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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

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ABSTRACT: A compact, low-profile, coplanar waveguide fed elliptical patch UWB antenna is proposed in this paper, and then imposed on human body environment for Wireless Body Area Network (WBAN) applications. A comparison of performance of the designed antenna is done in free space and modeled layered human body tissue phantom in terms of reflection co-efficient, radiation pattern and voltage standing wave ratio (VSWR). The antenna is designed in such a way that it can give good performance over free space as well as over modeled human tissue phantom without any prerequisite. The antenna provides a wide usable fractional bandwidth of more than 143% (2.39-14.43 GHz) with substrate permittivity ε_r =3.38 which is a RO4000® series high frequency circuit material. A human body model having three layers (skin, fat and muscle) is developed to investigate the characteristics and performance of the antenna and also the impact of human body layers on the designed antenna. The entire observation over modeled human tissue phantom is carried out at six different frequencies: 3 GHz, 5 GHz, 7 GHz, 9 GHz, 11 GHz and 13 GHz.

KEYWORDS: Healthcare Monitor, Wireless Body Area Networks (WBAN), Coplanar waveguide, Elliptical Patch Antenna, Ultra-Wideband (UWB), Human tissue.

1 INTRODUCTION

Over the past few years the body-worn antenna and body-centric communication systems has received much attention for applications such as healthcare monitoring, sports and fitness, gaming, lifestyle and entertainment, military health. These applications have included WBAN, a highly localized wireless network [1], [2]. 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 [3], [4]. With the recent development of wireless communication technology, many researchers pay great attention to the study of Wireless Body Area Networks (WBAN). A number of 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) [1].

Ultra-Wideband (UWB) technology has emerged as an attractive solution for WBAN as it offers some benefits such as transmitting signals with an inherent noise-like behavior (due to low EIRP level), reduced probability of detection and intercept, robustness against multipath, and potentially high data rates over short distances. In February, 2002, the Federal Communications Commission (FCC) amended the part 15 rules and releases the UWB standards [7]. UWB technology defined by IEEE 802.15.6 TG- 6 [12], covers a huge Bandwidth of 7.5 GHz (from 3.1 GHz to 10.6 GHz) for communication. One of the main advantages of UWB technology is low power emission density (-41.3 dBm/MHz). UWB technology possesses a feature of variable data rate from few Kbps to Mbps. This features opened a new possibilities for potential application of UWB technology for WBAN, thus, ensuring low interference with other neighboring wireless devices [7].

Designing a body-worn antenna for body-centric communications would have to face several issues and challenges. The antenna needs to fulfill numerous desirable requirements, like small size, high radiation efficiency, occupy entire UWB frequency spectrum, better on-body propagation, and optimized characteristics in time and frequency domain [6]. The human body is complex structure comprised of several layers like skin, fat, muscle etc. These body layers have different dielectric constant, conductivity and thickness and acts as a non-uniform medium for RF wave propagation. Therefore depending upon the frequency of operation and most importantly presence of human body, which leads to high losses such as power absorption, destruction in antenna radiation pattern, shift in resonance frequency, reduced efficiency, and variations in feed- point impedance. One of the important challenges in antenna design is to occupy the entire UWB frequency spectrum (from 3.1 GHz to10.6 GHz) with better radiation efficiency, which is successfully met by the work of this paper.

In this paper, a novel, compact, low-profile, coplanar waveguide fed elliptical patch UWB antenna is designed which is flat and its planar structure allows it to be comfortably worn. And then, antenna's performance is examined in free space and in indirect contact to layered human body phantom. This phenomenon is achieved by creating three significant layers of human body which includes skin, fat and muscle. Originality of this work is, all the time the antenna occupies UWB frequency spectrum for planar structure irrespective of off or on body environment. All human phantom calculations and other specifications are done using same manner as in [8]. This paper also compares the performance and characteristics of the designed antenna at free space and on body area. Performance analysis over human phantom is carried out at six different frequencies: 3 GHz, 5 GHz, 7 GHz, 9 GHz, 11 GHz and 13 GHz. 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 elliptical patch UWB antenna is RO4000® series high frequency circuit material of Rogers Corporation with ε_r = 3.38. Selection of substrate material for designing the antenna is unique for this paper. Properties of substrate material include high tensile strength, high resistance to stretching, rigid, non flammable, durability, low temperature coefficient, outstanding electrical property [9]. The patch and ground planes are made of copper threads which are perfect electrical conductors (PEC).

3 ANTENNA DESIGN AND IMPLEMENTATION

The designed elliptical patch UWB antenna operates from the frequency of 2.39 GHz to 14.43 GHz. The disc of the antenna is fed by a 50 ohm Microstrip feed line with a width of 4.21 mm. A conductive ground plane with a length of 21 mm is placed on the same side of the disc and the feed on the substrate. The feed gap between the metal strip and the ground plane is 0.695 mm and the gap between the disc and the ground plane is set to 1 mm. The radiating patch and ground plane are made of copper tape with the thickness of 0.7 mm. However, the major and minor radius of the elliptical shape radiating patch are 15 mm and 10 mm respectively, substrate dimension is 35 x 45 x 2 mm3 and the each ground plane dimension is 14.7 x 21 x 0.7 mm3. In addition, there is a elliptical shape slot on the upper hemisphere of radiating patch, the major and minor radius of the elliptical slot are 5 mm and 3 mm respectively. Overall thickness of the antenna is 2.7 mm. Hence, the total dimension of the antenna is quite small. Commercial electromagnetic simulation package CST Microwave Studio was used for design & simulation purposes.

