Compact dual-band patch antenna design for on-body wireless communication system

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In this article, a highly efficient on-body wireless communication antenna has presented. The proposed antenna is dual-band in nature. The two rectangular shaped vertex at the two sides of the triangle (situated at the middle) is responsible for the two resonances of the antenna. The proposed modified triangular shape antenna is fabricated on low cost, durable FR4 PCB substrate material with a permittivity er = 4.3. To solve the complications of the on-body wireless communications, antenna design is proposed with dual-band performance. The antenna has an efficient reflection coefficient at 400 MHz and 2.45 GHz with increased. Bandwidth. The antenna is fabricated using the RMIT University PCB fabrication facility. The radiation performance of the antenna in free air and in the near field of human tissue shows efficient performance. The measured results highly agree with the simulated result found in the simulation. The antenna is characterized in both free air and in the near field of the human body. No change is found when the antenna is operating near the human body. The specific absorption rate is also calculated to achieve an operational design in the near field of the human body. The proposed antenna is an excellent choice for on-body communication system due to its dual-frequency operation along with the increased directivity performance than the literature.

1. Introduction

Human health monitoring, body enhancement, the consumable electronics development trend is blooming recently. The researchers of different discipline are now eager to develop things which are usable human health monitoring. The Health monitoring system inside the human body has gained its peak popularity recently due to the recent development in electromagnetic research. Moreover, to provide compatibility, compactness, and real-time monitoring, there is no alternative to a wireless health monitoring system. Compact and compatible antenna design is the key part of such a system. There are many antenna designs in the literature which are dedicated to operating in free air. For special cases such as in the near field of the human body, such antenna designed for air performs poorly. To mitigate this problem, the human body characteristics must be kept under consideration while designing the antenna to achieve high efficiency for such communication purposes with the body monitoring system. Moreover, the specific absorption rate (SAR) is another factor that determines the healthy environment for the human body for the antenna to operate in the near field of the human body. A SAR effect from an antenna that crosses the maximum threshold of SAR can harm human tissue resulting in damaging the human body, which is unwanted. To achieve efficiency from an antenna considering all the problems discussed above, a compatible, compact antenna design in the near field is important. This project aims to design an efficient, increased bandwidth and gain antenna which will provide enhanced transmission for on-body communication and monitoring system.

Wireless device utilization is now being exploited more than ever in diverse applications due to its affordability, ease of achieving accurate design, and compatibility. Some of the major applications that are looking at the possibilities of microwave regimes are personal communication, defense, public security, sports, and health care [1-3]. Due to the expensive nature of health care products, recently, the microwave regime is being looked into to find a solution that inexpensive compared to the current health care products. For attaining devices operating near the human body, few criteria need to be satisfied, such as compatibility. With the increasing trend of consumable wireless devices, it has become much of an interest to the researchers for making wireless devices for on-body applications. Applications in different areas such as defense, health care, personal communication, public security, and sports are currently on the verge of the rapid start of using the on-body communication system. To achieve optimum on-body wireless devices for different applications, there are some criteria that need to be optimized, namely: compact size, lightweight, compatible and multifunctional [4-7] with UWB applications [8-10]. The on-body wireless devices can vary depending on where it is being installed, e.g. on the skin of the human body [11], on wearable clothes [12]. An on-body antenna can work in many ways. For example, it can work as a repeater for implantable devices [13, 14]. As an on-body device, the operating antenna frequency can be chosen to be within the Industrial, Scientific, and Medical (ISM, 2.4–2.48 GHz) band, which is unlicensed and free to use [14]. Different kinds of antennas can be found in the pieces of literature that are designed for various applications of the on-body

