

16-bit frequency signed directly printable tag for organic electronics

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Abstract: A compact 16-bit chipless RFID moisture sensor tag with a size of $13.2 \times 19.6 \text{ mm}^2$ is designed, fabricated and analyzed. The presented moisture sensor tag is realized on a paper substrate with silver nano particle based ink patches as conducting material. The frequency band of operation is 0.5 to 14 GHz having an overall bandwidth of 13.5 GHz. It is loaded with slots of different lengths and widths, etched on the conductive material. The tag exhibits stable sensing characteristic towards moisture in the real environment. The flexible, sensitive and environmental friendly nature of the proposed tag makes it suitable for wider, low-cost and organic electronics applications.

Keywords: radar cross section, organic electronics, RFID, chipless tag

Classification: Microwave and millimeter-wave devices, circuits, and modules

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1 Introduction

Now a days, Radio frequency identification (RFID) is an emerging wireless technology to satisfy the demands of the modern era. An estimate is done which states that shortly trillions of sold products will be using RFID tags [1]. For an RFID technology, an integrated system is required which consists of a tag, reader and a host computer [2]. The phenomenon occurs with the help of radio frequency (RF) waves that carry useful information. The information is encoded in the form of unique frequency signature. RF waves are then transmitted over the medium to send the signal to distant objects i.e., the tag. A passive chipless tag receives the unique frequency signal, extracts energy from it and then sends back the signal to the reader. In case of chip-based tag, the tag gains energy from Application Specific Integrated Circuit (ASIC) embedded on it. The presence of an ASIC in the tag makes it unsuitable for various business applications due to its comparatively expensive nature [3]. Moreover, the overall cost of the system depends on the RFID tag used in it [4]. Therefore, an expensive tag will eventually make the system expensive. This provoked the need to design low-cost passive RFID tags that have the ability to take over chip-based tags. Recently, with the advancement of wireless technology, chipless tags are proved to be an economical alternative to chip-based tags. Furthermore, the elimination of chip in these tags, empower them to replace barcodes [5]. These chipless tags operate through incident plane waves that can be vertically, horizontally, circularly or elliptically polarized. Depending upon the orientation of radiating structure, specific polarization type can be used. The radiating structure of the tag can be metal strands, cascaded resonators, spurlines or slot-loaded structures, etc.

2 Chipless smart tags

Previously, chipless tags have only been used for data transmission. To meet the economical requirement of the industry, sensing characteristics are deployed on the chipless tags in addition to the data transmission. In result, these tags with integrated sensing behaviour have the ability to replace expensive discrete sensors. Chipless RFID tags can act as strain [6], temperature [7], humidity [8] and gas [9] sensors. For humidity sensing, paper substrate is ideal to use in low-cost commercial applications. Due to its flexible nature, it can be used on several types of surfaces. Besides this, compactness of the tag is equally important as data capacity [10] in order to directly reduce the manufacturing cost. In this letter, a novel miniaturized 16-bit moisture sensing RFID tag is presented. The tag structure consists of flexible organic substrate having conducting tracks of particle based silver nano ink. The novelty of the proposed tag is its flexible, sensitive, compact and low-cost nature. The proposed tag can be used for various commercial applications which need moisture sensing at extremely low price without the payload of discrete components.

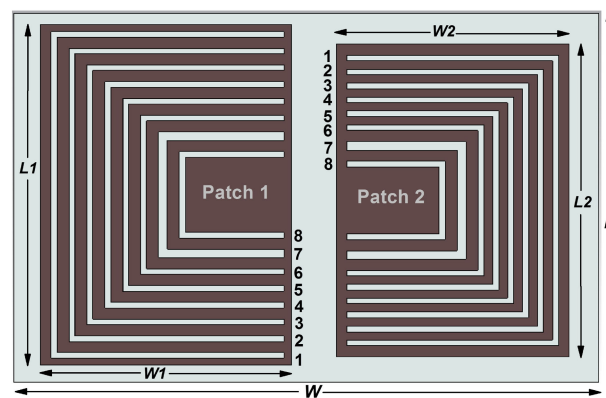


Fig. 1. The layout of designed tag

3 16-bit chipless RFID tag design

With the increasing demand of green electronics, there is a need to develop tags based on organic substrates. To cope with this demand, HP photopaper is chosen as substrate in tag design. Silver nano particle based ink (Cabot Ink CCI-300) is used for conduction and the tag is fabricated utilizing DMP2800 inkjet printer. The proposed tag is designed in CST STUDIO SUITE[®] having a size of $13.2 \times 19.6 \text{ mm}^2$ as shown in Fig. 1. Firstly, the characterization of paper substrate and ink used is performed for maintaining the design accuracy, and the results are shown in Table I.

