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Research Article

A REVIEW ON DESIGN ISSUES AND CHALLENGES OF WEARABLE ANTENNAS

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ABSTRACT
The COVID-19 pandemic has resulted in a significant increase in the need for wearable medical devices to monitor patients in their homes. For tele-healthcare, the antennas are the most significant component. Examples include wearable spirometers, hemodynamic/pressure monitoring devices, ECG patches, insulin pumps, and other health-related wearables. In order to keep track of the patient's health, these wearable medical devices rely largely on data communication to caregivers or doctors. Various researchers and academicians have developed a variety of antennas for wearable applications. This article will review the design issues and challenges of wearable antennas.

Keywords: *Wearable Antenna, Smart Wearables, SAR, ISM & MICS band, Wireless Body Area Network*

INTRODUCTION

In healthcare, wearable technology is frequently employed to provide patient condition monitoring, therapy delivery, and other functions. The wearable medical devices market was valued at $16.2 billion in 2021, and it is predicted to grow at a CAGR of 13.2 percent to $30.1 billion by 2026. The rise of lifestyle-related disorders (e.g., hypertension), the increasing demands for home healthcare, and the desire to enhance patient outcomes are all factors influencing the market growth. https://www.scnsoft.com/healthcare/medical-devices/wearable .With the advent of wearable medical gadgets to the market, medical research and healthcare have made a significant spot ahead this decade (Sakib *et al.*, 2020).An antenna device is also projected to evolve to become "truly wearable," suggesting that it would be affixed to or implanted on or into the human body or clothing.

Wearable antennas can help patients avoid protracted stays in hospitals by using remote health monitoring systems that eliminate the need for face-to-face consultations with doctors. The wearable antennas have a wide range of applications in the medical field, including health monitoring, human activity monitoring, and blood pressure monitoring, early disease diagnostics, as well as sports, navigation, and wearable computing. Wearable patient monitoring devices (such as glucose monitors) capture data about a patient's condition (such as blood glucose levels) and send it to a cloud-based medical software server. To study the change in the anonymized patient data, it is processed and evaluated. Doctors and patients can access the observed patterns, together with the source data, in their individual user applications, which can help track patient health status, improve treatment, and improve illness self-management. This remote health monitoring system can track a patient's medical data from the comfort of their own home, making the diagnosis, treatment, disease prediction, and condition management much easier (Sukhija and Sarin 2017).

The microstrip patch antenna become an important role in remote health monitoring applications and have a number of advantages, including cost-effectiveness, compact size, a simple production method, and the ability to be quickly altered. Because it has a low profile and has been set on a flat surface, it is excellent for biomedical applications (Rahaman and Hossain 2018). The human body surface is used as a transmission medium or path for electromagnetic waves by a wearable antenna (Rahaman and Delwar Hossain 2019).

The wearable on-body antenna utilizes almost all bands, including Medical Implant Communication Service(MICS,402-405MHz), Wireless Medical Telemetry Service(WMTS,420-1430MHz), Medical-BAN(2.36-2.4GHz) as well as Industrial, Scientific, and Medical (ISM,2.4-2.485GHZ) to transmit the Bio-signals from the wearable device to the cloud server and vice versa (Kumar, Badhai, and Suraj 2018). The design of a wearable antenna is challenging because it must meet several key objectives, including compact size, flexibility, biocompatibility, minimal sensitivity to the human body, and a low Specific Absorption Rate (SAR).

To design a compact size of wearable antennas, few techniques like meandering the monopole, loading the antenna with miniaturized high impedance surfaces, applying slotting to the patches can be proposed (Shubair *et al.*, 2015)

Wearable antennas, which are typically placed near the human body, are affected by biological tissues, resulting in antenna performance reduction. The specific absorption rate indicates the amount of radiation absorbed by the human body (SAR). Different countries have their own set of SAR guidelines. India and the United States are regulated by the Federal Communications Commission (FCC) to allow SAR values of less than 1.6 kg/W over a volume of 1 g of tissue. The European countries limit SAR values below 2 kg/W over 10 g of tissue, according to International Electrotechnical Commission (IEC) regulations. When the backward energy from the antenna is high when a human is present, the amount of energy absorbed by the human tissues is greater. The backward energy must be reduced in order to reduce the SAR value (Janapala *et al.* 2019).

The use of substrates plays a very important role in wearable antenna designs. Solid substrates, such as FR4, Rogers 3006, and 5880, are used in traditional antennas, whereas flexible antennas use polymer, textile, carbon nanotube, and microfluidic substrates. Each of these versatile substrates has its own set of benefits. Polydimethylsiloxane is one of the most widely utilised polymer-based dielectric substrates (PDMS). Impurities can be added to this PDMS to change its dielectric characteristics (Janapala *et al.* 2019).

This article is outlined as follows., survey on different wearable antennas like conventional Wearable Antenna Design , Textile antennas, Dielectric resonator Antennas , Wearable antenna analysis and conclusion.

SURVEY ON DIFFERENT WEARABLE ANTENNAS:

In the past, various types of wearable antennas were developed. The following section covers,

A. Conventional Wearable Antenna Design:

A wideband, low-profile, semi-flexible antenna for wearable biomedical telemetry applications was proposed by (Smida *et al.*, 2020). The antenna is made of semi-flexible RT/duroid 5880 material ($\varepsilon_r = 2.2$, $\tan \delta = 0.0004$) and has overall dimensions of 17 mm X 25 mm X 0.787 mm ($0.2\lambda_\circ \times 0.29\lambda_\circ \times 0.009\lambda_\circ$) as shown in Fig.1. The resonant frequency of a standard rectangular patch is lowered by adding rectangular slots, and the partial ground plane is adjusted to increase the operational bandwidth. The overall comparison of the antenna operated in unbent and bent scenarios is given in Table1. It shows that the antenna's gain and efficiency are slightly reduced when used in bending conditions. For the purpose of simulating a SAR, a 6 mm gap was maintained between the human body and the antenna. Table 2 and Fig.2 shows the S_{11} for 1gram of tissue when the applied power to the antenna is 1W. If the input power is less than 265 mW, the proposed antenna is safe to use in wearable devices.

(Shawkey and Elsheakh, 2020) proposed a compact dual-meander line (DML)-integrated antenna (Fig.3) for mm-wave BCN biomedical applications. The planned antenna was made up of two layers of meander lines layered on top of each other, as well as a ground metal layer. The dual-meander line layout expanded the number of tuning bands while also increasing bandwidth. The suggested antenna resonated at four frequencies: 22 GHz, 34 GHz, 44 GHz, and 58 GHz, with a maximum gain of 1 dB at 62 GHz and a 35 percent radiation efficiency. When compared to a standard single-meander line antenna, the suggested DML resonated at 22 GHz with a 6 GHz reduction in resonance, a 22 percent reduction in area, a large number of tuning bands, and a simplified integration with implantable/wearable systems. However, the SAR characteristics have not been revealed in this proposed paper. The reflection loss and the gain of this work is shown in Fig.4

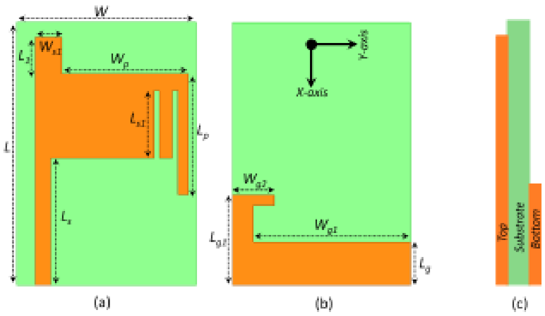


FIGURE 1. Proposed wearable antenna: (a) top view [$W = 17$, $L = 25$, $L_s = 12.1$, $L_1 = 3.5$, $W_{s1} = 2.5$, $W_p = 12$, $L_p = 11.5$, $L_{s1} = 6.4$ (unit = mm)], (b) bottom view [$W_{g1} = 15$, $W_{g2} = 4$, $L_g = 4.1$, $L_{g1} = 8.6$ (unit = mm)], and (c) side view.

