

Highly-dense flexible chipless RFID tag

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Abstract: A 27-bit circular shaped, highly-dense, fully printable chipless radio frequency identification (RFID) tag is presented in this letter. High data capacity is provided in a compact size. The total dimension of the tag is $22 \times 22 \text{ mm}^2$. For exciting the tag, the linearly polarized incident plane wave is used. The circular shaped tag structure is analyzed for three different substrates, i.e., Rogers RT/duroid[®]/5870, Taconic TLX-0 and DuPont[™] Kapton[®] HN. The spectral range for Rogers RT/duroid[®]/5870 is 3.3–13.5 GHz, 3.4–13.6 GHz for Taconic TLX-0 and 3.7–15.1 GHz for DuPont[™] Kapton[®] HN substrate. Flexibility is achieved by using Kapton[®] HN substrate. The presented tag is low-cost and flexible; hence it can be easily deployed on wide range of objects.

Keywords: chipless, radio frequency identification, radar cross-section, flexibility

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

References

- [1] A. Al-Fuqaha, *et al.*: “Internet of things: A survey on enabling technologies, protocols and applications,” *IEEE Commun. Surv. Tutorials* **17** (2015) 2347 (DOI: [10.1109/COMST.2015.2444095](https://doi.org/10.1109/COMST.2015.2444095)).
- [2] J. Pacheco and S. Hariri: “IoT security framework for smart cyber infrastructures,” *IEEE 1st International Workshops on Foundations and Applications of Self* Systems (FAS*W)* (2016) 242 (DOI: [10.1109/FAS-W.2016.58](https://doi.org/10.1109/FAS-W.2016.58)).
- [3] N. Zhang, *et al.*: “Localization of printed chipless RFID in 3-D space,” *IEEE Microw. Wireless Compon. Lett.* **26** (2016) 373 (DOI: [10.1109/LMWC.2016.2549264](https://doi.org/10.1109/LMWC.2016.2549264)).
- [4] A. Habib, *et al.*: “Frequency signatred directly printable humidity sensing tag using organic electronics,” *IEICE Electron. Express* **14** (2017) 20161081 (DOI: [10.1587/elex.14.20161081](https://doi.org/10.1587/elex.14.20161081)).

- [5] M. A. Islam and N. Karmakar: “A compact printable dual-polarized chipless RFID tag using slot length variation in I slot resonators,” IEEE European Microwave Conference (EuMC) (2015) 96 (DOI: [10.1109/EuMC.2015.7345708](https://doi.org/10.1109/EuMC.2015.7345708)).
- [6] M. S. Iqbal, *et al.*: “FSS inspired polarization insensitive chipless RFID tag,” IEICE Electron. Express **14** (2017) 20170243 (DOI: [10.1587/elex.14.20170243](https://doi.org/10.1587/elex.14.20170243)).
- [7] S. Genovesi, *et al.*: “Enhanced chipless RFID tags for sensors design,” IEEE International Symposium on Antennas and Propagation (APS/URSI) (2016) 1275 (DOI: [10.1109/APS.2016.7696345](https://doi.org/10.1109/APS.2016.7696345)).
- [8] T. Noor, *et al.*: “High-density chipless RFID tag for temperature sensing,” Electron. Lett. **52** (2016) 620 (DOI: [10.1049/el.2015.4488](https://doi.org/10.1049/el.2015.4488)).
- [9] N. Javed, *et al.*: “16-bit frequency signed directly printable tag for organic electronics,” IEICE Electron. Express **13** (2016) 20160406 (DOI: [10.1587/elex.13.20160406](https://doi.org/10.1587/elex.13.20160406)).
- [10] L. Xu and K. Huang: “Design of compact trapezoidal bow-tie chipless RFID tag,” Int. J. Antennas Propag. **2015** (2015) 502938 (DOI: [10.1155/2015/502938](https://doi.org/10.1155/2015/502938)).

1 Introduction

In a world aimed at increasing efficiency and multitasking, internet-of-things (IoT) is leading us to an era of smart objects, where many things can be connected and information can be shared via the internet [1]. The idea of IoT can be implemented by embedding sensors in already existing technologies such as in smart grids, smart identification and smart homes [2]. The radio frequency identification (RFID) technology has been widely in use because of its robust contribution in achieving the goal of IoT and its diverse applications such as access control, asset tracking and automatic tracking of the encoded data. RFID allows data transmission between the reader and tag wirelessly [3]. It rapidly identifies objects without requiring direct optical visibility [4]. It is for this reason that RFID is potentially replacing bar codes as identifying technology [5]. However, an important liability is the cost associated with integrated chips used in tag design, which can be overcome by introducing chipless RFID tags [6]. Chipless technology works on the modulation principle of the backscattered signal [7]. The fundamental module of a chipless RFID tag is its data encoding circuit. The data encoding technique applied can either be time domain signature or the most common, frequency domain signature. The use of flexible and lightweight substrates for printing the tag further reduces the cost and allows them to be deployed over a range of objects.