The dimensions of the tag are kept as $L = 13.2 \text{ mm}$ and $W = 19.6 \text{ mm}$ with the slots etched on silver nano ink patches. The dimensions for patch 1 are $L1 = 12.2 \text{ mm}$ and $W1 = 8.4 \text{ mm}$. Whereas, the dimensions for patch 2 are kept slightly different i.e., $L2 = 11.2 \text{ mm}$ and $W2 = 7.8 \text{ mm}$. The slots are designed on the patches keeping in view the concept that slots should be on alternate positions with metal gaps for adjacent patches. Therefore, each slot of the tag will be of a

Table I. Characterized properties of paper & ink

| Characteristics | HP photopaper | Silver nano ink |
|--------------------|---------------|-----------------|
| Thickness (mm) | 0.25 | 0.015 |
| Permittivity | 3.2 | - |
| Loss tangent | 0.04 | - |
| Conductivity (S/m) | - | 9×10^6 |

different length and consequently resonate on different frequencies. It gives the advantage of fully utilizing the frequency band without overlapping of resonant dips and thus prevents mutual coupling. To avoid any interference between the frequency responses, the slots are not closely designed. By measuring the slot length, the resonance frequency of the slot can be calculated theoretically by using the eq. (1) [11].

$$f = \frac{c}{2L} \sqrt{\frac{2}{\epsilon_r + 1}}. \quad (1)$$

Where ϵ_r is the relative permittivity of the substrate, L is the slot length and c is the speed of light.

The designed tag structure comprising of 16 slots, has 8 slots on each patch. All the slots of patch 1 & 2 are 0.2 mm wide except slot 7 (of both patches) that is 0.3 mm in thickness. The metal gap between each slot of patch 1 is kept at 0.4 mm. However, the metal gap between each slot of patch 2 is kept as 0.3 mm except between slot 6, 7 & 8 that is 0.4 mm.

4 Results and discussion

The proposed tag is realized for data transmission of 16 bits, where each bit corresponds to one slot. Hence, there can be a total number of 2^{16} unique bit combinations i.e., 65536 data encoding arrangements. The tag is deployed in a real environment in order to obtain measured results. The experimental setup is same as in [12] consisting of transmitting and receiving horn antennas, vector network analyzer (VNA) R&S®ZVL13 and the fabricated chipless RFID tag. To measure the radar cross section (RCS) of tag, the Fraunhofer (far-field) distance is calculated using eq. (2).

$$R = \frac{2D^2}{\lambda}. \quad (2)$$

D is maximum dimension of the tag and λ is the wavelength.

It is being observed that horizontally polarized slots yields frequency signature when excited with horizontally polarized plane waves and vice versa. Each slot in the patch is numbered according to its length and it is deduced that the shortest slot will give resonance at the highest frequency. Similarly, as the slot length increases, the frequency response drifts towards lower frequencies. The rectangular silver ink patches also resonate but their frequency responses are out of our desired band. Moreover, the collected data points show close correspondance to computed results. The frequency response of proposed tag is measured in terms of RCS

graph. The measured and computed results along with tested RFID tag having total size of $13.2 \times 19.6 \text{ mm}^2$, are shown in Fig. 2.

Each slot has a unique response at the corresponding resonance frequency. A slot depicts a logic state ‘1’ when interrogated with incident plane waves. To change the logic state to ‘0’, the slot is shorted or removed. The shorted slot will show no resonance in our desired band and thus absence of resonance dip corresponds to 0 bit at the respective resonance frequency. Incorporating this concept; numerous tag IDs can be generated by either shorting the slots or keeping them same as shown in Fig. 3. Therefore, a unique ID can be allocated to each tag which will result in avoiding collision of data in any network. The frequency response of all the slots are independent to each other ideally. In real environment, shorting of any slot will have a minor effect on frequency response of neighbouring slots which can also be observed in [12].

