DESIGN AND CHARACTERISATION OF WIDEBAND ANTENNAS FOR MICROWAVE IMAGING APPLICATIONS

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Specially dedicated to my children Nuralya Raihanah and Alif Raihan,
my husband Mohd Fariz, my mother Aminah Abdullah, my dearest siblings,
and in the memories of my father, Yahya @ Atan bin Mohamed

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ABSTRACT

Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) are well known equipments used to generate images to aid in diagnostic procedure. However, the imaging equipments have some limitations whereby the equipments are very expensive and therefore, they are not always accessible in many medical centres. Besides, the equipments are bulky and less mobility. Moreover, existing CT cannot be used frequently on the human body because the scanner exposes patients to more radiations of ionised frequency. The limitations of the equipment create a need to design an alternative imaging method which is relatively low cost, small in size, has high mobility, and non-ionise frequency. This research is to design an antenna for microwave imaging, namely corrugated u-slot antenna at 1.17-5.13 GHz with the reference of S_{11} less than -10 dB. Two corrugated u-slot antennas; namely antenna 1 and antenna 2 are placed on a mirror side of skull phantom to examine their ability to detect an object inside the skull. VeroClear-RGD810 skull phantom containing water is used, and the obtained results are verified using ZCorp zp-150 skull phantom which has approximately similar permittivity. Both the antennas are tested to detect the object which is located at 40 mm and 80 mm from the respective examined antenna. An Inverse Fast Fourier Transform (IFFT) technique is used to analyse the time domain reflection pulse according to the dielectric properties difference, as the electromagnetic wave propagates through the skull. The results show that the antenna 1 is able to detect the object faster than the antenna 2 for both skulls, due to inconsistent thickness of the phantoms. Furthermore, the antennas are fabricated in adjacent to measure decomposition and superposition specific absorption rate (SAR) in Specific Anthropomorphic Mannequin (SAM) head phantom at 1800 MHz and 2600 MHz. The maximum allowable SAR in head is 2 W/kg at 10 g contiguous tissue which is referred to International Commission on Non-Ionizing Radiation Protection (ICNIRP) guideline. Based on the measured results, superposition SAR of the antenna can reach up to ±12% of the maximum decomposition SAR. This research forms a significant contribution to medical engineering field in designing a corrugated u-slot antenna that serves to detect an abnormality inside human head at 1.17-5.13 GHz. The designed antenna satisfies the SAR standard, which is required in microwave imaging applications.

ABSTRAK

Pengimejan Salunan Magnet (MRI) dan Tomografi Berkomputer (CT) merupakan peralatan terkenal yang digunakan untuk menjana imej bagi membantu dalam tatacara diagnosis. Walau bagaimanapun, peralatan pengimejan tersebut mempunyai beberapa kekurangan yang mana peralatan tersebut adalah sangat mahal dan justeru, ia tidak selalu dapat diakses di kebanyakan pusat perubatan. Selain itu, peralatan tersebut adalah besar dan kurang kemudahgerakan. Tambahan pula, CT yang sedia ada tidak boleh digunakan secara kerap kepada tubuh badan manusia kerana imbasan mendedahkan pesakit kepada lebih banyak radiasi daripada frekuensi terion. Had peralatan ini mewujudkan keperluan untuk merekabentuk satu kaedah pengimejan alternatif dengan kos yang agak rendah, bersaiz kecil, kebolehgerakan yang tinggi, dan frekuensi yang tak-terion. Kajian ini bertujuan untuk merekabentuk antena bagi pengimejan gelombang mikro, iaitu antena alur-u beralun pada 1.17-5.13 GHz dengan rujukan S_{11} kurang daripada -10 dB. Dua antena alur-u beralun; iaitu antena 1 dan antena 2 diletakkan secara bertentangan di sisi fantom untuk memeriksa keupayaan mereka bagi mengesan objek dalam tengkorak. Fantom tengkorak VeroClear-RGD810 yang mengandungi air digunakan, dan keputusan yang diperoleh disahkan menggunakan fantom tengkorak ZCorp zp-150 yang mempunyai kebertelusan yang hampir sama. Kedua-dua antena diuji bagi mengesan objek yang terletak pada 40 mm dan 80 mm dari antena yang diperiksa. Teknik Jelmaan Fourier Pantas Songsang (IFFT) digunakan untuk menganalisis denyut pantulan domain masa berdasarkan perbezaan sifat dielektrik, apabila gelombang elektromagnet merambat melalui tengkorak. Keputusan menunjukkan bahawa antena 1 dapat mengesan objek lebih cepat daripada antena 2 bagi kedua-dua tengkorak, disebabkan ketebalan fantom yang tidak konsisten. Kemudian, antena-antena ini difabrikasi bersebelahan bagi mengukur kadar penyerapan tertentu (SAR) uraian dan tindihan dalam fantom kepala Patung Antropomorfik Khusus (SAM) pada 1800 MHz dan 2600 MHz. SAR maksimum yang dibenarkan dalam kepala adalah 2 W/kg pada 10 g tisu berdampingan dirujuk berdasarkan garis panduan Suruhanjaya Antarabangsa Perlindungan Sinaran Tak-Mengion (ICNIRP). Berdasarkan keputusan yang diukur, SAR tindihan bagi antena boleh mencapai sehingga ±12% daripada SAR uraian maksimum. Kajian ini membentuk satu sumbangan yang bermakna terhadap bidang kejuruteraan perubatan dalam merekabentuk antena alur-u beralun yang berfungsi untuk mengesan keabnormalan dalam kepala manusia pada 1.17-5.13 GHz. Antena yang direkabentuk memenuhi piawai SAR, yang diperlukan dalam aplikasi pengimejan gelombang mikro.

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LIST OF ABBREVIATIONS

ACA	-	Australian Communications Authority
ANSI	-	American National Standards Institute
BAVA	-	Balanced Antipodal Vivaldi Antenna
BAVA -D	-	Balanced Antipodal Vivaldi Antenna with Director
BW	-	Bandwidth
CNC	-	Computerized Numerical Control
CPW	-	Coplanar Waveguide
CSF	-	Cerebrospinal Fluid
CST	-	Computer Simulation Technology
CT	-	Computed Tomography
CW	-	Continuous Wave
DP	-	Dielectric Properties
EEG	-	Electroencephalography
EM	-	Electromagnetic
FCC	-	Federal Communications Commission
FDTD	-	Finite-Difference Time Domain
FT	-	Fourier Transform
FFT	-	Fast Fourier Transform
FPIFA	-	Fractal Planar Inverted-F Antenna
ICNIRP	-	International Commission on Non-Ionising Radiation Protection
IEC	-	International Electrotechnical Commission
IEEE	-	Institute of Electrical and Electronics Engineers
IFFT	-	Inverse Fast Fourier Transform
ISM	-	Industrial, Scientific, and Material
MI	-	Microwave Imaging

MIMO	-	Multiple Input Multiple Output
MRI	-	Magnetic Resonance Imaging
NCI	-	National Cancer Institute
VNA	-	Vector Network Analyzer
PCPWM	-	Plain CPW Monopole
PD	-	Power Divider
PET	-	Polyethylene Terephtalate
PPIFA	-	Planar Inverted-F Antenna
PVC	-	Polyvinyl Chloride
R2R	-	Roll-to-roll
RL	-	Return Loss
SAM	-	Specific Anthropomorphic Mannequin
SAR	-	Specific Absorption Rate
SIRIM	-	Standards and Industrial Research Institute of Malaysia
US	-	United State
UWB	-	Ultrawideband
TASPS	-	Time Averaged Simultaneous Peak SAR