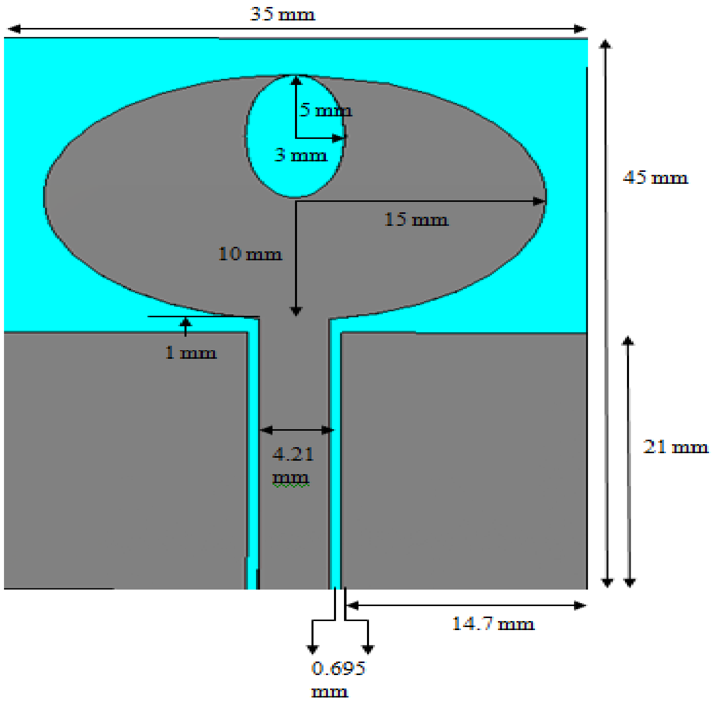
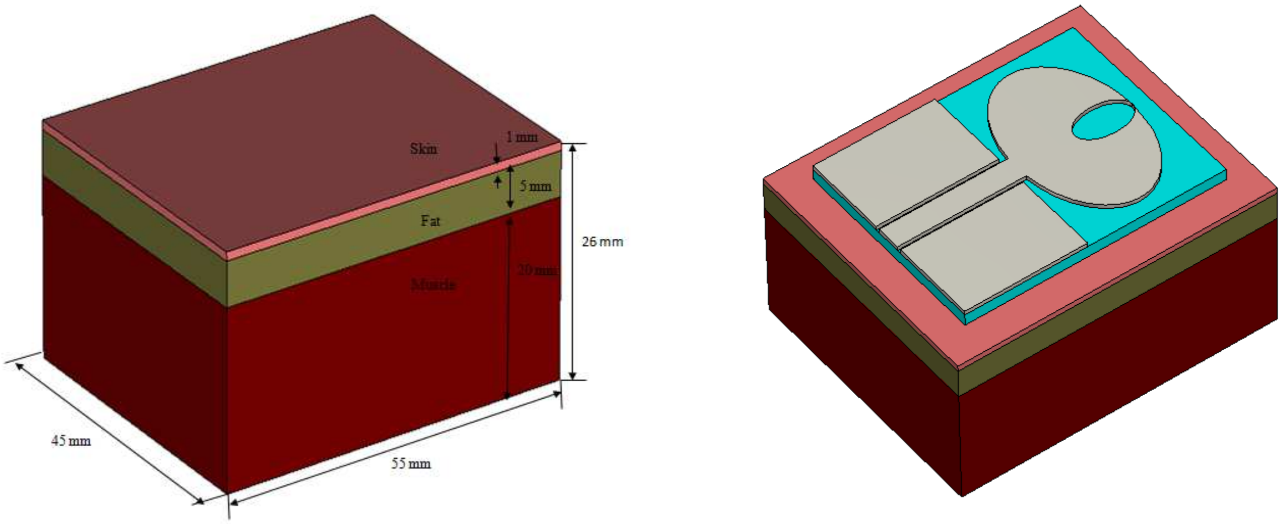


Fig. 1. Top view of designed Elliptical Patch UWB Antenna

Table 1. Measurements of Elliptical Patch UWB Antenna

Parameters	Dimensions (mm)	Material
Substrate: **Length** **Width** **Thickness**	 45 35 2	 RO4000® series circuit material (ε_r = 3.38 and tan δ= 0.0025)
Elliptical Patch: **Major Radius** **Minor Radius** **Thickness**	 15 10 0.7	 Copper
Ground Plane (each): **Length** **Width** **Thickness**	 21 14.7 0.7	 Copper
Elliptical Slot: **Major Radius** **Minor Radius** **Thickness**	 5 3 0.7	 -
Feed Line: **Length** **Width** **Thickness**	 22 4.21 0.7	 Copper

4 LAYERED HUMAN TISSUE MODELLING AND ANTENNA IMPLEMENTATION



(a) *(b)*

Fig. 2. (a) Layered Human Phantom and (b) UWB Antenna Implemented on Human Phantom

The dimension of modeled layered human body tissue is 45 mm x 55 mm x 26 mm. It comprised of three different tissues namely 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 [8]. Fig. 2(a) presents the modeled layered human phantom and 2(b) presents the implemented UWB antenna on Human Phantom. There is a gap of 0.7 mm between the designed UWB antenna and human phantom. Commercial electromagnetic simulation package CST Microwave Studio was used for design & simulation purposes. Table 2 shows the electrical dispersion of layered human body tissue model for UWB frequencies which is obtained by [11].