TABLE 1. Comparison of the antenna properties bending in x-axis and y-axis.

Bending in y-axis					
R_y (mm)	Unbent	80	60	40	30
Gain (dBi)	2.50	2.31	2.30	2.35	2.29
Efficiency	93 %	91.1 %	91 %	91.5 %	90.5 %
Bending in x-axis					
R_x (mm)	Unbent	80	60	40	30
Gain (dBi)	2.50	2.45	2.43	2.43	2.41
Efficiency	93 %	92.3 %	92 %	92.2 %	91.7 %

TABLE 2. Comparison of the antenna properties in the free space and on-body worn scenarios.

Parameter	Free Space	On-body		
		Chest	Legs	Arm
Resonant Frequency (GHz)	2.4	2.3	2.46	2.34
Bandwidth (%)	59.7	34.87	51.6	33.3
VSWR	1.06	1.09	1.17	1.14
Gain (dBi)	2.50	2.2	2.15	2.18
Efficiency (%)	93	80.2	81	81.4
SAR_{1g} (W/kg)	–	6.02	5.99	5.95

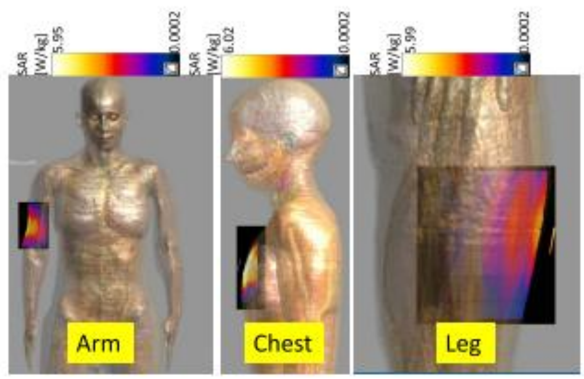


Fig 2.SAR $_{1g}$ at 2.4 GHz

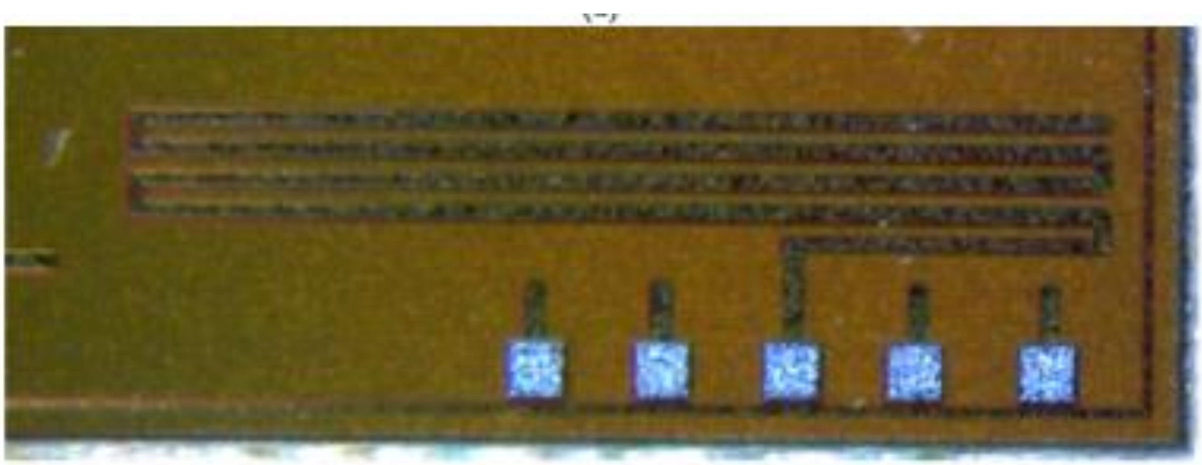
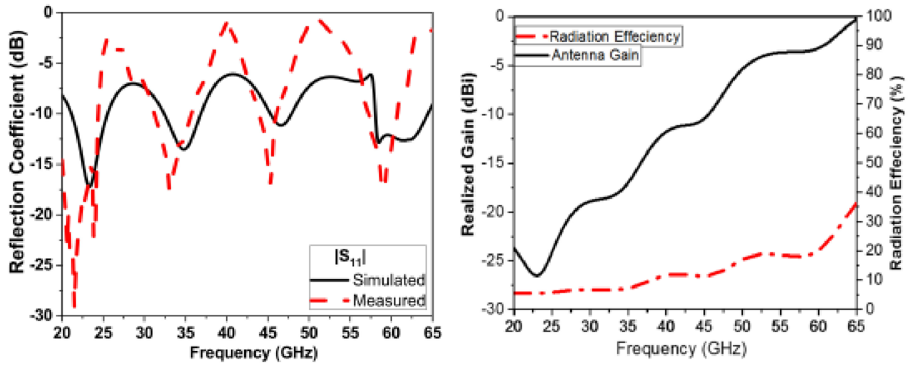


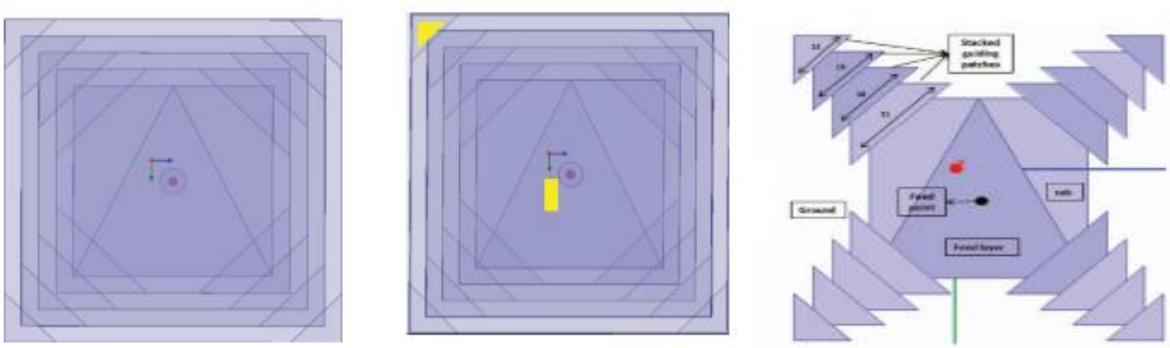
Figure 3: Fabricated DML antenna



(a) measured and simulated |S11| (b) gain and radiation efficiency

Figure 4: Measured and simulated results of DML antenna

(Shubair *et al.*, 2015) proposed two wearable antennas that exhibit reduced size while achieving maximum SAR value, low return loss, and E-field distribution all within acceptable limits. The first design utilizes stacked triangular guiding patches in comparison to the original design that adopts square ones. The second design applies slotting to one of the triangular patches on one corner of one of the four substrate layers. As shown in Fig.5 (a),(b),(c) The antenna operates in the Industrial, Scientific, and Medical (ISM) band are presented in this work (2.4-2.48GHz). 60 percent reduction in size is observed as that the original design. The dimensions of both designs are 39×39×2.1mm^3. For the stacked and stacked-slotted triangular patches, the return loss is -16.69 dB and -15.53 dB, respectively. The maximum observed SAR is 1.57 W/Kg with an input power of 0.15 W as shown in Fig.6. The maximum SAR values derived from both systems meet IEEE standard safety criteria, which is required for patient safety.



