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Radiation analysis of optimized wearable antenna sensor at 2.4GHz on human body for Wireless Body Area Network Applications

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Abstract: The technology of wireless wearable antenna sensors is driving the impressive expansion of wireless body area networks health and wellness monitoring applications. This is because body sensors are regarded as extremely sophisticated data collecting and information systems. Wearable, networked sensors that can be utilized on, inside, or outside of the body are a part of the human anatomy. The most recent international standard for wireless body area networks is IEEE 802.15.6, which attempts to establish a standard for very dependable, short-range, low-power communication inside the human body. In light of this, a study was conducted to investigate on optimal wearable antenna sensors and developed a novel compact slotted planar wearable antenna sensor operating at 2.4 GHz. Additionally, its performance including path loss, channel modeling, power transmitted, power received, and other factors was examined in order to determine how well these sensors would work for IEEE 802.15.6 wireless body area networks applications. This work provides a thorough theoretical and practical investigation of the behavior of the suggested antenna sensor in relation to the human body and free space. The theoretical and experimental results correspond quite well, despite the intricacy of the human body's physiological behavior.

Keywords: Wireless Body Area Networks; Wearable antenna sensor; Channel modeling; IEEE 802.15.6; Human Body

Analiza sevanja optimiziranega senzorja nosljive antene na človeškem telesu pri frekvenci 2,4 GHz za uporabo v brezžičnih omrežjih za telo

Abstract: Tehnologija brezžičnih antenskih senzorjev, ki se nosijo, je gonilna sila izjemnega razvoja brezžičnih omrežij za spremljanje zdravja in dobrega počutja. Senzorji za telo namreč veljajo za izjemno izpopolnjene sisteme za zbiranje podatkov in informacij. Nosljivi omrežni senzorji, ki se lahko uporabljajo na telesu, v njem ali zunaj njega, so del človeške anatomije. Najnovejši mednarodni standard za brezžična omrežja za območje telesa je IEEE 802.15.6, ki poskuša vzpostaviti standard za zelo zanesljivo komunikacijo kratkega dosega z majhno močjo znotraj človeškega telesa. Izvedena je bila študija, v kateri so bili raziskani optimalni senzorji za nosljive antene, in razvit nov kompakten senzor z režasto ploskovno nosljivo anteno, ki deluje pri frekvenci 2,4 GHz. Poleg tega je bila preučena njegova zmogljivost, vključno z izgubo poti, modeliranjem kanala, oddano in prejeto močjo ter drugimi dejavniki, da bi ugotovili, kako dobro bi ti senzorji delovali za aplikacije brezžičnih omrežij IEEE 802.15.6 za območje telesa. To delo zagotavlja temeljito teoretično in praktično raziskavo obnašanja predlaganega antenskega senzorja na človeško telo in prosti prostor. Teoretični in eksperimentalni rezultati se kljub zapletenosti fiziološkega obnašanja človeškega telesa precej dobro ujemajo.

Keywords: brezžična omrežja za območje telesa; nosljivi antenski senzor; modeliranje kanalov; IEEE 802.15.6; človeško telo

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1 Introduction

The proliferation of miniature sensors and the growing use of wireless networks have resulted in network applications that can be used on the human body to provide a wide range of services [1]. These days, the healthcare industry has seen a tremendous transformation because to the advancement of wireless wearable technologies [2]. A wireless body area network (WBAN), is essentially a wireless sensor network (WSN), put together with various nodes, actuators, and sensors, among other intelligent devices. Power consumption for WBAN data transmission is high; therefore selecting the appropriate antenna for a given application is crucial [3]. In this context, the WBAN uses have known a large field of application domains, such as the medical domain [4], the military domain [5], sports [6], multimedia [7], etc.

Antenna sensor designs are crucial for cutting down on power consumption, decreasing channel loss, and boosting throughput. Wearable antenna sensor deployment, however, is hampered by a number of electromagnetic factors that can impair WBAN performance and wireless channel stability, including multipath, human body shadowing, fading and interference effects from signal attenuation, and energy absorption by bodily tissues[8] [9]. The study [10] states unequivocally that the human body is made up of naturally occurring absorbent layers. The attenuation of propagation signals along the human body is caused by these tissue layers acting as a low-loss dielectric medium.

It becomes necessary to reduce multiple electromagnetic variables in order to guarantee reliable body surface-to-body surface communication between the coordinator and the sensor nodes within the human body propagation environment. These include the human body's tissues avoiding radio signal diffraction, reflection, and absorption. Furthermore, characterization and analysis of the behavior of the wireless communication channel between devices installed on the human body become essential due to the complexity of the environment surrounding the human body. Characterizing propagation properties, signal attenuation, interference, and other body-centric limitations is the aim of this endeavor. Furthermore, the design and optimization of resource allocation plans, antenna designs, power control mechanisms, and communication protocols in Body Area Networks depend heavily on precise channel modeling. Furthermore, this latter makes it possible for scientists and engineers to assess and enhance the functionality of wireless connections, guaranteeing dependable and effective communication between implanted or wearable technology and the outside network architecture.

