Design of an Ultra Wide Band (UWB) Antenna and its Performance Analysis at the on and off Body Environment

Md. Ashif Islam Oni[a], Shahriar Hasan Shehab[b], S.M. Reza Khurshid[c], Md. Badruzzaman[d], Shuvashis Dey[e]

[a,b,c,d] Department of Electrical and Electronic Engineering, American International University-Bangladesh (AIUB), Banani, Dhaka-1213, Bangladesh

[e] Department of Electrical and Computer Systems Engineering, Monash University, Australia

md.ashif.islam.oni@gmail.com, shahriar.hasan.shehab@gmail.com, rezablackberrybold@gmail.com, jitu_aiub@yahoo.com, shuvashis.dey@monash.edu

Abstract. Design of a U-slotted circular patch Ultra Wide Band)UWB(antenna on Jeans substrate which can be easily worn is presented in this paper, and then imposed on human body environment for Wireless Body Area Network (WBAN) applications. Comparison of the performance of the designed antenna is done at the on and off body environment in terms of return loss, radiation pattern and voltage standing wave ratio (VSWR). The antenna provides an operational frequency band from 6.6342 GHz to 16.58 GHz, but for analyzing the performance 7-14 GHz frequency band is used. Electro textile material, Denim jeans (ε_r= 1.7) is used as the antenna substrate. A human body model having three layers (skin, fat and muscle) is then developed and the antenna is applied on this body model to investigate the characteristics and performance and also the impact of human body layers on the antenna. The whole observation on human body model is carried out at four different frequencies: 8 GHz, 10 GHz, 12 GHz and 14 GHz.

Keywords: Ultra Wide Band(UWB), Textile Antenna, Circular patch, WBAN, VSWR, Human body model and Electro-textile material.

1 INTRODUCTION

Wireless Body Area Network (WBAN), a highly localized wireless network which includes healthcare monitoring, sports and fitness, gaming, lifestyle, entertainment and military health. And body-worn antenna for WBAN has received much attention since past few years (Hall *et al*. 2006), (Latre *et al*. 2011). Body area networks (BAN) are a Natural progression from the personal area network (PAN). This network enables wearable computer devices to interact with each other and exchange digital information using the electrical conductivity of the human body as a data network (Santas *et al.* 2007), (Dey *et al. 2011*). With the recent development of wireless communication technology, many researchers pay great attention to the study of Wireless Body Area Networks (WBAN). The application of WBAN has been expanding in medical services, national defense, wearable computing and so forth (KIM *et al.* 2011). Several frequency bands have been assigned for WBAN systems, such as medical implant communication system (MICS: 400 MHz) band, the Industrial Scientific Medical (ISM: 2.45 GHz and 5.8 GHz) band and the Ultra Wide band (UWB: 3.1-10.6 GHz) (Hall *et al*. 2006).

There will be no effective wireless communication between two entities without antenna. Antenna brings the whole wireless world together. Wearable intelligent textile system is an innovative fast growing field in application oriented field (Stamer 2005).The textile antenna is a fundamental part of wireless body area networks. Enhancement in communication and electronic technology has enabled the development of compact and intelligent antenna devices which can be positioned on the human body or implanted inside it (Alomainy *et al.* 2007). Such body wearable antennas should be hidden and unobtrusive (Hertleer *et al.* 2007). Miniaturization in microelectronics along with other technologies allows these antennas to integrate into clothing paving the way to the development of wearable wireless devices. The textile antenna system can be used for a wide variety of applications including solution for real time physiological measurements systems, pulse rate monitoring in sports, and navigation support in the car and so on. They can also be used to keep continuous record of wearer's health by monitoring their vital signs. Textile antennas also assist the emergency services such as fire fighters, detective and police (Hertleer *et al.* 2009). It also helps to establish communication between the soldiers and other units of the modern battle field including unmanned aerial vehicles (Hertleer *et al.* 2007).

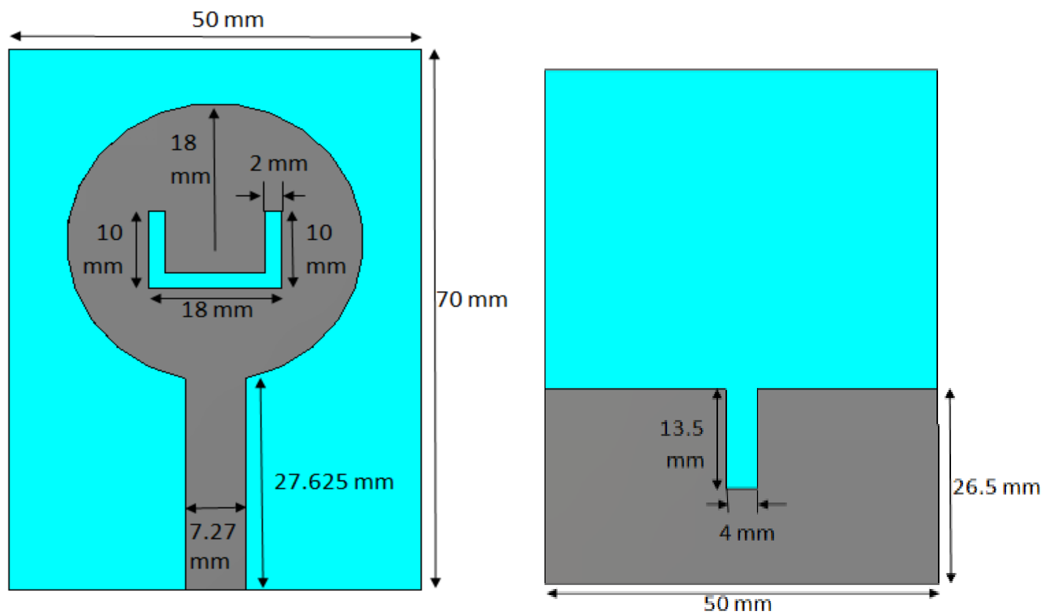
In this paper, the designed textile antenna is integrated fully into the garment to preserve flexibility and comfort. The antenna has a flat, planar structure to be comfortably worn. The antenna does not disturb the movement of the wearer since it is light weight and flexible. The radiation efficiency, cost effectiveness, ease of system integration and immunity to performance degradation are also the factors to consider while designing the antenna. The Ultra Wide Band antenna is designed here for operating at the wide band WBAN at the frequency level between 7-14 GHz for short range communication. This paper mainly focuses to evaluate the designed antenna's performance on human body. This phenomenon is achieved by creating three significant layers of human body which includes skin, fat and muscle. Originality of this work is-the antenna is designed on textile materials and works at 7-14 GHz frequency band for planar structure irrespective of off or on body environment. This paper also compares the performance and characteristics of the designed antenna at both the on and off body area in terms of return loss, radiation properties and VSWR. The structures are designed and analyzed using CST Microwave Studio software package.

