PLANAR MONOPOLE ANTENNAS WITH REFLECTION PLANE FOR HUMAN BODY CENTRIC COMMUNICATION

EBRAHIM SAILAN GUBRAN ALABIDI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Electrical Engineering)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JANUARY 2015

To my beloved mother and father

To my wife

And my friends

ACKNOWLEDGEMENT

In preparing this project report, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main project report supervisor, Assoc. Prof. Dr. Muhammad Ramlee Bin Kamarudin.for his encouragement, guidance, critics, and motivation. Without his continued support and interest, this project report would not have been the same as presented here.

I would like to thank Prof. Tharek Bin Abd Rahman and staff in Wireless Communication Center (WCC) for their help, facilities and for providing conducive working environment.

Finally, I am deeply and forever indebted to my wife, parents for their love, spiritual support, and encouragement throughout my entire life.

.

.

ABSTRACT

Wireless Body Area Network (WBAN) is an emerging technology that requires an antenna to be placed on human body for a wide range of applications such as healthcare, entertainment, surveillance, emergency and military. The reflection coefficient magnitude of the antenna in closeness to the human body is degraded and shifted. Essentially, efficiency and gain reduction are the main disadvantages of the antenna performances due to the body effect. In this research, methods of improving efficiency, gain, Specific Absorption Rate (SAR) and stabilizing reflection coefficient magnitude have been proposed. In this work, the design, simulation and fabrication of two monopole antennas with P-shaped and circular-shaped are presented. The proposed P-shaped monopole antenna is designed to operate from 3.1 to 5.1 GHz while the proposed circular-shaped monopole antenna operates at 3.1-5.1 GHz and 6.5-8 GHz. The simulation of the proposed antennas in free space and close proximity of body surface has been carried out using Computer Simulation Technology (CST) Microwave Studio. It has been found that when the P-shaped and circular elements are introduced to the ground plane of the antennas, the reflection coefficient magnitudes with the presence of body for both antennas remain the same as in free space. Moreover, the efficiency and gain of the antennas have been improved by attaching the glass substrate to the ground plane. P-shaped antenna with the glass substrate has demonstrated about 34.6%, 35% and 39.2% improvement of the antenna efficiency at 3.3, 4.45 and 5 GHz, respectively, when placed directly on the human head. For the human chest placement, the antenna demonstrates 30.7%, 33.4% and 36%, and the gain of 3.4, 2.8 and 4 dBi of antenna efficiency and gain improvement at 3.3, 4.45 and 5 GHz, respectively. Similarly, for circular-shaped monopole antenna the improvement of the antenna efficiency obtained for human head are 39.8% and 37.23% at 3.3 and 7.5 GHz, respectively, and for the chest are 36.5% and 32.8% at 3.3 and 7.5 GHz, accordingly. The antenna demonstrates 2.9 and 2.54 dBi improvement of the gain at 3.3 and 7.5 GHz, respectively. These improvements are compared with the antenna without the glass substrate. This study concludes that the glass substrate has improved the gain, efficiency and SAR when placed near human body compared to other antennas and the S_{11} remains stable when some additional elements are introduced to the ground plane. It was observed that there is good agreement between the simulation and measurement results, thereby showing that the antennas have potential to be deployed for WBAN application.

ABSTRAK

Rangkaian Kawasan Badan Tanpa Wayar (WBAN) adalah sebuah teknologi baru yang memerlukan antena diletakkan pada badan manusia untuk pelbagai aplikasi seperti penjagaan kesihatan, hiburan, pengawasan, kecemasan dan ketenteraan. Magnitud bagi pekali pantulan antena yang berdekatan dengan tubuh badan manusia adalah berkurangan dan berubah. Pada asasnya, kecekapan dan pengurangan gandaan adalah kelemahan utama ke atas keupayaan antena disebabkan oleh kesan badan. Dalam kerja penyelidikan ini, kaedah-kaedah bagi meningkatkan kecekapan, gandaan, Kadar Penyerapan Tertentu (SAR) dan penstabilan magnitud pekali pantulan telah dicadangkan. Dalam kajian ini, reka bentuk, simulasi dan fabrikasi antena ekakutub berbentuk P dan bulat telah dibentangkan. Antena ekakutub berbentuk P yang dicadangkan adalah direka bentuk untuk beroperasi daripada 3.1 ke 5.1 GHz manakala antena ekakutub berbentuk bulat dicadangkan bagi operasi dua jalur iaitu 3.1-5.1 GHz dan 6.5-8 GHz. Simulasi antena di ruang bebas dan ketika diletakkan pada permukaan badan telah dijalankan menggunakan Teknologi Simulasi Komputer (CST) Studio Gelombang Mikro. lanya telah didapati bahawa, apabila elemen bentuk P dan bulat diperkenalkan ke atas satah bumi, pekali pantulan dengan kehadiran badan manusia bagi kedua-dua antena adalah kekal sama seperti yang terhasil pada ruang bebas. Selain itu, keberkesanan gandaan pada antena diperbaiki dengan menggandingkan substrat kaca ke atas satah bumi. Antena berbentuk P dengan substrat kaca telah menunjukkan peningkatan terhadap kecekapan sebanyak 34.6%, 35% dan 39.2% pada 3.3, 4.45 dan 5 GHz apabila diletakkan berhampiran dengan kepala manusia. Manakala, apabila antena diletakkan pada dada manusia, peningkatan kecekapan yang diperoleh adalah 30.7%, 33.4% dan 36% dan gandaan pula memberikan peningkatan sebanyak 3.4, 2.8 dan 4 dBi pada 3.3, 4.45 dan 5 GHz. Kecekapan yang berjaya diperolehi apabila antena diletakkan pada bahagian kepala ialah 39.8% dan 37.23% pada 3.3 GHz dan 7.5 GHz. Bagi bahagian dada manusia pula pula 36.5% dan 32.8% pada 3.3 dan 7.5 GHz. Antena ini juga menunjukkan peningkatan gandaan sebanyak 2.9 dan 2.54 dBi pada frekuensi 3.3 dan 7.5 GHz. Peningkatan ini telah dibandingkan dengan antena tanpa substrat kaca. Kajian ini menyimpulkan bahawa substrat kaca telah meningkatkan gandaan, kecekapan dan memperbaiki nilai SAR apabila diletakkan berhampiran badan manusia berbanding antena lain, dan S_{11} kekal stabil apabila sebahagian elemen tambahan diperkenalkan pada satah bumi. Dapat diperhatikan bahawa terdapat perhubungan yang baik antara simulasi dan keputusan pengukuran, sekaligus menunjukkan bahawa antena mempunyai potensi untuk digunakan untuk aplikasi WBAN.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

