International Journal of Multimedia and Ubiquitous Engineering
Vol.9, No.2 (2014), pp.53-64
http://dx.doi.org/10.14257/ijmue.2014.9.2.06

Radiation Characteristics Improvement of Monopole Antenna for WBAN Applications

Ebrahim Sailan Alabidi[1], M. R. Kamarudin[1], T. A. Rahman[1], Mohsen Khalily[1], A. Y. Abdulrahman[1], M. F. Jamlos[2] and M. I. Jais[2]

[1]*Wireless Communication Centre (WCC), Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia*
[2]*Advanced Communication Engineering Centre (ACE), School of Computer and Communication Engineering, Universiti Malaysia Perlis, Kampus Pauh Putra, Arau, Perlis 02600, Malaysia*

ibrahimalabidi85@hotmail.com;ramlee@fke.utm.my; tharek@utm.my; mohsen@fkegraduate.utm.my; abdulrahman.yusuf@yahoo.com; faizal_hero@yahoo.com.sg; ilman_kun@yahoo.com

Abstract

The design, simulation and fabrication of a P-shaped monopole antenna for wireless body area networks (WBAN) applications is presented in this paper. It is noted that the radiation characteristics was improved by attaching a P-shaped element to the ground plane. The simulation of the proposed antenna in the free space and close proximity of body surface has been done using CST Microwave Studio. The proposed antenna is designed on the FR4 substrate with dielectric constant of 4.4 and 1.6mm thickness; and the operating frequency band is between 3.1 to 5.1GHz. The final optimized design has dimensions of 32mm ×28mm. The proposed antenna improves the gain of close proximity of body surface. In addition, the antenna improves the reflection coefficient when placed close human body compared to other antennas. It was observed that there is good agreement between the simulation and measurement results, thereby showing that the antenna is potential to be deployed for WBAN application.

Keywords: *Monopole antenna, Ultra wide band, WBAN applications, Wireless communication*

1. Introduction

The modern and future communication systems are being driven by various wireless technologies. An essential part of this concept is an approach that focuses on the user in the services that are available continuously and provide system's flexibility, modesty and the correct guidance of the human mind. A wireless body area network (WBAN) focuses on networks consisting of interconnected nodes. The units can be integrated into the human body or in the vicinity such as everyday clothing [1].

Ultra-wideband (UWB) technology is beneficial, as it offers low power spectrum and antenna compactness. Moreover, the UWB technology can also be used for the future short-range high-speed indoor wireless personal area networks (WPAN) and WBANs [2].

WBANs have been employed in such applications as medical purposes in order to keep continuous records and permanent monitoring of patients' health conditions anywhere at all times. These conditions include blood pressure, ECG, sugar level and temperature [3].

ISSN: 1975-0080 IJMUE

UWB has become one of the best technologies being applied in networking, radar, imaging, GPS systems and microwave imaging of abnormal tissues [4]. As contained in the Federal Communication Commission (FCC) in 2002, the full bandwidth (BW) of UWB technology covers from 3.1 to 10.6 GHz for UWB communication applications. For system efficiency, UWB system was divided into lower (3.1-5.1 GHz) and higher bands (6 -10.6 GHz) [6].

The antenna is an essential element of WBAN applications for off-body, in-body and on-body communication system [7, 8]. The proposed antenna must have a small size for human body application. The antenna must also put the three layers of body tissues (skin, fat and muscle) into consideration, with relative permittivity and different thickness [9].

The major drawback on the human body is the dispersive effects. Designing an antenna for WBAN applications is a challenging task. The reflection coefficient of the antenna in proximity of the human body is dropped and shifted compared to the free space scenario. In addition, reduced gain and efficiency are the main effects of the human body on such antenna's performance [10]. A new method of reducing these human-body effects on the antenna's performances, in terms of reflection coefficient and gain, is presented in this paper.

As reported in the previously published studies [11-12], it is preferable to use the lower band of UWB for WBAN applications due to high interference by WLAN, especially at 5.8 GHz. The interference scenario is illustrated in Figure 1. The simulation and measurement results of the proposed antenna have been presented both in free space and close proximity to body tissues The study has considered different dimensions of the antenna and the human body tissues. The antenna has been simulated using CST microwave Studio 2012 software package based on finite integral method [13]. The parametric studies were also carried out to investigate different antenna parameters in order to achieve the optimized design.

