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DESIGN AND PERFORMANCE ANALYSIS OF COMPACT WEARABLE ANTENNA FOR BODY-CENTRIC COMMUNICATION APPLICATIONS

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Abstract: The Wearable antenna for body-centric communication applications for military purposes that is for tracking and health monitoring is designed to cover ISM frequency bands of two different ranges 2.4GHz and 3.2GHz. The wearable antenna is composed of a dipole antenna which is liable to acquire dual-band on-body applications. The wearable antenna is designed using flexible substrate material with a dielectric constant of 2.9 and with a loss tangent of 0.008. The material analysis is accomplished to compare different flexible materials. The proposed antenna covers frequency bands of 2.2-3.5 GHz and 2.8-4.2 GHz with constituent bandwidth representing 41% and 28%. The wearable antenna gives firm dipole and omnidirectional patterns. The peak gain of the computed wearable antenna is 2.11 dBi at 2.5 GHz and 2.89 at 3.2 GHz radiation efficiency of 81% at 2.5 GHz and 88% at 3.2 GHz. To authenticate the proposed wearable antenna working and performance is undertaken for the comparison of simulation with different materials and the results are validated by placing on a human phantom model.

Keywords**: body-centric communication, Dipole antenna, On-body, Flexible antennas.**

I. INTRODUCTION

Technology for wearable communication offers potential applications in the field of biomedicine, smart electronic devices, military purposes, automated homes, and sports. The wearable devices should be lightweight, with low cost of manufacture, easy fabrication, and inexpensive substrates all of which make flexible electro-mechanical systems appealing candidates for consumer electronics.[1] A robust communication link is provided by the antenna of the wearable communication device by facilitating communication between various devices. Ideally, wearable antennas should be compact, low-profile, mechanically robust, efficient, as well as flexible to conform to body contours.[2-3] Flexible materials like textile materials and polymer materials as wearables substrates are gaining fashionability due to ease of integration of the antenna directly with the apparel the commonly used flexible substrates are polyimides (PI), polydimethylsiloxane (PDMS), polytetrafluoroethylene (PTFE), liquid crystal polymer (LCP), Kapton, paper-based substrates cotton cloth, felt, denim, fleece, nylon, and polyester. Antenna designs such as dipole, loop, spiral, and patch are commonly chosen structures for various communication applications.[4]

It is also important that these antennas perform well at close range to the human body, and that the operating frequency and emission characteristics are appropriate. The dynamic movements and postures that users make have caused some of the works to be fragile because they have been performed on rigid substrates lacking flexibility. Specific absorption rate (SAR) is a measure of how transmitted RF energy is absorbed by human tissue [5]. US SAR limits for mobile phones are 1.6 W/kg, which equates to over one gram of tissue. In Europe, the SAR limit is 2.0 W/kg, which equates to over ten grams of tissue. Inkjet printing, screen printing, 3D printing, sewing, and embroidered techniques are some of the fabrication methods available depending on the substrate material, application, and suitability [6]. The return loss and radiation patterns of various antennas will be analyzed for free space scenarios as well as experiments conducted on human subjects. Flexibility tests will also be carried out by bending the antenna at different radii that correspond to the limb joints of the subject [8]. In order to operate the wearable antenna in accordance with requirements, it is placed on the body and connected to any kind of wireless sensor handling mechanism. The wearable antenna will operate according to requirements and will store information on the server.

In this article, a flexible substrate is used to design and analyze a compact dual-band dipole antenna for on-body applications. The proposed model is surrounded by a Microstrip patch line antenna and derived iteration-wise. The SAR, as well as body-centric antenna applications, have been carried out in this paper successively. The simulated and evaluated results show a good correlation between each other. In this paper, we describe how we automated the simulation of highly conformal and flexible textile antennas using highly flexible materials [10].

