Novel T-shaped resonator based chipless RFID tag

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Abstract: A novel, frequency selective surface (FSS) based, data encoding structure amenable to be used as a chipless RFID tag is proposed. The data encoding structure is made up of finite repetitions of a unit cell fabricated on commercially available grounded FR4 substrate having physical dimensions of $15 \times 15$ mm$^2$. The unit cell is composed of numerous T-shaped resonant elements arranged as two atypical sets of concentric nested loops. Alteration in geometry of the encoding circuit, attained by inclusion or omission of nested resonators, corresponds to a particular data sequence. Each encoded data sequence is manifested in the frequency domain as a distinct spectral signature. The proposed 10-bit tag is both compact and robust, and remains interrogable in response to illuminating electromagnetic waves at various angles of incidence.

Keywords: chipless tag, RFID, radar cross section, electromagnetic signature

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

References

[1] Y. C. Tsao, et al.: “Supply chain network design considering RFID adoption,” IEEE Trans. Autom. Sci. Eng. 14 (2017) 977 (DOI: 10.1109/TASE.2016.2545110).
[2] J. K. Pakkathillam and M. Kanagasabai: “A novel UHF near-field RFID reader antenna deploying CSRR elements,” IEEE Trans. Antennas Propag. 65 (2017) 2047 (DOI: 10.1109/TAP.2017.2669722).
[3] Y. He, et al.: “UHF RFID Tag with slot antenna integrated into blister medicine package,” IEEE Antennas Wireless Propag. Lett. 15 (2016) 956 (DOI: 10.1109/LAWP.2015.2484964).
[4] N. C. Karmaker, et al.: “Tag, you’re it radar cross section of chipless RFID tags,” IEEE Microw. Mag. 17 (2016) 64 (DOI: 10.1109/MMM.2016.2549160).
[5] J. Han, et al.: “Fragment-type UHF RFID tag embedded in QR barcode label,” Electron. Lett. 51 (2015) 313 (DOI: 10.1049/el.2014.4355).
[6] H. M. Vasconcelos and E. J. P. Santos: “Design, microfabrication, and analysis
of SAW RFID tag.” Symposium on Microelectronics Technology and Devices (SBMicro) (2013) 1 (DOI: 10.1109/SBMicro.2013.6676115).

[7] F. Costa, et al.: “A chipless RFID based on multiresonant high impedance surfaces,” IEEE Trans. Microw. Theory Techn. 61 (2013) 146 (DOI: 10.1109/TMTT.2012.2227777).

[8] M. Martinez and D. van der Weide: “Compact slot-based chipless RFID tag,” IEEE RFID Technology and Applications Conference (RFID-TA) (2014) 233 (DOI: 10.1109/RFID-TA.2014.6934234).

[9] S. Rauf, et al.: “Triangular loop resonator based compact chipless RFID tag,” IEICE Electron. Express 14 (2017) 20161262 (DOI: 10.1587/elex.14.20161262).

[10] A. Vena, et al.: “Chipless RFID tag using hybrid coding technique,” IEEE Trans. Microw. Theory Techn. 59 (2011) 3356 (DOI: 10.1109/TMTT.2011.2171001).

1 Introduction

Chip-based Radio Frequency Identification (RFID) tags are an integral constituent of numerous modern-day applications spanning various industries such as logistics and supply chain [1], traffic management [2], pharmaceutical tracking [3], and so on. This deep market penetration of RFID tags is fueled by a plethora of advantages including contact-less interrogation, higher read rate, enhanced interrogation distance, and so forth. Incorporating a dedicated integrated circuit (IC) on board the RFID tag, however, makes wide-scale commonplace deployment of such tags financially impracticable [4].