A WBAN is regulated by IEEE Standard 802.15.6. This standard gives WBAN systems access to the physical and media access control levels. As a result, these layers are founded on precise simulations of wireless propagation channels and antenna layouts for various frequency ranges [9]. The IEEE 802.15.6 standard was created expressly to satisfy the requirements of various WBAN-dependent medical applications [1][2]. According to a study by Al Barazanchi et al. (2022) in [10], these applications include remote patient monitoring in healthcare institutions as well as the monitoring of elderly people in their homes. The primary objective of this standard is to enable short-range, energy-efficient wireless communication that can be used for applications on, inside, and around the human body.

Furthermore, there are three different categories for communications in WBAN networks: There are three types of communication: in-body, on-body, and off-body. [11] [8]. In order to account for this, different channel models have been categorized based on the kind of body communication link—in-body, on-body, and off-body [12] [13].

Three possible scenarios for deployment are suggested by the WBAN standard: The human body has three types of nodes: (I) an implant node injected beneath the skin, which can be put in the deep tissues or just beneath the skin; (II) a surface node on the skin's surface; and (III) an external node, also referred to as the Gateway Node. The latter node is off-body and situated a few centimeters away from the skin [8]. In addition, four channel models (CMs) have been established under the WBAN standard: CM1 refers to the implant to implant; CM2 to the body surface model; CM3 to the body surface model; and CM4 to the external model [8] are the body surface to body surface models.

An essential and crucial component of wireless body area networks is the RF antenna sensor, whose design greatly influences factors such as radiation pattern, energy efficiency, directivity, transmission range, and radiation pattern. Over the past ten years, wearable antenna sensors have become increasingly important for on-body applications because of their capacity to identify microstructure deformations, human motions, and to monitor and oversee human health [14].

Standard industrial antenna sensors may offer precise data, but if integrated into body wear for sensing purposes, their large and stiff design restricts the user's movements. Thus, the creation of new antenna sensors that are compact in size, light in weight, low in power consumption, and flexible is crucial for WBAN applications. [15]

When creating WBAN-focused antenna sensors, one of the main study areas is choosing or creating appropriate materials for wearable antenna sensors. While a wide variety of antenna sensors have been produced for WBAN in the past, new and improved designs are constantly being created in response to market requests [16].

Since microstrip patch antennas have so many benefits, including low production costs, light weight, durability and dependability, and compact size, they are typically used in sensing applications. Due to the interaction of electromagnetic waves with dielectric characteristics, these function as sensors. [17][18]

In light of the aforementioned topic, new wearable microstrip antenna sensors optimized for 2.4 GHz were investigated, put into use, and their performance (including path loss, channel modeling, power transmitted, power received, etc.) was examined in order to use them for IEEE 802.15.6 international standard wireless body area networks applications.

2 Literature Review

Numerous methods have been put out in the literature for WBAN network path loss performance evaluation and channel modeling, utilizing a variety of analytical channel models as well as numerous experiments and simulations. The literature has presented a number of methods for channel modeling between on-body sensors. Electromagnetic signals go through the human body in WBAN. Because of this, the human body is thought of as a wave propagation medium. The authors of the study [19] discussed, for example, how crucial channel modeling is in body area networks for estimating path gain and link loss using an electromagnetic propagation wave approach.

Furthermore, a number of methods have been presented in the literature to demonstrate the significance of WBAN channel models between on-body sensors for both the deployment of these sensors and their use in the assessment of body area network performance in accordance with IEEE 802.15.6 specifications.

In order to evaluate the effectiveness of the proposed WBAN in terms of energy consumption, packet loss, and radio modulation type, for instance, the authors of the studies[20][21] proposed a simulation and channel modeling of a WBAN network made up of one coordinator and eleven sensor nodes. The channel was characterized using a lognormal shadowing path loss model. Consequently, the authors of some studies [22] and [23] have stated that, for interior situations, the lognormal model is more accurate than the Nakagami and Rayleigh channel models. Additionally, the CM3A and CM3B on-body path loss models suggested by the IEEE 802.15.6 standard have been used by the authors of other studies[24],[25],[26], and [27] for channel modeling between on-body sensors. The two route loss models have been used to the frequency ranges of 2.4–2.45GHz in these investigations by the authors. Tests of CM3's efficacy have been conducted in anechoic chambers and hospital rooms. Furthermore, in the research done in [26], authors examined the effects of power and modulation scheme variations on BAN performance in terms of packets received at the coordinator, packet loss rate, and delay at 2.45 GHz frequency using the CM3B path loss model. Additionally, the CM3B path loss model has been suggested for usage by the authors in [27]. The purpose of this work is to investigate and assess how inter-body area networks interference affects a body area networks energy consumption performance.

However, a number of studies based on human-body phantoms and voxel-human body models have been presented to define the on-body channel between wearable antennas at various frequency bands. For instance, the authors of experiments conducted in[28][29][30] have demonstrated the applicability of the S21 parameter in channel modeling between wearable antennas and a capsule endoscope that is implanted inside the human body in the small intestine. The various biological tissues have been taken into consideration in these investigations. Additionally, the authors of the study conducted in[31] suggested a patch antenna design operating at 2.4 GHz as well as an analytical channel characterization between two wearable antenna sensors mounted on a straightforward 3D cylindrical phantom. Nevertheless, in this investigation, the human body phantom's muscular tissue was the sole thing taken into account.