antenna [13-15]. An on-body repeater antenna is presented in [13] for the aid of antennae implanted inside the body. Fig. 1 depicts the proposed antenna with the dimensions included. It can be observed from the figure that the dimension of the antenna is comparatively large to be used for the on-body application. A smaller dimension is always desired. Moreover, the resonance frequency of the antenna at the ISM band is narrow (2.4–2.48 GHz). The maximum far-field gain of this on-body antenna is reported to be -27.2 dBi. Another on-body antenna is reported in [15]. The multilayer structure of the antenna makes the fabrication process complicated. Nonetheless, the antenna is utilized for power penetration inside human tissue for medical diagnosis. A new repeater antenna is presented in [11] with on-body performance. The antenna exhibits a low gain of -18 dBi at ISM band with the bandwidth performance of 0.3 GHz. Another low profile on-body antenna is shown in [16] with embedded electronics. The antenna is compact in size. However, the antenna works at 10 GHz frequency which lets the size of the antenna become smaller and the frequency is out of ISM band. Another cavity backed antenna for on-body application is shown in [17] for hearing instrument applications. The antenna has a low efficiency when it is close to human body. The bandwidth of the antenna is 48.5 MHz in operational condition. An on-body antenna with the property of radiation pattern reconfiguration is shown in [18]. Again the antenna is multilayered with a ground dimension of 50×50 mm^2. Moreover, the resonance frequency is distorted away from the center frequency 2.4 GHz when measured. To construct an antenna for on-body application, in a simulation environment, the body material needs to be considered to have the real scenario performance. For the human body material characteristics properties extraction, there are few journals that can be followed such as [19]. However, the human tissue properties can be found in the simulation software Computer Simulation Technology (CST) as well [20], which makes the design consideration in simulation much easier.

To develop an antenna at the near field of the human body, a number of research challenges need to be faced according to the literature review. We highlighted the main aspects of the research challenges below:

➢   Achieving antenna resonance while the antenna is operating at the near field of the human body

➢   Increasing the directivity of the antenna while at the near field of the human body

➢   Bandwidth increment at the operating frequency region

➢   Making the design suitable for operation near the human body

As discussed before, achieving the antenna resonance frequency at the desired band at the near field of the human body is of a greater challenge compared to achieving the resonance bandwidth in air. This is due to the fact that very limited research work in the literature has been carried out so far to achieve such antenna characteristics in the near field of the human body, compared to the antenna research that is operating in free air. Due to a lack of literature, it is hard to achieve an optimum design of the antenna to operate

in such a situation. Another issue while designing the antenna in the near field of the human body is increasing the directivity. While the antenna radiation tends to stay at the same material environment it is operating into; it is hard to achieve increased directivity when the antenna radiation is operating at some other material after transitioning from the antenna body to air. This becomes more affected, especially when some highly lossy high dielectric material such as human tissue is at the near field of the antenna-operating region. Hence achieving directivity in such an environment is a true research challenge. To achieve increased data rate from implants of the human body to the outside antenna (proposed antenna), it is important to achieve increased bandwidth. With the increment of bandwidth, the transmission and reception data rate increases proportionally. The human body is a sensitive topic as it requires a lot of compatibility issue to check with and lab testing before anything can be directly applied towards human body. A lot of ethical approval is also involved while working with application involving human body. Hence, it is crucial to achieve compatibility or in other words suitability for the antenna to operate near human body without any hazardous characteristics in a short and long-term operation.

In this article, a dual band patch antenna was designed for wireless on-body communication. The proposed antenna consists of modified triangular patch antenna with coaxial feed in the downside. The antenna is designed using CST software and fabricated in the RMIT lab for characterization. The antenna exhibits better performance compared to the reference antenna as shown in the novelty section of this report. The reflection coefficient of the proposed antenna occurs at the same frequency as the reference. However, the bandwidth at both 400 MHz and 2.45 GHz frequency is increased compared to the reference antenna. Moreover, the Gain is also increased at the lower frequency compared to the literature. We have also discussed the SAR characteristics of the antenna, which is an important aspect while the proposed antenna is operating at the near field of human body. Overall, the proposed antenna shows better performance compared to the literature.

