A COPLANAR WAVEGUIDE-FED TWO ARM ARCHIMEDEAN SPIRAL SLOT ANTENNA

OMAR AHMAD ABDELAZIZ MASHAAL

UNIVERSITI TEKNOLOGI MALAYSIA

A COPLANAR WAVEGUIDE-FED TWO ARM ARCHIMEDEAN SPIRAL SLOT ANTENNA

OMAR AHMAD ABDELAZIZ MASHAAL

A dissertation submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Communication Engineering)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

FEBRUARY 2011

In the name of ALLAH the Most Beneficial and the most Merciful
Specially dedicated to my beloved Parents, Brothers and Sisters.

ACKNOWLEDGEMENT

I am so grateful to ALLAH the Almighty, for gracing me with strength wisdom and confidence to complete this project.

I owe my deepest gratitude to My Parents.Without their encouragement and support, I would not have a chance to complete this project.

I would like to express my sincere gratitude to my supervisor Assoc.Prof.Ir.Dr.Sharul Kamal Abdul Rahim for his guidance and support.

I owe my most sincere gratitude to Professor Peter S. Hall, for his advice, and crucial contribution, which made him a backbone of this research and so to this thesis.

Finally, I would like to express my gratitude to everybody who helped me to complete this thesis.

Omar Ahmad Mashaal

ABSTRACT

Spiral antennas gained a lot of popularity due to their circularly polarized radiation with a relatively constant input impedance and radiation pattern over wide frequency range.The conventional spiral antenna is fed from the center with the need for a balun and an impedance matching network. However, this way of feeding increases the size of the antenna and put more constraints and difficulties in the designing process. In this project a coplanar waveguide fed two-arm Archimedean spiral slot antenna loaded with a chip resistor with improved circular polarization bandwidth and reduced size is presented and investigated.The antenna is studied through simulation and fabricating a prototype to verify the simulated results.The geometry of the antenna is similar to the conventional Archimedean spiral antenna. However, the antenna is situated in one plane and fed without the need for an external balun or an impedance matching network which allows compact and completely planar structure. Moreover, the proposed antenna, possesses the advantage of wide band impedance bandwidth and circularly polarized radiation pattern, less than 3dB axial ratio, with good radiation efficiency, larger than 60%, over 1.6:1 bandwidth. Furthermore, two techniques to improve the axial ratio bandwidth, have been studied and investigated. Finally, the characteristic impedance of the antenna and the lower operating frequency can be designed to match the requirements for many systems.

ABSTRAK

Antena Spiral memperoleh banyak populariti kerana mereka sirkuler terpolarisasi radiasi dengan impedansi masukkan yang relatif konstan dan pola radiasi lebih luas rentang frekuensi. Antena uli konvensional diberi dilengkapi dari pusat dengan keperluan untuk balun dan rangkaian pencocokan impedansi. Namun, cara makan memperbesar saiz antena dan menempatkan lebih banyak kendala dan kesulitan dalam merancang proses. A coplanar waveguide dilengkapi dengan dua lengan slot antena uli Archimdean dilengkapi dengan sebuah perintang cip dengan bandwidth yang lebih baik ditunjukkan dan diteliti dalam tesis ini. Geometri antena adalah serupa dengan antena uli konvensional Archimedean. Namun, antena terletak di salah satu satah dan dilengkapi dengan tanpa perlu untuk balun luaran atau rangkaian yang sesuai yang membolehkan reka bentuk yang padat dan planar lengkap. Selain itu, antena, mempunyai kelebihan dari lebar jalur galangan band ultra lebar dan polarasi membulat pola radiasi dengan kecekapan radiasi yang baik atas 1.6:1 lebar jalur. Selanjutnya, dua teknik untuk meminimumkan nisbah paksi antena, telah dipelajari dan diselidiki. Akhirnya, ciri-ciri galangan antena dan frekuensi operasi yang lebih rendah boleh direka agar sesuai dengan keperluan untuk banyak sistem.

