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Button Shaped Wearable Dielectric Resonator Antenna for IoT Applications

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Abstract – **Machine to Machine communication or Internet of things are emerging fields of communication. To support such technologies advanced electronics like wearable devices are popular field of research. The proposed Button shaped wearable Cylindrical Dielectric Resonator Antenna (CDRA) is specially designed to support IoT applications at 2.4 GHz band. The planer section of the DR antenna is developed over FR4 substrate and Dielectric resonator consists of Alumina material. An Aperture coupled feed is used to excite the antenna. There are two holes arranged on the structure such that it can be easily placed over any upper outfit like jacket or coat. To investigate the performance of the proposed wearable DRA over the body and to identify the best portion of the body where the antenna can be worn, the simulation has been done on three different phantoms of different age groups and gender on CST voxel phantom models. To analyse the performance four important parameters reflection coefficient, gain, radiation pattern, and bandwidth are selected. It is discovered that the button-shaped wearable CDRA well satisfies the performance requirements for IoT applications at 2.4 GHz band. Finally, the proposed antenna is developed and its performance has been measured. The measured output and the simulated results have been found to be in good agreement.**

Keywords – **Internet of Things, Wearable Antenna, Dielectric Resonator Antenna, Button Antenna, Machine to Machine communication, 5G.**

I. Introduction

The conventional planar wearable antennas suffer from narrow impedance bandwidth and low radiation efficiency due to the use of lossy substrate. To meet the requirements of technological progression, an advanced design solution based on addition of appropriate dielectric superstrates is required. In this regard, Dielectric Resonator Antennas (DRA) are suitable candidates, as it shows very low conduction losses and mark high radiation efficiency when excited suitably. Various striking properties of DRAs make it a favorable choice to be selected as wearable antenna. Its performance characteristics can be easily controlled using appropriate design techniques [1-4]. It shows very good performance with materials of both low and high dielectric constant. Materials with low dielectric constant delivers high radiation efficiency while on the other hand, materials with a high dielectric constant provides smaller form factor [3-4].

The wearable antenna is a diverse area of research where number of factors need to be considered, since it has to be worn over human body so the adverse effect of electromagnetic interaction between the human tissue and antenna system is one of the serious concerns. It may introduce considerable amount of variation in resonance frequency and radiation characteristics of antenna. Developing traditional human outfit or accessories as wearable communicating electronics like antenna is a great idea and number of contributions in this regard are reported. Most of the on-body antennas are based on textile substrate due to its obvious benefits but it has some limitations too. The textile can be bent and crumbled very easily and may vary and deteriorate the radiation performance of antenna [5-12]. To overcome these difficulties clothing accessories like belt [13], watch [14], zipper [15], and button [16-18] are reported to be developed and used as wearable antennas since they are rigid and cannot bend or crumble and can be easily attached to the cloth.

In this paper, a new button shaped DR antenna is proposed that can be stitched with normal outfit like jacket or shirt. The button antennas are simple to attach on clothes by traditional sewing method also as it is not in direct contact of human body it has very low SAR. Studies on button antenna has been presented in various articles [16-21]. A miniature dual-band cylindrical dielectric resonator button antenna for wireless body area network (WBAN) applications is presented in [16]. In [17] A Single narrow band Button shaped antenna for RFID application, developed using 3D printing technology is presented. The design and use of Button Antenna Sensor for Power Transfer applications apart from traditional application of Wireless communication is discussed in [18]. Whereas Single and Dual band button antenna for on body communication is proposed in [19-20].

In [21] circularly polarized single band 5.8 GHz broadside button antenna for off body application is reported. A Dual-band dual mode button antenna for body centric communication is presented [22]. The antenna exhibits omnidirectional and directional radiation at 2.4 and 5.8 GHz respectively. In [23] Dual band -Dual mode button antenna for on body and off body communications is presented, the antenna can support both the linear and the circular polarization. Nevertheless, they all have low gain, small radiation efficiency and small reflection coefficient, also these discussions did not consider the performance of the antenna over the human body. The proposed wearable DRA Button Antenna is specially designed for Internet of Things application at 2.4 GHz band. It shows good gain, reflection coefficient, radiation pattern and bandwidth.

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The reminder of the paper is arranged in following sections. The geometry of the proposed DR antenna is discussed in section II. The dimension of the proposed antenna is decided on the basis of parametric studies. The design and development of the antenna is presented in section III. In section IV analysis of the antenna performance is discussed. Further, performance of the proposed wearable antenna over the body is presented in section-V. At last section -VI concludes the work.

