DOI:10.47904/IJSKIT.11.3.2021.1-5
SKIT Research Journal Vol 11 Issue Proc.-1 (2021) ISSN 2278-2508 (P) 2454-9673(O)

Design, Simulation and Analysis of Wearable 2.4 GHz U Shape Slotted Microstrip Patch Antenna for Wireless Body Area Network

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Received 13.02.2021, received in revised form 17.03.2021, accepted 25.03.2021

Abstract- **The wearable antenna for wireless body area network is trending in recent time. The demand for lightweight wearable antennas for body area networks is growing every day, as an antenna is one of the most vital parts of a wireless body area network. By putting numerous devices on the human body, WBAN has developed communication between them. Different types of miniaturized microstrip patch antennas play a different important role. This paper presents a small-sized, low-profile, and flexible antenna using FR-4 material as the substrate. An antenna's substrate has an impact on its properties. The proposed antenna operates at a 2.4 GHz frequency and has a return loss of less than -10 dB. The proposed antenna is intended to achieve a low human body SAR model and is recommended for continuous monitoring of important human signals such as blood pressure, heart rate, and body temperature via a wireless body area network. The results of the simulation show that the antenna has 2.2 dB gain, 5.4 directivity, -46.05 dB return loss, 95.8 MHz Bandwidth. This antenna is appropriate for WBAN applications because of its low profile, small size, and low price. The parameters such as VSWR, return loss, directivity, and gain of U shape slotted antenna are analyzed using CST software. This flexible and compact antenna is more suitable for various applications, specifically for wireless body area network applications.**

Keywords- Microstrip Patch Antenna, SAR, Wireless body area network, Wearable Antenna, FR-4 Substrate.

1. INTRODUCTION

In this era, the wireless body area network has gained a great concentration because of the modern development of wireless communication technology. It has grown quickly because of its application such as medical, sports, health care, personal security system, and so on. Wireless Body Area Network allows heath monitoring of medical patients continuously and keeps the daily record. Blood pressure, body temperature, EEG, EMG, respiratory rate can be measured by using the sensors of wireless body area network. In an emergency, it automatically transmits information regarding a patient's health status. As a result, a physician or doctor can give exact treatment immediately [1]. For this type of new technology, we need communication between the wearable device and external monitoring device. That's why we need to design an antenna that has good performance and lightweight. The wearable antenna can be attached to watches, shoes, health monitoring devices, etc. This type of wearable antenna has application in health monitoring like EEG, ECG, body temperature, sweat monitoring, etc. [2]. The material of the substrate of a wearable antenna is very important for its good performance. The antenna's impedance bandwidth and surface wave losses are both increased by using a substrate with a low dielectric constant [3]. Because of its lightweight, easy manufacturing, small size, and low cost, a microstrip patch antenna is one of the most popular. So, a microstrip patch antenna is more suitable for wearable applications [4]. A wearable patch antenna has a role in clothing so that it can be used for communication such as tracking, mobile computing, public safety, etc. This wearable antenna can be applicable for any type of aged person. The wearable antenna must be small in size, low cost, and maintenance-free. They must be more comfortable according to the body shape and they should be more efficient. Antenna design is a challenge in WBAN application because antenna characteristics like gain, bandwidth, efficiency, VSWR are significant. A wearable antenna can play an important role in this application [5]. In this paper, a U shape slotted patch antenna has been proposed. This paper introduces the design, simulation, and analysis of wearable antenna operating at 2.4 GHz which can be used in modern wireless applications like Wireless Body Area Network (WBAN). The simulation of this patch antenna is carried out by using CST microwave studio suite 2019. This antenna is designed to improve the VSWR, return loss, and bandwidth of the antenna. Many researchers designed this type of antenna for WBAN application. But this paper represents an antenna that has a U-shaped slot and a unique small size which improves its simulation

2. ANTENNA SHAPE

In this paper, the proposed antenna is a microstrip patch antenna that has u shaped slot. Microstrip antenna can be square, circular, rectangular, or elliptical. But the proposed antenna is a rectangular patch antenna. The used dielectric substrate is FR-4. The design dimensions of any patch antenna vary from substrate to substrate. This substrate material is very useful because of its flexibility and implantable in the human body or cloth. The antenna simulation result is improved by the use of a U-shaped slot in the design. This is a threefold antenna that consists of a ground plane, rectangular patch, and dielectric substrate.

