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Study of Performance and Propagation Characteristics of Wire and Planar Structures around Human Body

A. L. Praveen Aroul, *Student Member, IEEE*, Dinesh Bhatia, *Member, IEEE*

Abstract— **Continued miniaturization of electronic devices and technological advancements in wireless communications has made wearable body-centric telemedicine systems viable. Antennas play a crucial role in characterizing the efficiency and reliability of these systems. The performance characteristics such as the radiation pattern, gain, efficiency of the antennas get adversely affected due to the presence of lossy human body tissues. In this paper we investigate the above mentioned performance parameters and radio frequency transmission properties of wire and planar structures operating at ISM frequency band of 2.40 – 2.50 GHz in the proximity of human body.**

I. Introduction

WIRELESS body-centric telemedicine systems have gained considerable attention in the past decade because of continued miniaturization of electronic devices and technological advancements in wireless communications. These systems include sensors/actuators, radio transceivers and antennas. Body-centric communication systems can be classified as in-body with implantable sensors and on-body with sensors mounted on the surface of the body [1]. These systems have potential applications in medical therapy and diagnosis, health monitoring, disease, obesity and overweight management. The implantable sensors have been used for pacing the heart, listening aids, sensing the pressure in brain cavity and eyes [1]. The wearable sensors have been used for measuring some of the vital physiological parameters of the human body such as blood pressure, heart rate, ECG, blood glucose, blood oxygen saturation, temperature to name a few [2-5].

The antennas are essential components of these radio communication systems as they are responsible for proper communication with other body mounted nodes and/or off-body devices in the wireless network. At ultra-high and microwave frequencies, the human body tissues act as a large lossy irregularly shaped heterogeneous medium with frequency dependent dielectric parameters. The presence of the human body adversely affects the performance of the antennas in the body-worn or implantable systems. The wearable antennas show reduced efficiency, introduction of nulls in the radiation pattern and impedance mismatch because of the human body intervention [6]. Hence a clear understanding of the interaction of the body tissues with frequency dependent dielectric parameters and the radio system is pivotal for efficient and reliable communication.

Several research groups have analyzed the performance of antennas in the presence of body tissues. Werber et al. [7] have investigated the RF transmission properties of human tissues in the frequency range from 50MHz to 1GHz. See and Chen [8] have numerically investigated the performance of wearable PIFAs and RF transmission in the presence of human body. Kim and Rahmat-Samii [9] have examined spiral microstrip and PIFA implant antennas both numerically and experimentally using the spherical dyadic Green's function (DGF) expansions and Finite Difference Time Domain (FDTD) method.

In this paper we specifically address the antenna characteristics of the sensors used for swallow sound analysis used in obesity management studies and snore sound analysis used in Sleep Apnea studies. The transmitter antenna is placed on the jaw of the human body. In this paper, we present a numerical analysis to understand and characterize the interaction of the body tissues on the performance of these antennas. General antenna parameters such as the return loss, radiation pattern, gain, radiation efficiency are taken into account to evaluate the performance of the antennas. Transmission loss is investigated to understand the communication link between transmitter and receiver antennas. The motivation of this study is to come up with a model to accurately characterize the RF propagation links for optimal radio communication systems.

II. Antenna Geometries

Three antennas in the categories of wire structures and planar structures are considered for evaluating their performance parameters and characterizing radio propagation channels in the presence of the lossy human tissues. These antennas have a very low profile meeting the requirements of wearable antennas. The dimensions of both the antennas are selected so that they resonate at 2.45GHz. 2.45GHz is chosen as the solution center frequency since most of the current body area network applications using any of the following technologies such as Bluetooth, WiFi, and ZigBee operate at the Industrial Scientific and Medical (ISM) frequency band of 2.4 – 2.5 GHz. Fig. 1 shows the antenna structures and their dimensions employed for this

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A. L. Praveen Aroul is with the Embedded and Adaptive Computing Group at the University of Texas at Dallas, Richardson, TX 75080 USA (e-mail: alp052000@utdallas.edu).

D. Bhatia is with the Embedded and Adaptive Computing Group at the University of Texas at Dallas, Richardson, TX 75080 USA (e-mail: dinesh@utdallas.edu).

study. The planar structures are printed on FR4 substrate with thickness of 1.6mm and relative permittivity of 4.4.

