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Dielectric Resonator Antenna as a RFID Tag for Human Identification System in Wrist Watch

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Abstract—Radio Frequency Identification (RFID) has been considered as a time and money-saving solution for a wide variety of applications, such as manufacturing, supply chain management, and inventory control. However, there is a growing need in the RFID community to research and find out the tag with miniature, circular polarized radiation patterns, dual band operation, high radiation efficiency and high bandwidth operations. This paper presents compact radio frequency identification

(RFID) tag for human identification system in wrist watch. Dielectric resonator antenna (DRA) with patch is used as an active tag. The proposed antenna is operated on dual frequency bands. Simple microstrip line is used as a feeding mechanism. It is operated at 2.4 GHz and 5.8 GHz frequency band. It has circular polarization radiation patterns. Simulation results are presented on various parametric studies on the RFID tag.

Keywords- Dielectric Resonator Antenna, RFID tag, human identification system

I. INTRODUCTION

Radio frequency Identification (RFID) solution is a revolutionary applications of automatic identification and data capture technology that is contactless and does not require line of sight. RFID tags will be embedded in all kinds of consumer products and scanned from several meters away (The distance lies on types of the tag, operation frequency and type of technology), revealing the information about the product and (potentially) its owner. By attaching tags to products, an automated inventory will be easily maintained. Tags also allow customers to pay a reader. Postal services will equip shipped goods with tags for tracking purposes and read-write storage, integrated sensors, or more gates for computation purposes. In a word, RFID system is a common and useful tool in manufacturing, supply chain management, and inventory control [1]. Nowadays, it can be applied into some pretty new applications, like human identification. This application has wide use in military purpose to fight against terrorisms, border movement of troops, and hidden movement of criminals around the nation.

A typical radio frequency identification system is made up of three components: 1) an electronic data carrying device called RFID tag is combined with an antenna. The tag is usually a microchip and contains the item to be identified 2) a reader that communicates with the tag antenna by means of electromagnetic waves 3) a host data processing system embodies the information of the identified item and communicates with other remote data processing systems [2]. The RFID system [2, 3] covers frequency bands of low-band range 100-500 KHz, high frequency 13.56 MHz, ultra high frequency (UHF) 860-960 MHz, and microwave band range 2.4 GHz and 5.8 GHz. The most highlighted applications that utilize the UHF and microwave band. Owing to its long reading range and high reading speed, there has been more and more research into design of microwave RFID tag antenna [4]. Most applications require that the tags to be compact in size, low cost, easy fabrication, circular polarization, multiple bands, single feed, single layer, good matching, high directivity, high radiation efficiency, and easy to integrate with microwave circuits.

Various RFID antennas were reported in literature namely folded printed dipole antenna [2], patch antenna [5], two layered patch antenna[6], half-ring folded-slot antenna[7], slot-loaded patch antenna [8], loop antenna, spiral antenna [9], and other modified patch antennas with different feeding mechanism for various characteristics of RFID. There are various issues on printed patch antennas such as wide beam width, narrow bandwidth, surface wave excitation, radiation efficiency and radiation characteristics. Due to these, dielectric resonator antenna proposed for the RFID antenna in this paper. The DRA introduced by Long et al. in 1983 [10], could be used for such application due to higher radiation efficiency, versatility in their shape and feeding mechanism, and wide bandwidth at millimeter-wave frequencies where the conductor losses of metallic patches are considerable. The DRA is a resonant antenna, fabricated from a high-permittivity microwave material mounted on a ground plane and fed by a coaxial probe, aperture coupling, coplanar waveguide, and direct microstrip line. Various geometries of the DRA such as cylindrical, rectangular, hemispherical, spherical, and triangular are possible. The resonant frequency of the DRA is a function of size, shape, and permittivity of material used in DRA [11]. As compared to the other shapes, rectangular DRAs offer more design flexibility since, two of its dimensions can be varied independently for a fixed resonant frequency and known dielectric constant of the material. Also, In RDRA, the mode degeneracy can be avoided by properly choosing the three dimensions of the resonator. RDRA is also easy to fabricate as compared to the other shapes. Looking towards these advantages, rectangular dielectric resonator antenna is more suitable as compared to cylindrical and spherical DRAs for RFID applications.

