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An Inkjet Printed RFID-enabled Humidity Sensor on Paper based on Biopolymer

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Abstract

We report a novel fully printed RFID based sensor fabricated on paper substrate. The sensitive material is wheat gluten which is a biopolymer having electrical parameters correlated with relative humidity (RH). The sensor is validated with simulation and measurement results varying climatic conditions.

1. Introduction

RFID has become over the past years a leading technology in the field of wireless identification [1]. Adopting RFID tags to identify items is, most of the time, motivated by several strong arguments such its detection reliability even at a distance of several meters in UHF band, with no battery. The reading could be none line of sight, and recently the unit cost of RFID tags of several dollar cents makes it possible to address application that need item tagging. However, novel applications need even more functionalities such cryptography and sensing. RFID enabled sensors [2-5] are studied for several years because they can be deployed massively for a cheap cost and they don't need any maintenance in passive mode. This last point is really important because the battery is a drawback for conventional wireless sensors. Further, in some applications such as food industry, there is a need to embed sensors within the packaging in order to monitor food spoilage. For these applications the cost of the RFID sensor should not be higher than a classical RFID tag. This involves making sensors on paper.

A previous work [5] showed the performances of a similar design made on polyimide substrate with conventional fabrication technique involving humid etching of copper. The aim of this work is to prove the possibility of using paper substrate to realize an RFID enabled sensor that can be further integrated seamlessly within a food packaging. In this paper the realization of the tag involves inkjet printing technique on paper substrate and the use of a biopolymer [6] already used in the food packaging industry.

2. Design and Fabrication of an RFID sensor

We designed a passive RFID tag operating in the UHF band from 865 MHz to 927 MHz. To transform an RFID tag into an RFID sensor, several solutions are possible. The first one is to use a dedicated IC [7] which embeds an internal sensor (e.g. Temperature) or a digital to analog converter (ADC) connected to an external sensor. This solution is usually more expensive than a conventional tag because of the cost of the IC. Moreover, the detection performance of the tag is less because the activation power is worse. The second solution [2-5] which is under investigation in this work is to use a conventional IC connected to specific antenna. The idea is to modulate the matching between the antenna and the IC to generate a varying activation power and reflected power as a function of physical parameter. To extract the value of the sensor a relationship has to be found between the physical parameter and the activation power. The design shown in Fig. 1 is based on a folded dipole for sake of miniaturization. To modulate the mismatch between the IC and the antenna, we connected an interdigitated capacitor in parallel of the IC. The IC connected to the antenna is based on a Magicstrap Monza R6 RFID chip (Z_{ic} = 14 –j148 at 867MHz).

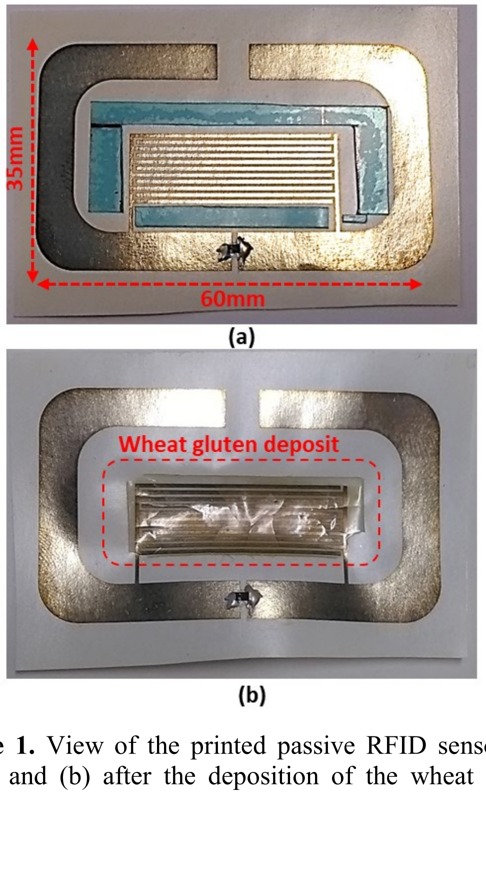

Figure 1. View of the printed passive RFID sensor. (a) before and (b) after the deposition of the wheat gluten layer.

