Analysis of a printed UWB antenna and the effects of human body in WBAN applications

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Abstract: *In this paper a microstrip patch antenna with slots for desirable return loss, gain, and bandwidth was designed and tested. Fr-4 was chosen as the substrate material and the antenna was simulated using CST (Computer simulation Technology) software, printed using MITS printing machine and all the parameters were measured. The designed microstrip patch antenna has a bandwidth from 2.02 to 5.71 GHz. The proposed antenna was put on the human body and a SAR value of 1.53 W/kg was measured, which was determined to be within the acceptable limit of 1.6 W/kg. Hence, the antenna can be used for on-body communication without causing harm to the human body.*

Keywords: **Microstrip Patch, Ultra-Wideband, Reflection Co-efficient, SAR.**

1. INTRODUCTION

Wearable devices to measure human body temperature, EEG, Blood sugar, Blood pressure etc are playing a very important role in the wireless medical applications. The antennas designed for these purposes must be placed on the human body and the characteristics of such antennas should be studied and also the effect of antenna on the human body due to the radiation of the antenna need to be analysed. There are many research going on for on-body communication [1]. At communication frequency, the human body functions as a lossy dielectric, and EM radiation produced by these antennas may penetrate semisolid objects such as living tissues [2]. The antenna models must be built and tuned in such a way that the human tissues should not be causing any negative consequences [3]. In [4], a voxel model of humans has been used which is developed in the

CST software simulation to obtain the effect of antenna behaviour on the human skin and a microstrip patch antenna was designed that operates from 2.8 to 12GHz with a gain of 3.5dBi. In [5], many feeding techniques are studied. In [6], effects of human body on antenna parameters are analysed.

2. ANTENNA DESIGN

The microstrip antenna was designed for a resonant frequency of 6 GHz. The size of the antenna is 30 x 20 x 1.6 mm^3 where the size of the patch is calculated using the formula:

$$L_p = W_p = \frac{c}{2 * f_r * \sqrt{\epsilon_r}}$$

Apart from the patch calculation, the rest of the antenna parameters' dimensions were calculated using equations present in [7].

The dimensions of the square antenna as shown in Fig.1. The resonant length is calculated to be 11.45mm and the thickness of the patch is taken as 0.035 mm. Both the ground plane and the patch are made from copper. Fr-4 material having a dielectric constant of 4.3, was employed as the substrate because of its availability, high dielectric strength, moisture resistance, low cost, and ability to produce accurate results at higher frequencies.

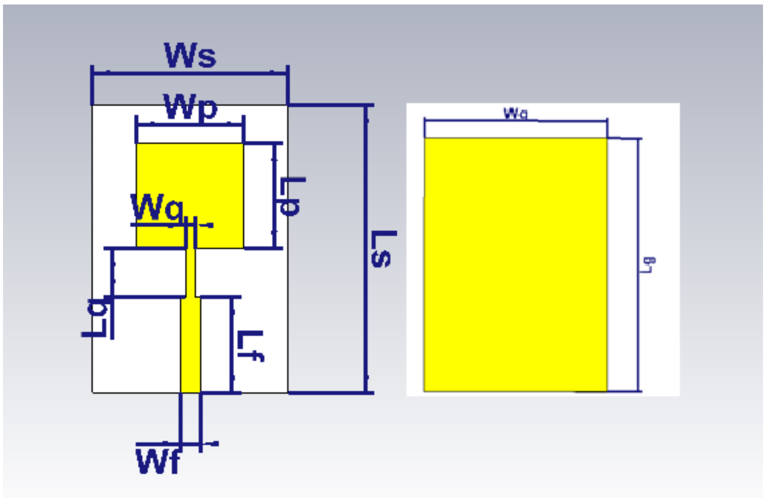

Fig 1. Structure of the Base Antenna (Front and Back View)

The square-shaped patch length was optimized to 11mm to improve the reflection coefficient. Later, as illustrated in Fig.2, slots and slits were incorporated, as well as a deformation in the ground plane, enhance impedance matching, and improve the antenna's bandwidth [8-10]. The base antenna has been modified by performing different iterations - introducing slits and slots on the sides of the antenna, and by reducing the ground plane to arrive at the proposed antenna design. The final antenna design parameters are as shown in Table 1.