Table 2. Layered Human Phantom Material Properties

Tissue name	Frequency [GHz]	Conductivity [S/m]	Relative permittivity, εr	Loss tangent, tan δ
Skin (Dry)	3	1.7406	37.45	0.27848
	5	3.0608	35.774	0.3076
	7	4.8175	34.084	0.36296
	9	6.8949	32.25	0.42701
	11	9.1658	30.310	0.49412
	13	11.514	28.342	0.56176
Fat	3	0.13004	5.2239	0.14916
	5	0.24222	5.0291	0.17315
	7	0.37353	4.8476	0.19787
	9	0.5138	4.6804	0.21926
	11	0.65669	4.5278	0.23701
	13	0.79829	4.3896	0.25146
Muscle	3	2.1421	52.058	0.24655
	5	4.0448	49.54	0.29353
	7	6.4607	46.865	0.35401
	9	9.1923	44.126	0.41607
	11	12.083	41.419	0.47672
	13	15.016	38.814	0.53495

5 Simulation Results

The performance of modeled UWB antenna was measured over free space and over modeled layered human phantom.

5.1 Performance Analysis of Elliptical Patch UWB Antenna Over Free Space

5.1.1 Reflection Coefficient (S_{11})

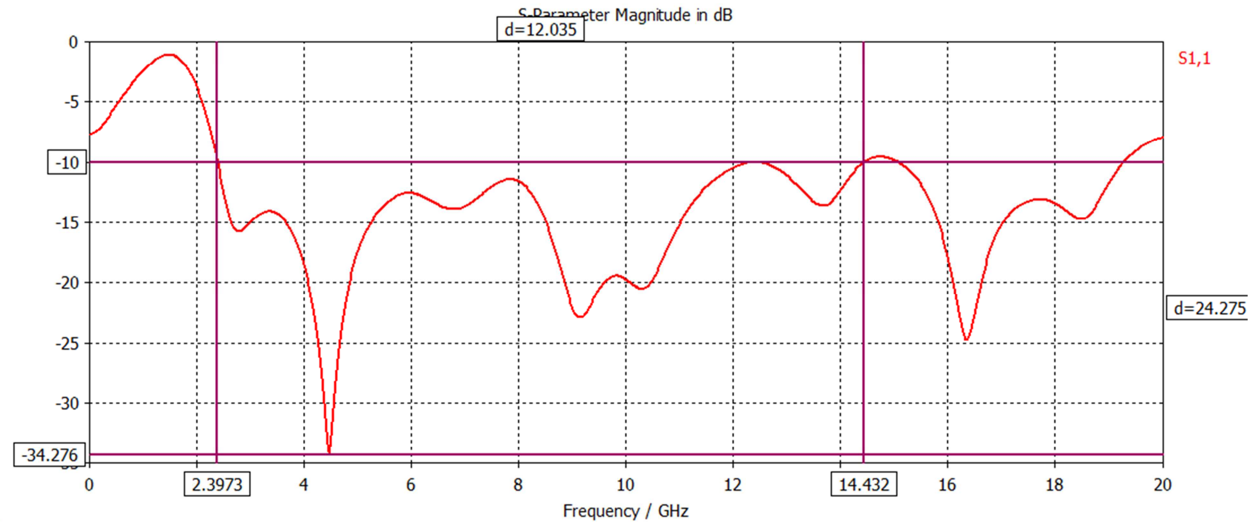


Fig. 3. Simulated S_{11} of proposed UWB antenna over free space

The S-parameter plot of the elliptical patch UWB antenna in Fig. 3 shows that a wide bandwidth of almost 12 GHz starting from 2.39 GHz to 14.43 GHz has been achieved for S_{11}< -10 dB with 3 significant resonances. It has got a good impedance matching with all over its occupied bandwidth.

5.1.2 Radiation Pattern

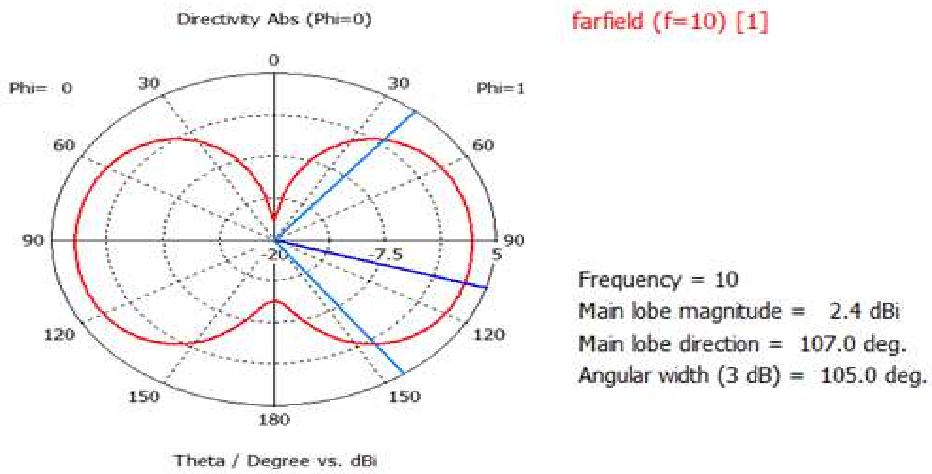


Fig. 4. Radiation Pattern of E- Plane of proposed UWB antenna over free space

For attaining the E- plane radiation pattern as shown in Fig. 4, 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 107 degree with main lobe magnitude of 2.4 dBi. 3 dB angular beamwidth (i.e., HPBW) is 105 deg. Omni directional radiation pattern is observed.