II. DESIGN METHODOLOGY OF ANTENNA

The basic structure of the antenna comprises of circular monopole with a CPW feeding technique. The antenna is designed on a flexible polyimide substrate with a dielectric constant of 2.9 and a loss tangent of 0.008. The antenna has dimensions of 40 x 30 x 0.1 mm^3. The circular patch is designed with a radius of 12.5 mm and the top corner is truncated with a rectangular slot of 2 x 22 mm^2. Further, the antenna is inserted slotted section into a circular patch. In the middle of the circular patch, a slot with a line of 2 mm is inserted. The antenna is fed by a 50-ohm microstrip line with CPW feeding. The ground structure consists of two rectangular elements on either side of the feed line. The antenna having the feed line of $L_{f\ x}\ w_f$ with the gap of 'g' in between the feed and ground.

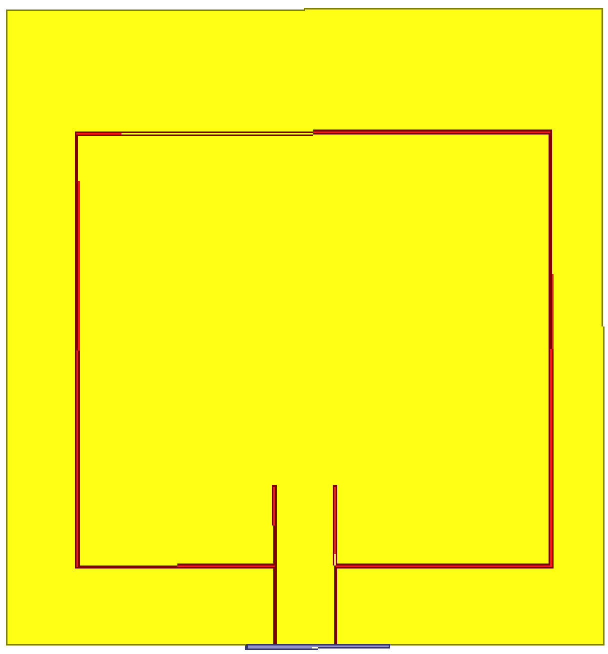


Fig 1: Proposed structure

III. RESULTS AND DISCUSSIONS

The reflection coefficient vs frequency of antenna is noted in the Fig.2 the basic antenna structure consists of circular patch antenna with CPW ground plane and antenna operates in the range of 2.3-2.8 GHz and covers many frequency applications like LTE2300(2.3-2.4 GHz) Bluetooth(2.4-2.48 GHz),ISM(2.45-2.48 GHz) and WiMAX (2.5-2.69 GHz). The antenna operates in the single frequency and provides the impedance bandwidth of 19.6%. In second step antenna is truncated at top corner of circular patch and operates in the frequency of 2.3-2.9 GHz with variation of 0.1 GHz and covers most of the similar application like the antenna1and provides the impedance bandwidth of 23.0%. In the third step antenna is inserted with small rectangular slot on the top of radiating circular patch with circular slot at the center of the patch. The designed antenna covers the frequency of 2.25-3.1 GHz with operating bandwidth of 0.8 GHz and provides the impedance bandwidth of 32% and till third step antenna operates in the single operating frequency. In final step antenna provides dual band operating characteristics and first operating frequency ranges from 2.3-3.5 GHz with bandwidth1.2 GHz and provides the impedance bandwidth 41% covers LTE2300,WLAN,WiMAX and ISM bands(2.45-2.48 GHz) and second operating band covers the frequency in the range of 5.1-6.8 GHz with bandwidth of 1.7 GHz and provides the impedance bandwidth of 28% and covers application like ISM (5.725-5.825 GHz).