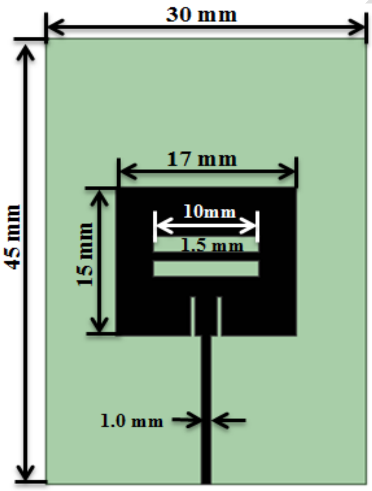
More recently, in the same field, the authors presented an analytical and experimental method for simulating the on-body route loss and path gain channel between two wearable antenna sensors for Wireless Body Area Networks in studies[32], [9]. Because the authors created an on-body channel model based on an earlier voxel-based channel model proposed in Hall et al.[33] and Alves et al.[34], these studies[31],[32],[9] generally share certain commonalities. They also suggested comparable experimental and analytical contributions. Even though these studies[31],[32],[9] use novel approaches, the authors neglected to consider the SAR study, which looked at how various antenna sensors behaved in the presence of a human body, particularly the effect of power absorption on bodily safety. They also neglected to use biological tissue such as skin, fat, and muscle for accurate and realistic channel modeling. As a result, the writers just take into account the muscle tissue. Furthermore, without considering the realistic biological properties of the conductivities and permittivities of each human body tissue, the authors of the studies by Hamdi et al.[32] and Hamdi et al.[9] altered the conductivity and permittivity of the human body muscle at random. Because of this, estimated return loss and path loss findings from simulations will be produced, which are not indicative of the real-world circumstances in the channel modeling of the human body environment.

By proposing a rigorous on-body path loss modeling theoretically and experimentally that takes into account the real dielectric biological tissue parameters of a human body and is based on our voxel-based channel model, we hope to add to the body of literature already in existence regarding on-body channel modeling between wearable sensors. Additionally, we aim to take into account the power absorption effects on the behavior of wearable antennas in both free space and the presence of a human body. For this reason, in addition to frequency and the distance between the Tx and Rx antennas, attenuation resulting from the human body should also be taken into account (IEEE 802.15.6 draft).

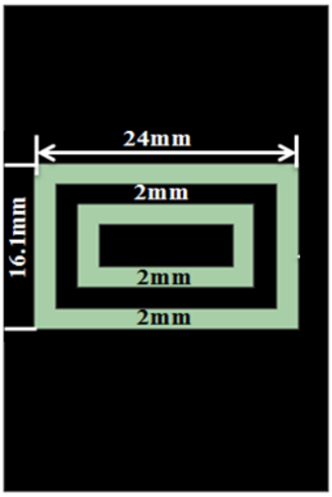
3 Antenna Sensor Design Flow:

This work proposes the use of HFSS-19 Software to operate a rectangular microstrip patch antenna at 2.4 GHz. Using a range of design flows and simulations, we have examined the effects of the human body on antenna performances. The suggested antenna is thought to be a very effective antenna for use in human body applications. The compact slotted Perfect Electrical Conductor (PEC) material is printed on a FR-4 dielectric substrate to create this wearable antenna. Because of its flexibility, this substrate material can be inserted into the body or fabric. Developing and positioning the antenna on the human body in a way that minimizes the impact of power absorption by the tissues is another difficult task. The substrate with a low dielectric constant of 4.3 and low dielectric height of 1.6mm was selected in order to lessen the influence that radiation waves would have on the human body and to have an efficient antenna in terms of radiation patterns.

The slotted ground plane and inset feed line are composed of copper-annealed material, which is advantageous for on-bodies applications since it lessens the power that 2.4 GHz creeping waves absorb from human body tissues. We have changed the printed patch's width, length, and widths of the two inset gaps in order to maximize the suggested antenna's performance in terms of impedance adaptation between the patch and the feed line. Fig. 1 depicts the suggested wearable antenna construction and its dimensional parameters.



(a) Top view



(b) Bottom view

Figure 1: Proposed microstrip antenna sensor

The proposed antenna sensor is developed in the dimensions of 30 x 45 x 1.6 mm^3 with respect to length, width and the height of antenna. It was fabricated and tested to analyze its performance over simulated antenna. The performance analysis is illustrated in results and performance analysis section. The fabricated antenna images and measuring views of antenna under test (AUT) is given as Fig. 2.

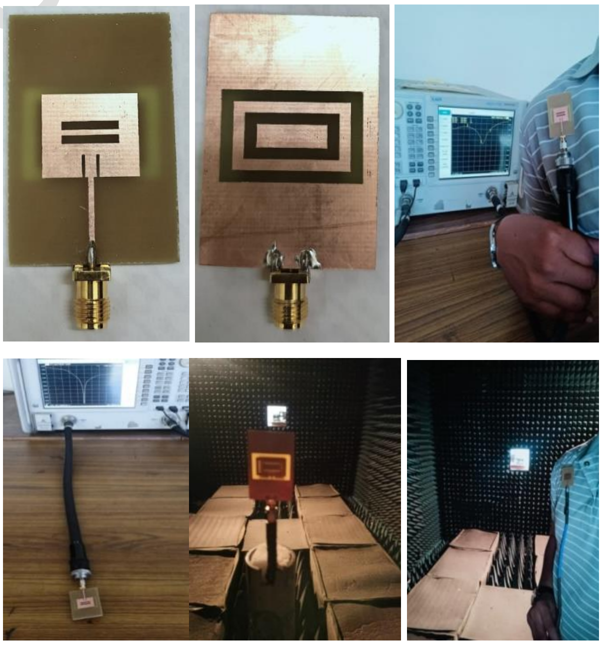


Figure 2: Fabricated and AUT views of proposed microstrip antenna sensor

4 Results and Performance Analysis

The radiation performance of the proposed antenna sensor is enhanced by incorporating slots on ground and patch as shown in Fig. 1. The radiation behavior of proposed antenna sensor with and without slots on ground and patch was explored below.

