Triangular loop resonator based compact chipless RFID tag

Shahid Rauf¹, Muhammad Ali Riaz¹(✉), Humayun Shahid¹, Muhammad Sohail Iqbal¹, Yasar Amin¹, and Hannu Tenhunen²,³

¹ ACTSENA, Department of Telecommunication Engineering, University of Engineering and Technology, Taxila-47050, Punjab, Pakistan
² iPack VINN Excellence Center, Royal Institute of Technology (KTH), Isafjordsgatan 39, Stockholm, SE-16440, Sweden
³ TUCS, Department of Information Technology, University of Turku, Turku-20520, Finland

✉ ali.riaz@uettaxila.edu.pk

Abstract: A novel, frequency selective surface (FSS) inspired, fully passive, chipless data encoding circuit capable of being operated as a radio frequency identification (RFID) tag is presented. The tag is composed of finite repetitions of the unit cell realized on a grounded FR4 substrate having an overall size of 27.5 × 30 mm². The unit cell is made up of several triangle-shaped resonators patterned in a looped fashion. Variation in the geometric structure of the tag, achieved by addition or removal of nested loops, corresponds to a specific bit sequence. Each sequence is represented in the spectral domain as a unique frequency signature of the resonators. The proposed 10-bit tag covers the spectral range from 4 to 11 GHz. The tag is compact, robust, and exhibits a stable response to impinging signals at different angles of incidence.

Keywords: chipless tag, RFID, radar cross section, data encoding circuit

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

References

[1] R. Rezaiesarlak, et al.: “Design of chipless RFID tags based on characteristic mode theory (CMT),” IEEE Trans. Antennas Propag. 63 (2015) 711 (DOI: 10.1109/TAP.2014.2382640).
[2] S. Preradovic, et al.: “Chipless RFID: Bar code of the future,” IEEE Microw. Mag. 11 (2010) 87 (DOI: 10.1109/MMM.2010.938571).
[3] S. Gupta, et al.: “Log-periodic dipole array antenna as chipless RFID tag,” Electron. Lett. 50 (2014) 339 (DOI: 10.1049/el.2013.4253).
[4] C. M. Nijas, et al.: “Low-cost multiple-bit encoded chipless RFID tag using stepped impedance resonator,” IEEE Trans. Antennas Propag. 62 (2014) 4762 (DOI: 10.1109/TAP.2014.2330586).
[5] M. W. Gallagher, et al.: “Mixed orthogonal frequency coded SAW RFID tags,” IEEE Trans. Ultrason. Ferroelectr. Freq. Control 60 (2013) 596 (DOI: 10.1109/TUFFC.2013.2601).
1 Introduction

Radio Frequency Identification (RFID) technology finds abundant deployment in various industry-specific applications such as product-level tracking, live-stock monitoring, supply chain management [1], and so on. This widespread acceptance is due to a number of advantages exclusive to RFID including enhanced interrogation distance, swift reading rate, and non-line-of-sight communication [2]. RFID systems typically consist of a tag, a reader circuit and a host computer connected with the reader [3]. While chip-based passive RFID tags offer lowered fabrication expense due to non-existence of battery, the cost per tag even then is impractical for large-scale deployment in low-end applications due to the presence of radio frequency integrated circuit (RFIC). Chipless passive RFID tags, requiring neither an integrated circuit nor a dedicated power source, offer an affordable alternative [4].

Chipless RFID tags, for the most part, can be categorized as: frequency domain and time domain tags. Surface Absorption Wave (SAW) tags are time-domain based and involve a series of complex sub micron photolithiographic processes for manufacturing [5], making the tags expensive and deterring mass adoption. Frequency-domain RFID tags transform the data to be encoded into a unique spectral signature using simple radiating structures [6]. The radiating structures onboard chipless RFID tags typically consist of stepped impedance resonators [4], spurline resonators [6], and so on. FSS based RFID tags presented in the literature exhibit certain operational constraints such as involvement of active components and noticeable design bulkiness [7].

This letter presents a novel passive chipless RFID tag leveraging electromagnetic properties of surfaces exhibiting high impedance [8] to achieve compactness and stable angular response [9]. The absorption and reflection characteristics of the proposed geometrical structure enable encoding of 0 and 1 bits respectively, resembling the operation of a finite-sized frequency-selective surface. The proposed tag offers a capacity of 10 bits in the frequency band ranging from 4 to 11 GHz.
2 Operating principle

The proposed chipless RFID tag is essentially a finite-sized, frequency selective surface comprising of merely a few repetitions of the unit cell. The metallic structure of the tag, realized over a dielectric layer and furnished with a ground plane, acts as a resonant cavity.

Depending on the relative dimensions of the tag resonator, certain illuminating electromagnetic waves get absorbed by the structures, while others are reflected and can be observed in the tag’s radar cross section (RCS) response [1]. By carefully designing a multi-resonant circuit based on this principle, a number of bits can be stored in the structure without requiring application-specific integrated circuits. Eliminating the silicon chip not only brings the cost per tag down, but also offers additional advantages such as enhanced tag robustness, scalable data storage potential, and ease of fabrication.

We start with an equilateral triangle-shaped resonator, as shown in Fig. 1, and transform it into a multi-resonant structure capable of being operated as a chipless RFID tag. The characteristic geometry of the triangle-shaped resonator renders the tag operable at various incident angles.

![Equilateral triangle-shaped resonator along with surface current distribution.](image)

When illuminated by a horizontally polarized plane wave, the structure presented in Fig. 1 resonates at 4.56 GHz as demonstrated by its surface current distribution. Fig. 2 shows that in presence of a corresponding loop, a resonance peak occurs at a particular frequency representing a ‘1’ bit. Similarly, where there is no loss associated with the resonant structure, complete reflection takes place signifying a ‘0’ bit, hence enabling the possibility of encoding an arbitrary bit combination.

