ELectronics EXpress

LETTER

IEICE Electronics Express, Vol.14, No.10, 1–6

Directly printable compact chipless RFID tag for humidity sensing

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Abstract: In this letter, 8-bit paper based printable chipless tag is presented. The tag not only justifies the green electronic concept but also it is examined for sensing functionality. The compact tag structure comprises of seven L-shaped and one I-shaped dipole structure. These conducting tracks/dipole structures are of silver nano-particle based ink having a conductivity of 1.1×10^7 S/m. Each conducting track yields one bit corresponding to one peak. The tag design is optimized and analyzed for three different flexible substrates i.e. paper, Kapton® HN, and PET. The tag has ability to identify $2^8 = 256$ objects, by using different binary combinations. The variation in length of particular conducting strip results in a shift of peak for that specific conducting track. This shift corresponds to logic state-1. The response of the tag for paper, Kapton® HN, and PET substrates is observed in the frequency band of 2.2–6.1 GHz, 2.4–6.3 GHz, and 2.5–6.5 GHz, respectively. The tag has an attractive nature because of its easy printability and usage of low-cost, flexible substrates. The tag can be deployed in various low-cost sensing applications.

Keywords: chipless tag, RFID, sensing, backscattering

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

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DOI: 10.1587/elex.14.20170169
Received February 24, 2017
Accepted April 3, 2017
Publicized April 28, 2017
Copyedited May 25, 2017

IEICE Electronics Express, Vol.14, No.10, 1–6

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1 Introduction

Today, to fulfill the growing communication needs of modern society the main focus of researchers is internet-of-things (IoT) paradigm. IoT is a network of millions of smart objects; paves the path for low-cost sensing systems [1]. IoT serves for many potential applications ranging from smart monitoring, smart sensing, and smart grids to green-electronic based tracking systems. Radio frequency identification (RFID) uses radio waves to transmit/receive data, and it is one among the supporting technologies for IoT [2]. To fulfill the data transmission and environment sensing requirements; RFID tags must be capable of sensing functionality along with data transmission. RFID is a potential substitute for barcode identification because of its various advantages like non-line of sight communication, longer read range, low-cost deployment, and energy harvesting [3, 4].

RFID is an emerging intelligent item/object recognition technology based on electromagnetic (EM) wave transmission. The main barrier to the deployment of RFID technology is its cost. The cost is due to the embedded silicon IC's [5] and the solution to this problem is chipless RFID. A RFID system without silicon IC's, known as 'chipless RFID system'. The chipless tag is excited through EM waves transmitted by the reader; in response, the tag sends the modulated backscattered signal. The data can be encoded in time as well as frequency domain. RFID technology has many applications in areas such as retail item management, asset/

DOI: 10.1587/elex.14.20170169
Received February 24, 2017
Accepted April 3, 2017
Publicized April 28, 2017
Copyedited May 25, 2017

object tracking, logistics, supply chain, transportation, and healthcare [6]. Still, there are many challenging areas in which there is a need to work for improved communication systems.

One of the key integrated functions of present devices is sensing. Integration of encoded information accompanied with sensing functionality is gaining significant interest [7, 8]. There are numerous applications of sensor RFID technology such as moisture sensing, monitoring weather, temperature sensing and gas sensing. By eliminating the discrete external sensor, the overall cost of RFID system is reduced [9, 10]. In this proposed reported work, 8-bit chipless RFID tag, exhibiting sensing behavior is presented. The tag structure is optimized for the organic substrate to meet the flourishing 'green electronic' concept. The proposed tag is loaded with seven L-shaped and one I-shaped dipole structure. In this research work, the silver nano-particle based conducting tracks are deposited on an organic substrate. This feature will allow the easy printability of tag design.

