Humidity passive sensors based on UHF RFID using cork dielectric slabs

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***Abstract*—In this paper we show the design of passive UHF RFID tag antenna on cork substrate. Due to the cork sensitivity to humidity changes, we can use the developed sensor to sense changes in the relative humidity of the environment, without the need for batteries. The antenna is built using inkjet printing technology, which allows a good accuracy of the design manufacturing. The sensor proved usable for humidity changes detection with a variation of threshold power from 11 to 15 dB between 60 and near 100% humidity levels. Presenting, therefore, reading ranges between 3 to 5 meters.**

***Index Terms*—RFID, cork substrate, humidity sensor.**

I. Introduction

Radio Frequency Identification (RFID) has been the focus of a lot of attention in the past decade. From business to academia, a lot of effort has been put into the development of this technology for all sorts of applications. From toll collection systems [1] to indoor tracking systems [2] and even human implants [3] or food and beverages monitoring [4], [5], [6]. The wide variety of scenarios of application rise challenges for the tag designs which have been shifting to the use of different materials and techniques, to create small and conformal antennas to be seamless in many different types of targets.

More recently RFID technology has been integrated with sensors. These sensing capabilities open the door to the development of a lot of responsive systems, which foster the concept of the Internet of Things (IoT) [7]. One of the technologies that has allowed the large development of these systems is inkjet printing of conductive inks on paper and other substrates [8]. The sensing applications developed upon RFID range from temperature and humidity, to chemicals and pH. The sensing mechanisms are also as diverse as the target applications. Three different approaches for passive temperature sensing can be found in [9], [10], [11]. In the first case a distilled water container is placed in the vicinity of the tag antenna, directly underneath the impedance matching network. The permittivity changes of the water with temperature cause a shift in the resonance of the antenna, the detection of this shift is used to estimate the temperature. In the second case a slot antenna is designed on Alumina substrate and the sensibility of this material to the temperature imposes a resonant shift on the slot antenna which is used to estimate the temperature. This design is used to detect vary large changes in temperature. In [11] UWB (Ultra Wideband) signals are used to detect the reflection coefficient of chipless tags. Resistive temperature sensors are used within the matching structure of the tags which will change the reflection characteristic. The change in reflected power of the chipless tags is then compared to a certain frequency.

A combined temperature and humidity sensor is explored in [12]. In this case a proposal for HF and UHF sensor tags is proposed. A microcontroller is used to interface a RFID chip and the sensor elements or ICs responsible for the temperature and humidity measurements. The microcontroller reads the data from the sensors and writtens these in the RFID chip memory, which is then accessed with a regular RFID reader. This solution seems to be the most mature and most reliable although is also the more expensive. It is also thought for harsh environments but is severely dependent on the packaging which may affect the correct temperature and humidity changes in many scenarios.

Other sensing capabilities are explored in [13] and [14]. In the first case a passive sensor for pH of solutions is presented. This one is based on HF RFID approach, by connecting pH sensing electrodes in paralel to a inductive coil which will impose a resonant shift of the coil. This resonance is measured and matched to a specific pH level of the target solution. A temperature dependent resistor is used in parallel with a varactor and the electrodes and coil in order to account for temperature. Temperature shifts will impose a change in the quality factor of the coil which can be detected therefore allowing a temperature compensated pH measurement. In [14] microfluidic channel are used to create a varactor sensor for chemicals which are introduced into an UHF RFID tag antenna. These microfluidic structures impose a resonant shift in the antenna for different chemicals, therefore allowing the detection of certain substances using passive remote sensing.

In this paper we present a passive tag that uses the cork properties for humidity sensing. Cork is a very porous dielectric material that has a small permittivity value [4]. The large number of air holes in its struture make this material vary sensible to humidity changes, since the cork traps the water molecules in the air inside itself. In that sense, its permittivity is dependent on the humidity of the environment it settles in. This property is explored in order to create passive sensor tags for humidity measurement.

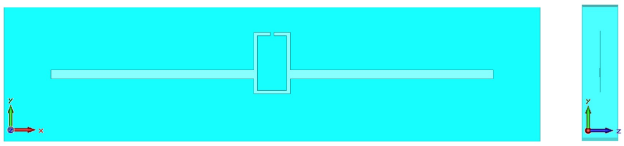

Fig. 1. Simulation model of the proposed RFID tag antenna (a) front view, (b) side view.

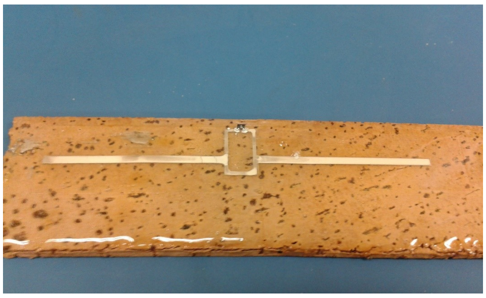

Fig. 2. Prototype photograph of the proposed RFID tag antenna.

