Journal of Industrial Information Technology and Application Vol.5 No.3
ISSN(Online) :2586-0852

8-bit Chipless RFID Tag with Humidity Sensing Capability

Junho Yeo [1, *)]
[1)] School of ICT Convergence, Daegu University, Gyeongsan, Korea

Abstract. In this paper, an 8-bit chipless RFID tag with identification information and humidity sensing capability was proposed. A compact high-sensitivity interdigital-capacitor(IDC)-based resonator was used for humidity sensing, whereas seven electric field-coupled resonators were used for identification information. These 8 resonators were placed in a 2 by 4 array arrangement. poly(vinyl alcohol)(PVA), a hygroscopic polymer material, was coated on the IDC-based resonator with a thickness of 0.02 mm for humidity sensing. A non-reflective temperature and humidity chamber was fabricated using styrofoam, and the relative humidity(RH) was varied from 50% to 80% with a 10% interval at a temperature of 25 degrees in order to measure a bistatic radar cross section(RCS) of the proposed tag. The humidity sensing performance of the tag was measured by the shift in the resonant peak frequency and magnitude level of the RCS. Experiment results show that when RH increased from 50% to 80%, the resonant peak frequency and magnitude of the PVA-coated IDC-based resonator were only changed, whereas those of the other seven resonators without PVA coating did not change.

Keywords; chipless radio frequency identification(RFID), humidity sensing, interdigital-capacitor(IDC), poly(vinyl alcohol)(PVA), radar cross section(RCS)

1. Introduction

RFID(radio frequency identification) technology uses electromagnetic waves in various radio frequency bands and identification information transmitted from tags attached to objects or people in order to automatically recognize the tag-attached object in a non-contact manner[1]. It was developed and used as an early stage technology of internet of things(IoT), which is the core technology of the 4th industrial revolution. It can be considered as a next generation automatic recognition technology to secure

---

[*] Corresponding author: jyeo@daegu.ac.kr
Received: Feb. 10, 2021; Revised: Feb. 26, 2021; Accepted: Sep. 30, 2021

visibility through product tracking and history management by supplementing the shortcomings of barcodes used in logistics and supply chain management. It has been widely used in real life such as transportation card, highway high pass, clothing and book theft prevention, parking management, access control, food waste management, e-passport, etc[2]-[4]. The RFID system consists of a tag attached to an object to provide identification information, and a reader that reads and processes information by communicating with the tag.

RFID tags can be classified into chipped and chipless RFID tags depending on the presence of semiconductor-based integrated circuit chips[5]. Chipped RFID tag uses a semiconductor process to make memories and main circuits, whereas chipless RFID tags do not use chips. Chipped RFID tags can store a variety of information on a chip and have the advantage of miniaturizing the tag, but it is difficult to lower the price of a chip manufactured by a semiconductor process. Chipless RFID tags can be manufactured at low cost because it does not use a chip, but it has limitations in performance such as recognition distance and memory storage. Chipless RFID tags can be classified depending on the operation method such as a magnetic material-based method, a printed electronic circuit-based method, and a microwave resonator-based method.

According to the method of using the electromagnetic waves reflected by the tag, the microwave resonator-base method can be divided into a time domain (or temporal) method, a frequency (or spectral) domain method, and a hybrid method[6]. In the time domain method, a delayed transmission line including a discontinuous reflector or a complex impedance is configured at a specific position on a substrate constituting a tag, and the identification code is composed of reflection generated by the tag. In order to avoid overlapping between reflected pulses and to generate a measurable delay, a transmission line must be implemented with a large length or a very narrow pulse must be used, so the information density per surface is low, and thus bit encoding capability is limited. The frequency domain method is implemented with multiple resonators adjusted to different predefined frequencies in a specific frequency band included in the interrogation signal from the reader, and is determined by the absence or presence of specificity in the amplitude and/or phase of the frequency response of the tag. It can be classified into a re-transmission based and a back scattering based, according to the interaction type between the interrogation signal of the reader and the tag. The retransmission-based tag is equipped with cross-polarized transmit and receive antennas to communicate wirelessly with a reader, and these antennas are used to receive an interrogation signal and transmit a spectrum signal of the tag. In the backscattering-based tag, the resonators provide spectrum signals through singular points in the response of a radar cross section (RCS), and the tag size of the tag is reduced because the tag does not require the use of the transmit and receive antennas. The hybrid method creates information simultaneously in one or more domains such as frequency-phase, frequency-amplitude, frequency-bandwidth, polarization diversity, etc. in order to increase the information density per surface of the tag substrate.