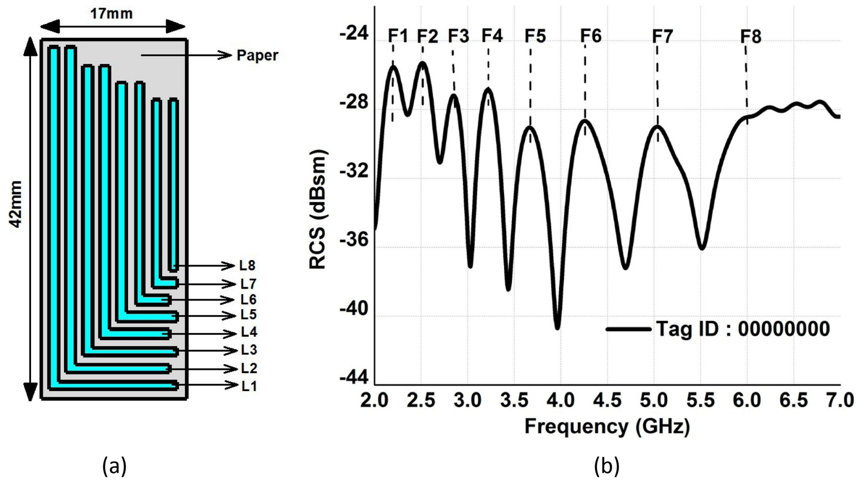

Fig. 1. (a) Labelled tag design; (b) RCS response of paper based tag

2 Flexible chipless RFID tag design

The tag design conforms eight dipole structures as shown in Fig. 1(a). The silver nano-particle based conductive tracks have conductivity of 1.1×10^7 S/m and thickness of 15 um. The paper substrate used in the design have an electrical permittivity 3.3 with the loss tangent 0.077, is optimized and analyzed using CST Studio Suite® (tool for simulation). Firstly, the tag is analyzed for $59 \times 17\,\text{mm}^2$ dimension and lately the tag structure is reduced by 28.81% to meet the race of modern compact technology.

The tag is capable of yielding 2^8 different combinations. The efficient band of 2.2–6.1 GHz has been used for data transmission. The eight dipole structures correspond to 8-bit data transmission. Each strip is 1 mm wide and substrate dimensions are 1 mm apart from all the sides. $L1$–$L8$ is showing the length of each strip. There is a uniform length difference among all the strips, i.e., $L1 =$ 55 mm, $L2 =$ 50 mm, $L3 =$ 45 mm, $L4 =$ 40 mm, $L5 =$ 35 mm, $L6 =$ 30 mm, $L7 =$ 25 mm, $L8 =$ 20 mm. The radar cross-section (RCS) response for paper based tag is shown in Fig. 1(b).

DOI: 10.1587/elex.14.20170169
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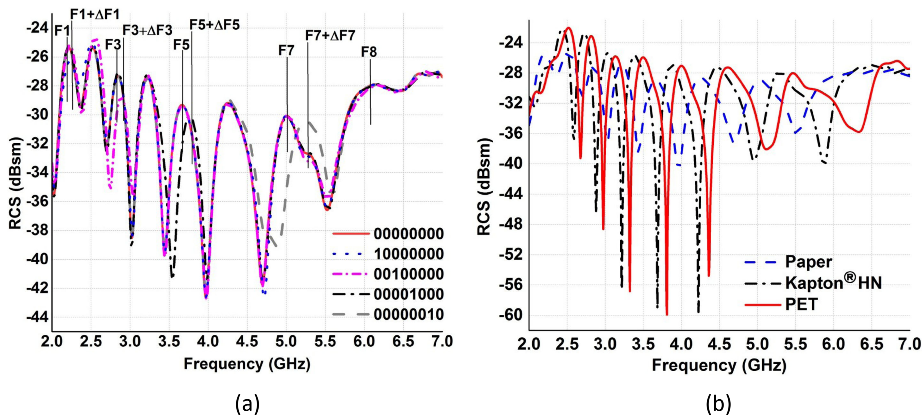

Fig. 2. (a) RCS response for different tag ID's; (b) Comparison graph for different substrates

The incident plane wave is used as an interrogation source and probes are set at a distance equal or greater than the far-field distance to observe the RCS response of tag. The backscattered signal from the tag contains the useful information in the form of tag ID. Each conducting track/strip is responsible for yielding data bit at a particular frequency. In Fig. 1(b), $F1$–$F8$ are resonant frequencies producing data word '00000000' as reference tag ID. Multiple tag ID's can be generated by opting frequency shift encoding principle. By changing the length of the particular resonator, a shift in the resonant peak is produced by a factor 'Δ'. This shift in resonant peak corresponds to logic state-1. The RCS response of tag for different tag ID's is shown in Fig. 2(a). The tag is also optimized and analyzed for other flexible substrates i.e. Kapton® HN and PET. The comparison graph presenting RCS response for different substrates is shown in Fig. 2(b). The electrical properties and behavior of tag using different substrates are elaborated in Table I.

Table I. Characteristic table

Substrate	Thickness (mm)	Permitivity	Loss Tangent	Freq. band (GHz)	Flexibility
Paper	0.25	3.3(average)	0.077	2.2–6.1	√
Kapton® HN	0.125	3.5(average)	0.0026	2.4–6.3	√
PET	0.1	2.9(average)	0.0025	2.5–6.5	√

Table II represents the tag ID's for different binary combinations where $A =$ 00000000, $B =$ 10000000, $C =$ 00100000, $D =$ 00001000, and $E =$ 00000010. It shows the principle of encoding for different data words i.e. change or shift (Δ) in particular peak depicts the logic state-1, while other peaks having no shift represents logic state-0. The logic state-1 corresponds to transmission of '1' bit while logic state-0 corresponds to '0' bit transmission.