WBAN	-	Wireless Body Area Network
FCC	-	Federal Communications Commission
FDTD	-	Finite Difference Time Domain
CST	-	Computer Simulation Technology
FR4	-	Flame Resistance 4
IEEE	-	Institute of Electrical&Electronics Engineers
ISM	-	Industrial, Scientific and Medical
SAR	-	Specific Absorption Rate
UWB	-	Ultra Wide-Band
VNA	-	Vector Network Analyser
WPAN	-	Wireless Personal Area Network
WLAN	-	Wireless Local Area Network
EM	-	Electromagnetic
PEC	-	Perfect Electric Conduct
EBG	-	Electromagnetic Band Gap
VSWR	-	Voltage Standing Wave Ratio
BW	-	Bandwidth
GPS	-	Global Position System
WCC	-	Wireless Communication Centre
UTM	-	Universiti Teknologi Malaysia

LIST OF SYMBOLS

f_h	-	High frequency
f_l	-	Low frequency
mm	-	Millimeter
Hz	-	Hertz
K	-	Kilo
G	-	Giga
d	-	Distance
h	-	Height
L	-	Length
W	-	Width
Γ	-	Reflection coefficient
Z0	-	characteristic impedance
λ	-	Wavelength
c	-	Speed of light 3x 10-8 m/s
dB	-	Decibel
Ω	-	Ohm
ε_r	-	Permittivity

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

The scientific community developed certain level of interest in the communication between electromagnetic fields (EMF) and the human body. This has gained a lot of attention particularly since the introduction of mobile telephony networks [1-4]. The main focus was the interaction between terminal antennas and a human body [5, 6].

Perfect understanding of a particular absorption capacity is an essential component in studying the communications of electromagnetic (EM) fields with biological tissue and living organism. In the review paper [7], it was introduced that SAR strength and the dispersion within the exposed objects are influenced by the shape, size, dielectric characteristics, frequency and kind of exposure.

After the current introduction of wearable computing and wireless body centric networks i.e. WBAN communication on the body are among the components of a Wearable Textile System, i.e. sensors, processor etc. Personal Area Network (PAN) communication flanked by the body and other applications in a short-range field (about 10 m). It adopts protocols such as 802.11b, Bluetooth, Wireless USB, Zigbee, that function in the 2.45 GHz ISM band. Information dissemination to the point of care via communication networks (GSM, GPRS, the Internet, etc.) as indicated in Figure 1.1 scenarios must be viewed for an added dimension for compliance testing [8].

WBAN is of extraordinary significance in new sensing and monitoring applications for the medical profession. Interactions from in-body implants and on-body sensors would enable proper diagnosis and therapy improvement. The Ultra-Wideband (UWB) mechanism with its special benefits over the narrow-band structure is a probable innovation for body area network [8]. For a better modification of effective body area network, this must occur with easy mobility, augment reality, sensitivity and compact size and light weight [9].

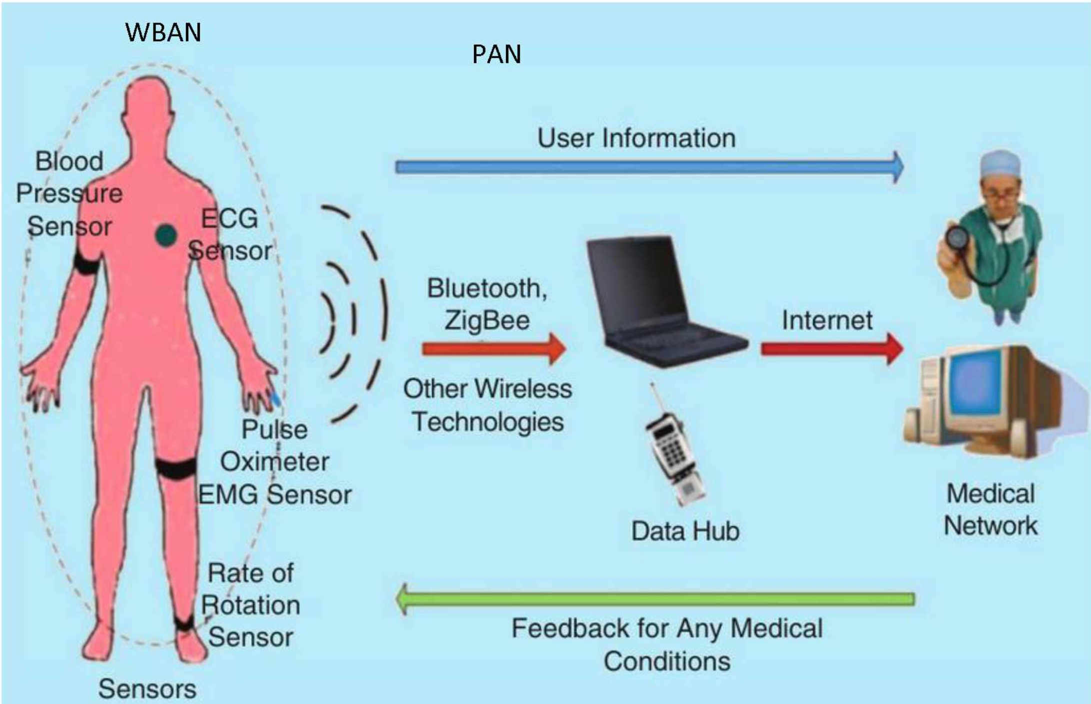

Figure 1.1 Envisioned WBAN in Healthcare Applications [10]

1.2 Problem Statement

Body-centric wireless networks should provide cost effective solutions and guarantee the mobility and freedom desired by the users. Therefore the various components of the radio system should provide light weight and low power consumption to prevent short battery life and unwanted obtrusiveness to the user. One of the major issues is designing antennas in such a wireless system in order to understand the effect of the human body on the antenna.