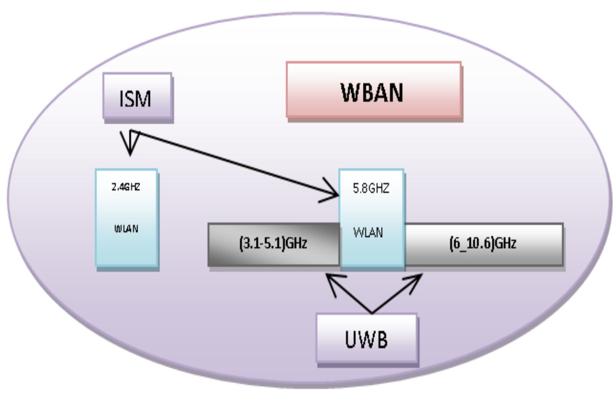
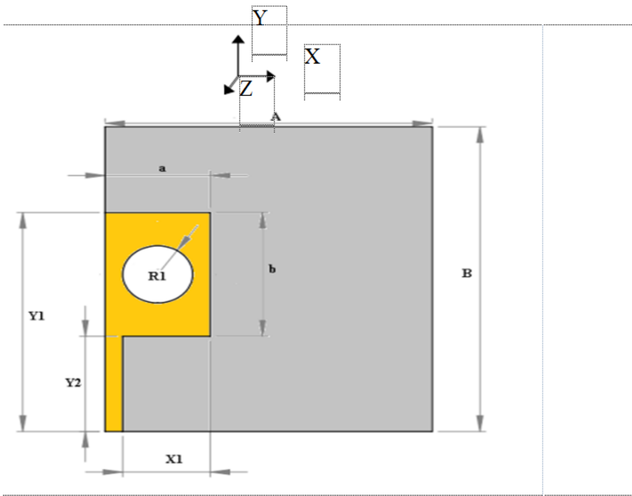


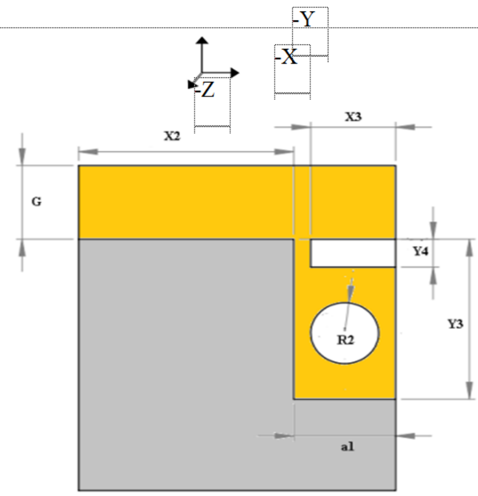
Figure 1. WBAN applications at ISM and UWB

2. Antenna Design

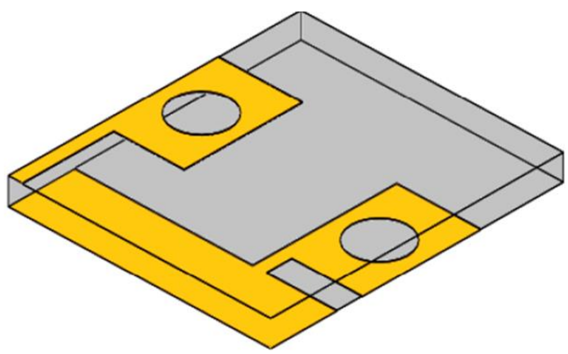
The proposed antenna is designed with a P-shaped radiator element Figure 2 (a) and (b) show that one P-shaped element is connected to the ground plane on the back side while the isometric view is shown in Figure 2 (c). Cost wise, the antenna is fabricated on FR4 substrate material with loss tangent of 0.02, dielectric constant of 4.4 and a thickness of 1.6 mm. The optimized dimension of the proposed antenna is $32 \times 28 \times 1.6 mm^3$. After few parametric studies, the optimized antenna parameters are as follows: A=28mm, B=32mm, a=10mm, b=13mm, X1=8.5mm, X2=19mm, X3=7.5mm, a1=10mm, Y1=23mm, Y2=10mm, Y3=15.75mm, Y4=2.75mm, R1=3mm, R2=3mm, G=8.4mm and feed line weight=1.5mm. The antenna prototype is shown in Figure 3.