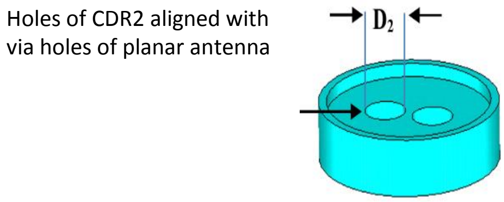
II. Geometry of Dielectric Resonator Button Antenna

The geometry of the proposed button shape DR Antenna is illustrated in Fig. 1. The structure consists of two cylindrical dielectric resonators (CDR), Upper cylindrical dielectric resonator CDR1 and lower cylindrical dielectric resonator CDR2. To make these Dielectric Resonators, Alumina material of dielectric constant ($\in r$), 9 is selected due to its excellent thermal, chemical & mechanical properties. The lower dielectric resonator CDR2 is a button with two holes whereas CDR1 acts as a cap of this button. The CDR 2 is attached to the ground plane of the substrate. The planer antenna is developed over FR4 substrate of dielectric constant ($\in r$), 4.3, thickness (t), 0.8mm and loss tangent ($\boldsymbol{\delta}$), 0.025. In the planer antenna two via holes of dimension D1 is arranged over a slot of dimension "L x W". To excite the antenna, Aperture coupled feeding technique has been used. The overall DRA structure is well aligned such that holes on the slot of planer structure coincide with the holes of diameter 'D2' of button shaped dielectric resonator CDR2. The antenna structure is simulated in CST microwave studio.

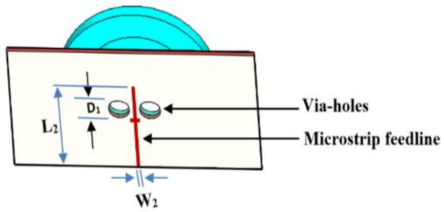
The proposed button DRA is the modified form of cylindrical DRA which supports all the three modes TEpqr, TMpqr, and HEpqr, or EHpqr. Where the subscript 'pqr' indicates field variation according to 'ф' (Azimuth), 'r' (radius) and 'Z'(axial) directions respectively, and their values can be in natural numbers only. The TE and TM modes are independent of Azimuth 'ф' while HE has a dependency on it. The Azimuth variation p=0 for cylindrical DRA therefore, it can be written as TE0qr+Δ, TM0qr+Δ and HE0qr+Δ or EH0qr+Δ. The value of 'Δ', can be in between 0 and 1. The value 1, indicates a higher value of ϵ_r.The resonance frequency for all modes

$$\begin{matrix} f_{TM_{pqr}} \\ f_{TE_{pqr}} \end{matrix} = \frac{c}{2\pi R\sqrt{\epsilon_r \mu_r}} \sqrt{\left(\frac{X_{pq}{}'}{X_{pq}}\right)^2 + \frac{(2r+1)\pi.R}{2h}} \quad (1)$$

Where, X_{pq} and $X_{pq}{}'$ are Bessel's solution (p,q,r) $\epsilon\ N^3$, R and h are the radius and the height of the dielectric resonator respectively [24].



(a)



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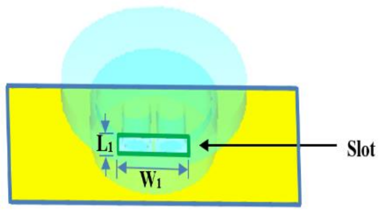

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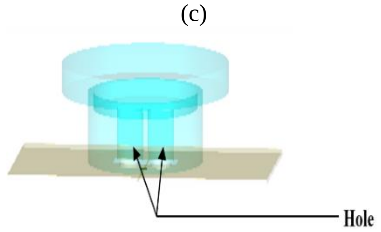

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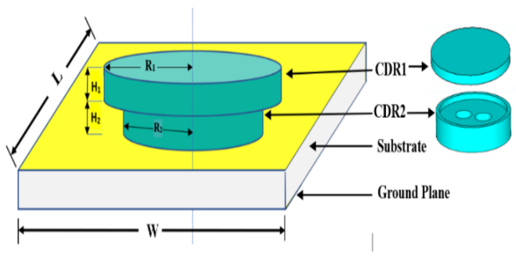

(e)

Fig. 1. Construction of proposed DRA: (a) geometry of CDR2, (b) Microstrip feedline of the substrate, (c) Slot on the ground plane, (d) Arrangement of Two holes inside the CDR2 with CDR1 lid on top, (e) Layout of proposed DR button antenna