5.1.3 3D Radiation Pattern, Directivity, Gain and Efficiency

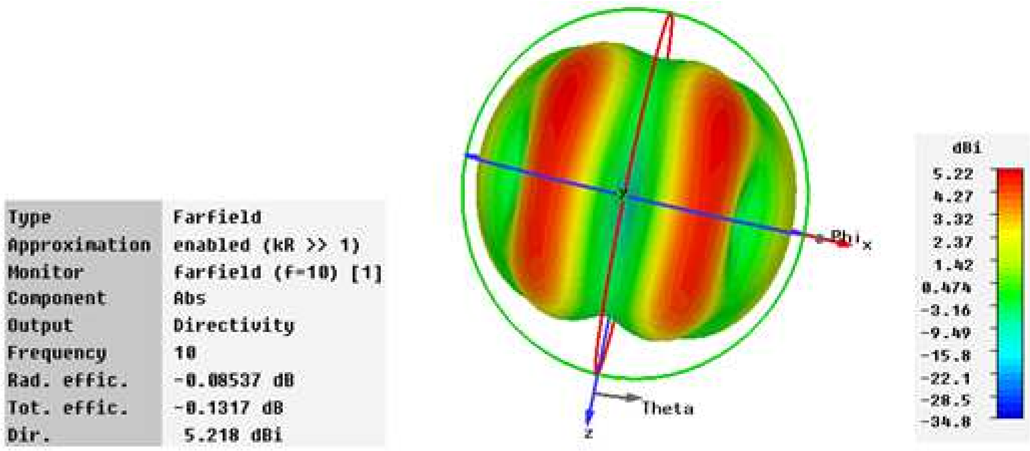


Fig. 5. 3D Radiation pattern of proposed UWB antenna over free space

The simulated result of Omni directional radiation pattern over free space is shown in 3D in Fig. 5. The result shows the directivity of 5.218 dBi of the proposed UWB antenna over free space. Gain and total efficiency of the antenna are measured 5.132 dB and 0.9701 respectively. Total efficiency is calculated in linear scale.

Table 3. Radiation characteristics of proposed UWB Antenna

Parameters	**Simulation Results**
Directivity (dBi)	5.218
Gain (dB)	5.132
Total Efficiency	0.9701

5.1.4 Voltage Standing Wave Ratio (VSWR)

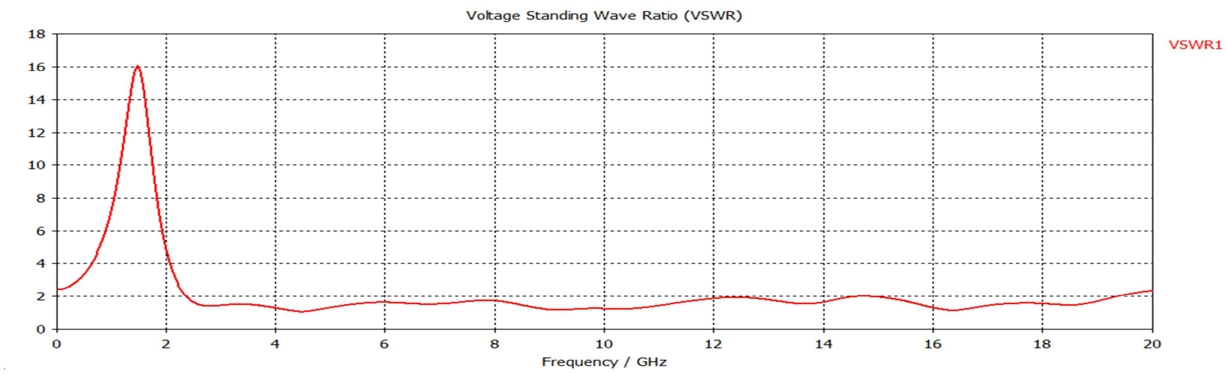
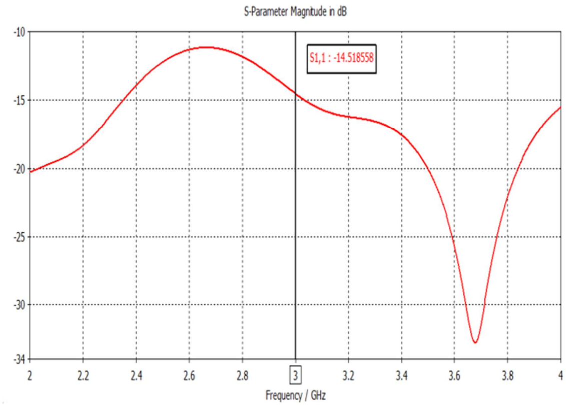


Fig. 6. Simulated VSWR of proposed UWB antenna over free space

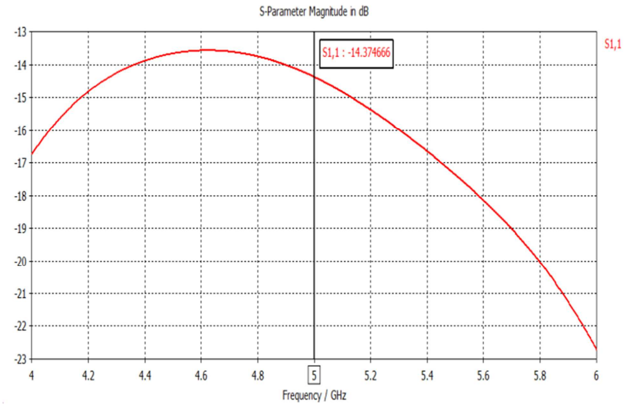
The simulated VSWR curve of proposed UWB antenna is shown in Fig. 6. VSWR below 2 is considered well for an antenna [1]. For this designed antenna, VSWR is less than 2 from 2.39-14.43 GHz over free space, which shows a good impedance matching between antenna and transmission line. Thus a very less number of incident waves reflect back to the source.