LIST OF SYMBOLS

ε	-	Permittivity
ε_r	-	Relative permittivity / Dielectric Constant
ε_{reff}	-	Effective dielectric constant
ε'	-	Real permittivity
ε''	-	Imaginary permittivity
ε_0	-	Permittivity of freespace
μ_0	-	Permeability of freespace
σ	-	Conductivity
E_i	-	Incident wave
E_t	-	Transmitted wave
E_r	-	Reflected wave
f_0	-	Frequency limit
f_r	-	Resonance frequency
f_l	-	Lower frequency
f_h	-	Higher frequency
l_p	-	length of radiating patch
t	-	Time
w_p	-	Width of radiating patch
h	-	Substrate thickness
ΔL	-	Extension of length

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CHAPTER 1

INTRODUCTION

1.1 Introduction

According to the National Cancer Institute report, 4.4% over 100000 persons' death due to brain cancer in 2012 [1]. This number is predicted to rise by 33.3% in 2015 based on statistical trends since 1990. Even though diagnostic devices such as Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) scans are commonly used for diagnostic procedures, the equipments still not widely available at all medical centres. This is due to their biggest drawback, which is very high cost. Hence, the diagnostic and detection process could be delayed due to high diagnostic cost. Therefore, an alternative lower cost device that can be implemented for diagnostic purpose is required.

An alternative lower cost method that can create a picture of body can be achieved by using microwave imaging (MI). MI is a technique that has an ability to detect the presence of abnormality or object embedded in the scanning area, based on the contrast in dielectric properties (DP) of object as compared to its surrounding. The contrast of DP will result to the scattering signals which further indicate the occurrence of an object and its locality. Since the detection of an object can be achieved by the study of the scattered signals, commonly used equipment in the communication field, such as vector network analyzer (VNA) can be used for the characterization and analysis of these signals. Thus, this makes the MI method relatively low cost as compared to CT and MRI.

There are many advantages of MI in detecting tumoureither in breast or in brain. MI that uses non-ionizing radiation does not cause any adverse health effects towards human tissues. Since MI detects the tumour based on the dielectric contrast, there is a high possibility of early stage cancer detection and diagnostic. Moreover, in breast cancer detection, MI gives more comfort to the patient as compared to the breast compression during mammography process.

There are growing numbers of MI detector antenna designed by researchers which can provide comfort to the user. Although, there is no restriction for the design frequency for MI antenna, however, narrow bandwidth (BW) produces low image quality as compared to wide BW antenna as stated in [2]–[4]. Thus, the greater the antenna BW, the better will be the quality of resulted image, which is also known as resolution of image.

Since the implementation of MI antenna is related to the human body, it is very important to consider specific absorption rate (SAR) into account. Antenna being designed for tumour detection purpose must comply with the established SAR standard in order to protect human cell from adverse health effects. Thus, the following section highlights the motivation towards this research study.

1.2 Problem Statement and Motivation

The effective imaging devices of Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) provide the diagnostic for the detection of tumour such as in breast and brain. However, the cost of these devices is very expensive and leads to high diagnostic expenditure. Furthermore, these devices are bulky and huge in size, allowing less mobility and require large installation area. Moreover, the existing CT cannot be used frequently on human because the scanner exposes patients to radiations of ionised frequency. Hence, in order to improve the drawback of the available imaging devices due to high expenditure and bulky size, MI technique has been introduced. Therefore, in this research work, antennas proposed for MI applications are studied.

In the practice of MI, many antennas are designed at narrowband frequency. The drawback of narrowband frequency in imaging is that it will lead to low quality of image. Therefore, wideband antenna is required to promise higher quality of the scanned image. Most of the wideband antennas proposed for MI are designed on hard structure of printed microstrip board. In addition, a wideband imaging system that was proposed for detecting brain tumour reported in [5] is too bulky. Meanwhile, the patient needs to hold static during the diagnostic process. Thus, the process will discomfort the patient. Hence, flexible material is seen to be the best option for the on-head bending capability and for the ease of user. As the research on the detection of tumour in human head using MI is still in small numbers, it is significant to investigate the existence of abnormality in the human head using radar-based concept.

Moreover, the implementation of antenna on the human head produces energy which can possibly harm the brain cells. The specific absorption rate (SAR) in human head is different at various frequencies and transmitted powers due to dissimilar energy absorbed to the head. In addition, the published investigations on SAR are mostly based on simulated investigations, which is not able to represent the real SAR. Furthermore, the simulated investigations are performed on the implementation of single antenna on the head. Thus, it is very significant to measure and monitor SAR in human head at different frequency and powers using single and multi-antenna on the head.

REFERENCES

1. National Cancer Institute: Surveillance, Epidemiology, and End Results Program. *SEER Stat Fact Sheets: Brain and Other Nervous System Cancer*. USA. Available from: <http://seer.cancer.gov/statfacts/html/brain.html>. [1 November 2015].
2. Sumin, Y., Kihyun, K., and Sangwook, N. Outer-Wall Loop Antenna for Ultrawideband Capsule Endoscope System. *IEEE Antennas and Wireless Propagation Letters*. 2010. *9*:1135–1138.
3. Zwick, T., Jalilvand, M., Kowalewski, J., and Li, X. Broadband Miniaturised Bow-tie Antenna for 3D Microwave Tomography. *Electronics Letters*. 2014. 50 (4): 244–246.
4. Irishina, N. *Microwave Medical Imaging using Level Set Techniques*. Thesis Doctoral. Universidad Carlos III de Madrid; 2009.
5. Abbosh, A. Microwave Systems for Head Imaging: Challenges and Recent Developments. *International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications (IMWS-BIO)*. December 9-11, 2013. IEEE: 2013. 1–3.
6. Pastorino, M. *Microwave Imaging*. Canada: John Wiley & Sons. 2010.
7. Henriksson, T., Joachimowicz, N., Conessa, C., and Bolomey, J. Quantitative Microwave Imaging for Breast Cancer Detection Using a Planar 2 . 45 GHz System. *IEEE Transactions on Instrumentation and Measurement*. 2010. 59 (10): 2691–2699.
8. Ireland, D. and Bialkowski, M. E. Microwave Head Imaging for Stroke Detection. *Progress In Electromagnetics Research M*. 2011. 21:163–175.
9. Mohammed, B. J., Ireland, D., and Abbosh, A. M. Experimental Investigations into Detection of Breast Tumour using Microwave System with Planar Array. *IET Microwaves, Antennas & Propagation*. 2012. 6(12): 1311–1317.

10. Ostadrahimi, M., Mojabi, P., Noghanian, S., Shafai, L., Pistorius, S., and Lovetri, J. A Novel MicrowaveTomography System Based on The Scattering Probe Technique. *IEEE Transactions on Instrumentation and Measurement*. 2012. 61(2): 379–390.

11. Qaddoumi, N., Khousa, M. A, and Saleh, W. Near-field Microwave Imaging Utilizing Tapered Rectangular Waveguides. *IEEE Transactions on Instrumentation and Measurement*. 2006. 55(5): 1752–1755.

12. Jofre, L., Hawley, M. S., Broquetas, A., De Los Reyes, E., Ferrando, M., and Elias-Fuste, A. R. Medical Imaging with a Microwave Tomographic Scanner. *IEEE Transactions on Biomedical Engineering*. 1990. 37(3): 303–312.