2 SUBSTRATE MATERIAL SELECTION

The permittivity of a material is usually given relative to that of free space which is known as relative permittivity or dielectric constant; ε_r. Dielectric constant of the antenna substrate has a significant role in the antenna designing. Different substrates having different dielectric constants affect the antenna performance in various ways. The substrate selected for the designed circular patch UWB antenna is electro textile material, denim jeans with $\varepsilon_r = 1.7$. Selection of material for designing the antenna is unique in this paper. Jeans is excellent in clothing, absorbency, durability, and resilience. Some other properties of jeans include high tensile strength and high resistance to stretching (Sankaralingam *et al.* 2010). It is less flammable too (Sankaralingam *et al.* 2010). The patch and ground plane are made of copper threads which are perfect electrical conductors (PEC).

3 ANTENNA DESIGN AND IMPLEMENTATION

The designed circular patch Ultra Wide Band Antenna has an operational frequency band from 7 GHz to 14 GHz. The circular patch of the antenna is fed by a 50 ohm Microstrip feed line with a width of 7.27 mm. The ground plane is attached on the lower half of the back of the substrate with the dimension 50 x 26.5 x 0.7 mm^3. There is a rectangular shape slot in the ground plane with dimension 4 x 13.5 x 0.7 mm^3. The radiating patch and ground plane are made of copper tape with the thickness of 0.7 mm. However, the dimension of the substrate is 50 x 70 x 2 mm^3, length of the transmission feed line is 27.625 mm and radius of the circular patch is 18 mm. There is a 2 mm thick U-shaped slot in the circular patch, two arms of the U-shape slot is 10 mm long and the base is 18 mm long. Overall thickness of the antenna is 3.4 mm.



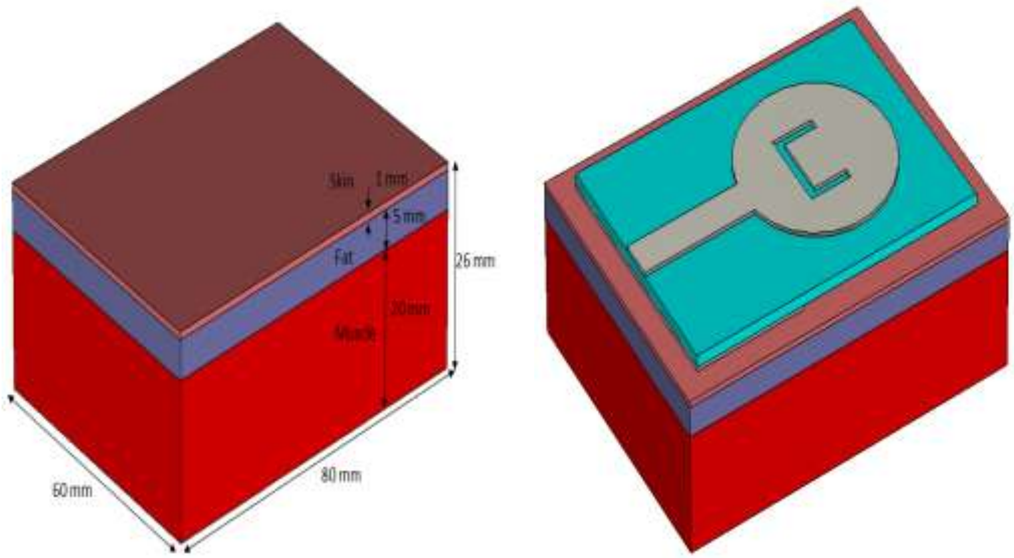
(a) Front view (b) Back view

Fig. 1. (a) Front view and (b) back view of designed Circular Patch UWB Antenna.

Table 1. UWB Antenna Measurements for Designing Purpose.

Parameters (mm)	**Dimensions (mm)**
Circular Patch Radius	18
Circular Patch Thickness	0.7
Substrate Length	70
Substrate Width	50
Substrate Thickness	2
Ground Length	26.5
Ground Width	50
Ground Thickness	0.7
Feed Length	27.625
Feed Width	7.27
Feed Thickness	0.7

4 LAYERED HUMAN BODY MODELLING AND ANTENNA IMPLEMENTATION



(a) (b)

Fig. 2. Layered Human Body Model and (b) UWB Antenna Implemented on Human Body Model.

The dimension of modeled layered human body is 60 mm x 80 mm x 26 mm. It consists of three different layers: skin (dry), fat and muscle. This layered model can quite well represent most of the body regions, since the fat has similar properties to the bone tissue, and the electrical parameters of the muscle and many inner organs are alike (Dey *et al.* 2013). Fig. 2(a) represents the layered human body model and 2(b) represents the implemented UWB antenna on human body model. Commercial electromagnetic simulation package CST Microwave Studio was used for design & simulation purposes. Table 2 shows the electrical dispersion of layered human body model for UWB frequencies which is obtained by (Calculation 2013).