However there are some tradeoffs when deploying antennas on the human body. These drawbacks can be classified into three main problems: first, the reflection coefficient magnitude (S_{11}) will not be stable and it is detuned to other frequencies when the antenna is brought closer to the human body. Second, the decrease in the efficiency and the gain of the antennas are more severe when placed close to the human body. And third, some of the antennas produce higher SAR values, which is unsuitable for WBAN applications.

1.3 Research Objectives

The main objectives of this study include:

1) To design and analyze the monopole antenna for wireless body area network applications at 3.1 to 5.1 GHz band and dual-band antenna at 3.1 to 5.1 GHz and 6.5 to 8 GHz, with stable reflection coefficient magnitude in free space and close to human body.

2) To design and analyze a new reflector plane (glass substrate) to improve the antenna efficiency and gain.

3) To investigate the Specific Absorption Rate (SAR) effect in many locations of the body using numerical phantom.

1.4 Scope of the Research

The scope of this research is to design a small size antenna at 3.1 to 5.1 GHz and dual band antenna at 3.1 to 5.1 GHz and 6.5 to 8 GHz. The antenna performances for both P-shaped and circular shaped monopole antennas are investigated in free space. Hence, improving the gain and efficiency of the proposed antennas with presence of human body and a glass substrate as a reflector. The overview of the works are stated in Figure 1.2.

The main scope of this research:

- Having stable reflection coefficient magnitudes for both antennas in contact with the human body by introducing modified elements in the antenna's ground plane.
- Using L-shaped and modified shaped glass substrates attached to the proposed antennas for efficiency improvement.
- Analyzing SAR carried out in CST in the human head and chest. Both CST and HFSS analyzed SAR in three layers of human tissue.
- Analyzing efficiency and SAR achieved in CST of the different human body locations.

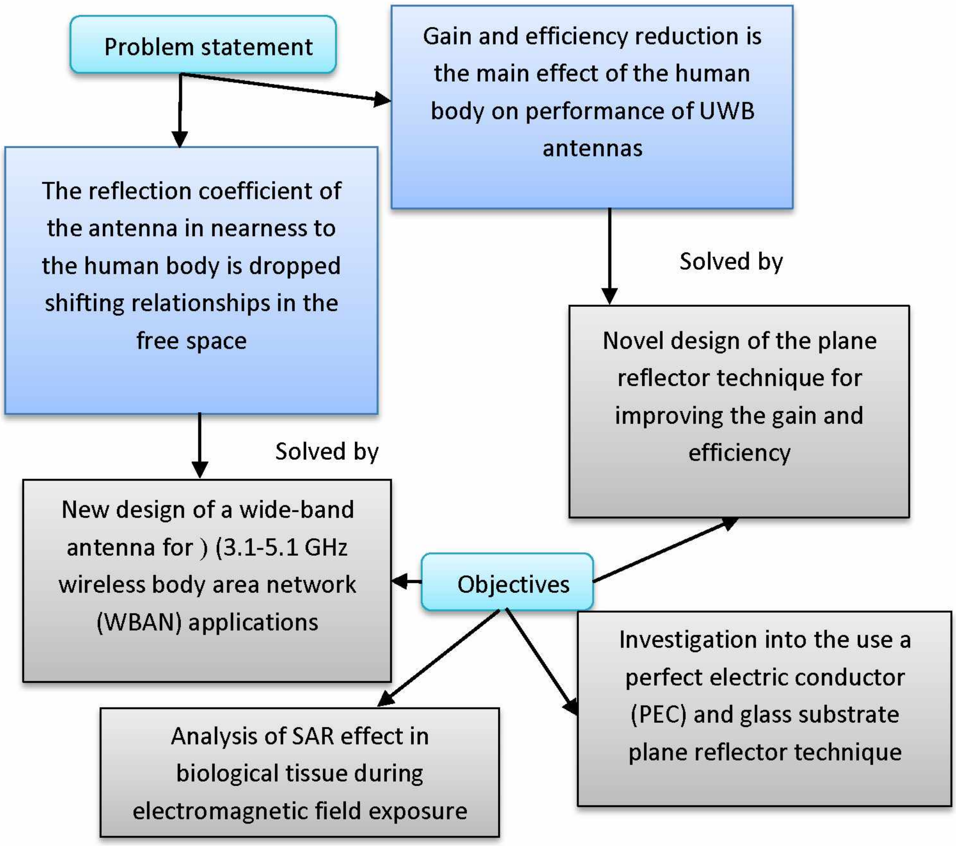

Figure 1.2 The scope of this research

1.5 Contribution of the Research

Following are the contributions of the thesis:

1) New design P-shaped monopole antenna with P-shaped element on the ground plane. In addition, design of an L-shaped glass substrate attached with the proposed P-shaped monopole antenna.

2) New design of a circular-shaped monopole antenna with modification on the ground plane. In addition, design of glass substrate attached to the proposed circular-shaped monopole antenna.

