Design of a Chipless RFID Tag for 2.4 GHz and 5.8 GHz ISM Band Applications

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***Abstract*—This paper presents the design, simulation, and fabrication of a two-bit chipless RFID tag dedicated to ISM band application. Now, tagging technology is getting more efficient than optical barcodes. The RFID technology has appeared as a promising alternative to extract the encoded data from the tags utilizing the radio frequency waves. Frequency coding techniques have been used to enhance the coding capacity of chipless radio frequency identification (RFID) tag as well as to improve the radar cross-section (RCS) magnitude level. The cost of the tag is potentially less due to the absence of a ground plane for the fabrication process. The proposed tag is fabricated on an FR-4 substrate having permittivity 4.4 and loss tangent 0.02. The proposed tag resonates at the frequency of 2.4 GHz and 5.8 GHz Industrial, Scientific and Medical (ISM) radio bands. The simulated results were validated by the bistatic measurement of the fabricated tag.**

***Index Terms*—Chipless tags, radio frequency identification (RFID), radar cross section (RCS), resonators**

I. Introduction

Radio Frequency identification (RFID) is a wireless technique to capture data, consisting of two primary components namely RFID tag, where information are encoded and RFID reader, which extract the encoded information from the tags [1]. Tracking or identification of objects using RFID can have advantages as compared to barcode, like the non-line-of-sight reading, identification and tracking automatically. However, barcode is preferred in comparison with RFID because of the low cost. The chipped tags have not been widely accepted, particularly in object-level tagging, where large no of tags are required. Eliminating the silicon chip in RFID tag results to chipless RFID tags. The focus of the research is to develop a chipless RFID tag without a ground plane to reduce the cost per unit tag.

RFID tags generally divided into two types according to power supply: active tags having onboard power supplies and passive tags without their own power supplies [2], [3]. Several chipless RFID tags have been accounted for utilizing encoding techniques based on time, frequency, phase-domain. The chipless tag is a tradeoff between chipped tag and barcode. With printing or etching technique, the manufacturing process becomes easy, so that the unit cost of chipless tag is relatively close to barcode [4].

TABLE I
Comparison among Existing Literature

References	Size(mm)	RCS(dBsm)	Operating Frequency(GHz)
[7]	7.2×5.8×1.6	$-36 \sim -42$	$7-12$
[8]	7.2×6.6×1.6	$-26 \sim -31$	$8-14$
[2]	30×50×0.8	$-28 \sim -30$	$2-5$
[6]	20×40×0.8	$-29 \sim -30$	$2.5-7.5$
[9]	70×30×1.6	$-28 \sim -32$	$3-6$
Proposed work	21×21×0.8	$-26 \sim -29$	$2-6$

Chipless RFID tags are classified into two primary domains. First is time domain (TD) and the second one is frequency domain (FD). The frequency domain class of chipless tags are based on one or several resonators that encode the information into frequency spectrum. A variation in the frequency response of the Radar Cross Section (RCS) is produced by utilizing the resonant structures. The tag is detected based on the basis of resonant frequency measurement [3], [5]. Passive tags are identified at 13.56 MHz using magnetic near field coupling of range 5 cm to 40 cm. Similarly, the passive tag identification can be extended to a maximum range of 10 m for pallet identification. Operating frequencies utilized are mostly in the UHF bands around 900 MHz, 2.4 GHz and 5.8 GHz [6].

A comparison between recently reported chipless RFID tag is presented in Table I. Dual polarized chipless RFID tag with 'U' shaped resonator used in both horizontal and vertical polarisations is designed in [7]. In [8], utilizing concentric square loops in nested manner a dual polarized chipless RFID tag is designed. In [2], [6] the tag's coding capacity is increased with the help of hybrid coding technique. Using the flexography technique the tag [9] is designed on a paper substrate.

