SWITCHABLE AND TUNABLE MULTIBAND SLOT DIPOLE ANTENNA

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Dedicated to my parents, Idris bin Ismail, Sulaihah Ab. Rashid,
my only sister with brother in law, Sakinah Idris, Mohd Zaidi Zuraini
my niece, Nur Wafa Imani Mohd Zaidi
my beloved husband, Muhammad Ubaidullah Ramlan
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ABSTRACT

Developments of frequency reconfigurable antennas in the wireless communication systems have attracted a lot of attention recently. Most reported antennas have narrowband to narrowband reconfiguration and multiband to multiband reconfigurations. In this research, a slot dipole antenna has been introduced with the ability to produce a multiband to narrowband reconfiguration. This type of antenna can suppress the problem of co-site interferences. Thus, two types of frequency reconfigurable antennas are studied and discussed which are switchable and tunable multiband antennas. The switchable multiband antenna is reconfigured by using Radio Frequency (RF) switches. The proposed antenna is capable to reconfigure from multiband to dual and/or single band. By having seven configurations of switches, this antenna can operate at 2.4 GHz, 3.5 GHz and/or 5.2 GHz. The antenna is able to have three states of single-band, three states of dual-band and one state of triple-band. Meanwhile, the tunable multiband antenna is reconfigured by using variable capacitors. The proposed antenna is capable to have a wide frequency tunability range for dual or single band operation (1.5 GHz - 4.5 GHz, ratio of 3:1). Each antenna has been successfully designed, fabricated and tested. The simulation and measurement results were analysed and presented in terms of reflection coefficient, radiation pattern and gain. The simulation and measurement results have been compared and a very good agreement was achieved. The reflection coefficient average accuracies of 98% has been achieved. These proposed antennas are suitable for future multi-mode applications such as cognitive radio systems.

ABSTRAK

Perkembangan antena konfigurasi semula frekuensi dalam sistem komunikasi tanpa wayar telah menarik banyak perhatian baru-baru ini. Kebanyakan antena yang dilaporkan mempunyai konfigurasi semula jalur sempit ke jalur sempit dan konfigurasi semula berbilang jalur ke berbilang jalur. Dalam tesis ini, antena slot dwikutub telah diperkenalkan dengan mempunyai keupayaan untuk menghasilkan konfigurasi semula berbilang jalur ke jalur sempit. Jenis antena ini boleh mengurangkan masalah gangguan kawasan sekitar. Oleh itu, dua jenis antena konfigurasi semula frekuensi dikaji dan dibincangkan iaitu antena berbilang jalur boleh ubah dan boleh tala. Antena berbilang jalur boleh ubah dibina dengan menggunakan suis radio frekuensi (RF). Antena yang dicadangkan ini berupaya untuk dikonfigurasi semula daripada berbilang jalur ke jalur dual dan/atau tunggal. Dengan adanya tujuh suis konfigurasi, antena ini boleh beroperasi pada 2.4 GHz, 3.5 GHz dan/atau 5.2 GHz. Antena ini mampu memiliki tiga keadaan jalur tunggal, tiga keadaan jalur dual dan satu keadaan berbilang jalur. Manakala, antena berbilang jalur boleh tala dibina dengan menggunakan kapasitor boleh tala. Antena yang dicadangkan berupaya mempunyai kebolehan penalaan dalam julat frekuensi yang luas bagi operasi jalur berbilang atau tunggal (1.5 GHz - 4.5 GHz, dengan nisbah 3:1). Kesemua antena telah berjaya direka bentuk, difabrikasi dan diuji. Hasil keputusan simulasi dan pengukuran dari segi pemalar pantulan, polaradiasi dan gandaan dianalisa dan ditunjukkan. Hasil keputusan simulasi dan pengukuran akan dibandingkan dan satu persetujuan yang baik telah dapat dicapai. Pemalar pantulan telah mencapai purata ketepatan sebanyak 98%. Antena yang dicadangkan sesuai untuk penggunaan berbilang-mod di masa akan datang seperti sistem kognitif radio.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CPW	-	Coplanar waveguide
CST	-	Computer Simulation Technology
DC	-	Direct current
DCS	-	Digital Cellular Service
EM	-	Electromagnetic
GPS	-	Global Positioning System
GSM	-	Global System for Mobile Communication
PIL	-	Planar inverted L
RF-MEMS	-	Radio frequency micro-electromechanical system
SMA	-	SubMiniature version A
UMTS	-	Universal Mobile Telecommunications System
UV	-	Ultra violet
VNA	-	Vector network analyzer
WiMAX	-	Worldwide Interoperability for Microwave Access
WLAN	-	Wireless Local Area Network