(a) **(b)** **(c)**

Figure 5(a) First proposed design 16 stacked triangular patches.
Figure 5(b) Second proposed design 16 stacked-slotted triangular patches (two slots shown in yellow
Figure 5(c) Geometry of the proposed antenna design (Top view)

The triangle feed layer is printed on the top view of a Taconic CER-10 substrate (ε_r= 10.1) with dimensions of 23x 23x 0.4mm^3. In order to produce a shift in the resonance frequency, a FR-4 substrate (ε_r = 4.4) with a thickness of 0.1 mm is put under the Taconic CER-10 substrate. Above the feed layer, four Taconic CER-10 substrates with a 0.4mm thickness are added. Each substrate contains four different-sized equilateral triangular guiding patches on its corners. The dimensions of the guiding patches are 21mm, 18mm, 15mm, and 12mm, respectively. The patches' respective heights are 18.18mm, 15.59mm, 12.99mm, and 10.39mm.

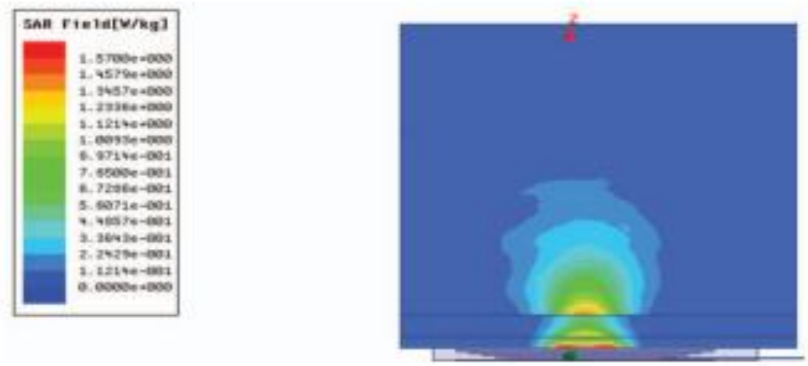


Figure 6: 1g-avg SAR distribution

B. Textile Antenna Design

Any textile that provides information about the wearer's physical status via an electronic system linked to it is considered intelligent. Smart garments, e-textiles, smart materials, garment tracking, and other terms are used to describe them. A textile antenna is used inside smart clothing to give wireless features such as detecting, identifying, processing, controlling, and so on without causing harm to the user. With the advent of fashion technology, the demand for a smart wearable antenna has recently increased. These textiles are typically vital to the growth of knowledge science, materials science, and other allied fusion technologies, in addition to keeping the original purpose of heat protection and attractiveness.

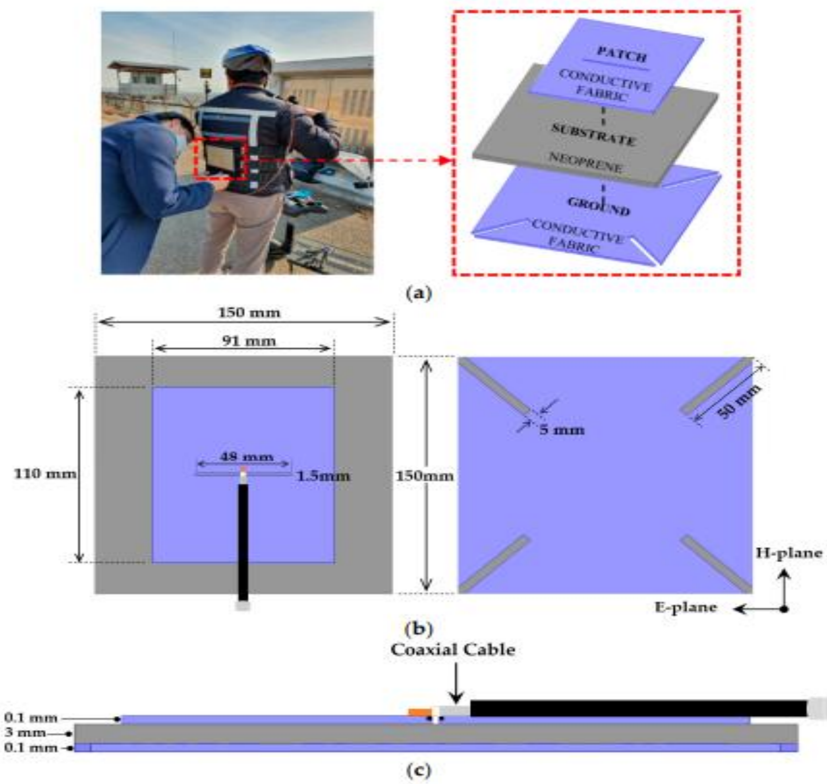


Fig.7. Geometry of proposed wearable antenna with cable placement
(a) left: textile antenna embed on vest/right: perspective view;
(b) top and bottom view; (c) side view.

Textile-based antenna performance is really challenging in terms of dielectric constant (ε_r), loss tangent (δ), and thickness (h) of the substrate materials, the high conductivity of the materials (σ), and the antenna in bending scenarios.

Textile antenna design necessitates an understanding of electromagnetic properties of the textile material, such as permittivity and loss tangent. Non-conductive textiles like as silk, felt, and fleece are frequently used as substrates, while conductive textiles such as Zelt, Flectron, and pure copper polyester taffeta fabrics are frequently utilized as radiating elements (Rais *et al.*, 2009)

The high-frequency connector required to feed the antennas is another challenge that wearable antenna technologies face. Even when the wearable antenna and cable are comprised of totally flexible materials, using a bulky stiff metallic connector on clothing is impracticable. Various textile-based wearable antennas have been investigated, but the majority of them rely on a hefty subminiature version A (SMA) connector, which is suitable for prototype testing but not for commercialization (Ibrahim *et al.*, 2021)

