

## RFID Enabled Chipless Humidity Sensor

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### ABSTRACT

This paper presents a conformable 9-bit chipless radio frequency identification (RFID) humidity sensor, with an overall diameter of 12.4 mm. The semi-circle shaped tag is operating within a frequency band of 6-16 GHz. The tag structure is based on Taconic TLX-0 (substrate), copper (radiator) and a thin Kapton<sup>®</sup>HN sheet (superstrate). The Kapton<sup>®</sup>HN sheet is deployed over the innermost slot to obtain the sensing response from the respective resonant slot. A comparative analysis is derived by analyzing the tag design for Rogers RT/5880, Taconic TLX-0 and FR4 substrates, to observe the quality of resonant dips. Linearly polarized plane waves are used for excitation of the tag. A simple tag composition enables easy printability feature without requiring highly precise printing devices. This proposed tag can be utilized in many areas including pharmaceutical industries, beverage items, agriculture and in various low-cost RFID sensing applications.

## 1. Introduction

Radio Frequency Identification (RFID) technology can access and authenticate remotely planted objects, thus surpassing barcodes [1]. The technology has a broad market spectrum due to its potential to support various daily life applications, including item-level tagging [2], inventory control [3] and sensing [4]. Non-line-of-sight communication and longer interrogation distance play a significant role in the rapid adaptation of RFID technology [5]. A typical RFID system is a platform for the implementation of RFID technology. It consists of a tag, interrogator (reader), database and electromagnetic waves for the propagation of information [6]. The selection of tag is dependent on the type of application and budget. Chipless tags do not have any chip, nor a battery source associated with them [7]. This lack of onboard power supply makes them suitable for a wide range of applications. The incorporation of sensing materials with chipless tags have accelerated their widespread usage. Chipless tags are being used as temperature [8], humidity [9], gas [10] and crack [11] sensors. The sensing functionality of a chipless RFID tag can be achieved by using a substrate or a combination of substrates accompanied with other sensing materials like carbon nanotubes, silicon nanowires and Kapton<sup>®</sup>HN heat resistant sheets. Hence, this sensing potential of smart materials eliminates the need for using separate sensing devices with data handling tags.

The previously reported research works [3] and [9] are based on humidity sensing by utilizing HP photopaper substrate and silicon nanowires as sensing materials, respectively. These materials have some limitations, i.e., HP

photopaper substrate-based tags are not long lasting due to the delicate nature of paper. They are the right choice when utilizing them as disposable tags. Similarly, Silicon nanowires are efficient sensing material, but they are expensive and requires precise and demanding printing technique. Contrary to this, Kapton<sup>®</sup>HN heat resistant sample sheets are readily available from DuPont<sup>®</sup>, and its deployment over the fabricated tag is a straightforward and easy procedure. Besides this, the moisture absorbing nature of Kapton<sup>®</sup>HN sheet makes it suitable for humidity sensing. These distinctive characteristics of Kapton<sup>®</sup>HN sheet prompted its use in designing low-cost chipless humidity sensor. In this paper, a compact linearly polarized chipless humidity sensing tag is presented.

## 2. 9-bit Chipless RFID Tag

In this paper, a 9-bit data encoding tag is proposed initially. The tag structure is analyzed for Rogers RT/5880 (Duroid), Taconic TLX-0 and FR4 substrates, for enhancing transmission bits within limited size. Copper is used as a radiator/reflector for each of the three substrates. The tag structure is a semi-circle loaded with nine slots etched in the copper radiator, as shown in Fig. 1.

CST STUDIO SUITE<sup>®</sup> is utilized for designing and analyzing proposed chipless RFID tags. The radius of the tag and copper reflector is 6.2 mm and 6 mm, respectively. Each slot and metal portion are 0.2 mm wide. The frequency band of operation is slightly different for each tag. The resonant frequency of any slot can be determined by using eq. (1) [12].