In this paper, an 8-bit chipless RFID tag with identification information and humidity sensing capability was proposed. First, a compact high-sensitivity compact resonator based on an interdigital-capacitor(IDC) structure was designed. The IDC structure was applied to miniaturize the size of the electric field-coupled(ELC) resonator[7], which was used as a high-sensitivity resonator among the frequency domain type chipless RFID tags. Next, a 2 by 4 array consisting of a IDC-based compact resonator and 7 ELC resonators was designed. The IDC-based resonator was used for humidity sensing, whereas 7 ELC resonators were used for identification information. The proposed chipless RFID tag with a 2 by 4 array structure was simulated and designed using CST's Microwave Studio (MWS), a commercial electromagnetic wave analysis software.

2. Compact resonator design using interdigital-capacitor structure

Fig. 1 shows the geometry of the existing ELC and the proposed IDC-based resonators. The resonators are printed on one side of the substrate, *L* and *W*, respectively. The length and width of the square loop are *l* and *w*, respectively. For the design of the resonators, an RF-301 substrate with a relative permittivity (ε_r) of 2.97, thickness (h) = 0.8 mm, and loss tangent (tan δ) = 0.0012 was used. Table I shows the final design parameters of the ELC and the proposed IDC-based resonators. The length of the square loop and the width of the strip of the two resonators were designed to be equal to 8 mm and 0.5 mm, respectively. Fig. 2 simulates and compares the monostatic RCS of the ELC and the proposed IDC-based resonators. RCS is defined as the ratio of the power of the scattered wave returned from the object to the power of the radar transmitted electromagnetic wave, and represents the ability of an object to reflect the electromagnetic energy sent from the radar[8].

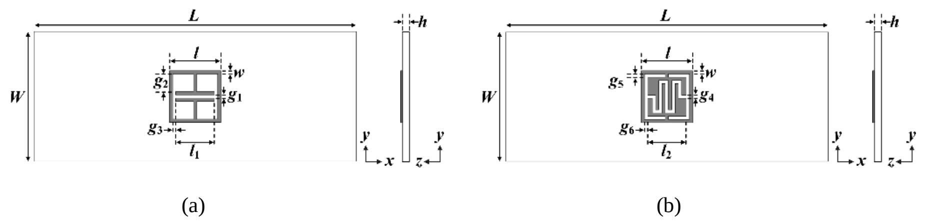


Fig 1. Geometry of resonators: (a) ELC resonator, (b) proposed IDC-based resonator.

TABLE I. FINAL DESIGN PARAMETERS OF ELC AND PROPOSED IDC-BASED RESONATORS

Parameter	Value(mm)	Parameter	Value(mm)
L	50	g_3	0.5
W	20	l_2	6
l	8	g_4	0.5
w	0.5	g_5	0.5
l_1	6	g_6	0.5
g_1	0.5	h	0.8
g_2	2.75		

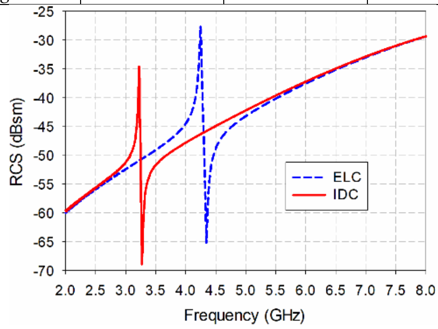
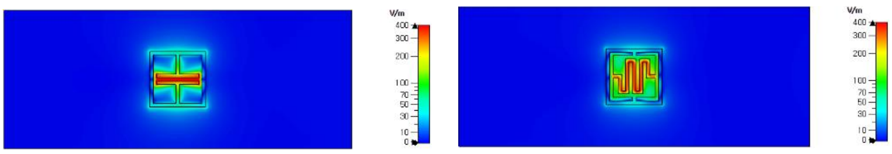


Fig 2. Comparison of simulated monostatic RCS for ELC and proposed IDC resonators.