2. The design structure of the antenna

Fig. 1 shows the antenna layout structure and dimensions of the proposed antenna. The proposed antenna is the dual-band in nature. The two rectangular shaped vertex at the two sides of the triangle (situated at the middle) is responsible for the two resonances of the antenna hence creating a dual-band antenna. Origin of the coordinate system is located at the centre of the rectangular ground plane. In order to excite dual resonances, the shape of the triangular patch is modified to include two conductive rectangles on its top vertex and bottom side, while a shorting pin is inserted to connect the ground and patch planes. The structure is also fed by a 50 Ohm coaxial cable, placed at the down side of the patch. By changing the dimensions of the two rectangles, the operating frequencies

can be optimized. Compared to the dimensions shown in the reference paper [13], the proposed antenna dimensions are modified to achieve increased bandwidth. Furthermore, the overall antenna dimension is minimized to 64 mm × 54 mm × 1.6 mm compared to the reference antenna which possess a dimension of 70 mm × 60 mm × 1.6 mm where 1.6 mm thickness is the thickness of the substrate material used to design the antenna. The antenna can be further minimized by using high permittivity substrates, however, to achieve cost effectiveness and due to high availability of FR4 substrate with the thickness of 1.6 mm in RMIT University, FR4 is used to achieve the final antenna design. FR4 is used as substrate due to availability with low cost compare to other material. The proposed antenna can receive data from implant devices using the lower operating frequency band and can transmit to the outer data processing unit using the higher frequency band. In other words, the lower frequency will aid in receiving weak signals transmitted from the lossy human body at medical radio band (0.401-0.406 GHz) and re transmission of the received signal to a further distance can be achieved using the frequency band 2.4-2.48 GHz which falls under free band range of industrial, scientific, and medical radio band (ISM).
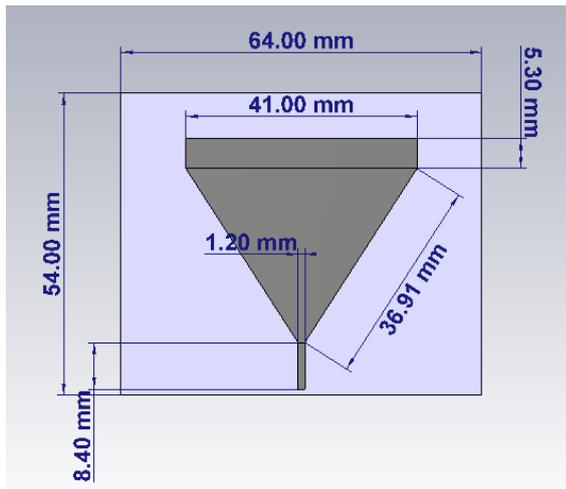

Fig. 1. Dimension of the proposed antenna (color online)

Fig. 2 shows the fabricated antenna (a) at the front side and (b) at the backside, which is the ground plane. It can be seen from the picture that, the front side is designed with the specification shown in Fig. 1. The backside is the ground plane and it consists of the SMA connector. A ruler is used beside the antenna design to show the achieved dimension during the fabrication. The antenna is probe fed from the ground plane to the patch plane. The probe of the SMA connector is resized to achieve 1.6 mm height, which matches exactly with the height of the substrate.

(a)
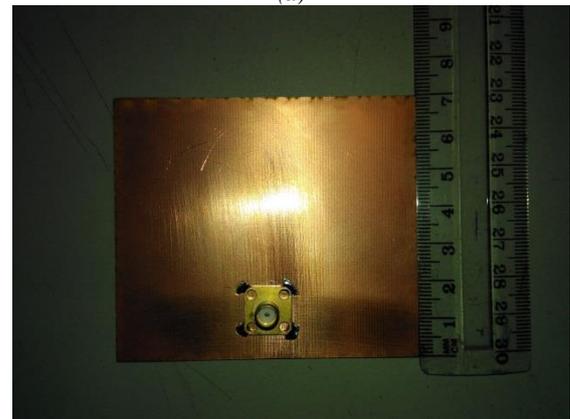
(b)

