Comparative Study of Chipless RFID Tag Resonator for Orientation-Independent Properties and Bit-Capacity

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Abstract— **Radio frequency identification (RFID) is a growing technology in various domains for identification and tracking purposes. Wearable and on-body sensing technology are significant topics in the industrial, scientific, and medical fields. Based on the presence of the IC chip, RFID tags can be classified into chipped and chipless tags. Recently, chipless RFID tags are being investigated because of their high usage and low cost. Orientation-independent chipless RFID tags are promising for future wearable sensing devices. Therefore, an understanding of the orientation-independent Chipless RFID tags is necessary to develop the sensor tags. The paper's main purpose is to explore the flexibility of the chipless RFID tag for rotation insensitivity and coding capacity. Here, conventional shapes of resonators like square, circle, triangle and hexagon in microstrip patch configuration are studied for the orientation-independent property. Further, concentric circular ring and slot configurations are discussed for high bit-capacity.**

***Index Terms*—Radio Frequency Identification (RFID), Orientation-Independent, Chipless tag, Concentric Ring, Bit-capacity.**

I. INTRODUCTION

Radio frequency identification, or RFID, is a term that refers to the technology which is constantly advancing in the area of wireless communications. The RFID system primarily consists of a tag fixed to an object and an interrogator/reader, where the reader serves as both a transmitter and receiver of electromagnetic (EM) signals. The use of RFID tags for automatic identification and authentication, supply chain automation, medical applications, and potential industrial uses like the identification of pathology and other medical test samples, scanning of credit cards and library cards, and inventory tracking in retail settings are all possible [6].

The working principle of RFID tags is similar to the RADAR system where the target is the tag and the transceiver system is the reader antenna. The principle is shown pictorially in Fig 1.

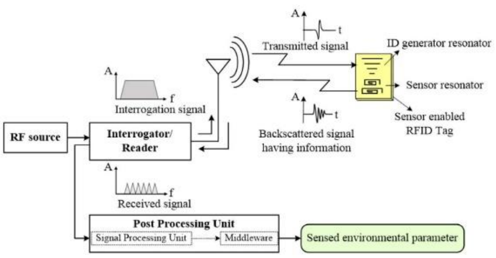


Fig 1. Working Principle of RFID system [13]

The tag is interrogated by an EM signal from the reader antenna and it is backscattered by the tag to the reader antenna again. The information present in the tag is analyzed by different parameters such as frequency, phase etc. Using several post processing techniques, the information ID and sensor information is obtained.

The RFID tags are classified into several categories based on different parameters. It can be separated into two categories based on the presence of the IC chip [11]. They are chipped tags and chipless tags. In chipped RFID, a chip is visible, whereas in, chipless RFID, the tag is devoid of a chip. Both chipless and chipped RFID tags use the passive backscattering principle as their data collection method. The main differences between chipless RFID and chipped RFID are listed in Table I. Due to their low cost, chipless RFID tags are being researched nowadays [10]. The main difficulty of chipless RFID is limited transmission power and read range. Also, the backscattered signal which is the signal that carries the information is combined with noise. Consequently, it also has low power [11].

An RFID tag's ability to be orientation-independent is important to most applications. If the tag is giving the same performance for any degree of rotation, the tag is orientation-independent. This property can be achieved by duplicating, rotating, and optimizing the resonator's shape. The orientation RFID tag is useful in modern life, and one of its important applications is as a wearable gadget. The benefit of the rotation-insensitive tag is that the reader antenna can detect the tag irrespective of its orientation [3].

TABLE I: FEATURES OF CHIPPED AND CHIPLESS RFID TAG

Features	**Chipless RFID**	**Chipped RFID**
Presence of chip	No IC chip	IC chip
Power transmitted	Low (10 mW)	Relatively more 3-4 W
Read range	Small (1-3 m)	more (10-20 m)
Reading speed	4.8 km/h	80 km/h
Tag density	less	more
Design complexity	Complex	Simple

Recently, more research work is being done toward making the tag orientation independent. A hexagonal tag is designed using triangular patches [4]. The same patches are duplicated six times to achieve a hexagonal shape and stitched together to create a very compact long-range chipless RFID tag. Its main purpose is to increase the reading range of the tag and also orientation-independent approach was proved. A finite frequency-selective surface (FSS) which gives a large read range and the ability to increase the bit number without increasing the size is proposed [1]. A depolarizing tag having orientation-insensitive property is presented in [8]. A combination of L-type resonators and compass-shaped resonators is used for the identification of cracks on the large metallic surface [9]. In there, resonant frequencies of L-shaped resonators are used to identify the metallic item under inspection, and a crack on the object is detected by a change in the resonant frequency of a compass-shaped resonator.