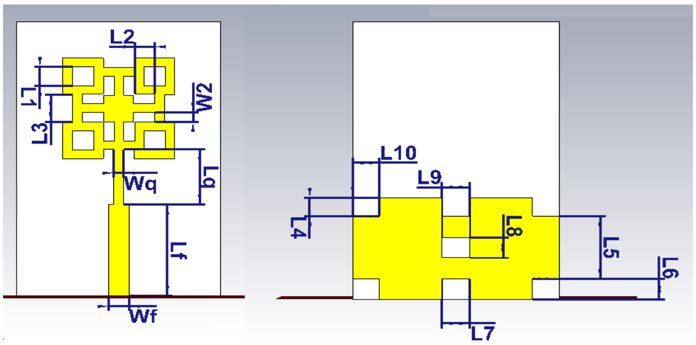

Fig 2. Structure of the Proposed Antenna (Front and Back View)

Table 1. Dimensions of the Proposed Antenna

Name of the parameter	Value (in mm)
Length of the substrate (L_s)	30
Length of the ground (L_g)	12
Width of the substrate (W_s) and width of ground (Wg)	20
Length of the feed (L_f)	10
Width of the feed(Wf)	2
Width and Length of the patch ($W_p = L_p$)	11
Height of the substrate (h)	1.6
The thickness of the patch (t)	0.035
Length of quarter wave transition (Lq)	6
Width of quarter wave transition (Wq)	1
W2	1
L1	2
L2	2
L3	3
L4	2
L5	6.8
L6	2.2
L7	2.7
L8	2.2
L9	2.7
L10	2.6

The antenna was then fabricated using MITS electronics' Eleven Lab antenna printing machine at RF lab of BNMIT and the antenna was then tested for return loss (S_{11}) measurement using Keysight's PNA-L N5232A Network analyser at BMSCE as in Fig.3.

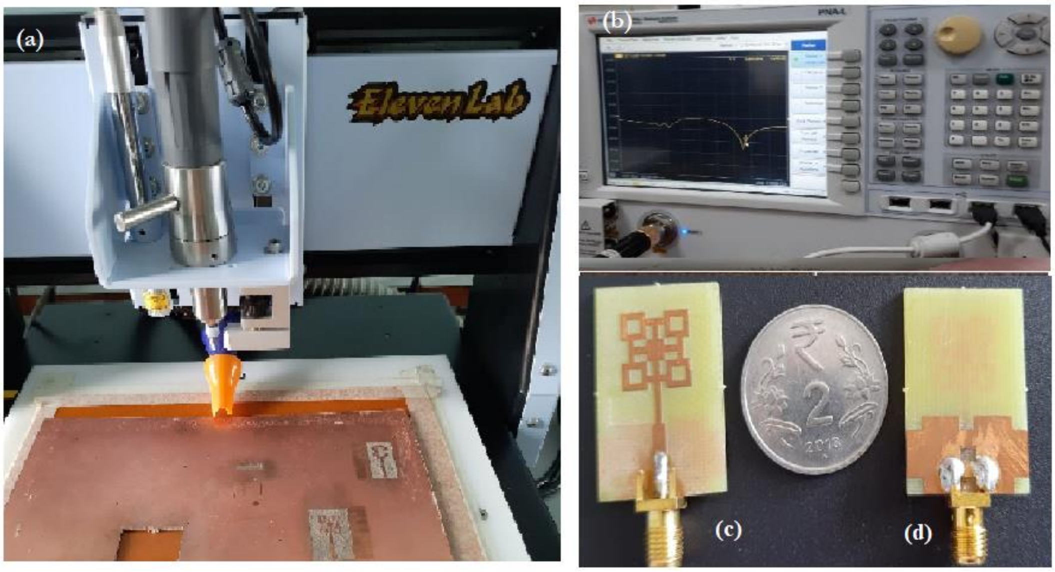

Fig. 3 Fabrication and return loss measurement setup: (a) Antenna milling Machine (b) Network analyzer (c) and (d) Front and Rear views of the printed antenna

3. RESULT AND ANALYSIS

The purpose of this section is to investigate the performance of the microstrip antenna in free space and on the human body. To achieve this, the antenna is simulated by using the CST Microwave Studio simulation tool. Fig.4 and Fig.5 illustrate the reflection co-efficient and the radiation pattern of the antenna in the free space.