II. RFID ANTENNA PROTOTYPE

The RFID tag antenna approach is a simple classic dipole with an inductive ring for impedance matching. The RFID tag chip used was the Alien Higgs 4, which has an input impedance of 18.4-j181.2Ω at 915 MHz. We used the impedance matching techniques as described in [15] in order to calculate the size and position of the inductive ring for perfect impedance match.

The designed RFID tag antenna is shown in Figure 1. The size of the prototype is 100 x 30 x 8 mm, length, width and height wise.

The antenna is printed in the middle of two cork slabs. By placing cork all around the antenna we expect to create an increased sensibility of the tag to the permittivity shift imposed by humidity changes.

To create the tag antenna prototype we used inkjet printing. A silver based ink is used to create the pattern of the antenna on the cork. However, due to the absorption properties of the cork, a coating process was developed in order to be able to print the ink in the surface. The coating is achieved with a thin epoxy layer placed on top of one of the cork slabs, topped with a photo-resistive material. The photo-resistive material used was SU8, which enables to create a coating with high surface energy so that the ink does not spill, therefore allowing good accuracy in the designs.

The photograph of the actual prototype is shown in Figure 2. On top of the antenna shown, another cork slab was glued in order to embed the antenna in the middle.

According to previously conducted tests and measurements on the cork sensibility to humidity, the permittivity is expected to change between 1.7 and 2.5, while the losses change between 0.01 and 0.03, for the totally dry and wet conditions. Therefore, we simulated the antenna response for several values in between this range. The simulated reflection coefficient of the antenna is shown in Figure 3.

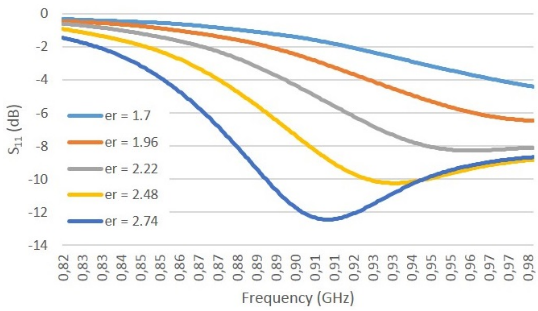

Fig. 3. Simulated reflection coefficient of the proposed tag antenna.

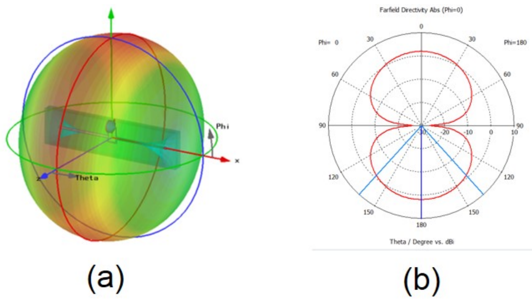

Fig. 4. Simulated radiation pattern of the proposed tag antenna (a) 3D view (b) XZ plane view.

Looking at the reflection coefficient of the antenna we can see that the permittivity of the slabs variation imposes considerable changes, both in terms of resonance as the input impedance of the antenna at each of these resonances. We can, therefore, use the properties of the dielectric itself to test for humidity changes, by looking at the shift in resonance and the turn on power of the tag with a RFID reader. This is discussed more further in the following section.

In terms of radiation the antenna shows the expected behavior with an omnidirectional pattern and a directivity of 1.96 dBi, which corresponds to a maximum gain of 1.1 dB, given the 82% estimated efficiency. The simulated radiation pattern is shown in Figure 4.

III. RFID TAG HUMIDITY SENSIBILITY

For measurement purposes we used the RFID testing equipment Tagformance 7 by Voyantic. A picture of the measurement scenario is shown in Figure 5.

The measurement equipment performs the reading of tags which implement the EPC Class 1 Gen 2 communication protocol. It measures the minimum transmitted power needed to reach the tag at each frequency, in a given set interval, up to a maximum power of 27 dBm.

The measured minimum threshold power to turn on the tag is shown in Figure 6. In order to emulate the wet condition of the ambient water was sprayed over the cork which emulates a state close to 100% humidity. After drying for a while another

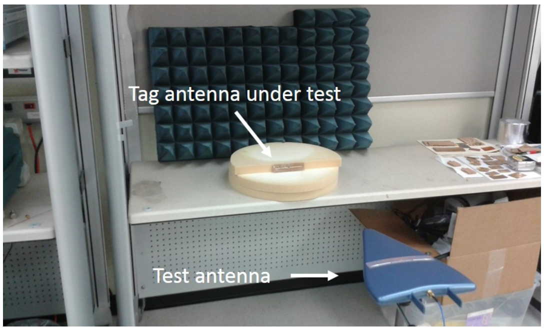

Fig. 5. Measurement setup of the UHF RFID tag antennas tested.