(a) front view



(b) back view



(c) isometric view

Figure 2. The proposed P-shaped monopole antenna geometry

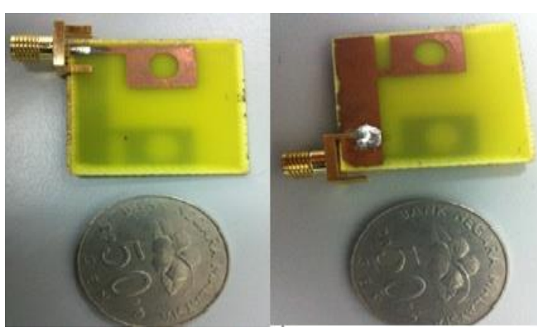


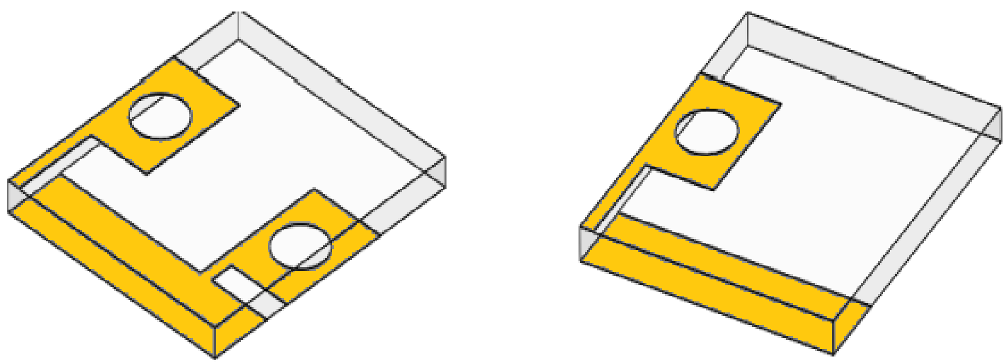
Figure 3. Prototype of the proposed P-shaped monopole antenna

3. Parametric Studies for the Proposed P-shaped Monopole Antenna

Different parameters of the ground plane with and without P-shaped element have been investigated. Also, the effects of the ground plane dimensions (G) on the performance of the proposed antenna has been analyzed.

3.1. Effect of the P-shape of the Ground Plane

The effect of the P-shape on the ground plane has been investigated. The proposed antenna with and without the P-shape in the ground plane is shown in Figure 4. The simulated reflection coefficient is shifted from (3.0-5.5GHz) to (3.85-6.77GHz) with P-shaped implementation as shown in Figure 5. The P-shaped element has been introduced in the ground plane in order to avoid the interference from 5.8 GHz WLAN. Besides enhancing the impedance bandwidth (BW), the proposed antenna radiation efficiency is improved to more than 90% with P-shape element as compared to without P-shape. Moreover, the antenna with P-shape has better gain of double the antenna without P-shape as summarized in Table 1.



(a) (b)

Figure 4. The proposed antenna (a) With P-shaped element in the ground plane (b) Without a P-shaped element in the ground plane

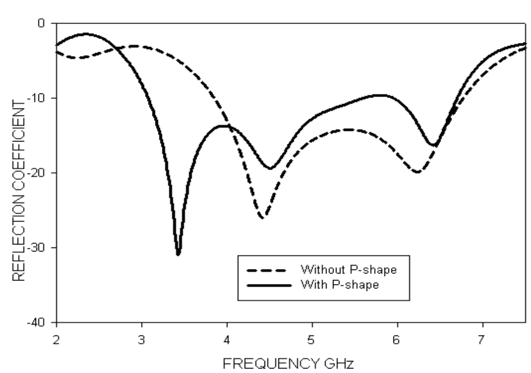


Figure 5. The simulated results of the reflection coefficient, S11

Table 1. The improved characteristics of the proposed antenna with and without P-shape in the ground plane

Ground plane	Operating frequency (GHz)	Gain at (4.5 and 5.1) GHz	Efficiency % at (4.5 and 5.1) GHz
With P- shape	(3.0 - 5.5)	2.4 and 2.2 dB	96% and 94%
Without P- shape	(3.85 - 6.77)	1,8 and 1.1 dB	73% and 78%

The P-shaped antenna without parasitic element in the ground plane covered a frequency range between 3.85 to 6.77GHz. It was noted that the WBAN frequency range is covered by attaching the P-shaped element in the ground plane.