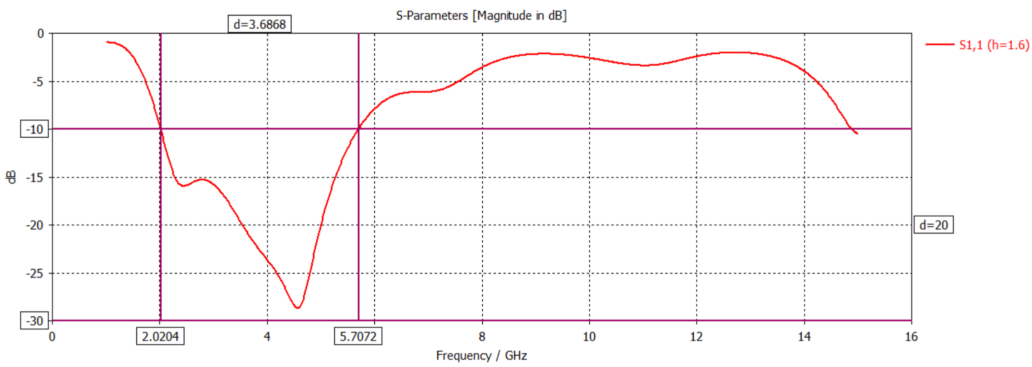

Fig 4. S_{11} of the proposed antenna in Free Space

The antenna has a wide bandwidth from 2.02 to 5.7 GHz, and it can be used for many wireless applications at 2.4GHz and 3.8GHz. The antenna's return loss in free space at 2.4GHz is -15.26 dB, and its directivity in free space is 2.988 dBi and at 3.8 GHz the return loss is -21dB and directivity is 2.981dBi.

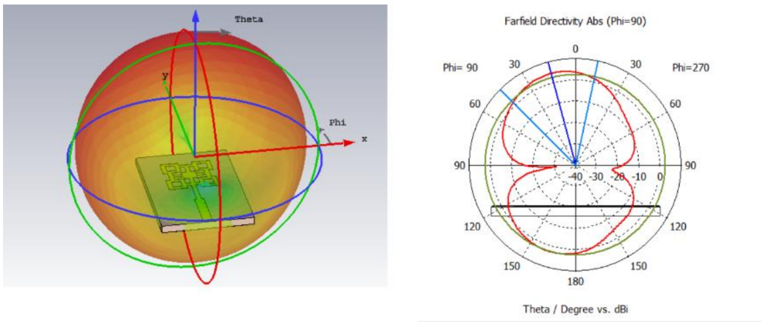

Fig 5. Radiation pattern in free space at 2.4 GHz

Furthermore, the antenna was placed on the human model, Gustav, a 38-year-old male who is 176 cm and 69 kg as shown in Fig.6. The antenna was simulated in CST to obtain the antenna parameters and SAR value. When the antenna was placed at a distance of 1mm from the human body model, the antenna detuned completely. To achieve the wide bandwidth, the antenna was moved away from the body and it was found that at 20mm from the body, the return loss of the antenna was found to be similar to that of free space return loss.Fig.7 and Fig.8 show the reflection co-efficient and the radiation pattern of the antenna on the human body .