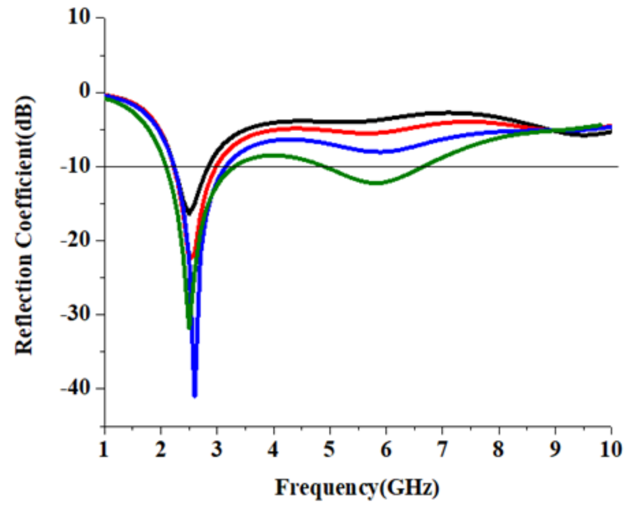


Fig.2: Reflection coefficient of antenna of different materials

3.1. Peak Gain and Radiation Efficiency of antenna

The peak gain, radiation efficiency of the proposed antenna is observed on the Fig.3. In the first peak gain of the antenna is observed with simulated peak gain of 1.85 dBi at 2.5 GHz and 4.9 dBi at 5.8 GHz .The measured peak gain of 2.3 dBi is observed at 2.5 GHz and 4.7 dBi at 5.8 GHz when antenna is in standalone condition. Similarly, the antenna radiation efficiency of the antenna is observed in standalone condition with simulated radiation efficiency of 82% is observed at 2.5 GHz and measured efficiency of 78%. At the 5.8 GHz simulated radiation efficiency of 85% and measured radiation efficiency of 84% is observed.

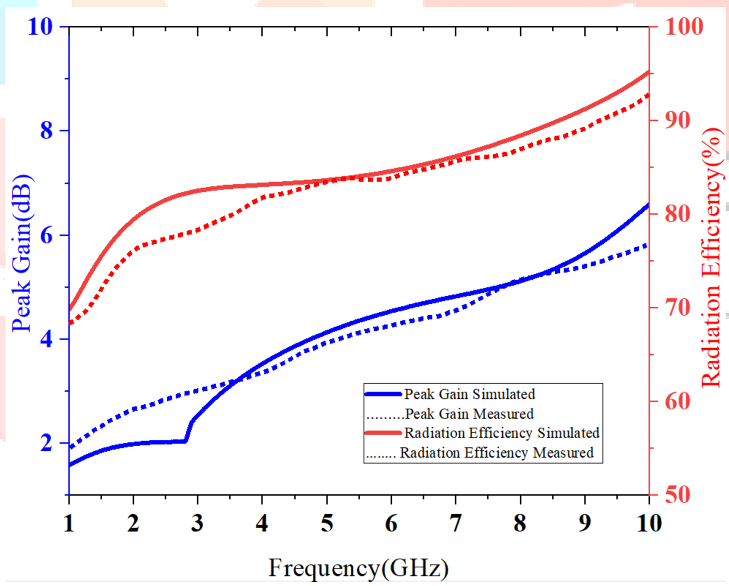
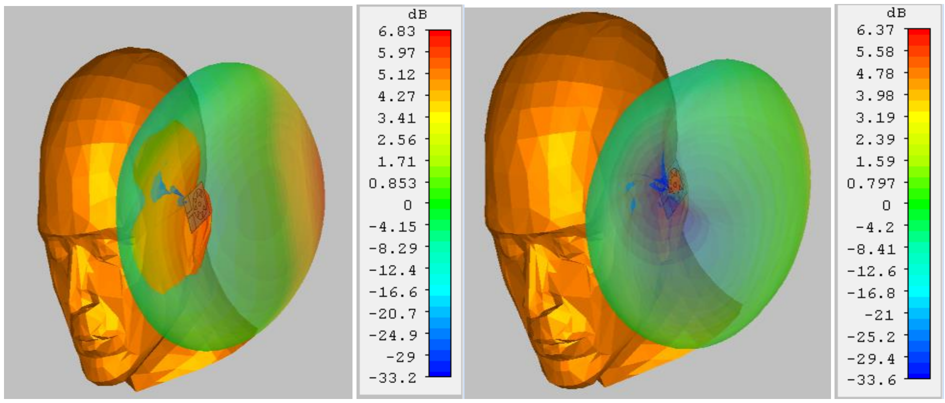


