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Design and Analysis of C Band Bracelet Shaped Wearable DRA with Low SAR

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***Abstract* - A Bracelet shaped wearable Dielectric Resonator Antenna (DRA) is designed and analyzed in this paper. The proposed DRA is made of Bakelite and is capable of operating efficiently in the vicinity of four different frequencies (5.9 GHz, 6.5 GHz 7.1 GHz, 7.6 GHz) in C Band. A performance characteristic of the Bracelet DRA is investigated with the help of a model of human wrist wearing the Bracelet DRA. The DRA worn on human wrist model gives directivity ranging from 7.4dBi to 8.3dBi at different operating frequencies. Radiation efficiency up to 82.1% at 5.9 GHz is obtained. Maximum Specific Absorption Rate (SAR) obtained is 1.15 W/Kg which is within the safe level of 1.6 W/kg set by the Federal Communications Commission (FCC), United States. Simulation of the designed DRA is done using CST Microwave Studio Software. Comparable or better performance characteristics of the proposed DRA is obtained than those of several C band wearable antenna structures reported in recent literature.**
***Keywords:* Dielectric Resonator Antenna, C Band DRA, Wearable Antenna, Multi Frequency DRA, Low SAR Wearable DRA**

I. INTRODUCTION

Wearable antennas become increasingly important in modern society with the emergence of networked world, where wireless communication technology plays an important role. Wearable wireless system applications cater to many areas like personal communication, health care, military, entertainment and aeronautics [1]. An antenna as a wearable device in the terminal equipment of the wireless communication system, has become an important topic of research interest [2]. A number of factors is required to be considered while designing a wearable antenna which includes prevention of degradation in the performance of the antenna due to proximity of human body, robust performance of the wearable antennas in various weather conditions, good electrical and mechanical properties, low cost, lightweight, low loss, flexibility, convenience for wearers and accuracy in fabrications methods.

Besides, electromagnetic radiation from such body worn antennas must be within safe limit so that human tissues are not affected. Textile antennas are widely used as wearable antennas. However, the stretching and crumpling of the wearable devices result in minor cracks, which reduce the performance of the wearable antennas. Various expensive and complex composites make wearable antennas are costly due to complexity in the fabrication methods [3]. Solid dielectric resonator wearable antenna is not much studied in literature except for a few papers [4, 5].

Solid wearable dielectric resonator antennas have the advantages of robustness and repeatability in fabrication process. They are free from stretching and not much affected by weather conditions or wetness like textile antennas. They can be used as wearable accessories like bangle, bracelet, ring or button. In this paper a bracelet shaped Bakelite made multi frequency C band DRA is proposed which can be worn on wrist and looks like a fashion accessory. C band is chosen since this frequency range (4GHz-8GHz) has a number of applications in wireless communication which includes satellite communication systems, Wi-Fi, Cordless telephones, surveillance and weather radar.

II. ANTENNA DESIGN

The circular bracelet shaped dielectric antenna is shown in Fig.1. The antenna is made of Bakelite (ε_r=4.8) sheet of rectangular cross section. The inner portion of the bracelet is coated with metal and act as ground plane of the antenna. Different parameters of the antenna are given in Table I.

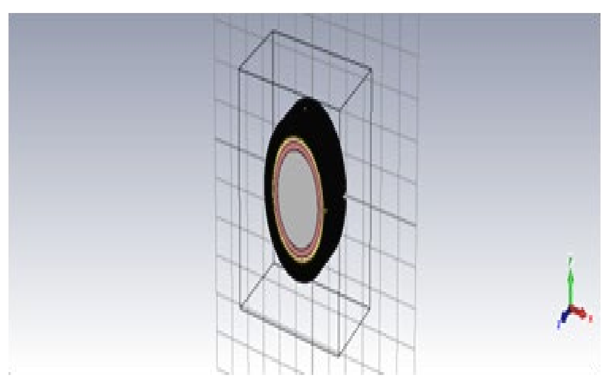


Fig. 1(a) Bracelet shaped DRA

This bracelet is worn on human wrist. A model of human wrist is shown in Fig. 2 and parameter values of the wrist model is given in Table II. Inner solid cylinder is made of bone of radius 24mm, over this cylinder there is a concentric cylinder made of fat of thickness 4mm and outer concentric cylinder is made of skin of thickness 2mm. Width of the wrist model is the same as that of bracelet.