Table 2. Layered Human Body Model Material Properties.

Tissue name	Frequency [GHz]	Conductivity [S/m]	Relative permittivity, ε_r
Skin (Dry)	8	5.8242	33.184
	10	8.0138	31.29
	12	10.337	29.327
	14	12.688	27.364

Fat	8	0.44301	4.7622
	10	0.58521	4.6023
	12	0.72783	4.457
	14	0.86783	4.3255
Muscle	8	7.7978	45.497
	10	10.626	42.764
	12	13.55	40.101
	14	16.472	37.564

5 PERFORMANCE ANALYSIS OF DESIGNED UWB ANTENNA

The performance of the designed UWB antenna was measured at the on and off body environment over the frequency range (7-14) GHz.

5.1 Performance Analysis at Off Body Environment

5.1.1 Return Loss (S_{11})

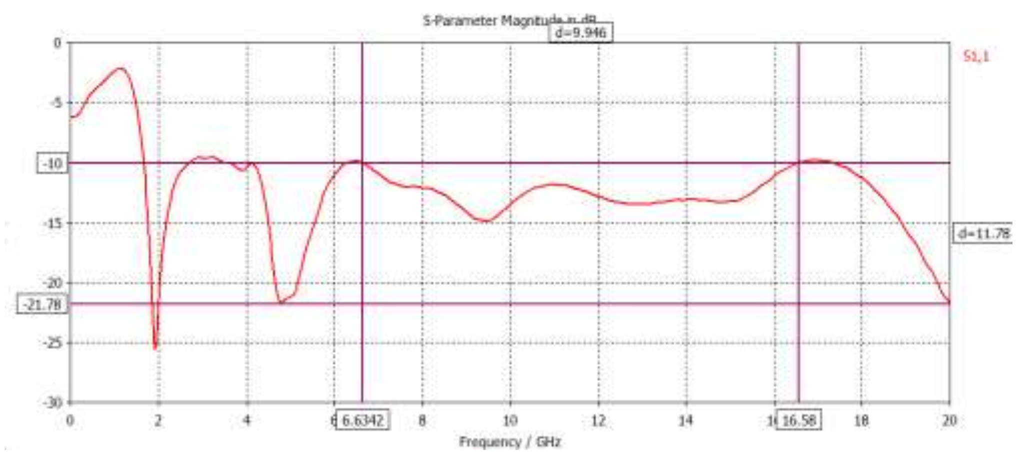


Fig. 3. Simulated S_{11} of designed UWB antenna at off body environment.

The S-parameter of circular patch UWB antenna in Fig. 3 demonstrates a good impedance matching with a return loss less than -10 dB achieving frequency band from 6.6342 GHz to 16.58 GHz for Jeans fabric substrate. This indicates that the performance of the textile material is better on the antenna perspective. But here in this paper, frequency band 7-14 GHz is considered for performance analysis which satisfies S_{11}< -10 dB condition and that means it has got good impedance matching with all over its occupied bandwidth.

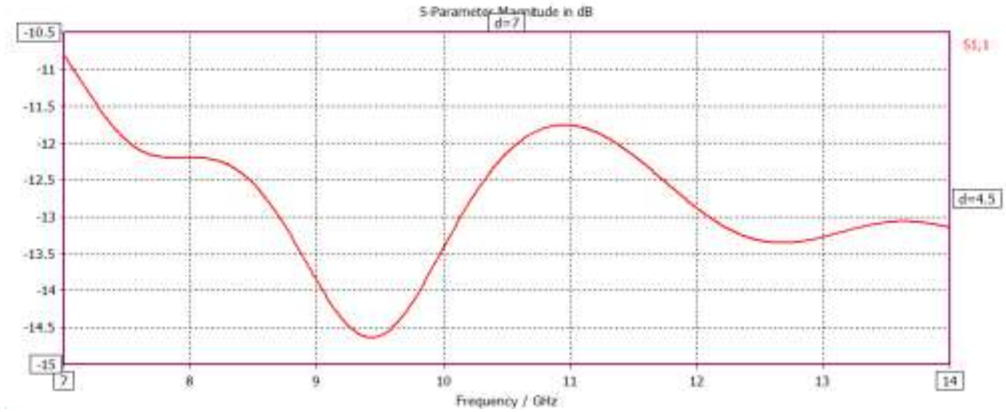


Fig. 4. Considered S_{11} of designed UWB antenna for performance analysis.

5.1.2 Radiation Pattern

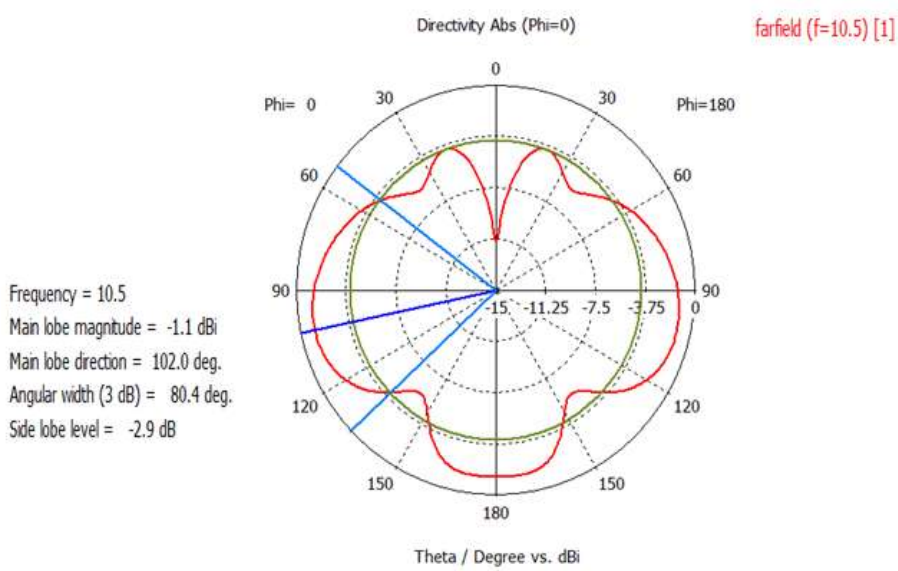


Fig. 5. Radiation Pattern of E-plane of designed UWB antenna at off body environment.