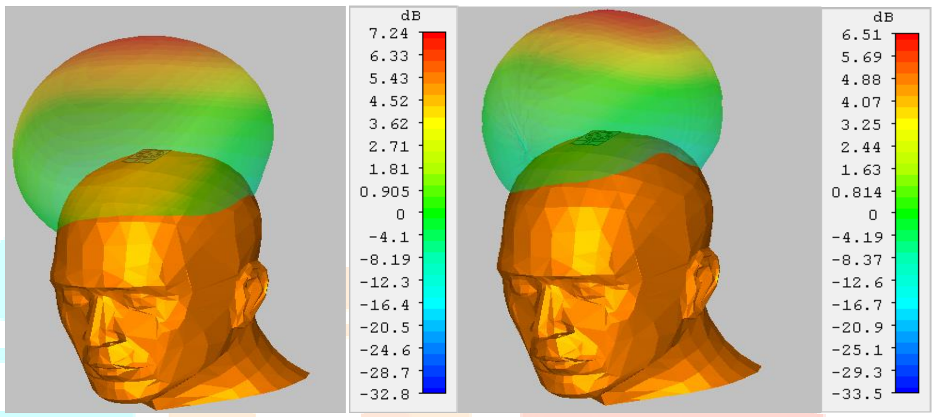
Fig.3 Simulated and measured peak gain of antenna

3.2. Gain characteristics of antenna placed on the Human head

The gain of the antenna is noted when the antenna placed on the two different locations of human head. The 3D-gain patterns of antenna are observed at two different frequencies 2.5 GHz and 5.8 GHz. The direction of propagation of maximum radiation from the anatomical human head model is observed towards outside the human head model. Which is an important thing on-body communication for reduced radiation effects. In the Fig.4 3D radiation patterns are nearly omnidirectional and observed the gain 6.83 dBi at 2.5 GHz and at 5.8 GHz it is 6.37 dBi when antenna is placed near human ear. Similarly, 3D gain patterns are observed at when antenna is placed on the top of the human head. The gain of the antenna is 7.24 dBi at 2.5 GHz and at 5.8 GHz it is 6.51 dBi respectively.



(a)2.5 GHz (b)5.8 GHz



(c) 2.5 GHz (d) 5.8 GHz

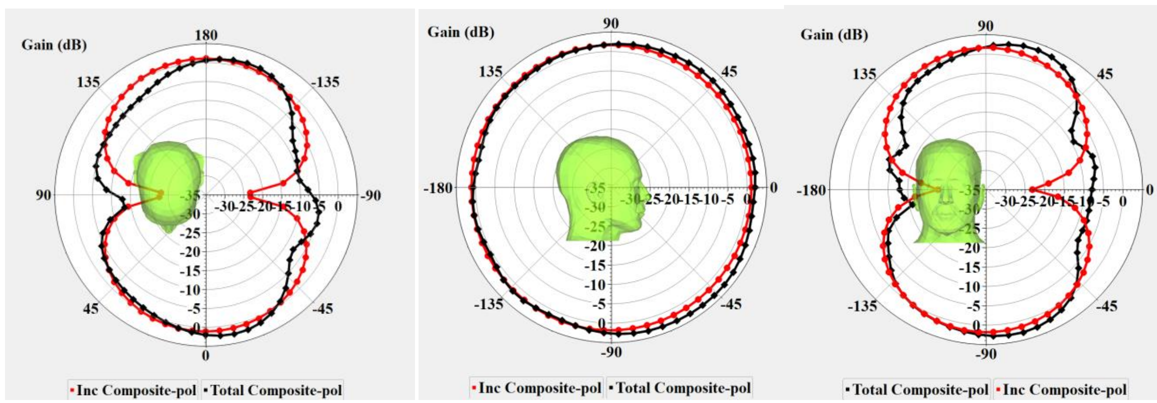
Fig.4: Gain characteristics of antenna on Human ear (a)2.5 GHz (b)5.8 GHz on Top of head(a)2.5 GHz (b)5.8

