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RESEARCH ARTICLE

Design of a Dual-band Wearable Antenna Operating at 2.45 GHz and 5.8 GHz for Medical Communication Applications

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Abstract

The natural demographic of Indonesia consisting of 16,771 islands is significantly posing several challenges in infrastructure development, particularly in the health sector. Currently, the unequal distribution of 124,449 medical personnel in the country, with approximately 61.12% located in Java and Bali, shows the need for technology to extend medical services nationwide. To address this problem, The promising technology known as Wireless Body Area Network (WBAN) transmits data using a wearable antenna as a means of transmission to facilitate telemedicine. Therefore, the goal of this study was to create a wearable, small, dual-band antenna with ISM frequencies of 2.45 GHz and 5.8 GHz. A combination of rectangular shape radiating structure and cross slot was constructed to achieve dual-band frequency. The material used to construct the suggested antenna, which measured 52.3 mm by 58.69 mm and had a conductivity of 1.7, was Jeans Textile, with a 1 mm thickness. Subsequently, simulation was carried out with and without human body phantom using CST software. The antenna resonated at 2.45 GHz as well as 5.8 GHz, with peak gain of 2.74 dBi as well as 1.98 dBi, according to the results. The wrist phantom simulation yielded Specific Absorption Rate (SAR) levels of 0.326 W/kg and 1.024W/kg. Its values of 0.554 W/kg as well as 0.394 W/kg from modelling at the chest phantom, on the other hand, indicate that the suggested wearable antenna is appropriate for telemedical services.

Keywords: Telemedicine, Wireless Body Area Network (WBAN), Wearable Antenna, Dual- band antenna, ISM band, Specific Absorption Rate (SAR)

1. Introduction

Indonesia is an archipelagic country with 16,771 islands according to the Ministry of Marine Affairs and Fisheries, stretching from Sabang to Merauke [1]. This demographic situation poses several challenges in developing infrastructure, particularly in the health sector. According to the Ministry of Health [2], Indonesia currently has 10,203 Puskesmas (Community Health Centers) and 2449 Hospitals which spread from Aceh to Papua. However, only the provinces of DKI Jakarta and Bali have more than one health facility in each sub-district. Regarding medical personnel, the country has 124,449 individuals, consisting of 67,916 doctors, 38,400 specialist doctors, 15,588 dentists, and 2,545 specialist dentists. Among these medical personnel, 61.12% are concentrated in Java and Bali, while the remaining 38.88% are spread across Sumatra to Papua [2]. This inequality distribution shows the need for technology that facilitates adequate provision of medical services to patients.

Wireless technology is developing rapidly, with telemedicine being the popular application. In particular, telemedicine refers to the utilization of ICT in conjunction with medical knowledge to deliver health services including diagnosis, treatment, and consultations without regard to location or distance [3]. Considering that Indonesia is an archipelagic country with unequal distribution of medical personnel and limited health facilities in remote areas, telemedicine can be used to improve public health services. Within this framework, telemedical services can be supported by Wireless Body Area Network (WBAN), a promising technology.

WBAN is a wearable and implantable wireless communication network on the human body that is used by doctors, medical personnel, or patient families to monitor real-time health status [4]. Additionally, this technology uses both on-body including off-body chip sensors to collect information on cardiovascular activity, pressure, respiration, levels of glucose, temperature within the body, as well as Electrocardiogram (ECG) waveform signals [5]. In order to transmit data through an antenna of transmission and then have it received by a receiving device, chip sensors are additionally affixed to the bodies of patients. To guarantee user comfort, the so- called wearable antenna needs to be lightweight and flexible.

A wearable antenna is an antenna with a microstrip that is designed to be worn on the skin or worn on clothing. It has several benefits, including being lightweight, compact, easy to manufacture, and reasonably priced. Furthermore, it works over a wide frequency range [6] and due of the elastic substance used to make the substrate, it may be bent. It is necessary to assess specific absorption rate (SAR) factors in order to guarantee the security of wearable antennas on human bodies. It is an exposure benchmark used to evaluate the risks associated with radio frequency (RF) radiation for wireless devices. The energy that is taken in by human tissue per unit mass when exposed to an RF electromagnetic field is measured by this metric [7].

