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Design of compact microstrip patch antenna for WBAN applications at ISM 2.4 GHz

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ABSTRACT

This paper introduces the design of compact microstrip patch antenna for wireless body area network (WBAN) applications at ISM 2.4 GHz. The design consists of a radiating patch on one side of the substrate and a ground plane is located on the other side of the substrate. The antenna is fed through an inset transmission line and then loaded by two triangles, and shorting pins on both sides of the radiating patch to lengthen the path for current, as result it reduced the overall size. The dimensions of radiating patch antenna are 62 mm× 43 mm × 1.67 mm. By locating the proposed antenna On and Off body communication, it can maintain compact and stable far field radiation characteristics and negligible specific absorption rate (SAR). Furthermore, high efficiencies of about 53 % and 46% are obtained during off and on body, which is higher than recent similar works in the literature. The simulated results showed a good agreement with the measured results. Owing to the acceptable results, the proposed design can be a reliable candidate for WBAN applications at ISM band.

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1. INTRODUCTION

Recently, the wireless body area networks (WBAN) are progressing swiftly. As The wireless body area network is a new developed wireless communication technology which is used for wireless communication In and On and Off a human body wirelessly like health monitoring for different age peoples, tracking, observing human vital signs, physical training, tracking and emergency rescue systems [1]. For health application, it is able to offer continuous and unobtrusive monitoring and sensing for healthcare In and On human bodies of different factors such as ECG,EEG,PH, temperature, blood pressure, level of patient etc. [2-5]. For On body wireless communication system, the system is continuously demanded to be lightweight, small, flexible, low profile, robust as well as capable of unobtrusive and continuous monitoring, all of which must mentioned the reliable communication with high performance. One of the key issues associated with the device and circuit of body area network (BAN) is the suitable design of antenna, as the system requirements are directly related to the antenna performance, according to the link budget. Usually it is used to transfer sensor data wirelessly to the nearest central station [4, 5].

In fact, when an antenna is kept near to a human body, the degradation of antenna performance is inevitable. For instance, the input impedance and resonant frequency of the antenna will be significantly influenced by capacitive coupling between the body and antenna. The antenna can also suffer from reduced radiation efficiency due to bulk power absorption by the body. Also, depending on the propagation condition, the radiation pattern can be considerably distorted [3, 4]. As a result, these phenomena can increase the transmission errors or, may be cause a loss of marginal communication link [5] in case of extreme case.

To obtaining a good and reliable performance of an antenna, it should be insensitive to the proximity effect to the human body an also needs to have minimum radiation towards a human body. But, when an omnidirectional antenna placed near to a human body, as a result the radiation efficiency is significantly reduced. Thus, the antenna having unidirectional radiation pattern is suitable choice for In and On and Off body communication to minimize the effects of the human body and reduce body exposure to electromagnetic radiation (EM), it should be insensitive to the proximity effect to human body and needs to have a minimum radiation toward a human body [6].

However, it is cleared that the antenna polarization is typically required in normal direction to the body surface for on body communication. Thus, the patch antenna is considered as an important device in body area network due to its low profile, low cost, planar structure, easy to fabricate as well as provide unidirectional radiation pattern [7, 8]. A large ground which is placed under the patch; it is essentially used to reduce the mutual coupling between the human body antenna and as a result it enhances forward radiation at the bore sight. These studies presented that the SAR and radiation characteristics were not only enhanced but also the directional pattern could be obtained using ground on the back side of the monopole type antenna [9]. However, all these previous works are not suitable for practical for BAN applications due to their bulky size and rigidness and complicated manufacturing procedures.

Generally, there are several designs have been studied and tested by researchers as a wearable antenna like cavity-backed [10], microstrip [11], inverted-F [5, 12], planar, and vertical monopole antennas [13]. However, all these antennas have suffered due to the large footprint, narrow bandwidth, and high front-to-back ratio (FBR). It has emphasized that the aim of this paper is to design a small dimension microstrip patch antenna for wearable applications due to its planar, versatile structure and provide broader dimension for the electromagnetic waves. The result showed a stable radiation characteristic for off and on body at 2.4 GHz. Hence, it can be deployed for continuously monitored the bio signals in the real-life scenarios.
This paper is organized as follows: Section.2 describes the proposed antenna design. Section.3 expands upon the result and discussion about the Off and On Body communication. Section.4 and 5 provides conclusion and references.