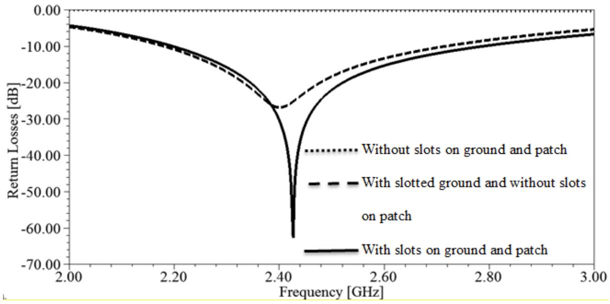


Figure 3: Return losses of proposed microstrip antenna sensor at different stages

In telecommunications measurements, the return loss term represents the loss of power, which have been returned or reflected from an antenna to a transmission line. It's a ratio between the incident power and the reflected power. For improved impedance matching, the return loss measurement should falls below -10 dB line [41], [42]. The proposed antenna sensor without slots on ground and patch is not given any operating band below -10dB and the planar sensor with slotted ground and patch achieved improved return losses than the sensor with slotted ground and without slots on patch at 2.4GHz. The return losses enhancement for different stages of design can observe in Fig.3.

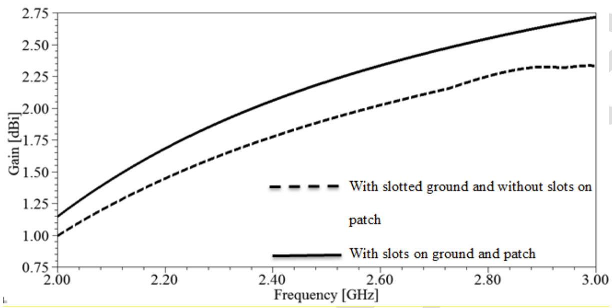


Figure 4: Gain of proposed microstrip antenna sensor at different stages

The gain was extracted for the designs, those showed the return losses less than -10dB and shown in Fig.4. Here also observed the sensor with slotted ground and patch achieved improved gain than the sensor with slotted ground and without slots on patch. The extracted results from different stages of sensor design are listed in Table 1.

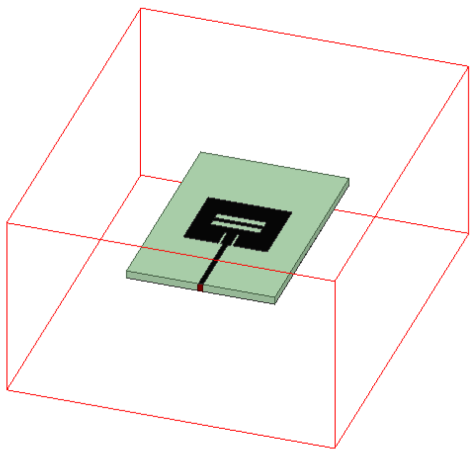
Table-2 Results of proposed microstrip antenna sensor at different stages

Antenna Sensor Design stage	Frequency (GHz)	Return losses (dB)	Operating band (GHz)	Gain (dBi)
Without slotted ground and patch	-	-	-	-
With slotted ground and Without slots on patch	2.4	-26.88	2.18-2.72	1.78
With slotted ground and patch	2.43	-62.76	2.20 -2.79	2.1

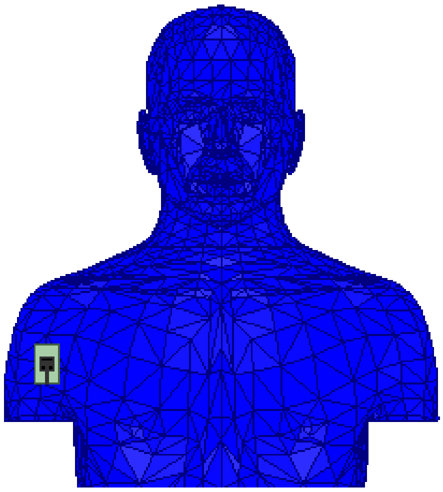
From the above results analysis, it is justified that the proposed antenna sensor with slots on ground and patch reflecting significant radiation than other stages of design. So it was implemented as shown in Fig.1, fabricated and tested as shown in Fig. 2.

4.1 Near Field Radiation Analysis:

With aim to use the proposed antenna sensor for IEEE 802.15.6 international standard wireless body area networking applications, the radiation activities from proposed antenna sensor are observed by mounting the antenna sensor in free space and on human body as shown in Fig. 5 i.e. the radiation behavior of the proposed antenna sensor on the free space and human body is theoretically and experimentally explored as below.



