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Flexible and Wearable Antenna Design for Bluetooth and Wi-Fi Application

Gaurav Kumar Soni[1], **Dinesh Yadav**[2], **and Ashok Kumar**[3]

[1]Department of Electronics and Communication Engineering, Manipal University Jaipur, Jaipur, Rajasthan, India, gksoni2709@gmail.com
[2]Department of Electronics and Communication Engineering, Manipal University Jaipur, Jaipur, Rajasthan, India, dinesh.yadav@jaipur.manipal.edu
[3]Department of Electronics and Communication Engineering, Government Mahila Engineering College, Ajmer, Rajasthan, India, kumarashoksaini@gmail.com

***Correspondence:** Dinesh Yadav (dinesh.yadav@jaipur.manipal.edu)

ABSTRACT- The emergence of wearable technology has revolutionized the way we interact with electronic devices, integrating them into our daily routines. From fitness trackers, smart watches to augmented reality glasses and medical monitoring devices, wearable have become increasingly prevalent. Among the most commonly employed wireless technologies within wearables are Bluetooth and Wi-Fi. The design of efficient and reliable antennas for Bluetooth and Wi-Fi applications in wearable is of paramount importance to ensure optimal performance and user satisfaction. In this paper presented a flexible and wearable antenna design for Bluetooth and Wi-Fi application utilizing the Rogers RT5880 flexible substrate, characterized by a dielectric constant of 2.2 and a thickness of 20mil. The study delves into various analyses of the antenna, including its performance concerning on-body and off-body communication, along with an exploration of the antenna's response to different bending effects. Moreover, the research investigates how the antenna interacts with a human tissue model, providing insights into its behavior and performance in diverse usage scenarios.

Keywords: Flexible, Wearable, On Body, Off Body, Wi-Fi, Bluetooth, SAR(1g), SAR(10g), Farfield Directivity, Return Loss, Human Body Tissue Model.

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1. INTRODUCTION

Antennas for Bluetooth and Wi-Fi applications are essential components that enable wireless communication between devices, facilitating data transfer and connectivity. These antennas come in various forms and designs, each tailored to meet the specific requirements of Bluetooth and Wi-Fi technology in different devices and use cases [1-2]. Wearable technology has become an integral part of our daily lives, revolutionizing the way we interact with devices and data [3]. From smartwatches and fitness trackers to medical devices and virtual reality headsets, wearables have brought unprecedented convenience and functionality to users [4]. Central to the successful operation of many wearables is the integration of wireless communication capabilities, with Bluetooth and Wi-Fi being two of the most widely adopted wireless technologies [5]. The design of efficient and reliable wearable antennas for Bluetooth and Wi-Fi applications is crucial to ensure seamless connectivity and superior user experience [6-7]. In the wireless communication Bluetooth frequency band is between 2.4 GHz and 2.483 GHz and WiFi communication works on the 2.4GHz frequency ranges [8]. Various application of wearable technology is shown in the *figure 1* [9].

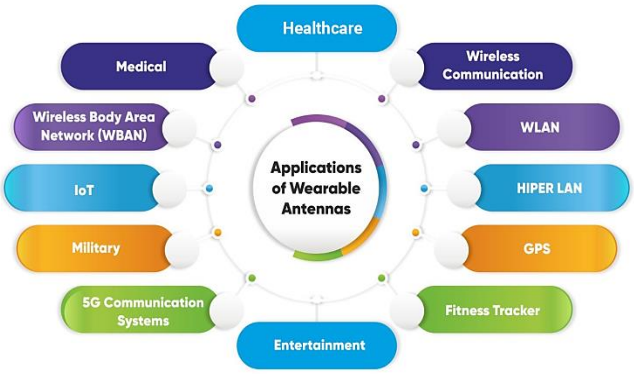

Figure 1: Various application of wearable technology [9]

Revolutionizing antenna technology, flexible and wearable antennas are designed to conform and adapt to diverse shapes and surfaces, seamlessly integrating into flexible devices like smart clothing, fitness trackers, medical wearables, and beyond. Their adaptable nature enables comfortable attachment to curved or irregular surfaces while ensuring dependable wireless communication. Crucial for wearable tech advancement, these antennas facilitate uninterrupted connectivity without sacrificing device comfort or aesthetics.