1.1. Comparison of Proposed Antenna with Literature

However, the antenna is compared to the similar antennas in the literature in Table 1. Thus, it features small dimensions and reaches the highest efficiency and stable far field radiation characteristics in the 2.4GHz ISM Band, respectively.

Table 1. Comparison Between Proposed Antenna and Similar Antennas in the Literatures

S.no	Band GHz	Dimension (mm^3)	SAR(w/kg)	Efficiency %
[14]	2.4	46 × 46 × 2.4	6.19 (W/EBG)	N/A
[15]	2.4	202×115× 0.01	N/A	48
[16]	2.4	100x100x4.975	0.58	42
[17]	2.4	60×60x6.34	0.66/0.18	51.4
[18]	2.4	100×100x3.34	0.05/0.01 (CRLH)	38/45
[19]	2.4	100×100 x3.34	0.046	50
[20]	2.4	70×70x0.237	N/A	N/A
[21]	2.4	119×184x3.34	N/A	N/A
[22]	2.4	88 × 142x1.34	N/A	N/A
[23]	2.4	121.9 × 109.1	N/A	-8.11
[24]	2.4	75×75x1.34	N/A	N/A
[25]	2.4	80×98	> 2 W/KG	3.3
[26]	2.4	114.5×101x2.34	N/A	48.75
Proposed	2.4	62x43x1.67	0.44 W/KG	53/46

2. ANTENNA STRUCTURE

A final design of proposed microstrip patch antenna was fabricated, shown in Figure 1 (b), which can be attached directly to the human body to constantly measure the vital signals of an individual like patients or athletes, shown in Figure 1(c).

The patch and the ground of the antenna are constructed using a 0.035-mm-thick copper [27] with an approximated conductivity of 1.18 × 105 S/m. The antenna substrate is a nonconductive material with 1.6-mm thick FR-4 [28]. Its relative permittivity and loss tangent are 4.3 and 0.025, correspondingly. The overall size of the antenna is 62 mm× 43 mm × 1.67 mm at 2.45 GHz, which is the smallest size in the reported Table.1. In addition to that, the two triangular offsets are introduced to radiating patch, which is also short-circuited to the ground by using shorting pins. The antenna is loaded by these pins and triangular offsets to improve the antenna performances in radiation characteristics and to miniaturize the patch, the current path was lengthened by realizing the compound shape with a shorting pin to the ground. Cooperating with the reflection of the ground, the long rectangular path work in the 1/2 wavelength resonance mode, which increase the radiation outward and reduce the undesired back radiation towards the body. The reason that another triangular is used to the opposite side of the first one, is to further miniaturize the patch and change the current flows. Besides, the locations of the shorting pins are optimized based on the surface current and the electric field (the location which has zero E-field) around the patch and load. Thus, this way of working guarantees the stability of the antenna structure when the rest of the antenna deforms. The antenna is fed through inset fed line, though in such type of feeding process, shown in Figure 1 (a), the edge of the microstrip patch is connected directly to a conducting strip. This type of feeding method suggested the benefit that the conducting line can have the opportunity of engraved on same substrate of patch antenna providing a planar shape. Hence, Thus, length of conducting element is smaller as compared to the width of the patch antenna. The detail dimensions of a proposed design are listed in Table 2.