1.6 Organization of the thesis

This thesis contains seven chapters. Chapter 1 presents the introduction, problem statement, research objective, scope of the research and contribution of the thesis. The rest of the thesis is organized as follows:

Chapter 2 presents the literature review as studied by several previous authors. This includes the fundamental theories and concepts of Antennas, particularly the UWB antennas, the impact of the EMF on human body, the SAR factors and how it affects the human body.

Chapter 3 describes the methodology used to achieve this research with illustration of the flow chart for research schedule. This chapter presents the CST Microwave Studio simulation software to design and emphasizes the equations and algorithms adopted in combining approaches on body communication process. In addition, explanation of the dielectric constant measurement of glass substrate. The chapter illustrates the electromagnetic properties of body tissues and antenna design with reflection plane technique for WBAN applications.

In Chapter 4, the P-shaped antenna is described and results and discussion for the proposed antenna are provided. The antenna is designed with the P-shaped radiator element with element connected to the ground plane on the proposed antenna.

In Chapter 5, the plane reflector approach is built to have shapes, PEC and glass substrate by integrating the proposed antenna. In addition, the results reported from this study are discussed.

Chapter 6 presents a description of the circular-shaped antenna and provides results and discussion for the proposed antenna. The plane reflector approach is built to have glass substrate.

Finally, Chapter 7 discusses the conclusions of the research and recommendations for future researchers.

REFERENCES

1. Stuchly M., “Electromagnetic fields and health”, *IEEE Potentials*, Vol. 12, Issue 2, 34–39, Apr. 1993.

2. Rosen A., et al, “Applications of RF/microwaves in medicine”, *IEEE Transactions on Microwave Theory and Techniques*, Vol. 50, Issue 3, 963–974, March 2002.

3. Chatterjee I., et al, “Electromagnetic absorption in a multilayered slab model of tissue under near field exposure conditions” *Bio electromagnetics*, Vol. 1, Issue 4, 379–388, 1980.

4. Chatterjee I., et al, “Plane-wave spectrum approach for the calculation of electromagnetic absorption under near-field exposure conditions” *Bio electromagnetics*, Vol. 1, Issue 4, 363–377, 1980.

5. Kuster N., “Multiple multipolemethod for simulating EM problems involving biological studies” *IEEE Transactions on Biomedical Engineering*, Vol. 40, Issue 7, 611–620, July 1993.

6. Kuster N. and Balzano Q., “Energy absorption mechanism by biological bodies in the near field of dipole antennas above 300 MHz” *IEEE Transactions on Vehicular Technology*, Vol. 41, Issue 1, 17–23, Feb. 1992.

7. Lazzi G., et al, “FDTD computation of electromagnetic absorption in the human head from mobile telephones” Proc. of the 18th *Annual Technical Meeting of the Bio electromagnetics Society* - BEMS, 1996.

8. Christ A. and Kuster N., “Differences in RF energy absorption in the heads of adults and children” *Bio electromagnetics*, September 2005.

9. Zasowski T., et al, "UWB for noninvasive wireless body area networks: Channel measurements and results" *IEEE Conference on Ultra Wideband Systems and Technologies*, UWBST 2003, Reston, Virginia, USA, Nov. 2003.

10. Duney C. H., Massoudi H. and Iskander M. F., "Radiofrequency radiation dosimetry handbook," *USAF School of Aero-space Medicine*, October 1986.

11. Jovanov E., ODonnell-Lords A., Raskovic D., Cox P., Adhami R. and Andrasik F., "Stress monitoring using a distributed wireless intelligent sensor system," *IEEE Engineering in Medicine and Biology Magazine*, vol. 22, no. 3, pp. 49–55, 2003.

12. Matsushita S., "A headset-based minimized wearable computer," *IEEE Intelligent Systems*, vol. 16, no. 3, pp. 28–32, May/June 2001.

13. Lukowicz P., Anliker U., Ward J., Troster G., Hirt E. and Neufelt C., "AMON: a wearable medical computer for high risk patients," *Proceeding Sixth International Symposium on Wearable Computers 2002*, Seattle, pp. 133–134, October 2002.

14. Kunze C., Grossmann U., Stork W. and Muller-Glaser K., "Application of ubiquitous computing in personal health monitoring systems," *Biomedizinische Technik: 36th Annual meeting of the German Society for Biomedical Engineering*, pp. 360–362, 2002.

15. Hall P. S. and Hao Y., "Antennas and Propagation for Body-Centric Wireless Communications," *Artech House*, 2006.

16. Z. N. C. "Antennas for Portable Devices." *wiley & Sons,* Inc., 2007.

17. "Federal communications commission (FCC), code of federal regulations (CFR), title 47 part 95, MICS band plan, 2002.

18. "International telecommunications union-radio communications (ITU-R), radio regulations, section 5.138 and 5.150, 2002.

19. Drude S. "Tutorial on body area networks" *IEEE 802.15-06-0331," IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs),* 18 July 2006.

20. *International telecommunications union-radiocommunications (ITU-R),* radio regulations, Section 5.138 and 5.150," URL: http://www.itu.int/home.

21. "IEEE 802.15,an international standards working group, IEEE 802.15," URL: *http:// grouper.ieee.org/groups/802/15/.*

22. Alomainy A. "Antennas and radio propagation for body-centric wireless networks," *Ph.D. dissertation*, Queen Mary, University of London, 2007.

23. Ben Allen, et al, "Ultra-wideband Antennas and Propagation fir Communications, Radar and Imaging", *Wiley* , vol. 13, no. 6, pp. 39–45, 2007.

24. Faranak Negookar. "Ultra-wideband Communications: Fundamentals and Applications". *Prentice Hall.* August 31 St 2005.

25. Dowla F. and Nekoogar F. "Multiple access in ultra-wideband communications using multiple pulses and the use of least squares filters," *Radio and Wireless Conference,* RAW-CON, pp. 211-214, 2003.

