A Biopolymer-based UHF RFID Sensor for Humidity Monitoring

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Abstract

This article presents a novel passive UHF RFID sensor for moisture monitoring. The sensor is composed of an antenna connected to an inter-digitated capacitor on which a layer of bio-polymer (wheat gluten) is deposited. Electromagnetic coupling between the capacitor and the deposition of wheat gluten is used to modulate the impedance matching between the chip and the antenna of the tag, according to the relative humidity. The proposed design has a cost comparable to an ordinary passive UHF RFID tag but with an additional sensor functionality.

1. Introduction

The possibility of using tags as devices for the detection of objects, people and the environment becomes one of the most interesting and promising applications of radio frequency identification (RFID). This technology targets a wide range of applications such as in healthcare, pharmaceuticals and agri-food industry. An RFID system consists of a reader and a tag (consisting of an antenna, and a chip with a unique identifier). Currently, various types of RFID technology have been defined based on the frequency of use (Low Frequency: 125 kHz, High frequency: 13.56 MHz, Ultra High Frequency: 860 - 960 MHz (UE), Super High Frequencies: 2.45 or 5.8 GHz), and their mode of operation (passive, semi-passive or active) [1].

The RFID technology attracts a lot of interest due to its added functionalities such as the ability to operate as a sensor. To achieve this functionality, two solutions can be envisaged. The first is a semi-passive solution, for dedicated RFID sensor chips. The sensor is directly integrated in the IC and may have specific inputs for the connection of an external sensor. The sensor information is transmitted by data exchange between the tag and the RFID reader, for example, to measure physical activity [2]. The second is totally passive. It consists in transforming a conventional tag composed of an antenna connected to an RFID chip, into an RFID sensor by deposition of a sensitive material on the antenna [3-5]. A possible alternative is to place a tag on a sensitive substrate, acting as a sensor [6].

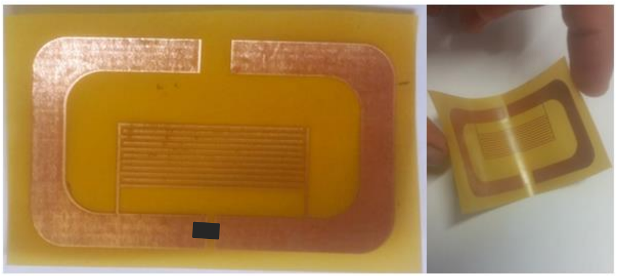

Figure 1. Prototype of the humidity sensor.

The principle of detection of a passive RFID sensor is based on the monitoring of the impedance matching between the antenna and the chip. This matching can be modified either by structural modification of the antenna or with the deposition of a sensitive material whose complex permittivity is a function of the physical parameter being monitored.

In this paper, we investigate for the first time the coupling of a bio-polymer with passive RFID technology for humidity sensing. For this purpose, the tag antenna is functionalized using a localized deposit of wheat gluten - a simple eco-friendly bio-polymer. The detection of moisture is carried out by means of an inter-digitated capacitor positioned in parallel with the chip on which the wheat gluten is deposited. The prototype is made on a flexible substrate, compatible with industrial printing processes such as flexography or screen printing. This makes a a competetivet wireless sensor in terms of cost of realization.

2. Design

The proposed RFID sensor prototype presented in Figure 1 is composed of a Murata MagicStrap chip embedding a NXP IC featuring a power activation of -8dBm. This chip is connected to a planar antenna in which we positioned an inter-digitated structure in parallel with the chip. The bio-polymer deposition is carried out over the entire surface of the inter-digitated structure.

2.1 Characterization of wheat gluten

The wheat gluten (Amygluten 110) is an organic polymer which has been characterized in a previous study [7], the solution is composed of 30 g of wheat gluten powder diluted in 50 ml of a sodium sulfite solution.

The pH of the solution was adjusted to 4 by adding 3.4 ml of 50/50 v/v acetic acid. The final quantity of the solution is 130 ml by addition of deionized water. We deposited the wheat gluten on an inter-digitated capacity with a scrubber (Erichsen E409) to control the thickness of the deposit.

In order to extract the dielectric permittivity parameters of the gluten, impedance measurements were carried out using a network analyzer (Hewlett-Packard 8753D) over a range of frequencies up to 1 GHz [7]. The device was then characterized as a function of the relative humidity (20% to 95% (± 1%)) in a climatic chamber in which both the temperature and the humidity are controlled [7].