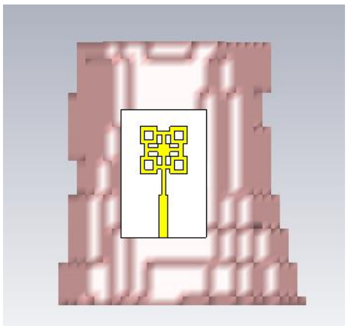

Fig 6. Antenna on the human body model Gustav

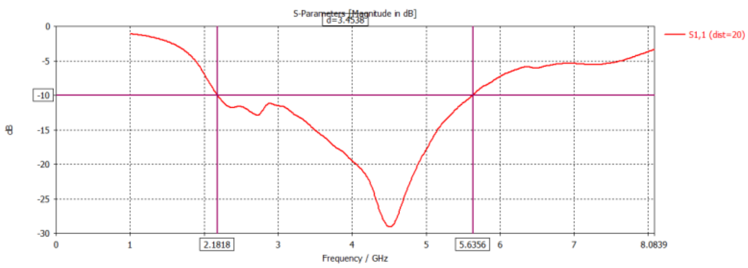

Fig 7. S_{11} of antenna at a distance of 20mm from the human body model

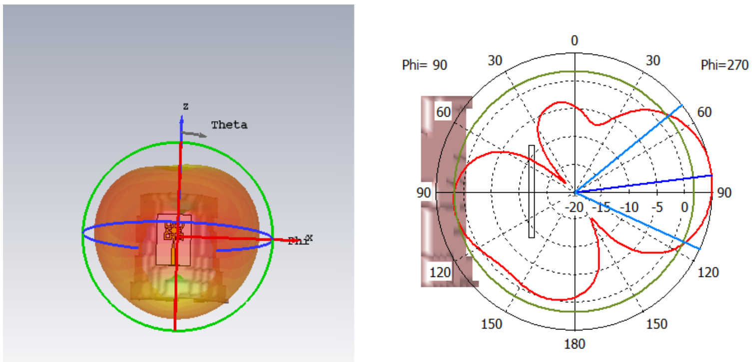

Fig 8. Radiation pattern on the human body

At a distance of 20 mm from the human body, the antenna was found to have a bandwidth of 2.18 – 5.63 GHz. The gain of the antenna on the human body is 1.601 dBi and 1.757dBi at 2.4GHz and 3.8GHz respectively.

Specific Absorption Rate, also known as SAR, is a measurement of how much energy is absorbed per unit mass. The unit for SAR is W/kg. The SAR is calculated for 1g at different frequencies and for different input powers are tabulated in Table 2.

Table 2. SAR of the Antenna at Different input power and frequencies

Input Power (W)	Frequency (GHz)	SAR Value (W/kg)
0.5	2.4	2.565
	3.8	1.298
0.4	2.4	2.052
	3.8	1.03894
0.3	2.4	1.53902
	3.8	0.77923

The SAR value of the antenna was determined to be 1.53902W/kg for 1g of tissue at the frequency of 2.4 GHz with an input power of 0.3 W, as illustrated in Fig.9. The SAR value is well within the Federal Communications Commission's (FCC) public exposure standard. As a result, the suggested ultra-wideband antenna can be utilised for on-body communication.

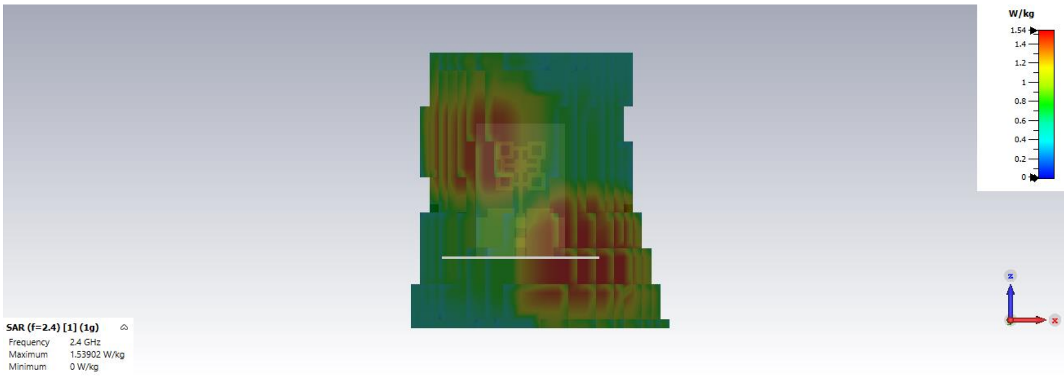

Figure 9: SAR of the Antenna for 1g of tissue at 2.4GHz

Furthermore, various parameters such as directivity, gain, VSWR, etc are measured and compared when the antenna is in free space and at a distance of 20mm from the human body, which is tabulated in Table 3.

Table 3. Antenna parameters when the antenna is in free space and on the human body.

Antenna Parameters	In Free Space @2.4GHz	In Free Space @3.8Ghz	At a distance of 20mm from Human Body@2.4GHz	At a distance of 20mm from Human Body@3.8Ghz
Directivity (in dBi)	2.988	2.981	4.983	4.101
Gain (in dB)	0.5073	0.9223	1.601	1.757
Reflection Coefficient (in dB)	-15.26	-21	-11.73	-17.64
Peak Surface Current (in A/m)	97.93	73.60	58.408	53.27
VSWR	1.33	1.19	1.69	1.30
Radiation Efficiency (in dB)	-2.481	-2.059	-3.383	-2.344

4. CONCLUSION

In this work, a slotted microstrip patch antenna in the UWB band was simulated, printed and tested. Because of its compact size and ease of manufacture, this antenna is a preferable choice. Several simulated results in free space and on the human body were seen. In free space, the antenna was found to operate from 2.02GHz – 5.7GHz, with 3.68GHz bandwidth. On the human body, the antenna was found to operate from 2.18GHz – 5.63 GHz, with 3.45 GHz bandwidth. The SAR value of the antenna on the body was also well within the limit of 1.6 W/kg. Lastly, from all the results, it was understood that the antenna was capable of on-body communication and produced less detrimental effects on the human body.

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