For attaining the E- plane radiation pattern as shown in Fig. 5, phi (φ) has been set to 0 for all values of theta (θ). The power is radiated mostly in the left and right hemisphere; the power is directed towards 102 degree with main lobe magnitude of -1.1 dBi. 3 dB angular beamwidth (i.e., HPBW) is 80.4 deg. Omni directional radiation pattern is observed.

5.1.3 3D Radiation Pattern, Directivity, Gain and Efficiency

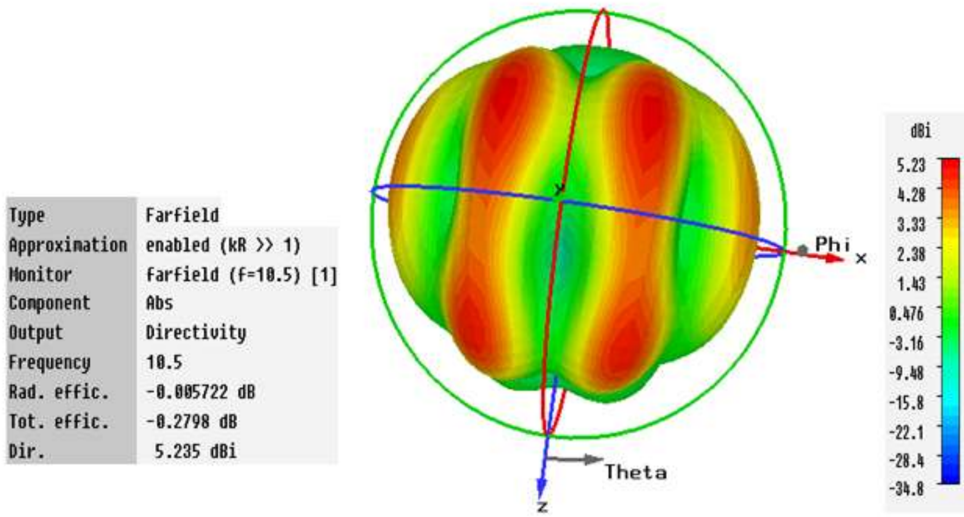


Fig. 6. 3D Radiation Pattern of designed UWB antenna at off body environment.

The simulated result of Omni directional radiation pattern at off body environment is shown in 3D in Fig. 6. The result shows the directivity of 5.235 dBi of the designed UWB antenna at off body environment. Gain and total efficiency of the antenna are measured 5.229 dB and 0.9376 respectively. And radiation efficiency is 0.9987. Total efficiency and radiation efficiency are calculated in linear scale.

Table 3. Radiation characteristics of designed UWB antenna.

Parameters	**Simulation Results**
Directivity (dBi)	5.235
Gain (dB)	5.229
Total Efficiency	0.9376
Radiation Efficiency	0.9987

5.1.4 Voltage Standing Wave Ratio (VSWR)

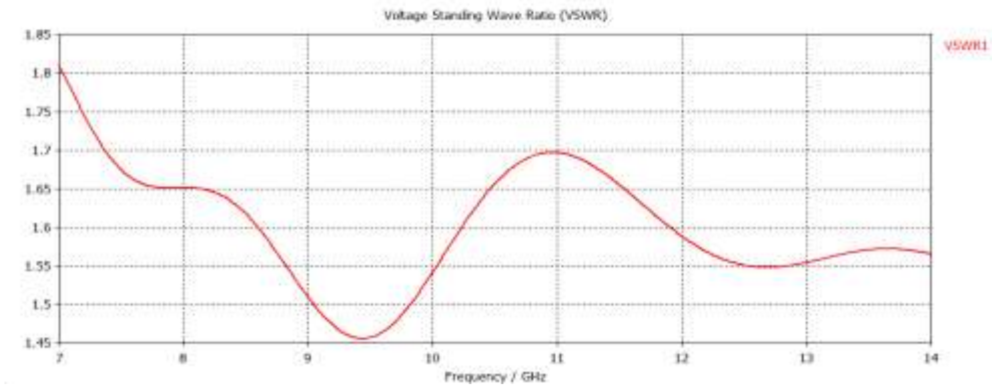
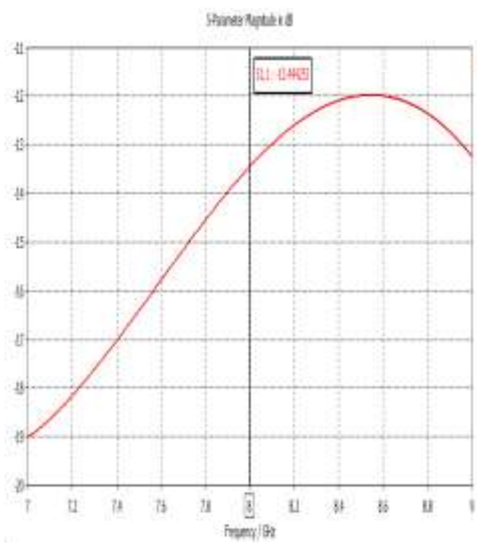


Fig. 7. Simulated VSWR of designed UWB antenna at off body environment.