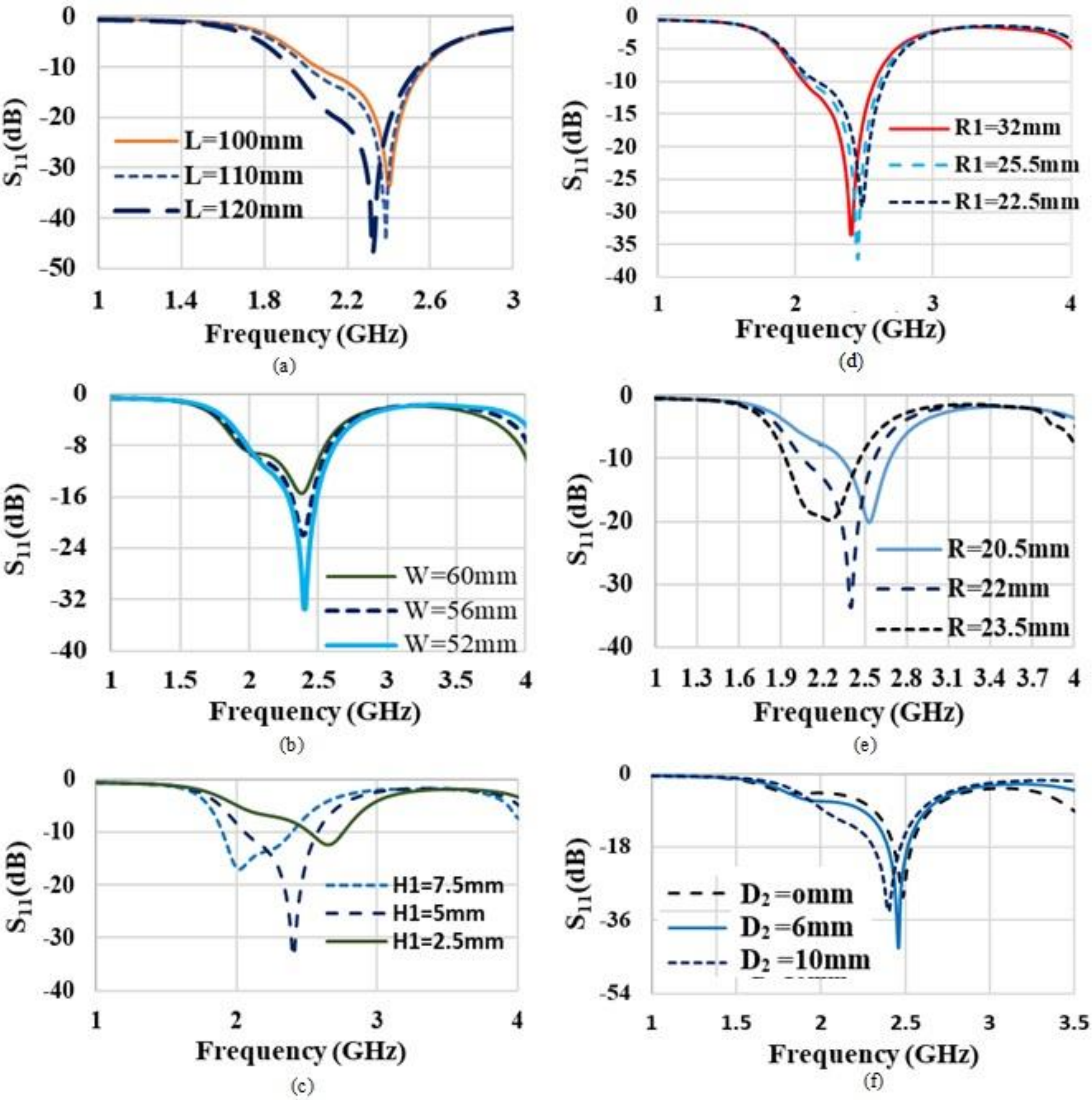

Fig. 2. Parametric study effect on S11 due to variation of: (a) substrate length L, (b) substrate width W, (c) height H1 of dielectric resonator CDR1, (d) radius R1 of dielectric resonator CDR1, (e) radius R of dielectric resonator CDR2, (f) diameter D2 of the two symmetric holes of CDR2

III. Antenna Design and Development

The dimension of the antenna structure is obtained from respectable volume of parametric study. The effect of variation of various parameters over performance parameters S_{11} and Gain is presented in Fig.2 and 3 respectively.