We targeted an optimal matching for an operating frequency a bit higher the North America band. The idea was to compensate for the detuning brought by the sensitive deposit.

We fabricated the antenna with a Dimatix DMP-2831 inkjet printer. The conductive strips are made of silver ink from Genesink company. To get a rather good conductivity we printed two layers followed by a curing at 150°C during 15 min. The substrate is based on a paper already treated with a specific coating in order to improve the surface tension and to decrease the roughness of the surface. The paper weight is $80 g/m^2$. We then connected the IC with help of a conductive epoxy-based glue.

The second step consist in depositing the wheat gluten [6], a low cost and versatile biopolymer, on top of interdigitated capacitor. We used a micro-pipette for this purpose. The Fig. 1 (a) shows the tag with the mask use for deposition. Fig. 2 (b) show the final tag with the biopolymer. To get a solid sensitive layer we left the sensor for curing at ambient temperature during 12 hours.

3. Validation

We first measured the transmit power of the realized sensor within the UHF frequency band from 860MHz to 1GHz with the help of the Voyantic Tagformance Pro system. This first measurement was performed at ambient temperature and RH, that is, close to 25°C and 50% RH. The sensor is placed at 40 cm from the reader antenna so that it can be considered in far field region. Fig. 2 shows the two different measurements.

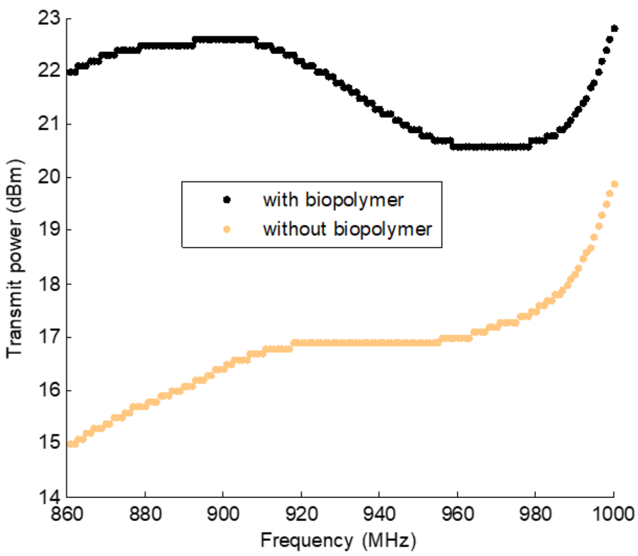

Figure 2. Measurement results showing the transmit power in presence or absence of biopolymer on top of the interdigitated capacitor.

We observed that the transmit power in the case without deposit shows a flat response from 900MHz to 980MHz, with a value close to 17dBm. For the final sensor with the biopolymer we observed an optimized bandwidth between 940MHz 980MHz with a transmit power close to 20dBm that is 3dB higher to compare with the previous case. This can be explained by the additional losses brought by the biopolymer [6]. Even though the target operating frequency was the North America band, we focus our study within the 940MHz to 980MHz band to maximize the power transfer and improve the detectability of the sensor.

Second, we carried out measurement of the sensor as a function of the RH of its surrounding environment. We placed the tag within a plastic box containing a small amount of water as shown in Fig. 3.

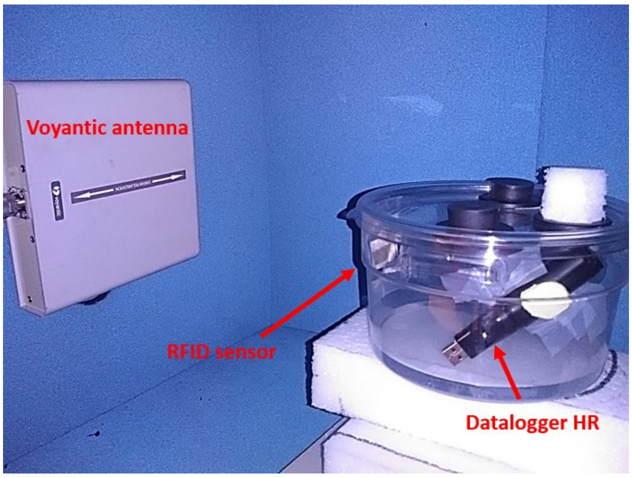

Figure 3. Measurement setup to extract transmit power of the RFID sensor as a function of the RH. The temperature is constant and close to 25°C during the measurement.