(a) Free space



(b) Human body

Figure 5: Mounting of antenna sensor in free space and on human body

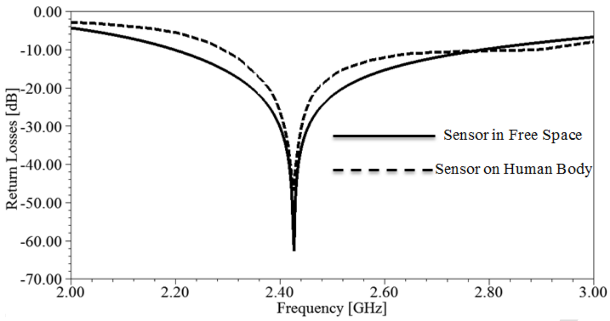


Figure 6: Return losses simulated antenna

Primarily, the performance analysis is done by measuring return losses (reflection characteristics) for simulated and fabricated wearable antenna sensors. The return losses extracted from simulation of the proposed antenna sensor by placing it in free space and on human body was plotted in Fig. 6. Similarly, the return losses measured from fabricated antenna sensor under test by placing it in free space and on human body was plotted in Fig. 7. It's clearly observed from Fig. 6 and Fig. 7 that the antenna exhibit improved impedance matching, as indicated by a return loss measurement that falls below -10 dB line at 2.4 GHz in free space and in human body environments.

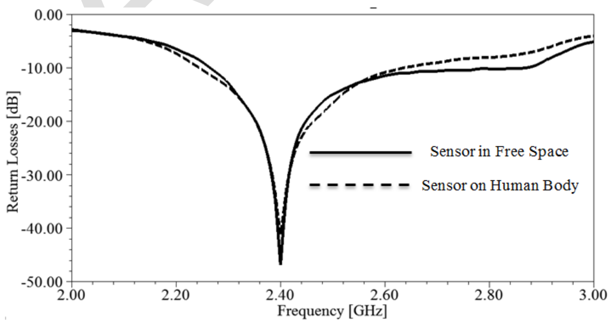


Figure 7: Return losses fabricated antenna

From extracted results of return losses, it was observed more return losses when the antenna placed on human body compared to the return losses when the antenna in free space, it may be due to the highest values of physiological parameters of the human body such as the conductivity of the muscle tissue and the power absorbed by each different tissue layers (Skin, fat, Muscle). The observed reflection characteristics (return losses) of the proposed antenna sensor from simulation and AUT are listed in Table 2.

Table-2 Reflection characteristics of simulated and fabricated antenna

Simulated/ Fabricated	Free Space / On Body	Operating Frequency band	Peak Resonant Frequency	Return Losses at PRF
Simulated antenna	Free Space	2.20 -2.79	2.43	-62.76
	On Body	2.29-2.9	2.42	-46.88
Fabricated antenna	Free Space	2.26-2.87	2.40	-46.9
	On Body	2.24-2.64	2.40	-41.1

Power is one of the important radiation characteristic in telecommunications measurements why because the transmission and reflection parameters are related to the power. The incident power on proposed antenna sensor, the accepted power and radiated power by the proposed antenna sensor are measured from simulation and AUT. The respected results are given as Fig. 8 and Fig. 9.

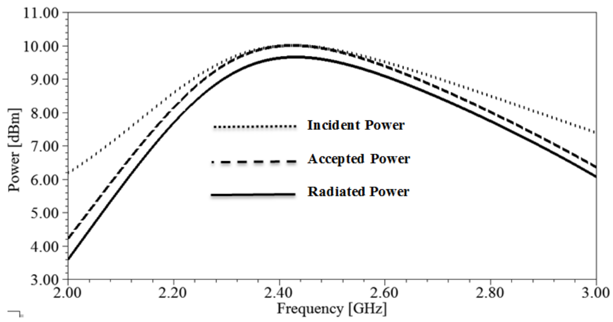


Figure 8: Incident, accepted and radiated powers from simulation of proposed antenna

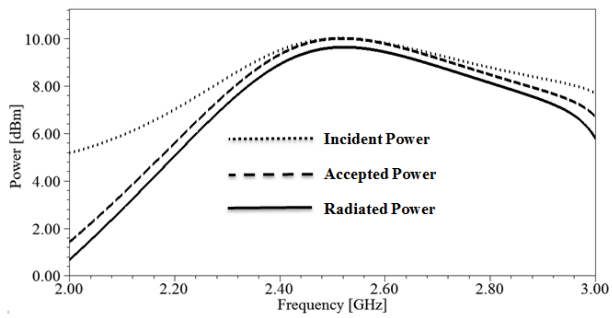


Figure 9: Incident, accepted and radiated powers from measurements of AUT

From the above power measurements, it is observed that, as return losses states, the proposed antenna transmitting more than 90% of incident power. It is the good evidence to the achieved significant return losses as shown in Fig. 6. The Power measurements taken from simulated and fabricated antenna are listed in Table 3.

Table-3 Power measurements of simulated and fabricated antenna

Simulated/ Fabricated	Frequency (GHz)	Incident Power (dBm)	Accepted Power (dBm)	Radiated Power (dBm)
Simulated antenna	2.4	9.98	9.98	9.62
Fabricated antenna	2.4	9.5	9.32	8.91

4.2 Far Field Radiation Analysis:

The analysis of far field radiation is necessary and essential to study the impact of electromagnetic phenomena such as the influence of energy absorption on the power and gain of wearable antenna sensors in free space and especially in the presence of a human body. It is, therefore, necessary to understand the behavior of these devices in free space and in close proximity to the human body, as well as the influence of human body power absorption on the radiation performance of the wearable antenna.