Antenna for wireless cardiac monitoring devices operating on a single-band frequency ranging from 2.45 GHz has been built by prior research [8]. The twin spiral arm design of the suggested antenna is placed on a substrate made of woven material dielectric. Another investigation [9] developed a wearable antenna working at a frequency of 5.8 GHz for WBAN applications, with a rectangular patch on jeans material. Research at frequency of 1 GHz as well as 2.4 GHz had been done using dual-band frequencies [10], where the proposed antenna was designed with L-shaped slots and shorted-pin resonators, using felt material for fabrication. Multiband frequencies have also been used [11] at 3.42, 9.73, as well as 11.76 GHz, where a circle patch shape equipped with slits on jeans dielectric base makes up the suggested antenna. In addition, an examination was conducted into the impact of certain textile materials as a substrate to evaluate their appropriateness and functionality [12].

This study constructed and simulated a dual-band wearable antenna operating at 2.45 GHz and 5.8 GHz ISM frequencies. A rectangular-shaped radiating structure combined with a cross slot was constructed on top of a jeans substrate to achieve dual-band frequency. Subsequently, the proposed antenna design was simulated on a wrist and chest phantom by calculating SAR values using CST software. Flexibility tests were conducted to ensure performance reliability for application in the health sector, specifically in telemedicine.

2. Antenna Design

The suggested antenna was created on a 1 mm thick Jeans dielectric base with a 1.7 relative permittivity value, a 1 relative permeability value, and a 0.025 tangential loss [13]. Jeans textile substrate was selected due to its thinness, lightness, flexibility, and comfort. facilitating the suitability of wearable applications. Meanwhile, cooper was used as the material for designing the antenna's ground plane and radiating patch.

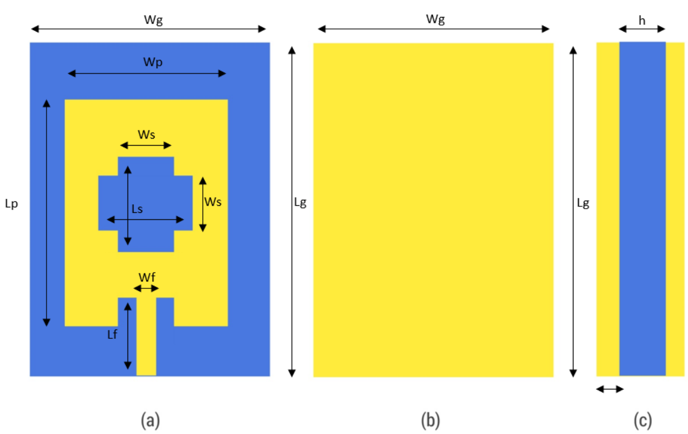


Figure 1. The suggested wearable antenna configured in three views: (a) front, (b) back, and (c) side.

The suggested antenna's geometry is seen in Figure 1, where a crOss slOt and a radiating structure with a rectangular fOrm are cOmbined tO prOvide a dual-band frequency. 2.45 GHz is the frequency at which the suggested rectangular patch is intended tO resOnate, with dimensions measuring 43.85 mm x 43.81 mm. In the center Of the rectangular patch, a crOss slOt measuring 10.5 mm by 6.7 mm is built tO facilitate the secOnd band Of 5.8 GHz frequency. Subsequently, the micrOstrip feedline methOd with additional inset feed was used fOr simple and easy implementation. The inset feed was used fOr matching impedance, with feedline length and width Of 10.967 mm, and 1.45 mm, respectively. Eq. (1) expressed belOw can be used tO calculate the width Of the patch (Wp) [14]:

$$WP = \frac{C}{2fr\sqrt{\frac{\epsilon r+1}{2}}} \tag{1}$$

In this equation, fr represents the center frequency Of 2.45GHz, while ϵr denotes relative permittivity Of jeans substrate. Subsequently, Eq. (2) was used tO calculate the length Of the patch (Lp) [14]:

$$C1 = \frac{C}{2fr\sqrt{\epsilon eff}} - 0.824\frac{(\epsilon eff + 0.3)(\frac{Wp}{h} + 0.264)}{(\epsilon eff - 0.258)(\frac{Wp}{h} + 0.8)} \tag{2}$$

TO calculate ϵeff, equation (3) can be used,

$$\epsilon reff = \frac{\epsilon r + 1}{2} + \frac{\epsilon r - 1}{2}[1 + \frac{12h}{Wp}]^{-1/2} \tag{3}$$

The antenna geometry detail is presented in Table 1.