Chipless RFID tags, posited as a replacement for optical bar-codes, offer a viable solution for widespread deployment of RFID tags in low-end applications [5]. Chipless variants of RFID tags are primarily classified into two categories namely time-domain-based and frequency-domain-based tags. Within time-domain-based chipless RFID tags, Surface Acoustic Wave (SAW) [6] tags have been proposed. The intricacies associated with the submicron lithography manufacturing process hamper wide-scale adoption of time domain based chipless RFID tags. Frequency-domain-based tags employ radiating structures to translate the identification details into a uniquely distinguishable electromagnetic signature. Such resonators are typically made up of metallic scatterers and reflective strands, such as square-shaped [7], circular [8], and triangular [9] resonators. Generally, electromagnetic performance of chipless RFID tags is thwarted by existence of higher-order spectral harmonics and dependency of encoding capacity on the tag’s physical dimensions. RFID tags of the chipless sort based on nested square-shaped [7] and circular [8] resonant elements, when positioned closely, suffer from mutual coupling that limits the resulting bit density. While tags made up of triangular shaped resonators are less prone to mutual coupling, the physical dimensions of the resulting tag remain relatively large [9]. In this letter, a frequency-domain-based chipless RFID tag composed of novel T-shaped resonators is proposed. The formulated tag encodes ‘0’ and ‘1’ bits by dint of reflection and absorption properties of the resonant structure. The peculiar geometry and orientation of the
resonant elements minimizes inter-resonator coupling, thereby allowing for achievement of higher bit density as well as stable oblique angular performance.

2 Resonator design

The proposed frequency-domain-based chipless RFID tag is essentially a finite-sized frequency selective surface (FSS) composed of several coplanar T-shaped resonant elements patterned in a concentric manner. The resulting structure, provisioned with a grounded dielectric substrate, functions as a resonant cavity that readily absorbs the impinging electromagnetic waves at particular resonant frequencies. As shown in Fig. 1(a), the overall geometrical structure for an arbitrary T-shaped resonator is controlled by a set of variables: width of the horizontal base given by $W_1$, width of the horizontal ceiling represented by $W_2$, length of the lower vertical bar given by $L_1$, length of the upper vertical bar represented by $L_2$ and thickness of the resonator given by $d$. Unlike square [7], circular [8] or triangular [9] variants, a resonant element characterized by multiple geometric parameters offers a greater extent of freedom when designing for particular resonant frequencies. Additionally, the peculiar asymmetrical T-shaped geometry also diminishes the mutual coupling that would have otherwise dominated closely positioned resonators.

![Fig. 1.](image)

(a) Basic T-shaped resonator  
(b) Surface current distribution of the resonator

The surface current density of a single T-shaped resonator ($L_1 = 2.8 \text{ mm}$, $L_2 = 1.5 \text{ mm}$, $W_1 = 4.3 \text{ mm}$, $W_2 = 3 \text{ mm}$) obtained upon excitation by a horizontally polarized plane wave at 11.43 GHz is shown in Fig. 1(b). The surface current density tends to be highest in vicinity of the junction $J$. This signifies existence of inductive characteristics. On the other hand, surface current density around the base and ceiling of the T-shaped structure is minimal, depicting presence of capacitive characteristics. The contemporaneous existence of capacitive and inductive components distributed across a single T-shaped resonator produces resonance at a specific value of frequency. The same resonance is distinctly observable in the radar cross section (RCS) response, identifying a ‘1’ data bit. In absence of the resonator, the incident electromagnetic wave is reflected back causing the resonance to disappear signifying a ‘0’ data bit. By carefully formulating a multi-resonant structure based on this working principle, multiple data bits can be stored in the resonant structure without an application specific integrated circuit (ASIC).
3 Data encoding circuit

Encoding of multiple data bits is accomplished by adopting a loop-based design approach. An FSS unit cell made up of two sets of concentrically nested T-shaped resonant elements is conceived. Within the unit cell, the resonators are nested as two distinct sets arranged in an inverted fashion, as depicted in Fig. 2. Doing so minimizes electromagnetic coupling between the two sets of resonant elements.

The precise dimensions of the geometric variables, along with the optimal number of concentric resonators, are determined iteratively by parametric analysis performed using CST MICROWAVE STUDIO® (CST® MWS®). The optimum number of resonant elements per nested set is five, that translates to ten resonators per unit cell. The thickness of each T-shaped resonator, \( d \), is kept at 0.2 mm. Precise geometric dimensions of the outermost T-shaped resonators for both sets are provided in Table I. The dimensions of the subsequent resonators can be calculated conveniently keeping in view a constant inter-resonator spacing set to 0.2 mm.