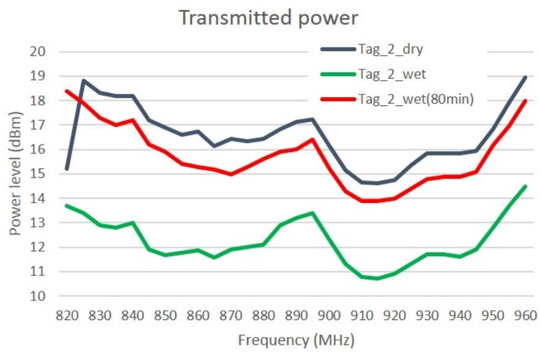

Fig. 6. Minimum transmitted power to activate the prototype tag for different wetting conditions.

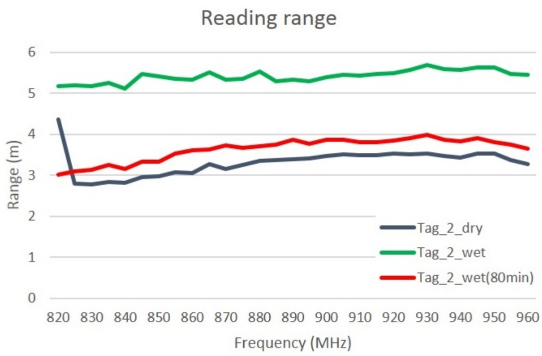

Fig. 7. Reading range obtained for the proposed prototype considering the calibration channel.

measurement was taken and we can see that the antenna response returns to the initial condition of a dry state.

We can also look at the reading range of the proposed tag for different wetting conditions. The reading range measurements are showcased in Figure 7. According to the results, we can see that there is a huge difference between the wet and the dry condition. Moreover, we can see that while the cork is getting dry, the measurements tend to the initial dry condition. Which means that it is possible to create a mapping of the humidity variation.

The reading range plot is clearly different from the threshold power measurement plot. This is due to the fact that the reading range is obtained for a specific propagation channel, obtained with the calibration of the measurement equipment

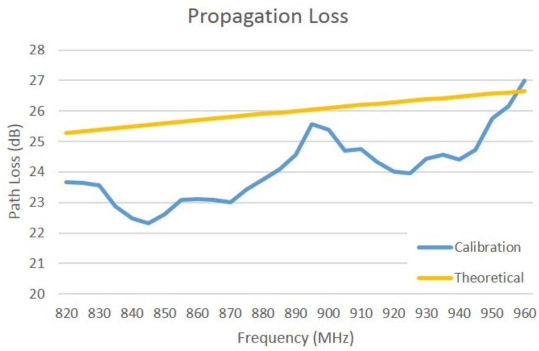

Fig. 8. Theoretical prediction and measured propagation channel comparison.

with a standard tag, instead of being obtained from the typical calculation with the Friis formula. The comparison between the losses obtained from the theoretical estimation based on the Friis formula and the calibration channel model obtained, is depicted in Figure 8.

During the course of these experiments we didn't have access to a humidity controlled chamber. Therefore we could not make do the matching between a specific humidity level and a transmitted power. Still, the presented results show that there is an easy way to track humidity levels by keeping track of the transmitted power.

It is also clear that the tags, no matter what is the wetting condition, present really good reading ranges. From more than three meters when dry and up to more than five meters in a wet condition. We can also see a parallel between the reading ranges and the simulated reflection coefficient of the antenna by looking at the large bandwidth obtained.

IV. Conclusion

We were able to actually create an effective method to use inkjet printing on natural cork surfaces. By using the epoxy coating with photo-resist SU8, we could effectively create a cover for the cork with enough surface tension to stand the inkjet printing process without spilling and good design accuracy. Therefore allowing the design of a UHF RFID antenna tag and use the cork itself as a sensing surface for humidity changes.

Due to the porous characteristic of natural cork it is rather sensible to the presence of water particles which get trapped in its holes. The high permittivity of water contrasts with the low permittivity of the cork and considerable changes occur with humidity variation. This was clearly observed by the results obtained with the measurements of the RFID tag prototypes designed.

The next step is to make measurements inside a humidity controlled chamber in order to map turn on power with humidity levels and evaluate the response time of the sensor.

Acknowledgment

The authors acknowledge the Portuguese FCT/MCTES for financing the PhD grant SFRH/BD/91249/2012 and the project

CREATION EXCL/EEI-TEL/0067/2012. Plus by EU COST Action IC1301 “Wireless Power Transmission for Sustainable Electronics (WIPE)”, by sponsoring the STSM reference 17043.

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