This paper presents different shapes of patch type resonators, concentric ring resonators and their slot configurations are designed and compared for the orientation-independent property as well as the coding capacity of the tags.

II. Design and Analysis of Conventional Tags for Orientation Independent Property

The tags are designed at 5.8 GHz frequency for ISM band applications. They are designed on FR-4 Substrate with dielectric permittivity of 4.3 and a loss tangent of 0.025 with the dimensions of 30 × 30 mm^2. The probe is placed 30 cm from the tag position and the entire simulation is carried out using CST Microwave Studio software.

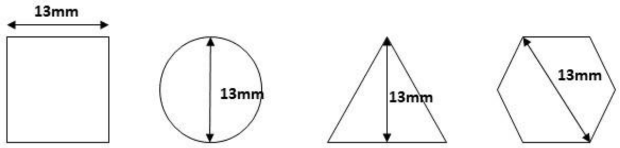


Fig 2: Selected Patch shapes

All the tags are designed at λ/4 length to the parameters of the geometrical shapes as shown in Fig 2 at 5.8 GHz frequency. The free–space wavelength at the operating frequency can be expressed as

$$\lambda = \frac{c}{f} \tag{1}$$

where λ is the wavelength, c is the speed of light, and f is the resonant frequency.

A. Square Patch Tag:

The optimal length of the side of the square patch is found to be 11.25 mm for it to resonate at 5.8 GHz resonant frequency. The tag is rotated with 15° steps and the RCS responses are plotted in Fig. 3. The response is same for every 90°. However, there is a maximum frequency shift of 0.2 GHz for every 15° of rotation angle. So, it is understood that the square patch is not completely orientation-independent.

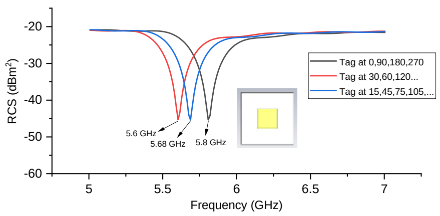


Fig 3: Geometry and RCS plot of square patch type tag

B. Circular Patch Tag:

For the circular patch, it was found that the diameter of a 13.2 mm circular patch is the nearest length that shows resonant frequency of 5.8 GHz. The RCS plot of the circular tag for different angle of rotation is shown in Fig. 4. As we know from basic geometry, the circle is an orientation-independent shape. Here, it exhibits an insignificant frequency shift of 0.06 GHz for every 15° rotation. The true orientation-independent property is not obtained due to the square-shaped ground plane and substrate. The surface current on circular patch of tag at its resonating frequency is shown in Fig. 5 for 0° and 45°. At 0°, the electric and magnetic fields of incident plane wave are aligned to length and width of tag. However, at 45°, fields are aligned to diagonal of tag which slightly reduces the resonant frequency.