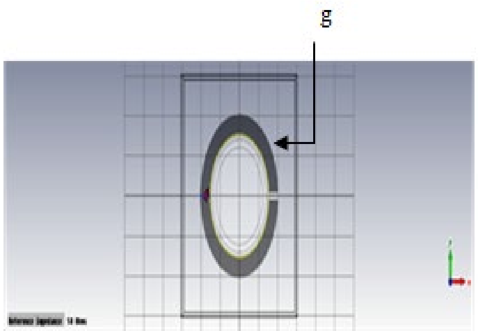


Fig. 1(b) Top View of Bracelet shaped DRA

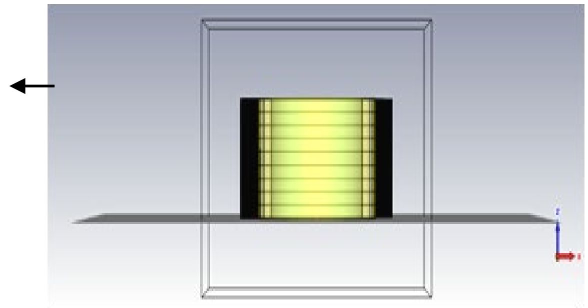


Fig. 1(c) Cross-sectional View of Bracelet shaped DRA

TABLE I DIMENSIONS OF THE PROPOSED DRA

	Inner Radius Bakelite (r_i) mm	**Outer Radius Bakelite (r_o) mm**	**Inner ground plane thickness (t)mm**	**Width (W)mm**	**Gap (g)mm**
Bracelet DRA	31	40	1	30	4

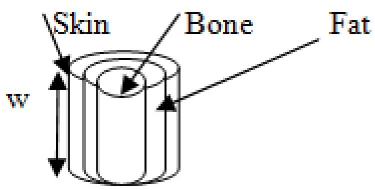


Fig. 2 Human Wrist Model

TABLE II HUMAN WRIST MODEL PARAMETERS

Wrist model	**Skin**	**Fat**	**Bone**
Thickness mm	2	4	-
Radius mm	-	-	24
Dielectric constant (ε_r)	31.29	4.6023	12.661

III. ANTENNA ANALYSIS

This bracelet is similar to a circular ring resonator made of dielectric material. Resonant frequencies of different modes of oscillation for a ring resonator is given by

$$L= n\lambda_g = nc/(f_r\sqrt{\varepsilon_{reff}})$$

or,

$$f_r = nc/(L\sqrt{\varepsilon_{reff}}) \quad (1)$$

where, L is length of the mean circumference of the ring , n is an integer , λ_g is wavelength, c velocity of light in free space and ε_{reff} effective permittivity of the dielectric material.

$$\varepsilon_{reff} = (\varepsilon_r+1)/2 + \{(\varepsilon_r-1)/2\}[1+12h/W]^{-1/2} \quad (2)$$

h = thickness of the ring and W is width of the rectangular cross section of the ring.

In the present model of bracelet shaped DRA

$$L= 2\pi r-g \quad (3)$$

where, $r = (r_o+r_i)/2$ and g= gap length [Fig1(b)]and $h= (r_o-r_i)$.

The modes of oscillation will be supported by the resonator if it has resonant frequency greater than the cut off frequency. Cut off frequency is given by

$$f_c = c/(\lambda_c\sqrt{\varepsilon_{reff}}) \text{ where , } \lambda_c= 2W \quad (4)$$

Since this antenna is wearable and remains in the proximity of human body, radiation from it should be kept under the allowable standard limit. The maximum radiation that can be absorbed is estimated as Specific Absorption Rate (SAR). It is a measure of the rate of RF (radio frequency) energy absorption by the body from the source being measured. The SAR values are acceptable under the standard limit of 1.6W/Kg as defined by the Federal Communication Commission (FCC). SAR for electromagnetic energy can be calculated from the electric field within the tissue as:

$$SAR=\frac{1}{V}\int \frac{\sigma(r)|E(r)|2}{\rho(r)}dr \quad (5)$$

where, ρ is the sample density, E is the r.m.s. electric field, σ is the sample electrical conductivity and V is the volume of the sample.