Fig. 2. Fabricated antenna (a) front side, and (b) ground plane (color online)
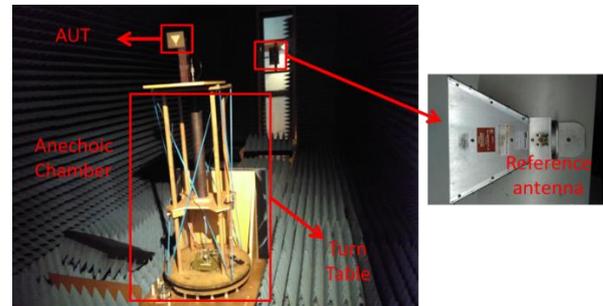

Fig. 3. Antenna measurement facility (color online)

The RMIT antenna measurement facility at 12.8.21 consists of an anechoic chamber, a turntable, an AUT holder, and a reference antenna holder. The reference antenna and the turntable are situated at the two ends of the anechoic chamber. The distance between the reference antenna and the AUT is 3 meters. According to the antenna operating frequency and the equation below [21], the antenna was characterized in far field.

$$Far\_Field \geq \frac{2D^2}{\lambda} \qquad (1)$$

where

$$\lambda = \frac{speed\_of\_light}{Operating\_Frequency}$$

and D = antenna dimension

A parametric design of the proposed antenna is given as Fig. 4. Antenna 1 is as described as only rectangle without a shorting pin. Antenna 2 is described as antenna rectangle patch with shorting pin. Antenna 3 is as described as triangular patch with shorting pi. Finally, the proposed antenna is constructed with a shorting pin triangular attached with a small rectangle. Fig. 5 describes the different antenna design reflection coefficients.
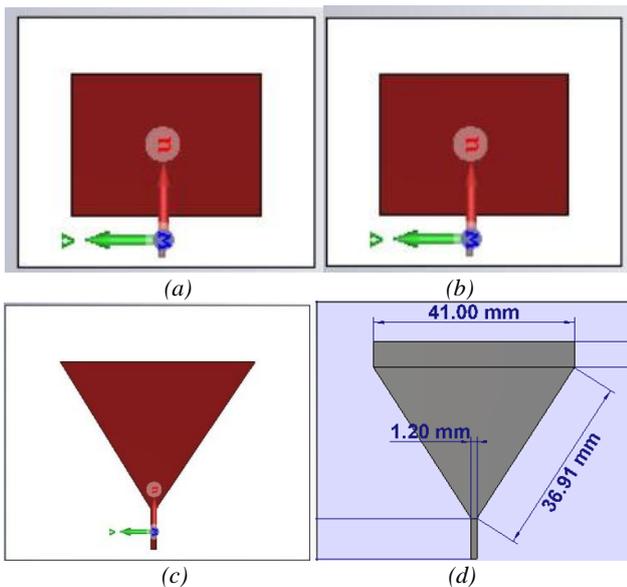

Fig. 4. Antenna design procedure of the proposed antenna a) Antenna -1 b) Antenna-2 c) Antenna 3 and d) Antenna 4 (color online)
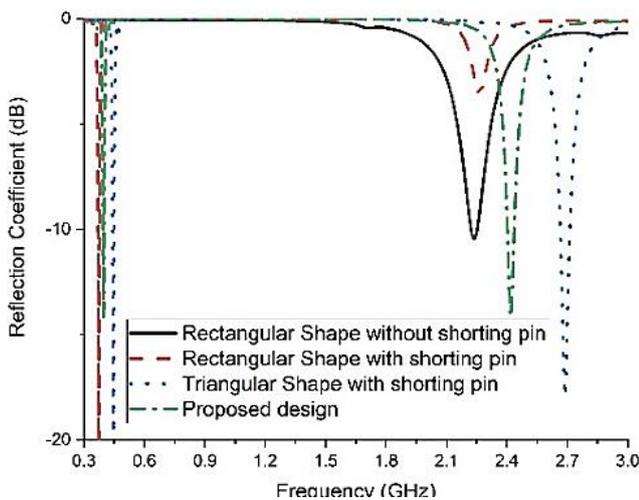