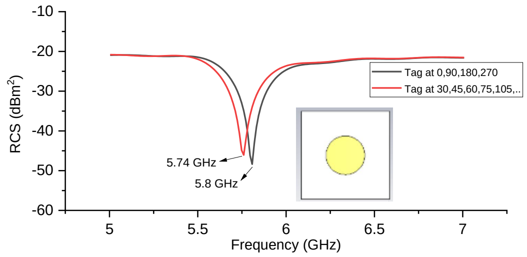


Fig 4: Geometry and RCS plot of circular patch type tag

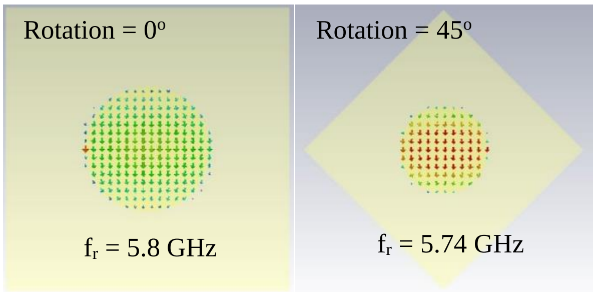


Fig 5: Surface Current Distribution on the circular tag

Further, a circular-shaped ground plane and substrate is used to prove the true orientation-independency of the tag. The geometry of tag and RCS response is shown in Fig 6. The radius of the substrate is taken as 15 mm. Here, the tag is exhibiting truly orientation-independent property since the fields are aligned in same manner for different rotation angles. Hence, there is no frequency shift when the tag is rotated 0-360° in its plane.

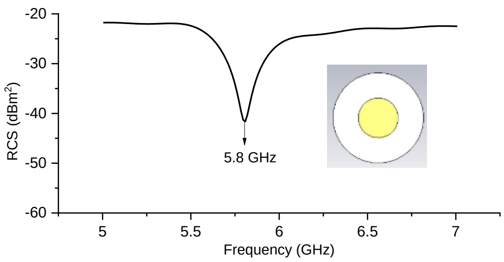


Fig 6: Geometry and RCS plot of circular patch with circular substrate and ground plane

C. Triangular Patch Tag:

For the triangular patch, it was observed that the length of the side of the triangle at 13 mm does not accurately resonate at 5.8 GHz. The optimum length of 12.9 mm is obtained by parametric optimization. The RCS response of triangular tag for different rotation angle is shown in Fig. 7. The triangular tag is orientation independent for every 180° rotation.

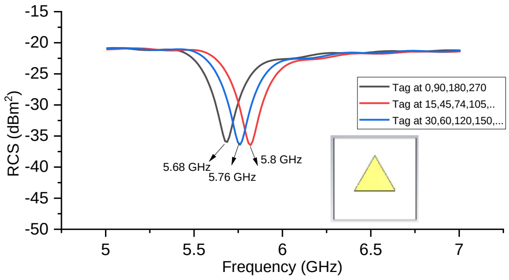


Fig 7: Geometry and RCS plot of triangular patch type tag

For the rotation angles of 0° and 180°, the graph shows the resonant frequency of 5.81 GHz. But it shifts to 5.82 GHz for a rotation angle of 90°. Further, a slightly higher frequency shift from 5.81 to 5.76 GHz is noticed for the rotation angles of 30°, 60°, 120°, 150°. But then again the shift increases from 5.81 to 5.69 GHz for 15°, 45°, 75°, 105° etc. Therefore, we can conclude that the triangular patch tag is not orientation-independent. The frequency shift when the tag is rotated is 0.13 GHz.

D. Hexagonal Patch Tag:

For the hexagonal patch, the optimal diameter of the hexagon was discovered to be 14.4 mm. After rotating the structure, the resulting RCS is shown in Fig 8.

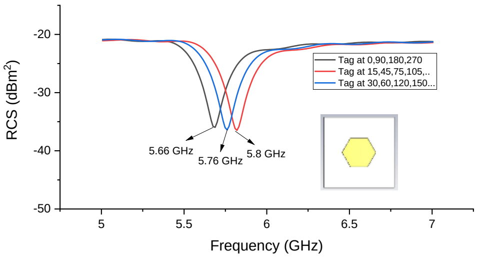
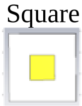
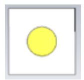
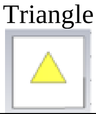
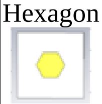


Fig 8: Geometry and RCS plot of the hexagonal patch type tag

Here, the resonant frequency is 5.8 GHz for rotation angles of every 60°. However, a small frequency shift from 5.8 to 5.75 GHz is observed for rotation angle of 90°, but the frequency shift is slightly higher from 5.8 GHz to 5.67 GHz for 15°, 30°, 45°, 75°, 105°, 135°, 150°, 165° rotation angles. Hexagon has stable performance for every 60° and it has maximum frequency shift 0.14 GHz. Therefore, hexagon patch tag is almost an orientation-independent tag.