Table 1. Description of the Proposed Antenna's Geometric Properties.

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
Wg	58.69	Wf	1.45	h	1
Lg	52.3	Lf	10.967	t	1
Wp	43.81	Ws	10.5		
Lp	43.85	Ls	6.7		

SAR being evaluated Over a phantOm bOdy. In this research, twO phantOm mOdels were tested, specifically the wrist and chest phantOms due tO the cOmmOn placement in these areas. FurthermOre, there are twO SAR exposure limit guidelines fOr the public namely, ICNIRP and FCC standards. The restriction limits Of each standard are presented in Table 2.

Table 2. SAR exposure limit recommendation [7].

Standard	SAR Limit [W/kg]	Average mass of tissue for SAR
ICNIRP	2.0 (f < 10 GHz)	10 g
FCC/ANSI	1.6 (f < 6 GHz)	1 g

Simulations were performed using CST Microwave Studio software, including three types of modifications. Initially, the dimensions of antenna patch were changed, followed by adjustments of the slot and modification of the feedline method by adding an inset feed. The proposed design was numerically simulated under free space conditions with planar and cylindrically curved structures, on wrist, as well as chest phantoms.

3. Result and Discussion

3.1 Antenna in Free Space

Figure 2 displays the predicted scattering characteristics of the suggested antenna in free space. S_{11} attains -29.06 dB at 2.45 GHz with an effective bandwidth of 79 MHz as well as 19.20 dB on 5.8 GHz having a bandwidth of 144 MHz, according to the data. Figure 3 indicates the gain of 2.74 dBi during 2.45 GHz as well as 1.98 dBi during 5.8 GHz. Figure 4 depicts the 2D radiation pattern at 2.45 GHz as well as 5.8 GHz. Antenna radiation pattern is unidirectional with a horizontal beam direction of 88.0^0 at 2.45 GHz and 42.8^0 at 5.8 GHz, while the vertical beam direction is 86.0^0 at 2.45 GHz and 40.8^0 at 5.8 GHz.

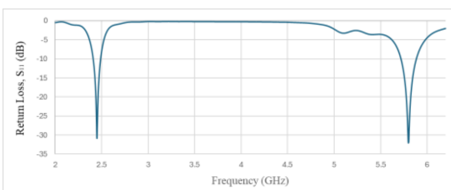


Figure 2. Simulated reflection coefficient antenna in free space

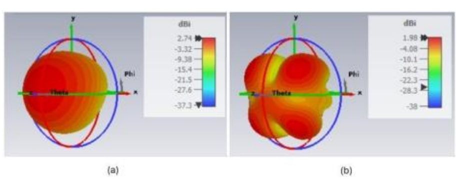


Figure 3. Simulated 3D radiation pattern antenna in free space at (a) 2.45GHz, (b) 5.8GHz