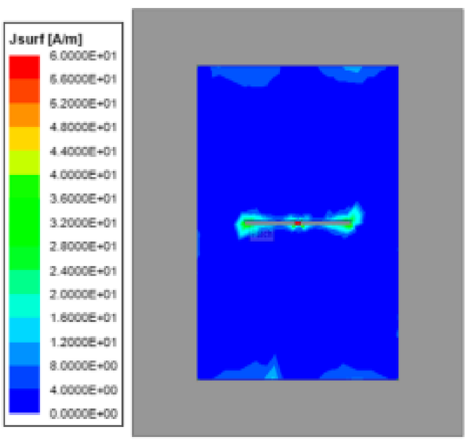


Figure 8.Simulated surface current density on the

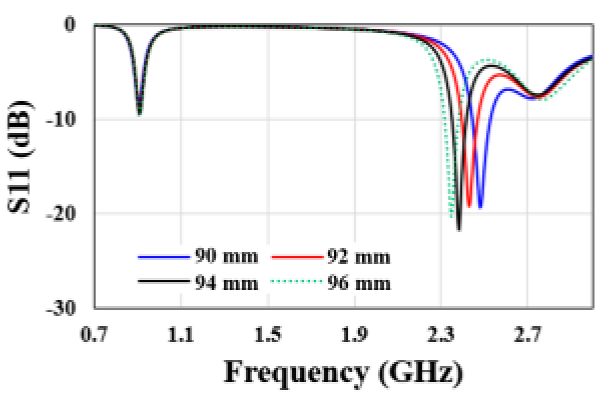


Figure 9: Simulated antenna's reflection coefficient antenna's radiating patch at 2.4 GHz (S11)

Ibrahim *et al.*, 2021 proposed a wearable antenna that is small and low-profile. For LoRa and BLE wireless communication, the suggested antenna feeding approach creates dual-band resonances at 868 MHz and 2.44 GHz. It also makes it easier to easily integrate wearable antennas into normal apparel without the inconvenience of metallic hookups. 854–886 MHz and 2.4–2.65 GHz are the measured S_{11} 10 dB impedance bandwidths, respectively. When the antenna is integrated into garments, there is minor drop in the S_{11} readings see Fig.7.For 854–886 MHz and 2.4–2.65 GHz the gain was 3.28dBi and 3.23dBi respectively. In comparison to the other choices, the proposed antenna is constructed on a flexible neoprene substrate and directly fed by a coaxial cable using the aperture-coupling approach, making it more viable as a wearable antenna. Neoprene has a relative permittivity (ε_r) of 1.95 and a loss tangent (tan δ) of 0.02, which are similar to felt, a popular substrate candidate for textile-based antennas. The simulated results of thi work is as shown in Fig 8,9.

Technique to reduce back radiation:

Increased high-frequency back radiation is a disadvantage of using the aperture-coupled feeding approach. Strong slot currents produce fringing fields that diffract at the ground's borders, resulting in a significant quantity of back radiation and lowering the antenna's front-to-back ratio (FBR). Four diagonal slots in the ground, as shown in Figure 1b, are used to alleviate this problem. The current induced at the ground edges is efficiently choked by these quarter-wavelength slots. As a result, not only is back radiation lowered, but the forward radiation is also improving.

C. Dielectric Resonator Antennas:

DRAs (dielectric resonator antennas) are attractive candidates to replace traditional radiating elements at high frequencies, particularly for millimeter-wave and beyond applications. This is mostly due to the fact that DRAs do not suffer from conduction losses and have a high radiation efficiency when suitably stimulated. Radiating resonators as shown in Fig.10 are used in DRAs to convert directed waves into unguided waves (RF signals). In the past, these antennas were mostly made out of ceramic materials with high permittivity and factor (between 20 and 2000). DRAs constructed of plastic (PolyVinyl Chloride (PVC)) are currently being developed. The problems of microstrip patch antennas were overcome using DRA **(Keyrouz and Caratelli 2016).**

The advantages of dielectric resonators antennas (DRAs) include their small size, excellent radiation efficiency, wide impedance bandwidth, and ease of system integration. Their shape adaptability and range of alternative feeding mechanisms allow for improved control of the results and also research to increase the impedance bandwidth (Iqbal, Esselle, and Ge 2013) DRA can be miniaturized if a high permittivity biocompatible dielectric material like as TiO2 or Al2O3 is used.

The cylindrical and rectangular radiating dielectric resonators are the most common. The relevant resonant frequencies are calculated using design equations. Spherical/hemispherical, cross-shaped, and supershaped dielectric resonators are more complex dielectric resonators (Keyrouz and Caratelli, 2016). The various radiating structures are shown in Fig.

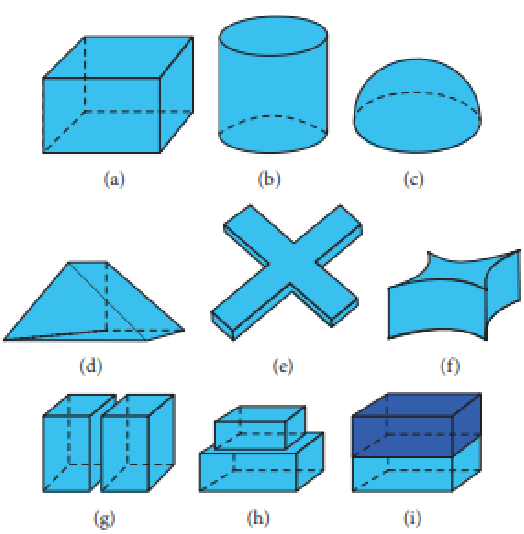


Fig.10 Different radiating structures of DRA

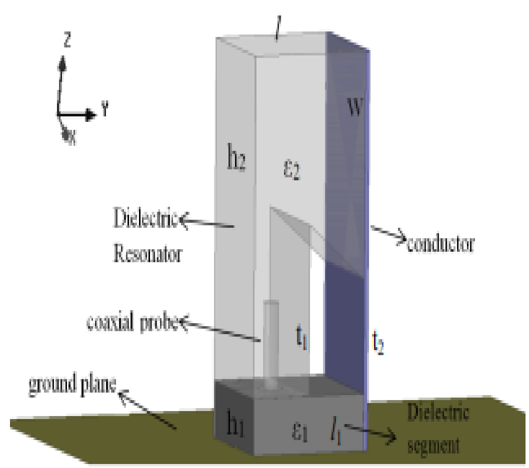
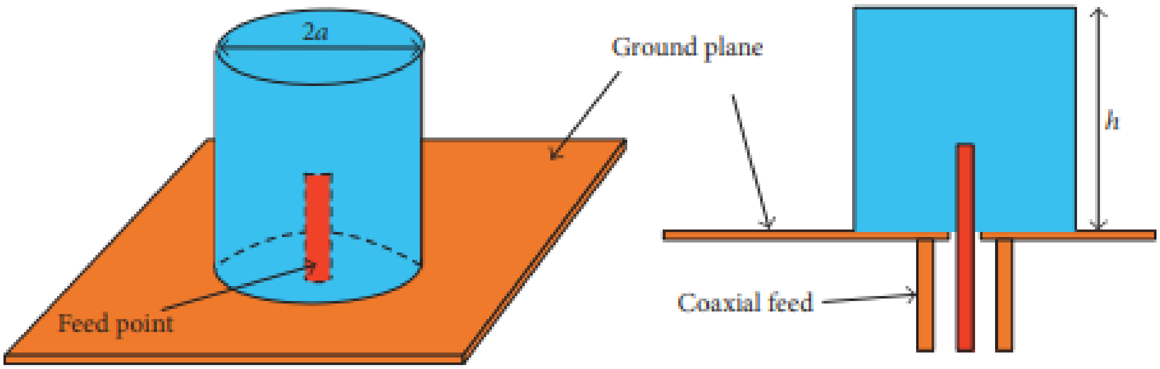