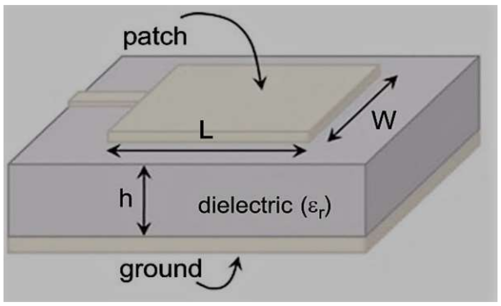

Fig.1 Rectangular Microstrip Patch Antenna

3. ANTENNA STRUCTURE

The proposed antenna is a rectangular patch antenna with a U-shaped slot. It can be attached to the patient's body for measuring the necessary signals. The advantages of microstrip patch antenna are small size, low cost, and ease of construction. As a result, it is very popular in wireless communication applications. Resonance frequency, bandwidth, radiation pattern, etc. requirements are responsible for its design. The patch material is copper and it is rectangular in size. The design of a wearable antenna requires some parameters.

Table 1 shows the design requirements of the wearable antenna. The requirements of operating frequency, VSWR, SAR, return loss, impedance is shown. A dielectric substrate with a dielectric constant of 4.3 is used to design the patch antenna. The general equation of antenna is taken into consideration for calculating the dimension of the design which is given below.

$$W = \frac{co}{2fr}\sqrt{\frac{2}{\varepsilon r + 1}} \quad \text{(i)}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \quad \text{(ii)}$$

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

$$L_{eff} = L + 2\Delta L \quad \text{(iv)}$$

$$L = \frac{c_o}{2fr\sqrt{\varepsilon_{eff}}} - 2\Delta L \quad \text{(v)}$$

$$Zc = \frac{120\pi}{\sqrt{\varepsilon_{reff}}}\left[\frac{Wf}{h} + 1.393 + 0.667.\ln\left(\frac{Wf}{h} + 1.444\right)\right] \quad \text{(vi)}$$

Table 1 Design requirement

Parameters	Value
Operating Frequency	2.4GHz
Dielectric Substrate	FR-4
Dielectric Constant (ε_r)	4.3
Height of dielectric substrate	1.6 mm
Return loss, S_{11}	< -10 dB
VSWR	< 2
Impedance of Antenna	50Ω
Specific Absorption Rate (SAR)	1.6 W/kg

The width of the feed line and the input impedance, which is typically 50Ω, determine the microstrip feed line. W stands for the patch's width, εr for the substrate's dielectric constant, h for the substrate's height, and L for the patch's actual length. The values of design parameters for 2.4GHz frequency are given in Table 2.

Table 2 Design element and values

Element	Value (mm)
Width of ground, W_g	43
Length of ground, L_g	41
Patch width, w	39
Length of feed line, F_i	7.21
Width of feed line, w_f	3.13
Patch Length, L	28.83
Gap, gpf	0.39
Height of Conductor, ht	0.035
Height of substrate, hs	1.6
Length of slot	3.5
Width of slot	0.5
Slot length offset	3.5

Fi is the length of the feedline which is used for port creation in CST software. Table 2 shows the design element and its values. The U-shaped slot is used so that it can improve the performance of the antenna based on its gainThe patch is separated from the ground plane by a dielectric substrate layer. According to recent study, choosing the correct substrate for dielectric materials improves the antenna's efficiency. The antenna substrate FR-4 material is 1.6 mm thick and the loss tangent of this material is 0.025. The overall dimension of this antenna is relatively smaller than any other wearable antenna because the width and length of the ground are only 43 mm and 41 mm at 2.4 GHz frequency.

Fig.2 shows the proposed wearable antenna at 2.4 GHz which is designed in CST software. A U-shaped slot of the order of λ/2 is integrated on the patch of the antenna in the suitable position. The substrate is very flexible. As a result, it can be very easily implanted in any clothing element or any portion of a patient.

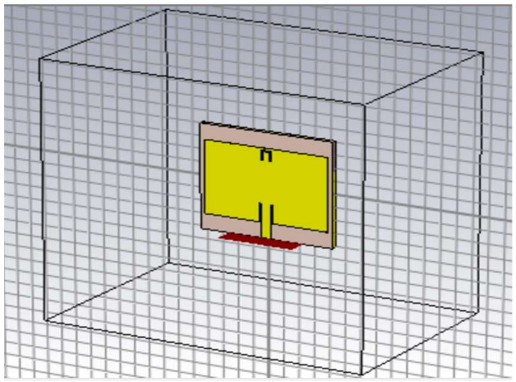

Fig.2 Design of the proposed antenna using CST software

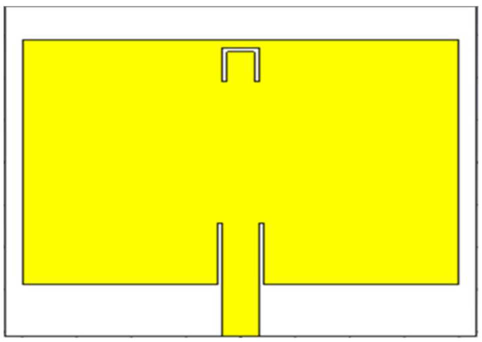

Fig.3. Top view of the proposed wearable antenna

The top view of the microstrip patch antenna for the 2.4 GHz frequency, which was designed using Computer Simulation Technology software, is shown in Fig.3. This U-shaped microstrip is simpler in construction which consists of a patch on one side and ground on the other side.