In the present paper all the simulations for analysis of the antenna is done using CST Microwave Studio software including SAR calculation.

IV. RESULTS AND DISCUSSIONS

Fig. 3 shows the s_{11} vs. frequency plot for the bracelet shaped DRA. It has s_{11} values less than -10dB at a number of frequencies within 4GHz to 8GHz range. It is clear from the plot that it can be operated efficiently at multiple frequencies in C band. These frequencies correspond to different modes for different values of n. Fig. 4 shows the s_{11} plot when the bracelet is put on human wrist model. It is seen from Fig. 4 the resonant frequency values are slightly shifted due to the proximity of wrist. Four distinct resonant frequency values 5.904GHz, 6.480GHz, 7.060GHz and

7.639 GHz are observed from the graph. Fig. 5 shows a plot of calculated values of resonant frequency against mode number n using equations (1), (2) and (3). In Fig. 5 simulated values of resonant frequency against mode numbers are also shown. Mode number is determined from simulation using peak H field plot. One of such plots is shown in Fig. 6. This plot shows mode number n=10 for resonant frequency f_r= 7.6387 GHz. Calculated values in Fig.5using equation (1) are somewhat lower than simulated values. This can happen if effective dielectric constant value, ε_{reff}, is actually smaller than that is calculated from equation (2) which equation is generally used for rectangular microstrip antenna. The smaller value of ε_{reff} for a DRA than that for a comparable microstrip antenna occurs due to more number of fringing electric field lines passes through air (ε_r=1) to reach the ground plane than that in case of similar microstrip antenna. Fig. 7 shows the E field plot at f_r = 7.6387GHz and this shows E field is distributed considerably in air. Contribution of air dielectric (ε_r=1) is significant in the effective value of dielectric constant which reduces the value of ε_{reff}. Fig. 8 shows far field polar plots at four resonant frequencies. It is seen from Fig. 8 that field is more or less uniformly azimuthally distributed. Thus, reception of signal is possible from all directions which is an important criterion of wearable antennas. Fig. 9 shows 3D far field radiation characteristics relative to the bracelet worn on wrist model. Directivity values lie between 7.3dBi to 8.3 dBi. These values are better than most of the comparable wearable antennas reported in recent literature [Table IV]. Fig. 10 shows SAR plot at four resonant frequencies and its maximum value is 1.15 W/kg at f_r = 7.6387GHz. Thus SAR values are well within the safe limit of 1.6W/kg even in the worst case. It is also evident from these figures that SAR value is much less than maximum SAR in the wrist model for most of the cases.