3.3. Far field radiation characteristics on ear and top the head

The far field analysis of antenna is carried out in Ansys savant simulation tool. The human head CAD model is considered and the antenna ais placed with the distance of 2 mm from the human head model and ear. The antenna is placed in flat condition at two different parts of human head. In the Fig.4 far field characteristics are noted when antenna is placed on human ear at two different frequencies like 2.5 GHz and 5.8 GHz. Far field characteristics are noted at three different planes like XZ, YZ and XY-planes. At 2.5 GHz, YZ-pane far field radiation characteristics are dipole type of radiation patterns and distributed along180^0 and 0^0. In the XY-plane radiation patterns are distributed in omnidirectional radiation patterns. In XZ-plane the radiation patterns are showing dipole type of radiation patterns and distributed along +/-90^0 angles. At 5.8 GHz far field radiation patterns are like that 2.4 GHz frequency.

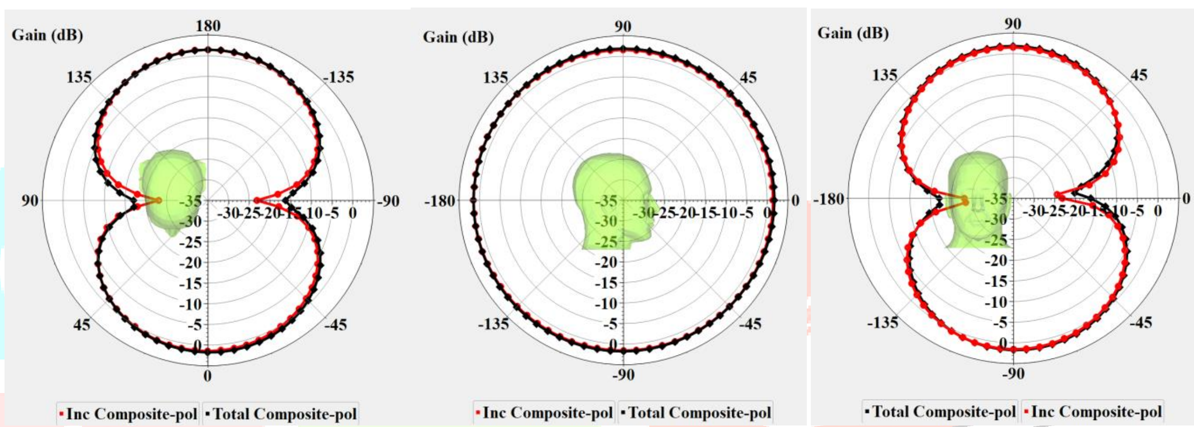
IV. RADIATION CHARACTERISTICS ON HUMAN EAR

YZ-Plane **XY-Plane** **XZ-Plane**



(a) 2.5 GHz

YZ-Plane **XY-Plane** **XZ-Plane**



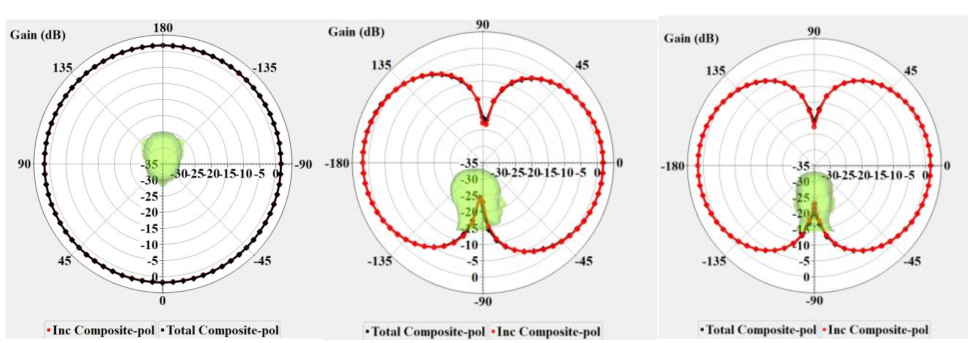
(b) 5.8 GHz

Fig. 5: Far field radiation characteristics of antenna on human ear at 2.5 GHz and 5.8 GHz