III. ANALYSIS OF ANTENNAS IN FREE SPACE

This section explains the free space analysis of the proposed antennas. The performance characteristics such as the return loss and radiation pattern of the antennas are analyzed. Return loss is the ratio of reflected power and incident power of the antenna. Fig. 2 presents the return loss of the chosen antennas. The radiation pattern is a graphical representation of the radiation properties of antenna as a function of space coordinates. The radiation patterns of the simulated antennas in the azimuth plane (XY) (θ=90°) and in the elevation planes (XZ and YZ) (φ=0° and 90°) are presented in Fig. 3 and Fig. 4 respectively.

Good impedance matching within the ISM frequency band of 2.4 – 2.5 GHz is observed from Fig. 2.The simulated antennas have shown expected performance in free space in the ISM frequency band with omni-directional patterns. Since the antennas in free space were placed at an angle of 20° from X axis to mimic the position of these antennas near the left jaw of the human body model, the elevation plane radiation patterns are also tilted 20°. This is quite evident from Fig. 4(b).

IV. HUMAN BODY MODEL

The numerical simulations are performed on Ansoft's HFSS [10] which is a 3D full-wave electromagnetic field simulator. The material parameters for the objects of the human body have been obtained from [11]. The data are based on the work done by [12]. We conducted simulations to find out how much the performance parameters of the antennas deviate using the human body model without bones, muscles and organs and the human body model with bones, muscles and organs. We find that there is a less than one dB deviation in the performance parameters. Based on these simulations, we used the human body model without bones, muscles and organs for all our subsequent simulations. The human body model with the reference plane used in our simulations is shown in Fig. 5.

V. ANALYSIS OF ANTENNAS IN THE PRESENCE OF HUMAN BODY MODEL

Numerical simulations are conducted to investigate the performance of the aforementioned antennas due to the presence of the frequency dependent human body tissues near the antennas. Fig. 6 illustrates the return loss of the simulated antennas and provides a comparison between the antennas placed in free space and on the left jaw of the human body model. The planar structures are oriented parallel to the jaw. Two phenomena are observed from the return loss. The first one is the resonance frequency detuning and the second one is the degradation of the impedance matching. All the simulated antennas show detuning of the resonant frequency when they are on the left jaw of the human body model.

Both the planar antennas show more detuning from free space resonance compared to wire dipole. Also the degradation of the impedance matching is most severe for the planar dipole. The detuning in resonance frequency is observed due to change in the wavelength from free space value. Increasing the ground plane of the PIFA antennas further decreases the resonant frequency.

Fig. 7 and Fig. 8 present the radiation patterns of the simulated antennas placed in free space and on the human body model. The radiation patterns are simulated at 2.45 GHz. in the azimuth plane (XY) (θ=90°) and in the elevation planes (XZ and YZ) (φ=0° and 90°). Fig. 7 and Fig. 8 show the radiation pattern and the degradation in the backward radiation. Since the human body is a lossy medium, the electromagnetic waves get attenuated quickly leading to the distortion in the radiation pattern.

The transmission characteristics for the simulated antennas are shown in Table I. The path loss is dependent on the antenna type used and also in the presence of the body on the transmission path.