TABLE OF CONTENTS

CHAPTER	TITLE		PAGE
	DECLARATION		ii
	DEDICATION		iii
	ACKNOWLEDGEMENT		iv
	ABSTRACT		v
	ABSTRAK		vi
	TABLE OF CONTENTS		vii
	LIST OF TABLES		x
	LIST OF FIGURES		xi
	LIST OF ABBREVIATIONS		xiii
	LIST OF SYMBOLS		xiv
	LIST OF APPENDICES		xv
1	**INTRODUCTION**		1
	1.1	Project Background	1
	1.2	Problem Statement	2
	1.3	Objective	3
	1.4	Project Scope	3
	1.5	Dissertation outlines	3
2	**LITERATURE REVIEW**		5
	2.1	Polarization	5
		2.1.1 Linear Polarization	8
		2.1.2 Circular Polarization	9
		2.1.3 Elliptical Polarization	11
	2.2	Spiral Antennas	12
	2.3	Frequency Independent Antennas	14
	2.4	Two Arms Archimedean Spiral Antenna	14
		2.4.1 Antenna Geometry	15
		2.4.2 Operating Principle	16

	2.5	Conventional Spiral antenna Feeding Network	19
	2.6	Spiral Antenna with Planar External Feeding	21
	2.7	Three-Arm Spiral Antenna	22
	2.8	CPW-Fed Two-Arm Spiral Slot Antenna	23
	2.9	CPW-Fed Spiral Slot Antenna	24
	2.10	Summary	25
3	**METHODOLOGY**		26
	3.1	Project Methodology	26
	3.2	The Proposed Spiral Antenna	28
	3.3	Design Parameters	31
		3.3.1 Design Specifications	32
	3.4	Simulation	33
		3.4.1 Simulation Software	33
		3.4.2 Solver	34
		3.4.3 Meshing	34
	3.5	Model Construction	38
	3.6	Fabrication	39
	3.7	Antenna Measurements	40
		3.7.1 Return Loss Measurement	40
		3.7.2 Radiation Pattern Measurement	40
	3.8	Summary	41
4	**RESULTS AND DISCUSSION**		42
	4.1	Introduction	42
	4.2	Simulation Results	42
		4.2.1 Radiating Region Demonstrating	43
		4.2.2 Presence of the Circular Slot	44
		4.2.3 Gap Width Variation	46
		4.2.4 Arms Tapering	53
	4.3	Adding Chip resistor	60
	4.4	Decreasing Number of Turns	60
	4.5	Simulation and Measurements Results	62
	4.6	The Proposed antenna performance compared to other antennas	67
	4.7	Summary	68

5	**CONCLUSION AND RECOMMENDATIONS**		69
	5.1	Conclusion	69
	5.2	Recommendations for Future Work	70
REFERENCES			71
Appendix A			75

LIST OF TABLES

TABLE NO.	TITLE	PAGE
3.1	The effect of line width variation on other parameters	31
3.2	Antenna Specifications	32
4.1	Design parameters for four antenna models	46
4.2	Performance comparison between the proposed antenna and other antennas	67

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Rotation of a plane electromagnetic wave	6
2.2	Wave polarization	6
2.3	Polarization ellipse	7
2.4	Linear polarization	8
2.5	Circular Polarization	10
2.6	Helical antenna	11
2.7	Equiangular spiral slot antenna	11
2.8	Elliptical polarization	12
2.9	Structure of the Archimedean spiral antenna	15
2.10	Active region forming	17
2.11	Active region forming waveform	18
2.12	Several wideband baluns used in spiral antennas	19
2.13	Three different center-fed spiral antennas	20
2.14	Spiral antenna with planar external feeding	21
2.15	3-arm spiral antenna fed from the outer edge	22
2.16	CPW-fed two-arm spiral slot antenna structure	23
2.17	CPW-fed spiral slot antenna	24
3.1	Project Methodology Flow chart	27
3.2	The proposed antenna geometry diagram	29
3.3	Electrical length difference caused by the width of the arms	30
3.4	CST MWS user interface window	33
3.5	Antenna model with low mesh resolution	35
3.6	Adjusting mesh properties	36
3.7	Antenna model with high mesh resolution	37
3.8	Extruding geometry data of the first spiral arm	38
3.9	The constructed antenna geometry in CST	39
3.10	The Fabricated prototype	40
3.11	Agilent E5071C network analyzer	41