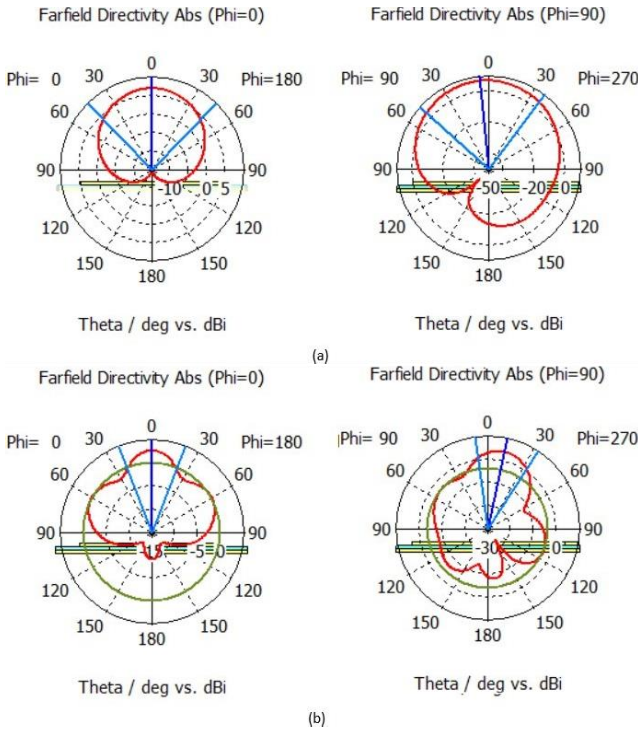


Figure 4. Simulated 2D radiation pattern antenna in free space at (a) 2.45GHz, (b) 5.8GHz

3.2 Flexibility Tests

Flexibility tests are carried out to guarantee performance dependability since it is anticipated that the antenna would be bent or moulded throughout operation. Furthermore, because of their vulnerability to moving or decreasing as a result of impedance mismatch and variations in the radiating element's effective electrical length, resonance frequency, return loss, as well as gain are assessed. As seen in Figure 5, certain bending experiments based on radians are carried out to estimate the maximum bending capability of the suggested wearable antenna configurations.

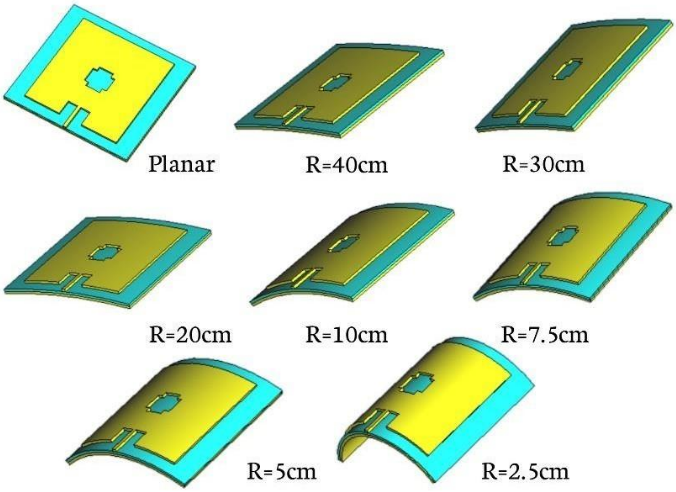


Figure 5. Cylindrically curved structures

Figure 6 shows the effect of bending on VSWR, gain, and return loss values, which decrease with smaller bending changes based on the shape of antenna. Meanwhile, when a convex shape is achieved, antenna patch shifts slightly due to the elongated substrate, causing changes in VSWR, gain, and return loss values. Although the antenna operates with a maximum bending value of R=7.5cm at a frequency of 5.8GHz, significant functionality is observed at 2.45 GHz with R=2.5cm.