Fig. 5. Parametric design results of the proposed antenna (color online)

From Fig. 5, it can be stated that, antenna 1 will only responsible for higher resonance only. After adding the shorting pin in the downside of the coaxial feed, lower frequency resonance has come but higher resonance near to 5 –dB with shifted to lower frequency. To balance the lower

(400 MHz) and higher frequency resonance (2.40 GHz) at -10dB, a triangular shape patch is introduced to achieve dual band at specific frequency. Final, a small rectangular is attached to triangular to achieve 400 MHz and 2.40 GHz resonance frequency from the proposed design.

3. Results and discussion

The simulated and measured results of the proposed antenna are shown in terms of reflection coefficient (S_{11}) and radiation pattern. Fig. 6 shows the simulated and measured operating frequency response of the antenna in terms of reflection coefficient (S_{11}) vs frequency. From Figure 6(a), it can be stated that the two resonance frequencies are overserved at 400 MHz and 2.45 GHz in the simulation in CST 3D electromagnetic simulator. The -10 dB impedance bandwidth of lower resonance frequency at 400 MHz is more than 10 MHz whereas the upper frequency of -10dB impedance bandwidth of 2.45 GHz is about 45 MHz. The reflection coefficient values of the designed antenna at 400 MHz and 2.45 GHz is near about -13.7 dB and -13.5dB, respectively. The reflection coefficient shows that the impedances are matched over the range of frequencies with the increase of return loss values. The measured result follows similar pattern, which can be seen, from the Fig. 6 (b) with the resonance frequencies occurring at 400 MHz and 2.45 GHz. The measured bandwidth is 11 MHz and 49 MHz at 400 MHz and 2.45 GHz respectively. In simulation and measurement of the proposed antenna S_{11} results, there is a little bit discrepancy due to the fabrication and soldering effect compare to ideal simulation environment.
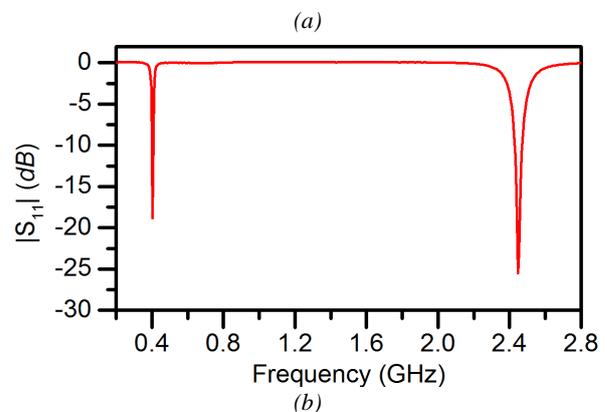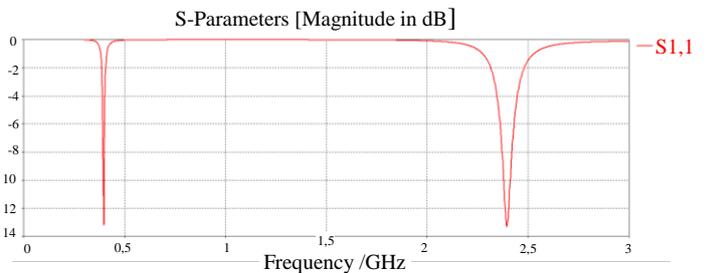

(a)

(b)