From all the above patch type tags, it is observed that the circular patch resonator with circular substrates and the ground plane is purely orientation-independent. The summary of all the patch type tags is listed in Table II.

TABLE II: COMPARISON OF PATCH TYPE TAGS FOR ORIENTATION INDEPENDENT PROPERTY

Tag		**Response**		
Shape	**Max. length** (mm)	**f$_r$** (GHz)	**RCS** (dB/m^2)	**Δf** (GHz)
Square 	11.25	5.8	-45.2	0.2
Circle 	13.2	5.8	-48.4	0.06
Circle 	13.2	5.8	-41.45	0
Triangle 	12.9	5.8	-36.9	0.13
Hexagon 	14.4	5.8	-49.9	0.14

III. STUDY ON BIT-CAPACITY OF CIRCULAR TAGS

For further study on the bit-capacity of tags, the circular-shaped resonator on the circular substrate is considered. The overall size of the circular tag with a radius of 15 mm is kept the same as mentioned in previous section. In this section, two configurations: concentric rings and slots are considered for analyzing the bit capacity.

A. Concentric Ring Tag:

The circular ring tag is designed to investigate the coding capacity of the RFID tags. Here single circular ring is designed with outer radius of 6.6 mm and width of conducting ring is 1.8 mm as shown in Fig 9(a). It is observed from the RCS response, that the resonant frequency is 4.74 GHz with an RCS value of -37.7 dB/m^2. The ring-type resonator has a lower resonance frequency when compared to the circular patch resonator.

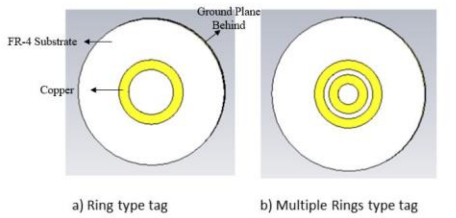


Fig 9: Geometry of concentric circular ring tags

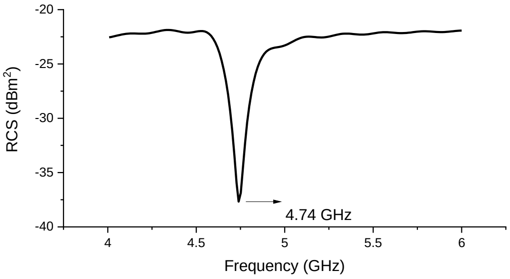


Fig 10: RCS plot of circular ring tag

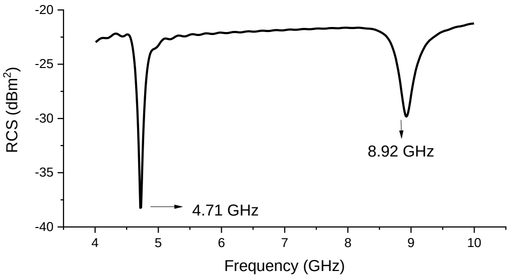


Fig 11: RCS plot of multiple circular ring tag

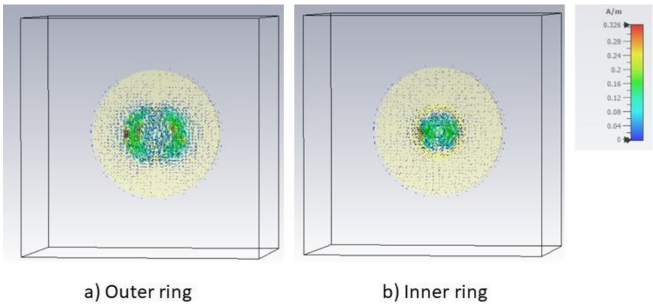


Fig 12: Surface current distribution on Multiple ring type tag (a) at 4.71 and (b) 8.92 GHz

To increase bit capacity from one to two bits, one smaller circular ring is designed concentric to the existing circular ring. The additional ring of the same conducting width is designed with an outer radius of 3.8 mm. Because of two concentric rings, two resonant frequencies: 4.71 and 8.92 GHz are observed in the RCS response as shown in Fig. 11. By looking at the surface current distribution as shown in Fig. 12, we can determine the outer ring is resonating at a lower frequency 4.71 GHz while the inner ring is resonating at 8.92 GHz. The RCS value for the second ring is -29.82 dB/m^2 which is lower than the outer ring's RCS level of -38.25 dB/m^2. Keeping the same outer ring, it is difficult to further increase the bit capacity of concentric ring type tag due very less space in the center of the tag. Therefore, slot type tag having concentric slots is designed in next sub-section.