4. SIMULATED RESULT

The basis for modern communications is antennas. The proposed antenna is designed using CST software. All of the simulation results are found by using it. Due to the ease of simulation, CST is popular among antenna designers. Antenna design is one of the CST Studio Suite's largest application areas. After optimization of the antenna using CST software, simulation has to be done and all of the performance parameters are calculated from the software.

Table 3 Simulation Result

Frequency (GHz)	Return Loss(dB)	Band-width(MHz)	VSWR	Gain(dB)
2.4	-46.05	95.8	1:1.01	2.2

The antenna has been framed for operating in the ISM (Industrial, Scientific and Medical) band at 2.4 GHz. Simulating the proposed patch antenna with the FR-4 Glass Epoxy substrate at a frequency of 2.4 GHz, substantial gain, bandwidth, directionality, and radiation pattern values are calculated. The bandwidth for this antenna in 2.4 GHz is 95.8 MHz. The return loss of this microstrip wearable patch antenna is -46.05 dB which is below -10dB according to the requirement. The scatter parameter S11 of an antenna refers to the relation between the input terminal and output terminal on the basis of power. It is the function of frequency that varies with frequency.

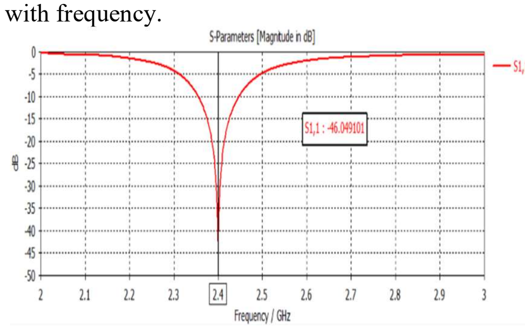

Fig.4.S-parameter of the proposed antenna

The voltage standing wave ratio (VSWR) is defined as the ratio between the maximum and minimum amplitudes of a voltage standing wave. VSWR of this designed antenna is found which is 1:1.01. Voltage Standing Wave Ratio must be less than 2. VSWR of this antenna is 1.01 and it indicates that this antenna is matched with the transmission line. The minimum required VSWR is 1.0 which is called the ideal condition.

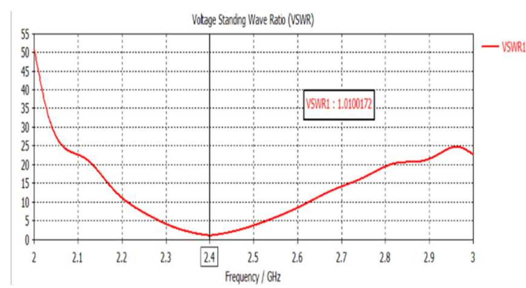

Fig.5 VSWR of the proposed antenna

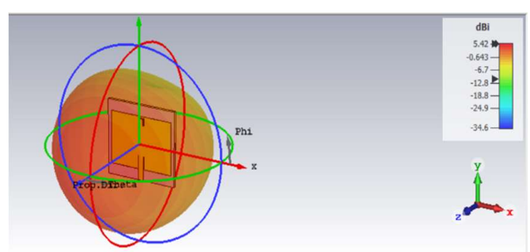

Fig.6 3-D radiation diagram of the proposed antenna

The antenna's directivity can be calculated using the 3-D radiation diagram shown in Fig.6. At 2.4GHz, this antenna has a directivity of 5.4 dB. It is the ratio of the normalized power in a specific direction to the average normalized power. It measures the concentration of antenna radiation in a specific direction. The higher directivity means the more concentrated beam is radiated by the antenna.