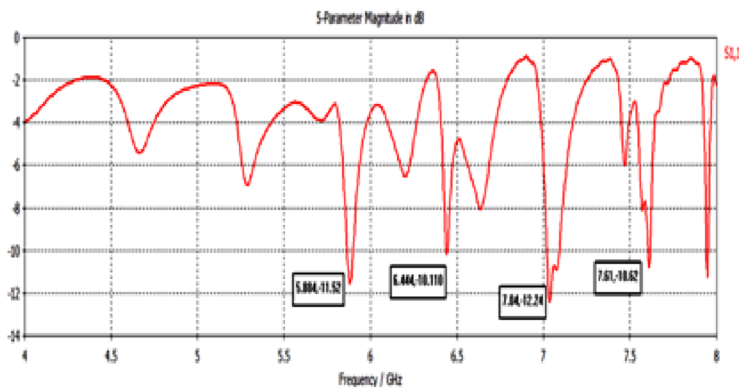


Fig. 3 s_{11} vs frequency plot for the bracelet DRA

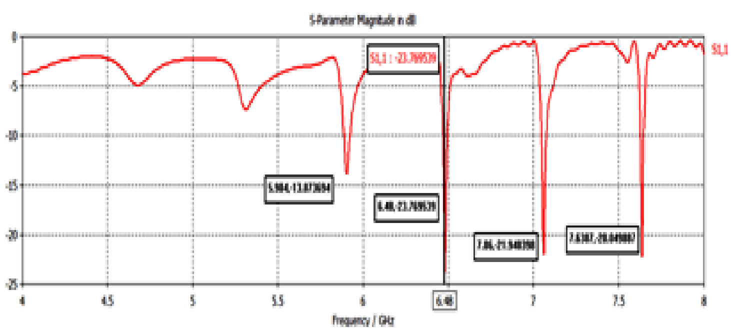


Fig. 4 s_{11} vs frequency plot for the bracelet DRA when put on human wrist

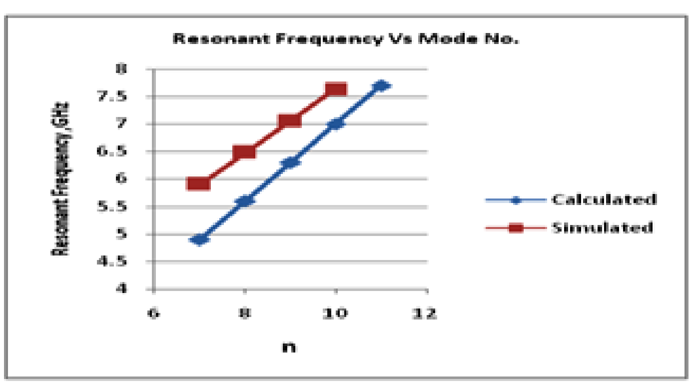


Fig. 5 Resonant frequency of DRA vs. mode number

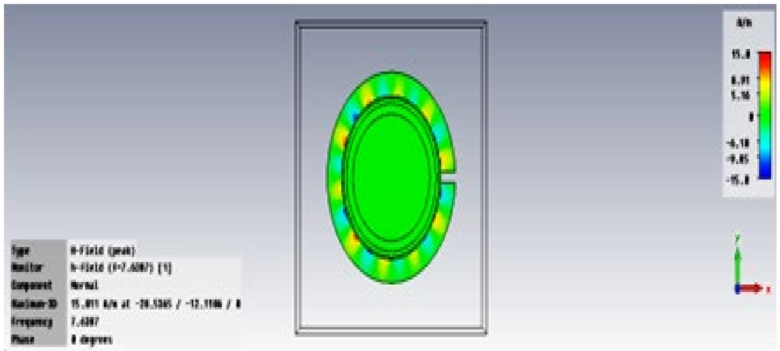


