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LETTER
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Frequency signatured directly printable humidity sensing tag using organic electronics

Ayesha Habib[1a)], **Yasar Amin**[1,2], **Muhammad Awais Azam**[1], **Jonathan Loo**[3], **and Hannu Tenhunen**[2,4]

[1] *ACTSENA Research Group, University of Engineering and Technology (UET), Taxila, Pakistan*

[2] *iPack VINN Excellence Center, Royal Institute of Technology (KTH), Isafjordsgatn 39, Stockholm, SE-16440, Sweden*

[3] *Department of Computer and Communications Engineering, Middlesex University, UK*

[4] *TUCS, Department of Information Technology, University of Turku, Turku-20520, Finland*

a) *ayesha.habib@uettaxila.edu.pk*

Abstract: In this paper chipless RFID tag, capable of carrying 9-bit data is presented. The tag is optimized for several flexible substrates. With growing information and communication technology, sensor integration with data transmission has gained significant attention. Therefore, the tag with the same dimension is then optimized using paper substrate. For different values of permittivity, the relative humidity is observed. Hence, besides carrying information bits, the tag is capable of monitoring and sensing the humidity. The overall dimension of the tag comprising of 9 ring slot resonators is 7 mm. Due to its optimization on the paper substrate, the tag can be an ideal choice for deploying in various low-cost sensing applications.

Keywords: RFID, ring resonator, sensing, radar cross section

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

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1 Introduction

Radio-frequency identification (RFID) is a wireless technology used in various applications such as logistics [1], asset tracking [2] and supply-chain [3]. Due to its numerous advantages over previous technologies, it has gained significant interest. It is capable of providing non-line-of-sight communication with long read ranges. RFID tag and RFID reader are responsible for carrying communication process in RFID system. Passive chipless RFID tag itself is an economical solution to previous chip-based approaches [4]. RFID tags with integrated sensors have paved the path for numerous low-cost sensor applications. The ultimate cost of the system is further reduced by integrating sensor with chipless RFID tag.

Table I. Substrate parameters

Substrate	Thickness (mm)	Permitivity	Loss Tangent
FR4 epoxy	0.5	4.4 (average)	0.02
Kapton® HN	0.175	3.5 (average)	0.04
PET	0.1	3.3 (average)	0.003
Paper	0.25	3.3 (average)	0.077

In this proposed research work, a 9-bit chipless RFID tag structure is analyzed for different substrates. It has been motivated by the fact that the cost of chipless RFID system is reduced as compared to previous chip-based researches. Furthermore, the proposed tag is realized on PET and Paper substrates, while analyzed for complete set of parameters defined for flexible electronics.

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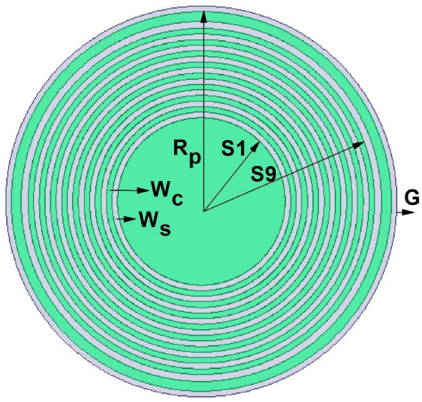
2 Working principle of chipless tag

A chipless RFID tag is a fully passive circuit having no external power recovery system [5]. Incident plane wave is used to excite the tag and radar cross section (RCS) parameter is used to observe the reflectivity level of a particular tag. The reader sends the signal to excite the tag, and the backscattered signal is received by the reader [6]. Radio-frequency spectrum is used to transmit the encoded information. The communication is carried out between tag (RFID) and reader (RFID), where the tag is responsible for encoding the data and thus the encoded data is identified by RFID reader [7]. The encoded information is based on frequency signature and hence, each tag has unique tag ID.



