Design of UWB Antenna for Human Body Communication

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Abstract:*A diamond-shaped patch antenna with slots for desirable return loss, gain, and bandwidth was designed to achieve the intended goal. ROGERS 5880 was chosen as the substrate material and the antenna was simulated using CST (Computer simulation Technology) software. The designed microstrip patch antenna has a bandwidth from 2.12 to 9.24 GHz. The proposed antenna was put on the human body and had a SAR value of 1.44 W/kg, which was determined to be within the acceptable limit of 1.6 W/kg. Hence, the antenna can be used for on-body communication which is not detrimental to the human body.*

Keywords:**Microstrip Patch, SAR, Ultra-Wideband, SAR, Reflection Co-efficient, S_{11}, CST.**

1. INTRODUCTION

Due to the compact use of electronic embedded systems and hardware for a range of applications, such as medical sensor networks, emergency service personnel, and personal communications, on-body communication channels are becoming increasingly common. [1]. For on-body communication, the antennas must comply with certain requirements. The UWB technology has shown promising results since it can provide a broad BW with less power, and the usage of ultra-wideband communication for antenna design gives numerous benefits over the typical narrow band. UWB is feasible due to its higher attainable data rates and increased immunity to interference due to lower spectral power density.

On the other hand, antenna designing for a UWB is very challenging as there are effects on the human body that needs to be considered. It should be kept in consideration of the gain and radiation pattern of the antenna on the human body for on-body communication. At communication frequency, the human body functions as a lossy dielectric, and EM radiation produced by mobiles may penetrate semisolid objects such as living tissues [2]. The antenna models must be built and tuned in such a way that the most important human tissues in the abdomen area may be modelled without causing any negative consequences. [3]. 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. [4]. The microstrip line feed is a popular feeding approach because it is simple to construct, model, and match impedance. The varied shapes in which the patch is designed to give a variety of output parameters that allow the antenna to get better and efficient [5]. Since the antenna stands out for high frequencies the slotted patch antenna models serve for large bandwidth and therefore these types of antennas become an effective candidate [1].

In [4], the impedance bandwidth attained is 130 percent from 2.8 to 12 GHz, with an average gain of around 3.5dBi. Because the antenna has a basic construction and is straightforward to make, it might be utilized for wireless communication. When modelled on the human body, the results demonstrate that this antenna does not suffer from significant frequency detuning due to free space resonance over the entire frequency range.

The effects of the human body on antenna gain are investigated and a mathematical relationship is put forward relating the fluctuation of distance from the body and the antenna gain. Using a half-wave dipole antenna, the analysis indicates that the gain values are linear up to a quarter wavelength, exponential up to one wavelength, and then linear again[6].

2. ANTENNA DESIGN

The microstrip antenna was designed for a resonant frequency of 8.9 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 formulae:

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

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

The side of the diamond-shaped antenna as shown in Fig.1, is calculated to be 11.36 and the thickness of the patch is taken as 0.035 mm. Both the ground plane and the patch are made from copper. ROGERS 5880 having a dielectric constant of 2.2, 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.

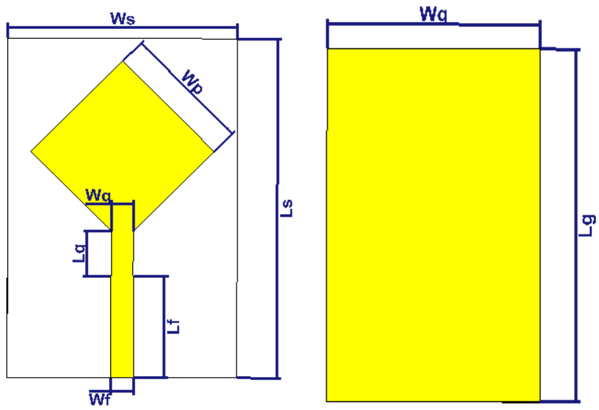

Figure 1. Structure of the Base Antenna (Front and Back View)

The diamond-shaped patch length was optimized to 11.31mm to improve the bandwidth. Later, as illustrated in Fig.2, slots and slits were incorporated, as well as a reduction in the ground plane, to boost efficiency, enhance impedance matching, and expand the antenna's bandwidth. [10].