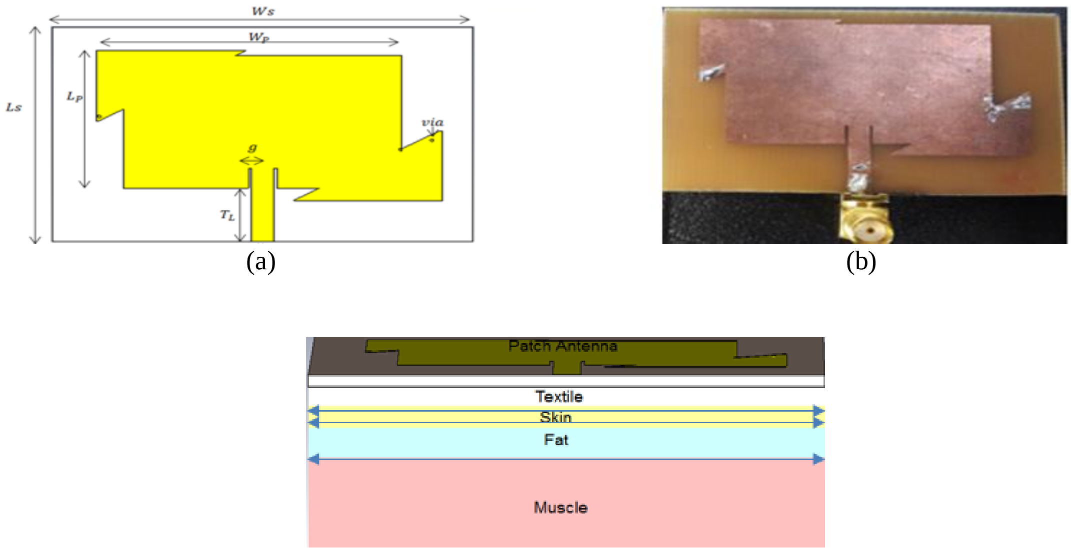


Figure 1. Design of Microstrip patch antenna. (a) Simulated, (b) Fabricated, (c) On Human Mode

The dimensions of the antenna are calculated from the transmission line equations [29].
Step 1) the width of patch calculated by using:

$$w = \frac{c}{2fo\sqrt{\frac{(Er+1)}{2}}} \quad (1)$$

Where c is the velocity of light, $f_{0=}$ resonance frequency, ε_r =Dielectric constant of the substrate
Step 2) Calculation of the effective Dielectric constant (εreff)

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \times \left(\sqrt{(1 + (\frac{12h}{w}}\right)) \quad (2)$$

Step 3) Calculation the extension Length: It can be used to calculate the resonant frequency (fc) for Micostrip antenna.

$$\Delta L = 0.412h \,\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \quad (3)$$

Step 4) Length of the patch calculated using effective Length (Leff)

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \quad (4)$$

$$L = L_{eff} - 2\Delta \quad (5)$$

Step5) The Ground Dimension for the Antenna: The length and width of the ground plane is calculated using the following,

$$L_g = L + (6h) \quad (6)$$

$$W_g = W + (6h) \quad (7)$$

Thus, the proposed antenna is operated as Microstrip patch antenna with ground plane, which worked as shielding for the back-ward radiation. Thus, by varying the width and length of the patch antenna, the antenna can be adjusted and optimized for the WBAN. Thus, Figure 1 and Table 2 described the final geometry of the proposed Microstrip Patch antenna.

Table 2. Geometrical Parameters of Microstrip Patch Antenna

S.no	Dimensions	Values/mm
1	Over All Antenna Size	$62x43x1.67mm^3$
2	thickness of substrate(ts)	FR4(1.6 mm)
3	Patch Size (W_P x P_L)	41x26.50mm
4	thickness of patch(tp)	Copper (0.035)
5	Transmission Line (T_W x T_L)	3.36x14.75mm
6	Slot g (w x l)	0.4x4.00mm
7	Off set Triangles (w x l)	22.0x14.00mm
8	Shorting Pin(via)	Radius (0.25)

3. RESULTS AND DISCUSSION

In this paper, the patch antenna is designed for application of WBAN, which is shown in Figure 1. The design antenna is then placed on human sample to check the effect of SAR, which is shown in Figure 6. The human model is designed by using CST MWS and it consists of different layers and thickness such as skin (2mm), fat (8mm), muscle (20mm). Thus, the properties of each layer are summarized in given Table 3 given below.