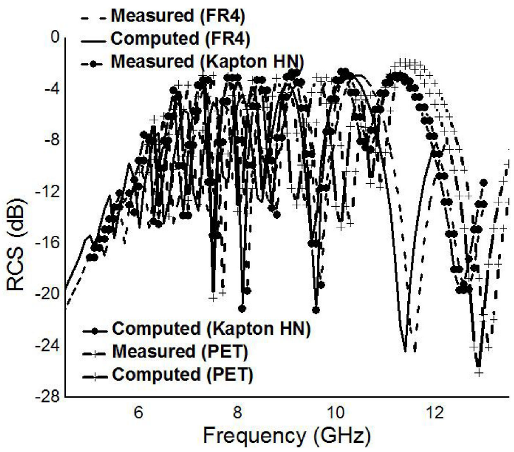


Fig. 1. (a) 9-bit tag design with ID '111111111'; (b) Measured and computed RCS response

In this paper, printable chipless RFID tag capable of encoding 9-bit information has been proposed. Data encoding is based on multiple ring slot resonators. The tag structure is analyzed for different substrates. Table I shows the evaluated substrate parameters.

3 Chipless RFID tag design

The tag structure is designed and computed in ANSYS HFSS™ and excited by a plane wave. The 9-bits ring slot resonator is shown in Fig. 1(a). The dimensions of the proposed optimized tag are shown in Table II. $S1$–$S9$ are the radius of resonating slots, Rp is the radius of patch, Wc is the width of copper, Ws is the width of slot and G is the gap between overall patch and substrate. The radius of patch $Rp = 6.8$ mm and gap between the patch and substrate $G = 0.2$ mm. The slots are numbered according to their lengths. $S1$ is the smallest slot corresponding to the highest frequency, while $S9$ is the largest slot corresponding to the lowest frequency.

The increasing width of slots enhances the sharpness of resonances, but in order to make tag design more compact the optimized tag is having a slot width of 0.2 mm. Therefore, all slots from $S1$–$S8$ are of uniform width i.e., 0.2 mm while the slot with the largest radius $S9$ is of width 0.25 mm for better results. The

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Table II. Proposed optimized tag dimensions

No. of slots	Radius of slot (mm)	Width of slot (mm)	Width of copper (mm)
1	3	0.2	0.2
2	3.4	0.2	0.2
3	3.8	0.2	0.2
4	4.2	0.2	0.2
5	4.6	0.2	0.2
6	5	0.2	0.2
7	5.4	0.2	0.2
8	5.8	0.2	0.2
9	6.2	0.25	0.2

experimental setup consists of chipless RFID tag, transmitting and receiving horn antennas and vector network analyzer (VNA) R&S®ZVL13. The tag is placed at far-field distance to measure the RCS of the tag.

3.1 FR4 substrate

The results of optimized tag using FR4 epoxy substrate is shown in Fig. 1(b). The computed results are for tag ID 11111111. The 9-bit data covers a band of 5.1–11.4 GHz with the bandwidth of 6.3 GHz. Each resonance corresponds to one bit data. Hence, nine resonances show 9-bit data. The 9-bit data is yielded for the resonance frequencies 5.1, 5.5, 6.0, 6.5, 7.2, 7.8, 8.5, 9.5 and 11.4 GHz, respectively.

3.2 Kapton® HN substrate

The optimized tag design using Kapton® HN yields 9-bits for the frequency range of 5.8–12.5 GHz. The band of 6.7 GHz has been utilized to transmit the encoded information. The tag response for tag ID 111111111 using Kapton® HN is shown in Fig. 1(b). The resonating frequencies corresponding to 9-bit data are 5.8, 6.3, 6.9, 7.5, 8.1, 8.7, 9.6, 10.6 and 12.5 GHz.

3.3 PET substrate

The RCS response of optimized tag structure using polyethylene terephthalate (PET) substrate is shown in Fig. 1(b). Each resonance corresponds to data transmission of one bit, therefore, nine resonances for 9-bit data can be observed. The corresponding resonating frequencies are 6.4, 7.0, 7.5, 8.0, 8.5, 9.2, 10.1, 10.7, 12.9 GHz covering the overall bandwidth of 6.5 GHz.

3.4 Paper substrate

The printed tag structure and the analysis for 9-bit data transmission using paper substrate is shown in Fig. 2 to overcome the limitation of previous researches [8, 9]. The RCS response for the paper substrate is analyzed for a band of 5.6–12.9 GHz using the overall bandwidth of 7.3 GHz. The RCS response for tag

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ID having all ones i.e., 111111111 and for tag ID consisting one 0 bit in it i.e., 111111101 is shown in Fig. 2. Likewise, multiple tag IDs can be generated for tagging multiple objects.

