A Technique to Improve RCS in Passive Chipless RFID Tags by Incorporating Array Structure

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***Abstract*—The vast applications and advantages of chipless Radio Frequency Identification (RFID) tags have taken a broad role in wireless and identification technologies. RFID is replacing barcodes in many contexts due to being in the advantage of not requiring communication with a line of sight. The IoT industry and biomedical sector have seen an enormous use of RFID tags as a sensor for interfacing with different devices. This paper aims to analyze and compare two 5-bits resonator tags. Based on the resonator techniques, the octagonal ring structure and the array of the ring structure are analyzed. The Radar Cross Section (RCS) of both designs is compared to show a better RCS curve was obtained with the array structure. The paper analyses the improvement in RCS using a resonator array. The design uses the substrate of dimensions having a length and width of 26 mm for both. The structure designed for the tag can be used for Ultra-Wideband (UWB) applications.**

Keywords—Array, Radio Frequency Identification (RFID), resonators, chipless tag, passive RFID, Radar Cross Section (RCS).

I. Introduction

Improvement in communication technologies led to the rise of RFID tags to establish a wireless communication network that is secure as well as easily usable. Advancements in IoT technology led to a great demand for RFID in the application program interface and machine learning [1]. RFID proved to be a great alternative compared to barcode technology, increasing efficiency in decoding and communication. RFID makes use of Radio Frequency waves to encode data and get information from tags and establish communication. The whole RFID model can be understood as the synergy of two main blocks first, a reader, which reads the data encoded in the tags, and second a tag, which has the information encoded. RFID tags can be classified as chipless and chipped tags, in which the difference comes from the presence of an Application-Specific Integrated Circuit (ASIC) chip in the RFID transponder. The cost of a semiconductor chip integrated into tags weighs over its advantages of identification, communication, and tracking compared to barcodes that have less cost per unit. Here chipless RFID tags are the saviour to overcome the mass manufacturing cost of RFID tags, which can be easily get printed, like barcodes, on a daily using materials such as paper and packets made of plastic [2]. We do not require any chips and communication protocol with Chipless RFID technology. Chipless works on the principle of radar, where information is stored in the structure's Electromagnetic Signature (EMS). In this technology, there is a challenge of embedding information in the passive structure's low-cost substrate, similar to Barcodes in the function. But it can be more compatible due to the advantages of sensing capabilities, efficiency in green IoT technologies, and non-line-of-sight (NLOS) interrogation [3].

In many applications, chipless RFID tags have been introduced because of the wide range of available bandwidth incorporating ultra-wideband (UWB) of 3.1-10.6 GHz, which varies from country to country, according to the requirements. Data encoding is done using two approaches, i.e., frequency-domain and time-domain approaches. The time-domain approach works on the concept of time delay, and the frequency-domain approach works on the concept of frequency responses of different frequency resonators. The frequency-domain approach seems easy as it doesn't require any extra time delays while encoding and storing information in the tags [4].

The RCS is a significant parameter to measure the efficiency of RFID. In [5], different polarization encoding methods are used to enhance the structure's performance and efficiency. In this paper, two designs are analyzed and compared. One design is based on an octagonal ring resonator and the other is an array of the resonator structure. In the paper, Section II presents the different categories under chipless RFID tags; the working of the chipless RFID tag is summarized in Section III. A brief difference between the chipped and chipless categories is discussed in Section IV. The concept of the Radar Cross Section (RCS) is discussed in Section V followed by the analysis of structures 1 and 2 in Sections VI and VII, respectively. Finally, Section VIII provides a comparative analysis with the conclusion in Section IX and references at the end.

II. Chipless RFID Tag – Categories

Fig. 1 suggests the classification of five tags in three different categories. Category 1 includes the tag's retransmission and time domain reflectometry (TDR). Data encoding and antennas are designed separately under this category. These types of tags have UWB with the pattern of omnidirectional radiation. Generally, monopoles are preferred in such cases. This antenna category is an efficient radiator. Category 2 comprises tags categorized by millimeter-wave (mmW) imaging or backscattering. Here, the antenna acts as a radiator and a data encoding resonator. Such antenna has high Q and high data encoding capacity. Patch antennas are generally preferred for backscattering because of their high Q. This antenna category is an efficient reflector. Special types of near-field printed coil antennas RFID tags come under category 3. Its primary coupling mechanism can be capacitive or inductive. In [6], the techniques for reduced dimensions of passive tag designs are discussed.