4.1. Radiation Characteristics on Human ear

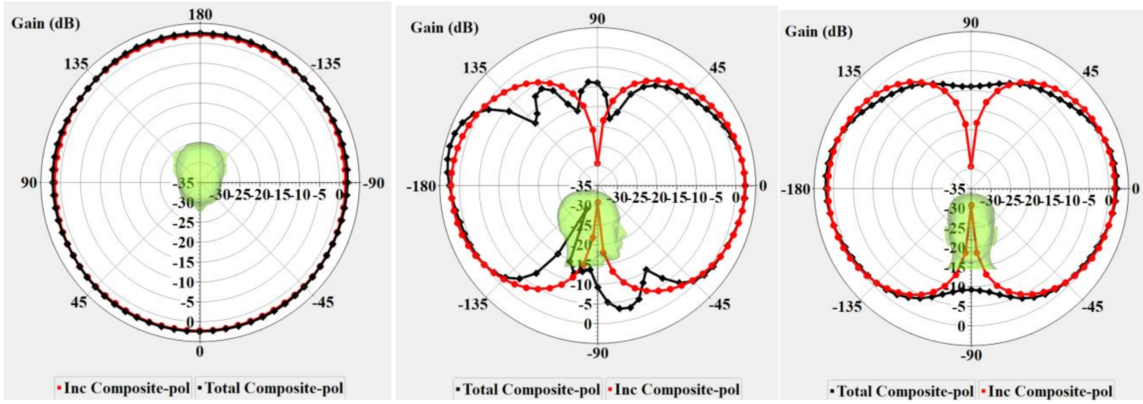
The far field radiation patterns of antenna when antenna is placed on the top of the human ear is observed in the Fig 5. At the 2.5 GHz in YZ-plane omnidirectional radiation patterns and in XY and XZ- planes dipole type of far field radiation patterns is observed.

YZ-Plane **XY-Plane** **XZ-Plane**



(a) 2.5 GHz

YZ-Plane **XY-Plane** **XZ-Plane**

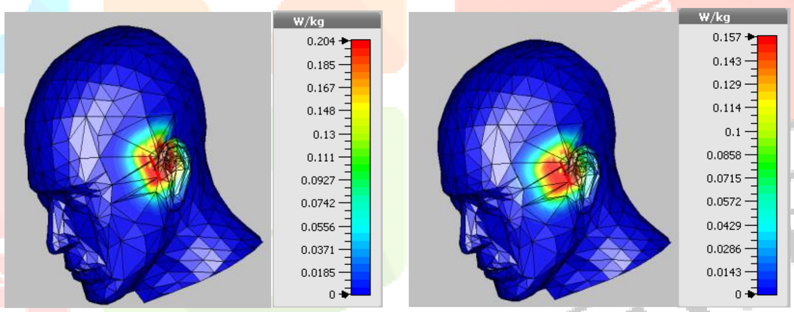


(b) 5.8 GHz

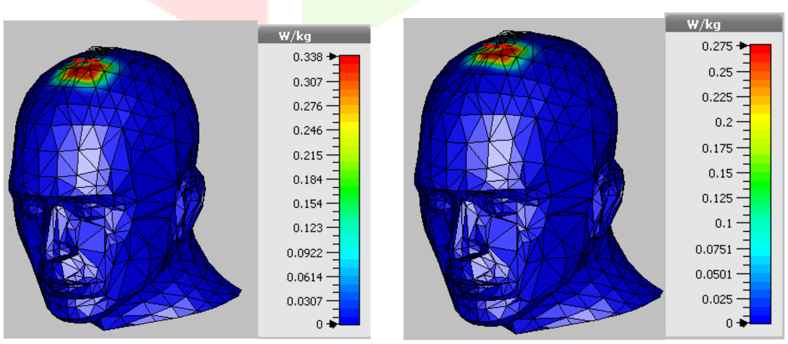
Fig.6: Far field radiation characteristics of antenna on human head at 2.5 GHz and 5.8 GHz