In the Fundamental mode of excitation, the proposed antenna radiates with significant gain towards the direction perpendicular to the patch. Fig. 10 showing the three dimensional (3D) polar gain radiation pattern of proposed antenna at 2.4GHz when it placed on shoulder of on human body. Fig. 11 is the plot of measured and simulated gain over all frequencies in sweep when the antenna in free space and on human body. In the free space environment, the proposed antenna has a gain of 2.1 dBi at 2.4 GHz. In the human body environment, the proposed antenna has a gain of 1.62 dBi at 2.4 GHz. However, according to the obtained results when the antenna is placed on human body, it was noticed a slight decrease of the antenna gain. Therefore, during transition, from free space to human body environment, the peak gain is reduced from 2.1dBi to 1.62 dBi, for proposed antenna sensor.

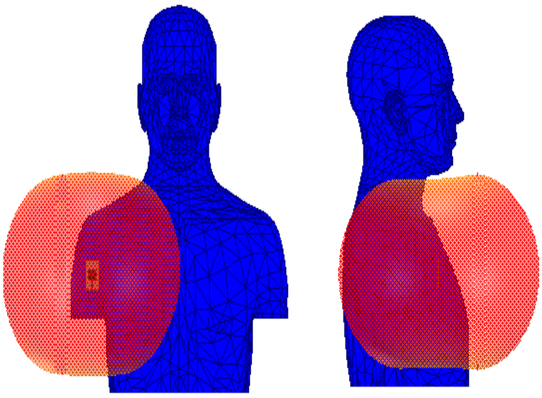


Figure 10: Proposed antenna 3D polar gain pattern of on human body at 2.4GHz

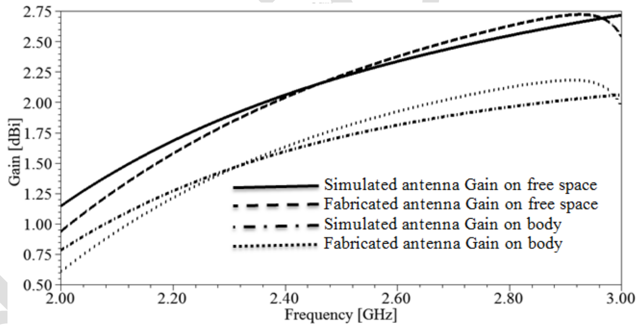
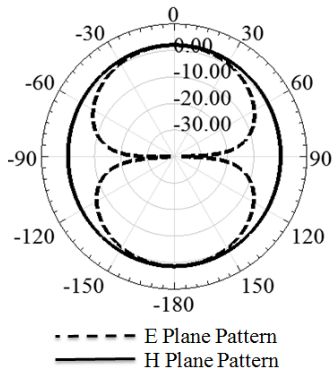
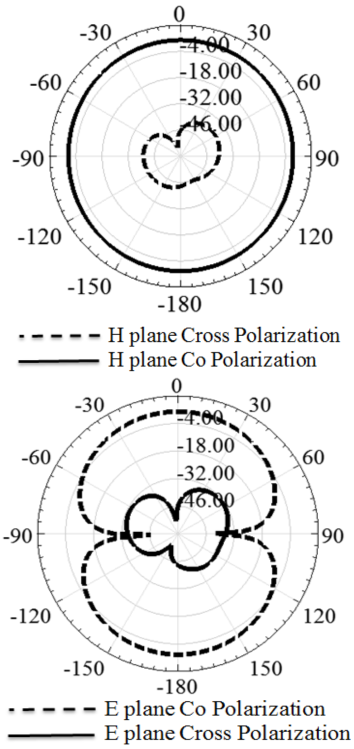


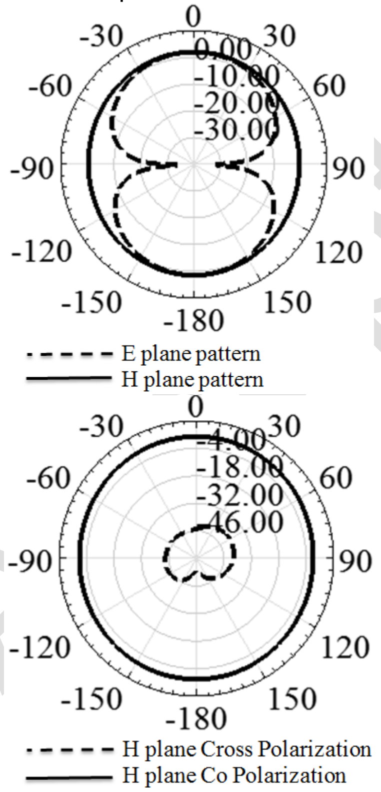
Figure 11: Gain over the sweep when the antenna in free space and on human body.