(a) (b)

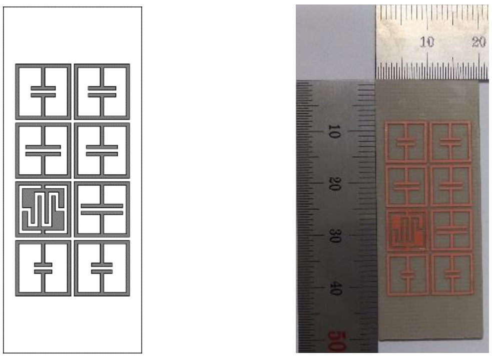
Fig 3. Comparison of electric field distributions at resonant peak frequencies for : (a) ELC resonator, (b) proposed IDC resonator.

The unit of RCS is expressed in m^2 or dBsm (decibel per square meter). When the transmission and reception locations are the same, it is called a monostatic RCS, whereas it is called a bistatic RCS when the transmission and reception locations are different.

It is observed from Fig. 2 that the ELC resonator has a resonant peak at 4.245 GHz and the RCS value is -27.58 dBsm. For the proposed IDC-based resonator, it has a resonance peak at 3.22 GHz and the RCS value is -34.55 dBsm. Since the length of the square loop consisting the resonators is the same, the size of the resonator is reduced by 24.2% based on the resonance peak frequency, and the RCS value is reduced by 6.97 dB due to the size reduction.

Fig. 3 compares the electric field distribution at the resonant peak frequency of the ELC and the proposed IDC-based resonators. In the ELC resonator, the electric field is concentrated between the capacitor-shaped electrode plates, whereas it is concentrated between the electrode plates of the IDC structure for the proposed IDC-based resonator. It can be seen that the length of the electrode plate of the IDC structure is longer than that of the conventional capacitor-shaped electrode plate, so the equivalent capacitance of the resonator is larger, and the resonance peak frequency shifts to a lower frequency because of this.

3. Design of 8-bit chipless RFID tag for humidity sensing and identification information



(a) (b)

Fig 4. 8-bit chipless RFID tag: (a) geometry, (b) fabricated photograph.

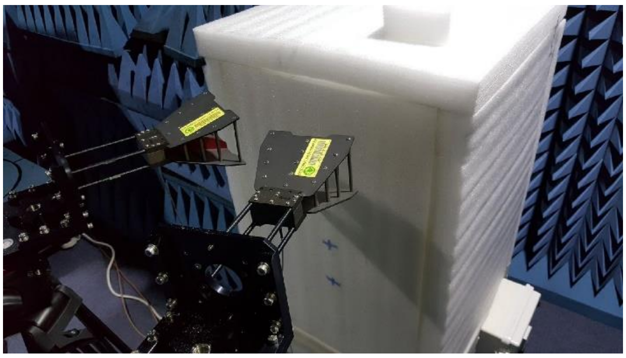


Fig 5. Measuremnt set-up with non-reflective temperature and humidity chamber.

Fig. 4 shows the geometry and fabricated photograph of a chipless RFID tag that simultaneously provides humidity sensing and identification information using the existing ELC resonator and the proposed IDC resonator. For humidity sensing, one IDC-based resonator with a resonant peak frequency at 3.195 GHz was used, whereas seven ELC resonators were design to resonate at 4.135 GHz, 4.31 GHz, 4.56 GHz, 4.78 GHz, 4.995 GHz, 5.19 GHz, and 5.485 GHz, respectively, by adjusting the length of the capacitor-shaped electrode plate for identification information. The IDC-based resonator was designed to be located second to the left from the bottom in a 2 by 4 arrangement on a 20 mm×50 mm RF-301 substrate (ε_r = 2.97, h = 0.76 mm, tan δ = 0.0012). The spacing between the resonators was chosen to be 0.5 mm.

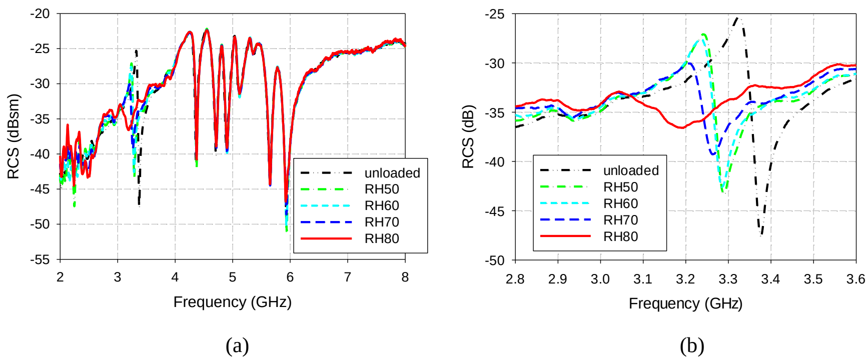


Fig 6. Measured bistatic RCS results of 8-bit chipless RFID tag: (a) 2 ~ 8 GHz, (b) 2.8 ~ 3.6 GHz.