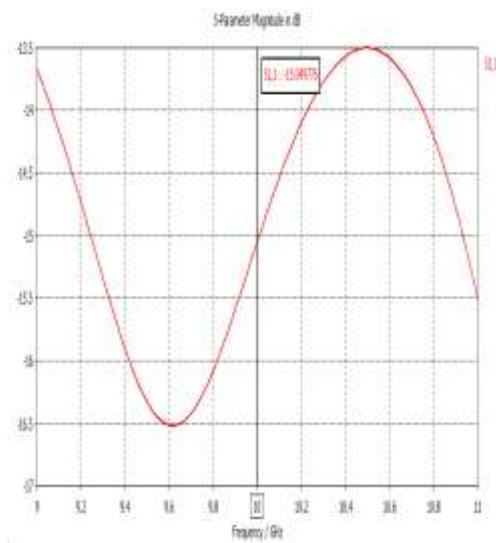
The simulated VSWR curve of designed UWB antenna is shown in Fig. 7. VSWR below 2 is considered well for an antenna (Hall *et al. 2006*), (Oni *et al.* 2014). For this designed antenna, VSWR is less than 2 from 7-14 GHz at off body environment, which shows a good impedance matching between antenna and transmission line. Thus a very less number of incident waves reflect back to the source.

5.2 Performance Analysis at On Body Environment

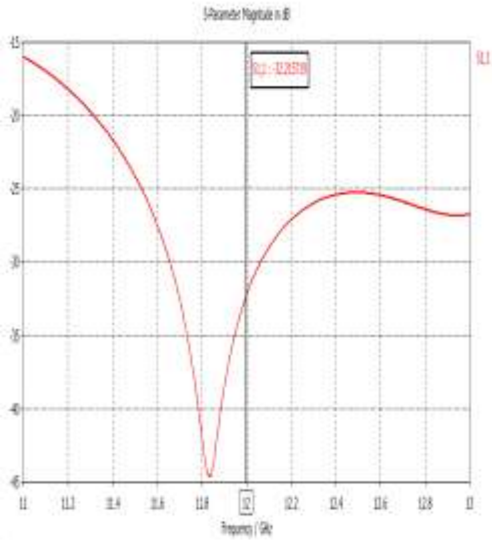
5.2.1 Return Loss (S_{11})



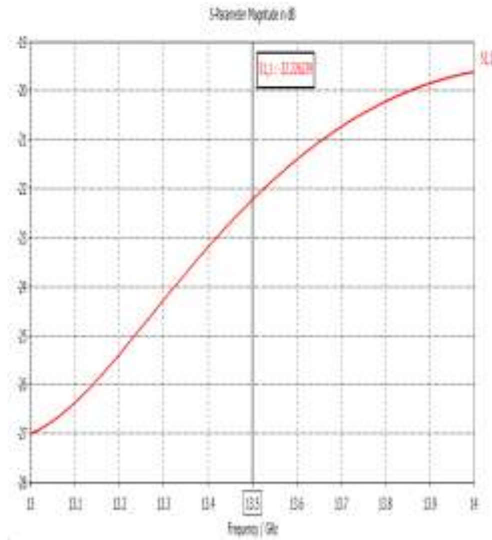
(a) 8 GHz



(b) 10 GHz



(c) 12 GHz



(d) 14 GHz

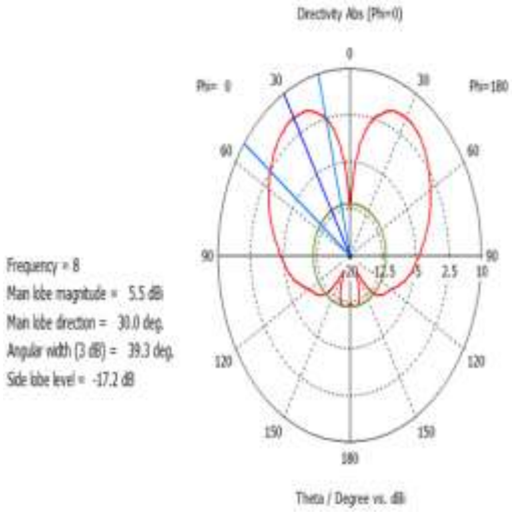
Fig. 8. Simulated S_{11} of designed UWB antenna at on body environment at (a) 8 GHz, (b) 10 GHz, (c) 12 GHz and (d) 14 GHz.

Fig. 8 illustrates the simulation result of S_{11} of designed antenna at on body environment at different frequencies. Table 4 summarizes the simulation result of S_{11} at different frequencies. Table 4 shows that all the S-parameters maintain $S_{11} < -10$ dB, which means antenna has got a good impedance matching with all over its occupied bandwidth.

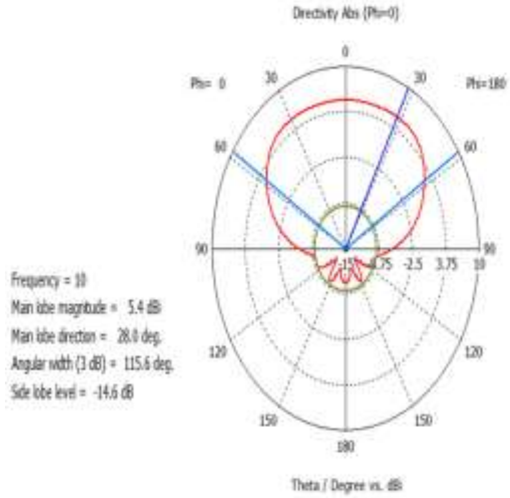
Table 4. S-parameter of designed antenna at on body environment at different frequencies.