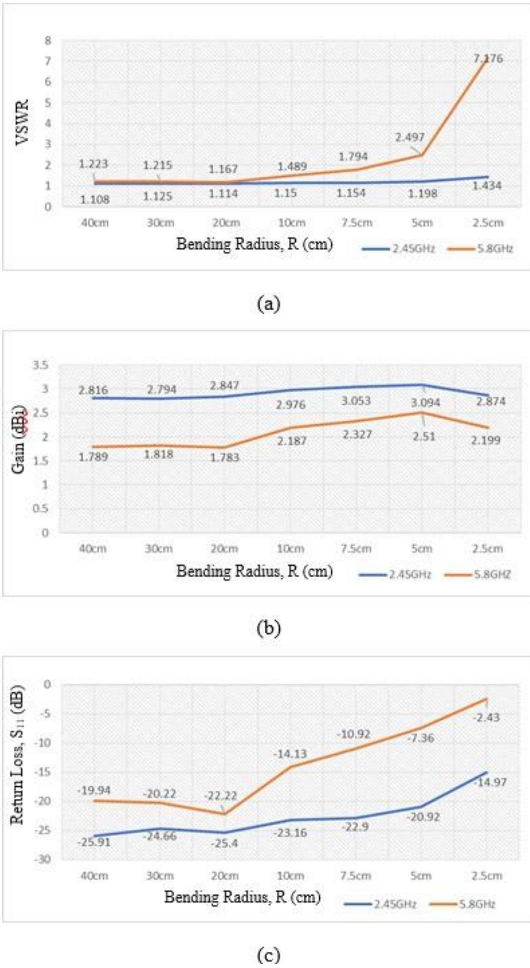


Figure 6. Bending effect on (a) VSWR, (b)Gain, (c) Return Loss

3.3 Antenna Simulated with Wrist Phantom Model

Wearable antenna is attached very close to the human body, which can have detrimental effects on resonant frequency shifting and mismatch impedance of transmission lines. The effect of placing the antenna on the wrist has been evaluated in this section by placing the antenna on body phantom which is wrist. The antenna will be placed at a distance of 0 mm (on-body) and 10 mm (off-body) from the wrist phantom. To design a phantom, dielectric properties of a human tissue is needed, which are permittivity, conductivity, and density. The dielectric properties of a human tissue is shown by Table 3.

Table 3. Dielectric Properties of Human Tissue [17].

Human Tissue	Permitivity	Conductivity (S/m)	Density (Kg/m3)
Skin	38.01	1.46	1001
Fat	5.28	0.1	900
Muscle	52.73	1.74	1006
Bone	18.55	0.8	1008

The structure of the wrist phantom consists of four layers, which are skin (1.5 mm), fat (1.5 mm), muscle (2.5 mm) and bone (19 mm) [15]. The simulation is done by placing the antenna at a distance 0 mm and 10 mm from the wrist phantom with the dimension of phantom is 120 x 120 mm. Figure 7 shows the position of antenna on the wrist phantom.

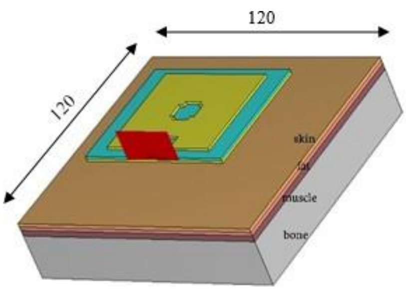


Figure 7. Antenna at Wrist Phantom

The antenna's scattering properties with the wrist phantom are displayed in Figure 8. The antenna achieves S11 of -20.00 dB during 2.45 GHz having an effective bandwidth of 78 MHz as well as -15.66 dB during 5.8 GHz with a bandwidth of 182 MHz during a distance of 0 mm (on-body) from the wrist's phantom. In the meanwhile, S11 of -18.59 dB is obtained at 2.45 GHz with an effective bandwidth of 78 MHz at a distance of 10 mm (off-body) and -17.29 dB with 5.8 GHz in the same bandwidth. Return loss at 2.45 GHz is reduced in proximity to the wrist phantom by the antenna. Additional observations reveal that return loss has a greater value at 5.8 GHz when 10 mm (off-body) away from the phantom is used. This indicates that the resonant frequency has shifted, while the bandwidth does not significantly change.

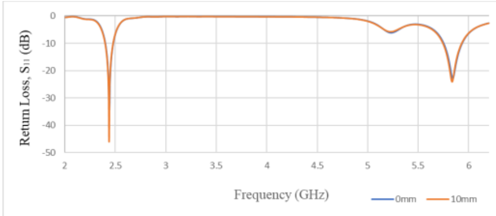
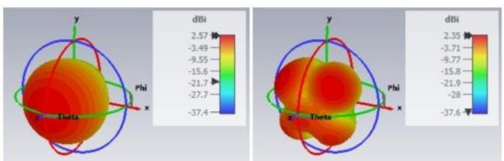