A hygroscopic polymer material, poly(vinyl alcohol)(PVA), was coated on the IDC-based resonator with a thickness of 0.02 mm for humidity sensing. In order to measure the bistatic RCS change of proposed 8-bit chipless RFID tag according to the relative humidity, a non-reflective temperature and humidity chamber was manufactured using styrofoam, as shown in Fig. 5. Relative humidity(RH) was varied from 50% to 80% with a 10% interval at a temperature of 25 degrees in order to measure a bistatic radar cross section(RCS) of the proposed tag.

Fig. 6 shows measured results of an 8 bit chipless RFID tag for varying RH. The IDC-based resonator for humidity sensing has a resonant peak frequency of 3.324 GHz for the bistatic RCS when it is not coated with PVA. The resonant peak frequencies of the 7 ELC resonators were measured as 4.258 GHz, 4.55 GHz, 4.802 GHz, 5.034 GHz, 5.292 GHz, 5.464 GHz and 5.778 GHz, respectively, which are slightly shifted to higher frequencies compared to the simulated results. When RH varied from 50% to 80% with 10% increments, the bistatic RCS resonance peak frequency and magnitude of the IDC-based resonator for humidity sensing was changed, and the 7 ELC resonators used for identification information did not change.

4. Conclusion

An 8-bit chipless RFID tag for providing humidity and identification information simultaneously has been proposed. A 2 by 4 array consisting of one IDC-based resonator for humidity sensing and seven ELC resonators for identification information was fabricated on , an RF-301 substrate. poly(vinyl alcohol)(PVA), a hygroscopic polymer material, was coated on the IDC-based resonator with a thickness of 0.02 mm for humidity sensing.

When RH increased from 50% to 80% by using a non-reflective temperature and humidity chamber, the resonant peak frequency and magnitude of the PVA-coated IDC-based resonator in the 8-bit chipless RFID tag were only changed, whereas those of the other seven resonators without PVA coating did not change.

Acknowledgment

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education(2018R1D1A1B07046040).

References

[1] K. Finkenzeller, RFID Handbook: Fundamentals and Applications in Contactless Smart Cards, Radio Frequency Identification and Near-Field Communication, 3rd ed. Hoboken, NJ: Wiley-Blackwell, 2010.

[2] How the use of RFID improves the supply chain, visibility, and inventory optimization [Internet]. Available: https://trans.info/en/how-the-use-of-rfid-improves-the-supply-chain-visibility-and-inventory-optimization-171088

[3] Complete Guide to RFID: Benefits, Applications, and Challenges [Internet]. Available: https://dzone.com/articles/ complete-guide-to-rfid-its-application-to-supply-c

[4] WHERE DO YOU FIND RFID TECHNOLOGY IN EVERYDAY LIFE? [Internet]. Available: https://www. trace-id.com/where-do-you-find-rfid-technology-in-everyday-life/

[5] T. Athauda and N. Karmakar, "Chipped versus chipless RF identification: A comprehensive review," *IEEE Microwave Magazine,* Vol. 20, No. 9, pp. 47-57, Sep. 2019.

[6] C. Herrojo, F. Paredes, J. Mata-Contreras, and F. Mart´ın, "Chipless-RFID: A review and recent developments," *Sensors,* Vol. 19, No. 15, pp. 3385, 2019.

[7] E. M. Amin, N. C. Karmakar, B. W. Jensen, "Fully printable chipless RFID multi-parameter sensor," Sensors and Actuators A: Physical, Vol. 248, pp. 223-232, Sep. 2016.

[8] A. Vena, E. Perret, and S. Tedjini, "Chipless RFID tag using hybrid coding technique," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 59, No. 12, pp. 3356-3364, Dec. 2011.