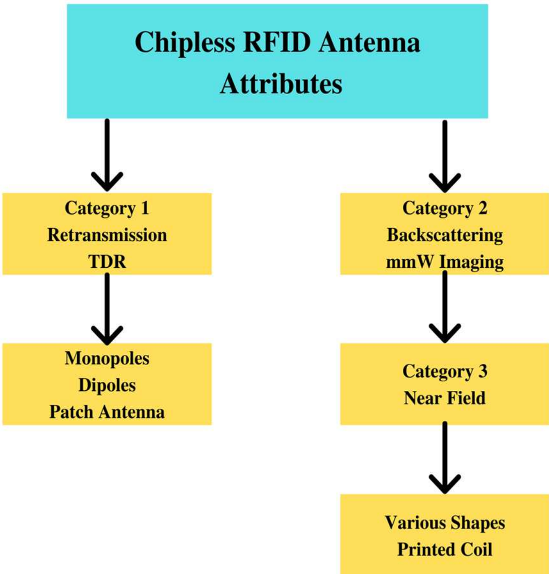

Fig. 1. Categorization of five chipless RFID tags.

A descriptive comparison between the different categories of chipless tags is given in [7].

There is a need for RCS understanding for the efficient design of an RFID tag. Retransmission tags are an efficient UWB radiator whose operation mainly depends on bandwidth and antenna gain, whereas the backscattering type performs data encoding as well as backscattering, whose principle works on the tag's RCS.

III. WORKING OF CHIPLESS RFID

A basic RFID system is displayed in Fig. 2, consisting of a tag and a reader. The component which is attached to the object is the tag, where information is stored. RFID reader in the system sends the signal to the tag to read the encoded information and turn on the tag; in return,a backscattered signal is received at the reader's receiver. Such operation of receiving the signal gets the information in a suitable form to get sensed [8]. Sometimes there is the need for amplification of RF signal from the passive RFID tag; several techniques for this purpose have been observed in [9]. Here the purpose is to detect the information and communicate wirelessly and enhance the parameters involved in the operation of RFID tags, such as RCS, range, quality factor, resonant frequency, and many others.

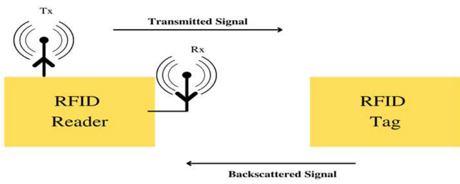

Fig. 2. RFID operation.

IV. CHIPPED VS CHIPLESS RFID

Chipped and chipless RFID tags differ from each other in several ways. Differences in these tags create several challenges in antenna design, such as transmission power, the absence of chip, which causes a problem for signal processing capabilities, and limitation of the tag antenna size due to microwave operating frequency bands.

Table I provides brief differences and comparisons between all the parameters of chipped and chipless RFID tags, such as cost, size, range, nature, etc.

TABLE I.

CHIPPED VS CHIPLESS RFID

Ref.	Parameter	Chipped RFID	Chipless RFID
[2]	Cost	High	Low
[2]	ASIC chip	Embedded	Absent
[10]	Average reading distance	5 meters	1 meter
[11]	Noise and interference	Low	High due to low power signal
[10]	Frequency range	125 KHz to 5800 MHz	Can be even more than 20 GHz
[11]	Power transmitted	3 to 4 W or more	< 10 mW
[11]	Nature	Brittle	Flexible in versatile applications

V. RADAR CROSS SECTION : AN OVERVIEW

RCS parameter shows how the reader's receiver receives the backscattered signal. RCS expression can be written as in (1) [2].

$$\sigma = A \times |\Gamma|^2 \times D \quad (1)$$

Where A denotes the cross-sectional area of the target which is projected towards reader in the m^2 unit, $|G|^2$ is the reflectivity, i.e., coefficient of power reflection, and D is directivity.