B. *Slot Tag:*

The slot type tag is designed on a similar substrate of circular shape of radius 15 mm radius. The slot type tag is uniplanar due to the absence of ground plane on the back side of substrate, hence it is cost effective.

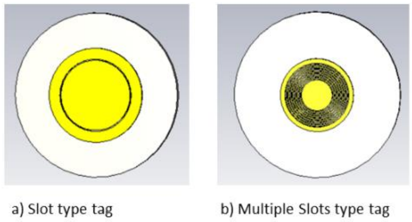


Fig 13: Geometry of circular slot type tags

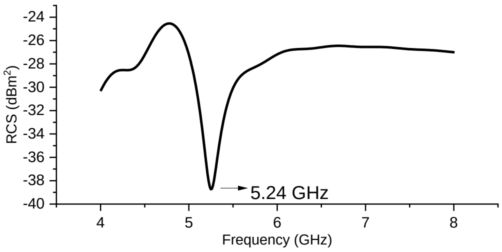


Fig 14: RCS plot of the single slot type tag

The circular slot with an outer radius of 6.1 mm and a slot width of 0.5 mm is designed on conducting a circular patch of the same size (6.6 mm radius). The geometries of slot-type tags are shown in Fig. 13(a). The single slot type tag provides single bit capacity due to a single circular slot resonator. It is resonating at 5.24 GHz as sown in Fig. 14.

To increase the bit-capacity, multiple slots are created keeping the outer outermost radius the same as 6.6 mm as shown in Fig. 13(b). Eight multiple concentric slots are designed to encode 8-bit data. Due to the presence of eight slot type resonators, eight different resonant frequencies corresponding to each slot are obtained as shown in Fig. 15. Hence, this tag has the capability to encode 8-bit data. Here, the bit capacity is determined by the ratio of total number of bits encoded to the area of the tag [12].

$$\text{Bit Capacity} = \frac{No.of\ bits\ encoded}{Total\ area\ of\ the\ tag} \quad (2)$$

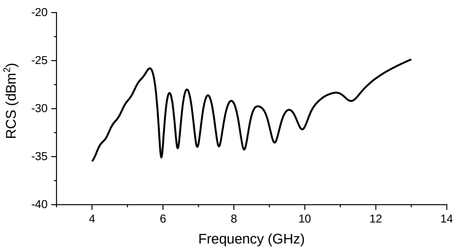


Fig 15: RCS plot of the multiple slot type tag

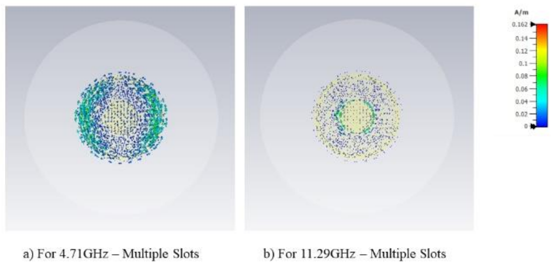


Fig 16: Surface Current Distribution on circular slot tag

The number of bits encoded in tags having different configurations of circular resonators are summarized in Table III as per equation (2). It is found from the analysis that the slot type tag having multiple concentric slot resonators is advantageous in terms of bit-capacity.