The design of Bluetooth and Wi-Fi antennas for wearables involves careful consideration of factors like form factor, radiation pattern, efficiency, gain, and impedance matching [10]. The antenna's performance can significantly impact the overall wireless connectivity and user experience of the device. Engineers and designers must strike a balance between antenna performance and the constraints imposed by the wearable's size, shape, and closeness to the human body [11].

The evolution of flexible and wearable antenna designs has revolutionized wireless technology, meeting the specific requirements of Bluetooth and WiFi applications within wearable devices. Engineered to seamlessly conform to flexible substrates and mold to the shapes of wearable gadgets, these antennas bring exceptional versatility and functionality to the forefront.

As technology continues to advance, so will the design and implementation of antennas for Bluetooth and Wi-Fi applications in wearables. Researchers and engineers continually explore innovative solutions to improve wireless connectivity, making wearable's more seamless, efficient, and integral to our daily lives.

The advantages of a flexible and wearable antenna design designed for Bluetooth and Wi-Fi applications include:

Adaptability: Its capability to conform and integrate with wearable devices or flexible structures allows for versatile applications in various forms.

Mobility: Due to its flexible nature, it facilitates easy movement, ensuring unobtrusive and comfortable user experiences.

Wireless Connectivity: Despite being embedded in wearable devices or flexible surfaces; it enables seamless connections to Bluetooth and Wi-Fi networks without compromising performance.

Versatility: Its wearable and flexible attributes allow for multiple applications in diverse scenarios, expanding its range of potential uses.

Reliable Performance: Maintains consistent signal strength and connectivity despite its flexibility, ensuring dependable wireless performance.

In the ever-changing landscape of wireless communication, the need for flexible and wearable antennas is crucial, especially in applications such as Wi-Fi and Bluetooth. This paper introduces the design of an antenna tailored for the 2.4GHz band, specifically intended for Bluetooth and Wi-Fi applications. The 2.4GHz band is extensively utilized in wearable devices and various wireless technologies, serving as a widely adopted ISM band. Its frequency range extends from 2.4GHz to 2.4835GHz.

2. ANTENNA DESIGN & ITS PARAMETERS

The flexible and wearable antenna introduced in this study is designed using the Rogers RT5880 substrate, featuring a dielectric constant of 2.2, a thickness of 20 mil, and a thermal conductivity of 0.2W/K/m. The presented wearable microstrip patch antenna front view design consists of inset feed with circle shape slot cut that is shown in the *figure 2* and the back view is fully ground. The size of presented antenna is L×W×h. The designing parameters of the presented flexible and wearable antenna is described in *table 1*.

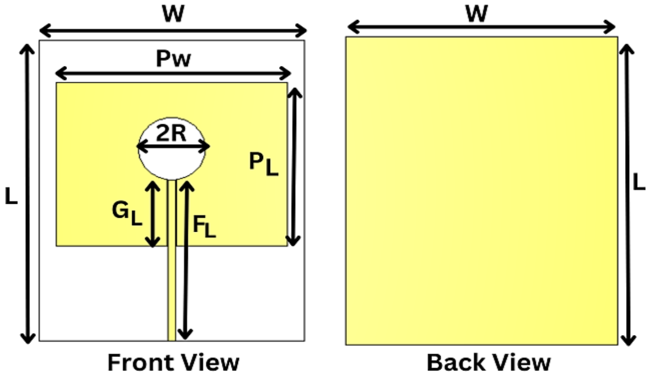

Figure 2: Presented flexible and wearable antenna

Table 1: Parameters Used in Presented flexible and wearable antenna design

Parameters	Values (mm)
Subtract Width (W)	55
Subtract Length (L)	65
Thickness of Subtract (h)	0.508
Thickness of Copper	0.035
Patch Length (P_L)	37
Patch Width (P_W)	48
Feed Length (F_L)	21.23
Feed Width	1.5
Insert Feed Length (G_L)	15
Insert Feed Width	0.2
Circle Radius (R)	8