13. Hagness, S. C., Taflove, A., and Bridges, J. E. Two-dimensional FDTD Analysis of a Pulsed Microwave Confocal System for Breast Cancer Detection: Fixed-focus and Antenna-array Sensors. *IEEE Transactions on Bio-Medical Engineering*. 1998. 45(12): 1470–1479.

14. Khor, W., Bialkowski, M., Abbosh, A., Seman, N., and Crozier, S. An Ultra Wideband Microwave Imaging System for Breast Cancer Detection. *International Symposium on Antennas and Propagation (ISAP)*. IEICE. 2006. 1–5.

15. Fallahpour, M. *Synthetic Aperture Radar-based Techniques and Reconfigurable Antenna Design for Microwave Imaging of Layered Strutures*. Doctor of Philosophy Dissertation. Missouri University of Science and Technology. 2013.

16. Pozar, D.M. *Microwave Engineering*. 4th edition. USA: John Wiley & Sons. 2009.

17. E. O. Brigham, *The Fast Fourier Transform and Its Applications*. Englewood Cliffs, New Jersey : Prentice-Hall. 1988.

18. Lazaro, A., Girbau, D., and Villarino, R. Weighted Centroid Method for Breast Tumor Localization using an UWB Radar. *Progress In Electromagnetics Research B*. 2010. 24: 1–15.

19. Klemm, M., Gibbins, D., Leendertz, J., Horseman, T., Preece, A. W., Benjamin, R., and Craddock, I. J. Development and Testing of a 60-Element UWB Conformal Array for Breast Cancer Imaging. *Proceedings of the 5th European Conference on Antennas and Propagation (EUCAP)*. April 11-15, 2011. IEEE. 2011. 3077–3079.

20. Kirshin, E., Oreshkin, B., Zhu, G. K., Popovic, M., and Coates, M. Microwave Radar and Microwave-Induced Thermoacoustics: Dual-Modality Approach for Breast Cancer Detection. *IEEE Transactions on Biomedical Engineering*. 2013. 60 (2): 354–360.

21. Sill, J. M. and Fear, E. C. Tissue Sensing Adaptive Radar for Breast Cancer Detection-Experimental Investigation of Simple Tumor Models. *IEEE Transactions on Microwave Theory and Techniques*. 2005. 53(11): 3312–3319.

22. Bassi, M., Caruso, M., Khan, M. S., Bevilacqua, A., Capobianco, A.-D., and Neviani, A. An Integrated Microwave Imaging Radar with Planar Antennas for Breast Cancer Detection. *IEEE Transactions on Microwave Theory and Techniques*. 2013. 61(5): 2108–2118.

23. Chew, K. M., Sudirman, R., Mahmood, N. H., Seman, N., and Yong, C. Y. Human Brain Microwave Imaging Signal Processing: Frequency Domain (S-parameters) to Time Domain Conversion. *Engineering*. 2013. 5: 31–36.

24. Jamlos, M.A., Jamlos, M.F., and Ismail, A.H. High Performance Novel UWB Array Antenna for Brain Tumor Detection via Scattering Parameters in Microwave Imaging Simulation System. *The 9th European Conference on Antennas and Propagation (EuCAP)*. April 13-17, 2015. Lisbon, Portugal: EurAAP. 2015.1–5.

25. Jalilvand, M., Zwick, T., Wiesbeck, W., and Pancera, E. UWB Synthetic Aperture-based Radar System for Hemorrhagic Head-stroke Detection. *IEEE Radar Conference (RADAR)*. May 23-27, 2011. Missouri, USA: IEEE. 2011. 956–959.

26. *Sectional Models of the Human Head*. Available from: <http://www.einsteins-emporium.com/human-anatomy/sh202.htm>. [11 November 2015].

27. Fenn, A. *Breast Cancer Treatment by Focused Microwave Thermotherapy*. Sudbury: Jones and Bartlett. 2007.

28. Baskharoun, Y., Trehan, A., Nikolova, N. K., and Noseworthy, M. D. Physical Phantoms for Microwave Imaging of the Breast. *IEEE Topical Conference on Biomedical Wireless Technologies, Networks, and Sensing Systems (BioWireleSS)*. January 15-18, 2012. California, USA: IEEE. 2012. 73–76.

29. Ortega-Palacios, R., Leija, L., Vera, A., and Cepeda, M. F. J. Measurement of Breast - Tumor Phantom Dielectric Properties for Microwave Breast Cancer Treatment Evaluation. *7th International Conference on Electrical Engineering*

Computing Science and Automatic Control. September 8-10, 2010. Tuxtla Gutierrez, Mexico : CCE. 2010. 216–219.

30. Lazebnik, M., Hagness, S. C., and Booske, J. H. Dielectric-Properties Contrast Enhancement for Microwave Breast Cancer Detection: Numerical Investigations of Microbubble Contrast Agents. *URSI General Assembly*. August 7-16, 2008. Chicago, USA: IEEE. 2008. 1–4.
31. *An Internet Resource for the Calculation of the Dielectric Properties of Body Tissues in the Frequency Range 10 Hz - 100 GHz.* Available from: <http://niremf.ifac.cnr.it/tissprop/>. [20 August 2014].
32. Shmueli, K., Thomas, D. L., & Ordidge, R. J. Design, Construction and Evaluation of an Anthropomorphic Head Phantom with Realistic Susceptibility Artifacts. *Journal of Magnetic Resonance Imaging*. 2007. 26: 202–207.
33. Croteau, J., Sill, J., Williams, T., and Fear, E. Phantoms for Testing Radar-based Microwave Breast Imaging. *13th International Symposium on Antenna Technology and Applied Electromagnetics and the Canadian Radio Science Meeting*. May 15-18, 2009. Alberta, Canada: IEEE. 2009. 1–4.
34. Kao, T., Saulnier, G. J., Isaacson, D., Szabo, T. L., and Newell, J. C. A Versatile High-Permittivity Phantom for EIT. *IEEE Transactions on Biomedical Engineering*. 2008. 55(11): 2601–2607.
35. Vincent, R. *Simulated Brain Database.* Available from: <http://mouldy.bic.mni.mcgill.ca/brainweb/>. [5 July 2015]
36. Collier, T. J., Kynor, D. B., Bieszczad, J., Audette, W. E., Kobylarz, E. J., and Diamond, S. G. Creation of a Human Head Phantom for Testing of Electroencephalography Equipment and Techniques. *IEEE Transactions on Biomedical Engineering*. 2012. 59(9): 2628–2634.
37. Sperandio, M., Guermandi, M., and Guerrieri, R. A Four-shell Diffusion Phantom of the Head for Electrical Impedance Tomography. *IEEE Transactions on Biomedical Engineering*. 2012. 59(2): 383–389.
38. Mobashsher, A. T. and Abbosh, A. M. Three-Dimensional Human Head Phantom With Realistic Electrical Properties and Anatomy. *IEEE Antennas and Wireless Propagation Letters*. 2014. 13:1401–1404.
39. O'Halloran, M., Glavin, M., & Jones, E. Rotating Antenna Microwave Imaging System for Breast Cancer Detection. *Progress In Electromagnetics Research*. 2010. 107: 203–217.

40. Adnan, S., Abd-Alhameed, R. A., See, C. H., Hraga, H. I., Elfergani, I. T. E., and Zhou, D. A Compact UWB Antenna Design for Breast Cancer Detection. 2010 *Progress In Electromagnetics Research Symposium*, 2010, 6(2). 129–132.