26. Porcino D. and Hirt W. "Ultra-wideband radi technology: potential challenges ahead," *IEEE Communications Magazine*, vol. 41, no.7, pp. 66-74, July 2003.

27. *FCC First Report and Order, Revision of the Part 15 Commission's Rules Regarding Ultra-Wideband Transmission Systems*, pp. 98-153, April 22, 2003.

28. Dowla F. and Nekoogar F. "Multiple access in ultra-wideband communications using multiple pulses and the use of least squares filters," *Radio and Wireless Conference,* RAWCON, pp. 211-214, 2003.

29. Zhao L. and Haimovich A. M. "Performance of ultra-wideband communications in the presence of interference," *IEEE Journal on Selected Areas in Communications,* vol. 20, no. 9, pp. 1684–1691, 2002.

30. Scholtz R. A. “Multiple access with time-hopping impulse modulation,” *Proceedings of IEEE MILCOM*, pp . 447–450, 1993.

31. Karus D. K. and Fleisch D.A., “Electromagnetics with applications”, *4th edition, WCB/McGraw-Hill*, ISBN: 0-07-116429-4.

32. Kraus J.D. and Marhefka R.J., “Antennas for all applications”, *3rd edition, McGraw-Hill Higher Education*,

33. Schelkunoff A. “Some equivalence theorems of electromagnetics and their applications to radiation problems,” *Bell Syst.* Tech. J., vol. 15, pp. 92-112, 1936.

34. Huygens C. “Traite de lumiere,” *Leyden*, 1960.

35. Love A. E. H. “The integration of the equations of propagation of electric waves,” *Philos.* Trans. R. Soc. London, Ser., vol. 197, pp. 1–45, 1901.

36. Sani, A, “Modeling and characterization of antennas and propagation for body-centric wireless communication,” IEEE Engineering in Medicine and Biology Magazine, vol. 29, no. 1, pp. 66–72, April 2010.

37. “Calculation of the dielectric properties of body tissues,” *Institute for Applied Physics, Italian National Research Council.*

38. Gabriel C. and Gabriel S. “Compilation of the dielectric properties of body tissues at RF and microwave frequencies,” 1999.

39. Villegas D. Marchaland M., Baudoin G., Tinella C. and Belot D.“Novel Pulse Generator Architecture dedicated to Low Data Rate UWB Systems,” *ECWT*, vol. 4, pp. 34–39, October 2005.

40. Zhao Y., Hao Y., Alomainy A. and Parini C. “Ultra wide- band body area channel model,” *IEEE Transaction on Microwave Theory and Techniques*, vol. 54, no. 4, pp. 1827–1835, April 2006.

41. Xu X., Chao T. and Bozkurt A. “VIP-Man: an image-based whole-body adult male model constructed from color photographs of the visible human project for multi-particle Monte Carlo calculations,” *Health Physics*, vol. 78, no. 5, p. 476, 2000.

42. Hall P. S. and Hao Y. “Antennas and Propagation for Body-Centric Wireless Communications.” *Artech House*, 2006.

43. Guy A. “Analyses of electromagnetic fields induced in biological tissues by thermo graphic studies on equivalent phantom models,” *IEEE Transactions on Microwave Theory and Techniques,* vol. 19, no. 2, pp. 205–214, 1968.

44. Ito K., Furuya K., Okano Y. and Hamada L. “Development and characteristics of a biological tissue-equivalent phantom for microwaves,” *Electronics and Communications in Japan (Part I: Communications*, vol. 84, no. 4, 2001.

45. Sani A., Rajab M., Foster R. and Hao Y. “Antennas and propagation of implanted RFIDs for pervasive healthcare applications,” publication in the *Proceeding of the IEEE*. vol. 9, no. 3, pp. 66–72, 2008.

46. M. F. Abedin, and M. Ali, "Modifying the ground plane and its effect on planar inverted -F antennas (PIFA) for mobile phone handsets," *IEEE Antennas and Wireless Propagation. Letters*, Vol. 2, 226-229, 2003.

47. X. K., Kang, L. W. Li, M. S.L eong, and P. S. Ko oi, "A spheroidal vector wave function analysis of field and SAR distributions in a dielectric prelate spheroidal human head model," *Progress In Electromagnetics Research*, Vol. 22, 149-179, 1999.

48. J. Fuhl, P. Nowak and E. Bonek, “Improved Internal An-tenna for Hand-Held Terminals,” *Electronics Letters*, Vol. 30, No. 22, pp. 1816-1818. 1994.

49. F. R. H. Siaho and K. L. Wong, “A Shorted Patch Antenna With an L-shaped Ground Plate for Internal Mobile Hand-set Antenna,” *Microwave and Optical Technology Letters*, Vol. 33, No. 4, pp. 314-316, 2002.

50. K. Kiminami, A. Hirata, Y. Horii, and T. Shiozawa, "A Study on human body modeling for the mobile terminal antenna design at 400MHz band," *Journal of Electromagnetic Waves and Application*, Vol. 19, No. 5, 671-687, 2005.

51. 5. Jensen, M. A. and Y. Rahamat-Samii, EM interaction of handset antennas and a human in personal communication, *Proceeding of the IEEE*, Vol. 83, No. 1, pp 7-17, 1995.

52. T. V. Yioultsis, T. I. Kosmanis, E. P. Kosmidou, T. T. Zygiridis, N. V. Kantartzis, T. D. Xenos, and T. D. Tsiboukis, "A comparative study of the biological effects of various mobile phone and wireless LAN antennas," *IEEE Trans. Magnetics*, Vol. 38, No. 3, pp. 777-780, 2002.

53. O. A. Saraereh, M. Jayawadene, P. McEvoy, and J. C. Vardaxoglou, "Simulation and experimental SAR and efficiency study for a dual-band PIFA handset antenna (GSM 900/DCS 1800) at varied distances from a phantom head," *Technical Seminar on Antenna Measurements and SAR(AMS)*, pp. 5-8, 2004.

