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LETTER

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Dual-polarized chipless humidity sensor tag

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Abstract: In this letter, a miniaturized, flexible and high data dense dual-polarized chipless radio frequency identification (RFID) tag is presented. The tag is designed within a minuscule footprint of $29 \times 29\,\text{mm}^2$ and has the ability to encode 38-bit data. The tag is analyzed for flexible substrates including Kapton® HN DuPont™ and HP photopaper. The humidity sensing phenomenon is demonstrated by mapping the tag design, using silver nano-particle based conductive ink on HP photopaper substrate. It is observed that with the increasing moisture, the humidity sensing behavior is exhibited in RF range of 4.1–17.76 GHz. The low-cost, bendable and directly printable humidity sensor tag can be deployed in a number of intelligent tracking applications.

Keywords: humidity sensor, green electronics, low-cost, chipless RFID

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

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1 Introduction

Man has always strived for a better, easier and more comfortable living standard and the revolutionary technology of Internet of things (IoT) is thought to be one of the most effective platforms in changing this dream to reality. IoT acts as a bridge between human beings and all the objects in the physical world around them; so as to create a meshwork of closely associated objects/items [1]. Radio frequency identification (RFID) is the imperative prerequisite of IoT; without this IoT would not have been known better than a fantasy. RFID is a contactless wireless technology [2], which has earned widespread popularity, owing to its unique attribute of readily identifying/tracking the objects without requiring any line of sight communication [3] for its operation. RFID system [4] comprises of two basic components; RFID reader or interrogator that is attached to a computer and RFID tag, more specifically known as a transponder. RFID is used in a number of applications including health care, asset tracking [5], logistics [6] and supply chain management [7] etc.

Chip-based tags consist of an integrated circuit [8] that poses strict monetary limitations and therefore are no longer the ideal choice of academic as well as the industrial sector. Chipless RFID tags have gathered much attention of the researcher community due to their low-cost, ability to cater high data capacity and simple design. They work on the principle of backscattering i.e., the reader showers the interrogating signal on the tag which then reflects the encoded information back to the reader. Furthermore, in order to achieve smart working, sensing feature is integrated along with data storing characteristic of chipless RFID tags. Depending on the environment and nature of a particular application chipless tags can be deployed as crack, moisture, gas and temperature sensors [9, 10].

In past, the researchers have achieved 24-bits within a tag dimension of $20.6 \times 19.9\,\text{mm}^2$ covering a bandwidth of 13.5 GHz [10], whereas in the proposed research work the tag yields 38-bits in a squeezed bandwidth of 13.66 GHz within a compact size of $29 \times 29\,\text{mm}^2$. The tag has a dual-polarized circuitry which depict its polarization independent nature. The uniqueness of proposed backscattering based chipless RFID tag relies on its compact size, low budget requirement, and

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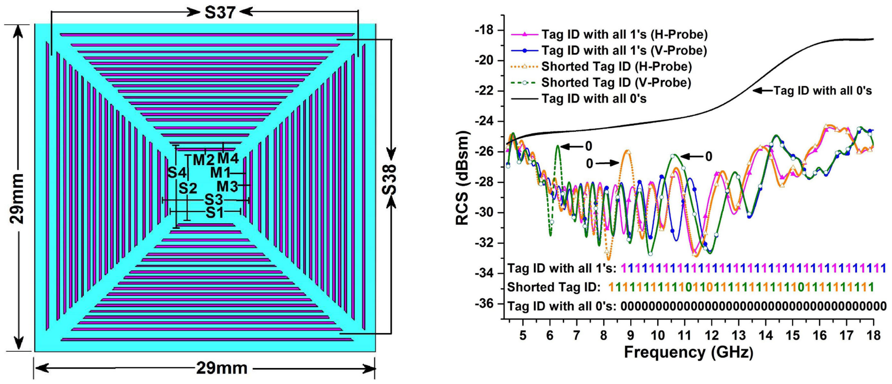
38-bit high data capacity together with the ability to yield a better paper based radar cross section (RCS) response.

2 Proposed chipless tag design

The proposed chipless tag is designed using different substrates and radiators. Initially, the tag is analyzed and optimized for item-level tagging using flexible substrate Kapton® HN DuPont™ along with aluminum and silver nano-particle based conductive ink as radiators. Keeping in view, the ample accessibility and low manufacturing cost of paper the tag is also scrutinized for green electronic based moisture sensing using HP photopaper substrate along with silver nano-ink as radiator. Thus the flexible paper based tag can be easily deployed on irregular surfaces. From previous researches, it is observed that the RCS response degrades with the use of paper substrate [8]. In [10] the quality of the RCS response is much degraded. Contrary to this, the proposed tag structure is designed in such a manner that significantly improves the quality of the RCS response which ultimately leads to its use in long read range applications. The tag is designed using CST Studio Suite® tool. The labelled tag design is shown in Fig. 1(a).