LIST OF SYMBOLS

λ	-	Wavelength
ε_r	-	Dielectric constant
λ_0	-	Wavelength in free space
f	-	Frequency
l_t	-	Slot arm total length
X_c	-	capacitive reactance
π	-	constant approximated as 3.14159
C	-	capacitor value

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Reconfigurable antenna has received much attention lately. According to [1], reconfigurable antenna has been used in many applications such as mobile and satellite communications, cellular radio system and radar application. This antenna has its own unique appearance due to the overall size, lower cost and ability to reduce the complexity of a system compared to multiple single-function antenna. There are many types of reconfigurable antennas depending on their properties such as frequency, radiation pattern, bandwidth and polarization. Tuning or switching the antennas operating frequency can filter out interfering signals. In addition, changing the antennas radiation pattern into the desired direction can result in less power consumption. Thus, based on the aforementioned criteria, reconfigurable antenna has the ability to serve in many applications due to its significant advantages [2].

This thesis presents a study on frequency reconfigurable antenna. Frequency reconfigurable antenna only change its operating band and generally will not affect the antenna's radiation pattern. Frequency reconfigurable antenna can be divided into two types which are continuous and discrete tuning. Continuous tuning has a smooth tuning between one to another operating frequency. Discrete tuning, on the other hand, switches its operating frequencies from one to another. Frequency reconfigurable antennas are known to provide transceiver flexibility by switching the operating frequency to different bands. This allows them to operate in multiple operations. It can be done by using some mechanisms that can provide the reconfigurability to the antenna, such as switching and variable reactive loading [2]. Switching can be done by using pin-diode or radio frequency micro-electromechanical system (RF-MEMS), while the variable reactive loading mechanism can be operated by using the varactor or capacitance. Generally, frequency reconfiguration can be obtained by switching in and

out some parts of the antenna. Another way to achieve this is by means of changing the antenna structure mechanically or adjusting the antenna matching externally. In this study, frequency reconfigurable antennas were manipulated to reconfigure either by switching in and out some parts of the antenna or changing the antennas effective length to switch and tune the operating bands, respectively.

There are three main classes of techniques for frequency reconfiguration: 1) switching between narrowband, 2) switching between wideband to narrowband, and 3) switching between multiband. An antenna that can be reconfigured from one narrowband to another narrowband is only capable of supporting one radio standard at a time, whereas an antenna that can be reconfigured from wideband to narrowband can support multiple radio standards at a time. However, the wideband operation inherently provides less interference rejection compared to narrowband operation. This limitation can be overcome by employing an antenna that can be reconfigured from one multi-band to multi-band, as proposed in this thesis.

1.2 Problem Statement

Reconfigurable antenna can provide multi-function antenna which can serve in many wireless systems applications such as cognitive radio system. Unlike multiple antennas which can increase the cost and size of the system, reconfigurable antenna is believed as a new approach or technique that can eliminate the problem towards the system. Reconfigurable antenna can operate in different frequencies, radiation pattern, polarization and others at a time. It can be classified depending on their functions which are frequency reconfigurable antenna, radiation pattern reconfigurable antenna, polarization reconfigurable antenna and bandwidth reconfigurable antenna.

Most studies on frequency reconfigurable antennas implemented frequency switching between one narrowband to another narrowband configuration. In addition, multiband to another multiband configuration has also been demonstrated. The former configuration can only support one service at a time, while the latter can support multiple services simultaneously. In recent trends, the multiband operation is more favorable and applicable. However, by having multiple operating bands, the system itself will be exposed to more co-site interferences. In order to reduce this, the antenna should have some degree of electrical flexibility which able the antenna to operate either in single, dual or multi-band modes when required. This flexibility can also

overcome the problem of serving only one frequency band at a time, as implemented by conventional reconfigurable antennas. Therefore, the presented antenna which can reconfigure from one narrowband to another multi narrowband is a potentially suitable antenna in cognitive radio applications.