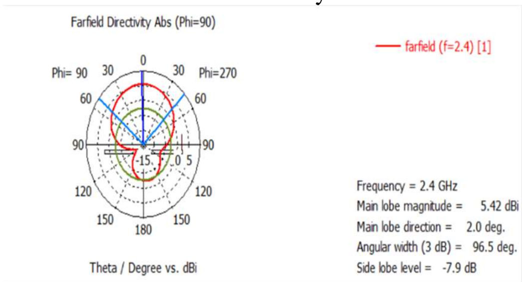

Fig.7 Polar radiation diagram of the proposed antenna

Fig.7 shows the polar radiation diagram of the antenna and it is obtained that the main beam width is 96.5 degrees at 2.4 GHz. The antenna has a wide angular range of transmission and reception. Again, the higher radiation always takes place in the main lobe. The secondary lobes of this patch antenna can produce interference. The difference level between the secondary and main lobe must be large. It has a level of 13.3 dB in this proposed antenna.

At 2.4 GHz, the antenna's gain is 2.2 dB. The antenna gain for phi equal to 90 degrees is shown in Fig.8, which is intimately allied to the directivity. Gain of an antenna refers to how strong a signal of any antenna can transmit or receive in a particular direction. As an antenna can't create radio energy, but it can direct or concentrate radio energy in a specific direction. The antenna's gain is defined by its directional feature.

$$G = \eta * D \qquad \text{(vii)}$$

Where, η = efficiency, D = directivity

SAR is the specific absorption rate which values are calculated over 1gm or 10 gm. It is the rate of radio frequency energy absorption by the body while using a wearable antenna. According to IEEE C95.1: 1999, the threshold value is 1.6 W/Kg for 1gm of tissue mass. In this wearable antenna, the SAR level is 0.6 W/Kg which is less than 1.6 W/Kg. So, the SAR level is matched with the requirement.

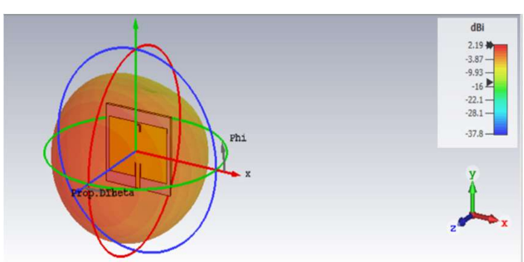

Fig.8 3-D gain of the proposed antenna

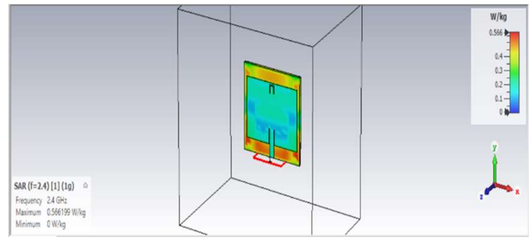

Fig.9 SAR level for this proposed antenna at 2.4GHz

Table 4 Comparison between existing works and proposed design

Ref.	S_{11}, dB	Frequency, GHz	Gain, dBi	Bandwidth, MHz
[13]	-23	2.45	-	80
[14]	-25	2.4	-	70
[15]	-30.92	1.32	-	20
[18]	-27.6	2.45	1.2	-
This paper	-46	2.4	2.2	95.8

Due to the new advancement of wireless communication technologies, the wireless body area network has gained great concentration in this period. Due to its introduction, such as medical, sports, health care, personal security system, and so on, it has evolved rapidly. Antenna for wireless body area network application is a very important feature in the wireless body area network. For the application of WBAN, a microstrip patch antenna is proposed. The proposed antenna has good performance than other antennas for WBAN application. The size of the antenna is also smaller than the other antenna. It has a low cost and low profile too. The comparison between some existing work and this work is given in TABLE IV. This table shows the operating frequency, gain, bandwidth, and S11 parameter of some existing works and this work.

From Table 4, the overall result of this work is better than the other works. Again the size of this antenna is also smaller than some existing works. This proposed antenna has low weight, low cost because of its small size. So, it can be said that this proposed antenna has better performance than the other existing works.

5. CONCLUSION

An antenna is a very important element in a wireless body-centric network for wireless body area network application. Strong impedance matching, better performance could have been achieved by the suggested antenna. The simulated result shows that the directivity, VSWR, Return loss, gain are 5.4 dB, 1.01, -46.05 dB, and 2.2 dB respectively at 2.4 GHz frequency for WBAN application. To design and simulate the antenna, CST software was utilized. Again, the SAR value is less than the SAR limitation. So, it will not create any radiation problem while placing it on the human body. This antenna provides the safety of the patient, immediate health monitoring, and many other services. In this analysis, in on-body biomedical applications, the designed antenna can be used. As it is small in size, light weight, and it has given good results in all the properties, it is a better candidate for wireless body area network. This proposed antenna is better than other existing works because the performance parameters are relatively good. In the future, the size, complexity, performance can be more improved for the development of WBAN application by upgrading the design and proper substrate. The enhancement of any antenna performance can be achieved by using the DGS method.

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