Parameters	**Simulation Results**			
Frequency (GHz)	8	10	12	14
S Parameter (dB)	-13.444253	-15.049776	-32.215719	-22.2262

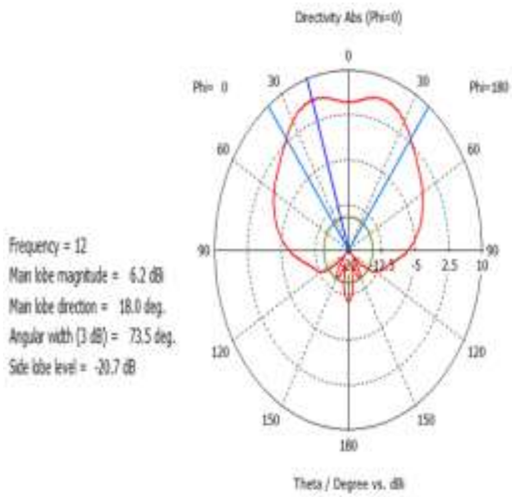
5.2.2 Radiation Pattern



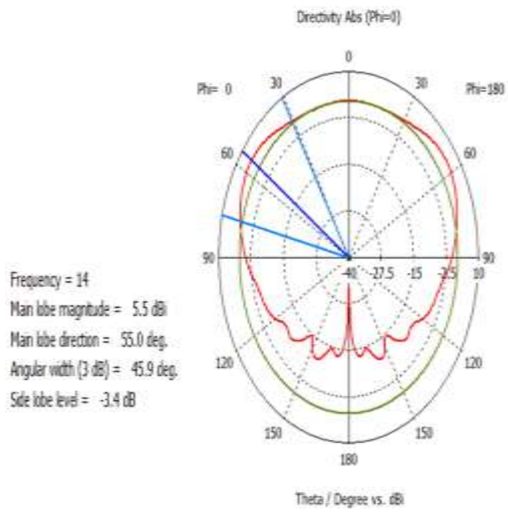
(a) 8 GHz



(b) 10 GHz



(c) 12 GHz



(d) 14 GHz

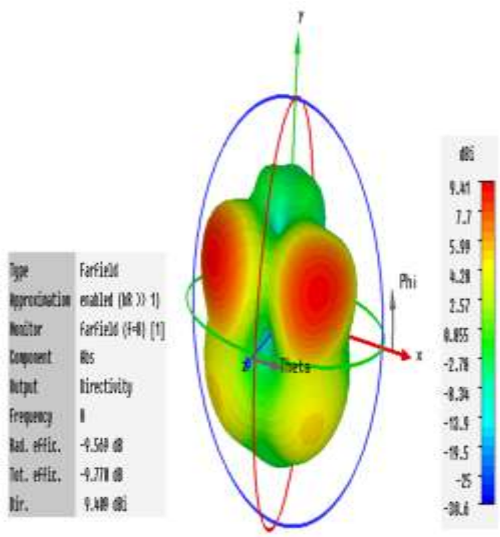
Fig. 9. Radiation pattern of E-plane of designed UWB antenna at on body environment at (a) 8 GHz, (b) 10 GHz, (c) 12 GHz and (d) 14 GHz.

E- plane radiation patterns of the designed antenna at on body environment at different frequencies are shown in Fig. 9. Fig. 9 shows that most of the power is radiated in the upper hemisphere at all the observed frequencies. Directional radiation patterns are observed except at 8 GHz. Other parameters are summarized in Table 5.

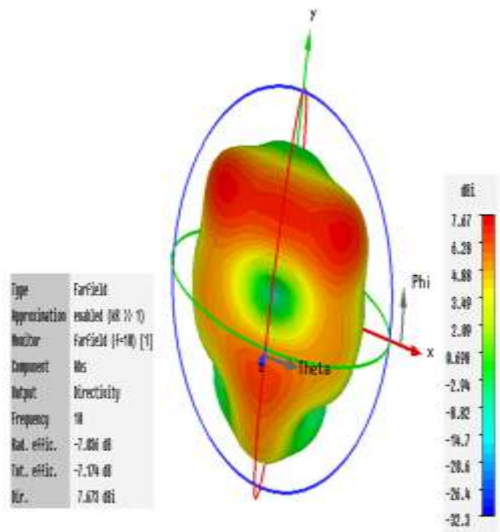
Table 5. Radiation pattern of designed antenna at on body environment at different frequencies.

Parameters	**Simulation Results**			
Frequency (GHz)	8	10	12	14
Main Lobe Magnitude (dBi)	5.5	5.4	6.2	5.5
Main Lobe Direction (deg.)	30.0	28.0	18.0	55.0
HPBW (deg.)	39.3	115.6	73.5	45.9

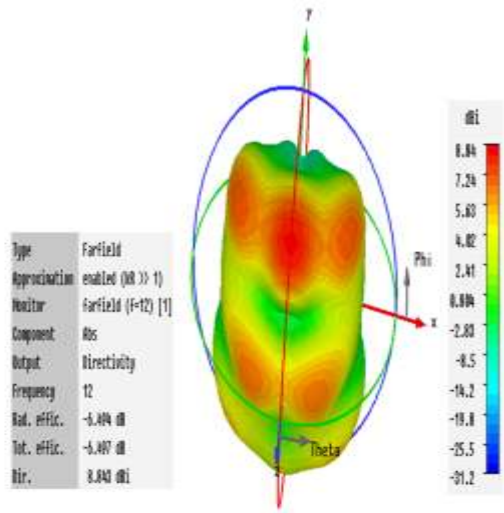
5.2.3 3D Radiation Pattern, Directivity, Gain and Efficiency