41. Yu, J., Yuan, M., and Liu, Q. H. A wideband Half Oval Patch Antenna for Breast Imaging. *Progress In Electromagnetics Research*. 2009. 98: 1–13.

42. Guardiola, M., Jofre, L., Gedda, F., Capdevila, S., Romeu, J., and Blanch, S. 3D Arrayed Microwave Tomographic System for Medical Imaging. *IEEE International Conference on Wireless Information Technology and Systems (ICWITS)*. August 28- September 3, 2010. Hawaii, USA: IEEE. 2010.1–4.

43. Mobashsher, A. T., Mohammed, B. J., Mustafa, S., and Abbosh, A. Ultra Wideband Antenna for Portable Brain Stroke Diagnostic System. *IEEE MTT-S International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications (IMWS-BIO)*. 2013. 1032: 2–4.

44. Stang, J. P. and Joines, W. T. A Tapered Microstrip Patch Antenna Array for Microwave Breast Imaging. *IEEE MTT-S International Microwave Symposium Digest*. June 15-50, 2008. Atlanta, Georgia: IEEE. 2008. 1313–1316.

45. Shrestha , S. and Agarwal, M. Microstrip Antennas for Direct Human Skin Placement for Biomedical Applications. *Progress In Electromagnetics Research Symposium*. July 5–8, 2010. Cambridge, USA: The Electromagnetics Academy. 2010. 926–931.

46. Fhager, A., McKelvey, T., and Persson, M. Stroke Detection using a Broadband Microwave Antenna System. *European Conference on Antennas and Propagation (EuCAP)*. April 12-16, 2010. Barcelona, Spain: IEEE. 2010. 1–3.

47. Trefná , H. and Persson, M. Antenna Array Design for Brain Monitoring. *IEEE International Symposium on Antennas and Propagation and USNC/URSI National Radio Science Meeting (APS-URSI)*. July 5-11, 2008. California, USA: IEEE. 2008. 1-4.

48. Aguilar, S. M., Al-Joumayly, M. A., Shea, J. D., Behdad, N., and Hagness, S. C. Design of a Microwave Breast Imaging Array Composed of Dual-band Miniaturized Antennas. *XXXth URSI General Assembly and Scientific Symposium*. August 13 - 20, 2011. Istanbul, Turkey: IEEE. 2011. 1–4.

49. A. F. Sheta, I. Elshafiey, A. Mohra, Z. Siddiqui, and A. R. Sebak, "A Compact Antenna for Microwave Imaging and Hyperthermia Treatment of Brain Tumor," *15th International Symposium on Antenna Technology and Applied Electromagnetics*, 2012, pp. 1–4.
50. Al-Joumayly, M. a, Aguilar, S. M., Behdad, N., and Hagness, S. C. Dual-band Miniaturized Patch Antennas for Microwave Breast Imaging. *IEEE Antennas and Wireless Propagation Letters*. 2010. 9:268–271.
51. Zhou, Y. and Jaworski, D. CPW Integrated Microstrip Array for Three-dimensional Microwave Imaging. *IEEE International Symposium on Antennas and Propagation Society (APSURSI)*. July 7- 13, 2013. Orlando, Florida:IEEE. 2013.1408–1409.
52. Yazhou Wang, Fathy, A. E., and Mahfouz, M. R. Novel Compact Tapered Microstrip Slot Antenna for Microwave Breast Imaging. *IEEE International Symposium on Antennas and Propagation (APSURSI)*. 3-8 July 2011. Washington, USA: IEEE. 2119–2122.
53. Ahadi, M., Hasan, W. Z. W., Saripan, M. I. Bin, and Isa, M. B. M. Square Monopole Antenna for Microwave Imaging, Design and Characterisation. *IET Microwaves, Antennas & Propagation*. 2015. 9(1):49–57.
54. Rezaeieh, S. A., Abbosh, A., & Wang, Y. Wideband Unidirectional Antenna of Folded Structure in Microwave System for Early Detection of Congestive Heart Failure. *IEEE Transactions on Antennas and Propagation*. 2014. 62(10): 5375–5379.
55. Ahdi Rezaeieh, S., Zamani, A., and Abbosh, A. M. 3-D Wideband Antenna for Head Imaging System with Performance Verification in Brain Tumor Detection. *IEEE Antennas and Wireless Propagation Letters*. 2015. 14:910–914.
56. Mohammed, B. J., Abbosh, A. M., and Sharpe, P. Planar Array of Corrugated Tapered Slot Antennas for Ultrawideband Biomedical Microwave Imaging System. *International Journal of RF and Microwave Computer-Aided Engineering*. 2013. 23(1): 59–66.
57. Zhu, F. and Gao, S. Compact Elliptically Tapered Slot Antenna with Non-uniform Corrugations for Ultra-wideband Applications. *Radioengineering*. 2013. 22(1):276–280.

58. Mohammed, B. J., Bialkowski, K., Mustafa, S., and Abbosh, A. Investigation of Noise Effect on Image Quality in Microwave Head Imaging Systems. *IET Microwaves, Antennas & Propagation*. 2015. 9(3): 200–205.

59. Mohammed, B., Abbosh, A., David Ireland, A., and Bialkowski, M. E. Wideband Antenna for Microwave Imaging of Brain. *International Conference Series on Intelligent Sensors, Sensor Networks and Information Processing*. December 6-9, 2011. Melbourne, Australia: IEEE. 2011. 17–20.

60. Mohammed, B. J., Abbosh, A. M., Member, S., Mustafa, S., and Ireland, D. Microwave System for Head Imaging. *IEEE Transactions on Instrumentation and Measurement*. 2014. 63(1):17–123.

61. Belamgi, S. B., Member, S., and Ray, S. *Third International Conference on Computer, Communication, Control and Information Technology (C3IT)*. February 7-8, 2015. Hooghly, India: IEEE. 2015. 1–4.

62. Abed , D. and Kimouche, H. Design and Characterization of Microstrip UWB Antennas. In: Lembrikov, B. *Ultra Wideband.* Rijeka, Croatia: InTechOpen. 347–37; 2010.

63. Azari, A. A New Super Wideband Fractal Microstrip Antenna. *IEEE Transactions on Antennas and Propagation*. 2011. 59(5): 1724–1727.

64. Dastranj, A. and Abiri, H. Bandwidth Enhancement of Printed E-Shaped Slot Antennas Fed by CPW and Microstrip Line. *IEEE Transactions on Antennas and Propagation*. 2010. 58(4):1402–1407.

65. Adnan, S., Abd-Alhameed, R., Hraga, H., Elfergani, I. T. E., Noras, J. M., and Halliwell, R. Microstrip Antenna for Microwave Imaging Application. *Progress In Electromagnetics Research Symposium (PIERS).* March 20–23, 2011. Marrakesh, Morocco: The Electromagnetics Academy. 2011. 431–434.

66. Nilavalan, R., Craddock, I. J. J., Preece, A., Leendertz, J., and Benjamin, R. Wideband Microstrip Patch Antenna Design for Breast Cancer Tumour Detection. *IET Microwaves, Antennas & Propagation*. 2007. 1(2):277-281.

67. Kharkovsky, S., Ghasr, M. T., Kam, K., Abou-Khousa, M. A., and Zoughi, R. Out-of-Plane Fed Elliptical Slot Array for Microwave Imaging. *IEEE Transactions on Antennas and Propagation*. 2013. 61(10): 5311–5314.