In this paper, L-shaped dielectric resonator antenna (DRA) with metallic conductor is proposed as a RFID antenna for human identification system with dual mode, circular polarized, compact in size, single layered, single feed, high radiation efficient, and easy to integrate and to fabricate. Simulation is carried by Ansoft HFSS simulation tool. Various characteristics such as return loss characteristics, resonant frequency, impedance bandwidth, and gain of the antenna are studied. Parametric study has been performed by placing the metallic conductor on three side of L-Shaped DRA and length of metallic conductor on arm-length of the antenna. Based on these parametric studies, effect of the metallic conductor (patch) and length of metallic conductor on resonant frequency and impedance bandwidth has been discussed.

II. ANTENNA GEOMETRY AND THEORY

A. Geometry of the proposed RFID Antenna

Figure 1 shows the geometry of the proposed dielectric resonator antenna. L-shaped DRA with metal plate (patch) is placed on one of corner of a wrist watch. A 50 Ω microstrip line is used, which is printed on top of the grounded substrate with thickness h = 0.76 mm, dielectric constant of 10.2 and loss factor of 0.0017, length L_s and width W_s. L-shaped DRA is characterized by arm lengths L_1 & L_2, width W, height H, and dielectric constant ε_r.

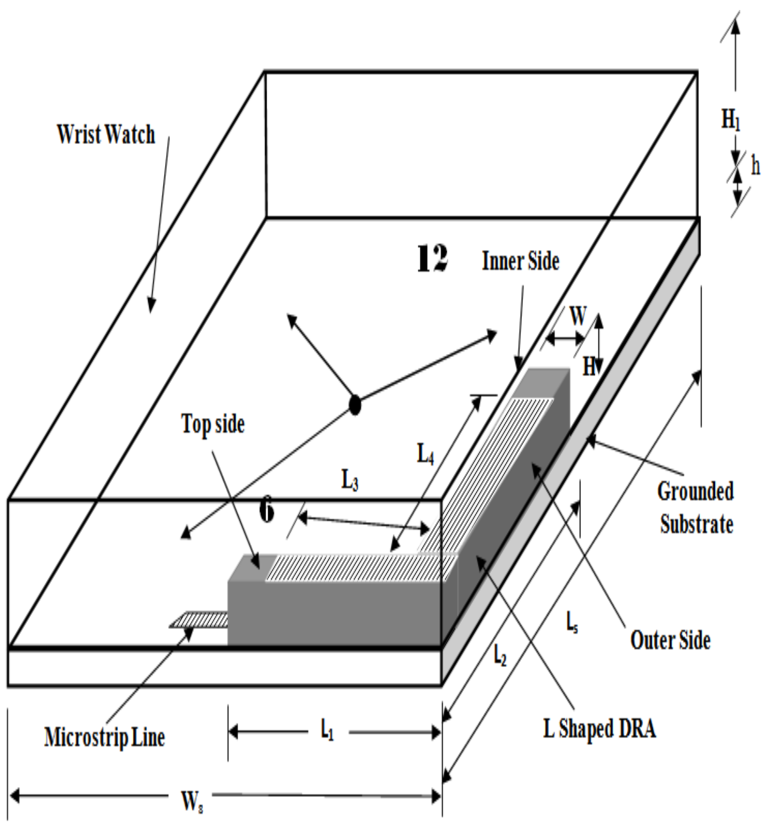

Figure 1 Geometry of the proposed antenna in wrist watch

Compact designed is achieved by placing conducting plate on conventional dielectric resonator antenna with arm lengths L_3 & L_4 and width W. The wrist watch is made of plastic material with dimension of L_s x W_s x (H_1+h). The field equations of the antenna and initial equations of resonant frequency are given in [12] for rectangular DRAs. The proposed antenna has metallic plate on conventional dielectric resonator antenna so it gives decreased in resonant frequency and volume with the cost of impedance bandwidth as compared to the conventional dielectric resonators. By used of metallic patch, compact DRA is efficient candidate to use as a RFID tag. Due to two arms of DRA, it gives circular polarization as well as dual mode operation.