By using the parametric analysis, following inferences has been drawn:

- With the extension in the length of the planar antenna, improvement in reflection coefficient (S11) and bandwidth (BW) has been noted, whereas the frequency (f) and the antenna gain decreases.
- With the extension in the width of the planar antenna, the frequency, bandwidth and reflection coefficient decreases.
- The frequency, reflection coefficient, & antenna gain has increased whereas bandwidth has decreased with the decrease in the radius of the CDR2.
- Improvement in antenna gain and bandwidth is observed whereas, decrease in frequency has been noted with the extension in the radius of CDR1.
- The frequency decreases whereas bandwidth improves with the increment in the height of CDR1.
- When the diameter of both the holes D2 of CDR2 are expanded, frequency reduces whereas reflection coefficient, antenna gain and bandwidth improve.
- When, either the radius of the CDR2 or the height of the CDR1 or both increases, the resonant frequency decreases.

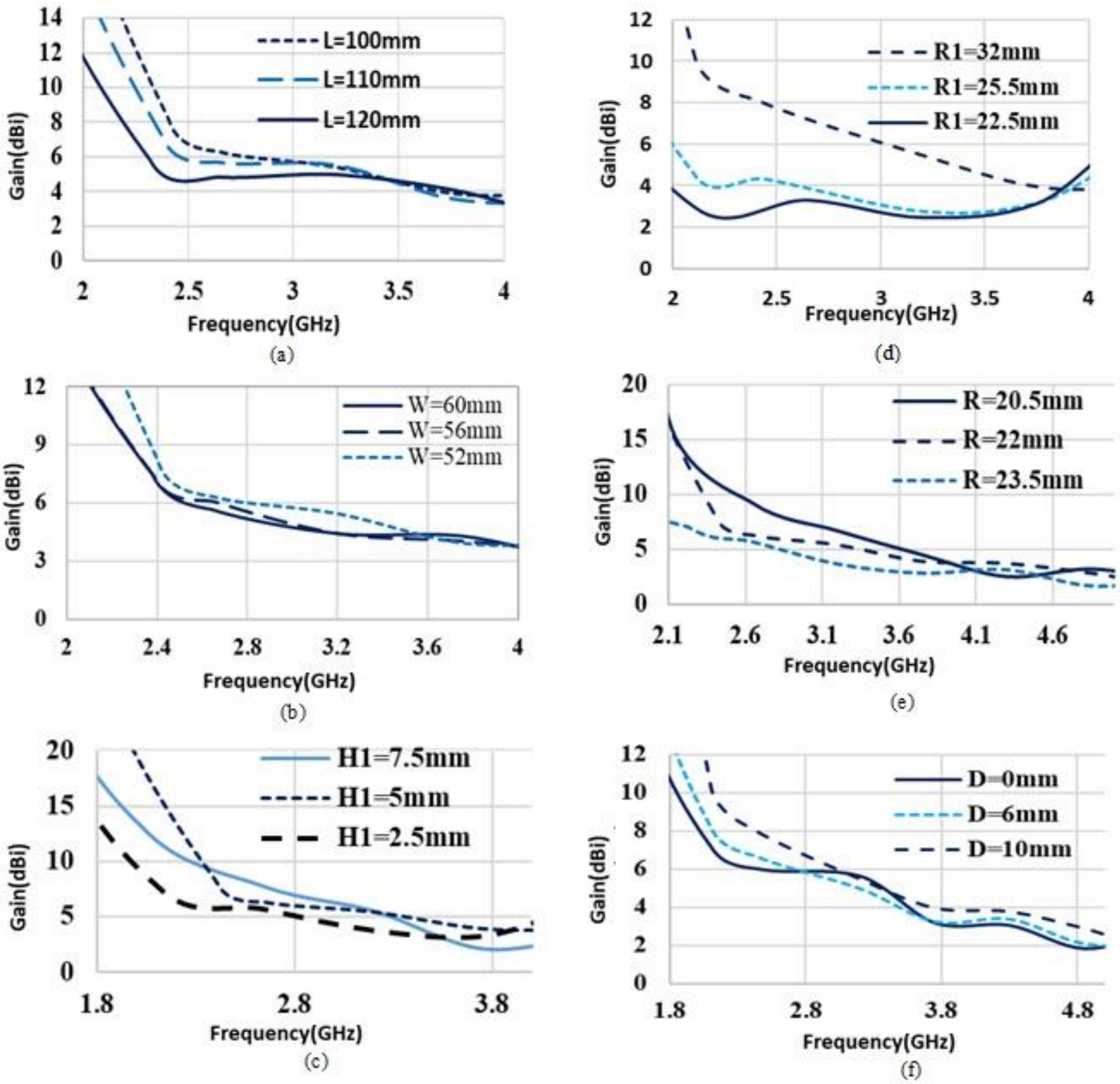

Fig. 3. Parametric study effect on Gain of the antenna due to variation of: (a) substrate length L, (b) substrate width W, (c) height H1 of dielectric resonator CDR1, (d) radius R1 of dielectric resonator CDR1, (e) radius R of dielectric resonator CDR2, (f) diameter D2 of the two symmetric holes of CDR2