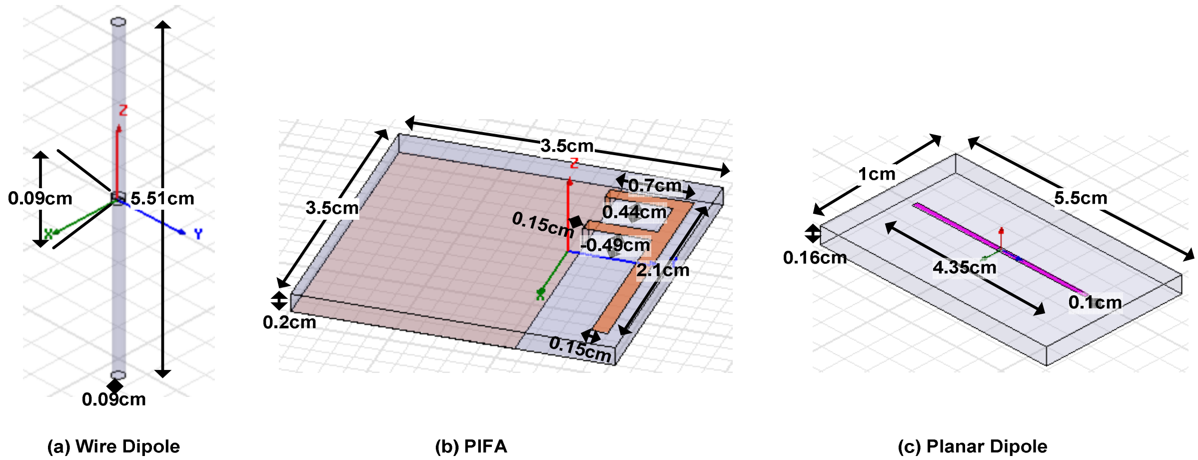


Fig. 1. Antenna Structures used in the study (a) Wire Dipole (b) Planar Inverted F Antenna (PIFA) (c) Planar Dipole.

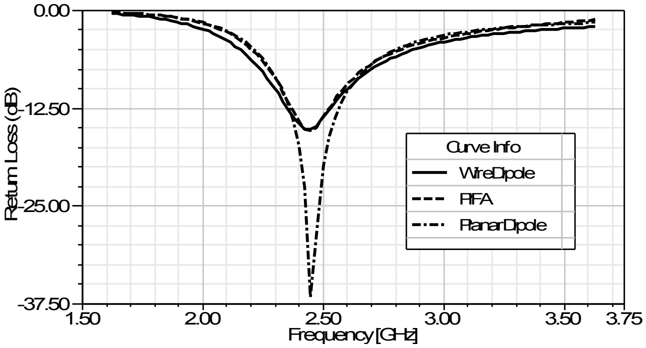


Fig. 2. Return loss of the simulated antennas in free space

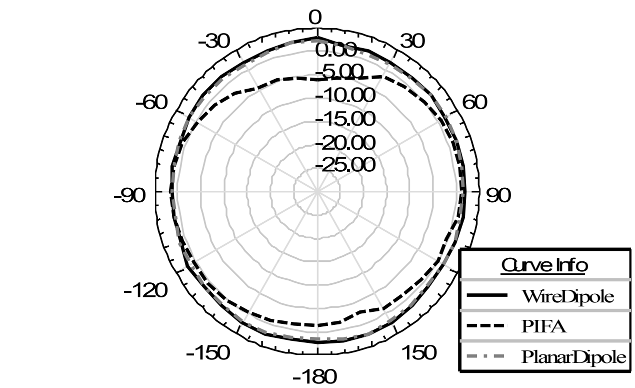
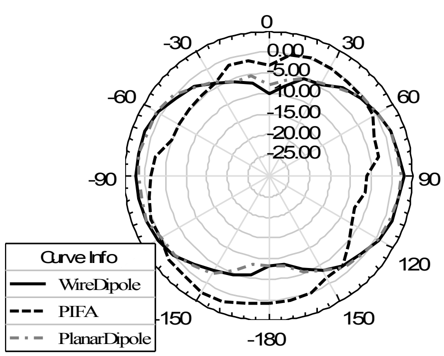
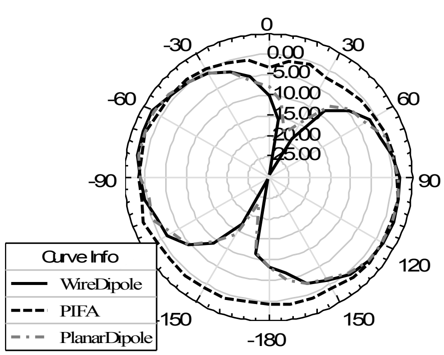


Fig. 3. Azimuthal plane ($\theta = 90°$) radiation patterns at 2.45GHz



(a) $\varphi = 0°$



(b) $\varphi = 90°$

Fig. 4. Elevation plane radiation patterns of the simulated antennas at 2.45GHz (a) $\varphi = 0°$ (b) $\varphi = 90°$