(a) (b)

Fig. 1. (a) Tag design (b) Shorted Tag ID's

The proposed tag is capable of transmitting 38 number of bits, which signifies that it can generate 2^{38} number of unique ID's in a compact dimension of $29 \times 29\,mm^2$. The square-shaped geometrical structure of the tag jointly comprises of thirty-eight slot resonators having different lengths, which is a combination of nineteen horizontally polarized and nineteen vertically polarized bar-shaped slot resonators. The encoded information is stored in the tag's resonating structure. In the proposed tag design, the metallic radiators are symbolized as *M1-M38* and have fixed width of *0.2 mm*. Whereas, the slots i.e., (gaps between the metal portions) are referred as *S1-S38*. The vertical slot resonators are represented by even numerals and are labeled as *S2*, *S4* so on. Moreover, the horizontal slot resonators are represented by odd numerals and are labeled as *S1*, *S3* so on. In order to to achieve better RCS response, there is a non-uniformity in the width of the slots i.e., (*S1, S2 = 6.5 mm*), (*S3, S4, S7, S8, S35 and S36 = 0.4 mm*), (*S5, S6, S9 and S10 = 0.5 mm*). The slots *S11-S34* are of *0.3 mm* width, whereas, slots *S37*, *S38*

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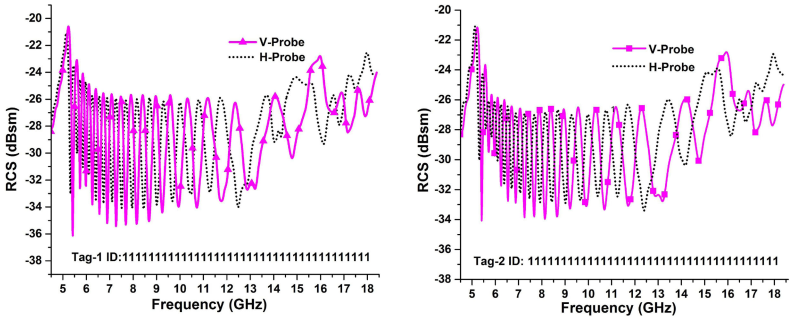
are of *0.7 mm* width. When the incident electromagnetic (EM) waves energize the metallic radiators then, each slot produces one dip, which ultimately corresponds to one bit or a logic state-1. The logic state-1 can be changed to 0 by shortening a slot. A shorted slot does not give a resonant dip at a particular frequency and thus corresponds to 0 bit. Hence by shortening, multiple tag ID's can be generated. Consequently, each tag can be identified through a unique ID code, which prevents the data collision in a network. Since each slot resonates at a different frequency, so shortening any slot has a minor impact on frequency response of the neighboring slots [11]. Fig. 1(b) illustrates, the RCS response of paper based tag labelled as (tag ID with all 1's), secondly, shorted tag ID (generated by shortening slot *S12*, *S15* and *S28*) and tag ID with all 0's (obtained by shortening all slots).

Table I. Characteristic comparison table

Parameters	Tag-1	Tag-2	Tag-3
Substrate	Kapton® HN	Kapton® HN	HP photopaper
Thickness (mm)	0.125	0.125	0.25
Permittivity	3.5	3.5	3.2
Loss Tangent	0.0026	0.0026	0.04
Radiator	aluminum	silver nano-ink	silver nano-ink
Thickness (mm)	0.007	0.015	0.015
Freq. band (GHz)	5.3–17.9	5.3–17.93	4.1–17.76

3 Results and discussion

The tag is analyzed using flexible Kapton® HN substrate along with two different radiators; aluminum and silver nano-ink. They are referred as 'Tag-1' and 'Tag-2', respectively. Whereas the paper based tag is named as 'Tag-3'. A comparison of Tag-1 and Tag-2, reveal that the resonant dips shift slightly, by changing the radiators while keeping the same Kapton® HN substrate. The frequency bands of Tag-1 and Tag-2, given in Table I justify this fact. A characteristic comparison of the proposed tag structure, analyzed using different substrates and radiators, is presented in Table I. The RCS curves, of Tag-1 and Tag-2, are shown in Fig. 2(a) and Fig. 2(b), respectively.