3 Data encoding circuit: Design and optimization

Data encoding circuit is conceived by adapting a loop-based design approach. This peculiar design strategy also enables structural nesting which is imperative for embedding multiple bits of information in the same tag. The number of nested loops is determined iteratively such that the contribution of each nested loop in the frequency spectrum is both observable and distinct, and does not manifest as a spurious dip.

The geometrical optimization of the data encoding circuit is carried out using CST MICROWAVE STUDIO® (CST® MWS®). The optimal number of resonators
for each unit cell is five. The width of the triangular-shaped resonator, \( t_1 \), is 225 \( \mu m \). The inter-resonator spacing, \( g_1 \), is kept at 338 \( \mu m \). The optimized value for the parameter \( L_1 \), the length of each side for the outermost resonator, is 14.55 mm. For the remaining inner resonators, the dimensions can be calculated using the same method considering each nested loop positioned at a spacing of 338 \( \mu m \) from the other. The overall dimensions of the designed tag are \( 28 \times 28 \) mm\(^2\). Each unit cell is replicated four times. The proposed tag is realized on commercially available FR4 substrate having a thickness of 1.6 mm provisioned with a metallic ground plane. The thickness of both the copper cladding and the ground plane is 35 \( \mu m \). The fabricated prototype, placed beside a two euro coin for the purpose of size comparison, is shown in Fig. 3(a). As it can be observed, the proposed chipless RFID tag is conveniently compact which is a highly sought after design feature.

A technique for enhancing the tag data capacity is devised. Modified version of FSS unit cell is realized by placing triangular resonators side by side with an inherent offset equal to 0.98 mm. The proposed method is leveraged to effectively double the information carrying capacity of the previously proposed data encoding circuit from 5 to 10 bits, without a significant increase in tag size. The new tag, offering twice the capacity, is demonstrated in Fig. 3(b), where \( D_1 \) and \( t_2 \) equal \( L_1 \) and \( t_1 \), respectively. Incorporating the offset requires \( D_2 \) to be kept at 13.57 mm. The modified unit cell employs nested triangular resonators with each of them contributing to the overall back-scattered frequency signature with an absorbing peak of its own. However, with this new tag, five additional resonances have been accommodated in the same spectral range. The modified unit cell is repeated to obtain overall tag dimensions of \( 27.5 \times 30 \) mm\(^2\). The capacity-enhanced chipless RFID tag still occupies a minuscule footprint, making it both compact and portable. The
information carrying capacity of the circuit can be enhanced further by appending additional loops to the exterior of the unit cell. Doing so repeatedly, however, increases the tag size.

4 Results and discussion

Computed and measured results for electromagnetic descriptors of the proposed chipless data encoding circuit are covered in this section. The simulations have been carried out using CST® MWS®. The effect on the backscattered frequency signature of the tag upon an increase in number of repetitions of the unit cell is investigated. Fig. 4(a) illustrates the computed radar cross section (RCS) for two variants of the same 5-bit tag when illuminated over a common range of radio signals. For comparison purpose, RCS response of the $1 \times 1$ arrangement involving a single instance of the unit cell is overlaid with that for the $2 \times 2$ version of the same tag. It can be observed that an increase in number of repetitions of the unit cell results in the obtainment of a larger RCS. The observation can be leveraged to accentuate the read range of the postulated tag, at cost of larger tag dimensions.

![Fig. 4. (a) RCS of 5-bit tag for two configurations. (b) Oblique incidence performance of 5-bit tag.](image)

Oblique angular performance exhibited by the $2 \times 2$ variant of the 5-bit tag is presented in Fig. 4(b). The tag demonstrates a stable response for an angular variation up to 60 degrees, enabling the tag to operate in a slanted orientation. The proposed tags are scrutinized for their real-world electromagnetic performance. The measurement setup is same as that in [10] employing a pair of identical linearly polarized horn antennae, vector network analyzer model R&S® ZVL-13 and a number of tag prototypes under test. The measured backscattered RCS response of the fabricated tag prototypes is illustrated in Fig. 5. Tag prototypes that encode both repetitive and alternating bit sequences are investigated. Fig. 5(a) shows the results obtained for two $2 \times 2$, 5-bit tags encoding the bit sequence 11111 and 10101. The absence of a nested triangular resonator in the structure encoding the alternating bit sequence results in the corresponding spectral dip to disappear, signifying a 0 bit. Similarly, Fig. 5(b) depicts the results obtained for two $2 \times 1$, 10-bit tags encoding the bit sequence 1111111111 and 1100110011, whereby 0 bit representation in the frequency domain is achieved by removing the corresponding resonator.
From Fig. 5, it can be seen that simulated and measured results exhibit good overall agreement. The measured results, however, depict a subtle drift in the location of a few resonant dips along the frequency axis when compared with the simulated outcome. The drifted resonances remain easily distinguishable with a reader setup capable of detecting local minima over a predefined spectral neighborhood.

5 Conclusion

A novel passive chipless RFID tag based on finite-sized frequency selective surfaces has been proposed. The formulated tag is composed of two different unit cells realized as nested triangular resonators in a 2 × 1 configuration. The tag makes use of the structure’s absorption and reflection characteristics at particular resonant frequencies to encode ‘0’ and ‘1’ using on-off signaling. The design occupies a small footprint of 27.5 × 30 mm², and offers an encoding capacity of 10 bits. The tag is both compact and robust, and operates suitably at a variety of incident angles.

Acknowledgments

This work is financially backed by UET, Taxila via the ACTSENA research group funding. Furthermore, National Institute of Electronics, Islamabad is acknowledged for extensive support during prototype fabrication phase.