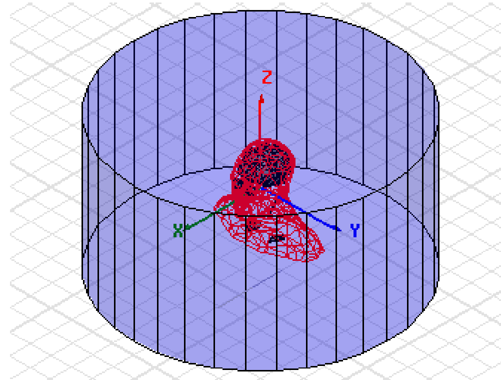


Fig. 5. The male human model used in the study

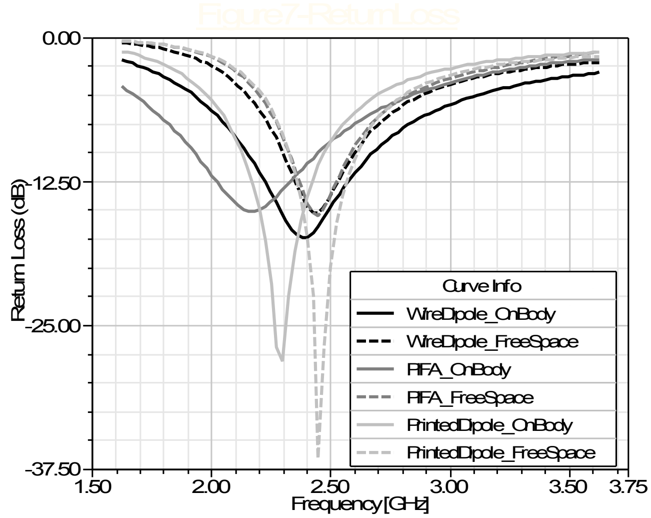


Fig. 6. Return loss of the simulated antennas in free space and directly on left jaw on the human body model

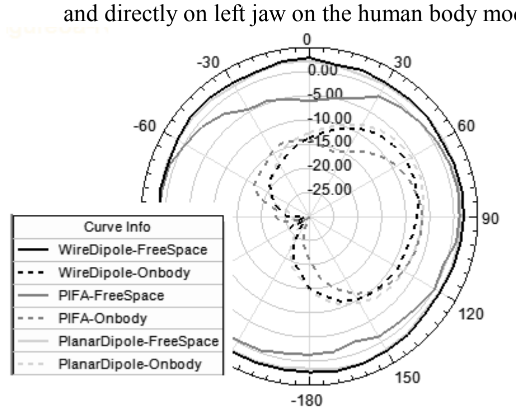
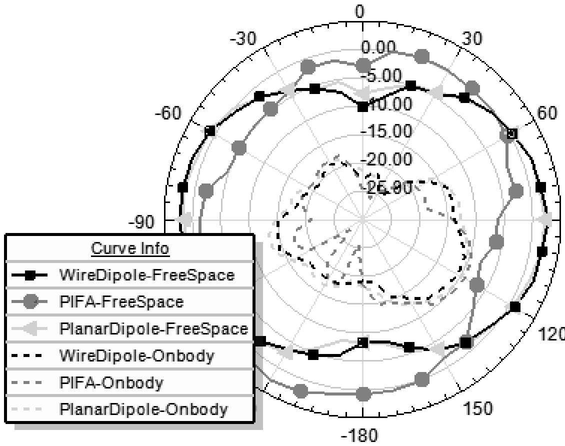
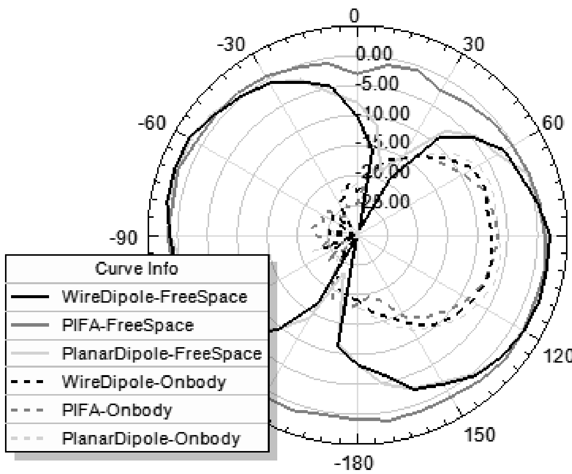


Fig. 7. Azimuthal plane ($\theta = 90°$) radiation pattern of simulated antennas at 2.45GHz in free space and on left jaw on the human body model



(a) $\varphi = 0°$



(b) $\varphi = 90°$

Fig. 8. Elevation plane radiation pattern of the simulated antennas at 2.45GHz in free space and on left jaw on the human body model. (a) $\varphi = 0°$ (b) $\varphi = 90°$.