On the basis of parametric study dimension of the proposed antenna is finalized, as mentioned in TABLE I

In Table I, L be the substrate's length, W be the substrate's width, t be the substrate's thickness, R_1 be the radius of CDR1, H_1 be the height of the CDR1, the diameter of both the holes inside the substrate are D_1 and the diameter of both the holes inside CDR2 is D_2. The radius of the CDR2 is R_2, the height of the CDR2 is H_2 and the height of the two holes of the CDR2 is H2 & H3. The wall of the outer edge of the cylindrical DR2 is H4, L1 be the length of the rectangular slot and W1 be the width of the rectangular slot. Through the slot, the guided wave that is moving along the transmission line has been propagating to the DR's resonant modes. The aperture-coupled microstrip feedline DRA provides high radiation efficiency, improves impedance matching and reduce energy loss. CDR1 and CDR2 are well deployed on the top of the rectangular slot of planer antenna to obtain the required resonance. The lower DR button is stitched to the ground plane of the slot antenna through the holes mentioned above and shown in the diagram and then the upper DR lid fits over it well making it a complete fabricated wearable button DR antenna.

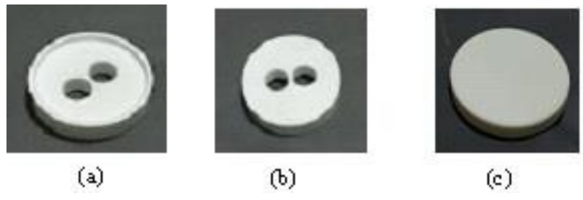

Fig. 4. Layout of fabricated Dielectric resonators: (a) Front Side of CDR2, (b) Back Side of CDR2, (c) Top lid CDR1 of Button CDR2

TABLE 1
PARAMETER VALUES IN MM SELECTED FOR DESIGN BASED ON PARAMETRIC STUDIES

L	W	t	R_1	H_1	R_2	H_2	D_1	D_2	H_2	H_2	L_1	W_1	L_2	W_2	L_3	W_3
100	52	0.8	32	5	22	12	8	10	20	3	8	24.6	36	0.6	0.8	2

The Layout of fabricated Dielectric resonators, both front side and back side of CDR2 and Top lid CDR1 of Button structre is shown in Fig. 4. The final fabricated button shaped DR antenna is shown in Fig. 5. The proposed antenna stitched over a jacket is shown in Fig. 6

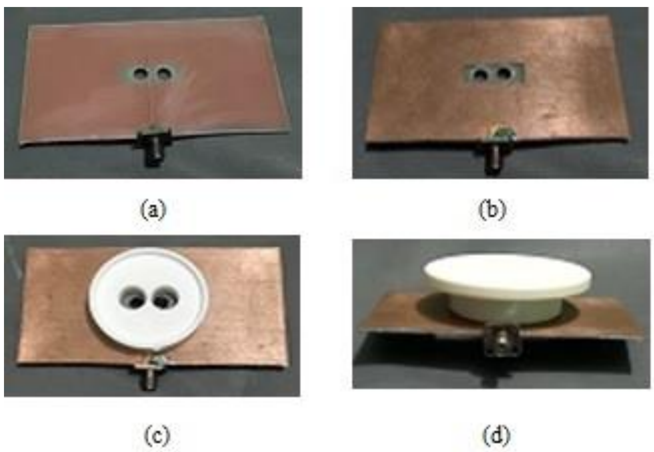

Fig. 5. Fabricated Layout of the proposed Dielectric Resonator Button Antenna: (a) Front Side of the planer antenna without DR, (b) Back Side of the planer antenna without DR, (c) Planer Antenna with CDR2, (d) Side view of the Proposed Wearable Button Dielectric Resonator Antenna with CDR1 and CDR2