B. Theory

The resonant behavior of the simplified case of an isolated conventional rectangular RDRA is analyzed here. The antenna is characterized by height b, width d, and length w, as shown in Figure 2 and is made of microwave material with dielectric constant ε_r. This geometry is equivalent to a RDRA of the same material placed over an infinite ground plane with dimensions w, d, and height h = b/2. Second order approximation model is used to predict the resonant frequency for lower order model, where two of the six surfaces of the resonator are assumed to be imperfect magnetic walls, while the remaining four are assumed to be perfect magnetic walls. This model is therefore a combination of magnetic wall model (MWM) and dielectric waveguide model (DWM) method [13]. The modes of RDRA can be divided into TE and TM modes. However, the lowest TM modes were never observed experimentally. The three TE modes with lowest order indices are TE^x_{111}, TE^y_{111} and TE^z_{111}. If the smallest dimension of the rectangular DRA is in x direction, then the dominant lowest order mode will be the TE^x_{111} mode. The equations for calculating the resonant frequency are

$$k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_0^2 \qquad (1)$$

$$k_0 = \frac{2\pi}{\lambda_0} \qquad (2)$$

$$k_y = \frac{\pi}{w} \qquad (3)$$

$$k_z = \frac{\pi}{b} \qquad (4)$$

$$k_x \tan\left(\frac{k_x d}{2}\right) = \sqrt{\left((\varepsilon_r - 1)k_0^2 - k_x^2\right)} \qquad (5)$$

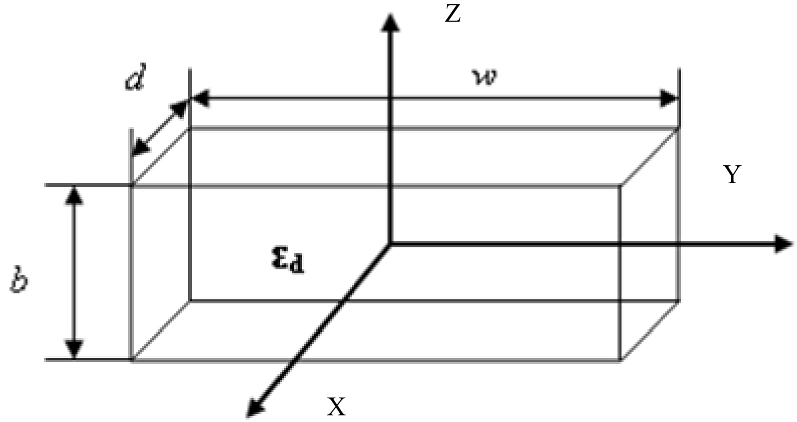

Figure 2 Isolated rectangular dielectric resonator antenna

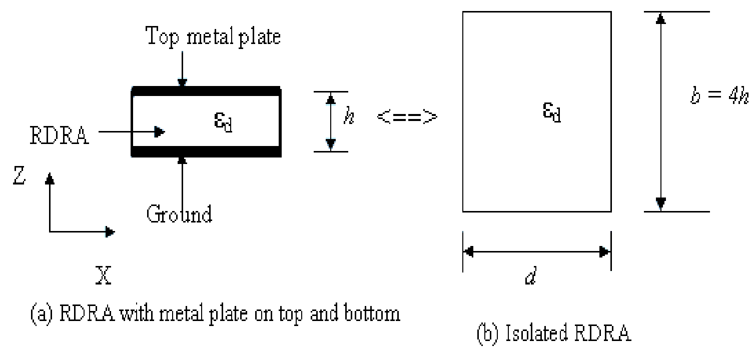

Figure 3 the compact DRA with metallic layer and its equivalent DRA in free space

Where k_x, k_y and k_z are wave number in x-, y- and z- direction. k_0 denotes the free space wave number corresponding to the resonant frequency. λ_0 is the free space wavelength corresponding to the resonant frequency. For given resonator parameters $\varepsilon_{r,}$ d, w, and h, the resonant frequency of RDRA is the one at which k_x, determined using (1-4) and also satisfies (5) [14]. For a given resonant frequency, $\varepsilon_{r,}$ w, h, the width d, determined using (2-5) and also satisfies (1).