3.2. Effect of length (G) on ground plane of the proposed antenna

The ground plane length (G) (see Figure 2) has an effect on the performance of the proposed antenna; which has been investigated in this study. The optimized dimensions of the P-shape of the ground plane are G=12mm, 8.4mm and 6mm. The simulated reflection coefficient at different G values of 6, 8.4 and 12 mm are compared and illustrated in Figure 6. As G=12 mm, the operating frequency ranges from 5 to 6.3 GHz. When G=6 mm the antenna caters from 2.86 to 3.33 GHz. The proposed antenna operates with a dual band from 2.9 to 3.5 GHz and from 6.2 to 6.55 GHz when G= 5.8mm. Therefore the optimum value of G=8.4mm for the 3.05 to 5.5 GHz band in WBAN applications.

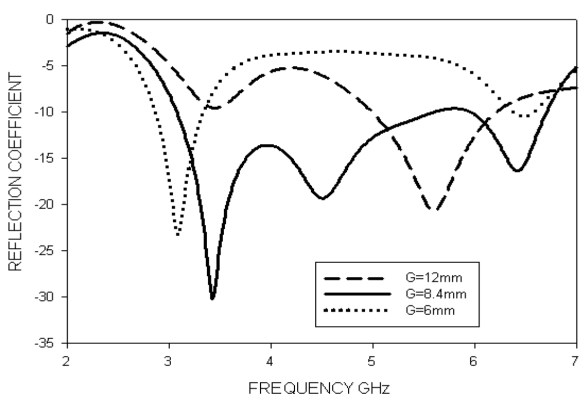


Figure 6. Comparison of the reflection coefficient S11 for different values of G

4. Results and Discussion

The simulated and measured reflection coefficient of the proposed antenna is shown in Figure 7, according to the design requirements. It refers to wide BW covering from 3.05 to 5.5 GHz. As shown in the figure, the reflection coefficient obtained is -30.7 dB (at 3.4 GHz). The proposed antenna has simulated BW and fractional BW of 2.52GHz and 58.2 % respectively.

The measured frequency band of the proposed antenna cater from 2.86 to 5.55 GHz (BW = 2.69 GHz). There are reasonable agreements between the measured and simulated reflection coefficient characteristics.

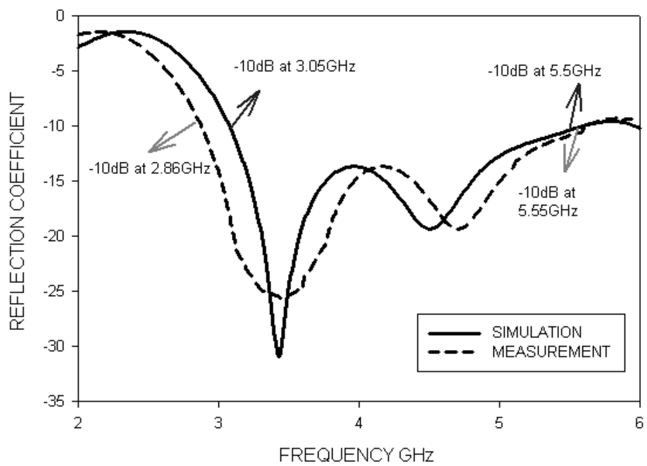


Figure 7. Measured and the simulated S11 results of the proposed antenna

Three layers are designed for the chest of human body tissues in this work, which consists of muscle, fat and skin. The chest body dimensions are about $150\times150\times36mm^3$; and the thicknesses of skin, fat and muscle are 1.0 mm, 5mm and 30mm, respectively. The distance between antenna and body surface is represented by (d). In this analysis, the proposed antenna is placed very close to the body (d=3mm).

The numerical value of specific absorption rate (SAR) can be seen to have increased from the lower frequency (3.1GHz) to the higher frequency (5.1GHz). The SAR (10g) values will be within the limit of allowable SAR. The SAR of the proposed antenna are 1.83W/kg, 2.04W/kg and 2.9 W/kg at 3.4GHz, 4.5GHz and 5.1 GHz respectively.

Furthermore, the reflection coefficient, antenna efficiency and radiation patterns of P-shaped antenna in the free space and near human body have been analyzed.