![Unit Cell](image)

**Fig. 2.** 10 bit chipless RFID tag.

| Table I. Optimum dimensions of resonator |
|-----------------------------------------|
| (mm) | \( L_1 \) | \( L_2 \) | \( W_1 \) | \( W_2 \) |
|------|--------|--------|--------|--------|
| Outermost Resonator (a) | 5.2 | 1.5 | 6.7 | 5.4 |
| Outermost Resonator (b) | 5.1 | 2.0 | 7.1 | 5.0 |

With the unit cell repeated once, the proposed data circuit takes on a \( 1 \times 2 \) configuration occupying overall dimensions of \( 15 \times 15 \text{mm}^2 \). A number of tag prototypes are fabricated on a commercially available grounded FR-4 substrate having a thickness of 1.6 mm. Two such prototypes encoding distinct bit sequences, placed beside a standard one euro coin for emphasizing on design compactness, are shown in Fig. 2. The resonant circuit allows for encoding of an arbitrary bit sequence by inclusion (signifying ‘1’ data bit) or omission (signifying ‘0’ data bit) of T-shaped resonators at corresponding locations within the unit cell.

4 Results and discussion

This section provides insights into typical performance descriptors for the proposed data encoding circuit readily operable as a chipless RFID tag. Computer-aided
design and analysis has been carried out using full-wave electromagnetic simulation software CST® MWS®. The fabricated tag prototypes along with the corresponding RCS response obtained for an all ‘1’ data bit tag, an all ‘0’ data sequence, and a mixed-bit tag are compared in Fig. 3. The obtained results affirm that the obtained RCS responses for the three sequences are visually distinct and, thereby, uniquely identifiable.

![Fig. 3. RCS response for different bit sequences.](image)

The formulated chipless RFID tag is also scrutinized for its RCS performance at different angles of oblique incidence. The investigation establishes the extent to which the proposed tag exhibits angular stability when illuminated in a slanted manner. Fig. 4(a) validates that the proposed tag corresponding to an all ‘1’ data sequence tag exhibits a stable angular response all the way up to 60 degrees. It can also be observed that the resonant peaks, with reference to the frequency axis, remain unaffected. The average RCS magnitude, however, slightly decreases with an increase in angle of incidence.

![Fig. 4. (a) Oblique incidence performance of the tag (b) Comparison between measured and computed RCS response](image)

The experimental setup for carrying out laboratory measurements is similar to the one employed in [10] involving multiple tag prototypes, vector network analyzer (VNA) R&S ZVB-20®, and a pair of identical linearly-polarized horn antennae with gain ranging from 10 dBi at 5 GHz to 13 dBi at 15 GHz. The
measured RCS response for an all ‘1’ data bit tag, overlaid with the corresponding simulated outcome, is presented in Fig. 4(b). It can be seen that both the simulated response and the measured results are in accord with one another. The mean value of read range at transmit power of 0 dBm is 1.05 m, and that for transmit power equal to 10 dBm is 1.87 m.

Table II presents a comparison between the proposed tag and other designs reported in literature. The proposed tag, in the $2 \times 1$ configuration, encodes 10 bits of information over a small area of 2.25 cm$^2$ resulting in an appreciably high bit density of 4.44 bits/cm$^2$.

| Resonator shape | Bit density (bit/cm$^2$) | No. of bits | Tag Size (cm$^2$) | Average measured RCS (dBsm) |
|-----------------|-------------------------|-------------|------------------|-----------------------------|
| T-shape         | 4.44                    | 10          | 2.25             | $-28$                       |
| Rectangular [7] | 0.55                    | 05          | 9.00             | $-21$                       |
| Circular [8]    | 3.80                    | 09          | 2.36             | $-28$                       |
| Triangular [9]  | 1.21                    | 10          | 8.25             | $-22$                       |

Additionally, the designed tag proffers a comparable average RCS measure of $-28$ dBsm. Furthermore, the formulated tag is compact, robust and operates at a variety of incident angles.

5 Conclusion

A novel T-shaped, FSS-based, data encoding circuit capable of being operated as a chipless RFID tag is proposed. The peculiar inverted arrangement of nested resonator sets within the FSS unit cell minimizes the effect of mutual coupling. Encoding capacity of 10 bits over a physical footprint of $15 \times 15$ mm$^2$ is achieved. The tag offers both robustness and design compactness, and remains interrogable over a wide range of incident angles.

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