TABLE I
PATH LOSS OF SIMULATED ANTENNAS IN FREE SPACE AND ON BODY

Distance	Antenna / FSPL	WireDipole Freespace/ On-body	PIFA Freespace/ On-body
12cm	21.8dB	21.05dB/29.43dB	27.52dB/31.92dB
24cm	27.9dB	25.68dB/32.77dB	32.08dB/34.81dB
36cm	31.4dB	29.08dB/36.75dB	35.23dB/38.05dB
60cm	35.8dB	33.27dB/42.14dB	39.49dB/42.99dB
-24cm	27.9dB	-/68.60dB	-/64.57dB
-36cm	31.4dB	-/66.89dB	-/62.40dB

There is a huge drop in the path loss (32dB to 68dB in wire dipole case) with the introduction of human head on the path. This is because the propagation mode is assumed to be creeping wave which demonstrates an exponential decay of power [1]. Also, the transmission loss in dipole antennas is higher than that of PIFA which can be attributed to the presence of ground plane in PIFA.

VI. CONCLUSION

This paper offers an analysis to understand and characterize the interaction of the body tissues on the performance of wire and planar antennas fixed to the jaw of the human body emulating sensors in swallow sound analysis used in obesity management studies and snore sound analysis used in Sleep Apnea studies. From the return loss analysis, we conclude that planar dipole and PIFA antennas require a redesign when they must be used in body sensor networks. In the electric field distribution analysis we find that the presence of human head attenuates the radiated electric field. Also the transmission loss analysis indicates that there is atleast 30dB loss when the human head is introduced in the transmission path. This implies that introduction of human model can be substantially detrimental to the antenna performance characteristics in any body sensor network. Future analysis will include creating a model to accurately characterize the RF propagation links for optimal radio communication systems.

REFERENCES

[1] Hall, P. S., & Hao, Y. (2006). "Antennas and Propagation for Body-Centric Wireless Communications". *Artech House Publisher*.

[2] Aroul, A. L., Bhatia, D., & Estevez, L. (2008). "Energy-efficient Ambulatory Activity Monitoring for Disease Management". Proceedings of the 5th International Workshop on Wearable and Implantable Body Sensor Networks, (pp. 201-204).

[3] Aroul, A. L., Manohar, A., Bhatia, D., & Estevez, L. (2008). "Power Efficient Multi-band Contextual Activity Monitoring for Assistive Environments". Proceedings of the 1st International Conference on Pervasive Technologies Related to Assistive Environments. 282, p. 19. ACM International Conference Proceedings Series.

[4] Walker, W., Polk, T., Hande, A., & Bhatia, D. (2006). "Remote Blood Pressure Monitoring Using a Wireless Sensor Network". IEEE Sixth Annual Emerging Information Technology Conference.

[5] Walker, W., Aroul, A. L., & Bhatia, D. (2009). "Mobile Health Monitoring Systems". Engineering in Medicine and Biology Society, 2009. EMBC 2009, (pp. 5199-5202).

[6] Scanlon, W. G., & Evans, N. E. (2001). "Numerical Analysis of Body worn UHF Antenna Systems", Electronics & Communication Engineering Journal, Vol. 13, Issue 2, pp: 53-64.

[7] Werber, D., Schwentner, A., & Biebl, E. M. (2006). "Investigation of RF transmission properties of human tissues", Advance Radio Sci., vol. 4, pp. 357.

[8] See, T. S. P., & Chen, Z. N. (2005) "Effects of human body on performance of wearable PIFAs and RF transmission," IEEE Antennas and Propagation Society Internal Symposium Digest, vol. 1B, pp. 686689..

[9] Kim, J., & Rhamat-Samii, Y. (2004) "Implanted antennas inside a human body: Simulations, designs and characterizations," IEEE Transactions on Microwave Theory and Techniques, vol. 52, no. 8, pp. 1934—1943.

[10] Ansoft HFSS: http://www.ansoft.com/products/hf/hfss/.

[11] Italian National Research Council, Institute for Applied Physics: http://niremf.ifac.cnr.it/tissprop/ #cred

[12] Gabriel, C. (1996). "Compilation of the dielectric properties of body tissues at RF and microwave frequencies", Report N.AL/OE-TR-1996-0037, Occupational and environmental health directorate, Radiofrequency Radiation Division, Brooks Air Force Base, Texas (USA).