Fig.11.Proposed DRA Configuration (Iqbal, Esselle, and Ge 2013)



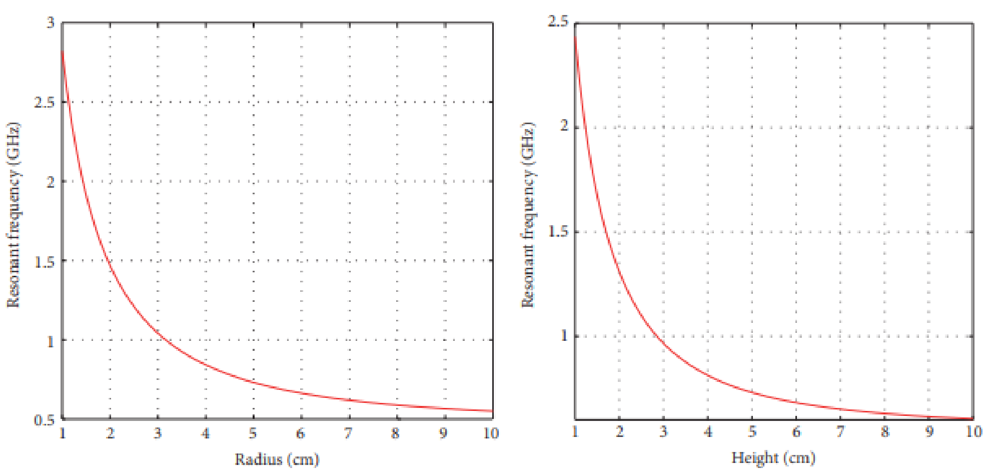
(a) (b)

Fig.12.a) Cross sectional View **Fig.12.b)the probe fed cylindrical DRA**

A cylindrical dielectric resonator (DR) with height h, radius a, and dielectric constant r makes up the antenna as shown in Fig 11,12,13. A coaxial link feeds the DR, which is mounted on top of a ground plane. The cylindrical DRA's key advantages are its ease of manufacture and capacity to excite several modes. The resonant frequency depends on the radius and height of the DRA as shown in Fig.13.The resonant frequency of the cylindrical DRA is calculated as follows,

$$f_{\mathrm{TE}_{npm}} = \frac{c}{2\pi\sqrt{\epsilon_r \mu_r}} \sqrt{\left(\frac{X_{np}}{a}\right)^2 + \left(\frac{(2m+1)\pi}{2h}\right)^2},$$

$$f_{\mathrm{TM}_{npm}} = \frac{c}{2\pi\sqrt{\epsilon_r \mu_r}} \sqrt{\left(\frac{X'_{np}}{a}\right)^2 + \left(\frac{(2m+1)\pi}{2h}\right)^2},$$



(a) (b)

Fig.13.Resonant frequency of DRA as a function of radius and height of the resonator

When the dielectric constant of the DRA is increased, the resonance frequency of the fundamental mode lowers. This is the most crucial feature of the DRA since it allows the DRA to reduce in size by raising its dielectric constant. It's worth noting that the DR's relative permittivity is inversely proportional to the impedance bandwidth.

To enhance the impedance bandwidth of DRAs, the fractal boundary structures are proposed as shown in Fig.14.

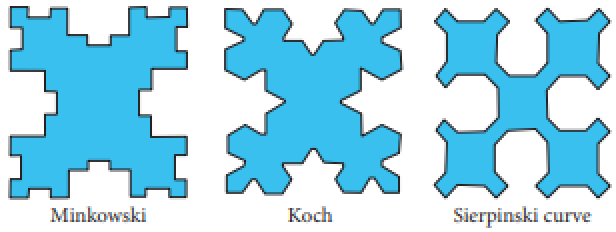
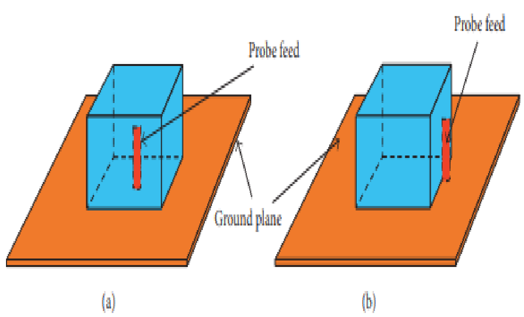


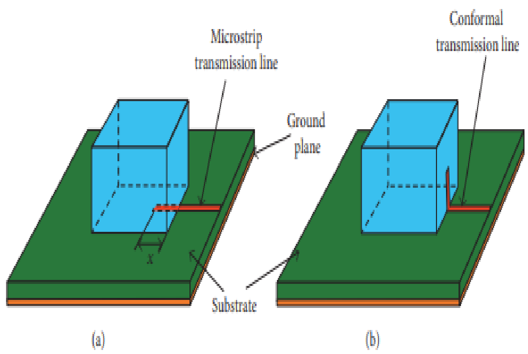
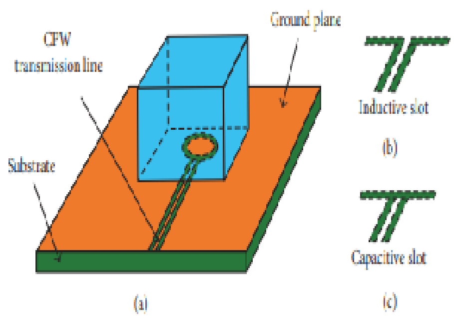
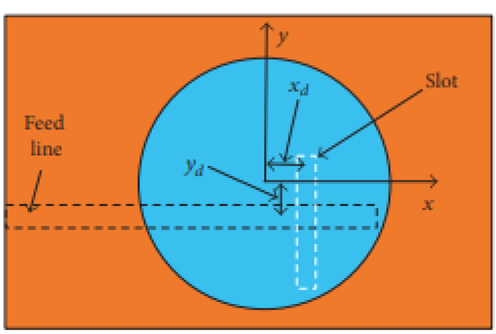
Figure 14: Different fractal boundary structures of DRA

A dielectric resonator antenna (DRA) with a tiny footprint for biomedical communication is proposed in (Iqbal *et al.*, 2013). The antenna is designed to work in Europe's lower ultrawideband (UWB) frequency band (3.4-5.0 GHz). The DRA geometry chosen, when combined with a reduced permittivity material, results in a smaller antenna with a wider impedance bandwidth. By removing the air zone from the Dielectric resonator (DR), the bandwidth is increased, and a high dielectric material is employed to make the design more compact. The suggested DRA has a predicted bandwidth of 74% between 3.4 and 7.2 GHz for S_{11} of -10 dB and has good radiation characteristics.

One of the most significant advantages of DRA technology is the ability to excite the radiating modes of a dielectric resonator using a variety of feeding approaches. Different feeding mechanisms have been applied to DRA as shown in Table 3.