TABLE III : SUMMARY OF CIRCULAR RESONATORS

Type	Frequency GHz)	RCS (dB/m^2)	No. of bits	Bit Capacity
Circular Patch	5.8	-41.45	1	0.14 bits/cm^2
Ring	4.74	-37.70	1	0.14 bits/cm^2
Multiple Rings	4.71	-38.25	2	0.28 bits/cm^2
	8.92	-29.82		
Slot	5.24	-38.72	1	0.14 bits/cm^2
Multiple Slots	4.71	-38.25	8	1.13 bits/cm^2
	5.95	-35.09		
	6.41	-34.12		
	6.96	-33.97		
	7.57	-33.93		
	8.29	-34.24		
	9.14	-33.53		
	9.92	-32.15		
	11.29	-29.20		

IV. CONCLUSION

The paper presents the fundamental study of various types of resonator shapes and different configurations of chipless RFID tags for orientation-independent property data encoding. All the tags were designed on the same substrate with the same size. It has been found that circular shape is purely orientation-independent and provides the exact same RCS response when the substrate is made circular too. To increase the bit capacity of orientation-independent tags of circular shape, ring-type slot-type resonator tags are designed and analyzed. It has been clearly noticed that the slot type tag having multiple concentric slot resonators is better to encode more bits in the given overall size of the tag. These tags can be useful for ISM band applications because of easy frequency tenability, uniplanar structure and low cost.

V. ACKNOWLEDGEMENT

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REFERENCES

[1] Z. Ali, O. Rance, N. Barbot, and E. Perret, “Depolarizing Chipless RFID Tag Made Orientation Insensitive by Using Ground Plane Interaction,” IEEE Trans Antennas Propag, vol. 70, no. 7, pp. 5235–5245, Jul. 2022.

[2] S. K. Behera, “Chipless RFID Sensors for Wearable Applications: A Review,” IEEE Sens J, vol. 22, no. 2, pp. 1105–1120, Jan. 2022.

[3] C. S. Kumar and S. R. Patre, “Array of chipless RFID sensor tag for wireless detection of crack on large metallic surface,” in 2021 IEEE International Conference on RFID Technology and Applications, RFID-TA2021, 2021.

[4] S. K. Behera and N. C. Karmakar, “Wearable Chipless Radio-FrequencyIdentification Tags for Biomedical Applications: A Review [Antenna Applications Corner],” IEEE Antennas and Propagation Magazine, vol. 62, no. 3. IEEE Computer Society, pp. 94–104, Jun. 01, 2020.

[5] F. Babaeian and N. C. Karmakar, “Development of Cross-Polar Orientation-Insensitive Chipless RFID Tags,” IEEE Trans Antennas Propag, vol. 68, no. 7, pp. 5159–5170, Jul. 2020.

[6] T. Athauda and N. Karmakar, “Chipped versus chipless RF identification: A comprehensive review,” IEEE Microw Mag, vol. 20, no. 9, pp. 47–57, Sep. 2019,

[7] G. S. Shehata, “High RCS compact orientation independent chipless RFID tags based on slot ring resonators (SRR),” in National Radio Science Conference, NRSC, Proceedings, May 2018, vol. 2018-March, pp. 69–76.

[8] A. Islam, Y. Yap, and N. Karmakar, “ Slotted compact printable orientation insensitive chipless RFID tag for long range applications,” in Proceedings of 9th International Conference on Electrical and Computer Engineering, ICECE 2016, Feb. 2017, pp. 283–286.

[9] N. C. Karmaker, “Tag, You’re It Radar Cross Section of Chipless RFID Tags,” IEEE Microw Mag, vol. 17, no. 7, pp. 64–74, Jul. 2016,

[10] F. Costa, S. Genovesi, and A. Monorchio, “A chipless RFID based on multiresonant high-impedance surfaces,” IEEE Trans Microw Theory Tech, vol. 61, no. 1, pp. 146–153, 2013

[11] M. A. Islam, Y. Yap, N. Karmakar, and A. K. M. Azad, “Orientation independent compact chipless RFID tag,” in 2012 IEEE International Conference on RFID-Technologies and Applications, RFID-TA 2012, 2012, pp. 137–141.

[12] S. U. Khan, H. Shahid, Y. Amin, M. J. Khan and M. A. Riaz, "Orientation Independent, Polarization Insensitive High-Density Flexible Chipless RFID Tag for IoT Applications," 2021 3rd International Symposium on Material and Electrical Engineering Conference (ISMEE), Bandung, Indonesia, 2021, pp. 73-77.

[13] S. R. Patre, "Passive Chipless RFID Sensors: Concept to Applications—A Review," in IEEE Journal of Radio Frequency Identification, vol. 6, pp. 64-76, 2022.