54. M. Jin, Z. Ying, and S. He, "The impact of mobile shell materials on SAR", *Asia-Pacific Microwave Conference Proceedings*, Vol. 5, 2005.

55. Li, Z. and Y. Rahmat-Samii, "SAR in PIFA handset antenna designs: an overall system perspective", *IEEE Antennas and Propagation Society International Symposium*, Vol. 2B, pp. 784-787, 2005

56. K. L. Wong, "Compact and Broadband Microstrip Antennas," *John Wiley & Sons*, Hoboken, vol. 5, no. 5, pp. 36–42, 2002.

57. IEEE Std 1528TM-2003, "IEEE recommended practice for determining the peak spatial-average Specific Absorption Rate (SAR) in the human head from wireless communications devices" *Measurement techniques, IEEE*, New York, vol. 37, no. 7, pp. 97–108, 2003.

58. K. R; Mahmpud, et al., "Investigating The Interaction Between a Human Head and a Smart Handset for 4G Mobile Communication Systems," *Progress in Electromagnetics Research*, Vol. 2, pp. 169-188. 2008.

59. Tamura H., Ishikawa Y., Kobayashi T. and Nojima T. "A dry phantom material composed of ceramic and graphite powder," *IEEE Transactions on Electromagnetic Compatibility*, vol. 39, no. 2, pp. 132-137, 1997.

60. Nikawa Y., Chino M. and Kikuchi K. "Soft and dry phantom modeling material using silicone rubber with carbon fiber," *IEEE Transactions on Microwave Theory and Techniques,* vol. 44, no. 10 Part 2, pp. 1949-1953, 1996.

61. Kamya and Ryuji Kohno "UWB Antenna for Wireless Body Area Network," *Asia-Pacific Microwave Conference,* vol. 53, no. 17, pp. 456-462, 2006.

62. See T. P. and Chen Z. N., "Expermiental characterization of UWB antennas for on-body communications," *IEEE Transctions on Antennas and Propagation*, vol. 57, no. 4, pp. 866-874, April Apr. 2009.

63. Kamya Yekeh Yazdandoost and Kiyoshi Hamaguchi, "Very Small UWB Antenna for WBAN Applications," *Proceedings of IEEE*, vol. 62, no. 47, pp. 243-254, 2011.

64. Schantz H. G. and Fullerton L. "The diamond dipole: a Gaussian impulse antenna," *Antennas and Propagation Society International Symposium*, vol. 3, no. 3, pp. 34-43, July 2001.

65. Yazdanboost K. Y.; Kohno R., "Ultra wideband L-loop antenna," Ultra-Wideband,.ICU 2005. *IEEE International Conference* on , pp.201-205, 5-8 Sept. 2005.

66. Tommi Tuovinen, Kamya Yekeh Yazdandoost and Jari Iinatti "Ultra Wideband Loop Antenna for On-Body Communication in Wireless Body Area Network," *6th European Conference on Antennas and Propagation*, vol. 23, no. 7, pp. 766-474, 2011.

67. Sara Sadat Karimabadi and Amir Reza Attari, "Gain Enhancement of Small Size UWB Antenna for Wireless Body Area Network Applications," *Proceedings of ICEE*, vol. 66, no. 3, pp. 76-84, 2010.

68. Hall P. S. and Hao Y., "Antennas and Propagation for Body-Centric Wireless Communications," *Artech House*, 2006.

69. Bernardhard J., Nagel P., Hupp J., Strauss W. and von der Grun T. "BAN – body area network for wearable computing," *9thWirelessWorld Research Forum Meeting,* Zurich, July 2003.

70. Kunze C., Grossmann U., Stork W. and Muller-Glaser K. "Application of ubiquitous computing in personal health monitoring systems," *Biomedizinische Technik: 36th*

Annual meeting of the German Society for Biomedical Engineering, pp. 360-362, 2002.

71. Rahman A., Alomainy A. and Hao Y. “Compact Body-Worn Coplanar Waveguide Fed Antenna for UWB Body- Centric Wireless Communications,” *Antennas and Prop*., EuCAP 2007. The Second European Conference on pp. 1-4, 11-16 Nov., 2007.

72. Rahman A. and Hao Y. ‘‘A Novel Tapered Slot CPW-fed Antenna for Ultra-Wideband Applications and Its On/Off Body Performance,” *International Workshop on Antenna Technology,* iWAT 2007, 21–23 March, 2007, Cambridge, UK.

73. Alomainy A., Sani A., Santas J., Rahman A. A. and Hao Y. “Transient Characteristics of Wearable Antennas and Radio Propagation Channels for Ultra Wideband Body-Centric Wireless Communications,” *IEEE Transactions in Antenna and Propagation,* vol. 57, no.4, pp.875-884, April 2009.

74. Suh S.Y., Stutz man W. L. and Davis W. A. “A New Ultra Wideband Printed Monopole Antenna: The Planar Inverted Cone antenna (PICA),” *IEEE Transaction on Antennas and Propagation*, vol. 52, no. 5, pp. 1361–1364, May 2004.

75. Alomainy A., Hao Y., Parini C. G. and Hall P. S. “Characterization of Printed UWB Antenna for On-Body Communications,” *IEEE Wideband and Multiband Antenna Arrays, Birmingham*, UK, pp. 167-175, Sep. 2005.

76. Alomainy A. and Hao Y. “Radio Channel Models for UWB Body Centric Networks with Compact planar Antenna,” *in Proc. IEEE APS Int Symp. Antennas Propag.*, Albuquerque, NM, Jul, 9-14, pp. 2173-2176, 2006.