Table 3: Comparison of Feeding Mechanisms of DRA

Feeding type	Advantages	Disadvantages
Probe -Fed DRA  	As a result of the high coupling to the DR, high radiation efficiency can be achieved.	In the DRA, a hole must be drilled. The length and radius of the drilled hole must match the length and radius of the probe, or the effective dielectric constant of the resonator will be changed, producing a shift in the antenna's resonance frequency. Drilling a hole in the DR complicates and increases the cost of the production process. This feed has an impact on the structure's radiation properties. Probe-fed DRAs are not practicable for high-frequency applications where the antenna is fabricated on a Printed

		Circuit Board (PCB) or is directly integrated on chip.
Microstrip Transmission Line-Fed DRA  	When x is slightly shorter than one-quarter of a dielectric wavelength of the resonance frequency, the strongest coupling occurs.	The feeding line is not isolated from the dielectric resonator, hence the DRA's radiation performance may be affected. When a dielectric resonator is placed directly on top of a transmission line, an unwanted air gap is generated between the resonator and the PCB substrate.
Coplanar-Waveguide-Fed DRA  	The main advantage of the CPW excitation is that the coupling slot that is underneath the dielectric resonator can be modified to optimize the performance of the DRA.	The inductive clot or the capacitive slot has to be properly selected for compactness and maximum radiation efficiency.
Slot-Fed DRA (aperture coupling)  	The direct electromagnetic connection between the feed line and the DRA is avoided with this feed. The feeding network's spurious radiation can be decreased, improving the DRA's polarisation purity.	At lower frequencies, the slot length should be roughly $\lambda/2$, which is difficult to achieve while keeping the DRA compact.

Many applications, particularly in consumer wireless, necessitate the integration of small antennas into small containers, such as cell phones, laptops, or other portable / wearable electronics. Dielectric resonator antennas can be made small by strategic application of metal plates in addition to using high dielectric constants to reduce size. Using a combination of metal loading and high dielectric substrates, more compact designs should be attainable.

Although this will result in a decrease in bandwidth, and it may be useful in narrowband applications. It's also worth noting that the size of the limited ground plane can have a big impact on the dielectric resonator antenna's radiation pattern, gain, and bandwidth (Petosa and Ittipiboon 2010)

A wearable DRA in the style of a wristwatch has been proposed and investigated for devices on limps as shown in Fig.15 (Boyuan et al. 2020). Truncating an annular dielectric block (ε_r=12.3, tan δ=0.00014) yielded the DRA. The substrate (ε_r=5.8, tan δ=0.0015) is comprised of ceramic material. The conformal strip and microstrip line were then printed on the substrate and DRA, respectively. The technology used was silk-screen printing with molecular silver paste. Epoxy adhesive (ε_r =3.6) was used to adhere the DRA to the substrate. An SMA connector was welded to the substrate edge for ease of measurement. The antenna operates at 2.5 GHz with simulated and measured gains of 5.15 and 4.6 dBi, respectively. A frequency variation of over 0.5 GHz is found when the device is worn on the human forearm and ankle. To aid in alignment and isolation, coplanar feeding strips have been used. Ground slots were created to compensate for the substrate impact in real-world circumstances where the substrate could not be constructed arbitrarily.

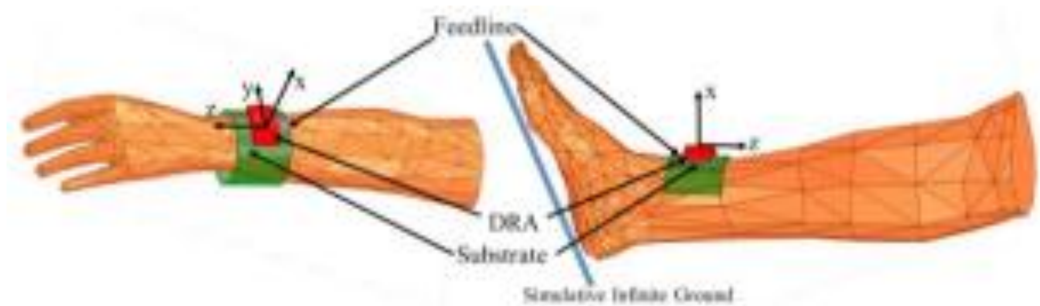


Fig. 15.Wearable DRA on limp phantom models (a) On forearm. (b) On ankle

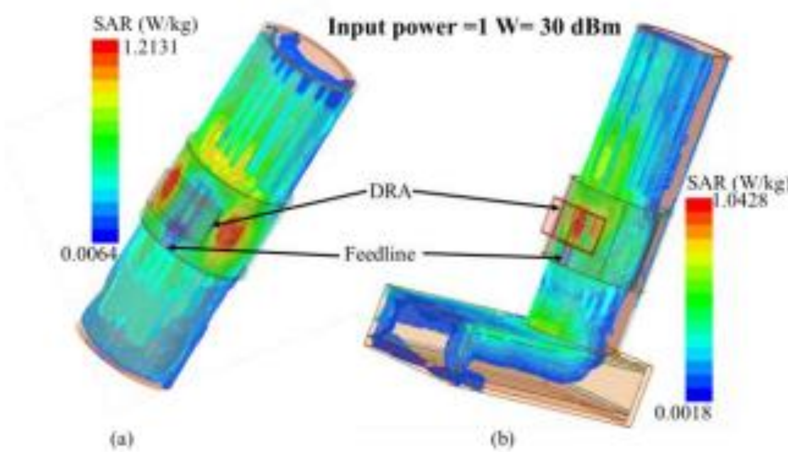


Fig.16. SAR from biological tissue models

a) Forearm in free space. (b) Ankle in free space

Even if the input power is 1 W, the average SAR over one-gram tissue remains below 1.6 W/kg as shown in Fig.16.Because of structural discontinuity, the highest SAR level arises towards the substrate's margins.

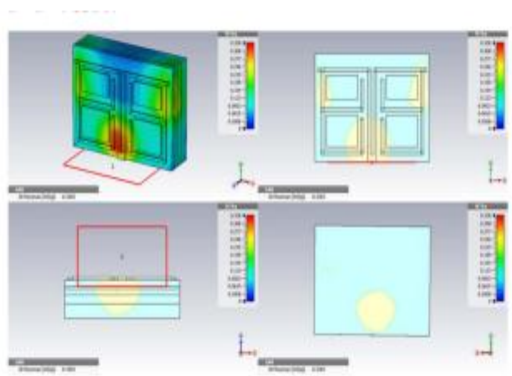
WEARABLE ANTENNA ANALYSIS

Return loss, radiation pattern, gain, and efficiency are the most common measures required for traditional antenna design. Conventional planar antennas, on the other hand, are flattened, therefore studying their bending characteristics isn't necessary. On the contrary, in order to ensure the antenna's effectiveness in a body-worn setting, other elements must be carefully considered. Other measurements that must be made when assessing a wearable antenna design will be included in this section.

A.SAR Modelling Analysis:

Engineers and researchers throughout the world have been asked to always consider the amount of power received by the human body due to public concern about the health impacts of radiation and regulatory obligations around the world. As a result, wireless devices' specific absorption rate (SAR) has been established.

IEEE 1.6W/kg for any 1g of tissue and ICNIRP (International Commission on Non-Ionizing Radiation Protection 2W/kg for any 10g of tissue are the two most often utilized SAR limits. (Rahaman and Hossain 2018) The SAR distribution of the human body is shown in fig.17.