68. Pozar, D. M. and Schaubert, D. H. *Microstrip Antennas: The Analysis and Design of Microstrip Antennas and Arrays*. Wiley-IEEE Press, 1995.

69. Li, X., Zwirello, L., Jalilvand, M., and Zwick, T. Design and Near-field Characterization of a Planar on-body UWB Slot-antenna for Stroke Detection. *IEEE International Workshop on Antenna Technology (iWAT)*. March 5 - 7, 2012. Arizona, USA: IEEE. 2012. 201–204.

70. Tsai, C. and Yang, C. Novel Compact Eye-shaped UWB Antennas. *IEEE Antennas and Wireless Propagation Letters.* 2012. 11:184–187.

71. Wayne S. T. and Rowe, R. W. *Printed Antennas for Wireless Communications*. West Sussex: John Wiley & Sons. 2007.

72. Abbosh, A. M., Kan, H. K., and Bialkowski, M. E. Compact Ultra-wideband Planar Tapered Slot Antenna for use in a Microwave Imaging System. *Microwave and Optical Technology Letters*. 2006. 48(11): 2212–2216.

73. Mobashsher , A. T. and Abbosh, A. M. Compact Wideband Directional Antenna with Three-dimensional Structure for Microwave-based Head Imaging Systems. *IEEE International Symposium on Antennas and Propagation Society (APSURSI).* July 6-11, 2014. Tennessee, USA: IEEE. 2014. 1141–1142.

74. Latif, S., Flores-Tapia, D., Shafai, L., and Pistorius, S. An Ultrawideband Elliptical Monopole Antenna for Breast Microwave Radar Imaging. *IEEE International Symposium on Antennas and Propagation Society (APSURSI)*. July 7- 13, 2013. Orlando, Florida: IEEE. 2013. 686–687.

75. Langley, J. D. S., Hall, P. S., and Newham, P. Novel Ultrawide Bandwidth Vivaldi Antenna with Low Crosspolarization. *Electronics Letters*. 1993. 29(23):2004–2005.

76. Bourqui, J., Okoniewski, M., and Fear, E. C. Balanced Antipodal Vivaldi Antenna with Dielectric Director for Near-Field Microwave Imaging. *IEEE Transactions on Antennas and Propagation*. 2010. 58(7): 2318–2326.

77. B. J. Mohammed, A. M. Abbosh, D. I., and Bialkowski, M. E. Compact Wideband Antenna Immersed in Optimum Coupling Liquid for Microwave Imaging of Brain Stroke. *Progress In Electromagnetics Research C*. 2012. 27:27–39.

78. Betancourt , D. and Castan, J. Printed Antenna on Flexible Low-Cost Pet Substrate for UHF Applications. *Progress In Electromagnetics Research C*. 2013. 38: 129–140.

79. *Polyethylene Terephthalate - PET Amorphous.* Available from : <http://www.azom.com/article.aspx?ArticleID=796>. [1 November 2015].

80. Sankaralingam, S. and Gupta, B. Development of Textile Antennas for Body Wearable Applications and Investigations on Their Performance Under Bent Conditions. *Progress In Electromagnetics Research B*. 2010. 22: 53–71.

81. Mantash, M., Tarot, A. C., Collardey, S., and Mahdjoubi, K. Wearable Monopole Zip Antenna. *Electronics Letters*. 2011. 47(23):1266-1267.

82. Osman, M., Rahim, M., Azfar, M., Samsuri, N. A., Zubir, F., and Kamardin, K. Design, Implementation and Performance of Ultra-wideband Textile Antenna. *Progress In Electromagnetics Research B*. 2011. 27: 307–32.

83. McArthur, A. *Textiles Technology*. United Kingdom: Nelson Thornes. 2004.

84. Tabár, L. and P Dean. B. A New Era in the Diagnosis and Treatment of Breast Cancer. *The Breast Journal*. 2010. 16(s1): S2–S4.

85. Siu, A. L. Screening for Breast Cancer: U.S. Preventive Services Task Force Recommendation Statement. *Annals of Internal Medicine*. 2016. 164(4): 279–296.

86. Berg, W. A., Gutierrez, L., NessAiver, M. S., Carter, W. B., Bhargavan, M., Lewis, R. S., and Ioffe, O. B. Diagnostic Accuracy of Mammography, Clinical Examination, US, and MR Imaging in Preoperative Assessment of Breast Cancer. *Radiology*. 2004. 233(3):830–849.

87. Vertiy, A. and Gavrilov, S. Microwave Tomography for Human Body Imaging. *International Conference on Electromagnetics in Advanced Applications (ICEAA)*. September 17- 21, 2007. Torino, Italy: IEEE. 2007. 336-339.

88. Guardiola, M., Jofre, L., and Romeu, J. 3D UWB Tomography for Medical Imaging Applications. *IEEE International Symposium on Antennas and Propagation Society (APSURSI)*. July 11-17, 2010. Ontario, Canada: IEEE. 2010. 3–6.

89. Grzegorczyk, T. M., Meaney, P. M., Kaufman, P. A., DiFlorio-Alexander, R. M., and Paulsen, K. D. Fast 3-d Tomographic Microwave Imaging for Breast Cancer Detection. *IEEE Transactions on Medical Imaging*. 2012. 31(8): 1584–1592.

90. Klemm, M., Leendertz, J. A., Gibbins, D., Craddock, I. J., Preece, A., and Benjamin, R. Microwave Radar-Based Breast Cancer Detection: Imaging in Inhomogeneous Breast Phantoms. *IEEE Antennas and Wireless Propagation Letters*. 2009. 8: 1349–1352.

91. Klemm, M., Leendertz, J. A., Gibbins, D., Craddock, I. J., Preece, A., and Benjamin, R. Microwave Radar-Based Differential Breast Cancer Imaging:

Imaging in Homogeneous Breast Phantoms and Low Contrast Scenarios. *IEEE Transactions on Antennas and Propagation*. 2010. 58(7): 2337–2344.

92. Winters, D. W., Shea, J. D., Madsen, E. L., Frank, G. R., Van Veen, B. D., & Hagness, S. C. Estimating the Breast Surface using UWB Microwave Monostatic Backscatter Measurements. *IEEE Transactions on Biomedical Engineering*. 2008. 55(1): 247–56.

93. Fear, E. C., Meaney, P. M., and Stuchly, M. A. Microwaves for Breast Cancer Detection?. *IEEE Potentials*. 2003. 22(1): 12.

94. Khor, W. C. and Bialkowski, M. E. nvestigations into Cylindrical and Planar Configurations of a Microwave Imaging System for Breast Cancer Detection. *IEEE Antennas and Propagation Society International Symposium*. July 9 - 14, 2006. New Mexico, USA: IEEE. 2006. 263–266.

95. Pack, J.-K., Kim, T.-H., Jeon, S.-I., Lee, J.-M., and Kim, K.-C. Breast Cancer Detector using Microwave Tomography Image Technology. *Asia-Pacific International Symposium on Electromagnetic Compatibility*. April 12-16, 2010. Beijing, China: IEEE. 2010. 362–365.

96. Khor, W. C. K. W. C., Bakar, A. A., and Bialkowski, M. E. Investigations into Breast Cancer Detection using Ultra Wide Band Microwave Radar Technique. *Asia Pacific Microwave Conference*. December 7-10, 2009. Singapore: IEEE. 712–715.