77. Stutz man S. Y, W. L., and Davis W. A. “A Novel CPW fed Disk Antenna,” *in Proc. IEEE Antennas Propag.* Soc. Symp., Jun. vol. 3, pp. 2919-2922, 2004.

78. Chen Z. N., See T. S. P., Qing X. ‘‘Small Printed Ultra Wideband Antenna with Reduced Ground Plane Effects,” *IEEE Transactions on Antenna and Propagation*, vol, 55, no 2, Feb. 2007.

79. Sani A., Santas J., Alomainy A. and Hao Y. "Time Domain Characterisation of Ultra Wideband Wearable Antennas and Radio Propagation for Body-Centric Wireless Networks in Health Care Applications," *Proceeding of the 5th International Workshop on Wearable and Implantable Body Sensors Networks*, The Chinese University of Hong Kong, HKSAR, China, June. 1-3, 2008.

80. Guo L., Wang S., Chen X. and Parini C. G. ''A Small Printed Quasi-Self Complementary Antenna for Ultra Wideband Systems,'' *IEEE Antennas and Wireless Propagation Letter*, vol. 8, no. 5, pp. 161–164, 2009.

81. Xu H. -J., Zhang Y. -H. and Fan Y., "Analysis of the connection between k connector and microstrip with electromagnetic band gap (EBG) structures," *Progress In Electromagnetics Research*, Vol. 73, pp. 239-247, 2007.

82. Scanlon W. G. "Body-worn antennas for ISM-band applications including Bluetooth TM," in vol. 65, no. 5, pp. 1-5, 2001.

83. Kamya and Ryuji Kohno "UWB Antenna for Wireless Body Area Network," *Asia-Pacific Microwave Conference*, vol. 55, no. 2, pp. 64–69, 2006.

84. Duan, Z.; Linton, D.; Scanlon, W.; Conway, G. "Using EBG to Improve Antenna Efficiency in Proximity to the Human Body," *Wideband, Multiband Antennas and Arrays for Defence or Civil Applications*, 2008 Institution of Engineering and Technology Seminar on , vol., no., pp.173-180, 13-13 March 2008.

85. Tommi Tuovinen, Kamya Yekeh Yazdandoost and Jari Iinatti "Ultra Wideband Loop Antenna for On-Body Communication in Wireless Body Area Network," *6th European Conference on Antennas and Propagation*, vol. 34, no. 1, pp. 45-53, 2011.

86. Economou, L. and Langley, J. "Circular microstrip patch antennas on glass for vehicle applications," *IEEE Proceedings Microwaves, Antennas and Propagation,* Vol. 145, no. 5, p.416-420, 1998.

87. Bogdanov, F.; Karkashadz, D.; Jobava, R.; Gheonjian, A.; Yavolovskaya, E.; Bondarenko, N., "Hybrid MoM Scheme with Incorporation of Equivalent Glass

Antenna Model in Application to Automotive EMC Problems," *Electromagnetic Compatibility, 2009 20th International Zurich Symposium* on , vol., no., pp.217,220, 12-16 Jan. 2009.

88. B. Lee et al., "A CPU on a Glass Substrate Using CG-Silicon TFTs," ISSCC Digest of Technical Papers, pp. 164-165, 2003.

89. T. Ikeda et al., "Full-Functional System Liquid Crystal Display Using CG-Silicon Technology," SID Digest of Technical Paper, pp. 860-863, 2004.

90. T. Takayama et al., "A CPU on a plastic film substrate," VLSI Technology Digest of Technical Papers, pp. 230-231, 2004.

91. M. Usami, A. Sato, K. Sameshima, K. Watanabe, H. Yoshigz and R. Imura, "Powder LSI; An Ultra RF Identification Chip for Individual Recognition Applications," ISSCC Digest of Technical Papers, pp. 398-399, 2003.

92. Mendes, P.M.; Polyakov, A.; Bartek, M.; Burghartz, J.N.; Correia, J.H. "Design of a folded-patch chip-size antenna for short-range communications", Microwave Conference, 2003. 33rd European, On vol.2, pp. 723 - 726 7-9 Oct. 2003

93. Dong-Hee Park; Yoon-Sik Kwak "Design of Novel On-Chip Antennas with Multi-band for UWB Applications", Future Generation Communication and Networking, 2008. FGCN '08. Second International Conference on, On Vol. 2, pp. 103 – 105, 13-15 Dec. 2008

94. Park, D.H. "Design of novel on-chip antennas with multi-band for wireless sensor networks", Antennas and Propagation Conference, LAPC 2008. Loughborough, vol.3, pp. 413 - 416 , 2008.

95. Bogdanov, F. G.; Karkashadze, D. D.; Jobava, R. G., "Efficient MOM-based technique for fast analysis of layered microstrip geometries using equivalent glass antenna model," *Direct and Inverse Problems of Electromagnetic and Acoustic Wave Theory, 2008*. DIPED 2008. 13th International Seminar/Workshop on , vol. 22, no. 3, pp.114,118, 22-25 Sept. 2008.

96. Peter, T.; Yuk, T.I.; Nilavalan, R.; Cheung, S.W., "A novel technique to improve gain in transparent UWB antennas," *Antennas and Propagation Conference (LAPC),* 2011 Loughborough , vol. 23, no. 3, pp.1-4, 14-15 Nov. 2011.

97. Drossos A., et al, “The dependence of electromagnetic energy absorption upon human head tissue composition in the frequency range of 300-3000 MHz,” *IEEE Trans. on Microw.* Theory and Tech., no. 48, pp. 1988-1995, 2000.

98. Bernardi P. “Power absorption and temperature elevations induced in the human head during a dual-band monopole-helix antenna phone,” *IEEE Trans. on Microwave Theory and Techniques*, no. 12, pp. 2539-46, 2001.