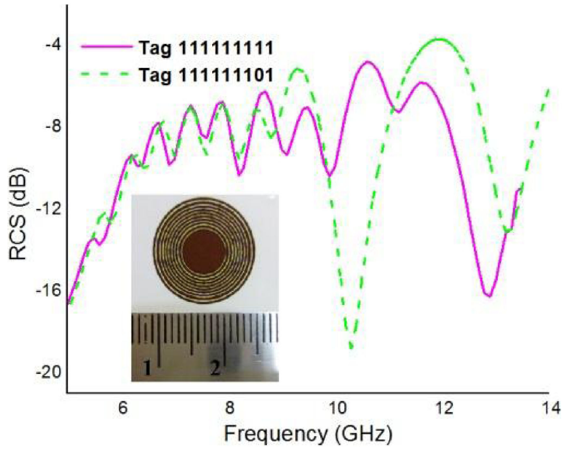

Fig. 2. RCS response of paper printed tag

The 0 bit in tag ID is achieved by removing particular slot. Therefore, multiple tag IDs can be generated and number of objects can be facilitated by using this method.

4 Result and analysis

The comparison between the designs using different substrates is shown in Table III. It has been analyzed that, with the change in permittivity there is a shift in resonances. Fig. 3(a) shows the RCS plot for all three substrates i.e., FR4 epoxy, Kapton® HN and PET. It can be observed from the following graph that, with the decrease in permittivity there is a right shift in resonant frequencies.

Table III. Substrate parameters

Substrate	Data bits (mm)	Bandwidth (GHz)	Flexibility	Sensing
FR4 epoxy	9	6.3	No	No
Kapton® HN	9	6.7	Yes	No
PET	9	6.5	Yes	No
Paper	9	7.3	Yes	Yes

The proposed tag is designed and analyzed for the paper substrate using the same overall dimension but with a small variation in slot widths. The tag design with the paper substrate is exhibiting as a humidity sensor in addition to identification [10]. Consequently, the tag is analyzed for different values of permittivity ranging from 3.3–5. It has been observed that with increasing humidity there occurs an increase in permittivity value. Therefore, increasing humidity will result in a left shift of resonant frequencies.

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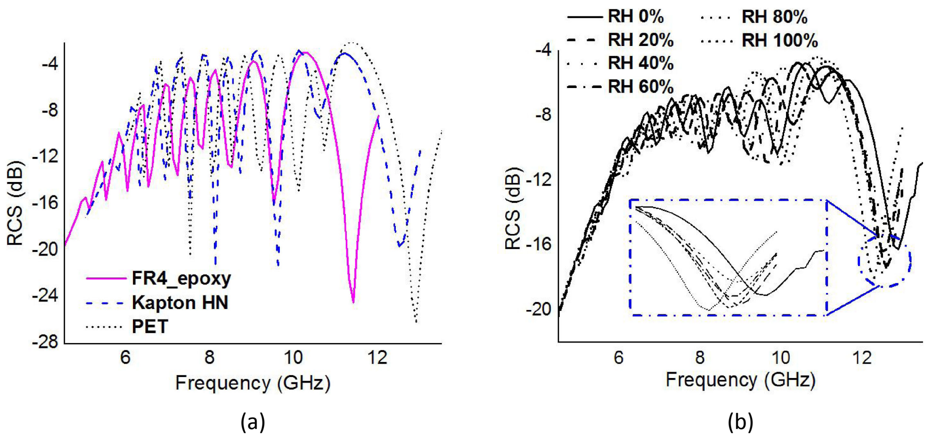

Fig. 3. RCS response of paper printed tag

The relative humidity can be depicted for different humidity levels from Fig. 3(b). From these results, it can be observed that with the change in permittivity of substrate material there will be a shift in resonances. Hence, the overall band for data transmission will also shift.

5 Conclusion

In this paper, a compact chipless RFID tag has been presented for 9-bit data capacity. Firstly, the tag is optimized using FR4 epoxy substrate, then using Kapton® HN and PET substrates to yield the results for flexible electronics. The tag exhibits an extra degree of application by incorporating the humidity sensor functionality by using paper substrate. The shift in resonances due to the change in dielectric constant in a controlled manner is exploited for implementing the sensor behaviour along with the tag. The proposed chipless RFID tag can be deployed for many low-cost sensing applications.

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