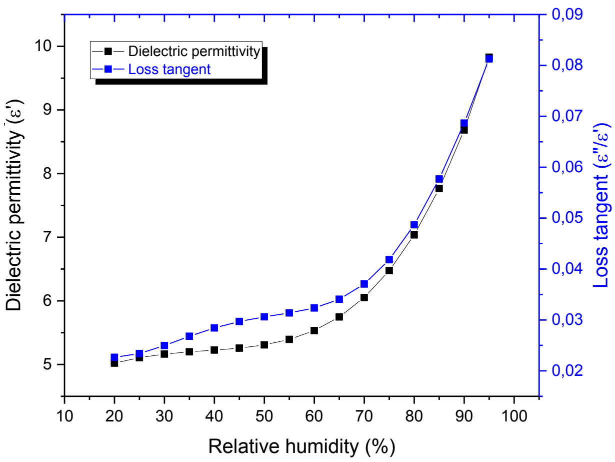

Figure 2. Simulated dielectric loss and dielectric permittivity of wheat gluten as a function of relative humidity (RH) at 868 MHz, at 25 ◦C.

As a result, (Figure 2) a mathematical model of the dielectric permittivity and the dielectric losses of the wheat gluten layer was obtained by comparing the simulated impedance values with the measured values.

2.2 RFID sensor design

The design of the proposed tag, given in Figure 3, consist a folded dipole for miniaturization purposes associated with an inter-digitated capacitance positioned in parallel with the chip. The clearance at the end of the antenna folding makes it possible to adapt the antenna to other frequencies, depending on the intended application. The inter-digitated capacitor has a surface of 31.5mm x 10.5mm, on which the gluten is deposited allows having a good sensitivity according to humidity variations. The substrate used is polyimide with a thickness of 75 µm and a dielectric constant of 3.5.

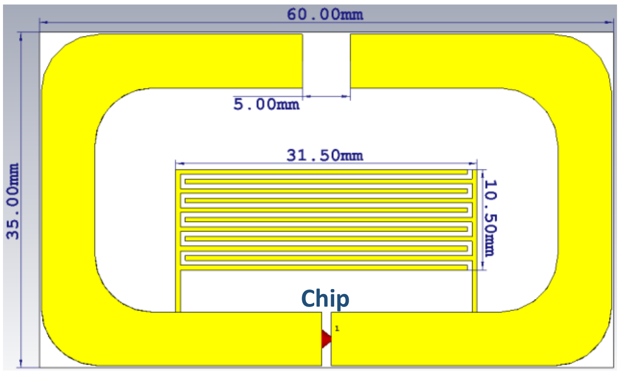

Figure 3. Geometry of RFID moisture Sensor.

We used the mathematical model to design the RFID sensor shown in Figure3 with the help of CST-MWS. To do that we defined a dielectric material according to the frequency-dependent complex permittivity shown in Figure 2. As shown in Figure 4, even when it is deposited as a thin superstrate layer (100µm), the bio-polymer has a strong impact on the matching between the antenna and the RFID IC. We targeted a conjugate complex matching between the antenna and the impedance of the chip (Z = 25-j200Ω) at 915MHz (FCC frequency band) and for the lowest relative humidity detectable with the bio-polymer, that is 20%. We can see in Figure 5 the 2D directivity radiation pattern in (a) H-Plane and (b) E-Plane of the dipole antenna, the realized gain at 915 MHz is -1.22dB. The radiation pattern is similar to that of a classical dipole with a small dissymmetry in the H-plane due to the folding of the antenna.

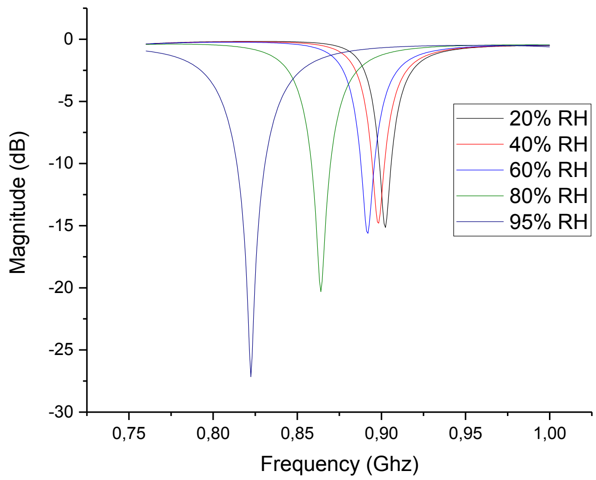

Figure 4. Simulation results showing the variations in S-parameter as a function of relative humidity.

As shown in Figure 4, a good matching is obtained for a relative humidity of 20% and for a wheat gluten deposit of thickness 100 µm. Moreover, the effect of the relative humidity between 20% and 95% on matching is very significant and makes it possible to modulate very clearly the activation power of the RFID tag.