The analysis of the presented antenna for Bluetooth and Wi-Fi applications, both on-body and off-body, is conducted using a four-layer human tissue model illustrated in *figure 3*. The properties employed in designing this comprehensive human tissue model are outlined in *table 2*, encompassing skin, bone, fat, and muscle layers.

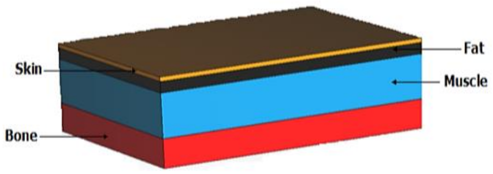

Figure 3. Model of Human Body Tissues with Four Layers

Table 2: Characteristics of the Employed Human Tissue Model [3, 9]

Human Tissue	Relative Permittivity (ϵ_r)	Conductivity σ (S/m)	Thickness (mm)
Skin	37.88	1.44	2
Fat	5.28	0.1	5
Muscle	52.73	1.74	20
Bone	11.4	0.39	13

3. RESULTS AND DISCUSSION

The operating frequency of the presented flexible and wearable antenna is 2.413GHz that is used for the 2.4GHz band. The 2.4GHz band is also known as ISM band. The 2.4GHz frequency band is used in Wi-Fi and Bluetooth both. So, the presented antenna is work for both the application.

In the field of designing flexible and wearable antennas for Bluetooth and Wi-Fi applications, giving thoughtful attention to return loss is essential. Return loss plays a pivotal role as a key metric for evaluating the performance and efficacy of antennas, offering insights into the extent of power reflected back caused by impedance mismatches. In *figure 4* shown S11 of presented antenna that is obtained from simulation is -28.53dB at 2.413GHz.

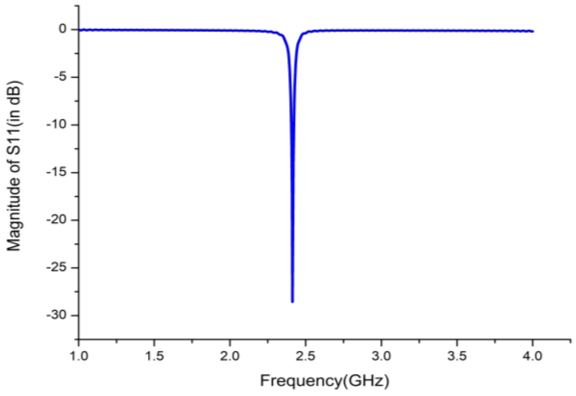

Figure 4: Obtained return loss of presented antenna from simulation

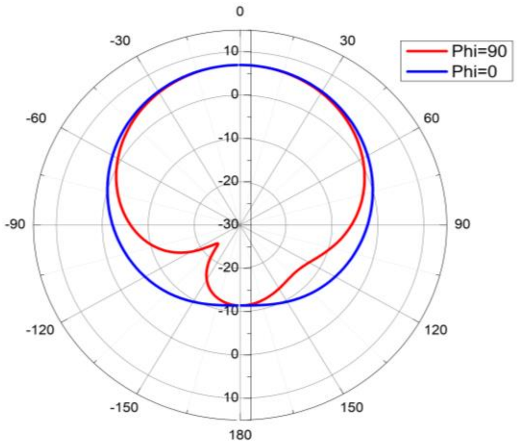

Figure 5: Farfield Directivity gain of the presented antenna

Farfield Directivity Gain plays a crucial role in the domain of flexible and wearable antenna design, particularly within applications like Bluetooth and Wi-Fi. This metric takes a central position, offering valuable insights into how effectively the antenna can focus and steer its radiation pattern. This study explores the significance of integrating Farfield Directivity Gain as a key parameter in antenna design, with the goal of improving performance and maximizing signal coverage in the dynamic and ergonomic environment of wearable devices. Through an in-depth exploration of this metric, the research contributes valuable insights to the progression of antenna design methodologies, addressing the evolving requirements of contemporary communication technologies. In *figure 5* display the Farfield Directivity gain that is 6.95dBi.