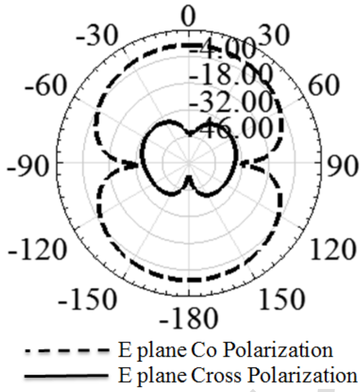
The slight decrease and attenuation in radiation patterns is may be due to the impacts of biological parameters of the human body such as the high conductivity of the muscle, skin and fat tissues. The Co and Cross polarizations of proposed antenna in free space and on human body environments were developed to know matching between the transmitting and receiving antennas.





(a) Co and Cross polarization of proposed antenna in free space environment





(b) Co and Cross polarization of proposed antenna on human body environment
Figure 12: Co and Cross polarizations of proposed antenna at 2.4GHz.

The co and cross polarization results are shown in Fig. 12 along with principle plane (E & H plane) patterns. From Figure 12, it is observed low cross polarization compared to co polarization and co polarized patterns have same level as principle plane patterns. So, as discussed [35][36][37], if observed low cross polarization compared to co polarization and co polarized patterns have same level as principle plane patterns, the characteristics of both transmitting antenna and receiving antenna are same. So, these observed far field gain radiation characteristics confirm that the proposed wearable designed antenna is suitable for free space and on-body medical applications.

It is summarized in table 4 the performance comparison of the proposed designed antenna with other antennas designed in several recent studies in the existing literature. In comparisons in terms of all performance metrics, it is noticed that the proposed antenna is more efficient than several other antennas presented in the literature.

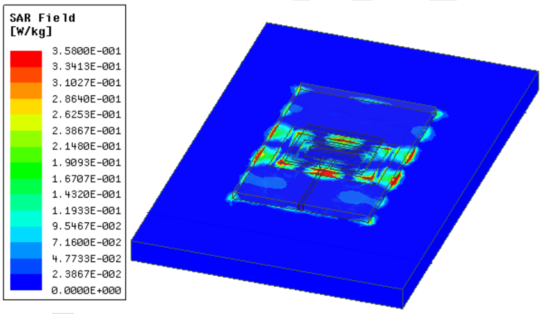
Table-4 Proposed antenna performance comparisons with previous works

Reference Number	Frequency (GHz)	Return Losses (dB)	Gain
This paper	2.4	-62.76	2.1
[2]	2.4	-43.01	2.61
[31]	2.4	-23.91	-
[9]	2.4	-21	6.37
[38]	2.45	-23.94	-
[39]	2.4	-15	-
[40]	2.4	-22.13	-

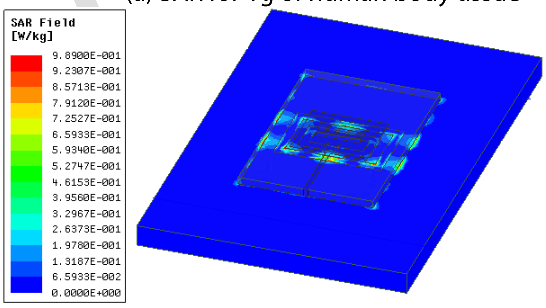
4.3 Specific Absorption Rate (SAR)

` Here presented a Specific Absorption Rate (SAR) analysis of proposed wearable antenna at 2.4 GHz for on-Body medical applications. A Human body is a complex propagation medium, it is highly conductive. As a result, human body tissue leads to additional effect to propagation waves such as diffraction, reflection, shadowing and power absorption. Considering the losses due to the human tissue frequency absorption and the complexity of this propagation environment, one of the most critical challenges in WBAN is the design of efficient wearable antennas and the analyses of the Specific Absorption Rate to protect the human body from radio frequencies and to ensure human body safety. The absorbed power per unit mass of human body is analyzed by the SAR. Moreover, electromagnetic waves radiated by wearable antennas and penetrated in human body tissues can cause harmful and devastating effects of human body. The specific Absorption Rate quantifies electromagnetic energy radiation absorbed by tissues and represents the amount of energy or power deposition per unit mass of biological tissue. The standard unit for SAR is watt per kilogram (W/kg).

According to the study conducted in [2], the international community has standardized and regulated the SAR limitations. The maximum safety limit of SAR specified by the federal Communications Commission is 1.6 W/kg for 1 g of tissue and 2 W/kg for each 10 g of tissue. In this work, it is calculated the SAR over 1g and 10g of human body tissue and shown in Fig. 13. As shown Fig. 13, it is observed 0.358 W/kg SAR over 1g and 0.989 W/kg over 10g of human body tissue. These SAR results make the proposed antennas suitable for Wireless Body Area Networks and for wearable applications.