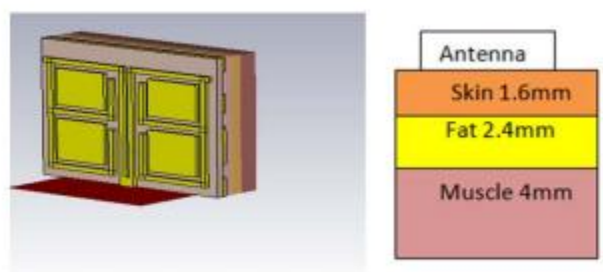


Fig.17. Distribution of SAR (Rahaman and Hossain 2018) **Fig. 18. Antenna with Phantom model**

To reduce SAR, the meta-surfaces with their unique qualities have proven effective in either absorbing energy in one direction or reflecting energy back in another to improve gain. In recent years, several attempts have been made to incorporate metasurface (MS) based structures such as artificial magnetic conductors, electromagnetic band gap structures, frequency selective surface (FSS), resonators, and some parasitic elements into flexible antennas to redirect this backward energy and reduce the SAR (Janapala *et al.*, 2019). The SAR modeling for the antenna proposed by Janapala et al. 2019 is as shown in fig.18.

B. Measurement with Bending:

Flexible wearable antenna measurements must be carried out in a variety of bending positions. This is to verify that the antenna's performance in real-world applications is up to pace, especially when it's attached to rounded body parts like an arm. S_{11} observations were performed in with various antenna bending conditions.

The resonance changed towards lower frequencies and the bandwidth shrank when bent, according to the research, regardless of the bending direction.

When assessing the bending, measurement trends are important. One way to get around this was to construct the antenna with a wide frequency spectrum. This ensures that even if the frequency shifts, the antenna can still work within the specified frequency range.

From literature survey, it is evident that the return loss when the antenna's H-plane and E plane were bent in Degrees were used to differentiate the bending circumstances. The antenna was flattened with a 0^0, while the H plane was bent into a V-shape at the centre of the microstrip antenna with a 90^0 bending. The antenna was bent, as indicated by a bending of 180^0.forming a U-shape The E plane of the antenna is subject to similar bending circumstances.

The antenna as shown in fig 19 is analyzed while bending along X-axis and Y-axis with a bending radius 40, 60, and 80 mm. In a flat situation, the antenna efficiency for both without MS and with MS is nearly identical, but it is altered by varied bending, off and on body conditions. The gain and directivity increased in opposite direction, due to that the front to back ratio for WMS is better than NMS case in all bending conditions in the case of (Janapala *et al.*, 2019) as shown in Fig.20.

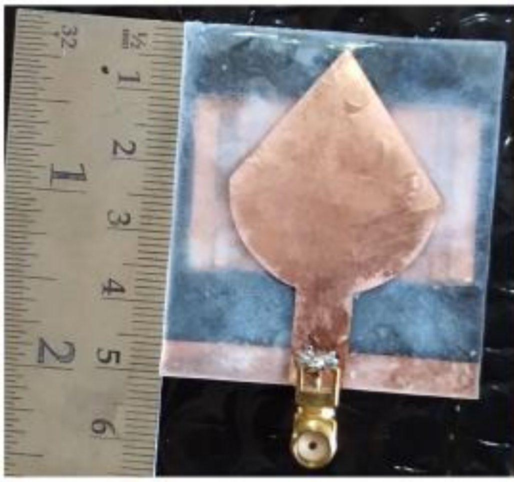


Figure 19. a) Fabricated meta surface Antenna **Figure 19.b) Bending test**

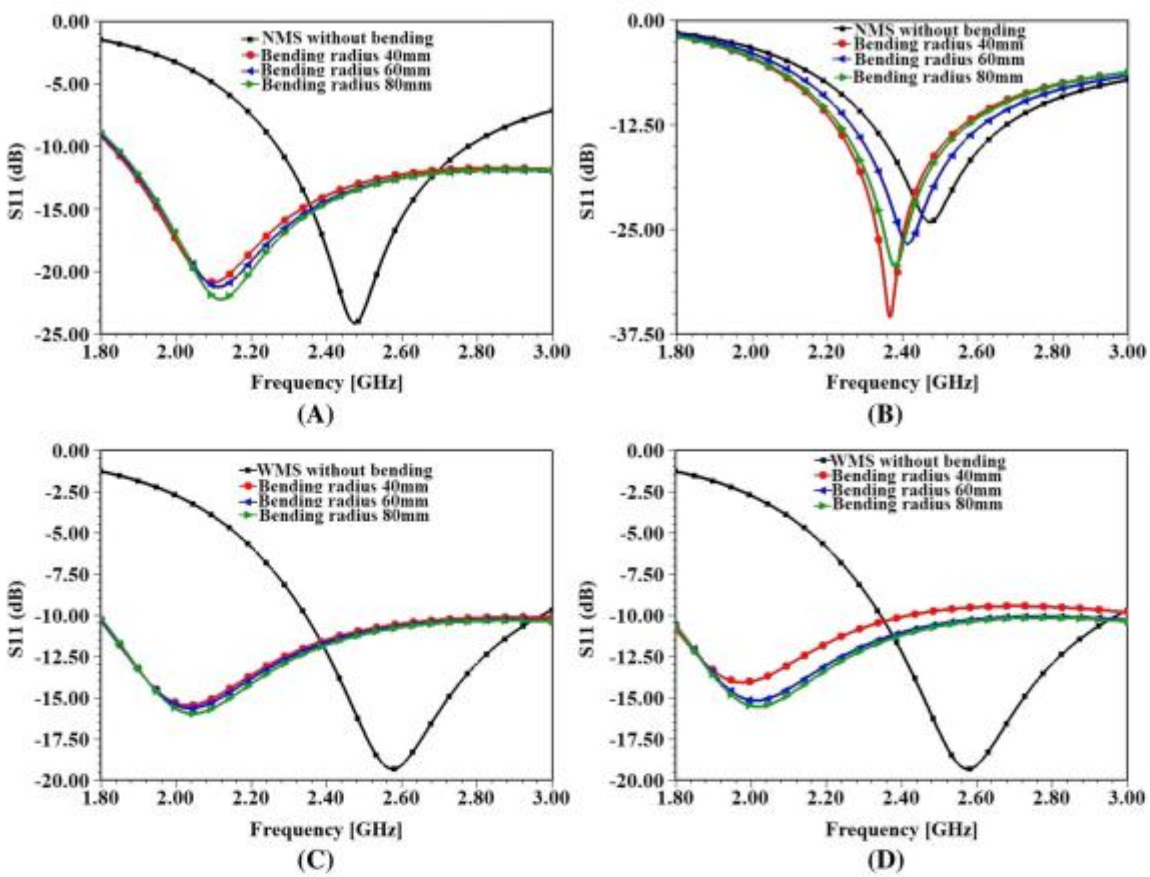


Figure 20 Simulated comparison of reflection coefficient S_{11} vs frequency curve for proposed antenna NMS and WMS cell before bending and after bending: A, NMS-bended along X-axis; B, NMS-bended along Y-axis; C, WMS-bended along X-axis; and D, WMS bended along Y-axis. NMS, without metasurface; WMS, with metasurface (Janapala *et al.*, 2019).