To use the presented antenna for wearable application it is also need to band the antenna. In *figure 6 (a)* to *figure 6(e)* shown that the different banding condition of the antenna at different radius (R). In *figure 6(a)* shown the banding of the antenna at the radius of 10mm, in *figure 6(b)* shown that the banding of presented antenna at the radius of 15mm, In *figure 6(c)* shown the banding of the antenna at the radius of 20mm, In *figure 6(d)* shown the banding of the antenna at the radius of 25mm and In *figure 6(e)* shown the banding of the antenna at the radius of 30mm.

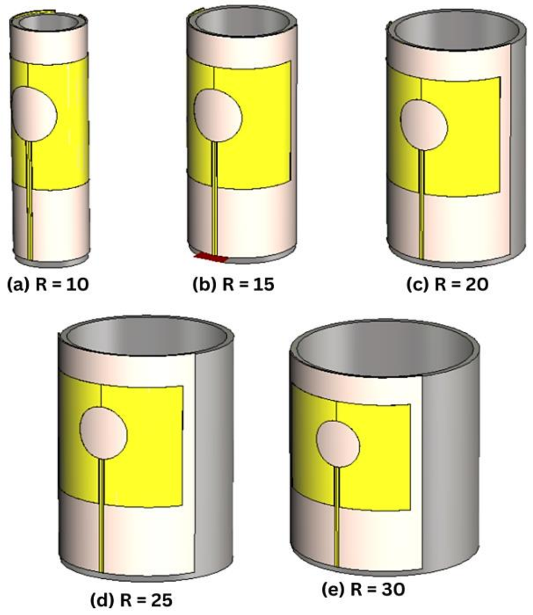
(a) R = 10
(b) R = 15
(c) R = 20
(d) R = 25
(e) R = 30

Figure 6: Banding of antenna at different radius (R), (a) banding at R=10mm, (b) banding at R=15mm, (c) banding at R=20mm, (d) banding at R=25mm and (e) banding at R=30mm

The return loss of the presented antenna from without banding state to the different banding state have done at different radius (R) is shown in the *figure 7*. At without banding the antenna obtained the return loss (S11) is -28.53dB at 2.413GHz, banding the antenna at radius (R) of 10mm the obtained return loss (S11) is -8.08dB, banding the antenna at radius (R) of 15mm the obtained return loss (S11) is -16.13dB, banding the antenna at radius (R) of 20mm the obtained return loss (S11) is -21.63dB, banding the antenna at radius (R) of

25mm the obtained return loss (S11) is -22.17dB and banding the antenna at radius (R) of 30mm the obtained return loss (S11) is -24.75dB.

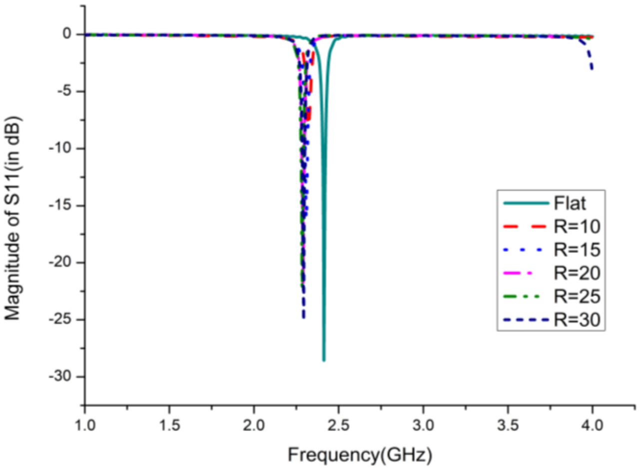

Figure 7: Return loss (S11) of the presented for without banding (Flat) to the different banding of antenna at different radius (R), R=10mm to 30mm