The cross sectional view of a compact rectangular DRA with metallic plates on top and bottom surfaces is shown in Figure 3. Image theory to be used to replace the geometry with an isolated RDRA of height equal to four times of original height i.e. b = 4h. Physically, dielectric resonator antenna with patch is equivalent to conventional DRA with four times height. The above equations can therefore be uses for calculating the resonant frequency of this antenna geometry also. It may however be noted that this model does not include the effects of the top metal layer

The field equations inside the rectangular DRA for $TE^x{}_{111}$ mode are

$$H_x = \frac{\left(k_z^2 + k_y^z\right)}{j\omega\mu_0} \cos(k_x x) \cos\left(k_y y\right) \cos(k_z z) \qquad (6.1)$$

$$E_x = 0 \qquad (6.2)$$

$$E_z = -k_y \cos(k_x x) \sin\left(k_y y\right) \cos(k_z z) \qquad (6.3)$$

$$E_y = k_z \cos(k_x x) \cos\left(k_y y\right) \sin(k_z z) \qquad (6.4)$$

$$H_y = \frac{k_y k_x}{j\omega\mu_0} \sin(k_x x) \sin\left(k_y y\right) \cos(k_z z) \qquad (6.5)$$

$$H_z = \frac{k_z k_x}{j\omega\mu_0} \sin(k_x x) \cos\left(k_y y\right) \sin(k_z z) \qquad (6.6)$$

being finite. Similarly the effects of dimensions of the feed microstrip line and the presence of the dielectric laminate beneath this are not considered here [15]. So It was investigated that drastically decreased in volume, resonant frequency, impedance bandwidth achieved for patch on DRA [16], while impedance bandwidth improved for a DR on patch [17].

III. RESULT AND DISCUSSION

Based on extensive numerical studies, design parameters of the proposed antenna have been optimized. L-shaped DRA is made of microwave material with dielectric constant of 32 and tan delta (loss factor) of 0.0017. Dimension of one arm are L_1 = 10 mm, W = 2 mm, H = 3 mm, while second arm are L_2 = 12 mm, W = 2 mm, H = 3 mm used. A 50 Ω microstrip is placed on the ground substrate with L_s = 25 mm, W_s = 25 mm and h = 0.76 mm. The dimension of wrist watch is L_s = 25 mm, W_s = 25 mm, H_1 + h = 5.76 mm with plastic material. Copper foil as a patch is placed on top side of the L-shaped DRA. Initial dimension of patch are L_3 = 12 mm, L_4 = 10 mm, W = 2 mm used.

Simulations are carried out for placing L- shaped patch on top , outer, top + inner, top + outer, top + inner + outer sides of the L-shaped DRA, and without patch (only L-shaped DRA). For each case, the length of microstrip line is optimized for better return loss characteristics.

Table 1 Parametric study of patch placed on sides of DRA

Patch on the DRA	Fr. (GHz)	S_{11} (dB)	BW (MHz)	%BW
Outer side	2.30	-10.5	--	--
Top + outer side	2.55	-18.25	16	0.62
Top side	2.67	-23.84	20	0.7
Top + outer + inner side	2.72	-26.41	18	0.64
Top + inner side	2.77	-33.93	20	0.7
Without patch	7.56	-12.95	240	3.17