5.2 Performance Analysis of Elliptical Patch UWB Antenna over Modeled Layered Human Phantom

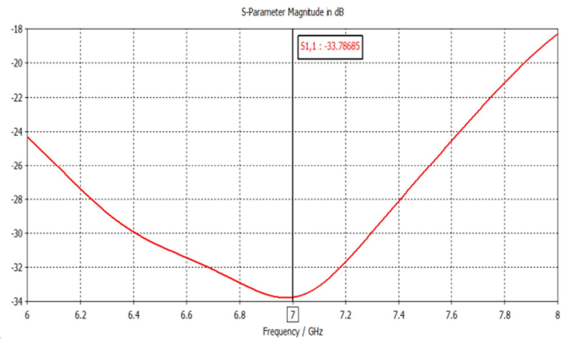
5.2.1 Reflection Coefficient (S_{11})



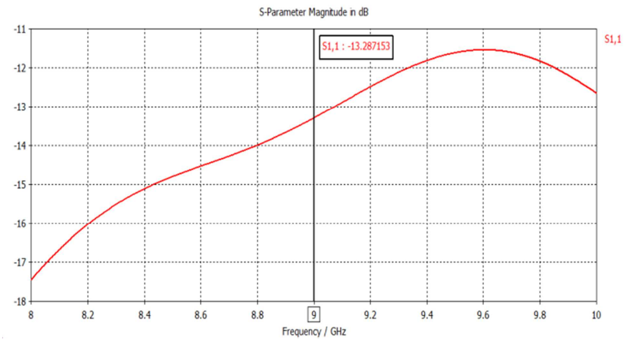
(a) 3 GHz



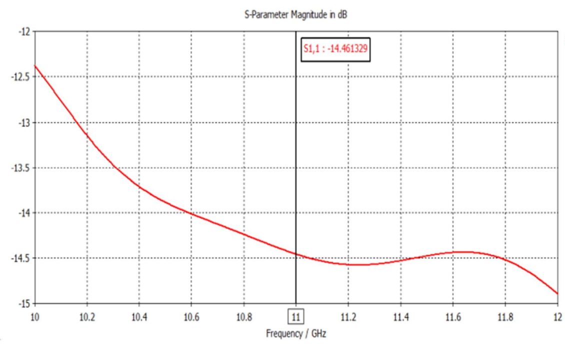
(b) 5 GHz



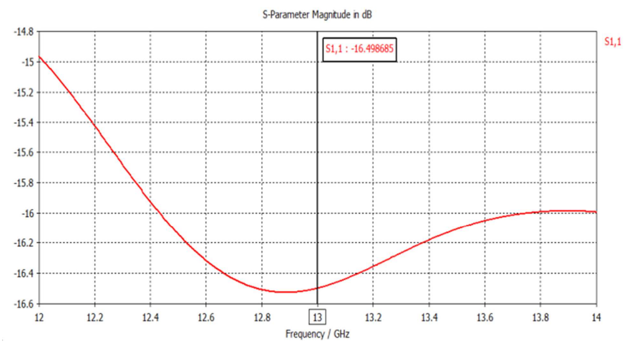
(c) 7 GHz



(d) 9 GHz



(e) 11 GHz



(f) 13 GHz

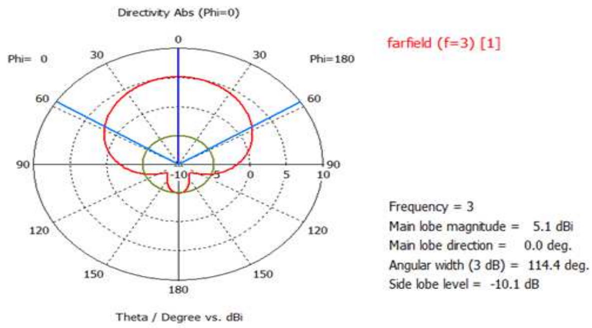
Fig. 7. Simulated S_{11} of proposed UWB antenna over modeled layered human phantom at (a) 3 GHz, (b) 5 GHz, (c) 7 GHz, (d) 9 GHz, (e) 11 GHz and (f) 13 GHz

Fig. 7 illustrates the simulation result of S_{11} of proposed antenna over modeled human phantom at different frequencies. Table 4 summarizes the simulation result of S_{11} at different frequencies. Table 4 shows that all the S-parameters maintain S11< -10 dB, which means antenna has got a good impedance matching with all over its occupied bandwidth.

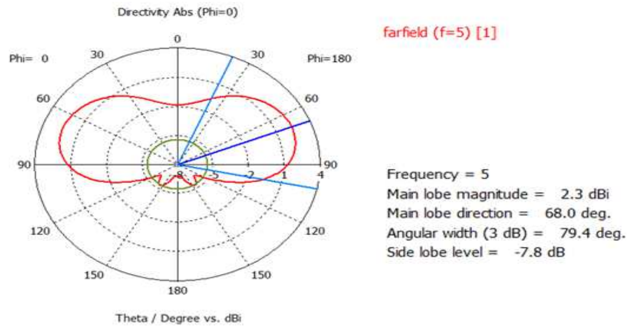
Table 4. S Parameter of proposed Antenna on Human Phantom at different frequencies

Parameters	Simulation Results					
Frequency (GHz)	3	5	7	9	11	13
S Parameter (dB)	-14.51855	-14.3747	-33.7868	-13.2871	-14.4613	-16.4986