1.3 Research Objectives

The objectives of this thesis are :-

i To design switchable multiband antenna that has the capability to switch its operating bands from triple to dual or single-band, and vice versa by means of pin-diode switches.

ii To design tunable multiband antenna that has the capability to tune its multiband operating frequency to other set of bands by means of varactor diodes.

1.4 Scope of Research

In this research, a triple band antenna was designed. The antenna in [3] was chosen as a basis structure. Two designs were developed, namely a switchable multiband antenna and a tunable multiband antenna. In the former design, pin-diode switches were used, while for the latter, varactor diodes were be employed.

As a first approximation, a prototype with ideal switches (copper strips) and a prototype with fixed capacitors were developed and tested. Later, the ideal switches and fixed capacitors in the prototypes were replaced with pin-diode switches and varactor diodes, respectively. The effect of switches toward the antenna performances was then investigated and compared in terms of reflection coefficient, gain and radiation pattern of the prototypes with ideal and real switches. Lastly, all data were compiled for thesis documentation.

1.5 Thesis Outline

This thesis is divided into seven chapters. The first chapter consists of a brief introduction to the reconfigurable antenna, which focuses on frequency reconfigurability, problem statement, research objective and scope of the research.

In the second chapter, literature review on frequency reconfigurable antenna is discussed. Previous works on frequency reconfigurable antenna regarding continuous and discrete tuning are also presented. This chapter includes discussion on two types of antennas, which are narrowband to narrowband and multiband to multiband reconfigurations.

The third chapter presents the methodology applied in this research project. The content of this chapter consists of the flow chart of the research, overall process of designing the switchable and tunable multiband antenna, including the simulation, fabrication and measured process.

The fourth chapter discusses about fixed non-reconfigurable multiband antenna, as well as parametric studies to investigate the parameters that could affect the performance of the antenna. The final design of the fixed non-reconfigurable multiband antenna is presented here.

Chapter five presents the switchable multiband antenna. This chapter also discusses the procedure to validate the concept of reconfigurability, where ideal switches (i.e. copper strips) are used in the antenna design. This chapter also presents an attempt of applying several numbers of pin-diodes to replace the ideal switches. The proposed antenna in this research is designed capable to operate in seven different modes, which are three single-band, three dual-band and/or one triple-band of operations. It can operate at three main frequencies, 2.4 GHz, 3.5 GHz and 5.2 GHz. The effect of the pin-diode is also discussed through gain analysis.

In chapter six, tunable multiband antenna is presented. It has the capability to tune the operating frequency by means of variable capacitor. The antennas are able to tune into triple-band, dual-band and single-band operating frequency. This chapter start with the design of an antenna with fixed capacitor to validate the concept of tunability. Also included is the design of the antenna with several numbers of varactor diode. The gain analysis in this chapter discusses the effect of using varactor diode.

Finally, the last chapter concludes the overall research work and discusses some future works.

REFERENCES

1. Haider, N., Caratelli, D. and Yarovoy, A. G. Recent Developments in Reconfigurable and Multiband Antenna Technology. *International Journal of Antennas and Propagation*, 2013. 2013.
2. Bernhard, J. L. T. *Reconfigurable Antennas*. California: Morgan and Claypool. 2007.
3. Chen, S.-Y., Chen, Y.-C. and Hsu, P. CPW-Fed Aperture-Coupled Slot Dipole Antenna for Tri-Band Operation. *IEEE Antennas and Wireless Propagation Letters*, 2008. 7: 535– 537.
4. Yang, S., Zhang, C., Pan, H. K., Fathy, A. E. and Nair, V. K. Frequency-Reconfigurable Antennas for Multiradio Wireless Platforms. *IEEE Microwave Magazine*, 2009. 10(1): 66–83.
5. Zhao, Q., Gong, S. X., Jiang, W., Yang, B. and Xie, J. Compact Wide-slot Tri-band Antenna for WLAN/WiMAX Applications. *Progress in Electromagnetics Research Letters*, 2010. 18: 9–18.
6. Rhee, S. and Yun, G. CPW Fed Slot Antenna for Triple-frequency Band Operation. *Electronics Letters*, 2006. 42(17): 952–953.
7. Ma, R., Zhang, W. and Han, L. Design of CPW-fed Tri-band Coplanar Slot Antenna. *IEEE Electrical Design of Advanced Packaging and Systems Symposium (EDAPS)*, 2011: 1–4.
8. Abutarboush, H., Nilavalan, R., Cheung, S. and Nasr, K. Compact Printed Multiband Antenna with Independent Setting Suitable for Fixed and Reconfigurable Wireless Communication Systems. *IEEE Transactions on Antennas and Propagation*, 2012. 60(8): 3867–3874.
9. Yang, X.-S., Wang, B.-Z., Wu, W.-X. and Xiao, S. Yagi Patch Antenna With Dual-Band and Pattern Reconfigurable Characteristics. *IEEE Antennas and Wireless Propagation Letters*, 2007. 6: 168–171.
10. Mansoul, A. and Ghanem, F. Frequency and Bandwidth Reconfigurable Monopole Antenna for Cognitive Radios. *2013 IEEE Antennas and Propagation Society International Symposium (APSURSI)*, 2013: 680–681.