The motivation behind this article is to survey the feasibility of the magnitude coding approach [2] and to decide an adequate magnitude level for practical applications in ISM band. In this article, using two modified rectangular resonators a two bit chipless RFID tag is designed. The structure is designed to resonate at 2.4 GHz and 5.8 GHz ISM bands. A prototype was designed and fabricated for the proposed tag. The simulation results indicate that the tag resonates at 2.4 GHz and 5.8 GHz. This chipless tag can be suitable for ISM

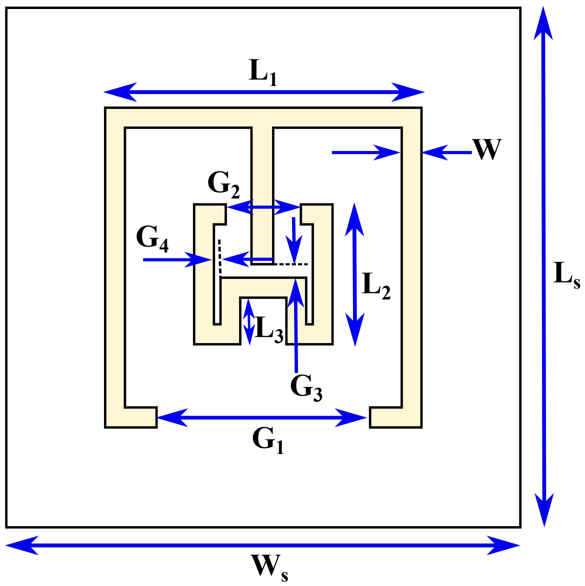


Fig. 1. Layout of the proposed tag.

TABLE II
DIMENSIONS OF CHIPLESS RFID TAG

Ls	Ws	hs	L1	L2	L3
21 mm	21 mm	0.8 mm	16 mm	7 mm	2.3 mm
G1	G2	G3	G4	W	
10.8 mm	3.8 mm	0.5 mm	0.3 mm	1 mm	

band applications. Geometry and design of chipless RFID tag is described in section II. Simulated results with analysis are discussed in section III. Conclusion is described in section IV followed by the references.

II. Geometry and Design of Chipless RFID Tag

A. Chipless RFID RCS

RCS is the most significant parameter in the chipless RFID tag design which shows the effective area from which the receiver can receive the desired backscattered signal for detection. The RCS is defined in [10] for a tag antenna and is presented in (1).

$$\sigma_{tag} = (\lambda^2 R_a G_{tag}^2)/\pi|Z_a + Z_c| \quad (1)$$

Where $\lambda =$ wavelength of operating signal, R_a =real input impedance of Z_a, Z_c = impedance of chip for a RFID tag and G_{tag} = tag antenna gain. As in chipless RFID there is no chip, Z_c can be assumed to be 50-Ω and Z_a can be assumed to have real value. Now at the resonant frequency, RCS of RFID tag with no chip [10] can be reduced to (2).

$$\sigma_{tag} = (\lambda^2 R_a G_{tag}^2)/\pi|Z_a + Z_c| = \lambda^2 G_{tag}^2)/2\pi \quad (2)$$

In general the RCS (σ) can be represented as (3) [10].

$$\sigma = A \times |\Gamma|^2 \times D \quad (3)$$

Here, $A =$ Projected cross sectional area of the target in m^2, $|\Gamma|^2 =$ Reflectivity, and $D =$ Directivity. For a small flat plate, the RCS is approximated as (4) [10].

$$\sigma_{plate} = 4\pi W^2 h^2/\lambda^2 \quad (4)$$

Here W is width and h is height of the plate and λ represents wavelength. The working principle of conventional RFID tags with ASIC microchips depend on antenna loading. Theoretical investigation [3], [10] indicates that in terms of throughput the chipless RFID tag design optimized for suitable RCS, can provide better performance in comparison with the chipped RFID. There is significant decrement in RCS if line of sight and proper alignment are affected which in turn reduces the read range.

Without any tag an isolation measurement and with a metallic plate of known RCS a reference measurement was performed in [2], [7]. The RCS cam be measured using (5) [2], [7].

$$\sigma^{tag} = [(S^{tag} - S^{isolation})/(S^{ref} - S^{isolation})]^2 \times \sigma_{ref} \quad (5)$$

where S^{tag} denote the measured S-parameter and σ^{tag} denote the RCS of the measured tag. $S^{isolation}$ is measured without tag and S^{ref} is measured by taking equivalent size of one copper plate exactly as per the size of the tag.