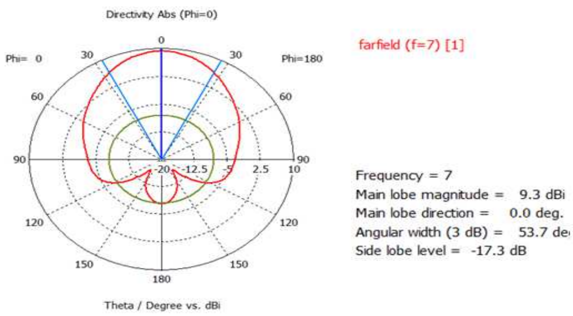
5.2.2 RADIATION PATTERN



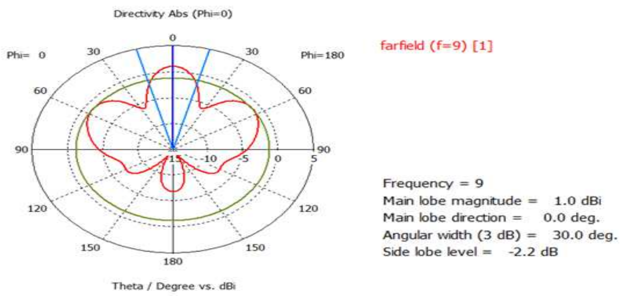
(a) 3 GHz



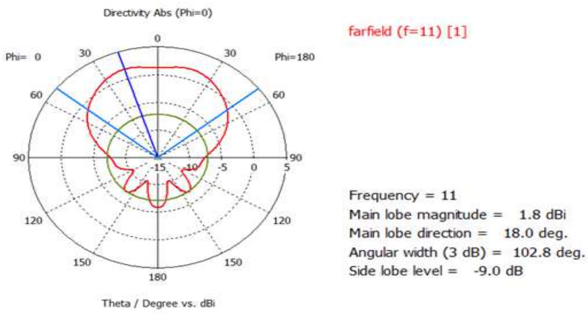
(b) 5 GHz



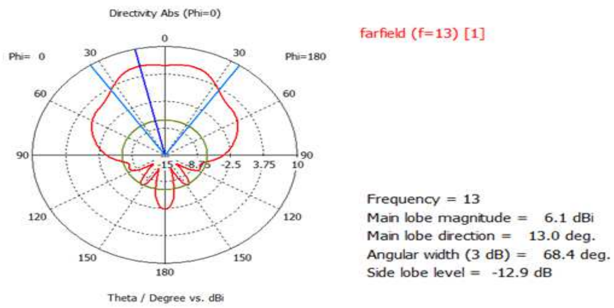
(c) 7 GHz



(d) 9 GHz



(e) 11 GHz



(f) 13 GHz

Fig. 8. Radiation pattern of E- plane of proposed UWB antenna over modeled layered human phantom at (a) 3 GHz, (b) 5 GHz, (c) 7 GHz, (d) 9 GHz, (e) 11 GHz and (f) 13 GHz

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

Table 5. Radiation pattern of proposed Antenna on Human Phantom at different frequencies

Parameters	Simulation Results					
Frequency (GHz)	3	5	7	9	11	13
Main Lobe Magnitude (dBi)	5.1	2.3	9.3	1.0	1.8	6.1
Main Lobe Direction (deg.)	0.0	68.0	0.0	0.0	18.0	13.0
HPBW (deg.)	114.4	79.4	53.7	30.0	102.8	68.4