97. Bialkowski, M., Wang, Y., Bakar, A. A., and Khor, W. C. Microwave Imaging using Ultra Wideband Frequency Domain Data. *Microwave and Optical Technology Letters*. 2012. 54(1):13–18.

98. Bialkowski, M. E., Khor, W. C., and Crozier, S. A Planar Microwave Imaging System with Step-frequency Synthesized Pulse using Different Calibration Methods. *Microwave and Optical Technology Letters*. 2006. 48(3): 511–516.

99. Panagopoulos, D. J., Johansson, O., and Carlo, G. L. Evaluation of Specific Absorption Rate as a Dosimetric Quantity for Electromagnetic Fields Bioeffects. 2013. *PLoS ONE*. 8(6):1-9.

100. ICNIRP Secretariat. *ICNIRP Guidelines for Limiting Exposure to Time Varying Electric, Magnetic and Electromagnetic Fields (up to 300 GHz)*. 1998. 74(4): 494–523.

101. *SAR Values: The Facts and Figures on Cellular Phone Radiation!*. Available from: <http://sarvalues.com/what-is-sar-and-what-is-all-the-fuss-about/>. [6 July 2015].

102. Picher, C., Anguera, J., Andujar, A., Puente, C., and Kahng, S. Analysis of the Human Head Interaction in Handset Antennas with Slotted Ground Planes. *IEEE Antennas and Propagation Magazine*. 2012. 54(2): 36–56.

103. Li, C.-H., Douglas, M., Ofli, E., Derat, B., Gabriel, S., Chavannes, N., and Kuster, N. Influence of the Hand on the Specific Absorption Rate in the Head. *IEEE Transactions on Antennas and Propagation*. 2012. 60(2):1066–1074.

104. Khalatbari, S., Sardari, D., Mirzaee, A. A., and Sadafi, H. A. Calculating SAR in two Models of the Human Head Exposed to Mobile Phones Radiations at 900 and 1800 MHz. *Progress In Electromagnetics Research Symposium*. March 26-29, 2006. Cambridge, USA: The Electromagnetics Academy. 2006. 104–109.

105. Khodabakhshi, H., and Cheldavi, A. Irradiation of a Six-layered Spherical Model of Human Head in the Near Field of a Half-wave Dipole Antenna. *IEEE Transactions on Microwave Theory and Techniques*. 2010. 58(3): 680–690.

106. Lak, A., Oraizi, H., Lak, A., and Oraizi, H. Evaluation of SAR Distribution in Six-Layer Human Head Model. *International Journal of Antennas and Propagation*. 2013. 2013: 1–8.

107. Zhao, K., Zhang, S., Ying, Z., Bolin, T., and He, S. SAR Study of Different MIMO Antenna Designs for LTE Application in Smart Mobile Handsets. *IEEE Transactions on Antennas and Propagation*. 2013. 61(6):3270–3279.

108. Li, H., and Lau, B. K. Efficient evaluation of specific absorption rate for MIMO terminal. *Electronics Letters*. 2014. 50(22):1561–1562.

109. Li, H., Tsiaras, A., Derat, B., and Lau, B. K. Analysis of SAR on Flat Phantom for Different Multi-antenna Mobile Terminals. *The 8th European Conference on Antennas and Propagation (EuCAP)*. April 6-11, 2014. The Hague, Netherlands: IEEE. 2014. 2365–2369.

110. Pinho, P., Lopes, A., Leite, J., and Casaleiro, J. SAR Determination and Influence of the Human Head in the Radiation of a Mobile Antenna for Two Different Frequencies. *IEEE International Conference on Electromagnetics in Advanced Applications*. September 14 - 18, 2009. Torino, Italy: IEEE. 2009. 431–434.

111. Lias, K., Mat, D. A. A., Kipli, K., and Marzuki, A. S. W. Human Health Implication of 900MHz and 1800MHz Mobile Phones. *IEEE 9th Malaysia International Conference on Communications*. December 15-17, 2009. Kuala Lumpur, Malaysia : IEEE. 2009. 146–149.

112. Soh, P. J., Vandenbosch, G. A. E., Wee, F. H., van den Bosch, A., Martinez-Vazquez, M., and Schreurs, D. M. M.-P. Specific Absorption Rate (SAR) Evaluation of Biomedical Telemetry Textile Antennas. *IEEE MTT-S International Microwave Symposium Digest (IMS)*. June 2-7, 2013. 2013.1–3.

113. Soh, P. J., Vandenbosch, G. a E., Wee, F. H., Van Den Bosch, A., Martinez-Vazquez, M., and Schreurs, D. M. M. P. Specific Absorption Rate (SAR) Evaluation of Textile Antennas. *IEEE Antennas and Propagation Magazine*. 2013. 57(2):229–240.

114. Abbosh, A. and Mobashsher, A. T. Development of Compact Directional Antenna Utilising Plane of Symmetry for Wideband Brain Stroke Detection Systems. *Electronics Letters*. 2014. 50(12): 850–851.

115. *Lessemf*. Available from: <http://www.lessemf.com/fabric.html>. [2 July 2015].

116. Mantash, M., Tarot, a.-C., Collardey, S., and Mahdjoubi, K. Investigation of Flexible Textile Antennas and AMC Reflectors. *International Journal of Antennas and Propagation*. 2012. 2012:1–10.

117. Nelson, S. O., Stuchley, S., and Kent, G. *Agilent 85070E Dielectric Probe Kit*. 2013.

118. Langhe, P. De, Martens, L., and Zutter, D. De. Design Rules for an Experimental Setup using an Open-ended Coaxial Probe Based on Theoretical Modelling. *IEEE Transactions on Instrumentation and Measurement*. 1994. 43(6): 810–817.

119. El-rayes, M., and Ulaby, F. Microwave Dielectric Spectrum of Vegetation-Part I: Experimental Observations. *IEEE Transactions on Geoscience and Remote Sensing*. 1987. GE-25(5):541–549.

120. Lee, T. *Keysight Vector Network Analyzer Calibration and Connector Care*. Keysight Technologies. 2007.

121. Q. A. Acton, *Breast Cancer: New Insights for the Healthcare Professional: 2013 Edition*, 2013th ed. ScholarlyEditions, 2013.

122. Al-Khatib, M. and Alam, M. S. IPTV Multimedia Networks: Concepts, Developments, and Design. *International Engineering Consortium, Chicago, Illinois*. 2007.

123. Yang, F. and Mohan, A. Microwave Imaging for Breast Cancer Detection using Vivaldi Antenna Array. *IEEE International Symposium on Antennas and Propagation (ISAP)*. October 29 - November 2, 2012. Nagoya, Japan, IEEE. 2012. 479–482.

124. Chew, K. M., Sudirman, R., Seman, N., and Yong, C. Y. Reflection Coefficient Detection of Simulation Models for Microwave Imaging Simulation System. *Bio-Medical Materials and Engineering*. 2014. 24(1):199–207.

125. Unal, I., Turetken, B., Surmeli, K., and Canbay, C. An Experimental Microwave Imaging System for Breast Tumor Detection on Layered Phantom Model, *IEEE XXXth URSI General Assembly and Scientific Symposium*. August 13-20, 2011. Istanbul, Turkey: IEEE. 2011. 1–4.

126. Wessapan, T., Srisawatdhisukul, S., and Rattanadecho, P. The Effects of Dielectric Shield on Specific Absorption Rate and Heat Transfer in the Human Body Exposed to Leakage Microwave Energy. *International Communications in Heat and Mass Transfer*. 2011. 38(2): 255–262.