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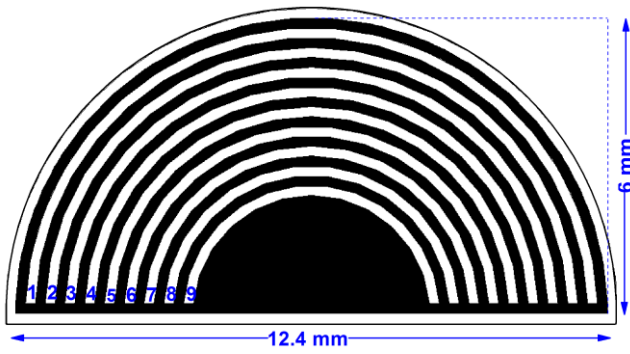


Fig. 1: 9-bit chipless RFID tag.

$$f_{res} = \frac{c}{2\pi R_{slot}} \sqrt{\frac{2}{\epsilon_r + 1}} \quad (1)$$

Here,  $f_{res}$  is resonant frequency,  $R_{slot}$  is the radius of that specific slot,  $c$  is the speed of light and  $\epsilon_r$  is relative permittivity of the substrate.

In the next step of research, the proposed 9-bit chipless tag is designed for sensing humidity. The tag can detect the changing moisture levels in the environment. The sensing characteristic is embedded on a passive chipless RFID tag by placing Kapton<sup>®</sup>HN film over the innermost slot of optimized tag structure. There is no other change in the tag hierarchy as compared to other designed tags; instead, the innermost slot is 0.4 mm apart from the second last slot, as shown in Fig. 2.

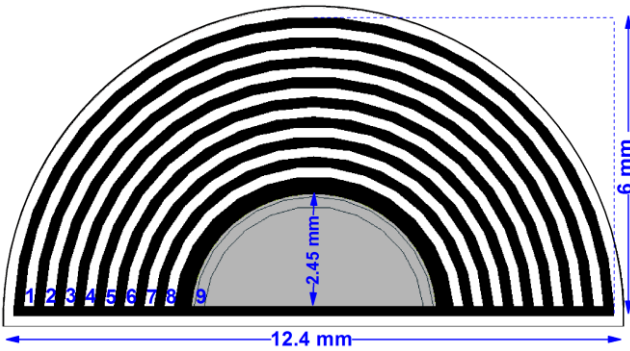


Fig. 2: 9-bit humidity sensor.

### 3. Results and Discussions

The proposed tag design is tested for three different substrates, including Rogers RT/5880 (tag 1), Taconic TLX-0 (tag 2) and FR4 (tag 3) substrates. The comparative radar cross-section (RCS) responses of all the three designed tags are shown in Fig. 3.

There is a shift observed in the RCS responses of each tag, even though tag dimensions are precisely the same for all designed tags. This shift in frequency resonances is due to the differences in their electrical properties. The tag with Taconic and Duroid substrate is providing an almost identical response (neglecting the slight change in frequency dips). While the tag with FR4 substrate has a lower depth of frequency dips due to increased loss tangent value of 0.025. Table 1 contains the properties of materials used in designing proposed tags.

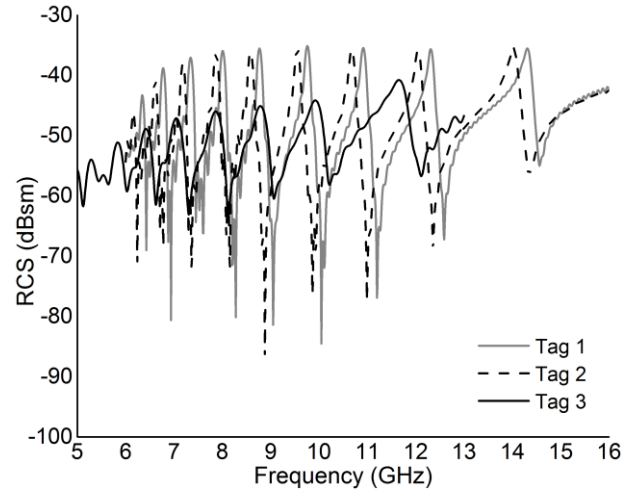


Fig. 3: Comparison of three proposed tags using different substrates.

Table 1: Material properties.