Fig. 6 (a) Simulated and (b) measured |S11| response of the proposed antenna (color online)
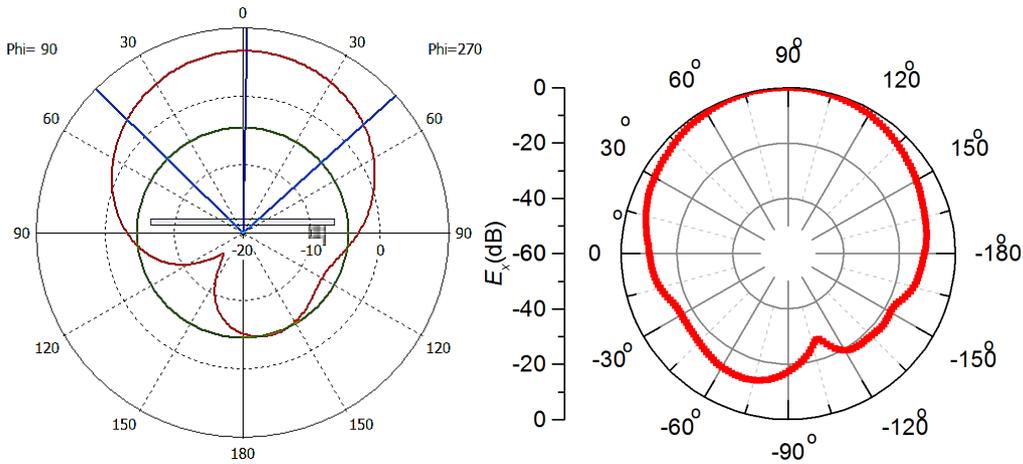
Fig. 7 shows the radiation pattern of the proposed antenna in simulation and in measurement. The E-plane at

400 MHz is shown in Fig. 7 (a). The simulated and the measured radiation pattern shows high similarity where the peak of the radiation is a bit offset in the measurement compared to the simulation result. Fig. 7 (b) shows the radiation pattern in the E-plane at 2.45 GHz. The simulation and measured results highly agree with each other. The only difference is at the back lobe where the back lobe is slightly tilted in the measurement result compared to the simulation result. The H-plane at 400 MHz for the proposed antenna is shown in Fig. 7 (c). Although a dual loop shape can be

observed in the simulation, the measured result shows insensitivity at the two sides of the proposed antenna. This could be due to the less sensitivity at the sides of the measuring antenna during the measurement. Fig. 7 (d) shows the radiation pattern at 2.45 GHz for the H-plane of the proposed antenna. The simulation and the measured radiation pattern highly agree with each other. Two deep occurs at both -120° and +120° in the simulation whereas the measured result follows similar pattern.
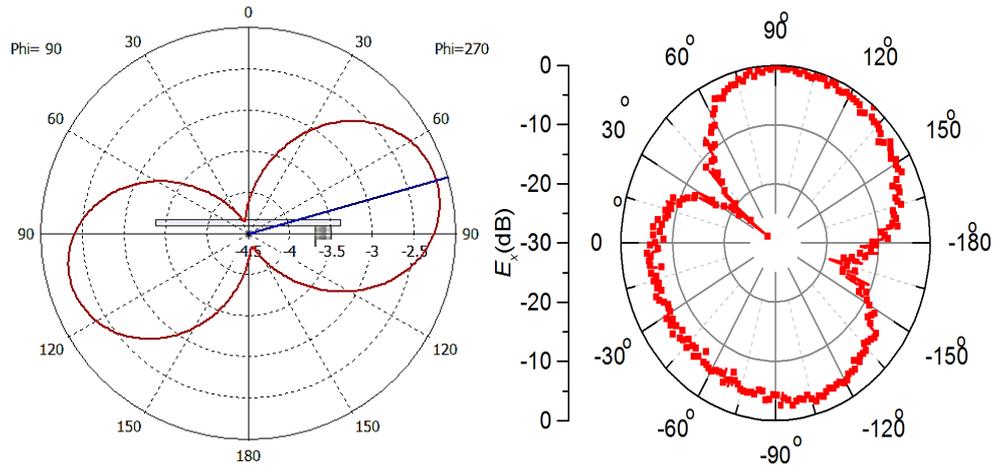
(a) E plane at 400 MHz (top simulated and bottom measured)