In *figure 8* display the Farfield Directivity gain of presented antenna at different bandings and without banding. In *figure 8(a)* its display 6.95dBi without any band of the antenna. In *figure 8(b)* to *figure 8(f)* shown the Farfield Directivity gain of the presented antenna at banding of antenna at radius (R) = 10 mm to the R=30mm and obtained the Farfield Directivity gain of 3.25dBi at R=10mm, 5.33dBi at R=15mm, 5.43 dBi at R=20mm, 5.82 dBi at R=25mm, 6.68dBi at R=30mm respectively.

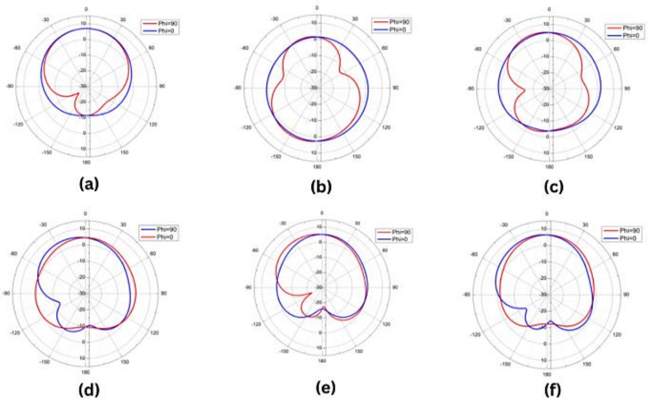

Figure 8: Far-field Directivity gain of the presented antenna for different banding at different radius (R), (a) No band (b) R=10mm, (c) R=15mm, (d) R=20mm, (e) R=25mm and (f) R=30mm

Human body tissue model simulation analysis is conducted for wearable antennas helps in evaluating performance, ensuring safety and SAR (Specific Absorption Rate) compliance, and enhancing antenna designs for optimal performance near the human body. In *figure 9*, the antenna is depicted alongside a human tissue model, positioned at different intervals from 0 to 20mm.

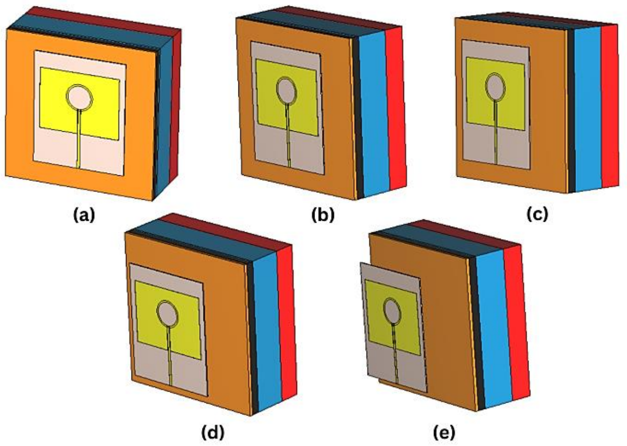

Figure 9: Depicting the antenna adjacent to the human tissue model at different intervals labeled as (a) D = 0mm, (b) D = 5mm, (c) D = 10mm, (d) D = 15mm, and (e) D = 20mm