Fig.6. Wearable DRA attached with the outfit

IV. PERFORMANCE ANALYSIS

The proposed cylindrical DR Antenna has been simulated in the CST studio software. The simulated structure is further developed to measure its performance. The final fabricated button shaped DR antenna is shown in Fig. 5. The proposed DRA has been placed in the cloths as shown in Fig. 6. The Reflection coefficient, radiation pattern, gain and bandwidth have been simulated and measured. The simulated value of reflection coefficient of the proposed DRA is -33.48dB at 2.40GHz and measured value is -25.08dB at 2.44GHz, the comparison is shown in Fig. 7. The simulated outcomes and the measured results match up really well. This is improved by adjusting the aperture's size. simulated and measured gains for the proposed DRA are 8.09dBi and 7.4dBi respectively as shown in Fig. 8. The simulated value of proposed button

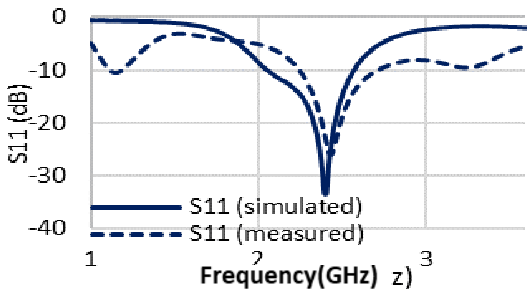

Fig.7. simulated and measured S_{11} (dB) vs frequency (GHz) plot for proposed DRA

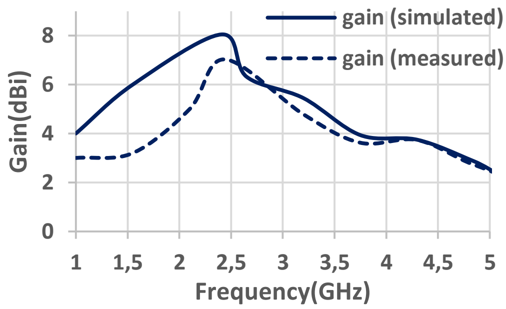

Fig. 8. simulated and measured Gain of proposed DRA

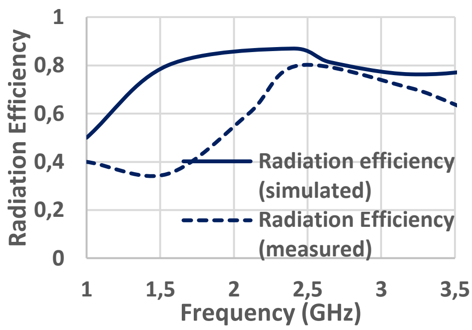

Fig. 9. simulated and measured Radiation Efficiency of proposed DRA

DRA's radiated power at 2.407 GHz is 87% and measured value at 2.44 GHz is 80% as shown in Fig. 9. In the wearable DRA, maximum power has been transmitted in the peak radiation's direction.

The radiation pattern has been controlled by exciting the aperture coupled microstrip feed line. Adding CDR1 over CDR2 improve the gain of the button Antenna. The two holes of the CDR2 are responsible for good antenna gain and bandwidth. Simulated and measured radiation pattern in H-plane and E-plane are shown in Fig. 10 and 11.

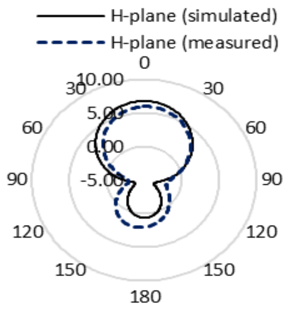

Fig. 10. Simulated and measured Radiation pattern in H-plane

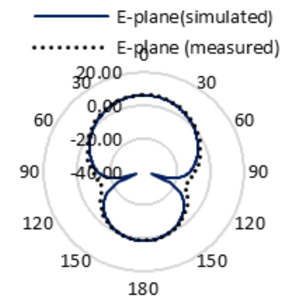

Fig. 11. Simulated and measured Radiation pattern in E-plane

TABLE 2
COMPARISON OF SIMULATED AND MEASURED RESULT OF PROPOSED ANTENNA

Analysis	Frequency (GHz)	S_{11}(dB)	BW(dB)	Gain(dBi)	Radiation Efficiency (%)
Simulated	2.407	-33.48	0.51	8.09	87
measured	2.44	-25.08	0.46	7.4	80

The simulated structure is developed and its simulated and measured result is compared. As presented in TABLE II, there is little deviation in frequency, the measured value of $S_{11,}$ BW, gain and radiation pattern show little lower than simulated one. But these deviations are acceptable and also very obvious. There are number of causes behind it, the effect of reflectors in the environment, fabrication error like metal accumulation due to soldering, use of adhesive, etc which are not included in the simulation.