In general RCS is defined as (2) [2].

$$\sigma = \frac{\lambda^2 R_a G_{tag}^2}{\Pi |Z_a + Z_c|} \quad (2)$$

Where λ is the operating frequency wavelength, R_a is the real part of the input impedance of antenna Z_a, G_{tag} is antenna gain, and Z_c is chip impedance of Chipped RFID tag.

Because of the absence of a chip in chipless RFID, Z_c is matched and assumed to the 50 Ω transmission line. Hence the equation will reduce to (3), assuming Z_a is a real quantity at the resonant frequency [2].

$$\sigma = \frac{\lambda^2 R_a G_{tag}^2}{\Pi |2 Z_a|} = \frac{\lambda^2 G_{tag}^2}{2\pi} \quad (3)$$

Chipped tag maximum range can be given by (4) [12].

$$R_{max} = \frac{\lambda}{4\pi} \sqrt{\frac{P_i P_{PLF} G_r G_t}{P_m}} \quad (4)$$

Where P_i is the tag's input power, P_{PLF} is Polarization Loss Factor, G_r is the gain of the reader antenna, G_t is the normalized gain of the tag antenna, and P_m is the chipset's minimum sensitivity.

VI. DESIGN OF STRUCTURE 1

An octagonal structure is used to design the tag, and it is fabricated on FR–4 substrate (epsilon (Ɛr) = 4.3 and loss tangent = 0.02), which is a low-cost material. The octagonal chipless tags are useful to work within a range of 3.1 to 11 GHz in UWB. With the backscattering phenomenon and geometry of the design, 5-bits can be obtained in the available bandwidth. Octagonal tags can be a good choice in terms of polarization feature independence. Due to existing symmetry in the structure, the octagonal shape can be read without the Fig. 3. Octagonal RFID structure.

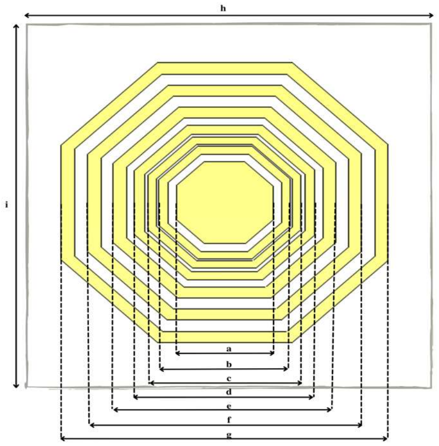

Fig. 3. The structure of orthogonal resonator based transponder.

constraint of rotation angle, which can be an advantage where it is difficult to get a stable tag position [13].

In the structure of octagonal tags, there are multi-octagonal rings, in which six octagonal rings are concentrically placed with a solid octagon at the center [13]. The dimensions of the designed tag substrate are 26 × 26 × 0.1 mm^3. The structure is shown in Fig. 3.

The data on the dimensions of the structure is shown in Table II. To get a better RCS, dimensions were chosen dynamically. The simulation of the structure was done through CST Studio Suite Student Version 2021. The tag was designed by taking the octagons with the suitable inner and outer radii to get the desired structure [13].

TABLE II.

DIMENSIONS OF STRUCTURE

Length	**Value**
a	6.6 mm
b	9.0 mm
c	10.5 mm
d	12.4 mm
e	15.3 mm
f	18.8 mm
g	22.4 mm
h	26 mm
i	26 mm

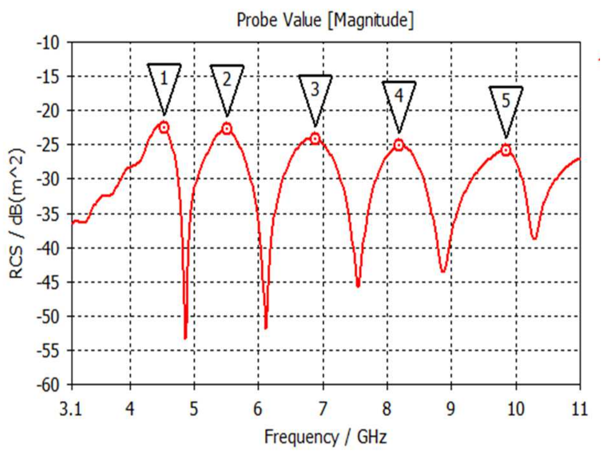

Fig. 4. Simulated RCS.