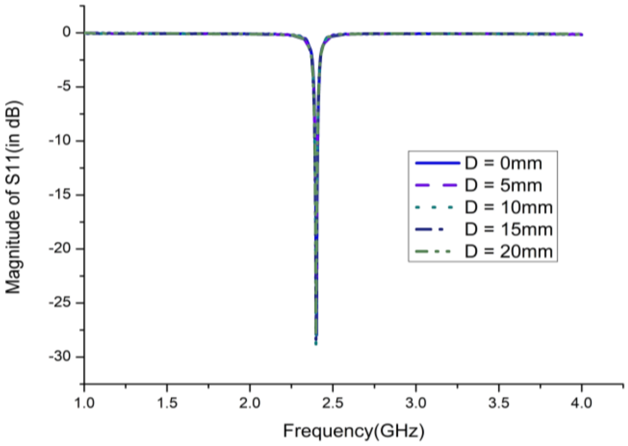

Figure 10: The antenna's return loss is analyzed concerning a human tissue model at varied intervals identified as D=0mm to D=20mm

In *figure 10* display the obtained simulation return loss (S11) at distance (D) = 0mm for on body is -27.73dB, at distance (D) = 5mm is -26.6dB, at distance (D) = 10mm is -28.7dB, at distance (D) = 15mm is -28.45dB and at distance (D) = 20mm is -27.89dB.

Far-field directivity gain serves as a metric for assessing an antenna's directional performance within its radiation pattern's far-field region. It signifies the antenna's capacity to concentrate emitted or received radiation toward a particular direction when compared to an ideal isotropic radiator. This parameter holds significant importance in antenna design and evaluation, providing engineers and designers with insights into an antenna's efficiency in directing radiation. Such understanding proves valuable in applications where precise directional coverage or reception is fundamental. In *figure 11(a)* to *figure 11(e)* display the simulated Farfield directivity of antenna alongside the human tissue model positioned at various distances for on body (distance (D) = 0mm) and off body (distance (D) = 5mm to 20mm) communication. The obtained Farfield directivity gain is (a) 6.87dBi at distance (D) of 0mm for on body, (b) 7.16dBi at distance (D) of 5mm, (c) 7.28dBi at distance (D) of 10mm, (d) 7.38dBi at distance (D) of 15mm and (e) 7.42dBi at distance (D) of 20mm. As the separation between antenna and human body tissue model extends within the far-field range, there is a corresponding rise in the directivity gain.

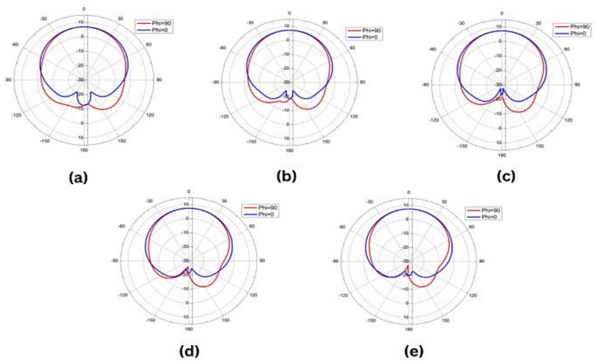
(a) (b) (c) (d) (e)

Figure 11: The far-field directivity gains with the human tissue model at various distances, shown as (a) D=0mm, (b) D=5mm, (c) D=10mm, (d) D=15mm, and (e) D=20mm