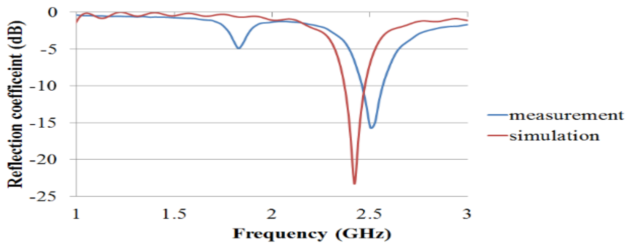
Table 3. Characteristics of Human Body Tissues[23]

Tissues	Permittivity (ϵr)	Conductivity (S/m)	Loss Tangent	Density (Kg/m^3)
Skin	31.29	5.0138	0.2835	1100
Fat	5.28	0.1	0.19382	1100
Muscle	52.79	1.705	0.24191	1060
Bone	12.661	3.8591	0.25244	1850

In this paper, the performance of Microstrip Patch antennas can be discussed into different stages:
a) Firstly, the wearable antenna is examined in off body communication at 2.4 GHz; b) Secondly, the wearable antenna is placed on the human body to investigate the performance and SAR near to the lossy human body at 2.4GHz.

3.1. Off-body Performance

The antenna is designed using CST simulation tool. The simulated and measured reflection coefficients agree well which is shown in Figures 2.The simulated -23 dB bandwidth is 104(2.3369-2.443 GHz) and measured is 105 MHz (2.33- 2.49 GHz). The radiation patterns are compared in Figures 3 given below. The front to back ratio (FBR) is higher in both the x-z and y-z plane. The gain of the antenna is about 3.01 dB for off body at 2.4 GHz. Moreover, the radiation efficiency is more than 53% for off body communication, maintained it wider half power beam Width (HPBW) throughout the whole operating band, which shows high stability during operation. Figure 3 shows the radiation pattern of the antenna for both E and H field. It’s obviously illustrated that all radiation is outwards and negligible back radiation and side lobe occurred. According to the radiation pattern, it has shown that the H filed is working inside E filed, as a result H filed is not changing the path of current for resonance frequency during off body condition.



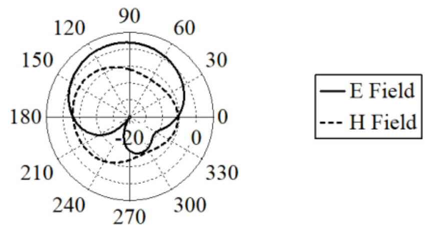
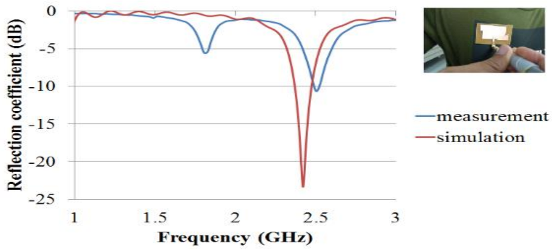


Figure 2. Simulated radiation patterns of antenna in free space at 2.4GHz

Figure 3. Simulated and measured S11

3.2. On-body Performance

The proposed antenna design was simulated and measured on body. It was located on various location of the human body like chest, arm (only chest presented here) etc. Figure 4 shows the simulated and measured reflection coefficients results on body. The bandwidth is larger compared to the off-body communication. This is because of the additional losses because of the proximity of the human body. The –24 dB band widths cover the ISM band with a bandwidth of 110 MHz which is acceptable for body area network. For on body application, the efficiency is 46% and gain is 2.11 dB on body application, which are still acceptable for wearable applications. Furthermore, the simulation and measurement results are in good agreement. Hence, same trend as off-body radiation pattern is followed by on-body presented in Figure 5. According to the radiation pattern, it has shown that the H filed is working inside E filed, as a result H filed is not changing the path of current for resonance frequency and provided stable radiation pattern during on body condition.