V. PERFORMANCE OF THE ANTENNA OVER THE BODY

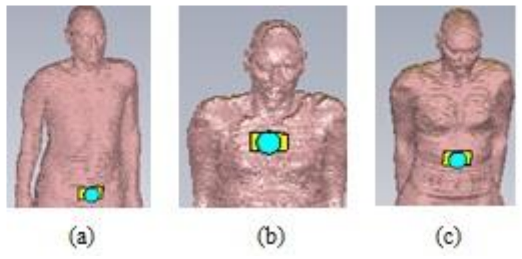

Fig. 12 To analyse performance of the proposed antenna at various section of body it is placed on: (a) chest, (b) stomach, (c) waist

TABLE 3
CCOMPARISON OF DR ANTENNA PERFORMANCE ON DIFFERENT PARTS OF DIFFERENT HUMAN BODIES

Body Position: Chest					
Model	Frequency (*f*)	S_{11}(dB)	Bandwidth (GHz)	Gain (dBi)	Radiation Efficiency (%)
Laura	2.42	-24.39	0.45	7.12	84
Gaustav	2.40	-34.05	0.54	8.74	88
Child	2.40	-23.26	0.63	7.87	83
Body Position: Stomach					
Model	Frequency(*f*)	S_{11}(dB)	Bandwidth(GHz)	Gain (dBi)	Radiation Efficiency (%)
Laura	2.40	-46.74	0.57	7.8	86
Gaustav	2.36	-44.61	0.55	7.47	88.7
child	2.38	-19.94	0.65	7.73	82
Body Position: Waist					
Model	Frequency(*f*)	S_{11}(dB)	Bandwidth (GHz)	Gain (dBi)	Radiation Efficiency (%)
Laura	2.38	-27.7	0.50	8.22	76
Gaustav	2.40	-26.42	0.48	7.47	78
child	2.36	-18.64	0.52	7.6	72

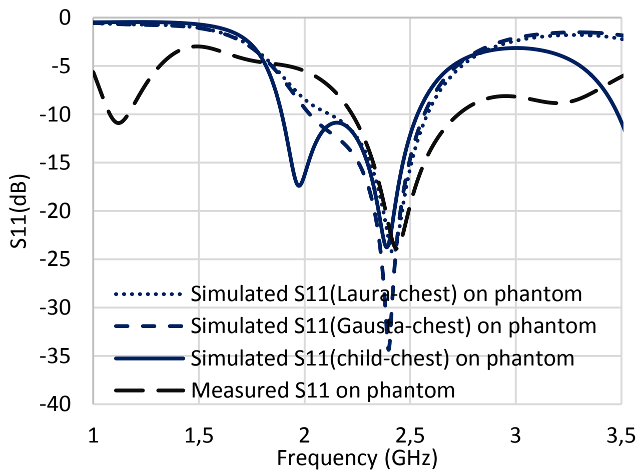

Fig. 13. Simulated Reflection coefficient the wearable button DRA for different phantom which has been placed on the chest and also measured on phantom.

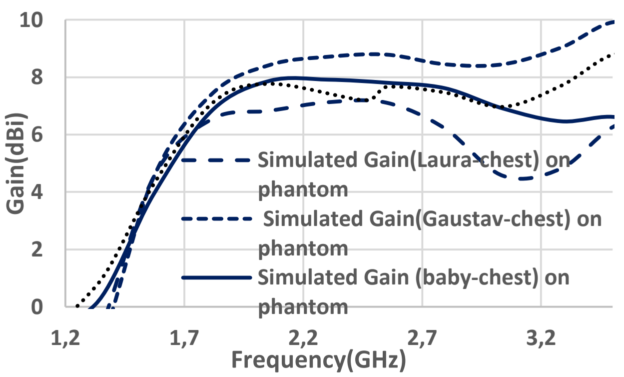

Fig. 14. Simulated Gain of the wearable button DRA for different phantom which has been placed on the chest and also measured on phantom.