4.2. SAR Characteristics of the antenna

The SAR calculation is used for evaluating the impact of radiation when antenna is placed on proximity of human body. The 3D-anotomical model available in the CST studio is employed for calculating the SAR. The antenna placed at two different locations of human head and observed SAR values. The benchmark 100 mw is applied as the input power for the antenna because as the power of the antenna is increased larger amount of SAR values which is hazardous to human head. To evaluate total human body simulation time will be very high with huge number of mesh cells so, only head phantom is considered. Fig. 7 shows 10 g averaged SAR values at two different location of head the peak 10 g averaged value is0.338 W/Kg, which is below 1.6 W/Kg and satisfies the FCC standards. In the Fig 7(a) antenna placed on the human ear observed the SAR values at 2.5 GHz it is 0.204 W/Kg and at 5.8 GHz it is 0.157 W/Kg. Similarly, when the antenna is placed on top of the human head the values are 0.338 W/Kg at 2.5 GHz and 0.275 W/Kg at 5.8 GHz.



(a) 2.5 GHz (b)5.8 GHz



(c)2.5 GHz (d) 5.8 GHz

Fig.7: SAR characteristics of antenna on Human ear (a)2.5 GHz (b)5.8 GHz on Top of head(a)2.5 GHz (b)5.8

Table:1 Comparison Table of previous literature

S.No	Antenna Dimensions (mm^3)	Operating band	Resonating Frequency	Substrate	SAR values(W/Kg)
[3]	29.4 x 19.6 x 6	402-405 (MHz)	403(MHz)	Silicon	0.29
[4]	22.5 x 22.5 x 2.5	402-405(MHz) 2.4-2.48(GHz)	403(MHz) 2.45(GHz)	Roger 3210	-
[7]	12 x 1.8	402-405(MHz) 902-928(MHz)	403(MHz) 910(MHz)	Rogers R03210	30.41
[17]	40 x 25 x 0.4	2.1-3.1(GHz) 4.4-7.7(GHz)	2.4(GHz) 5.8(GHz)	Rogers5880	0.926
[21]	30 x 25 x 0.8	3.1-10.6 (GHz)	3.6/7.2/10.5 (GHz)	Rogers 5880	1.23
Proposed Antenna	40 x 30 x 0.1	2.3-3.5 (GHz) 5.1-6.8 (GHz)	2.5 (GHz) 5.8 (GHz)	Polyimide	0.24 0.157

The comparison of literature is done in the Tab.2 and obtained the lower values of SAR values when compared with literature.

The propagating SAR along the ear and top of the head are used for the communication between wrist band sensors. In off-body communication it requires strong radiated power to enable wireless communication in 10-20 meters, the on-body radiated power levels will be very small to travel long distance. So, the distance between wearable antenna and on-body sensor typically placed very near to human body.

V. CONCLUSION

The dual band antenna to cover ISM frequencies for wearable applications is done in this article. The antenna having the compact dimensions of 40 x 30 x 0.1 mm^3. The on-body analysis of antenna is carried out using CST microwave studio. The 3D gain of the antenna is observed at operating frequency. The maximum gain of 7.24 dBi is observed when the antenna is placed on the top of the head. The antenna undergone with SAR analysis and obtained lower values of 0.157 W/Kg when the antenna is placed on the ear of human head. The antenna covering covers LTE2300, WLAN, WiMAX, and ISM bands (2.45-2.48 GHz) (5.725-5.825 GHz).

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