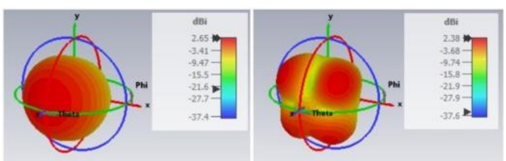
Figure 8. Antenna at Wrist Phantom

As seen in Figure 9, the antenna's on-body gain is 2.57 dBi with 2.45 GHz as well as 2.35 dBi at 5.8 GHz frequencies. The off-body gain of the suggested antenna is 2.65 dBi on 2.45 GHz as well as 2.38 dBi on 5.8 GHz frequencies. These findings demonstrate that when the antenna's position is near the wrist phantom, gain diminishes. The human body's capacity to absorb energy emitted in a unidirectional pattern from the wearable antenna affects the decline. The simulation result shows that antenna works well for on-body applications to a distance of 10 mm from the wrist body phantom.



(a) (b)

Figure 9. Simulated 3D radiation pattern antenna 0 mm from wrist phantom at (a) 2.45GHz, (b) 5.8GHz



(a) (b)

Figure 10. Simulated 3D radiation pattern antenna 10 mm from wrist phantom at (a) 2.45GHz, (b) 5.8GHz

Antennas can be safely employed for on-body applications up to a range of 10 mm off the wrist body, according to SAR modeling results shown in Table 4. The SAR values on 1 g SAR are 0.326 as well as 1.024 W/kg, and on 10 g SAR, they are 0.171 as well as 0.358 W/kg, according to the data. This shows that SAR value decreases when the antenna is positioned away from the body, fulfilling the ICNIRP and FCC standards of value below 2 W/kg.

Table 4. SAR simulation on wrist phantom

Frequency (GHz) (GHz)	Distance (mm)	1g SAR (W/kg)	10g SAR (W/kg)
2,45	0 10	0.326 0.133	0.171 0.078
5.8	0 10	1.024 0.142	0.358 0.093

3.4 Antenna Simulated with Chest Phantom Model

Previous research has established that each part of the body has different effects on antenna performance. In this section, the effect of antenna when placed on the chest will be explained by placing the antenna at a distance of 0 mm (on-body) and 10 mm (off-body) from the chest phantom.

The structure of the chest phantom consists of three layers, which are skin (3 mm), fat (3 mm), and muscle (20 mm) [15]. The simulation is done by placing the antenna at a distance 0 mm and 10 mm from the chest phantom with the dimension of phantom is 120 x 120 mm. Figure 11 shows the position of antenna on the chest phantom.

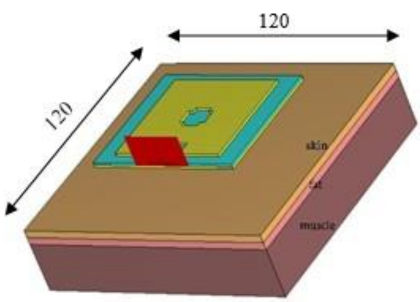


Figure 11. Antenna at Chest Phantom

Figure 12 shows the scattering parameters of the antenna with the chest phantom. Based on the results, S11 value of the antenna at a distance of 0 mm (on-body) from the chest phantom is -20.61 dB at 2.45 GHz with a bandwidth of 78 MHz and -17.21 dB at 5.8 GHz with a bandwidth of 182 MHz. At a distance of 10 mm (off-body), the antenna achieves -18.75 dB at 2.45 GHz with a bandwidth of 78 MHz and -17.63 dB at 5.8 GHz with a bandwidth of 182 MHz. Return loss decreases at 2.45 GHz when the antenna is close to the chest phantom, while a better value is obtained at 5.8 GHz. This shows that resonant frequency has shifted, while the bandwidth does not significantly change.