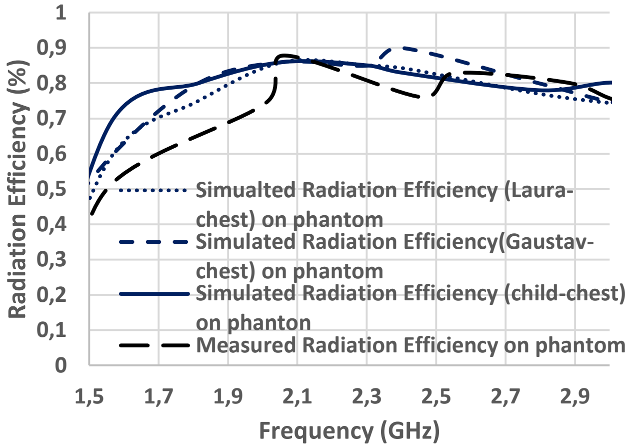

Fig. 15. The Radiation Efficiency of the wearable button DRA for different phantom which has been placed on the chest and also measured on phantom.

The proposed button antenna can be placed over any outfit, which can be wore on upper portion of the body (above the waist) or lower portion of the body (below the waist).. To decide the most suitable section of the body over which antenna can be placed Phantom analysis has been done.at ISM band. The simulation is done to analyse the effect of electromagnetic interaction between proposed antenna system with different parts of the body. For the simulation, 3 phantoms of different age group and different genders are selected. CST voxel phantom female model Laura, 36-year-old, height 176cm, weight 65 kg, Male Gaustav, 38 years old, height 176cm, weight 69 kg and female child 7 years old, height 115cm, weight 21.7kg in the CST voxel family. The button-shaped wearable DRA has been placed in the three different phantom's parts chest, stomach and waist of all the voxel human body as shown in the Fig. 12. The simulation is performed for 2.4 Ghz band. The simulated observation of the effect of electromagnetic interaction between the proposed button antenna and phantom of different age group & different genders at different part of the phantom is presented in TABLE III and also the graphical comparison is shown in Fig. 13 to 15. Like any other living being for human also the ratio of body components like fat, protein, calcium etc are different at different portion of the body, that varies with person to person, age, gender and there are number of factors. The bending capability of different parts of body is also different. Therefore, for analysis phantom of different age group and gender are considered. Little deviation in all the parameters can be noted as mentioned in TABLE III. It satisfies the concept of effect of body parts on antenna performance. The deviation in S_{11}, gain and radiation pattern are not of much concern as in all condition good value has attain for these parameters, but effect of frequency is very important, it should strictly satisfy the targeted band requirement. Thus Chest is found to be the best position as here the effect on frequency deviation is supportive for targe frequency band of 2,4 GHz.

In TABLE IV, The performance of proposed antenna is compared with previously reported contributions. The proposed antenna has achieved maximum S_{11}, radiation efficiency BW and gain.in 2.4 frequency band. Which makes it a suitable antenna for IoT applications to use over IEEE 802.15.1 and IEEE820.11 Network at 2.4 GHz band.

TABLE 4

COMPARISON OF PROPOSED ANTENNA WITH PREVIOUSLY CONTRIBUTIONS

Sl. No.	Ref Year	Substrate and material	Feed Mechanism	f (GHz)	S_{11}(dB)	Radiation Efficiency (%)	BW (GHz)	Gain (dBi)
1.	Proposed work	FR4 and Alumina for DR	Aperture coupled Microstrip feedline	2.407	-33.48	87.2	0.51	8.09
2.	[13]/2020	Textile EBG& metal	Microstrip feedline	2.45	Below -30	84.11	NA	7.7
3.	[14]/2021	PET and TPU material (transparent)	Microstrip feedline	2.45	-19.4	33.9	0.5	-1.9
4.	[14]/2021	PET and SEBS material (white)	Microstrip feedline	2.45	-14	56.2	0.55	0.3
5.	[23]/2020	SPEAG and Rogers RT 6006	Coaxial feed	`2.45	Below -10	NA	0.18	2.2
6.	[25]/2015	Substrate of relative dielectric is 2.65	Microstrip feedline	2.4	-23	64	0.36	0.97
7.	[26]/2008	FR4	CPW	2.46	-24	NA	0.44	1.127

VI. CONCLUSION

The wearable DR Antenna for Bluetooth application is designed, developed, and its performance is analysed. The proposed DRA is button in shape and can be stitched over a cloth. To identify the best position for the antenna to be worn on the phantom, the antenna performance analysis has also been done on three phantoms of different genders and ages of CST voxel family. Chest is found to be the best position on the phantom for the antenna to be worn, as frequency variation in this section is very less and it still lies in Bluetooth range. Therefore, the antenna is suggested to be stitched as first button on the coat or jacket or shirt. The simulated response shows that the antenna satisfies Bluetooth application requirements and also the measured results of the fabricated antenna back the simulated results. The suggested wearable button DR antenna is acceptable for use as a wearable Bluetooth antenna.

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