127. Mohra, A., Sheta, A., Siddiqui, Z., and Elshafiey, I. Development of Microwave System for Tumor Ablation and Imaging. *42nd European Microwave Conference*. October 29 - November 1, 2012. Amsterdam, Netherlands: IEEE. 2012. 803–806.

128. Beard, B. B., Kainz, W., Onishi, T., Iyama, T., Watanabe, S., Fujiwara, O., Nikoloski, N. Comparisons of Computed Mobile Phone Induced SAR in the SAM Phantom to that in Anatomically Correct Models of the Human Head. *IEEE Transactions on Electromagnetic Compatibility*. 2006. 48(2): 397–407.

129. Joó, E., Szász, A., and Szendrö, P. Metal-framed Spectacles and Implants and Specific Absorption Rate among Adults and Children using Mobile Phones at 900/1800/2100 MHz. *Electromagnetic Biology and Medicine*. 2006. 25(2):103–12.

130. Mohammed, B., Abbosh, A., Henin, B., and Sharpe, P. Head Phantom for Testing Microwave Systems for Head Imaging. *Cairo International Biomedical Engineering Conference (CIBEC)*. December 20-22, 2012. Giza, Egypt: IEEE. 2012. 191–193.

131. Balanis, C. A. *Antenna Theory: Analysis and Design*. 3rd edition. Canada: John Wiley & Sons. 2005.

132. Visser, H. J. *Antenna Theory and Applications*. West Sussex, U.K: John Wiley & Sons. 2012.

133. Hilberg, W. From Approximations to Exact Relations for Characteristic Impedances. *IEEE Transactions on Microwave Theory and Techniques*. 1969. 17(5):259–265.

134. Yang, Z.-X., Yang, H.-C., Hong, J.-S., and Li, Y. Bandwidth Enhancement of a Polarization-Reconfigurable Patch Antenna with Stair-Slots on the Ground. *IEEE Antennas and Wireless Propagation Letters*. 2014. 13:579–582.

135. Sujith, R., Mridula, S., Binu, P., Laila, D., Dinesh, R., and Mohanan, P. Compact CPW-fed Ground Defected H-shaped Slot Antenna with Harmonic Suppression and Stable Radiation Characteristics. *Electronics Letters*. 2010. 46(12):812-814.

136. Sharma, S., Saxena, V. N., Goodwill, K., Singh, S. K., and Sharma, K. CPW Fed Rectangular Slot Antenna with Dual H-Slot on Ground for Wideband Wireless Applications. 9th *International Conference on Signal Processing and Communication (ICSC)*. March 16-18, 2015. Greater Noida, India: IEEE. 2015. 439–442.

137. Chen, H. D. Broadband CPW-fed Square Slot Antennas with a Widened Tuning Stub. *IEEE Transactions on Antennas and Propagation*. 2003. 51(8):1982–1986.

138. Bangkok, T. N. A Multiband CPW-Fed Slot Antenna with Fractal Stub and Parasitic Line. *RadioEngineering*. 2012. 21(2):597–605.

139. Krishna, D. Das, Gopikrishna, M., Anandan, C. K., Mohanan, P., and Vasudevan, K. CPW-fed Koch Fractal Slot Antenna for WLAN/WiMAX Applications. *EEE Antennas and Wireless Propagation Letters*. 2008. 7:389–392.

140. Ojaroudi, N., Ojaroudi, M., and Ebarhimian, H. Band-Notched Uwb Microstrip Slot Antenna with Enhanced Bandwidth by Using a Pair of C-Shaped Slots. *Microwave and Optical Technology Letters*. 2012. 54(2):515–518.

141. Tzeremes, G., Liao, T. S., Yu, P. K. L., and Christodoulou, C. G. Computation of Equivalent Circuit Models of Optically Driven CPW-Fed Slot Antennas for Wireless Communications. *IEEE Antennas and Wireless Propagation Letters*. 2003. 2: 140–142.

142. Verma, A. K. and Singh, P. Loss Computation of Multilayer Coplanar Waveguide using Single Layer Reduction Method. *International Journal of Electromagnetics and Applications*. 2012. 2(6):174–181.

143. Pieter-Tjerk de Boer, PA3FWM Amateur Radio 2014, *Capacitance of Antenna Elements*, Available from: < http://www.pa3fwm.nl/technotes/tn08b.html> [10 June 2016].

144. Luis, J. R. De, Mahanfar, A., and Shewan, B. *Reconfigurable Monopole Antenna for Wireless Communications*. US20140159982 A1. 2014.

145. Madhav, B. T. P., Sanikommu, M., Pranoop, M. N. V. S., Bose, K. S. N. M. C., and Kumar, B. S. CPW Fed Antenna for Wideband Applications based on Tapered Step Ground and EBG Structure. *Indian Journal of Science and Technology*. 2015. 8:119–127.

146. Majidzadeh, M. and Ghobadi, C. Wide Band CPW-fed Circular Patch Antenna with Tapered Ground Plane. *Internatıonal Journal of Natural and Engineering Sciences*. 2012. 6(3):105–108.

147. Matin, M. A. *Ultra Wideband Communications: Novel Trends - Antennas and Propagation*. Croatia: InTech. 2011.

148. Baum, C. E., Carin, L., and Stone, A. P. *Ultra-Wideband, Short-Pulse Electromagnetics 3*. New York: Springer Science & Business Media. 1997.

149. Shirook, M. A. and Kanj, H. *Modified Ground Plane (MGP) Approach to Improving Antenna Self-matching and Bandwidth*. US8593367 B2. 2010.

150. Abbosh, A. M. Miniaturization of Planar Ultrawideband Antenna via Corrugation. *IEEE Antennas and Wireless Propagation Letters*. 2008.7:685–688.

151. Abbosh, A. M. Miniaturized Microstrip-fed Tapered-slot Antenna with Ultrawideband Performance. *IEEE Antennas and Wireless Propagation Letters*. 2009. 8:690–692.

152. Abbosh, A. Microwave-based System using Directional Wideband Antennas for Head Imaging. *IEEE International Workshop on Antenna Technology (iWAT)*. March 4-6, 2014. Sydney, Australia: IEEE. 2014. 292–295.

153. Chen, C. H., Yung, E. K. N. and, and Hu, B. J. Miniaturised CPW-fed Circularly Polarised Corrugated Slot Antenna with Meander Line Loaded. *IEEE Electronics Letters*. 2007. 43(25):1404 – 1405.

154. DeBra, D. B. and Gottzein, E. *Automatic Control in Aerospace 1992: Selected Papers from the 12th IFAC Symposium, Ottobrunn, Germany, 7 - 11 September 1992*. Great Britain: Elsevier. 1993.

155. Mofolo, M. O. R., Lysko, A. A., Clarke, W. A., and Olwal, T. O. Effects of Variations in Structural Parameters on Performance of Switched Parasitic Arrays.

Southern Africa Telecommunication Networks and Applications Conference (SATNAC). September 4-7, 2011. London: EE. 2011.