Fig. 6 Peak H field plot showing n=10 at fr= 7.6387 GHz

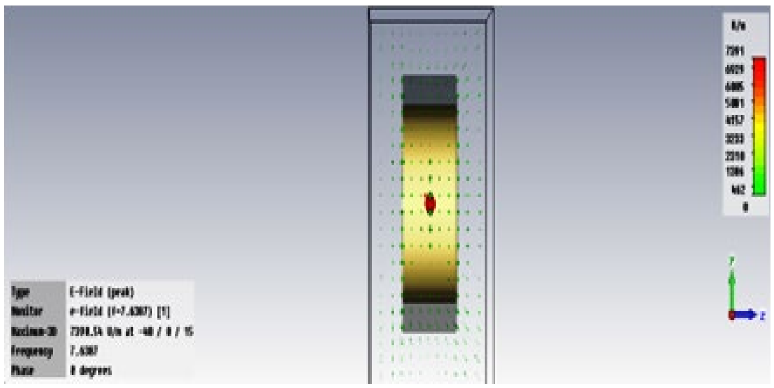
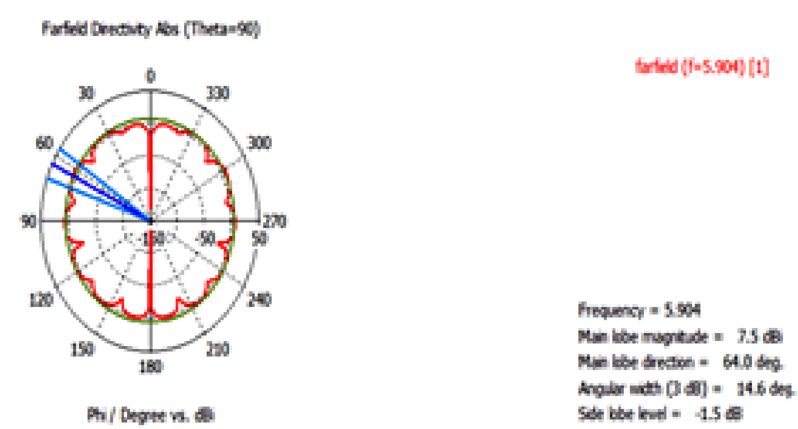
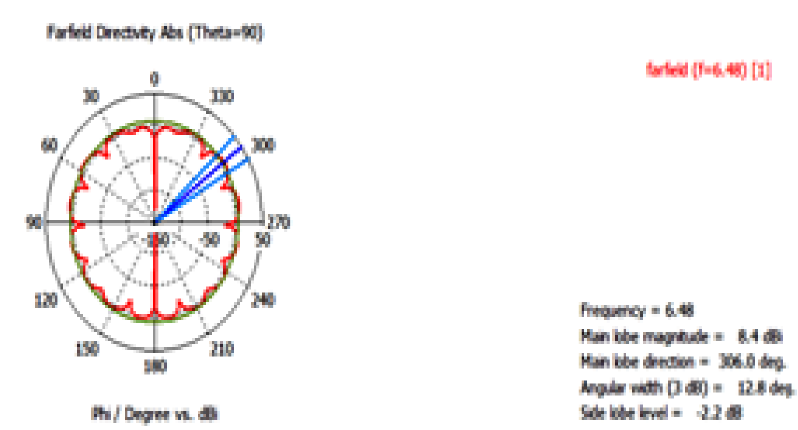


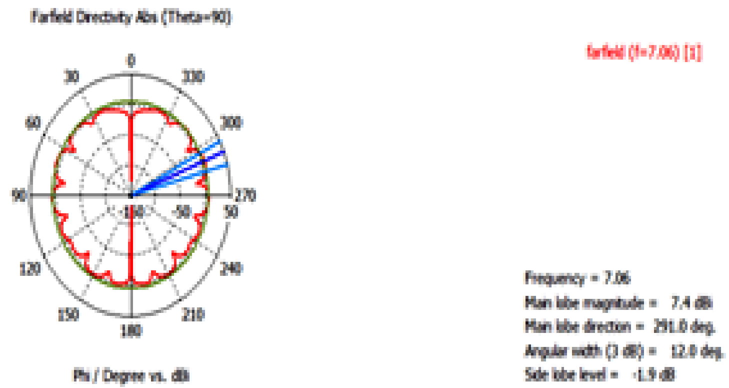
Fig. 7 E field plot at fr= 7.6387 GHz



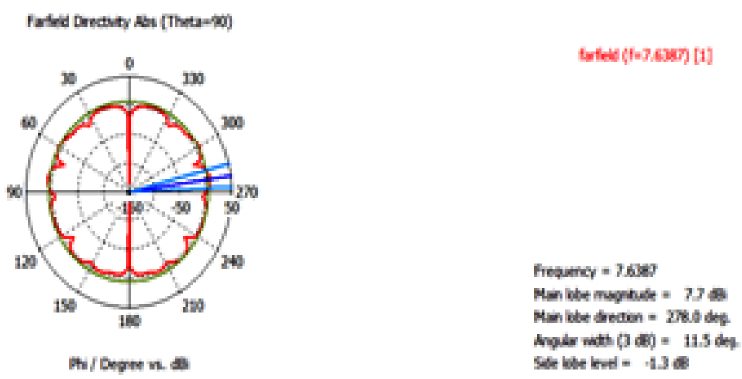
(a)



(b)