4.1. Reflection coefficient of the proposed antenna in the free space and near human body

One of the main problems encountered in using antenna near body is changing and shifting the s_{11} compared to in the free space. This means the BW and covering frequency will be shifted or changed when the antenna is used near human body.

By introducing P-shaped element in the ground plane, it is found that the covering band for free space and close to human body tissues is more stable. It can be concluded that the antenna's reflection coefficient is more stable, although the distance is much closer as long as the antenna. The comparison of the return losses in free space and close body surface is shown in Figure 8. The P-shaped monopole antenna improves the reflection coefficient, while decreasing the human-body effects compared to other antennas.

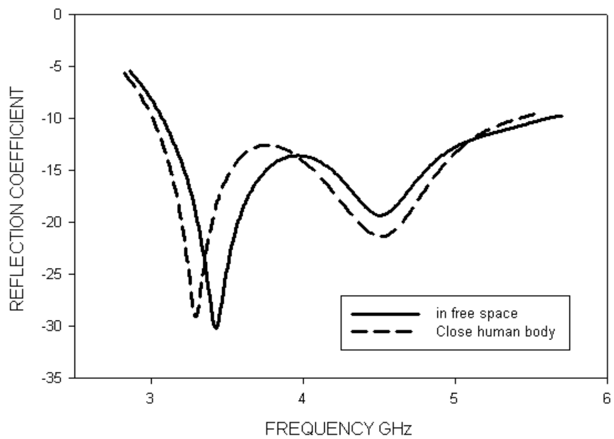


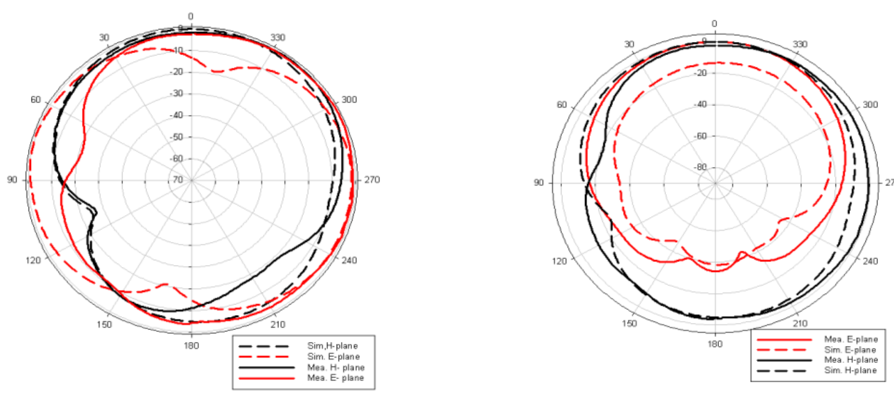
Figure 8. The comparison of the reflection coefficient S_{11} of the proposed antenna

4.2. The Radiation Patterns of the Proposed Antenna in the Free Space and Near Human Body

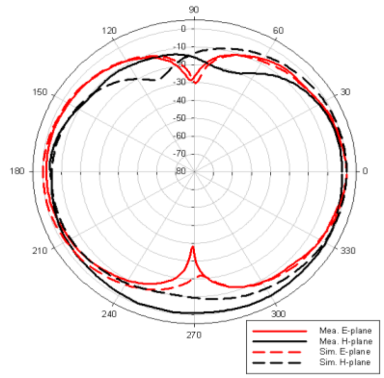
Another problem is the reduced gain when the antenna is placed near human body. In this work, it is found that the antenna can be increased by attaching the P-shaped element in the ground plane.

The proposed antenna has improved the gain when placed near human body compared to free space. The radiation pattern was measured and simulated in the free space, and the results have shown that the gains are 2.8 dB, 2.4 dB and 2.2 dB at 3.4 GHz, 4.5 GHz and 5.1 GHz respectively. When the P-shaped antenna is placed close to the body (d=3mm), the simulated and measured gains are 5.5 dB, 5.3 dB and 4.9 dB at 3.1GHz, 4.1 GHz and 5.1GHz respectively.

