum amount of power required to wakeup the RFID chip present on the sensor tag, at a certain frequency. Intuitively, this quantity is expected to be minimized around the antenna resonance frequency, where power transfer from the antenna to the chip is maximized. However, the return loss RL which relates to the antenna resonance, is not the only factor that affects P_{thr}. In this work, a dipole antenna for RFID sensors is designed and the aim is to predict the behavior of P_{thr} for different frequencies. Since there are commercially available readers that can provide the power-on threshold for a tag, the prediction of the function $P_{\text{thr}}(f)$ is essential, so that the frequency shift observed at the reader's side, can be directly decoded to a sensed value. In this work, the values for predicting the tag power-on threshold are obtained using a full wave simulator and are experimentally verified with measurements of the implemented inkjet-printed tag, conducted with a commercial RFID reader [3].

II. Antenna Design

The antenna consists of a customized folded dipole with a matching network. When the antenna is "loaded" with the appropriate sensing material blocks (e.g. PEDOT:PSS, that is sensitive to external humidity/moisture), the resistance of these added blocks and/or their capacitance changes as the parameter under sense changes. As a result the total impedance seen at the terminals of the IC changes and consequently the resonance seen at the reader shifts accordingly, allowing the remote sensing of the variation in the parameter under sense.

The layout of the designed antenna is shown in Fig. 1 and its dimensions are summarized in Table I in millimeters. The RFID integrated circuit (IC) position is marked, as well as the positions for deposition of a sensing material. The prototype antenna is fabricated by direct inkjet-printing on low-cost photo paper, with substrate thickness 210μm, relative permittivity $\epsilon_r = 2.9$, and dielectric loss tangent $\tan\delta = 0.045$. The silver nano particle ink used has 5×10^6S/m bulk conductivity. The antenna is conjugately matched to an RFID IC with input impedance $Z_c = 13.3 - j122$ at 915MHz. The fabricated prototype with the integrated IC that was used for measurements can be seen in Fig. 2.

TABLE I
Antenna Layout Dimensions

a	b	c	d	e	f	g	h	i
82.5	16	8.4	31	12	4.16	3	4	19

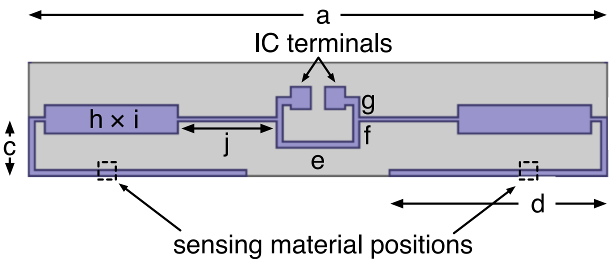

Fig. 1. Antenna layout.

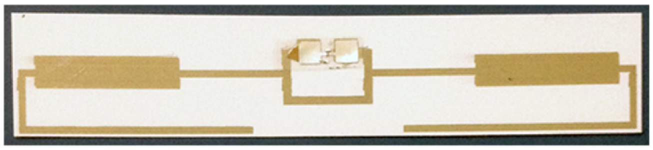

Fig. 2. Inkjet-printed IC-loaded antenna.

III. Measurements

The antenna structure was simulated using the High Frequency Structure Simulator (HFSS). The input impedance Z_a is obtained for the band 0.8–1GHz and the related return loss (RL) is calculated using the formula [4]

$$\mathrm{RL} = \left| \frac{Z_a - Z_c^*}{Z_a + Z_c} \right|^2. \tag{2}$$

By minimizing the function $\mathrm{RL}(f)$, the antenna resonance is found. It is noted that the resonance of the designed antenna occurs at 920MHz. To obtain the gain G_{tag} that is utilized in (1), the values $\theta = 0, \phi = 0$ are fixed for the simulated antenna gain $G(\theta, \phi, f)$, for all frequencies f. By using $\mathrm{RL}(f)$ and $G_{\text{tag}}(f)$, the power-on threshold function $P_{\text{thr}}(f)$ is calculated.

An experimental measurement setup is utilized consisting of a commercial RFID reader with a broadband antenna and the implemented IC-loaded antenna of Fig. 2. The reader interrogates the tag at the 0.8–1GHz band with transmitted power levels of up to 27dBm to determine the power-on threshold. The minimum power level that is sufficient to wakeup a tag and backscatter its response is recorded for each frequency. To account for path loss and multipath propagation, a system calibration is performed by measuring a reference tag with known response. This tag is placed at the exact same position and orientation as the tag under test (Fig. 3). The difference that occurs between the characterized and the measured responses is then taken account into all measurements of the sensor tag.

The calculated threshold is plotted alongside the threshold obtained from the experimental measurement with the fabricated tag in Fig. 4. The measurement agrees well with the simulation, while a slight frequency shift is within fabrication tolerances.

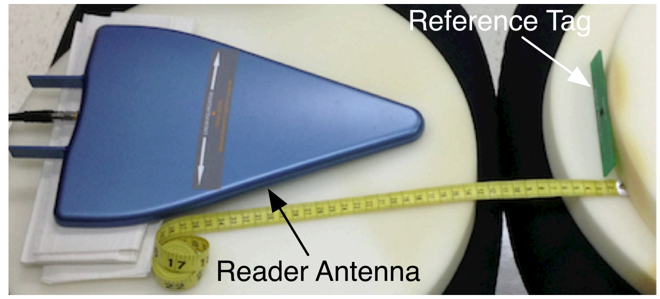

Fig. 3. Measurement setup. The calibration tag is shown at the same position that the tag under test is measured.

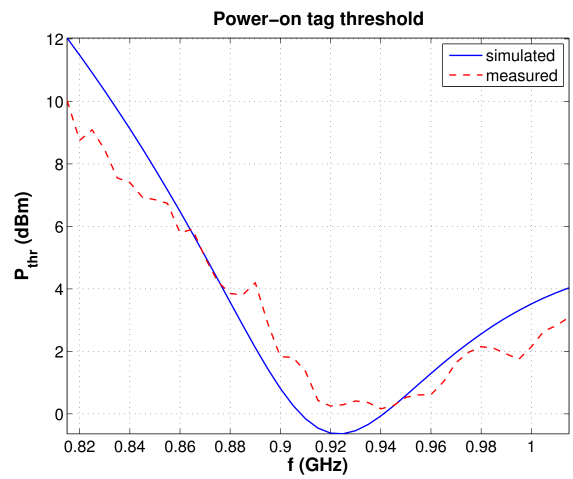

Fig. 4. Simulated and measured power-on tag threshold.

IV. Conclusion

In this work, the tag power-on threshold for a customized inkjet-printed UHF RFID folded dipole antenna, integrated with a commercially available IC has been simulated and experimentally verified. Originally the simulation results provided the set of values to calculate the threshold, which was later verified by measurements using a commercial reader. The presented method can be used to indirectly identify the return loss of the unloaded open terminal antenna. The suggested antenna with the integration of strategically placed sensing material blocks allows the wireless remote sensing of a parameter directly on the reader, making the antenna a good candidate for a number of RFID wireless sensing applications.

References

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