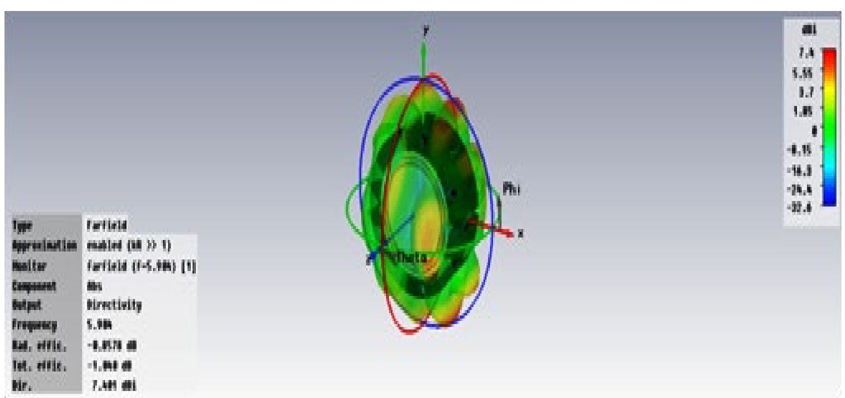


(c)

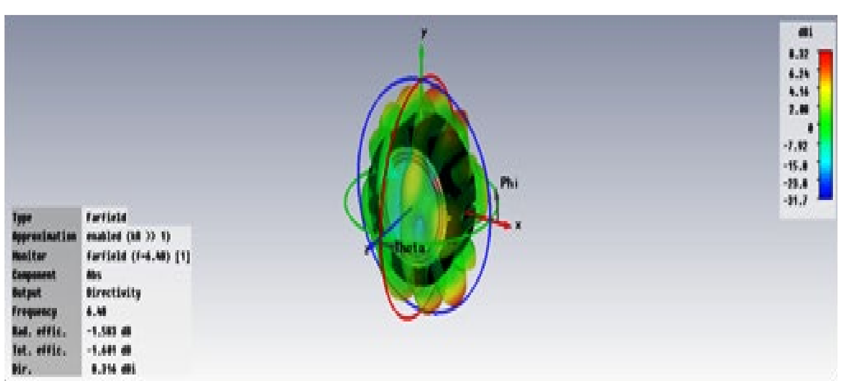


(d)

Fig. 8 Far field polar plot at different resonant frequencies
(a) 5.904GHz (b) 6.48 GHz (c) 7.06GHz (d) 7.6387GHz



(a)



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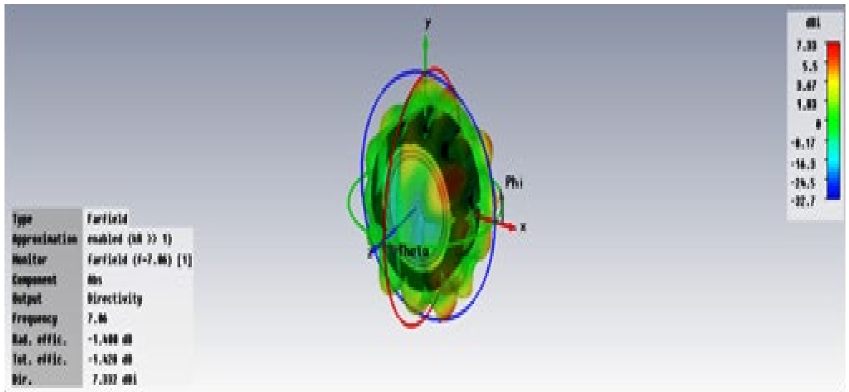