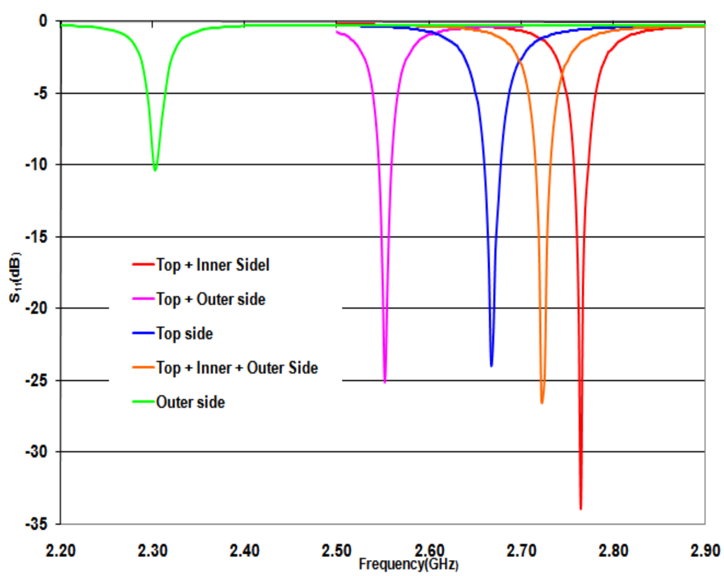

Figure 4 Return loss characteristics of patch placed on different combination of sides of the antenna

Return loss characteristics of patch on DRA for all five cases are shown in Figure 4. Resonant frequency, return loss characteristics, impedance bandwidth (S_{11} less than 10 dB) and % of bandwidth for all case are tabulated in Table 1. From Figure 3 and Table 1, it is observed that L-shaped DRA without patch resonant at 7.56 GHz with 240 MHz impedance bandwidth and has 3.17 % of bandwidth. By placing patch on outer side of the antenna, resonant frequency drastically decrease to 2.30 GHz with narrow bandwidth operation are observed. This kind of observation is also noticed for patch on top, top + inner, top + outer and top + inner + outer side of the antenna. Figure 5 shows the co and cross RHCP and LHCP radiation patterns at 2.30 GHz for patch on outer side of the antenna.

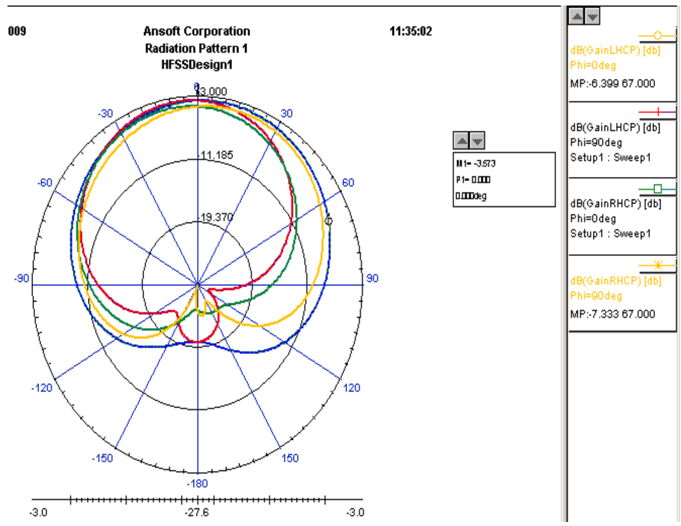

Figure 5 Circular radiation patterns at 2.30 GHz for patch on outer side of the antenna

Simulations are carried out for different arm lengths L_3 and L_4 of the patch placed on inner side of the antenna while keeping other dimensions of the DRA invariable. The arm length (L_3 and L_4) of patch vary from 3 mm to 8 mm. The return loss characteristics are shown in Figure 6. Various parameters of the antenna are listed in Table 2.