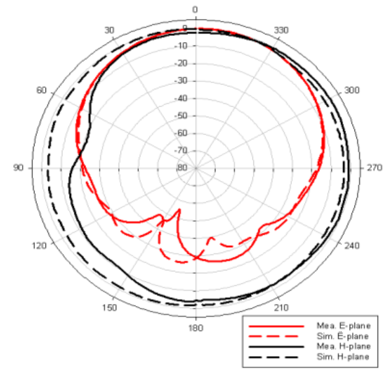
The measured and simulated of E-and H-plane patterns at 3.4, 4.5 and 5.1 GHz in the free space and close to human body tissues at d = 3mm are shown in Figure 9. It can be seen that the E-plane and H-plane radiation pattern are affected when the antenna is placed close to the body.



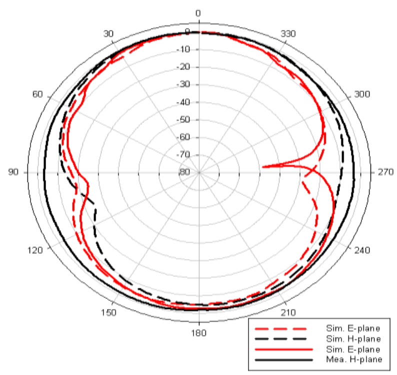
(a) **(b)**



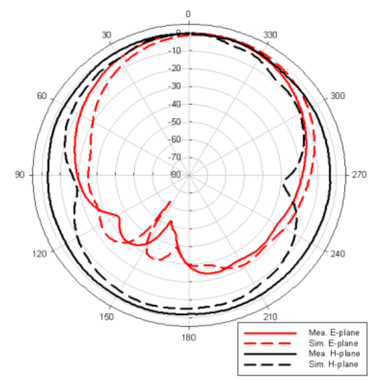
(c)



(d)



(e)



(f)

Figure 9. Measured and simulated radiation pattern of the proposed antenna (a) H- and E-plane pattern at 3.4GHz in free space. (b) H- and E-plane pattern at 3.4 GHz close human body. (c) H- and E-plane pattern at 4.5 GHz in free space. (d) H- and E-plane pattern at 4.5 GHz close human body. (e) H- and E-plane pattern at 5.1 GHz in free space. (f) H- and E-plane pattern at 5.1 GHz close human body

4.3. Radiation efficiency of the proposed antenna in the free space and near human body

The human body will affect the radiation efficiency. Indeed, the efficiency of the antenna near human body is less, compared to the free space efficiency. In [14], the antenna's near body efficiency are 12 %, 7 % and 27% at 3.4, 4.5 and 6 GHz respectively.

The comparison of proposed antenna efficiency in free space and close human body is presented in Figure 10. The P-shape monopole antenna with P-shaped element in the ground plane has improved efficiency close human body compared other antennas.

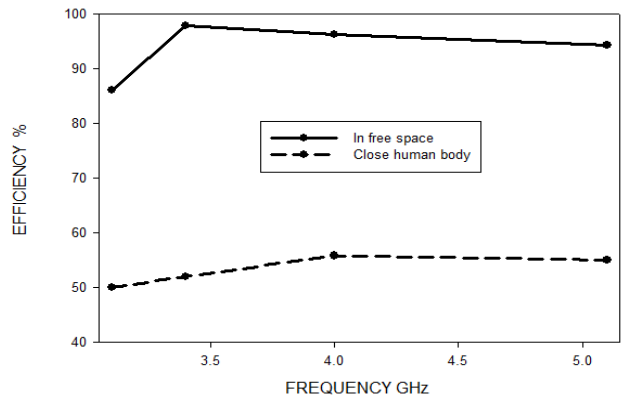


Figure 10. The comparison of proposed antenna efficiency

5. Conclusion

A P-shaped monopole antenna was designed, simulated and fabricated operable from 3.1 to 5.1 GHz, for WBAN applications. The antenna was designed with the P-shaped radiator element with one P-shaped element connected to the ground plane on the back side of the substrate. The proposed P-shape antenna's gain when placed close human tissue has been improved by attaching the P-shaped element in the ground plane. Moreover, the antenna has been able to solve the interference problem associated with WLAN in the 5 - 6GHz band at 5.8GHz. The antenna has improved the instability of antenna return loss at a closer range to the human body. It has improved the antenna efficiency at closer range of the human body. The measured and simulated results have shown that the proposed antenna provides good performance in terms of return loss and radiation pattern for WBAN applications.

