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Multiresonator-Based Printable Chipless RFID for Relative Humidity Sensing †

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Abstract: We present a chipless RFID for relative humidity sensing. It consists of three spiral resonators coupled to a 50 Ω microstrip line. One resonator is used for humidity sensing, and the other two are used for encoding ID. The sensing resonator is coated with a humidity sensitive polymer film. As the relative humidity changes the permittivity of the polymer film varies changing the resonant frequency of the sensing resonator. Results show that a dedicated resonator can sense relative humidity over 21–53% range with 2.5 MHz/%RH sensitivity whereas the other two resonators can represent the ID. The sensor does not require any IC and is amenable to low-cost production using printed electronic technology.

Keywords: antenna; chipless RF identification (RFID); multiresonator; polyvinyl alcohol; relative humidity

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1. Introduction

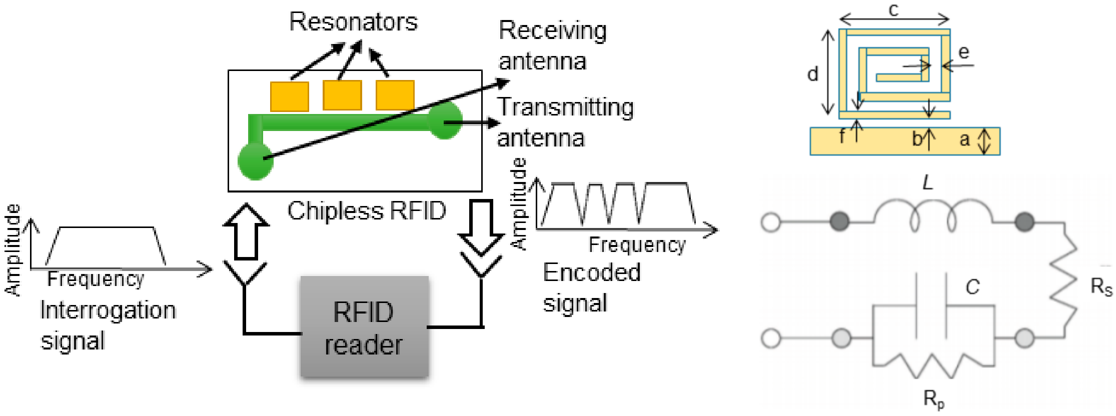
Significant research has been conducted in the development of low-cost relative humidity sensors due to their necessity for human life as well as for various areas of industry [1]. The conventional wireless humidity sensors have limitations in terms of power consumption and cost. In recent years, chipless RF identification (RFID) have received great interest as they offer promising solutions for cost effective item tagging. With the advancement of polymer and polymer nanocomposite, a considerable number of investigations have reported incorporating new sensing materials with chipless RFIDs to develop chipless RFID sensors. This has transformed the field of item tagging in combination with condition monitoring [2]. A planar, passive and fully printable chipless RFID based sensor does not require an internal power source and has potentials to overcome the limitations of conventional wireless sensors. Several researchers have developed sensors based on the chipless RFID technology. Buff et al. [3] has reported a passive surface acoustic wave (SAW)-based RFID temperature and pressure sensor. However, it is non-planar, expensive (cost in the order of a few dollars) and has complex circuitry and an inconvenient fabrication process. Schueler et al. [4] has reported a chipless RFID-based temperature sensor using composite right/left-handed (CRLH) lines and used the time domain reflectometry (TDR) technique to measure the sensing parameters. However, time domain chipless RFIDs are large and have low data capacity.

In this paper, a passive multi-resonator based chipless RFID relative humidity sensor is presented. It is based on cascaded spiral resonators coupled to a 50 Ω microstrip line. One resonator is used for humidity sensing, and the other two are used for encoding ID. The sensing resonator is coated with a humidity sensitive polymer film. The chipless RFID relative humidity sensor is based on frequency modulation and has high data density compared to time domain-based tags. It is compact and fully printable using printed electronics technology due to the lack of on-board. IC.