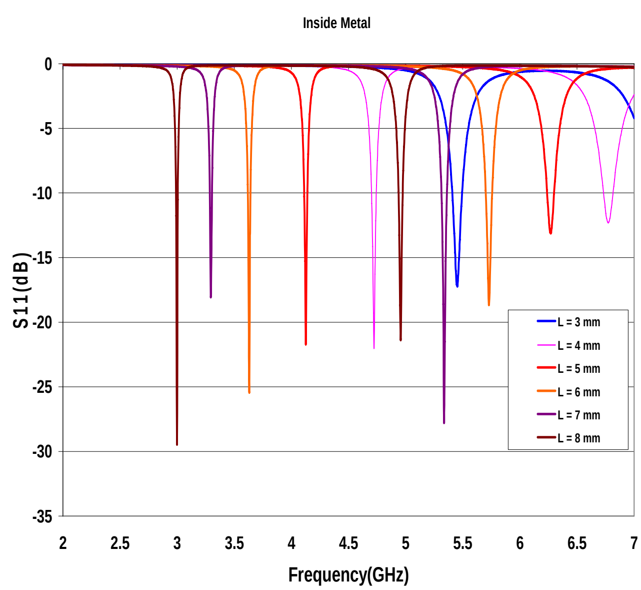

Figure 6 Return loss characteristics for different arm length of patch placed on inner side of DRA

Table 2 Parametric study of different arm length of patch on inner side of the antenna

L_3 & L_4 (mm)	Fr. (GHz)	S_{11} (dB)	BW (MHz)	Gain (dB)
3	5.45	-17.42	80	3.60
4	4.72 6.77	-21.95 -12.31	40 80	2.34 2.33
5	4.13 6.23	-21.72 -13.12	35 50	1.33 2.18
6	3.63 5.74	-25.44 -18.64	25 60	0.39 2.32
7	3.29 5.34	-18.05 -27.76	25 60	0.319 2.28
8	3.00 4.96	-29.46 -21.28	20 45	-0.8 1.92

By increasing the arm length of the patch from 3 mm to 8 mm, the antenna is operated with dual mode for patch placed inner side of the antenna. From Figure 6 and Table 2, It is observed that first and second order resonant frequency, impedance bandwidth and gain at boresite are decreased as increased in arm length. For all case, length of microstrip line is optimized for better return loss. It is concluded that by placing patch of shorter length compared to full length of patch on inner side of the DRA, two different resonant are excited with higher impedance bandwidth as compared to full length of the patch.

Also, simulations are carried out for different arm length of patch placed on outer side of the antenna while other dimensions of the antenna kept constant. The return loss characteristics for different arm length L_3 and L_4 are vary from 2 mm to 7 mm are shown in Figure 7. Various required parameters are listed in Table 3.

Based on numerical studies carried out by varying the arm length of the patch on outer side of L-shaped DRA, it is noticed that dual mode operation can be achieved with proper selection of arm length of patch. From Table 3 and Figure 7, it is concluded that by increasing arm length of patch, resonant frequency, impedance bandwidth and gain are decreased. It is observed that arm length is increased from 2 mm to 7 mm, the resonant frequency is decreased from 7.30 GHz to 3.19 GHz with cost of decreased in impedance bandwidth from 150 MHz to 20 MHz.

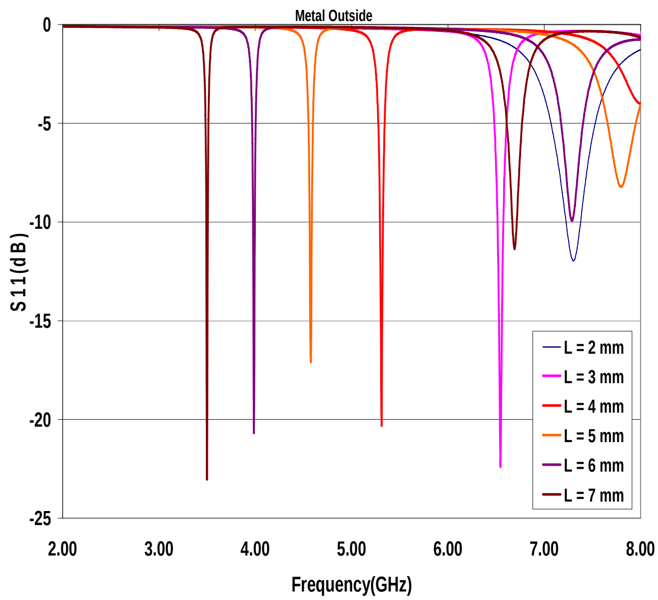

Figure 7 Return loss characteristics for different arm length of patch placed outer side of DRA

Table 3 Parametric study of different arm length of patch placed on outer side of the antenna