Acknowledgements

The authors would like to thank the Ministry of Science, Technology and Innovation (MOSTI) under Science Fund (Vote 4S056), Ministry of Higher Education (MOHE) and UTM for funding this project under GUP Grant (Vote 01H00, Vote 00G36, and Vote 04H36). They would also like to appreciate the members of WCC, UTM and ACE, UniMAP for their useful helps and technical advices.

References

[1] A. Alomainy, A. Sani, A. Rahman, J. G. Santas and Hao Yang, **"**Transient Characteristics of Wearable Antennas and Radio Propagation Channels for Ultra wideband Body-Centric Wireless Communications**"**, Antennas and Propagation, IEEE Transactions, vol. 57, no. 4, **(2009)**, pp. 875-884.

[2] C. H. Duney, H. Massoudi and M. F. Iskander, "Radiofrequency radiation dosimetry**",** handbook, USAF School of Aero-space Medicine, **(1986)**.

[3] M. R. Yuce, **"**Implementation of Wireless Body Area Networks for Healthcare Systems**"**, Sensors & Actuators: A. Physical, vol. 162, no. 1, **(2010)**, pp. 116-129.

[4] G. R. Aiello and G.D. Rogerson, "Ultra-wideband wireless systems**"**, IEEE Microw. Mag., vol. 4, no. 2, **(2003)**, pp. 36-47.

[5] Federal Communication Commission (FCC), Revision of part 15 of the commission's rules regarding ultra-wideband transmission systems, First Report and Order, ET Docket 98–153, FCC 02–48; Adopted, **(2002)**.

[6] T. S. P. See and Chen Zhi-Ning, "Experimental Characterization of UWB Antennas for On-Body Communications", Antennas and Propagation, IEEE Transactions, vol. 57, no. 4, **(2009)**, pp. 866-874.
[7] R. K. Kohno, H. B. Li Hamaguchi and K. Takizawa, "R&D and standardization of body area network (BAN) for medical healthcare", Proc. IEEE Int. Conference on Ultra-Wideband, (ICUWB), vol. 3, **(2008)**, pp. 5-8.
[8] A. W. Astrin, H. B. Li and R. Kohno, "Standardization for body area networks", IEICE Trans. Commune., vol. E92-B, no. 2, **(2009)**, pp. 366-372.
[9] W. G. Scanlon and N. E. Evans, "Numerical analysis of body worn UHF antenna systems", Electronics & Communication Engineering Journal, vol. 13, no. 2, **(2001)**, pp. 53-64.
[10] S. karimabadi and A. R. Attari, "Gain Enhancement of Small Size UWB Antenna for Wireless Body Area Network Applications", Proceedings of ICEE, **(2010)**.
[11] M. Naser-Moghadasi, L. Asadpor, S. F. Qotolo and B. S. Virdee, "A Small UWB CPW-FED Monopole Antenna with Double Band-Notch Property", Microw. Opt. Technol. Lett., vol. 55, no. 8, **(2013)**, pp. 1840–1845.
[12] G. M. Zhang, J. S. Hong and B. Z. Wang, "Two novel band-notched UWB slot antennas FED by microstrip line", Progress In Electromagnetics Research, vol. 78, **(2008)**, pp. 209-218.
[13] CST Microwave Studio, http://www.cst.com.
[14] M. Klemm, I. Z. Kovcs, G. F. Pedersen and G. Troster, "Novel small-size directional antenna for UWB WBAN/WPAN applications", Antennas and Propagation, IEEE Transactions, vol. 53, no. 12, **(2005)**, pp. 3884-3896.

Authors

Ebrahim Sailan Alabidi

He was born in 1985 in Sana'a, Yemen. He received the B.Sc. degree. Electrical Engineering from Jordan University of Science and Technology, Jordan, in 2003 and 2007. He received the M. A. Sc. degree. in Electrical Engineering from Universiti Teknologi Malaysia, Malaysia (UTM) in 2010.He is currently working toward the Ph.D. degree from UTM, Malaysia.