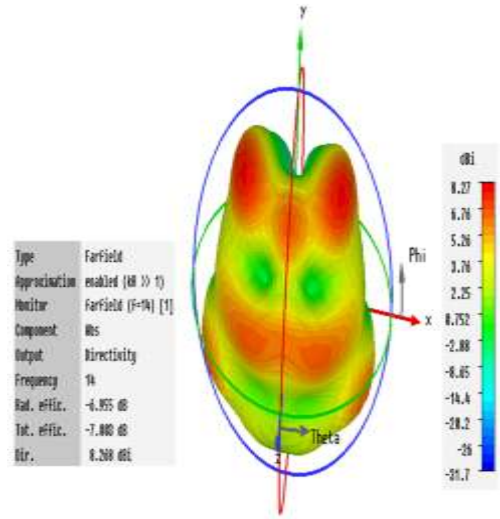
(a) 8 GHz



(b) 10 GHz



(c) 12 GHz

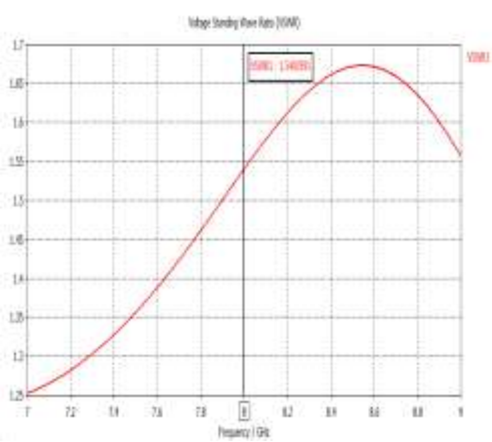


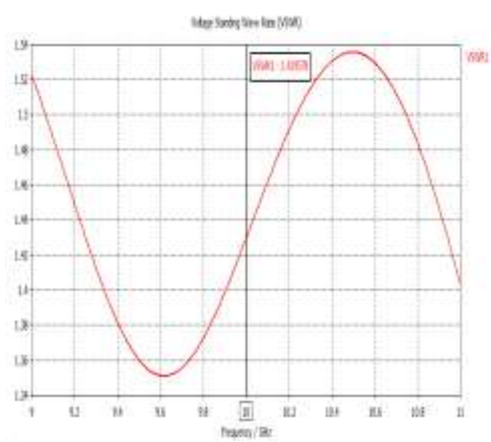
(d) 14 GHz

Fig. 10. 3D Radiation pattern of designed UWB antenna at on body environment at (a) 8 GHz, (b) 10 GHz, (c) 12 GHz and (d) 14 GHz.

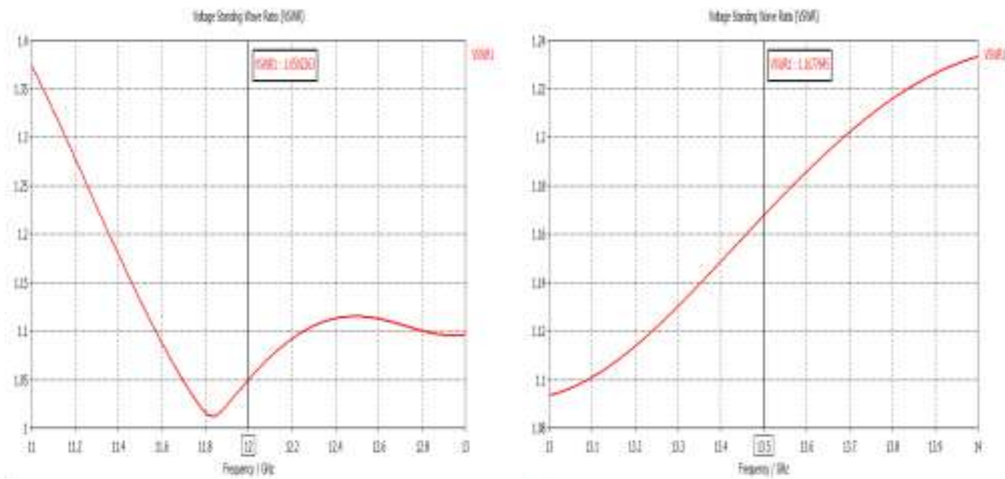
The simulated results of 3D radiation pattern of the antenna at on body environment at different frequencies are shown in Fig. 10. The results show the directivity at 8 GHz, 10 GHz, 12 GHz and 14 GHz are 9.409 dBi, 7.673 dBi, 8.843 dBi and 8.268 dBi respectively. Gain and total efficiency also have satisfactory results. Results show that the proposed antenna behaves as a directive antenna over the observed frequencies except 8 GHz. And directive antennas are desirable in WBAN as well as in UWB wireless communications. Since, the high value of directivity at a specific angle will lead to minimize power consumption and energy absorption within the body and most importantly minimize the path loss (Oni *et al.* 2014), (Kumar *et al.* 2014).

5.2.4 Voltage Standing Wave Ratio (VSWR)





(a) 8 GHz (b) 10 GHz



(c) 12 GHz (d) 14 GHz

Fig. 11. Simulated VSWR of designed UWB antenna at on body environment at (a) 8 GHz, (b) 10 GHz, (c) 12 GHz and (d) 14 GHz.

The simulated VSWR curves of proposed UWB antenna at on body environment at different frequencies are shown in Fig. 11. VSWR below 2 is considered well for an antenna (Hall *et al. 2006*), (Oni *et al.* 2014). For this designed antenna, VSWR is less than 2 at all the observed frequencies shown in Table 6, which shows a good impedance matching between antenna and transmission line. Thus a very less number of incident waves reflect back to the source.

Table 6. VSWR of designed antenna at on body environment at different frequencies.

Parameters	**Simulation Results**			
Frequency (GHz)	8	10	12	14
VSWR	1.5403591	1.429578	1.0502363	1.1677645

6 COMPARISON OF ANTENNA PERFORMANCE AT ON AND OFF BODY ENVIRONMENT

The simulated off body antenna parameters are compared here with those at the on body environment. To be more specific, the return loss, radiation pattern, directivity and VSWR for designed antenna are analyzed to investigate how the performance of the antenna is affected at the body area in comparison to off body environment. Table 7 illustrates the comparison of antenna performance at the on and off body environment.