5.2.3 3D RADIATION PATTERN, DIRECTIVITY, GAIN AND EFFICIENCY

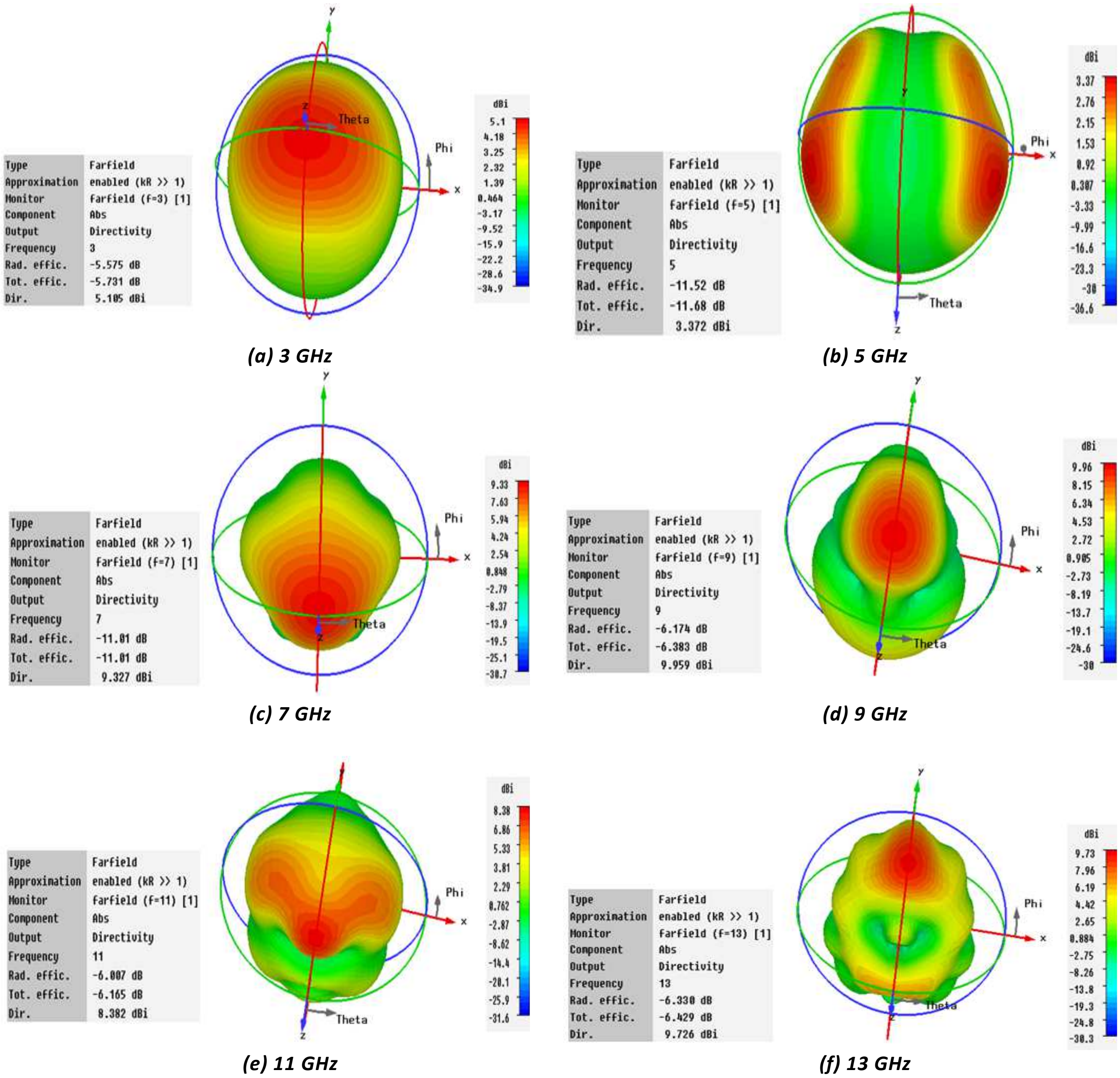
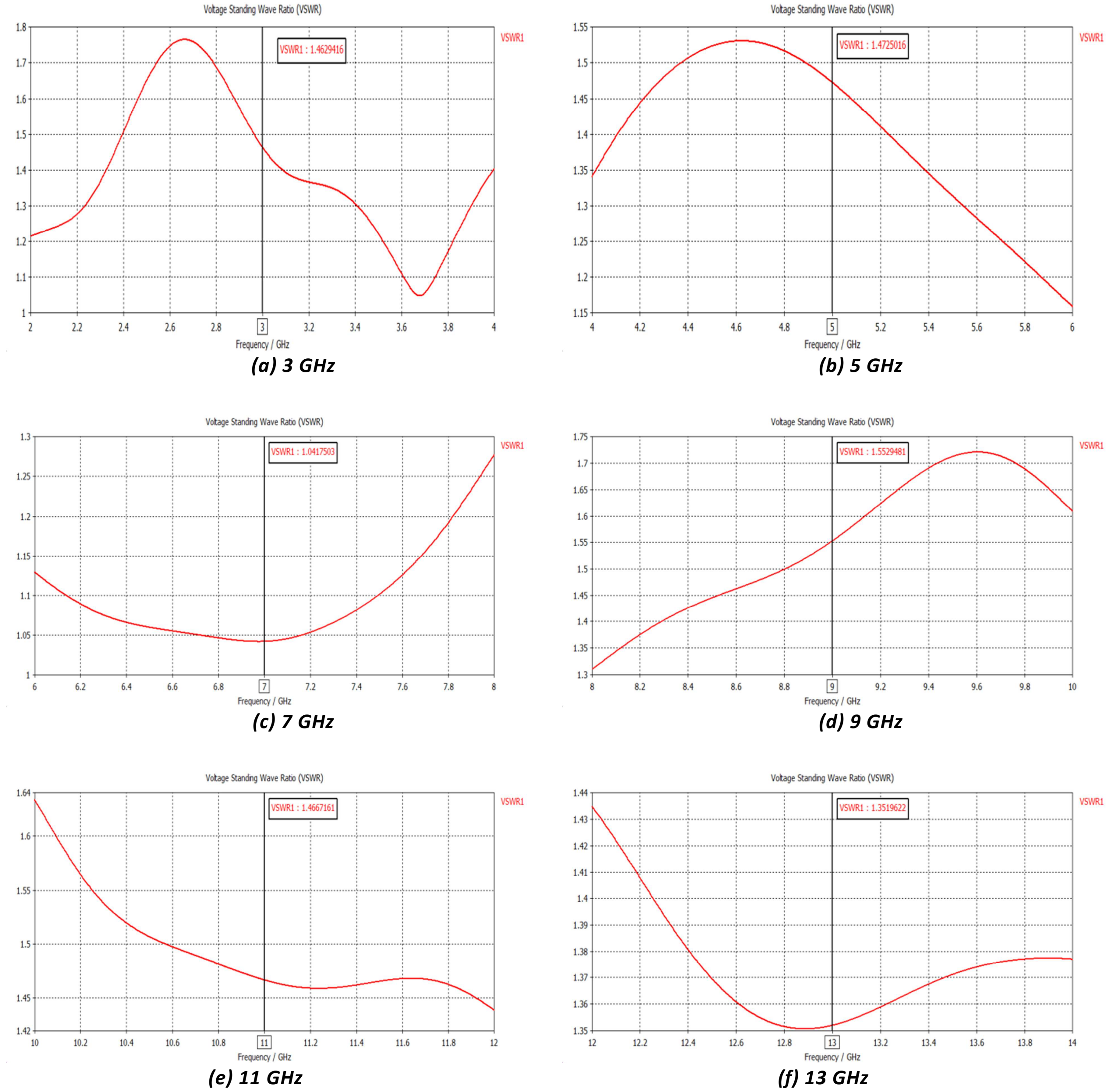


Fig. 9. 3D Radiation pattern of proposed UWB antenna over modeled layered human phantom at (a) 3 GHz, (b) 5 GHz, (c) 7 GHz, (d) 9 GHz, (e) 11 GHz and (f) 13 GHz

The simulated results of 3D radiation pattern of the antenna over human phantom at different frequencies are shown in Fig. 9. The results show the directivity at 3 GHz, 5 GHz, 7 GHz, 9 GHz, 11 GHz and 13 GHz are 5.105 dBi, 3.372 dBi, 9.327 dBi, 9.959 dBi, 8.382 dBi and 9.726 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 5 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 [6].