M. R. Kamarudin

He obtained his first degree from Universiti Teknologi Malaysia (UTM), Malaysia, with Honours, majoring in electrical and telecommunication engineering, graduating in 2003. He received the M.Sc in Communication Engineering in 2004 and PhD in 2007 from University of Birmingham, UK. Dr Kamarudin has published more than 90 technical journals including an IEEE Transaction on Antenna and Propagation and IEEE Antenna Magazine. Currently, Dr Kamarudin is a member of IEEE (MIEEE), a member of IET (MIET), an Executive Member of Antenna and Propagation (AP/MTT/EMC) Malaysia Chapter, Member of GOLD IEEE Malaysia, an Associate Professor at Wireless Communication Centre (WCC), Universiti Teknologi Malaysia (UTM) and is supervising a numbers of Post-Doc, PhD, Master and Undergraduate students.

T. A. Rahman

He is a professor in wireless communication at faculty of electrical engineering, Universiti Teknologi Malaysia. He obtained his BSc (Hons) (Electrical Engineering) from University of Strathclyde, UK MSc in Communication Engineering from UMIST, Manchester, UK and PhD in Mobile Communication from University of Bristol, UK. He is the Director of Wireless Communication Centre (WCC), Faculty of Electrical Engineering, Universiti Teknologi Malaysia and currently conducting research related to LTE (4G) for mobile communications, satellite communications, antenna and propagation. He has also conducted various short courses related to mobile and satellite communication to the telecommunication industry and government agencies since 1988. Prof. Dr. Tharek has published more than 120 scientific papers in journals and conferences and obtained many national and international awards.

Mohsen Khalily

He was born in Shahr-e-Kord, Iran in 1983. He received his PhD degree from the Universiti Teknologi Malaysia (UTM) in 2012. His research interest includes the areas of design dielectric resonator antennas, monopole antennas, reconfigurable antennas, and RF Microwave. He is currently a Postdoctoral Research Fellow with the Wireless Communication Center (WCC) at UTM.

Amuda Yusuf Abdulrahman

He obtained his Bachelor's (1999) and Master's Degrees (2005), from University of Ilorin, Nigeria; and PhD Degree in 2012 Universiti Teknologi Malaysia (UTM), Skudai, Malaysia. He is currently a Post-Doctoral Fellow at Wireless Communication Centre (WCC), Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM), Skudai, Malaysia. His research interests include wireless mobile systems, radio propagation and rain attenuation studies, especially in the tropics.

M. F. Jamlos

He obtained his Ph.D in 2010 from Universiti Teknologi Malaysia, Malaysia. He has received the Master of Engineering in Electrical & Electronic in 2008from University of Adelaide, Australia. Previously, he obtained his first degree from Universiti Malaysia Perlis (UniMAP), Malaysia, with Honours, in computer engineering, graduating in 2006. Dr Faizal is one of the authors of International Book Chapters entitled "Advanced Transmission Techniques in WiMAX" which is published by

InTech with 1434 citations. He has currently published more than 27 impact factor journals with cumulative impact factor (CIF) of 41.351 and 58 technical SCOPUS conference papers on electronic communication, antennas performance and design for wireless applications and antenna diversity. He is also a journal reviewer for Progress in Electromagnetics Research (PIER) Journal, IET Microwaves and international conferences such as Asia Pasific Microwave Conference (APMC), International Symposium on Antenna and Propagation (ISAP) and Asia Modeling Symposium and other international and national conferences. He is assigned as a guess editor at International Journal of Antennas and Propagation (IJAP) for Wi Max special issues. He recently appointed as a leader of profitable MikroTik Academy (MA) in Malaysia and certified as MikroTik Certified Network Associate (MTCNA). He is a co-founder of Centre of Excellence of Advanced Communication Engineering Centre (ACE). He is a member of IEEE (MIEEE), a member of Graduates Engineer (BEM), a member of Institute Engineers Malaysia (IEM), Member of National Medical Researcher (NMR), Deputy Dean of School of Computer & Communication Engineering, Universiti Malaysia Perlis and supervising a numbers of PhD, Master and Undergraduate students. His research interests include electronic communication engineering for Dielectric materials for wireless communication, Wireless Bridging, Nano Antenna Nano-biosensor, antenna diversity and reconfigurable and microwave sensor.

Mohd Ilman Jais

He was born in Selangor, Malaysia,in 1986. He received the first degree from Universiti Malaysia Perlis (UniMAP), Malaysia, with Honors in communication engineering, graduating in 2011, where he is currently working toward the MsC. degree in Communication Engineering. His research interests include reconfigurable antennas, RF-MEMS systems and electromagnetic optimization methodologies.