Parameter	Tag 1	Tag 2	Tag 3	Tag 4
Materials	Rogers RT/5880	Taconic TLX-0	FR4 Epoxy	Kapton <sup>®</sup> HN
Thickness (mm)	0.78	0.5	0.5	0.125
Permittivity	2.2	2.45	4.3	3.5
Loss tangent	0.0009	0.0019	0.025	0.0026

#### 3.1 Data Encoding Tags

Tag 1 and Tag 2 are operating in a 10 GHz band starting from 6 GHz to 16 GHz. Tag 3 has a frequency response in 5-13 GHz, covering an overall band of 8 GHz. Nine uniquely identifiable bits are observed in the RCS responses for each tag. The slots and metal gaps (between slots) are 0.2 mm. The dimensions are not changed for any of the three proposed tags.

#### 3.2 Humidity Sensing Tag

In the second step of research, the tag is optimized as a humidity sensor. To implement this idea, Kapton<sup>®</sup>HN film is used as a superstrate of the tag 2. It depends on the requirement of application either to fully deploy Kapton<sup>®</sup>HN film over the tag or to deploy it on the specific resonator. In our research, Kapton<sup>®</sup>HN film is used to cover the innermost slot to obtain humidity sensing response of that particular slot only. The remaining eight slots will handle the data for transmission bits. The measured and computed frequency response of this tag (Tag 4) is shown in Fig. 4, within a spectral range of 6-16 GHz. The measured results for the realized tag are obtained by utilizing a vector network analyzer (Model: R&S<sup>®</sup>ZVL-13), transmitting and receiving UWB antennas and a test tag, same used previously [13].

The surface current distribution pattern is obtained for different resonating frequencies. In Fig. 5, the current distribution at 11 GHz is graphically depicted. Only the slot resonating at that specific resonance frequency will be ignited. It can be seen that at 11 GHz; the surface current is only induced over the seventh slot of the tag.

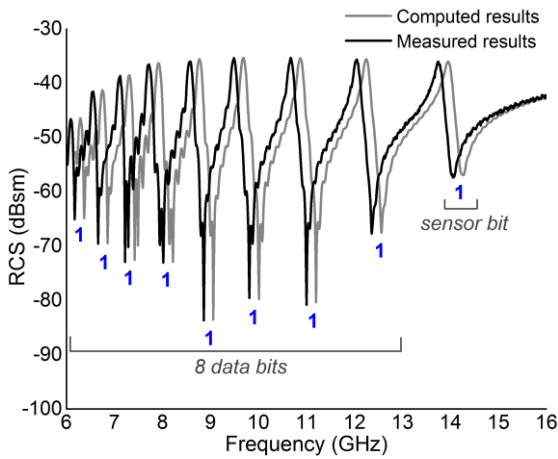


Fig. 4: RCS response of tag 4.

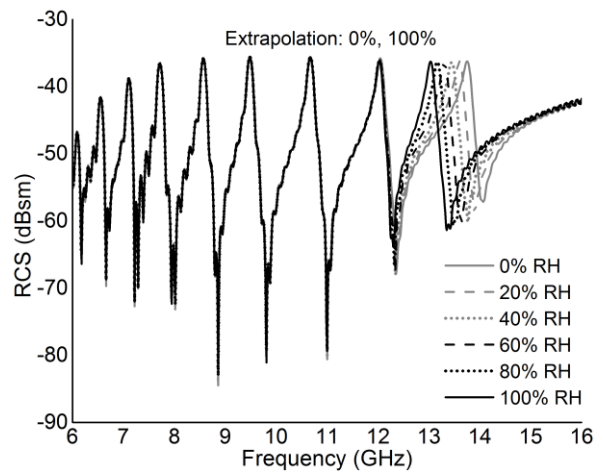


Fig. 6: Humidity sensing behavior of tag 4.

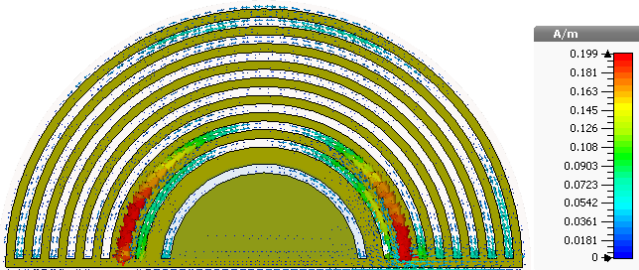


Fig. 5: Current distribution graph of tag 4 at 11 GHz.