B. Proposed Tag Design

The unique design described in this section is dependent on several coupled resonating elements. Every resonating element acts as a transponder and a resonator to have the smallest size. The proposed design is a chipless RFID tag with a modified ‘c’ structure resonator. The geometry of the proposed design with all the dimensional details is shown in Fig. 1. Table II defines the values of the variables used in the proposed design. The antenna is etched on the cost-effective FR4 substrate having $\varepsilon_r = 4.4$, and $tan\delta = 0.02$. The tag is designed on the substrate with the overall dimension of L_s, W_s, and h_s. The presented structure enhances the RCS of the tag.

The proposed chipless tag is compact, robust and maintenance-free having large frequency range which can be used in ISM band applications. Though the ground plane can provide good isolation between the tag and the container, to reduce the cost, chipless tags having no ground plane can be preferred. A single conducting layer facilitates the mass production of chipless RFID tags having less cost. Though the design of a single layer robust tag without a ground plane is a challenge, the proposed tag can perform well which can be observed from its RCS curve, surface current distribution plots and measured S_{21} response. The chipless tag store information in frequency domain [5]. Overall the proposed tag's response is excellent in a wide range of frequency to execute various applications in ISM band.

III. Results and Discussion

The proposed structure is fabricated as shown in Fig. 2 and the measurements are taken using Keysight PNA Network Analyser-N5222B. The experimental setup for measurement is

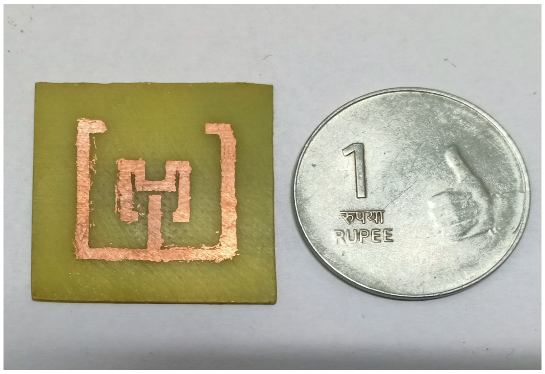


Fig. 2. The fabricated prototype of the proposed tag.

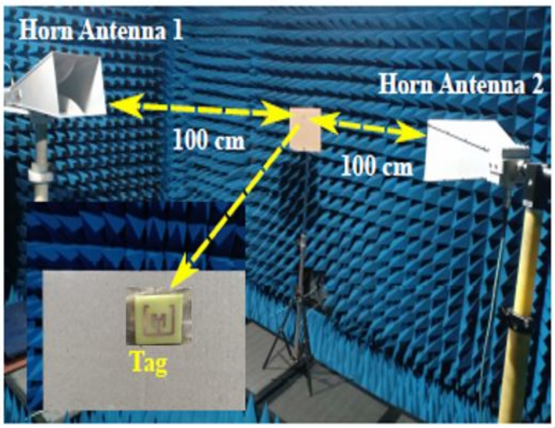
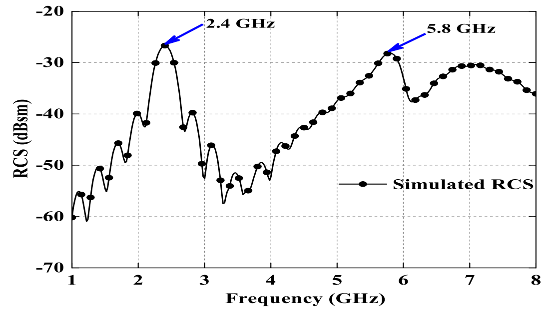


Fig. 3. Measurement setup for 2 bit chipless RFID tag.

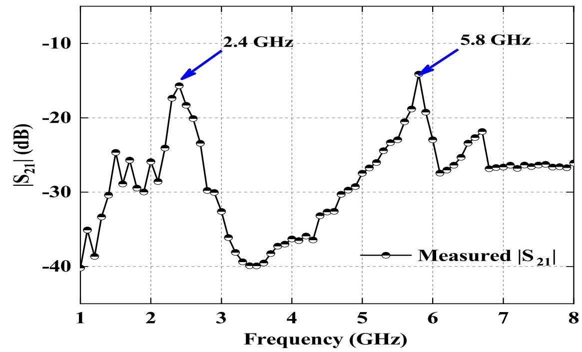
shown in Fig. 3. In comparison with the previously discussed tag antennas, the proposed tag antenna RCS is quite high and it is -26 dBsm in ISM band (Table-I).