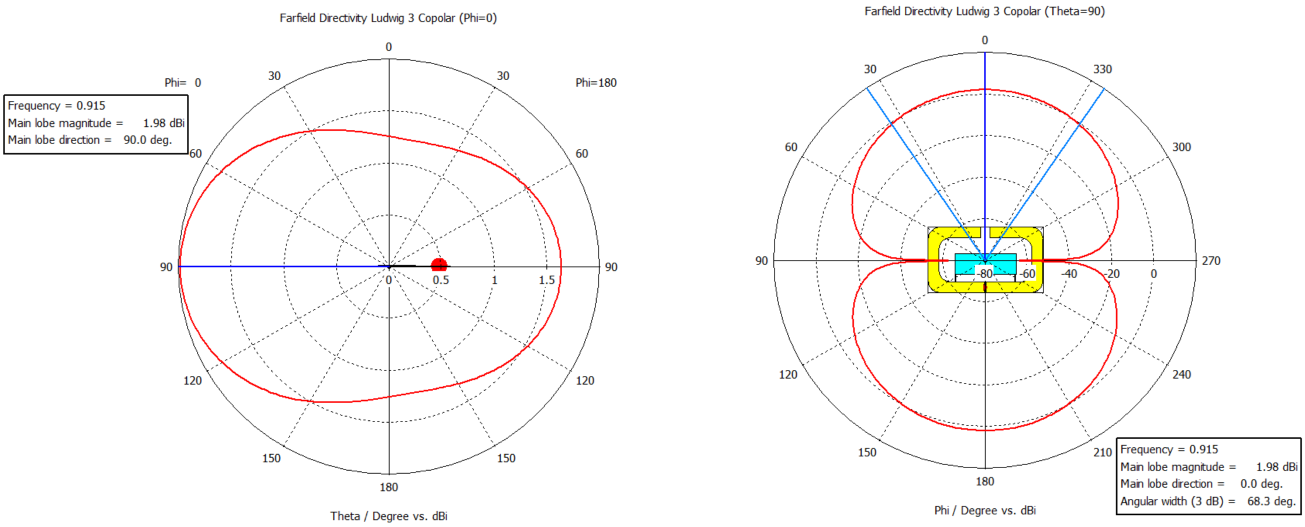

Figure 5. 2D Radiation pattern (a) H-Plane (b) E-Plane of the dipole antenna

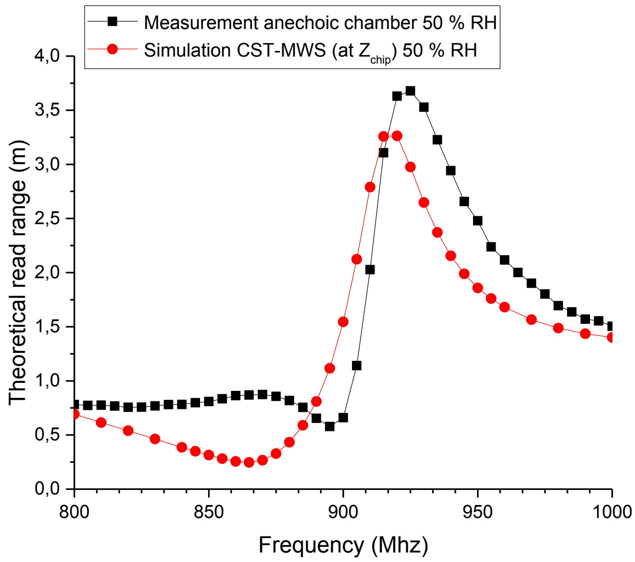

Figure 6. Theoretical reading distances obtained in simulation and by measurements.

The matching variation implies a variation of the activation power. The transmitted power at the reader needed to achieve the activation power of the tag evolves the same way so that a humidity change can be detected by the RFID reader. We can relate this parameter variation according to a modification of the theoretical tag reading range using Friss equation (1).

$$R = \frac{c}{4\pi f}\sqrt{\frac{G_t G_r P_t}{P_r}} \qquad (1)$$

With:

Pt (W) Power delivered to the transmit antenna
Pr (W) Power collected on the receiving antenna
Gt (dBi) Linear gain of the transmitting antenna
Gr (dBi) Linear gain of the receiving antenna
R (m) Theoretical reading distance
C (m / s) Celerity
F (Hz) Working frequency

In this equation, the read range *R* is related to the varying parameter *Gr* which is correlated to the matching of the tag that evolves according the humidity.

3. Validation

3.1 Test bench

To check for the read range performance of the RFID sensor we first carried out a measurement in anechoic chamber with the Voyantic Tagformance system at ambient temperature (20°C) and ambient humidity (50%). This device is used to characterize the performance of the tag in a frequency range from 700 MHz to 1.2 GHz with a minimum step of 0.1 MHz. In order to know the power required to activate the tag, this device gradually increases its output power in steps of 0.1dB, starting from 0dBm, up to 30dBm. Figure 6 shows the theoretical reading distance extracted both in simulation and with the measurement set-up described above. One can see the good correlation obtained between simulated model and the realized design. With ambient relative humidity, the read range is close to 3.5m.