(b) E plane at 2.45 GHz (top simulated and bottom measured

(c) H plane at 400 MHz (top simulated and bottom measured)
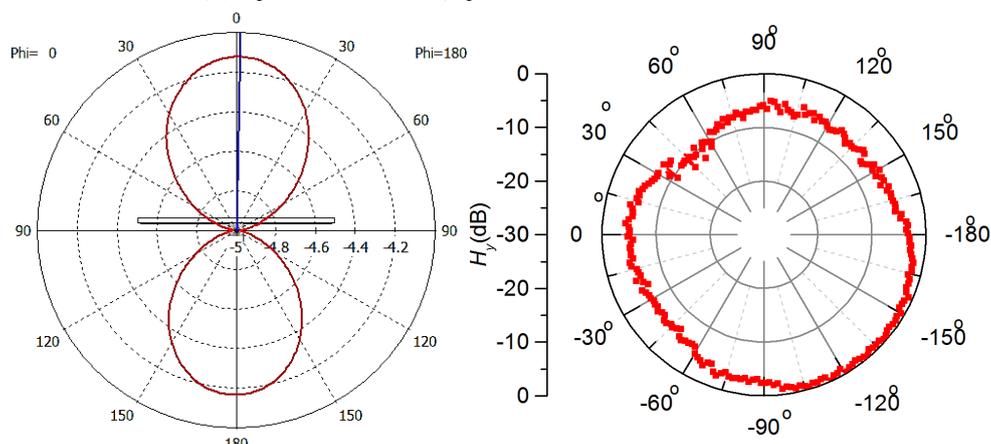
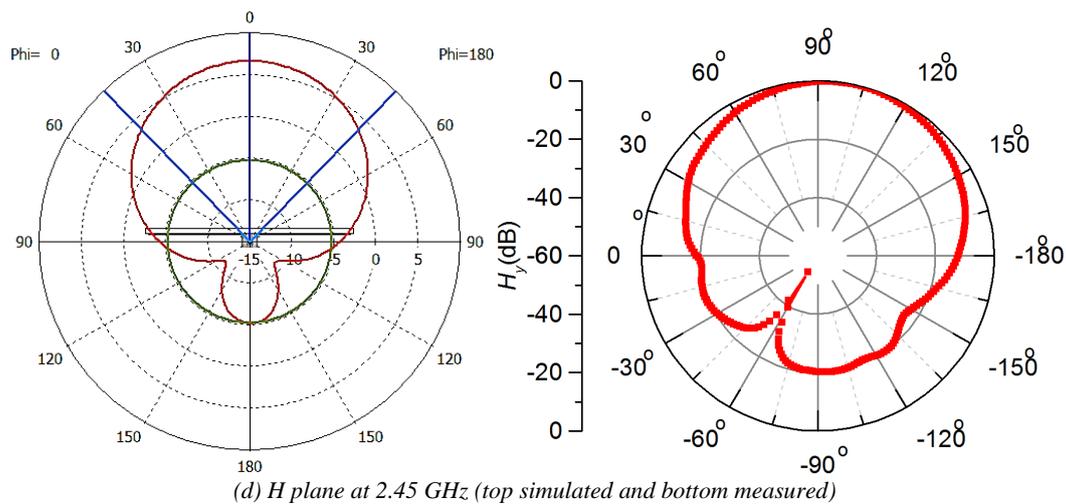*(d) H plane at 2.45 GHz (top simulated and bottom measured)*

Fig. 7 Simulated and measured radiation pattern of the proposed antenna at (a) E-plane 400 MHz, (b) E-plane 2.45 GHz (c) H-plane 400 MHz and (d) H-plane 2.45 GHz (color online)