99. CST MICROWAVE STUDIO software’s help available at: http://www.cst.com/Content/Products/MWS/Overview.aspx

100. Milavcic N. P. D. and Hart F. X. “Wiley Encyclopedia of Biomedial Enginnering,” John Wiley & Sons, Ltd., 2006.

101. Gajsek P., et al, “Predicted SAR in Sprague-Dawley rat as a function of permittivity values,” *Bioelectromagnetics* Vol. 22, no.6, P. 384-400, 2001.

102. Berenger J. P. “A perfectly matched layer for the absorption of electromagnetic waves,” *J. Computat. Phys*., vol. 114, no. 2, pp. 185-200, 1994.

103. Yee K. S. “Numerical solution of initial boundary value problems involving Maxwell’s equations in isotropic media,” IEEE Trans. Antennas Propgat., vol. 14, no. 3, pp. 302–307, 1966.

104. Scanlon W. G. and Evans N. E. “Numerical analysis of body-worn UHF antenna systems,” *Electronics & Communication Engineering Journal*, pp. 53-64, April 2001.

105. Qing X. and Chen Z. N. "Antipodal vivaldi antenna for UWB applications," *presented at the EUROEM 2004 Conf.*, Magdeburg, Germany, Vol. 32, no.2, pp. 384-400, Jul. 12–16, 2004.

106. Xu H. -J., Zhang Y. -H. and Fan Y. "Analysis of the connection between k connector and microstrip with electromagnetic band gap (EBG) structures," Progress In Electromagnetics Research, Vol. 73, 239-247, 2007.

107. Kohno, R., Hamaguchi K., Li H. -B. and Takizawa K. "R&D and standardization of body area network (BAN) for medical healthcare," *Proc. IEEE Int. Conf. on Ultra-Wideband, (ICUWB),* Sep. 2008, Vol. 3, pp. 5-8, 2006.

108. Astrin, A. W., H.-B. Li, and Kohno, R., "Standardization for body area networks," *IEICE Trans*. Commune. Vol. E92-B, no. 2, pp. 366-372, Feb. 2009,

109. Scanlon, W.G.; Evans, N.E., "Numerical analysis of body worn UHF antenna systems," *Electronics & Communication Engineering Journal*, Vol.13, no.2, pp.53-64, April 2001.

110. Hall P. S. , Hao Y. "Antennas and Propagation for Body-Centric Wireless Communications," *Artech House*, 2006.

111. Yazdandoost K. Y. and Kohno R. "Ultra wideband antenna," *IEEE Communications Magazine*, vol. 42, no. 6, pp. S29–S32, June 2004.

112. Foster P. R. "UWB antenna issues," *IEEE Seminar on UWB Communications*, London, UK, vol. 24, no. 4, pp. 41–48, July 2004.

113. Balanis Constantine A. "Antenna theory analysis and design," *Third edition, John Wiley and Sons,* Inc. Hoboken, New Jersey, 2005..

114. Garg, Ramesh. "Microstrip antenna design", handbook, *Artech House*, 2001.

115. J. Ollikainen, "Design and implementation techniques of wideband mobile communications antennas", Doctoral dissertation, Helsinki University of Technology, Radio Laboratory publications, Espoo, Finland, P70, 2004.

116. karimabadi Sadat, and Attari A. R. "Gain Enhancement of Small Size UWB Antenna for Wireless Body Area Network Applications," *Proceedings of.ICEE* vol. 26, no. 1, pp. 69–74, 2010.

117. Klemm, M.; Kovcs, I. Z.; Pedersen, G.F.; Troster, G., "Novel small-size directional antenna for UWB WBAN/WPAN applications," *Antennas and Propagation, IEEE Transactions* on , vol.53, no.12, pp. 3884-3896, Dec. 2005.

118. Qing X. and Chen Z. N. "Antipodal vivaldi antenna for UWB applications," *presented at the EUROEM 2004 Conf*, Magdeburg, Germany, vol. 23, no. 5, pp. 84-87, Jul. 12–16, 2004.

119. karimabadi S. and Attari A. R. "Gain Enhancement of Small Size UWB Antenna for Wireless Body Area Network Applications." *Proceedings of ICEE* , Vol. 77, pp. 65-71, 2010.

120. Scanlon W. G. "Body-worn antennas for ISM-band applications including Bluetooth TM," *Progress In Electromagnetics Research*, Vol. 65, pp. 5-1, 2000.

121. CST Microwave Studio http://www.cst.com

122. Ikeuchi R., Chan K. H. and Hirata A., "SAR and radiation characteristics of a dipole antenna above different finite EBG substrates in the presence of a realistic head model in the 3.5 GHz band," *Progress In Electromagnetics Research B*, Vol. 44, pp. 53-70, 2012.

123. Peiravi, Ali "Connectance and Reliability Computation of Wireless Body Area Networks using Signal Flow Graphs," *Lıfe Science Journal*, Vol. 7, no. 2, pp. 52-56, 2010.

124. Peiravi Ali "Reliability of Wireless Body Area Networks used for Ambulatory Monitoring and Health Care," *Lıfe Science Journal*, Vol. 6, no.4, pp. 5-14, 2010.

125. Kohno R., Hamaguchi K., Li H. B., and Takizawa K., *"R & D and standardization of body area network (BAN) for medical healthcare," Proc. IEEE Int. Conference on Ultra-Wideband, (ICUWB)*, Vol. 3, pp. 5-8, Sep. 2008.

126. Zhu S. and Langley R. "Dual-band wearable textile antenna on an EBG substrate," *IEEE Trans. Antennas Propag*ation., vol. 57, no. 4, pp. 926–935, 2009.

127. Zhu S., Liu L., and Langley R., "Dual Band Body Worn Antenna," *Antennas and Propagation Conference*, LAPC 2007, vol. 56, no. 6, pp. 137–140, Apr. 2007.

128. "IEEE standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz," *IEEE Standard C95*, vol. 36, no. 7, pp. 1–1999, 1999.