Results from the above Table indicate that in both on and off body environment antenna performance is satisfactory for WBAN as well as UWB wireless communications. And on human body at 12 GHz, all the parameters show a very satisfactory result as a whole. At 12 GHz, VSWR is almost 1; which means there is no reflection of incident wave back to the source. It is also seen from the results that, at higher frequencies proposed antenna becomes more directive which is desirable for WBAN.

Table 7. Performance of antenna at the on and off body environment.

Parameters	Off Body performance	On Body performance at Different Frequencies (GHz)			
		8	10	12	14
S-parameter (dB)	-12.2	-13.444253	-15.04977	-32.21571	-22.22623
Main Lobe Magnitude (dBi)	-1.1	5.5	5.4	6.2	5.5
Main Lobe Direction (deg.)	102.0	30.0	28.0	18.0	55.0
HPBW (deg.)	80.4	39.3	115.6	73.5	45.9
Directivity (dBi)	5.235	9.409	7.673	8.843	8.268
VSWR	1.65	1.5403591	1.429578	1.0502363	1.1677645

7 CONCLUSIONS

In this paper, designing a circular patch UWB antenna is proposed which has an operational bandwidth from 6.6342 GHz to16.58 GHz. The aim of this paper is to observe the performance and characteristics of the proposed antenna at the on and off body environment for Wireless Body Area Network (WBAN) applications. Three layered (Skin, Fat and Muscle) human body model is developed to investigate the characteristics and performance of the antenna and also the impact of human body layers on the designed antenna. The performance analysis of designed antenna was carried out from 7 GHz to 14 GHz at both on and off body environment. The designed antenna gives good performance at off body environment as well as on human body model throughout the occupied bandwidth. The key finding of this paper lies in the fact that at higher frequencies the radiation pattern of the proposed antenna becomes more directive at layered human model than off body environment which is desirable for WBAN. Increasing the bandwidth as well as decreasing the size could be focus towards the further step of this design.

References

Hall, P. S. & Hao, Y. (2006). *Antennas and Propagation for Body-Centric Wireless Communications*. Norwood, MA: Artech House, USA, ISBN-10:1-58053-493-7.

Latre , B., Bream , B., Moerman , I., Blondia, C. & Demeester, P. (2011, Jan.). A Survey on Wireless Body Area Networks. *Wireless Network.* (vol. 17, issue 1), pp. 1-18.

Santas , J. G., Alomainy, A. and Hao, Y. (2007). Textile Antennas for On-Body Communications: Techniques and Properties. *Antennas and Propagation, EuCAP 2007, the Second European Conference.* (978-0-86341-842-6), pp. 1-4.

Dey, Shuvashis, Saha, Nandita and Biswas, Subrata. (2011, Apr.). Design and performance analysis of UWB circular disc monopole textile antenna and bending consequences. *The 5th European Conference on Antenna and Propagation.* Rome, Italy.

KIM, Uisheon & CHOI, Jaehoon. (2011). Design of a Microstrip Patch Antenna with Enhanced F/B for WBAN Applications. *IEICE Transactions on Communications.* (VOL.2011; NO.5), ISSN:0916-8516, 1135-1141.

Starner, T. E. (2005, Jul.- Sep.). Wearable computing for the developing world. *IEEE Pervasive Computing.* (vol. 4), pp. 87–91.

Alomainy, A., Hao, Y. & Pasveer, F. (2007). Antennas for Wearable Devices In Zhi Ning Chen (Ed), Antennas for Portable Devices. *West Sussex, England: Academic.* (978-0-470-03073-8), pp.197 -226.

Hertleer, C., Tronquo, A., Rogier, H., and Langenhove, L. Van. (2007). An aperture-coupled patch antenna for integration into wearable textile systems. *IEEE Antennas Wireless Propagation.* (Letter vol. 6), pp. 392–395.

Hertleer, C., Tronquo, A., Rogier, H., and Langenhove, L. Van. (2009). A Textile Antenna for Off-Body Communication Integrated Into Protective Clothing for Fire-fighters. *IEEE Antennas Wireless Propagation.* (Letter vol. 57), pp. 919-925.

Sankaralingam, S. and Gupta, B. (2010). Use of Electro-textiles for Development of WiBro Antennas. *PIER C.* (Vol. 16), pp. 183-193.

Dey, Shuvashis, Dipto, Nafiz Akbar, Rafin, Md. Al-Raf, Mojumder, Shaown and Shahrin, Mehnaz. (2013, Jul.). Design of Wearable Antenna System on Different Materials & Their Performance Analysis at the Off and On Body Environment in terms of Impedance Matching and Radiation Characteristics. *American Academic & Scholarly Research Journal.* (Vol. 5, No. 5).

Calculation of the Dielectric Properties of Body Tissues in frequency range 10 Hz- 100 GHz. (Accessed: Mar. 27, 2013). *ITALIAN NATIONAL RESEARCH COUNCIL, Institute for Applied Physics*. [Online]. Available: http://niremf.ifac.cnr.it/tissprop/htmlclie/htmlclie.htm

Oni, Md. Ashif Islam and Ali, M. Tanseer. (2014, Oct.). Design of A Compact, Low-Profile, Elliptical Patch UWB Antenna and Performance Analysis in Vicinity of Human Layered Tissue Model for Wireless Body Area Network (WBAN) Applications. *International Journal of Innovation and Applied Studies.* (vol. 8, no. 4), pp. 1770–1781.

Kumar, Vivek and Gupta, Bharat. (2014). Swastika Slot UWB Antenna for Body-worn Application in WBAN. *8th International Symposium on Medical Information and Communication Technology (ISMICT).* pp. 1-5.