(a) SAR for 1g of human body tissue

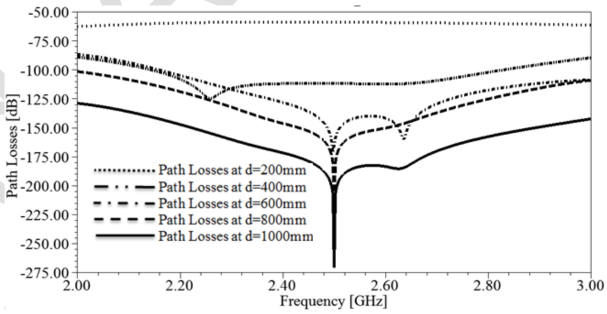


(b) SAR for 10g of human body tissue

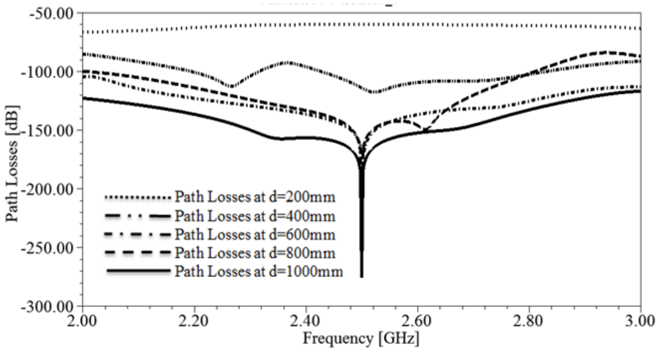
Figure 13: Proposed antenna SAR analysis

4.4 Path Loss Modeling:

As per the initial report on channel modeling for wearable and implantable Wireless Body Area Networks specified in the IEEE 802.15.6 standard, the S21 parameter serves as the channel parameter employed to measure the path loss between the wearable antennas [2]. Therefore, in this work, it was studied the S21 (path losses) channel parameter for path loss modeling in on-body antenna distances and free space antenna distances. Here, the S21 parameter signifies the path loss between the transmitting antenna and receiving antenna separated with the distance of 'd' mm within the topology of the Body Area Network. The study of S21 is the electromagnetic interaction between the transmitting and receiving antenna elements controlled by varying distance 'd' between them. Actually the S21 and 'd', both are inversely proportional to each other.



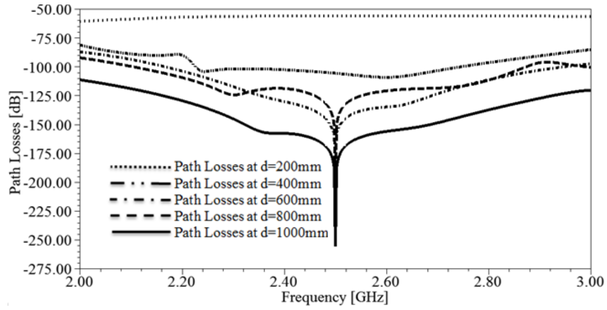
(a) Simulated Path loss characteristics at different values of d



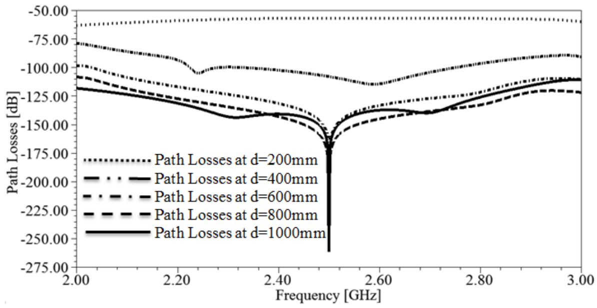
(b) Measured path loss characteristics at different values of d

Figure 14: Path loss characteristics from free space to free space over the sweep

In the proposed work, Fig. 14 (Path loss characteristics from free space to free space over the sweep) and Fig. 15 (Path loss characteristics from human body to human body over the sweep) presents the simulated and measured scattering S21 parameter between transmitting and receiving proposed antennas at various values of 'd' over the sweep. As per the survey, the researchers suggested less than of -15dB path losses. The studies from Fig. 14 and Fig. 15 justified the distinction path losses in proposed work. From this study of path losses over frequencies in sweep, it was computed path losses over different distances'd' at 2.4GHz and shown in Fig. 16.



(a) Simulated Path loss characteristics at different values of d



(b) Measured path loss characteristics at different values of d

Figure 15: Path loss characteristics from human body to human body over the sweep

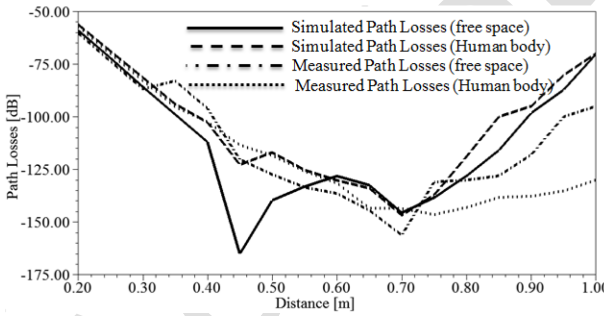


Figure 16: Path loss characteristics over distance between transmitting and receiving antenna at 2.4GHz

From Fig. 16, it was observed the shrinkage of path losses as distance increasing to certain value (700 mm) after that observed heightening the path losses with the increasing of distance with same amount from that certain distance value. From this study of path losses over the distance, it is summarized that the 700 mm distance is suggestible for better electromagnetic interaction between transmitting and receiving antenna on both free space and human body.

5 Conclusions

The proposed work presented path loss modeling between wearable antenna sensors in both free space and human body environments. The proposed model can be applied for channel modeling in the wireless body area networks field. Also, it is proposed a design flow and performance analysis of the wearable antenna in free space and on human body model. The performance of the proposed antenna in terms of return loss, and gain in both environments has been studied. Moreover, a specific absorption rate analysis has been performed to ensure human body safety. According to the obtained simulation results, we have examined the channel attenuation between the transmitting and receiving antenna placed on different positions using S21 parameter.

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