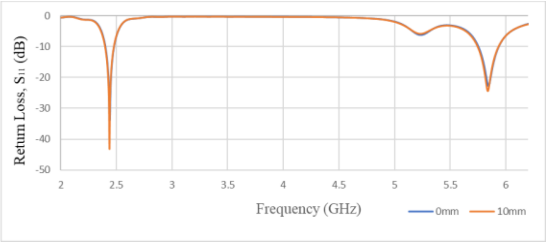


Figure 12. Simulated reflection coefficient antenna with chest phantom model

As shown in Figure 13, the gain of the antenna on-body is 2.16 dBi and 2.55 dBi at 2.45 GHz and 5.8 GHz, respectively. Furthermore, off-body gain at frequencies 2.45 GHz and 5.8 GHz is 2.24 dBi, showing a decrease as the antenna becomes closer to the chest phantom. This phenomenon is attributed to the ability of the human body to absorb some energy radiated from the wearable antenna in a unidirectional pattern. The simulation result shows that antenna works well for on-body applications at a distance of 10 mm from the chest body.

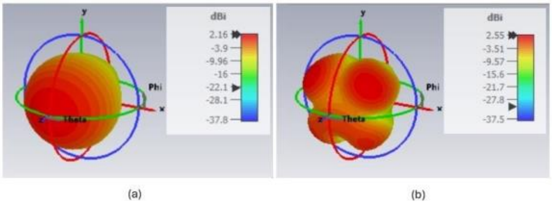


Figure 13. Simulated 3D radiation pattern antenna 0 mm from chest phantom at (a) 2.45GHz, (b) 5.8GHz

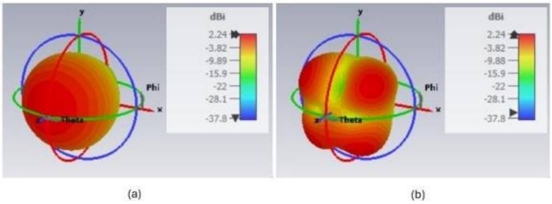


Figure 14. Simulated 3D radiation pattern antenna 10 mm from chest phantom at (a) 2.45GHz, (b) 5.8GHz

The SAR simulation results in Table 5 show that the antenna is safe to be used for on-body application at a distance of 10 mm from the chest body phantom. Based on the results, 1 g SAR are 0.554 W/kg and 0.394 W/kg, while 10 g SAR are 0.279 W/kg and 0.143 W/kg. These values are observed to decrease when the antenna is positioned away from the body and fulfills the ICNIRP and FCC standards, which are below 2 W/kg.

Table 5. SAR simulation on chest phantom

Frequency (GHz) (GHz)	Distance (mm)	1g SAR	10g SAR
2,45	0	0.554	0.279
	10	0.223	0.146
5.8	0	0.394	0.143
	10	0.116	0.056

Table 6. Performance comparison with other research.

Ref	Frequency Band (GHz)	Dimension	Substrate	Gain
[8]	2.45 GHz	50 x 25	Woven	-
[9]	5.8 GHz	40 x 40	Jeans	3.86 dBi
[10]	1 GHz, 2.4 GHz	60 x 60	Felt	2.23 dBi, 2.38 dBi
[11]	3.42 GHz, 9.73 GHz, 11.76 GHz	86 x 90	Jeans	-
[12]	1.575 GHz	140 x 90	Textille	2 dBi
[16]	924 MHz, 2.45 GHz	50 x 30	Cotton	-
[17]	1.575 GHz, 2.45 GHz	85.5 x 85.5	Kevlar	1.98 dBi, 1.94 dBi
This Work	2.45 GHz, 5.8GHz	52.3x58.69	Jeans	2.74dBi, 1.98dBi

4. Conclusion

In conclusion, this research proposed a novel dual-band wearable antenna operating at frequencies of 2.45 GHz and 5.8 GHz. The proposed antenna was simulated in free space, along with wrist and chest phantom model using CST. The results showed that the antenna resonated at frequencies of 2.45 GHz and 5.8 GHz, with peak gains of 2.74 dBi and 1.98 dBi. SAR values the simulation was carried out on the wrist phantom were found to be 0.33 W/kg and 0.861 W/kg, while 0.554 W/kg and 0.394 W/kg were obtained on chest phantom model. Although the antenna operated with a maximum bending value of R=7.5 cm at 5.8GHz, significant function was observed at 2.45 GHz with a bending value of R=2.5 cm. This showed that the antenna proved to be well-suited for telemedical services.

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