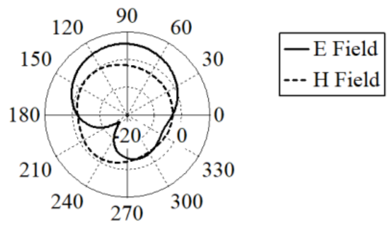


Figure 4. Simulated radiation patterns of antenna On body at 2.45 GHz

Figure 5. Simulated and measured S11

3.3. Signal Absorption Rate on Body

The SAR was simulated using a simplified human model, see Figure 6. This model consists of 3 layers: a 20 mm thick muscle layer, a 20 mm thick, 8mm fat layer, and a 2 mm skin layer. It was placed on real skin. The design antenna input power was set at 0.5 W (r.m.s). The SAR value was calculated based on the standard of IEEE C95.1 and averaged over 1 or 10 g of biological tissue. The result shows that the SAR is 0.44W/kg at 2.45 GHz. When the input power is 0.5 W (r.m.s), the maximum SAR value is 0.44 W/kg respectively, which is far under the limit of European standard of 2 W/kg.

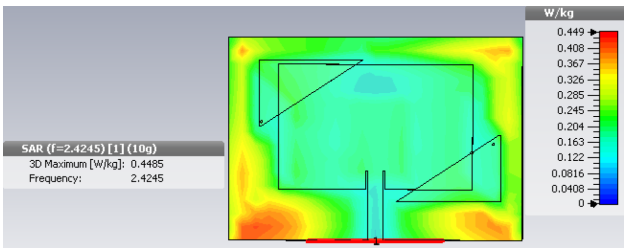


Figure 6. Simulated SAR value of the proposed antenna in free space at 2.45 GHz

3.4. Characteristics of the Proposed Antenna

The design and optimization are done using CST simulation tool. The patch antenna is positioned on top of the sample with a 0.17mm textile, to take it wearable, which is shown in Fig. 1(c). The design was finally simulated and measured. In figures 2 and 4, simulated and measured S parameters are given for the off and on body, such as all reflection coefficients are lower than the -10 dB. The patch antenna given an acceptable bandwidth (105 to 110 MHz), which is suitable for ISM band applications in both conditions along with stable radiation pattern. The Gain and efficiency of the ON-body state is shifted lower due to the presence of high dielectric constant of human body. Overall, it is realized that the presence of the body does not affect the performance of Microstrip patch antenna. This is due to the full ground plane that provides a good isolation between antenna and body. The Table 4 shows all the basic and important parameters of the proposed design.

Table 4. Summary of the Performance of the Antenna

ISM Band	Off Body	ON Body
Impedance BW(GHz)	108 MHz	105 MHz
Gain (dBi)	3.01	2.11
Directivity(dBi)	5.78	5.46
Efficiency (%)	53.0	46.0
SAR on Body(W/kg)	0.44 W/KG	
HPBW(Deg)	102.3	123.5
VSWR	1.46	1.15

Thus, optimizing the antenna and changing the size of element such as length(L), width(W) or using any cap active or inductive components, as a result it changes antenna characteristics. Because any changes in antenna element, it causes changes current distribution. However, any change in the current distribution, it causes changes electromagnetic fields around the antenna. These changes can be occurred in the input impedance, radiation pattern, bandwidth, resonance frequency etc. Thus, analyzing these behaviors that how variation in each element causes changes in the design characteristics, thus it is possible to find the best possible performance for a specific application. Hence, the proposed design is simulated measured and tested for bio signals in the body area network (BAN) at ISM band.

4. CONCLUSION

A compact Microstrip Patch antenna for WBAN at 2.4GHz applications were proposed, simulated, fabricated and measured. The proposed antenna features a very compact size, a good and robust impedance bandwidth performance, and stable far-field characteristics. The SAR value is negligible, according to the standard of FCC and CNIRP regulations due to large ground is existed at the bottom. Both On and Off body communication can be obtained in the 2.4 GHz bands, respectively. The antenna prototype covers the ISM band and a potential candidate for Wireless Body Area Networks (WBAN) applications.

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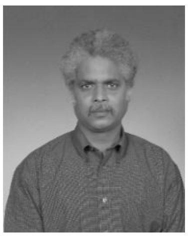

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