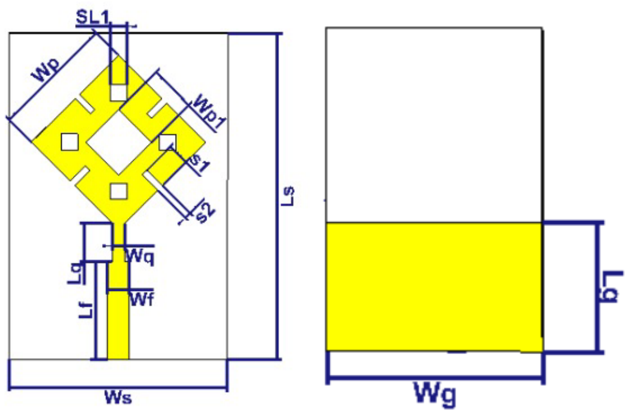

Figure 2. Structure of the Proposed Antenna (Front and Back View)

The base antenna has been modified by performing 3 different iterations - introducing a slot at the centre, 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 I.

Table I. 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)	20
Width of the ground (W_g)	20
Length of the feed (L_g)	9
Width and Length of the patch ($W_p = L_p$)	11.31
Height of the substrate (h)	1.6
The thickness of the patch (t)	0.035
Length of centre slot (W_{p1})	4.24
Length of slot (SL1)	1.5
Length of the slit (s1)	2
Width of the slit (s2)	0.6

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.3 and Fig.4 illustrate the reflection co-efficient and the directivity of the antenna in the free space.

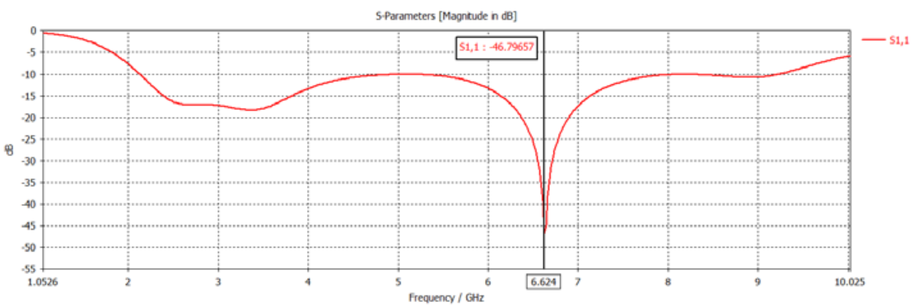

Figure 3. S11 of Antenna in Free Space

The antenna's return loss in free space is -46.79657 dB, and its directivity in free space is 2.638 dBi at 6.624 GHz, as illustrated in Figs. 3 and 4. Since the antenna operates from 2.12 - 9.24 GHz, it can be used for ultra-wideband applications.

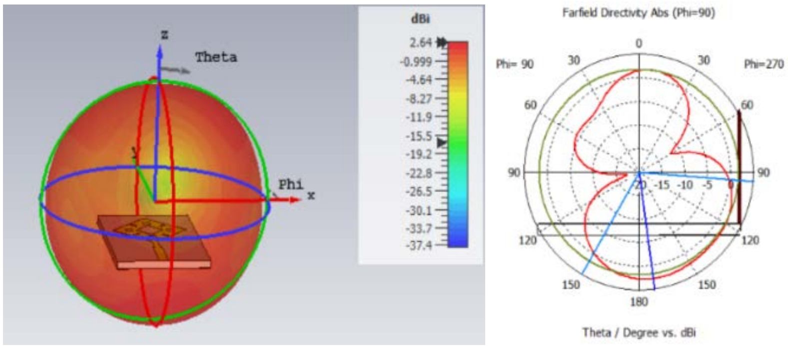

Figure 4. Directivity in Free Space at 6.624 GHz

Furthermore, the antenna is placed on the human model, Gustav, a 38-year-old male who is 176 cm and 69 kg as shown in Fig.5. The antenna is simulated in CST to obtain the antenna parameters and SAR value. Before the simulation, a layer called 'air' was constructed behind the ground plane and then the antenna was placed on the skin. The 'air' layer is important as the position of the antenna is critical due to the radiation effects on the human skin.

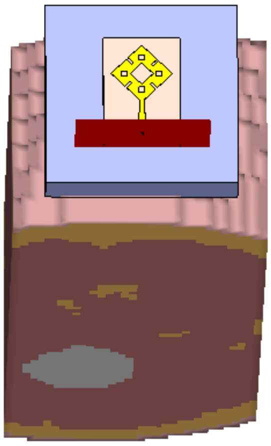

Figure 5. Antenna on the Human Body

Fig.6 and Fig.7 show the reflection co-efficient and the directivity of the antenna on the human body.