L_3 & L_4 (mm)	Fr. (GHz)	S_{11} (dB)	BW (MHz)	Gain (dB)
2	7.30	-12	150	5.57
3	5.77	-22.39	60	3.17
4	4.72	-20.31	30	2.11
5	4.11	-17.00	20	1.11
6	3.60 6.45	-20.68 -10.00	20 --	-0.28 2.64
7	3.19 5.90	-23.03 -11.16	20 40	-1.15 2.75

Extensive numerical studies on simple microstrip line fed patch on L-shaped DRA were carried out by placing patch on different combination of sides of the L-shaped DRA, varying arm length of the patch placed on inner and outer side of the antenna. It is concluded that by placing the patch on DRA, drastically decreased in resonant frequency and volume can be achieved. But impedance bandwidth is decreased. Also by proper selection of arm length of the patch, the antenna is resonated at two different frequencies with improvement of impedance bandwidth. Also the radiation patterns of the proposed antenna are circular polarized.

With proper selection of dimensions, the proposed antenna can be resonated at 2.4 GHz and 5.8 GHz free ISM bands for RFID applications. The proposed antenna has circular radiation pattern, high radiation efficiency, dual mode operation and enough bandwidth. It is easy to fabricate and integrate with microwave circuits. The proposed antenna has single feed, single layer technology.

Table 4 Comparison of reported RFID tags with the proposed tag

Type of Tag	**Volume (mm^3)**	**Frequency Band**	**Ref.**
Compact folded printed dipole	3900	UHF	2
Miniaturized printed dipole	2048	2.45 GHz	3
Fractal dipole	7062	UHF & 2.45 GHz	4
Circular polarized metallic patch antenna	188000	UHF	5
Aperture coupling two-layered dual band	1007400	UHF & 2.45	6
Broadband CPW-fed patch antenna	384	5.8 GHz	7
Rectangular dielectric resonator antenna	2916	2.45 GHz	18
Proposed DRA Tag	132	2.45 & 5.8 GHz	---

The size of the antenna is very small. In [17], rectangular dielectric resonator antenna (dielectric constant of 37) as a RFID tag is reported with 18 mm x 18 mm x 9 mm with planar area of 324 mm^2 operated at 2.4 GHz. Whereas, the proposed antenna has dimensions 22 mm x 3 mm x 2 mm with planar area of 44 mm^2 operated around at 2.4 GHz and 5.8 GHz. Thus the proposed antenna is one of major candidate in the field of RFID application work as reader and tag. This compact tag is appropriate in wrist watch for human identification system. Literature survey is carried out on various popular RFID tags. There are various patch antennas, printed dipole, and rectangular DRA were proposed for RFID application. Various RFID tags with frequency band, volume, and type of tags are tabulated as shown in Table 4 with the proposed tag. As shown in Table 4, it is noticed that the proposed RFID tag has volume of 132 mm^3 and operated around at 2.4 GHz and 5.8 GHz. Thus the proposed tag is compact as compared to the reported tags. It is observed that 95% volume reduction and 86% planar area reduction are achieved as compared to reported RDRA as a RFID tag.

IV. CONCLUSION

In this paper, a patch on dielectric resonator antenna has been proposed at 2.4 GHz and 5.8 GHz free ISM bands as a RFID antenna. Simple microstrip line is used as a feeding mechanism. Metallic patch is placed on side of the DRA to achieve compact in size. The volume of the antenna is 22 mm x 2 mm x 3 mm with planar area of 44 mm^2 which is smaller compared to reported RFID antennas as a dielectric resonator antenna in literature. By choosing proper arm length of patch, dual mode operation can be achieved. And also improvement of impedance bandwidth is observed. Radiation patterns of the proposed antenna are circular polarization. Due to absent of conductor loss in proposed antenna, high radiation efficiency can be achieved. Thus the proposed antenna has all required characteristics of RFID reader and tag antenna. This type of antenna has a potential in RFID application such as human identification system in a wrist watch for military purpose to fight against terrorisms, border movement of troops, and hidden movement of criminals around the nation.

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