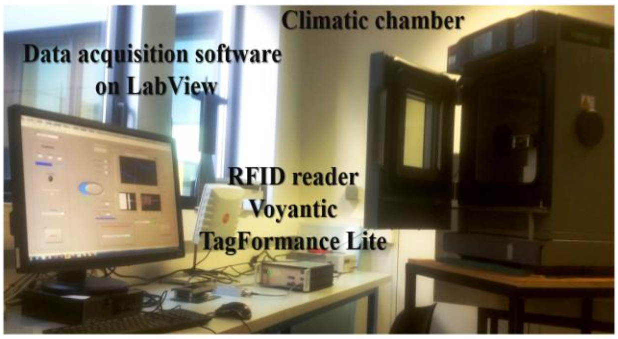

Figure 7. Test bench.

We then develop a test bench shown in Figure 7 to measure read range performances in a controlled environment. The measuring bench is composed of a climatic chamber (ESPEC SH-242) with a temperature range between -40 ° C and 150 ° C and relative humidity range between 30% and 95%. During the measurement, Taformance reading system is controlled using LabVIEW to perform measurements cycles. Because the climatic chamber is composed of metallic wall that strongly interfere with RFID tags, we connected the reading system to a Voyantic snoop-pro^{TM} antenna. This antenna operates in near field and allows for the extraction of the matching of the tag according to the frequency.

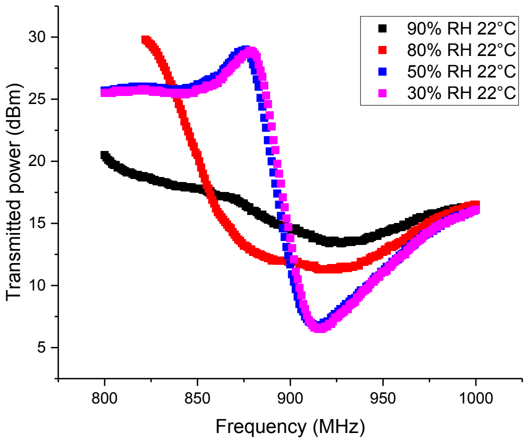

Figure 8. Test bench measurements by varying the humidity exposure of the sensor**.**

Figure 8 shows measurement results for varying humidity exposure from 30% to 90%. One can note significant variation of the transmitted power necessary to activate the RFID sensor (Figure 9). At 915MHz, we observe that the transmitted power increases as the humidity rises. This result is in compliance with what it was expected in simulation according to Figure 5.

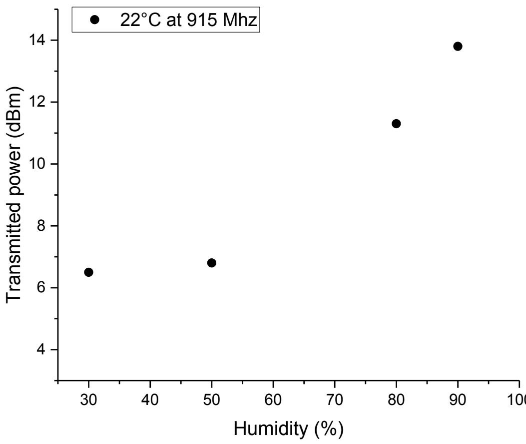

Figure 9. Variation of transmitted power at 915 MHz when the humidity increase.

We also carried out several measurement cycles varying relative humidity from 30% to 90% at a fixed temperature at 22°C. Table 1 represents the mean and the standard deviation of the transmitted power and the backscatter power values. It is to be noted that the humidity variation from 30% to 90% implies an average variation in the transmitted power from 6.5dBm to 13dBm which is a significant and detectable variation.

	Humidity 30 %RH	**Humidity 90 %RH**
Transmitted power (dBm)	6,48 ± 0,06	12,93 ± 0,32
Backscattered power (dBm)	-43,19 ± 0,07	-50,80 ± 0,33

Table 1. Average of 100 measurements at 915 MHz**.**

4. Conclusion

We have demonstrated the feasibility of a biopolymer-based passive RFID sensor for moisture measurement. The variations obtained in the antenna matching are detectable with an RFID reader system for relative humidity variations between 20% RH and 95% RH. The proposed design has been validated with the help of practical measurements of the sensor in a climatic chamber. A good correlation between the transmitted power and the relative humidity was observed, for the center frequency 915MHz. Repeatability measurements confirmed the great potential of biopolymer to make low cost, and green RFID sensors.

5. Acknowledgement

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