(a) (b)

Fig. 2. (a) RCS curve of Tag-1 (b) RCS curve of Tag-2

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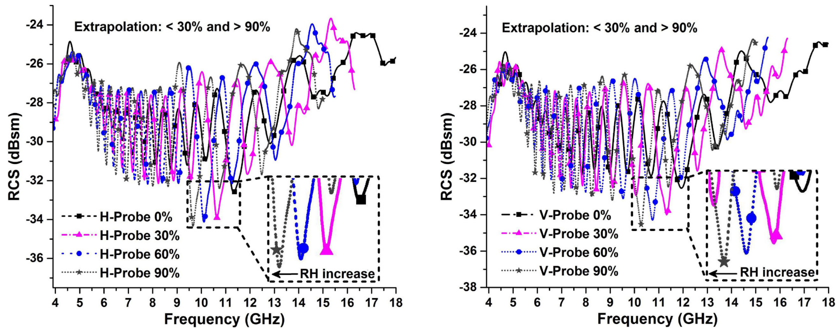
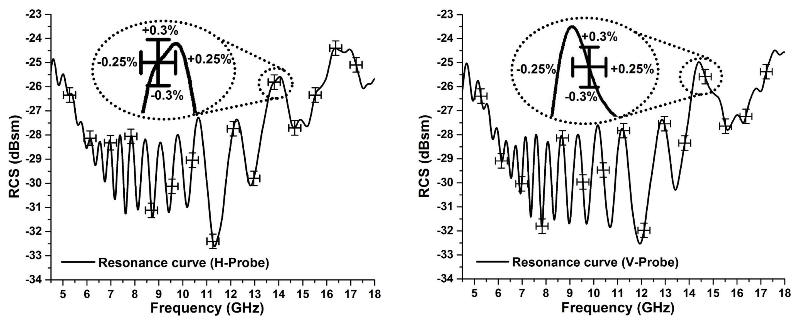
The proposed tag designed using HP photopaper substrate and silver nano-ink radiator constitutes a sound moisture sensing behavior, which is experimentally observed using climatic chamber by Weiss Technik WK11-180. The HP photopaper has the ability to absorb the moisture present in the environment. It is observed that, with the increasing humidity level inside the climatic chamber, the electrical properties of the substrate also vary, due to which the frequency response of the tag exhibits a subtle shift towards the lower frequencies. The moisture sensing behavior of the tag on H-Probe and V-Probe is studied for different RH values i.e., 30%, 60% and 90% which is portrayed in Fig. 3(a) and Fig. 3(b), correspondingly.



(a) (b)

Fig. 3. Humidity sensing curve (a) H-Probe (b) V-Probe

In order to examine the robustness of the paper-based tag its reliability factor is determined, for this reason five to six prototypes of proposed tag were fabricated and tested. It is observed that the tag depicts 0.3% tolerance along the RCS axis, whereas a tolerance of 0.25% is noticed in RF band of interest. Thus, the proposed tag renders a quite reliable behavior, the reliability curve of the tag on H-Probe and V-Probe is shown in Fig. 4(a) and Fig. 4(b), respectively.



(a) (b)

Fig. 4. Reliability curve (a) H-Probe (b) V-Probe

The tag is tested using the experimental setup as shown in [11]. It comprises of two horn antennas (one is transmitting and the other is receiving horn antenna), a Vector Network Analyzer (VNA) and the chipless RFID tag. The tag is positioned at a far-field distance from the antennas. The incident plane wave is showered on to

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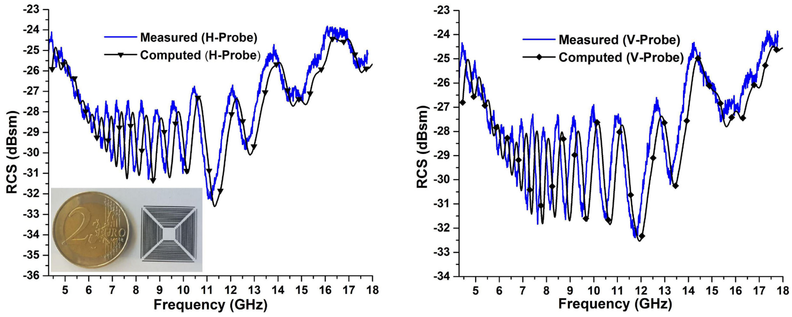
the tag using the transmitting antenna, while the receiving antenna gathers the backscattered signal with the help of (VNA) R&S®ZVL13. The computed and measured results on H-Probe along with the prototype of printed tag is shown in Fig. 5(a). The tag is printed using FUJIFILM DMP-2800 Dimatrix inkjet printer with silver nano-ink (Cabot CCI-300) as radiating material. Moreover, Fig. 5(b) depicts the computed and measured RCS response on V-Probe.



(a) (b)

Fig. 5. Computed and measured RCS response (a) H-Probe (b) V-Probe

4 Conclusion

A novel, dual polarized, 38-bit tag with a stable paper based RCS response is revealed. The compact $29 \times 29\,mm^2$ tag is liable to generate 2^{38} number of unique ID's with minimum ink consumption. The tag also exhibits humidity sensing functionality without requiring any external circutry. Owing to its numerous advantages involving compactness, low manufacturing cost, flexibility together with the ability to produce comparatively sharp and better resonant dips on paper substrate the tag is an impressive choice for long read range applications.

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