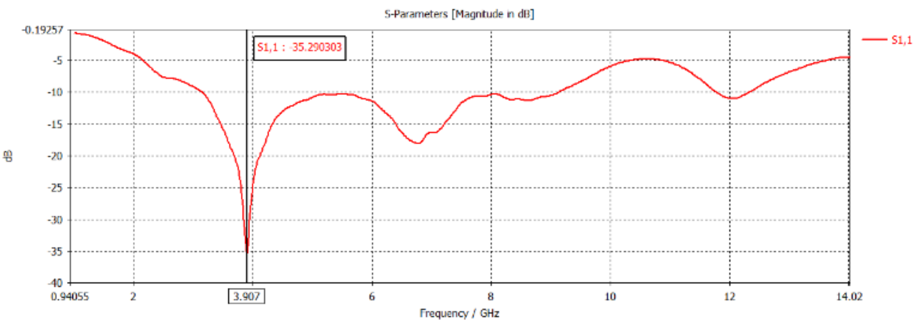

Figure 6. S_{11} of Antenna on the Human Body

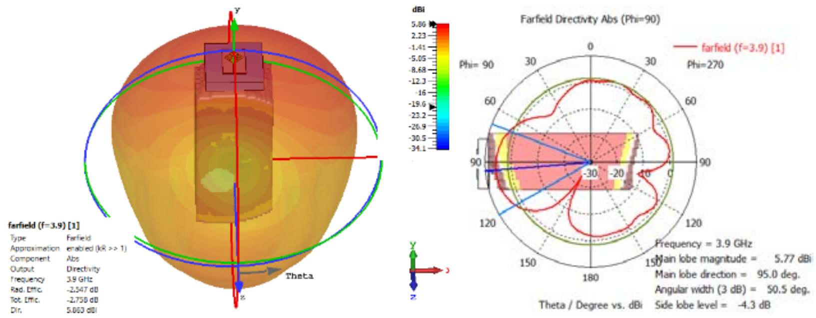

Figure 7. Directivity on the Human Body at 3.9 GHz

At a distance of 10 mm from the human body, the antenna was found to have a bandwidth of 3.152 - 9.132 GHz. As shown in Fig.6 and Fig.7, the return loss of the antenna on the human body is -35.29 dB and the directivity of the antenna on the human body is 5.852 dBi at 3.888GHz.

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 for different input powers regulated by IEEE C95.3 standard which are tabulated in Table II.

Table II. SAR of the Antenna at Different Frequencies

Input Power (W)	Frequency (GHz)	SAR Value (W/kg)
0.5	3.9	1.8511
	5.8	1.838
0.4	3.9	1.4809
	5.8	1.4708

The SAR value of the antenna was determined to be 1.4809 W/kg for 1g of tissue at the frequency of 3.9 GHz with an input power of 0.4 W, as illustrated in Fig.8. 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.

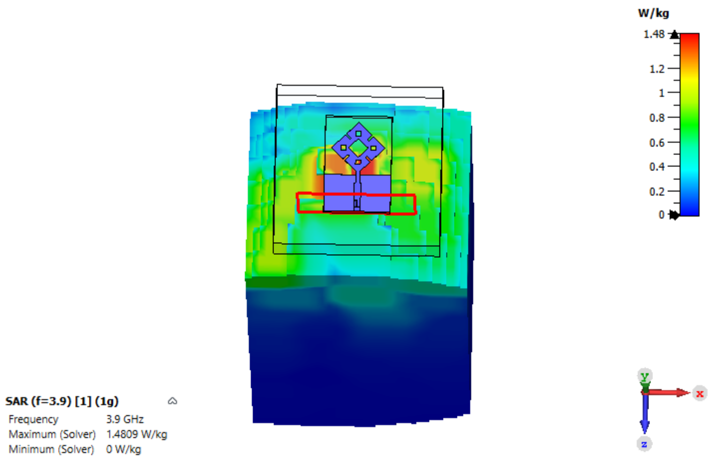

Figure 8: SAR of the Antenna for 1g of Tissue

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 10mm from the human body, which is tabulated in TABLE III.

Table III. Antenna Parameters when the Antenna is in Free Space and on the Human Body.

Antenna Parameters	in Free Space	At a distance of 10mm Human Body
Directivity (in dBi)	2.638	5.863
Gain (in dB)	1.392	3.36
Realized Gain (in dB)	1.16	3.105
Reflection Co-efficient (in dB)	-46.7966	-35.29
Peak Surface Current (in A/m)	114.774	38.0966
VSWR	1.009	1.034
Total Efficiency (in dB)	-1.478	-2.785
Radiation Efficiency (in dB)	-1.245	-2.547

4. CONCLUSION

In this work, a diamond-shaped microstrip patch antenna in the UWB band was developed and simulated. 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 2.12GHz - 9.24 GHz, with 7.12 GHz bandwidth. On the human body, the antenna was found to operate from 3.152 GHz – 9.132 GHz, with 5.98 GHz bandwidth. The SAR value of the antenna on the body was 1.44 W/kg which is 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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