The idea is to rise quickly the RH once the box is closed due to the pressure difference between the inner and the outer part of the box. During the measurement cycle, we monitor the RH, and the temperature with the help of a data logger (EL-USB-2 from Lascar Electronics). We observed a fast RH rise from 55% to 90% in 15 min once the box is closed as shown in Fig. 4. Fig. 5 shows transmit power of the sensor during the rising of RH from 57.5% to 87%. We can observe two phases: first, the transmit power doesn't change significantly during the first 15 min; second, we observe a strong variation of the transmit power of 10 dB during the last 10 min. This phenomenon is well correlated with the behavior of the biopolymer [6] featuring a delay before changing its electrical properties, when subject to a large RH increase. From the reader point of view, 10 dB variation is significant and enough to correlate without any doubt a transmit power variation with a HR change from 55% to 90%. Regarding the performance achieved, we can state that this device could be used as a wireless passive and low cost red/green sensor. Further investigations are required to test the reversibility and repeatability of the sensor over a long period of time.

4. Conclusion

A novel RFID-enabled sensor based on biopolymer has been successfully realized and validated. The sensor has been realized on paper substrate using inkjet printing, and validated with the help of a far-field measurement set-up. The measurement was performed during a large relative humidity variation from 55% to 90% inducing a huge 10 dB variation on the transmit power to detect the tag. This significant sensitivity combined to an overall realization cost similar to that of a conventional RFID tag is really promising for an eventual future implementation of the technology in the food industry.

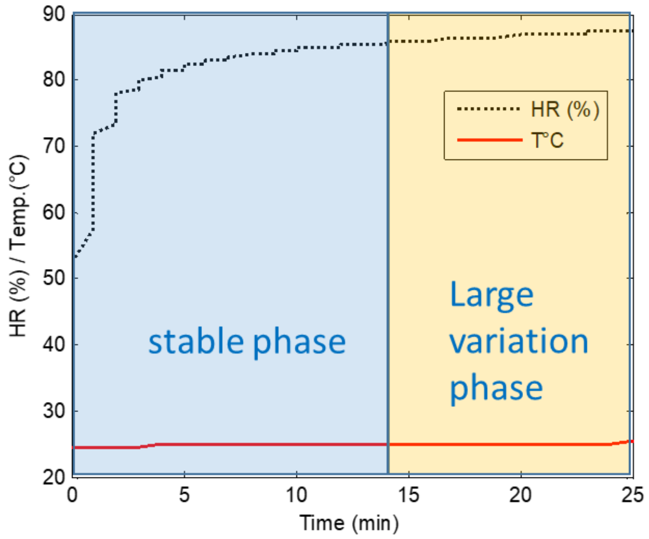

Figure 4. Record of RH and temperature using a data logger (EL-USB-2 from Lascar Electronics) during the measurement cycle.

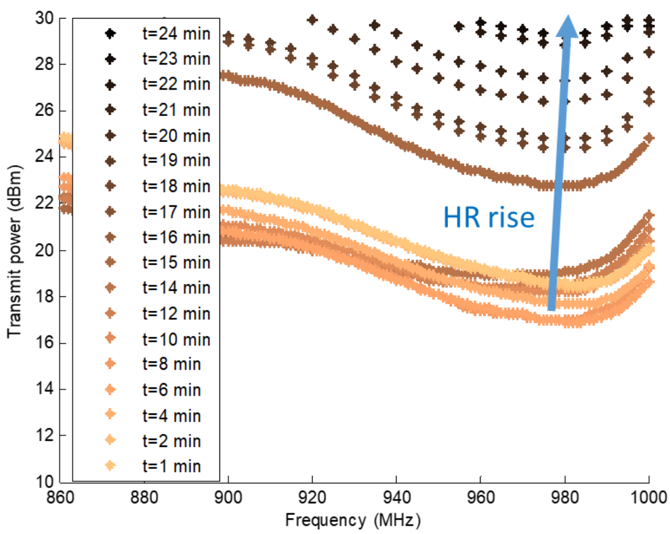

Figure 5. Measurement results showing the transmit power as a function of the RH. The RH range is between 57.5% and 87%.

6. Acknowledgements

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