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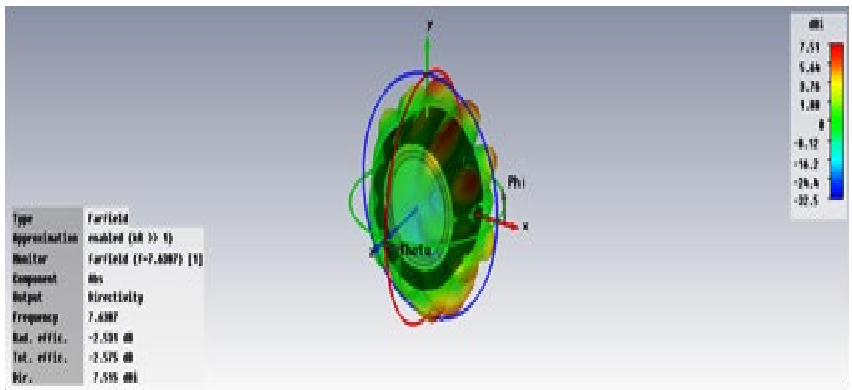
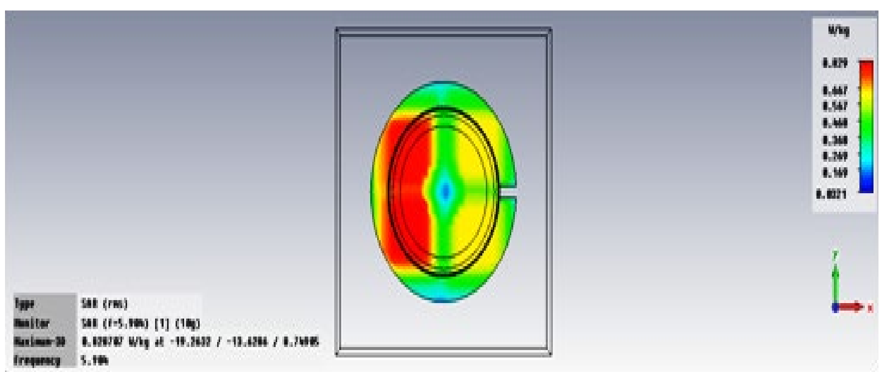
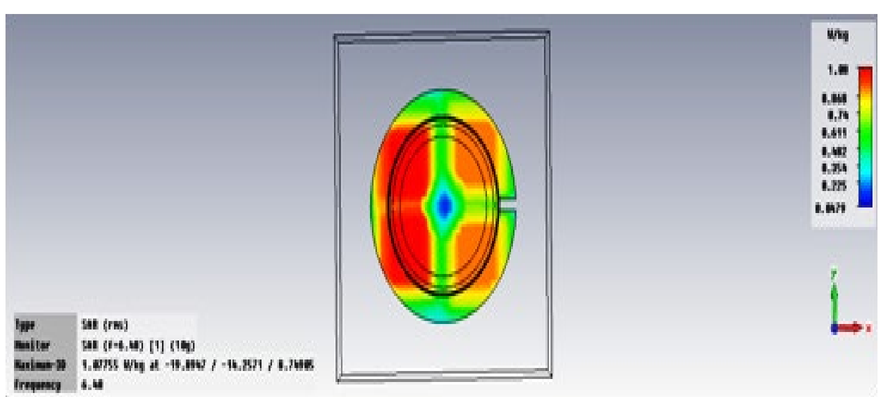


(d)

Fig. 9 Far field 3D radiation plot at different resonant frequencies
(a) 5.904GHz (b) 6.48 GHz (c) 7.06GHz (d) 7.6387GHz



(a)



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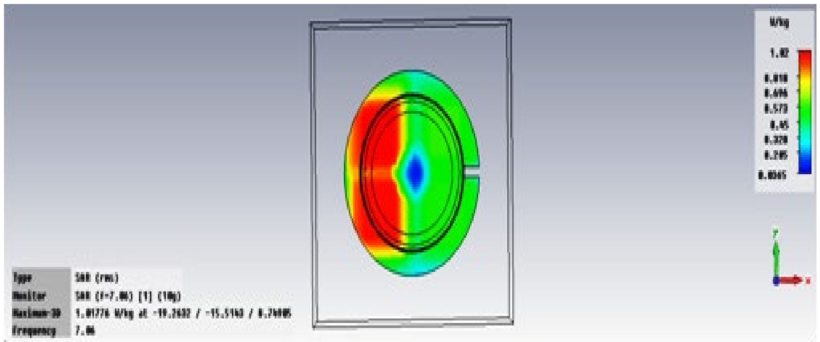
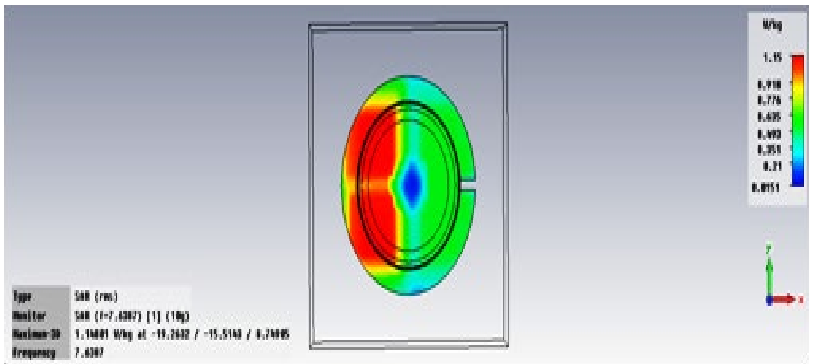