11. Cao, W., Zhang, B., Liu, A., Yu, T., Guo, D. and Pan, K. A Reconfigurable Microstrip Antenna With Radiation Pattern Selectivity and Polarization Diversity. *IEEE Antennas and Wireless Propagation Letters*, 2012. 11: 453–456.

12. Matthews, E. W., Cuccia, C. L. and Rubin, M. D. Technology Considerations for the Use of Multiple Beam Antenna Systems in Communication Satellites. *IEEE Transactions on Microwave Theory and Techniques*, 1979. 27(12): 998–1004.

13. Sorbello, R. M., Karmel, P. R. and Gruner, R. W. Feed Array and Beam Forming Network Design for a Reconfigurable Satellite Antenna. *Antennas and Propagation Society International Symposium*, 1980. 18: 78–81.

14. Lockyer, D., Moore, C., Seager, R., Simpkin, R. and Vardaxoglou, J. Coupled Dipole Arrays as Reconfigurable Frequency Selective Surfaces. *Electronics Letters*, 1994. 30(16): 1258–1259.

15. Lim, J.-H., Back, G.-T., Ko, Y.-I., Song, C.-W. and Yun, T.-Y. A Reconfigurable PIFA Using a Switchable PIN-Diode and a Fine-Tuning Varactor for USPCS/WCDMA/m-WiMAX/WLAN. *IEEE Transactions on Antennas and Propagation*, 2010. 58(7): 2404–2411.

16. Cetiner, B. A., Crusats, G. R., Jofre, L. and Biyikli, N. RF MEMS Integrated Frequency Reconfigurable Annular Slot Antenna. *IEEE Transactions on Antennas and Propagation*, 2010. 58(3): 626–632.

17. Zohur, A., Mopidevi, H., Rodrigo, D., Unlu, M., Jofre, L. and Cetiner, B. A. RF MEMS Reconfigurable Two-Band Antenna. *IEEE Antennas and Wireless Propagation Letters*, 2013. 12: 72–75.

18. Chen, K.-H., Wu, S., Kang, C.-H., Chan, C.-K. and Tarng, J.-H. A Frequency Reconfigurable Slot Antenna Using Pin Diodes. *Asia Pasific Microwave Conference (APMC)*, 2009: 1930–1933.

19. Peroulis, D., Sarabandi, K. and Katehi, L. P. B. Design of Reconfigurable Slot Antennas. *IEEE Transactions on Antennas and Propagation*, 2005. 53(2): 645–654.

20. Han, T. Y. and Huang, C. T. Reconfigurable monopolar patch antenna. *Electronics Letters*, 2010. 46(3): 199–200.

21. Row, J.-S. and Lin, T.-Y. Frequency-Reconfigurable Coplanar Patch Antenna With Conical Radiation. *IEEE Antennas and Wireless Propagation Letters*, 2010. 9: 1088–1091.

22. Ouyang, J., Yang, F., Nie, Z. P. and Zhao, Z. Q. A Novel Frequency Reconfigurable Microstrip Antenna for Wideband Application. *Journal of Electromagnetic Waves and Applications*, 2008. 22: 1403–1410.

23. Majid, H. A., Rahim, M. K. A., Hamid, M. R. and Ismail, M. F. A Compact Frequency-reconfigurable narrowband microstrip slot antenna. *IEEE Antennas and Wireless Propagation Letters*, 2012. 11: 616–619.