The tag prototype is printed by utilizing DMP2800 inkjet printer using silver nano-particle based ink (Cabot Ink CCI-300) as conducting strips. The computed and measured results for proposed tag are shown in Fig. 3(a). It has been observed that measured results are very close to the computed one. The experimental setup

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Copyedited May 25, 2017

Table II. Binary code representation for different tag ID's

Binary Code	Resonant Frequencies							
A	F1	F2	F3	F4	F5	F6	F7	F8
B	Δ	F2	F3	F4	F5	F6	F7	F8
C	F1	F2	Δ	F4	F5	F6	F7	F8
D	F1	F2	F3	F4	Δ	F6	F7	F8
E	F1	F2	F3	F4	F5	F6	Δ	F8

consists of two horn antennas (transmitting and receiving), chipless RFID tag and vector network analyzer (VNA) R&S®ZVL13 to measure the backscattered encoded signal, as in [4, 11]. The tag is placed at a far-field distance of 81.23 mm (as per calculated) from transmitting and receiving horn antennas to measure the RCS response. The Fraunhoffer distance formula is used to calculate the far-field distance, given by Eq. (1) [4]. Using climate chamber by Weiss Technik WK11-180, the humidity/moisture sensing attribute of the proposed tag is observed.

$$R = \frac{2D^2}{\lambda}. \tag{1}$$

Where D is the largest dimension of tag and λ is the wavelength.

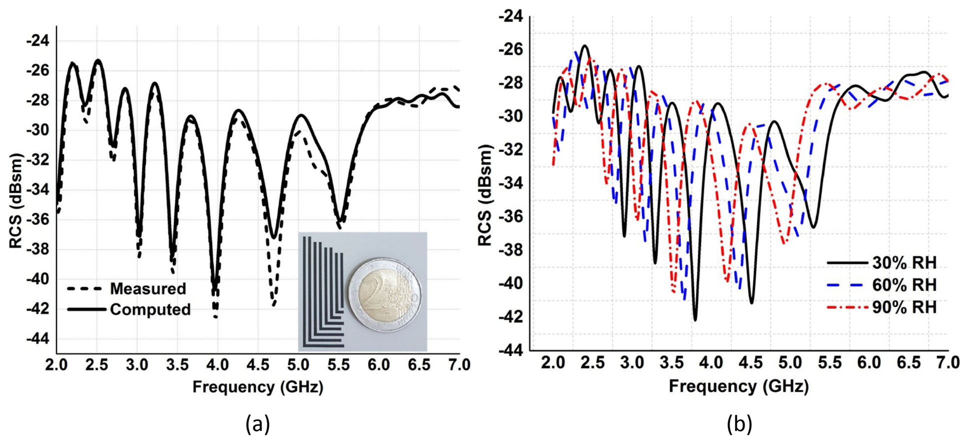

Fig. 3. (a) Printed tag structure & measured RCS response; (b) Humidity sensing curve

3 Humidity sensing

The proposed passive chipless RFID tag has the capability of automatic identification/tracking as well as it exhibits the moisture sensing functionality. With the change in relative humidity (RH), the electrical properties of paper substrate changes. The shift in overall response of tag is observed for increased humidity levels. The humidity sensing behavior of the tag is analyzed for different RH values i.e. 30%, 60%, and 90% shown in Fig. 3(b). It has been analyzed from this graph that with the increasing humidity, the RCS curve drifts towards lower frequencies.

DOI: 10.1587/elex.14.20170169
Received February 24, 2017
Accepted April 3, 2017
Publicized April 28, 2017
Copyedited May 25, 2017

4 Conclusion

In this letter, a passive chipless RFID tag with humidity sensing feature is presented. The printed flexible tag is excited using radio waves, and RCS is measured at a far-field distance. The design of tag is targeted for flexible substrates so that easy deployment of tag on irregular/curved surfaces can be possible. The eight dipole structures in tag design are responsible for producing 8-bit data; hence, yielding $2^8 = 256$ binary combinations. The tag design is well optimized in a way that efficient band utilization is achieved. The paper based passive chipless tag fulfilling the concept of 'green electronics' is suitable for organic substrate based applications. The dual feature tag exhibiting identification and moisture sensing functionalities can be used in various humidity sensing applications.

Acknowledgments

This work was financially supported by Vinnova (The Swedish Governmental Agency for Innovation Systems) and University of Engineering and Technology Taxila, Pakistan through the Vinn Excellence Centers program and ACTSENA research group funding, respectively.

DOI: 10.1587/elex.14.20170169
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