The simulated RCS plot and measured S_{21} response are similar for the proposed tag (Fig. 4) which shows that in the ISM bands of 2.4 GHz and 5.8 GHz it can be effectively used. The distinguished resonant frequencies correspond to the coding capacity of the tag [10]. From the simulated RCS curve as shown in Fig. 4 (a), the tag is capable of 2-bit information coding. The measured S_{21} response (Fig. 4 (b)) are in close proximity to simulated values. From the literature, RCS and the corresponding size of the tag is compared in Table I. It is clear that the proposed tag has high RCS magnitude and can be used for different ISM band applications due to its resonant frequencies at 2.4 GHz, and 5.8 GHz respectively.

The operation of the proposed structure can be explained with the help of surface current distribution in a wide frequency range (Fig. 5). Here the surface current has been analyzed at the resonating frequencies i.e. 2.4 GHz, and 5.8 GHz. It clearly demonstrates that at lower frequency the surface current is maximum in the outer resonator whereas at higher frequency the surface current is more in the inner resonator. This satisfies the concept of decrement in resonating frequency for the increment of the electrical length.

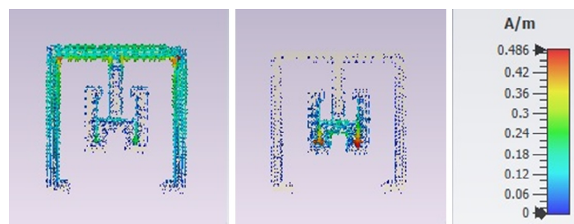


(a)



(b)

Fig. 4. (a) Simulated RCS response (b) Measured S_{21} of the proposed tag.



(a) (b)

Fig. 5. Simulated surface current distribution of the proposed tag at (a) 2.4 GHz, (b) 5.8 GHz.

IV. Conclusion

In this article, a 2-bit passive chipless RFID tag is presented. To feature the significance of designing different antennas for different tag types, appropriate antenna parameters like surface current distribution, and RCS have been described. The analysis shows that the proposed design can be used in ISM band of frequencies i.e 2.4 GHz and 5.8 GHz. In case of backscattered tag, the RCS is the primary parameter. The results for the proposed tag show that the tag design helps to increase the RCS. The S_{21} curve validates the resonant condition with the RCS simulation plot. The major advantage of the proposed chipless RFID tag is that it is maintenance-free and less costly for mass production.

References

[1] M. A. Islam and N. C. Karmakar, "Compact printable chipless rfid systems," *IEEE Transactions on Microwave Theory and Techniques*, vol. 63, no. 11, pp. 3785–3793, Nov 2015.

[2] O. Rance, R. Siragusa, P. Lematre-Auger, and E. Perret, "Toward rcs magnitude level coding for chipless rfid," *IEEE Transactions on Microwave Theory and Techniques*, vol. 64, no. 7, pp. 2315–2325, July 2016.
[3] N. C. Karmakar, *Handbook of smart antennas for RFID systems*. John Wiley & Sons, 2011.
[4] L. Wang, T. Liu, J. Sidn, and G. Wang, "Design of chipless rfid tag by using miniaturized open-loop resonators," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 2, pp. 618–626, Feb 2018.
[5] F. Costa, S. Genovesi, and A. Monorchio, "Normalization-free chipless rfids by using dual-polarized interrogation," *IEEE Transactions on Microwave Theory and Techniques*, vol. 64, no. 1, pp. 310–318, Jan 2016.
[6] 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.
[7] M. A. Islam and N. C. Karmakar, "Real-world implementation challenges of a novel dual-polarized compact printable chipless rfid tag," *IEEE Transactions on Microwave Theory and Techniques*, vol. 63, no. 12, pp. 4581–4591, Dec 2015.
[8] H. Huang and L. Su, "A compact dual-polarized chipless rfid tag by using nested concentric square loops," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 1036–1039, 2017.
[9] A. Vena, E. Perret, S. Tedjini, G. Eymin Petot Tourtollet, A. Delattre, F. Garet, and Y. Boutant, "Design of chipless rfid tags printed on paper by flexography," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 12, pp. 5868–5877, Dec 2013.
[10] N. C. Karmaker, "Tag, you're it radar cross section of chipless rfid tags," *IEEE Microwave Magazine*, vol. 17, no. 7, pp. 64–74, 2016.