Various researches have been made in the domain of chipless RFID to meet the demands of modern IT/communication era. In [8], a 30-bit, dual-polarized chipless RFID tag is presented within a patch diameter of 24 mm. The flexibility is achieved by utilizing Kapton® HN as a substrate and aluminium is used as a radiator. Whereas, the novelty of the proposed work relies on the fact that 27-bit data is stored within a compact patch diameter of 21 mm. The inkjet printing technique is applied for the flexible substrate which further reduces the cost of overall RFID system. The tag allows high data capacity while remaining in a restricted size. The

data encoding circuit includes a metal portion that corresponds to capacitive part, and the gap between the metal portions (i.e. slot) acts as the inductive part. Each slot portion corresponds to ‘1’ bit, and metal portion corresponds to ‘0’ bit. In this way, data is encoded as a binary combination. The design is based on slotted ring structure of varying lengths and widths of the slots. The proposed prototype has been analyzed on a range of substrates: from the rigid Rogers RT/duroid®/5870 and Taconic TLX-0 to the flexible DuPont™ Kapton® HN, in a compact tag dimension of $22 \times 22 \text{ mm}^2$. The RF range for the Rogers RT/duroid®/5870 is 3.3–13.5 GHz whereas frequency band of operation for Taconic TLX-0 is 3.4–13.6 GHz and for DuPont™ Kapton® HN is 3.7–15.1 GHz.

2 Working principle

The tag is excited by a linearly polarized incident plane wave, and the radar cross-section (RCS) parameter is analyzed. The working principle of chipless RFID tag is based on backscattering phenomenon in which the reader transmits an electromagnetic (EM) wave to excite the tag. Current distribution is induced by the EM wave on the metallic surface of the tag, which generates an encoded wave that is scattered back towards the reader [7]. The reader then processes the information by identifying the unique tag ID. The proposed chipless RFID tag consists of circular shaped resonators.

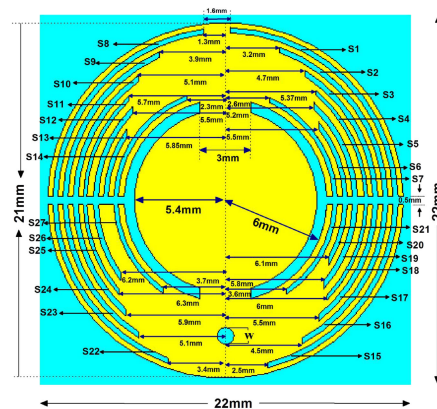


Fig. 1. 27-bit chipless tag design

The data is encoded by using slot resonator structure where each slot corresponds to resonance at a particular frequency. We can calculate the resonating frequency of each slot by Eq. (1).

$$f_{\text{res}} = \frac{c}{2\pi R_{\text{slot}}} \sqrt{\frac{2}{\epsilon_r + 1}} \quad (1)$$

Where R_{slot} is the radius of the resonating slot, ϵ_r is the relative permittivity of the substrate and f_{res} represents the resonating frequency of the slot. Also, it has been observed that the resonating frequency of each slot depends on the radius of the slot.

3 Twenty-seven bit circular chipless RFID tag design

The design of compact, circular-shaped RFID chipless tag capable of transmitting 27-bit data is shown in Fig. 1. It consists of twenty-seven open-ended slots that are placed in between the metallic rings. The metallic rings are filled with additional metal so that each bit resonates at different frequency. The lengths of the slots do not only depend on the radii of the rings but also on the metal fillings within the rings. The patch diameter is 21 mm, and the overall dimension of the substrate is $22 \times 22 \text{ mm}^2$. The inner circle has a radius of 5.4 mm. The diameter of w is 1 mm. The design is loaded with non-uniform lengths and widths of slots to achieve significant RCS response (sharp resonances) and to efficiently utilize the frequency band. These non-uniform lengths and widths play an important role in achieving more number of bits in the squeezed frequency band. The widths of the slots are given in Table I. The designing and simulation of the tag is performed using CST Microwave Studio Suite®.

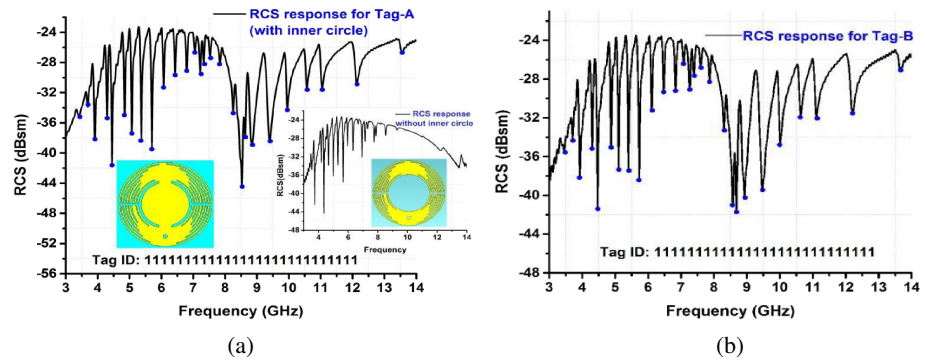


Fig. 2. (a) RCS response of Tag-A (b) RCS response of Tag-B

In Fig. 2(a) the RCS response of Tag-A is shown with and without the inner circle. Tag-A is designed on Rogers RT/duroid®/5870 ($\epsilon_r = 2.2$) with a thickness of 0.787 mm, which yields 27 bits for the frequency band of 3.3–13.5 GHz. From Fig. 2(a) it can be seen that the quality of the RCS response has been degraded by eliminating the central metallic patch of the design because it helps in achieving the improved RCS response for the proposed tag by inducing more current on the surface of the tag.