24. White, C. R. and Rebeiz, G. M. A Shallow Varactor-Tuned Cavity-Backed Slot Antenna with a 1.9:1 Tuning Range. *IEEE Transactions on Antennas and Propagation*, 2010. 58(3): 633–639.

25. Cai, Y., Guo, Y. J. and Weily, A. R. A Frequency-Reconfigurable Quasi-Yagi Dipole Antenna. *IEEE Antennas and Wireless Propagation Letters*, 2010. 9: 883–886.

26. Yang, S.-L. S., Kishk, A. A. and Lee, K.-F. Frequency Reconfigurable U-Slot Microstrip Patch Antenna. *IEEE Antennas and Wireless Propagation Letters*, 2008. 7: 127–129.

27. Sheta, A. F. and Mahmoud, S. F. A Widely Tunable Compact Patch Antenna. *IEEE Antennas and Wireless Propagation Letters*, 2008. 7: 40–42.

28. Jung, C. W., Kim, Y. J., Kim, Y. E. and Flaviis, F. D. Macro-Micro Frequency Tuning Antenna for Reconfigurable Wireless Communication Systems. *Electronics Letters*, 2007. 43(4): 201–202.

29. Mak, A. C. K., Rowell, C. R., Murch, R. D. and Mak, C.-L. Reconfigurable Multiband Antenna Designs for Wireless Communication Devices. *IEEE Transactions on Antennas and Propagation*, 2007. 55(7): 1919–1928.

30. Zhang, C., Yang, S., El-Ghazaly, S., Fathy, A. E. and Nair, V. K. A Low-Profile Branched Monopole Laptop Reconfigurable Multiband Antenna for Wireless Applications. *IEEE Transactions on Antennas and Propagation*, 2009. 8: 216–219.

31. Alkanhal, M. A. and Sheta, A. F. A Novel Dual-Band Reconfigurable Square-Ring Microstrip Antenna. *Progress in Electromagnetics Research*, 2007. 70: 337–349.

32. Shynu, S. V., Augustin, G., Aanandan, C. K., Mohanan, P. and Vasudevan, K. Design of Compact Reconfigurable Dual Frequency Microstrip Antennas Using Varactor Diodes. *Progress in Electromagnetics Research Letters*, 2009. 60: 197–205.

33. Shynu, S. V., Augustin, G., Aanandan, C. K., Mohanan, P. and Vasudevan,

K. C-Shaped Slot Loaded Reconfigurable Microstrip Antenna. *Electronics Letters*, 2006. 42: 316–318.

34. Soliman, A., Elsheakh, D., Abdallah, E. and El-Henawy, H. Reconfigurable Independent Multiband Printed Inverted F-Antenna for Wireless USB Applications. *Proceeding of the 43rd European Microwave Conference (EuMC)*, 2013: 767–769.

35. Li, Y., Zhang, Z., Chen, W., Feng, Z. and Iskander, M. F. A Quadband Antenna With Reconfigurable Feeedings. *IEEE Antennas and Wireless Propagation Letters*, 2009. 8: 1069–1071.

36. Cho, J., Jung, C. W. and Kim, K. Frequency-Reconfigurable Two-Port Antenna for Mobile Phone Operating Over Nultiple Service Bands. *Electronics Letters*, 2009. 45: –.

37. Alayesh, M. A., Christodoulou, C. G., Joler, M. and Barbin, S. E. Reconfigurable Multi-Band Stacked Micostrip Patch Antenna for Wireless Applications. *Loughborough Antennas and Propagation Conference (LAPC)*, 2008: 329–332.

38. Shynu, S. V., Augustin, G., Aanandan, C. K., Mohanan, P. and Vasudevan, K. Development of A Varactor-Controlled Dual-Frequency Reconfigurable Microstrip Antenna. *Microwave and Optical Technology Letters*, 2005. 46(4): 375–377.

39. Behdad, N. and Sarabandi, K. Dual-Band Reconfigurable Antenna With a Very Wide Tunability Range. *IEEE Transactions on Antennas and Propagation*, 2006. 54(2): –.