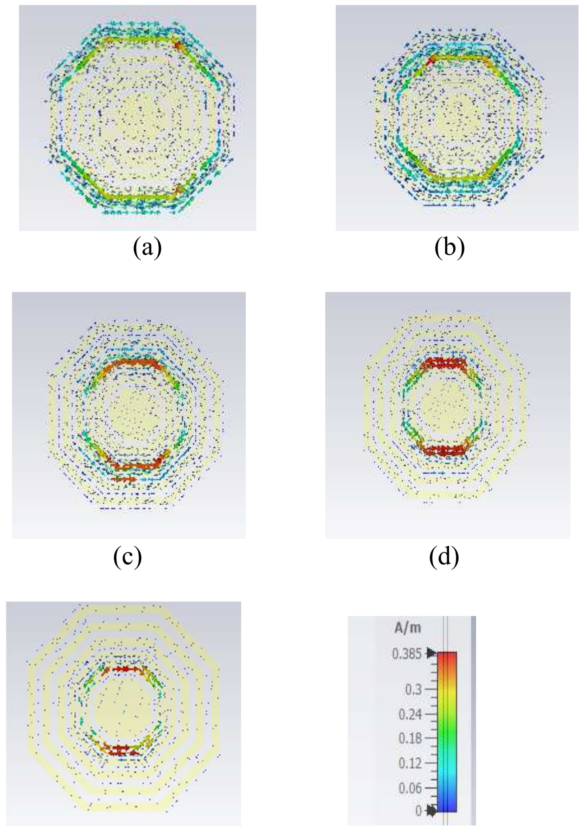

Fig. 5. Current distribution plots (a) 4.477 GHz, (b) 5.484 GHz, (c) 6.833 GHz, (d) 8.201 GHz, and (e) 9.816 GHz.

The RCS response simulated in the CST environment is shown in Fig. 4, in which we got five resonant peaks in available bandwidth at 4.477 GHz, 5.484 GHz, 6.833 GHz, 8.201 GHz, and 9.816 GHz.

The Simulated RCS suggests five encoding bits from five resonating peaks [14], which are also desired, hence validating the results. The surface current distribution for resonant peaks is shown in Fig. 5.

It can be noted at the lowest frequency peak, the current is maximum at the outer resonator, and as the frequency is gradually increasing, the maximum current is achieved at the inner resonators.

VII. DESIGN OF STRUCTURE 2

Structure 2 is based on structure 1, taking structure 1 as a unit element and forming an array of 2×2. It is fabricated on the same substrate which was taken for structure 1. The dimension taken for the substrate is 26×26 mm^2. The layout of the structure is shown in Fig. 6.

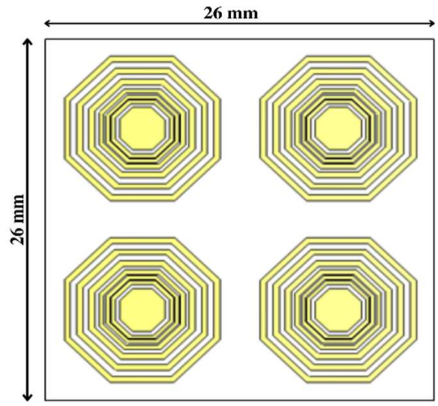

Fig. 6. Structure of octagonal unit array.

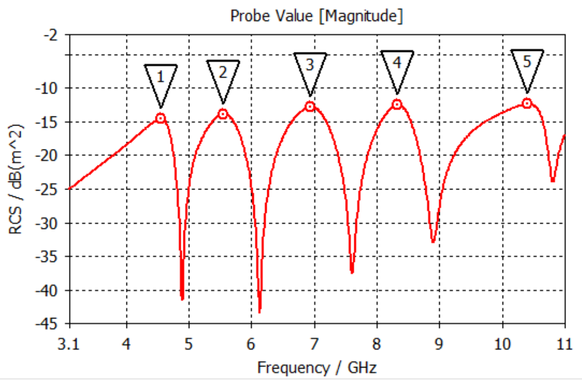

Fig. 7. Simulated RCS of structure 2.