(c)



(d)

Fig. 10 SAR plot at different resonant frequencies
(a) 5.904GHz (b) 6.48 GHz (c) 7.06GHz (d) 7.6387GHz

TABLE III PERFORMANCE CHARACTERISTICS OF THE ANTENNA WHEN WORN ON HUMAN WRIST MODEL

Frequency GHz	S11 dB	BW MHz	Radiation Efficiency dB	Total Efficiency dB	Directivity dBi	Maximum SAR W/kG
5.904	-13.874	36	-0.8578	-1.040	7.401	0.829
6.48	-23.769	26	-1.583	-1.601	8.316	1.08
7.06	-21.948	28	-1.400	-1.428	7.332	1.02
7.6387	-23.050	20	-2.531	-2.575	7.515	1.15

Table III gives output characteristics of the antenna when it is put on the wrist model. Increase in radiation efficiency, impedance bandwidth and improvement of SAR with the decrease in operating frequency are observed from this table. Radiation efficiency greater than 82% is obtained at 5.904 GHz. Comparison of performance characteristics of the designed antenna with those of C band wearable antenna as found in recent literature is shown in Table IV.

TABLE IV COMPARISON WITH SEVERAL WEARABLE ANTENNAS

Ref.	Antenna Size	Frequency GHz	Structure/ Material	SAR	Gain
[6]	-	3.01 to 5.30 & 8.12 to 12.35	copper tape/ jeans fabric material	-	5.7 dB
[7]	40 × 40 mm^2	3.4–8.3	adhesive copper tape /Jeans fabric textile material	-	5.2dBi
[8]	20 mm × 22 mm × 1.07 mm	4.45 and 8.75	flexible textile substrate	-	-
[9]	-	4 - 8 & 8 - 12	denim with laminate copper on top	-	9.46 dBi
[10]	22 × 22 × 1.6 mm	4.6 and 8.2		below 1 W/kg	-
[11]	-	4.34 and 5.96	Rigid Collar stay shaped structure	-	4.51& 5.37dBi
Proposed Antenna	30x220x9 mm^3	Four resonant frequency between 4 to 8GHz	Bracelet shaped	Max 1.15	Max 8.4dBi

V. CONCLUSION

A bracelet shaped wearable DRA made of Bakelite sheet which can be worn as a low cost ornament is proposed and its performance characteristics are investigated. This easy to wear DRA has simple construction and multi frequency operation in C band is possible. Its minimum and maximum directivities are 7.4dBi (at 5.9 GHz) and 8.3dBi (at 6.48GHz), respectively. Its maximum SAR value is 1.15 W/kg which is well within the safety limit of 1.6W/kg for human. From Table IV it is seen directivity values of the proposed DRA is greater than those of all comparable DRAs except [9]. However, the DRA of [9] is made of Denim and its performance can be degraded when subject to moisture and wetness. SAR value of the proposed DRA is somewhat greater than that of [10]. However, this DRA [10] is capable of only single frequency operation at C band whereas the proposed DRA is capable of quadruple frequency operation at C band. The results indicate that overall performance characteristics of the proposed DRA is very good, and it is suitable for using as wearable antenna for wireless communication at C band.

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