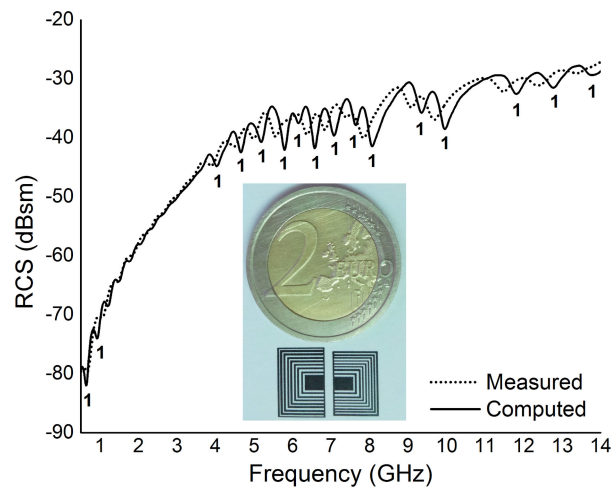


Fig. 2. Measured and computed RCS response.

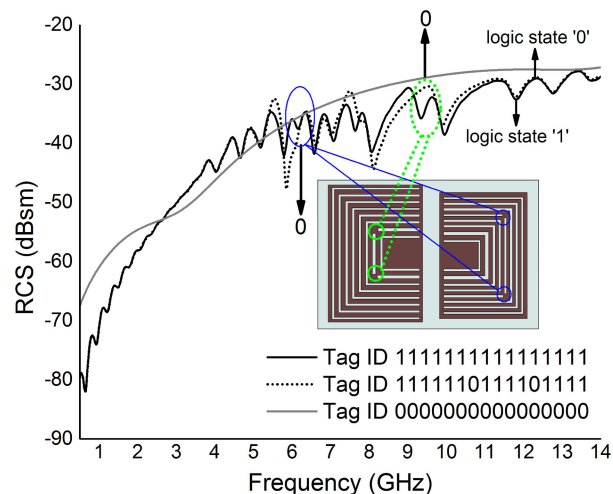


Fig. 3. Frequency response of tag IDs.

It is experimentally (analyzed using climate chamber by Weiss Technik WK11-180) observed that the proposed tag exhibits stable sensitivity towards moisture in ambient environment. The frequency response of the presented tag slightly drifts

towards lower frequency for a gradual increase in moisture. This sensing behaviour of the tag is inspected by applying different moisture levels in chamber. The HP photopaper substrate of the realized tag is capable of absorbing moisture. This eliminates the need to use any external circuit for sensing thus, intensifying its novelty. The proposed moisture sensor behaviour is categorically depicted in zoomed view of resonance bit at 8.45 GHz is shown in Fig. 4.

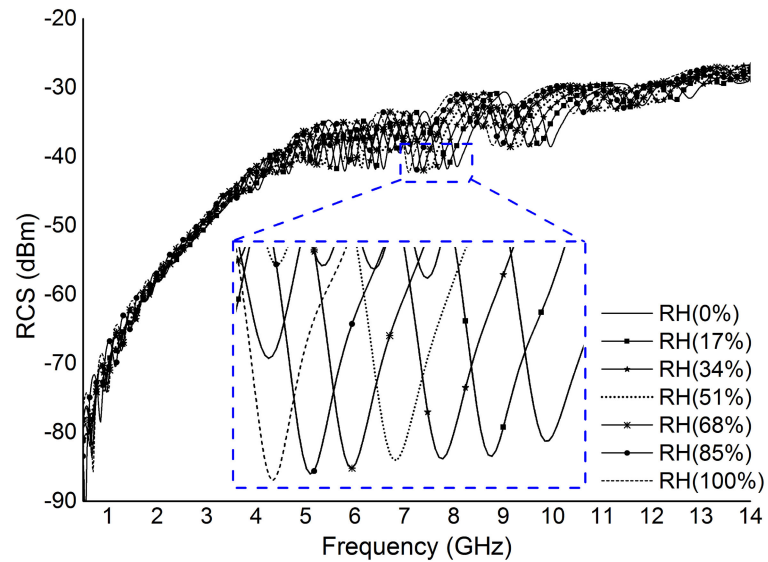


Fig. 4. Response of proposed moisture sensor

It is also observed that the quality factor of passive components which are realized on organic substrates is comparatively low [13], but these tags provide other numerous advantages which are incomparable. These advantages include recycling, environmental friendly, low-cost, easy availability and light weight nature of these tags.

5 Conclusion

A novel chipless RFID moisture sensor tag is realized. The tag, capable of generating 2^{16} (65536) unique IDs is systematically optimized using HP photopaper as substrate incorporating the benefits of flexible green electronics. The proposed tag not only enhanced the data capacity within the minimum possible area, but also exhibits the sensor function without involving any additional components. Moreover, the tag is roll-to-roll printable which is an efficient replacement to chip-based tags along with advantages of compactness, moisture sensing, flexibility and low-cost.

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