2. Operation

2.1. Multiresonator Based Chipless RFID System

A complete block diagram of the proposed chipless RFID system is shown Figure 1a. The chipless RFID is composed of three main components; a 50 ohm microstrip line, three cascaded spiral resonators, and crosspolarized ultrawideband (UWB) monopole receiving and transmitting antennas. The antennas are placed at each ends of the microstrip line, while the resonators are placed close to the microstrip line and coupled to it. Each spiral resonator acts as a bandstop filter and is tuned to a specific frequency. The reader antenna sends an UWB signal to the RFID tag's receiving antenna. When the signal passes through the microstrip line each resonators create magnitude attenuations at their bandstop frequency and generate a spectral signature. The attenuated frequencies provides a way to encode data into the spectrum. The presence of an attenuation corresponds to logic 1, while the absence of attenuation signifies logic 0. The signal containing spectral signatures is transmitted back to the RFID reader. Finally, the reader decodes data by detecting the attenuated frequencies. In this work, we focus on demonstrating the effective operation of a chipless RFID sensor part without the transmitting and receiving antennas.



(**a**) (**b**)

Figure 1. (**a**) Complete block diagram of the proposed chipless RFID sensor system; (**b**) Layout of a spiral resonator coupled to a microstrip line and the spiral's equivalent circuit.

2.2. Multiresonator Humidity Sensing

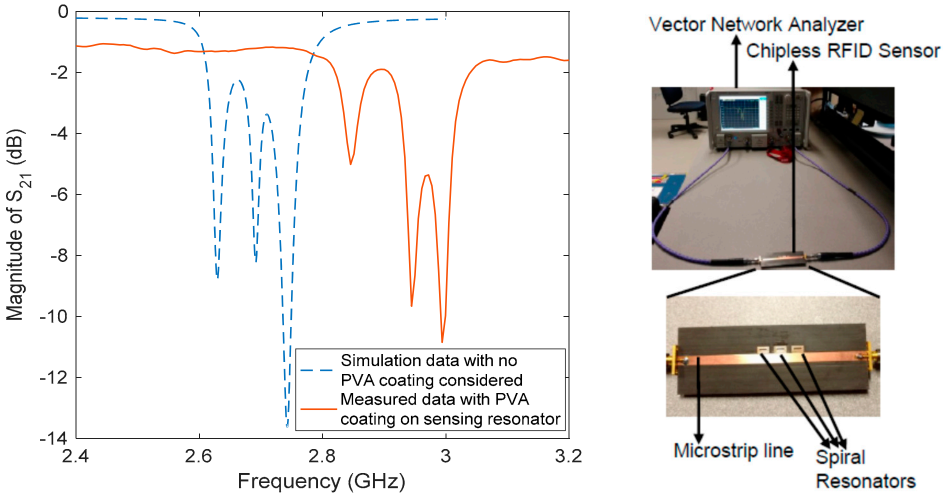
Figure 1b shows a single spiral resonator coupled to a microstrip line along with the spiral's equivalent circuit. In the equivalent circuit, the spiral is modeled by an inductor L and a capacitor C, and resistors R_S and R_P The value of these elements are affected by different structural parameters of the spiral defined in the Figure 1b. Therefore, the resonant frequency of a spiral can be varied by changing the structural parameters of the spiral. The resonant frequency of the spiral is given by (1).

$$f_0 = \frac{1}{\sqrt{LC}} \quad (1)$$

It should be noted that variation of a particular resonator's structural parameters does not affect the resonant frequencies of the others. Thus, the resonant frequency of the sensing resonator can be varied while the other two resonators maintain their frequency response to represent the ID. In the proposed chipless RFID humidity sensor, the sensing resonator is coated with a humidity sensitive polymer, 8% polyvinyl alchohol (PVA) film. With humidity change, PVA shows permittivity sensitivity. The permittivity of the PVA film affects the equivalent capacitance of the sensing resonator and thus the resonant frequency of the sensing spiral represents relative humidity variation.

3. Simulation and Results

A three bit chipless RFID was designed in HFSS operating over 2.6–2.67 GHz frequency range. Three cascaded spiral resonators were placed in series coupled to a 50 ohm microstrip line. The substrate was RT Duroid 5880 with relative permittivity, $\varepsilon_r = 2.2$, dissipation factor, $\tan\delta = 0.0004$, substrate thickness, h = 1.57 mm, and copper cladding thickness = 35 μm. The structural parameters (refer to Figure 1b) of the three spirals are given in Table 1. Figure 2a shows the simulation data for magnitude of insertion loss, |S21| of the designed RFID. There is maximum attenuation in amplitude spectrum at the resonant frequencies, f_0 of each spirals indicating the correct operation of the designed chipless RFID.