The Specific Absorption Characteristics (SAR) of the antenna from simulation is shown in Fig. 8 for both (a) 400 MHz and (b) 2.45 GHz. For analysis of the SAR of the proposed antenna, a 100 mm × 100 mm × 100 mm cube has been designed through CST simulation software, which is considered as human tissue phantom. The proposed antenna has been put on the phantom for analysis the antenna SAR performance. It can be observed from the Fig. 8 (a) and Figure 8(b) that for both frequencies, the SAR is maximum at the middle of the antenna location. From Fig. 8(a), it can explained that at 400 MHz, the maximum SAR value of the proposed design is near about 0.06 W/kg. On the other

hand, maximum SAR value of 2.16 W/kg is observed in Figure 8(b) at 2.40 GHz. The IEEE C95.1-1999 patient safety standard restricts the specific absorption rate (SAR) averaged over any 1 g of tissue in the shape of a cube to less than 1.6 W/kg [22]. The SAR is shown while the input power is 0.5 Watts. To achieve the maximum SAR limit of 1.6 W/kg, the input power can be decreased accordingly. It can be concluded from the Fig. 8(a) and Fig. 8(b) that the SAR distribution for this antenna can be controlled to achieve desired performance of biocompatibility.

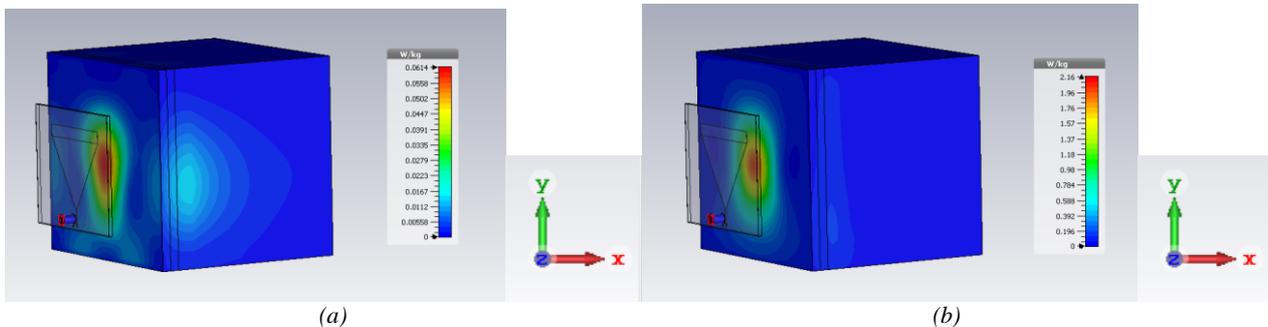A comparison of the proposed antenna with reference antenna as shown in Table 1 is as follows

Fig. 8. Proposed antenna SAR characteristics at (a) 400 MHz and (b) 2.45 GHz (color online)

Table 1. Comparison of the reference antenna with proposed antenna

Antenna characteristics	Proposed antenna	Reference antenna[13]
Reflection coefficient (S11)	400 MHz and 2.45 GHz	400 MHz and 2.45 GHz
Bandwidth (BW)	11 MHz and 49 MHz	6 MHz and 45 MHz
Gain	-16.5 dBi and 1.21 dBi	-27.2 dBi and 2.1 dBi
SAR	Explored	Not shown

4. Conclusion

In this research, a dual band microstrip antenna is proposed for on body wireless communication system. The proposed antenna is fabricated and measured for

characterization. In order to excite dual resonances, the shape of the triangular patch is modified to include two conductive rectangles on its top vertex and bottom side, while a shorting pin is inserted to connect the ground and patch planes. The bandwidth at both 400 MHz and 2.45

GHz frequency is increased compared to the reference antenna. Moreover, the gain is also increased at the lower frequency compared to the literature. To achieve cost effectiveness, the antenna is designed using easily achievable FR4 PCB substrate with dimension 64 mm × 54 mm × 1.6 mm. The SAR characteristics of the antenna is also investigated which is an important aspect while the proposed antenna is operating at the near field of human body. Overall, the proposed antenna shows better performance compared to the literature. The simulated and measured characteristics of the antenna shows efficient antenna design for on body communication system.

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