5.2.4 VOLTAGE STANDING WAVE RATIO (VSWR)



(a) 3 GHz *(b) 5 GHz*

(c) 7 GHz *(d) 9 GHz*

(e) 11 GHz *(f) 13 GHz*

Fig. 10. Simulated VSWR of proposed UWB antenna over modeled layered human phantom at (a) 3 GHz, (b) 5 GHz, (c) 7 GHz, (d) 9 GHz, (e) 11 GHz and (f) 13 GHz

The simulated VSWR curves of proposed UWB antenna over human phantom at different frequencies are shown in Fig. 10. VSWR below 2 is considered well for an antenna [1]. 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 proposed Antenna on Human Phantom at different frequencies

Parameters	**Simulation Results**					
Frequency (GHz)	3	5	7	9	11	13
VSWR	1.462941	1.47250	1.0417503	1.552948	1.4667161	1.3519622

6 COMPARISON OF ANTENNA PERFORMANCE OVER FREE SPACE AND LAYERED HUMAN PHANTOM

The simulated free space antenna parameters are compared here with those at the layered human phantom. To be more specific, the reflection coefficient, radiation pattern, directivity and voltage standing wave ratio for proposed antenna are analyzed to investigate how the performance of the antenna is affected at the body area in comparison to free space. Table 7 illustrates the comparison of antenna performance over free space and layered human phantom.

Table 7. Performance of Antenna over Free Space and Layered Human Phantom

Parameters	**Free Space**	**Layered Human Phantom at Different Frequencies (GHz)**					
		3	**5**	**7**	**9**	**11**	**13**
S- Parameter (dB)	-19.741	-14.518	-14.3747	-33.7868	-13.2871	-14.4613	-16.4986
Main Lobe Magnitude (dBi)	2.4	5.1	2.3	9.3	1.0	1.8	6.1
Main Lobe Direction (deg.)	107.0	0.0	68.0	0.0	0.0	18.0	13.0
HPBW (deg.)	105.0	114.4	79.4	53.7	30.0	102.8	68.4
Directivity (dBi)	5.218	5.105	3.372	9.327	9.959	8.382	9.726
VSWR	1.22971	1.46294	1.47250	1.04175	1.55294	1.46671	1.35196

Thorough analysis of the above results indicates that in both free space and layered human phantom antenna performance is satisfactory for WBAN as well as UWB wireless communications. Simulation results show that antenna performance is very good in free space. And in layered human phantom at 7 GHz, all the parameters show a very satisfactory result as a whole. At 7 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.

7 CONCLUSION

In this endeavor, designing a compact, low- profile, elliptical patch UWB antenna is proposed which has a wide usable fractional bandwidth of more than 143% (2.39-14.43 GHz). The aim of this paper is to observe the performance and characteristics of the proposed antenna in free space and in the indirect contact of layered human body environment for Wireless Body Area Network (WBAN) applications. Three layered (Skin, Fat and Muscle) human phantom is developed to investigate the characteristics and performance of the antenna and also the impact of human body layers on the designed antenna. The designed antenna gives good performance over free space as well as over modeled human tissue phantom 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 phantom than free space which is desirable for WBAN. Reducing the size with increased bandwidth could be the focus towards the further step of this design.

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REFERENCES

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

[2] B. Latre, B.Bream, I. Moerman, C. Blondia and P. Demeester, “A Survey on Wireless Body Area Networks,” Wireless Network, vol. 17, issue 1, pp. 1-18, January 2011.

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

[4] Shuvashis Dey, Nandita Saha and Subrata Biswas, “Design and performance analysis of UWB circular disc monopole textile antenna and bending consequences,” The 5th European Conference on Antenna and Propagation, 2011, April 2011, Rome, Italy.

[5] Mohsen Koohestani, J.-F. Zürcher, Antonio A. Moreira and Anja K. Skrivervik, “A Novel, Low Profile, Vertically-Polarized UWB Antenna for WBAN,” IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 62, NO. 4, APRIL 2014.

[6] Vivek Kumar and Bharat Gupta, “Swastika Slot UWB Antenna for Body-worn Application in WBAN,” ISMICT 2014 1569883139.

[7] First Report and Order of Federal Communications Commission (FCC) on Ultra Wideband Operation, 02-48, February 2002.
[Online] Available: http://www.ecfr.gov/cgi-bin/text-idx?SID=fb4eaf20044a7e9a2a942e41299c9caf&node=pt47.1.15&rgn=div5#sp47.1.15.f

[8] Shuvashis Dey, Nafiz Akbar Dipto, Md. Al-Raf Rafin, Shaown Mojumder and Mehnaz Shahrin, “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, July 2013.

[9] RO4000® Laminates- Data sheet- RO4000® series high frequency circuit materials. [Online] Available: http://www.rogerscorp.com/acm/products/54/RO4003C-Laminates.aspx

[10] M. Klemm and G. Troester, “EM energy absorption in the human body tissues due to UWB antennas,” Progress In Electromagnetic Research, Vol. 62, 261-280, 2006.

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

[12] Vivek Kumar, Sravanth Kumar and Bharat Gupta, “Performance Analysis of Swastika Slot UWB Antenna in Vicinity of Dispersive Human Layered Tissue Model,” 2014 IEEE Region 10 Symposium.