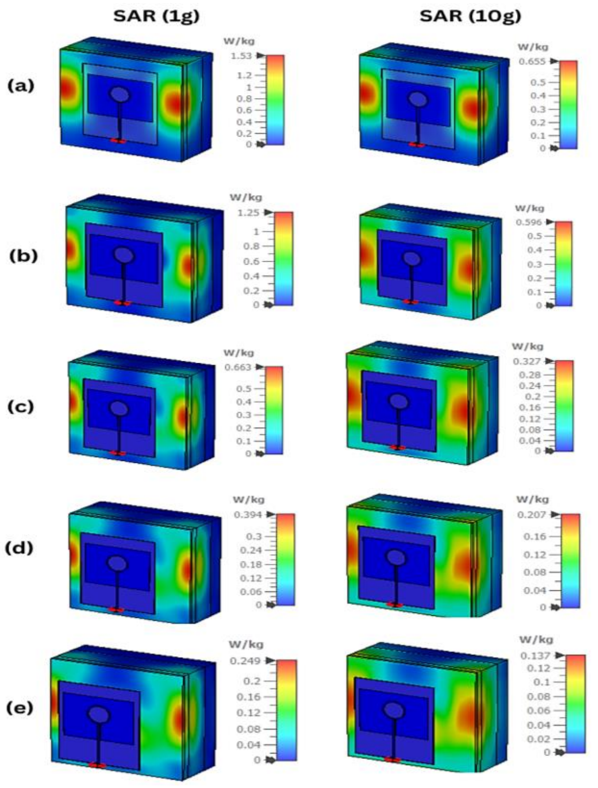

Figure 12: SAR for both 1g and 10g masses using the antenna with a human tissue model at various distances denoted as (a) D = 0mm, (b) D = 5mm, (c) D = 10mm, (d) D = 15mm, and (e) D = 20mm

The SAR quantifies the rate at which the human body absorbs energy when subjected to electromagnetic fields, typically emitted by devices such as mobile phones, wireless routers, or other wireless communication devices. It is utilized to evaluate the potential health implications linked to the absorption of electromagnetic energy by bodily tissues from exposure to radiofrequency (RF) electromagnetic fields. SAR values hold significant importance in ensuring compliance with regulations for devices emitting electromagnetic radiation. Manufacturers are obliged to disclose SAR data for their devices to ensure adherence to safety standards and guidelines established by regulatory bodies. This disclosure aims to minimize potential health risks associated with exposure to RF radiation. The standard value of SAR(1g) is 1.6W/kg, while SAR(10g) stands at 2W/kg for simultaneous transmission across various frequencies. In *figure 12(a)* to *figure 12(e)* shown the SAR obtained value of the presented antenna at varying distances ranging from 0mm to 20mm between the antenna and human tissue model.

4. CONCLUSION

Wearable devices commonly employ both Wi-Fi and Bluetooth technologies, utilizing the specified frequency bands to establish connections with other devices and networks. These frequencies are selected to achieve an optimal balance between data transfer rates, range capabilities, and power efficiency, making them well-suited for various wearable applications. This paper introduces the design of a 2.4 GHz band antenna tailored for Bluetooth and Wi-Fi applications, leveraging the widely adopted ISM band prevalent in wearable devices and various wireless technologies. The frequency range of interest spans from 2.4GHz to 2.4835GHz. The antenna presented in this study is specifically crafted for Bluetooth and Wi-Fi applications. The antenna's dimensions are 65×55×0.508mm³. The paper includes various simulation analyses, such as return loss, far-field directivity gain, SAR(1g) and SAR(10g), bending effect etc., for both on-body and off-body communication. In on-body communication, the antenna is positioned directly on the surface of a human body tissue model at a distance of 0mm. For off-body communication, the distance between the antenna and the human body tissue model is increased. This study successfully achieved remarkably low SAR values, both for SAR (1g) and SAR (10g), in both on-body and off-body communication.

The obtained result of this presented work is summarized in *table 3* and also compared it with previous related work done by the different authors.

Table 3: Comparative analysis of this work with previous related work

Ref No., Publication Year	**Frequency (GHz)**	**Reflection Coefficient (dB)**	**SAR (Kg/m^3)**	**Gain (dBi)**	**Size (mm^3)**
[12], 2023	2.4 5.8	-15 -29	0.955 0.478	3.47 5.13	41×44×1.52
[13], 2023	2.45	-23	0.759	5.19	20×40×2
[14], 2020	2.45 5.8	-20 -18	0.042 0.09	5.93 6.33	100×100×2
[15], 2019	2.45 5.8	-24.6 -23.9	1.67 1.12	1.69 4.12	50×50×0.076
[16], 2018	2.4	23	0.364	6.5	48×36×3.27
[17], 2017	2.4	-15	0.29	5.2	50×50×5.5
This Work	**2.413**	**-28.53**	**0.137**	**6.95**	**65×55×0.508**

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