156. Khaleel, H. R. *Innovation in Wearable and Flexible Antennas*. United Kingdom: WIT Press. 2013.
157. National Center for Health Statistics. Data Table of Infant Head Circumference-for-age Charts 2001. *Centers for Disease Control and Prevention*. Available from: <http://www.cdc.gov/growthcharts/html_charts/hcageinf.htm>. [8 May 2015]
158. Ching, R. P. *Relationship between Head Mass and Circumference in Human Adults*. 2007. 1-5.
159. Bushby, K. M. D., Cole, T., Matthews, J. N. S., and Goodship, J. A. Centiles for Adult Head Circumference. *Archives of Disease in Childhood*. 1992. 67:1286–1287.
160. Jarvis, J. B., Janezic, M. D., F.Riddle, B., Johnk, R. T., Kabos, P., Geyer, C. L. H. R. G., and Grosvenor, C. A. *Measuring the Permittivity and Permeability of Lossy Materials: Solids, Liquids, Metals, Building Materials, and Negative-Index Materials*. US: National Institute of Standards and Technology. 2005.
161. Mobashsher, A. T., Member, S., Abbosh, A. M., Member, S., and Wang, Y. Microwave System to Detect Traumatic Brain Injuries Using Compact Unidirectional Antenna and Wideband Transceiver With Veri fi cation on Realistic Head Phantom. *IEEE Transactions on Microwave Theory and Techniques*. 2014. 62(9):1826–1836.
162. Abbosh, A., and Bialkowski, M. Design of UWB Planar Antenna for Microwave Imaging Systems. 2007. *IEEE International Conference on Signal Processing and Communications (ICSPC)*. November 24-27, 2007. Dubai, United Arab Emirates: IEEE. 2007. 24–27.
163. Zeng, X., Fhager, A., Persson, M., Linner, P., and Zirath, H. Accuracy Evaluation of Ultrawideband Time Domain Systems for Microwave Imaging. *IEEE Transactions on Antennas and Propagation*. 2011. 59(11):4279–4285.
164. Xu, H.-Y., Zhang, H., Li, G.-Y., Xu, Q.-B., and Lu, K. An Ultra-wideband Fractal Slot Antenna with Low Backscattering Cross Section. *Microwave and Optical Technology Letters*. 2011. 53(5):1150–1154.
165. Zhang, H., Flynn, B., Erdogan, A. T., and Arslan, T. Microwave Imaging for Brain Tumour Detection using an UWB Vivaldi Antenna Array. *Loughborough*

Antennas & Propagation Conference. November 12-13, 2012. Leicestershire, United Kingdom: IEEE. 2012. 1–4.

166. Fear, E. C., Li, X., Hagness, S. C., and Stuchly, M. A. Confocal Microwave Imaging for Breast Cancer Detection: Localization of Tumors in Three Dimensions. *IEEE Transactions on Biomedical Engineering*. 2002. 49(8):812–22.
167. Soh, P. J., Bergh, B. V. D., Xu, H., Aliakbarian, Farsi, H., Samal, S. P., Vandenbosch, G. A. E., Schreurs, D. M. M. P., and Nauwelaers, B. K. J. C. A Smart Wearable Textile Array System for Biomedical Telemetry Applications. *IEEE Transactions on Microwave Theory and Techniques*. 2013. 61(5):2253–2261.
168. Sachs, J. *Handbook of Ultra-Wideband Short-Range Sensing: Theory, Sensors, Applications*. Weinheim, Germany: John Wiley & Sons. 2013.
169. Carin, L. and Felsen, L. B. *Ultra-Wideband, Short-Pulse Electromagnetics 2*. Brooklyn, New York: Springer Science & Business Media. 2013.
170. Denidni, T. A. and Augustin, G. *Ultrawideband Antennas for Microwave Imaging Systems*. Bonston, London: Artech House. 2014.
171. Karathanasis, K. T., Gouzouasis, I. A., Karanasiou, I. S., Giamalaki, M. I., Stratakos, G., and Uzunoglu, N. K. Noninvasive Focused Monitoring and Irradiation of Head Tissue Phantoms at Microwave Frequencies. *IEEE Transactions on Information Technology in Biomedicine*. 2010. 14(3): 657–663.
172. Golio, M. *The RF and Microwave Handbook*. US: CRC Press. 2000.
173. Lee, A. K. and Yun, J. A Comparison of Specific Absorption Rates in SAM Phantom and Child Head Models at 835 and 1900 MHz. *IEEE Transactions on Electromagnetic Compatibility*. 2011. 53(3):619–627.
174. Permana, H., Fang, Q., and Lee, S. Comparison Study on Specific Absorption Rate of Three Implantable Antennas Designed for Retinal Prosthesis Systems. *IET Microwaves, Antennas Propagation*. 2013. 7(11):886–893.
175. Davis, C. C. and Balzano, Q. The International Intercomparison of SAR Measurements on Cellular Telephones. *IEEE Transactions on Electromagnetic Compatibility*. 2009. 51(2):210–216.
176. Soh, P. J., Vandenbosch, G. A. E., Wee, F. H., Mercuri, M., van den Bosch, A., Martinez-Vazquez, M., and Schreurs, D. M. M.P. SAR Evaluation of Ultra Wideband (UWB) Textile Antennas. *IEEE Topical Conference on Biomedical*

Wireless Technologies, Networks, and Sensing Systems (BioWireleSS). Jan 19-23, 2014. California, US: IEEE. 2014. 13–15.

177. Iqbal-Faruque, M. R., Aisyah-Husni, N., Ikbal-Hossain, M., Tariqul-Islam, M., and Misran, N. Effects of Mobile Phone Radiation onto Human Head with Variation of Holding Cheek and Tilt Positions. *Journal of Applied Research and Technology*. 2014. 12(5):871–876.
178. Monebhurrun, V. Conservativeness of the SAM Phantom for the SAR Evaluation in the Child's Head. *IEEE Transactions on Magnetics*. 2010. 46(8):3477–3480.
179. Matin, Mohammad A. *Wideband, Multiband, and Smart Reconfigurable Antennas for Modern Wireless Communications*. USA: IGI Global. 2015.
180. Vidal, N., and López-Villegas, J. M. Changes in Electromagnetic Field Absorption in the Presence of Subcutaneous Implanted Devices: Minimizing Increases in Absorption. *IEEE Transactions on Electromagnetic Compatibility*. 2010. 52(3):545–555.
181. Bernardi, P., Cavagnaro, M., and Pisa, S. Evaluation of the SAR Distribution in the Human Head for Cellular Phones used in a Partially Closed Environment. *IEEE Transactions on Electromagnetic Compatibility*. 1996. 38(3): 357–366.
182. Kamepally, S. K., Kumar, B. P., and Paidimarry, C. S. FDTD Estimation for Accurate Specific Absorption Rate in a Tumor. *International Conference on Microelectronics, Communications and Renewable Energy (ICMiCR)*. June 4-6, 2013. Kanjirapally, India: IEEE. 2013.1–5.
183. Lazarescu, C., Dafinescu, V., and David, V. Specific Absorption Rate in the Human Head due to Different Far Field Exposure Sources. *International Conference and Exposition on Electrical and Power Engineering (EPE)*, October 25-27,2012. Iasi, Romania: IEEE. 2012. 683–687.
184. Wang, S., Shao, Y., and Li, S. Rapid Local Specific Absorption Rate Estimation for Magnetic Resonance Imaging. *IEEE Transactions on Electromagnetic Compatibility*. 2014. 56(4): 771–779.
185. Okano, Y. and Shimoji, H. Comparison Measurement for Specific Absorption Rate with Physically Different Procedure. *IEEE Transactions on Instrumentation and Measurement*. 2012. 61(2): 439–446.