C. Onbody Measurements

In addition to stand-alone antenna tests, where the antenna was measured without the presence of a human body, onbody measurements must be performed to determine the antenna's performance in various on-body positions. Wearable antennas may have different positions depending on the antenna's application. Wearable antennas could be worn on the chest, arm, back, or other parts of the body as shown in fig.21.(Janapala et al. 2019) measured the manufactured antenna in free space, on a human chest, and on a human arm. Based on literature survey, it was discovered that the antenna on the back of the body, as indicated in fig 7, is the most effective.

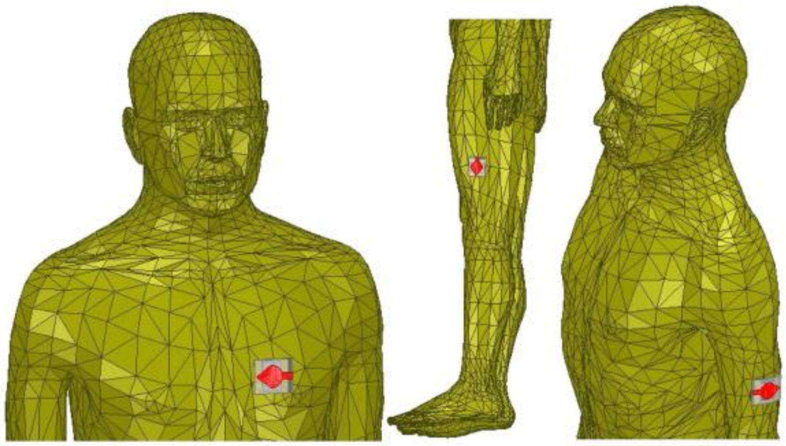


Figure 21: Position of the antenna on human phantom model

CONCLUSION

In comparison to a traditional antenna design, the review concludes that there are various additional considerations to consider when constructing a wearable antenna. While designing consideration should be given in the selection of substrates, as there are wide range of materials that might be used to design flexible wearable antennas. In order to obtain an antenna design that fits the wearable antenna standard, SAR analysis, measurements with varied antenna bending, and on body measurements must be performed. The antenna must be compact in size, so that it fits completely without any disturbance to the user. The design should be done carefully so that it covers the needed band and performance after being bent in various ways. There is still large of research scopes and development in the field of antennas used for wearable biomedical applications.

REFRENCES

1. Boyuan, Ma, Jin Pan, Enhao Wang, and Deqiang Yang. 2020. "Wristwatch-Style Wearable Dielectric Resonator Antennas for Applications on Limps." *IEEE Access* 8:59837–44. doi: 10.1109/ACCESS.2020.2983098.
2. Ibrahim, Nur Fatihah, Philip Ayiku Dzabletey, Hyoungsoo Kim, and Jae Young Chung. 2021. "An All-Textile Dual-Band Antenna for Ble and Lora Wireless Communications." *Electronics (Switzerland)* 10(23). doi: 10.3390/electronics10232967.
3. Iqbal, Mian Shahzad, Karu P. Esselle, and Yuehe Ge. 2013. "Miniaturization of Dielectric Resonator Antenna for Biomedical Communication." *IEEE Antennas and Propagation Society, AP-S*

International Symposium (Digest) 1904–5. doi: 10.1109/APS.2013.6711610.

4. Janapala, Doondi Kumar, M. Nesasudha, T. Mary Neebha, and Raj Kumar. 2019. "Specific Absorption Rate Reduction Using Metasurface Unit Cell for Flexible Polydimethylsiloxane Antenna for 2.4 GHz Wearable Applications." *International Journal of RF and Microwave Computer-Aided Engineering* 29(9):1–12. doi: 10.1002/mmce.21835.
5. Keyrouz, S., and D. Caratelli. 2016. "Dielectric Resonator Antennas: Basic Concepts, Design Guidelines, and Recent Developments at Millimeter-Wave Frequencies." *International Journal of Antennas and Propagation* 2016. doi: 10.1155/2016/6075680.
6. Kumar, Avinash, Ritesh Kumar Badhai, and Priyadarshi Suraj. 2018. "Design of a Printed Symmetrical CPW-Fed Monopole Antenna for on-Body Medical Diagnosis Applications." *Journal of Computational Electronics* 17(4):1741–47. doi: 10.1007/s10825-018-1233-6.
7. Petosa, Aldo, and Apisak Ittipiboon. 2010. "Dielectric Resonator Antennas: A Historical Review and the Current State of the Art." *IEEE Antennas and Propagation Magazine* 52(5):91–116. doi: 10.1109/MAP.2010.5687510.
8. Rahaman, Mohammad Anisur, and Quazi Delwar Hossain. 2019. "Design and Overall Performance Analysis of an Open End Slot Feed Miniature Microstrip Antenna for On-Body Biomedical Applications." *1st International Conference on Robotics, Electrical and Signal Processing Techniques, ICREST 2019* 200–204. doi: 10.1109/ICREST.2019.8644334.
9. Rahaman, Mohammad Anisur, and Quazi Delwar Hossain. 2018. "Design of a Miniature Microstrip Wide Band Antenna for On-Body Biomedical Telemetry." *Proceedings of the International Conference on Smart Systems and Inventive Technology, ICSSIT 2018* (Icssit):141–44. doi: 10.1109/ICSSIT.2018.8748503.
10. Rais, N. H. M., P. J. Soh, F. Malek, S. Ahmad, N. B. M. Hashim, and P. S. Hall. 2009. "Internet Search: A Review of Wearable Antenna." *Loughborough Antennas and Propagation Conference, LAPC 2009 - Conference Proceedings* (November):225–28.
11. Sakib, Nazmus, Siti Noorjannah Ibrahim, Muhammad Ibn Ibrahimy, Md Shazzadul Islam, and M. M. Hasa. Mahfuz. 2020. "Design of Microstrip Patch Antenna on Rubber Substrate with DGS for WBAN Applications." *2020 IEEE Region 10 Symposium, TENSYMP 2020* (June):1050–53. doi: 10.1109/TENSYMP50017.2020.9230707.
12. Shawkey, Heba, and Dalia Elsheakh. 2020. "Multiband Dual-Meander Line Antenna for Body-Centric Networks' Biomedical Applications by Using Umc 180 Nm." *Electronics (Switzerland)* 9(9):1–11. doi: 10.3390/electronics9091350.
13. Shubair, Raed M., Amna M. Alshamsi, Kinda Khalaf, and Asimina Kiourti. 2015. "Novel Miniature Wearable Microstrip Antennas for ISM-Band Biomedical Telemetry." *2015 Loughborough Antennas and Propagation Conference, LAPC 2015* (April 2018). doi: 10.1109/LAPC.2015.7366008.
14. Smida, amor, amjad Iqbal, abdullah J. alazemi, Mohamed I. Waly, Ridha Ghayoula, and Sunghwan Kim. 2020. "Wideband Wearable Antenna for Biomedical Telemetry Applications." *IEEE Access* 8. doi: 10.1109/aCCESS.2020.2967413.
15. Sukhija, Shikha, and R. K. Sarin. 2017. "Design and Performance of Two-Sleeve Low Profile Antenna for Bio-Medical Applications." *Journal of Electrical Systems and Information Technology* 4(1):49–61. doi: 10.1016/j.jesit.2016.10.013.
16. https://www.scnsoft.com/healthcare/medical-devices/wearable