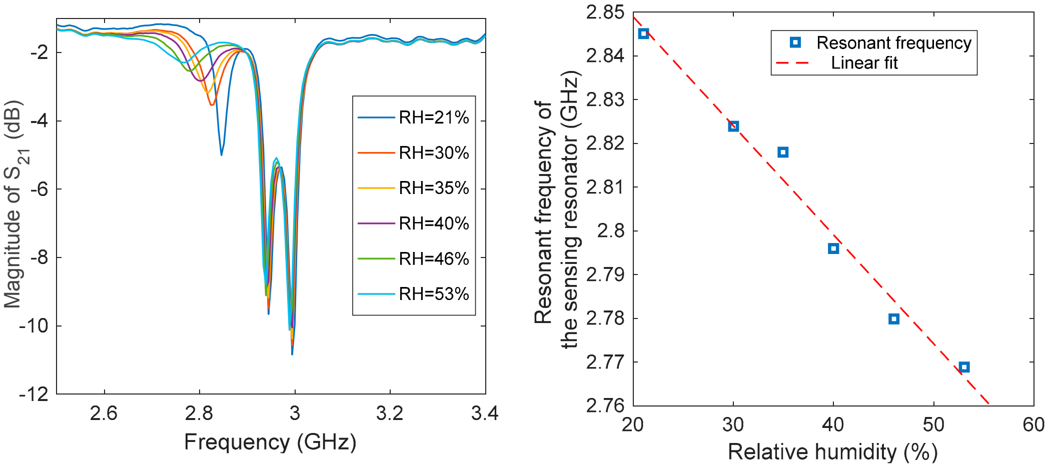
(**a**) (**b**)

Figure 2. (**a**) HFSS simulation data for the designed prototype and measured data for the fabricated prototype. Note that the simulation does not consider the PVA coating on the sensing resonator; (**b**) Measurement setup with Vector Network Analyzer.

Table 1. Design parameters of the prototype in HFSS. Parameters are named are according to Figure 1b.

Parameters (mm)	Resonator 1	Resonator 2	Resonator 3
a	4.86	4.86	4.86
b	0.28	0.28	0.28
c	6	6.1	6.2
d	3.4	3.4	3.4
e	0.3	0.3	0.3
f	0.3	0.3	0.3

According to the simulated design, three cascaded spiral resonators were fabricated on RT Duroid 5880 substrate. Copper was etched out to create the multiresonator-based chipless RFID structure. One of the resonator was coated with 8% polyvinyl alchohol (PVA) film. |S21| of the sensor was measured with a Vector Network Analyzer as shown in Figure 2b. The measured data are shown with the simulation data in Figure 2a. It is observed from the insertion loss characteristics that at frequencies 2.85 GHz, 2.95 GHz and 2.99 GHz there is maximum attenuation in the amplitude spectrum. Possible reasons for differences between the measured and simulated data are the PVA coating on the sensing resonator, the differences between the designed and manufactured dimensions and shape, and measurement error. The responses of the sensor were monitored at different %RH and are shown in Figure 3a. Resonant frequency, f_0 of the sensing spiral shifted with the change of %RH. f_0 of the other two spirals did not shift significantly demonstrating their effectiveness to represent ID. Figure 3b shows that f_0 of the sensing spiral has a linear relationship to the %RH with a sensitivity of 2.5 MHz/%RH over 21% RH–53% RH range and a maximum deviation of 6.7 MHz from linear fit. The quality factor of the sensing spiral decreases with increase of relative humidity making it impossible to measure resonant for RH > 53%.



(**a**) (**b**)

Figure 3. (**a**) Reponses of the chipless RFID sensor for different relative humidity levels. (**b**) Resonant frequency of the sensing resonator versus relative humidity level.

4. Conclusions

A multiresonator-based chipless RFID relative humidity sensor is presented. It has dual functionality of tagging and sensing relative humidity simultaneously. Results show that the sensing mechanism does not impact the tagging operation. The chipless RFID sensor does not contain any on board IC and power source, and is amenable to low-cost production using printed electronic technology. It has potential application in low cost item tagging and condition monitoring.

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Conflicts of Interest: The authors declare no conflict of interest.

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