Fig. 2(b) shows the RCS response for Tag-B. Tag-B is optimized and analyzed for Taconic TLX-0 substrate ($\epsilon_r = 2.45$) with a thickness of 0.5 mm. The analyzed RCS response illustrates twenty-seven resonance dips in the RF range of 3.4–13.6 GHz. In Tag-A and Tag-B, the copper cladding of 35 μm thickness is used as a radiator.

Table I. Widths of the slots

Slot Name	Slot Width (mm)
S1–S3, S5, S8–S10, S12, S15–S17, S19, S22–S24, S26	0.3
S4, S11, S18, S25	0.21
S6, S13, S20	0.27
S7, S14, S21, S27	0.26

4 Results and discussion

The proposed tag design has an additional characteristic of flexibility which is attained by using DuPont™ Kapton® HN as a substrate.

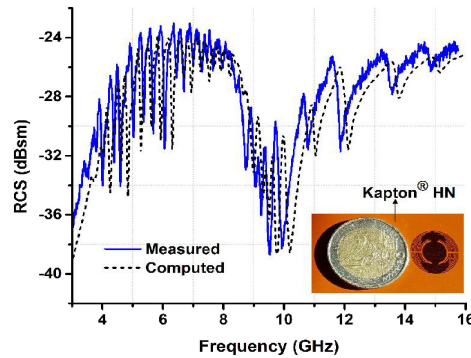


Fig. 3. Measured and computed response of Tag-C

The flexibility feature allows the tag to be deployed on curved surfaces. Kapton® HN has a thickness of 125 µm with $\epsilon_r = 3.5$ and $\tan \delta$ of 0.0026. The conductive silver nano-particle based ink (Cabot Ink CCI-300) is used as a radiator with a thickness of 15 µm and the printing of the tag is done by using DMP2800 inkjet printer.

Table II. Comparative analysis of proposed chipless tags

Characteristics	Tag-A	Tag-B	Tag-C
Substrate	Rogers RT /duroid®/5870	Taconic TLX-0	Kapton® HN
Thickness (mm)	0.787	0.5	0.125
Permittivity	2.2	2.45	3.5
Loss Tangent	0.0009	0.0019	0.0026
Radiator	Copper	Copper	Silver ink
Flexibility	-	-	✓
Freq. Band (GHz)	3.3–13.5	3.4–13.6	3.7–15.1

The backscattered encoded signal is measured by utilizing the experimental setup that comprises of a transmitting and receiving horn antennas, chipless RFID tag and vector network analyzer (VNA) R&S® ZVL13, as in [9, 10]. The tag is placed at a far-field distance to measure the RCS response, which is taken as 30.22 mm in the proposed research. The far-field distance R is given by Eq. (2), where D is tag's largest dimension, and λ is the wavelength [9].

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

The flexible tag possesses the ability of yielding twenty seven bits in the spectral band of 3.7–15.1 GHz. It has been observed that the measured RCS response of the tag shows a close association with the computed results. The measured and computed results along with the tag's prototype is shown in Fig. 3.

The proposed tag design has been slightly modified to switch on a flexible substrate, i.e., Kapton® HN. The slots $S1$ and $S2$ are re-optimized for the flexible substrate to achieve significant dips at particular frequencies. Moreover, the circle of diameter w is filled with metal to achieve sharper resonances.

A characteristic comparison of three tags (Tag-A, Tag-B, Tag-C) is shown in Table II which shows that by changing the substrate material, the relative permittivity also changes that alter the electrical properties of the tag and as a result there is a shift in the overall RCS response along the frequency band. The Table III shows a comparison of the proposed tag with already published chipless RFID tags.

Table III. Comparison with other tags

Resonator Shape	Tag size (cm ²)	No. of bits	Inkjet printing	Flexibility
Circular (proposed work)	4.84	27	✓	✓
I slot [5]	3.9	16	-	-
Circular [4]	1.54	9	✓	✓
Hexagonal [6]	2.30	14	-	-

5 Conclusion

In this letter, a compact, fully passive, 27-bit tag is proposed. The presented tag is capable of generating 2^{27} unique IDs for tagging multiple items, in a miniaturized tag size of $22 \times 22 \text{ mm}^2$. The RCS response of the tag is measured for three different substrates. The flexibility of the tag is achieved by using Kapton® HN substrate. With Kapton® HN heat resistant sheet and silver nano-particle based conducting tracks, the prototype produced is light weight and can be used in various low-cost applications. Therefore, the tag with its flexible nature can be deployed on irregular surfaces.

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