40. AbuTarboush, H. F., Nilavalan, R., Nasr, K. M., Al-Raweshidy, H. S. and Budamir, D. Widely Tunable Multiband Reconfigurable Patch Antenna for Wireless Applications. *Proceedings of the Fourth European Conference on Antennas and Propagation (EuCAP)*, 2010: 1–3.

41. Genovesi, S., Candia, A. D. and Monorchio, A. Compact and Low Profile Frequency Agile Antenna for Multistandard Wireless Communication Systems. *IEEE Transaction on Antennas and Propagation*, 2014. 62(3): 1019–1026.

42. Kimouche, H. and Mansoul, A. A Compact Reconfigurable Single/Dual Band Antenna for Wireless Communications. *Proceedings of the Fifth European Conference on Antennas and Propagation (EuCAP)*, 2011: 393–396.

43. Chen, Y. B., Liu, X. F., Jiao, Y. C. and Zhang, F. S. A Frequency Reconfigurable CPW-Fed Slot Antenna. *Journal of Electromagnetic Waves*

and Applications, 2007. 21(12): 1673–1678.

44. Ren, Z., Li, W., Xu, L. and Shi, X. A Compact Frequency Reconfigurable Unequal U-Slot Antenna with a Wide Tunability Range. *Progress in Electromagnetics Research Letters*, 2013. 39: 9–16.

45. Liu, K., Y.-C. amd Chang. Multiband Frecuency Reconfigurable Antenna by Changing the Microstrip Connecting Element Position. *IEEE Antennas and Propagation Society International Symposium (APSURSI)*, 2009: 1–4.

46. Park, D. H. Optimizing Single-Element Microstrip Patch Antenna for Multi-Band Operations. *IEEE International Conference on Microwaves, Communications, Antennas and Electronics Systems (COMCAS)*, 2011: 1–3.

47. Pan, Y., Liu, K. and Hou, Z. A Novel Printed Microstrip Antenna with Frequency Reconfigurable Characteristics for Bluetooth/WLAN/WiMax Applications. *Microwave and Optical Technology Letters*, 2013. 55(6): 1341–1345.

48. Kumar, A., Patnaik, A. and Christodoulou, C. G. Design and Testing of a Multifrequency Antenna with a Reconfigurable Feed. *IEEE Antennas and Wireless Propagation Letters*, 2014. PP(99): 1–4.

49. AbuTarboush, H. F., Nilavalan, R., Nasr, K. M., Cheung, S. W., Peter, T., Al-Raweshidy, H. S. and Budamir, D. Reconfigurable Tri-Band H-Shaped Antenna with Frequency Selectivity Feature for Compact Wireless Communication Systems. *IET Microwaves, Antennas and Propagation*, 2011. 5(14): 1675–1682.

50. The Half-Wave Dipole Antenna, Date accessed : 22 November 2014. URL http://www.antenna-theory.com/antennas/halfwave.php.

51. Directional Antenna, Date accessed : 22 November 2014. URL http://www.whatis.techtarget.com/definition/directional-antenna.

52. Majid, H. A. *Frequency Reconfigurable Microstrip Slot Antenna*. Dissertation. Universiti Teknologi Malaysia. 2013.

53. Hamid, M. R. *Wideband Reconfigurable Antennas*. Dissertation. University of Birmingham, United Kingdom. 2011.

54. Capacitive Reactance, Date accessed : 02 December 2014. URL http://www.learnabout-electronics.org/ac_theory/reactance62.php.

55. Bird, T. S. Definition and Misuse of Return Loss. *IEEE Antennas and*

Propagation Magazine, 2009. 51: 166–167.

56. Abutarboush, H. F. *Fixed and Reconfigurable Multiband Antenna*. Dissertation. Brunel University, United Kingdom. 2011.

57. Ismail, M. F. *Freguency Reconfigurable Log-periodic Antenna Design*. Dissertation. Universiti Teknologi Malaysia. 2011.

58. Antennas, Date accessed : 23 November 2014. URL http://www.navymars.org/national/training/nmo_courses/nmo1/module10/14182_ch4.pdf.

59. James, J. R., Hall, P. S. and Wood, C. *Microstrip Antenna Theory and Design*. United Kingdom: Peter Peregrinus Ltd. 1986.

60. Wire Antennas, Date accessed : 23 November 2014. URL http://www.ece.msstate.edu/~donohoe/ece4990notes4.pdf.