The innermost slot of tag 4 is 0.4 mm apart from the neighbouring slots. The reason for this change in the design is to elaborate the sensing distinctness of the slot. The sensing dip is meant to slides in either right or left direction as the humidity level changes. This can result in overlapping of sensing dip with the neighbouring frequency dips. Hence, by increasing the spacing between the slots, a significant spacing between respective frequency dips is observed. Rest of the tag dimensions are the same as that of previously designed tags. Tag 4 is exposed to different moisture levels by using Weiss Technik Chamber (WK11-180) and results are obtained. Different humidity levels ranging from 0% to 100% are set to detect changes in the behaviour of tag. 0% and 100% are extrapolation values used to elaborate on the sensing phenomenon only. It is observed that there appears no change in the first eight frequency dips while a shift in ninth frequency dip (sensor bit) is noted for every change in humidity level. It is due to the moisture sensing nature of Kapton<sup>®</sup>HN film covering the ninth slot. Fig. 6 shows the moisture sensing characteristics of tag 4.

In the proposed tag, each slot corresponds to one bit. Hence, nine slots will yield nine bits and  $2^9=512$  unique bit combinations (IDs). These bit combinations are useful in tagging multiple objects. The unique tag IDs are generated by combining logic state '1' and '0' in a unique fashion. In this paper, each frequency dip indicates a logic state '1'. To change the logic state to '0', the slot is filled with metal. Different tag IDs are shown in Fig. 7. The shorting of slots creates a negligible effect on the neighbouring frequency resonances by producing a minute shift in them [14].

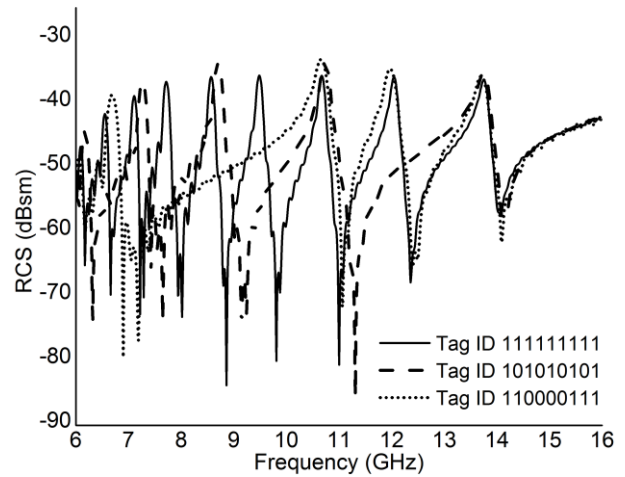


Fig. 7: Different tag IDs for tag 4.

In Table 2 the proposed research work is compared with some of the recent related research works to prove the novelty of the concept. The proposed research work is compared with some of the recent related research works in Table 2 to prove the novelty of the concept. The proposed semi-circle tag design provides the same number of bits as obtained through full circle chipless tag, providing additional benefits of compactness and utilization of less material. The comparison of some novel researches shows that the proposed tag exhibit high bit density with smart sensing feature.

Table 2: Summarized Comparison.

References	Encoded Bits	Size (mm <sup>2</sup> )	Bit Density (bit/cm <sup>2</sup> )	Sensing
Proposed Work	9	60.35	14.91	√
[5]	18	94.7	19	x
[6]	3	625	0.48	x
[12]	27	529	5.1	√
[13]	12	861	1.393	x

#### 4. Conclusions

In this research article, a 9-bit chipless tag with humidity sensing capability is proposed. The chipless tag is transformed into a humidity sensor by pasting Kapton®HN heat resistant sheet over the tag structure. The robust and humidity sensing nature of the tag makes it a reliable choice for many large humidity sensing business applications. The future work of this research is to optimize the tag structure for organic substrates. It will open a new dimension of green electronics. The reduced cost and environment-friendly nature of tag will make the tag suitable for numerous low-cost applications.

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