The array is formed with the symmetrical placing of the octagonal element in the structure. The RCS is simulated with the CST Studio Suite student version 2021. The RCS response with five peaks at 4.563 GHz, 5.550 GHz, 6.947 GHz, 8.333 GHz, and 10.402 GHz is shown in Fig. 7. In this structure, 5-bits can be encoded, hence validating the results with the desired number of bits. The distribution of surface current at various resonant frequencies is displayed in Fig. 8.

VIII. Comparative Analysis

Structure 1 and structure 2 are based on the octagonal rings resonator structure. Without affecting the coding capacity of the structure and with the same size, the RCS achieved was better in structure 2 of the array. Due to remarkable changes in inductive and capacitive effects, RCS resonating peaks were changed slightly. The maximum RCS peak in structure 1 is obtained at -22.126 dBsm, while the RCS peak for structure 2 is at -12.392 dBsm. The above paper shows the improved RCS with an array and is advantageous for many design parameters with multi-bit encoding, impedance matching, and wide bandwidth features. The applications for various frequency bands are given in Table III.

TABLE III.

Applications in Different Frequency Bands

Ref.	Frequency band	Applications
[15]	900 KHz–2.7 GHz	Fabric, tracking and identification, detection of various items
[2]	2.4 GHz-2.5 GHz	Band for Industrial, Scientific, and Medical (ISM)
[16]	2.6 GHz-2.9 GHz	Measurement of different liquids permittivity
[17]	4.3 GHz	Tagging of various products
[10][16]	5.725 GHz-5.875 GHz	Wearable technologies
[4][10]	3.1 GHz-10.6 GHz	Ultra wide-band (UWB) applications, e.g. medical imaging

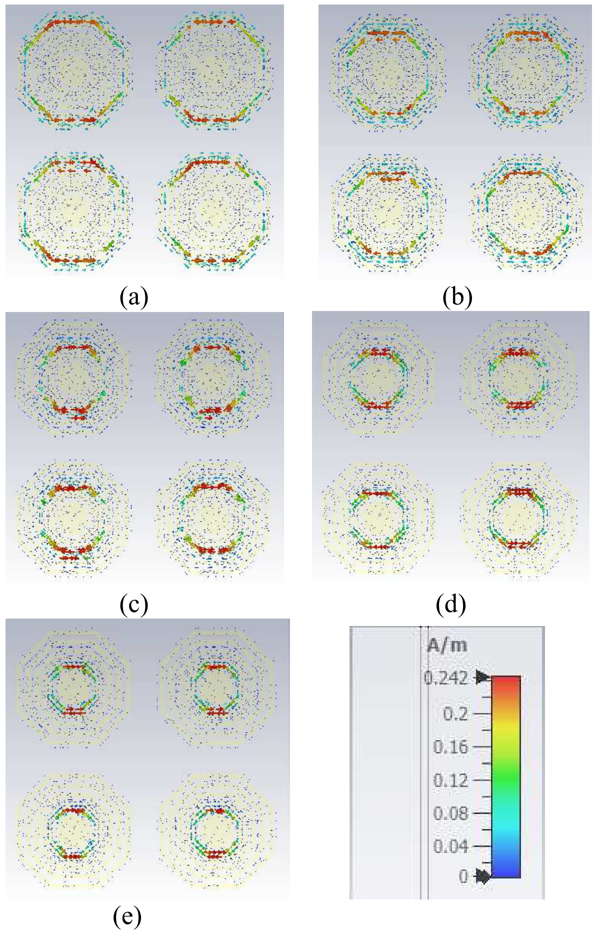

Fig. 8. Current distribution plots (a) 4.563 GHz, (b) 5.550 GHz, (c) 6.947 GHz, (d) 8.333 GHz, and (e) 10.402 GHz.

IX. Conclusion

This article presents the effectiveness of using an array structure to achieve a better RCS. The array structure provides a good scope for multi-bit encoding for tracking and identification. The RCS was improved using an array of 2 × 2 with an octagonal ring resonator as a unit element. The RCS peak of the unit element is found to be -22.126 dBsm which improved to -12.392 dBsm with structure 2. This research article with the comparison between two tag structures provides insights into applications in long-term durability in the industrial domain.

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