4.1	Surface current distribution for the proposed antenna	43
4.2	The proposed antenna without circular slot	44
4.3	The proposed antenna with presence of 2mm radius circular slot	44
4.4	The effect of the circular slot presence on simulated return loss	45
4.5	The effect of the circular slot presence on simulated axial ratio	46
4.6	Four spiral antenna models with different slots width	47
4.7	Simulated return loss over frequency for different gap widths	48
4.8	Simulated axial ratio over frequency for different gap widths	48
4.9	E and H plane pattern at three different frequencies for centred circular slot	49
4.10	E and H plane axial ratio polar plot at three different frequencies for a centred circular slot	51
4.11	Antenna Gain and directivity in the boresight direction over frequency	52
4.12	Antenna radiation efficiency in the boresight direction	53
4.13	Two different tapered antennas	54
4.14	Radiation efficiency improvement caused by arms tapering	54
4.15	Axial ratio improvement caused by arms tapering	55
4.16	Simulated directivity over frequency in the boresight direction	56
4.17	Simulated gain over frequency in the boresight direction	56
4.18	Simulated axial ratio polar plot in H and E planes at three different frequencies for two antenna models	57
4.19	Simulated directivity patterns in H and E planes at four different frequencies for two antenna models	59
4.20	Simulated axial ratios of a loaded and unloaded antennas	60
4.21	Simulated Axial ratios for two different number of turns tapered models	61
4.22	Simulated radiation efficiencies of three different models.	61
4.23	Fabricated prototype	62
4.24	Comparison between simulated and measured return loss	63
4.25	Simulated axial ratio over frequency	64
4.26	Three dimensional simulated radiation pattern	65
4.27	Comparison between simulated and measured normalized radiation pattern.	66

LIST OF ABBREVIATIONS

UWB	–	Wltra Wide Band
CP	–	Circular Polarization
balun	–	Balanced to Unbalanced
CPW	–	Coplanar Waveguide
MMIC	–	Monolithic Microwave Integrated Circuits
CST MWS	–	CST Microwave Studio
3D	–	Three-Dimensional
H-plane	–	Magnetic field plane
E-plane	–	Electric field plane
HPBW	–	Half-Power Beam-Width
RL	–	Return Loss
B.W	–	Bandwidth
AR	–	Axial Ratio
FI	–	Frequency Independent
ASA	–	Archimedean Spiral Antenna
CS	–	Circular Slot
FR-4	–	Fire Retardant-4
PCB	–	Printed Circuit Board

LIST OF SYMBOLS

dB	–	Decibel
λ	–	Wavelength
D	–	Directivity
dBi	–	Decibel isotropic
G	–	Gain
η_e	–	Radiation efficiency
Γ	–	Reflection coefficient
α	–	Spiral Growth Rate

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	APPENDIX SPIRAL GEOMETRY MATLAB CODE	75

CHAPTER 1

INTRODUCTION

1.1 Project Background

With the rapid progress in wireless technology the demand for compact, planar and wideband antennas that covers many communication services is becoming more attractive. Furthermore, many radio services, such as broadband satellite communication services, mobile systems, ground based and airborne direction finding systems, advanced electronic surveillance systems, etc. require antennas that are compact, wideband, and circularly polarized.

Spiral antennas, fall under the category of frequency independent antennas. This class of antenna is made up of antennas for which pattern, impedance and polarization remain virtually unchanged over large bandwidth [1, 2]. Spiral antennas gained a lot of popularity due to their circularly polarized radiation with a relatively constant input impedance and radiation pattern over wide frequency range [3]. Furthermore, spiral antennas have been used in many applications such as on board satellite services, radars and ultra wideband (UWB) communication. The Archimedean spiral and equiangular spiral antennas are two classical types of spiral antennas. However, most of the practical spirals are Archimedean type due to their better circular polarization (CP) properties [3].

Because of the balanced structure of the two-arm spiral antenna and the unbalanced structure of the coaxial cable, and the difference between the input impedance of the spiral antenna and the line impedance of the coaxial cable, a balanced to unbalanced (balun) circuit and an impedance transformer are added to the feeding structure of the spiral antenna [4].

Recently, coplanar waveguide (CPW)-fed slot antenna has received considerable attention owing to its preferable characteristics, easy fabrication and integration with monolithic microwave integrated circuits (MMIC), a simplified configuration with a single metallic layer [5] low radiation loss and the less dispersion in comparison to a microstrip feed.

1.2 Problem Statement

In spite of its promising performance, ”the conventional Archimedean spiral antenna feeding structure is situated in the center of the spiral and extends into the third dimension” [6] , this way of feeding bans the spiral antenna from possessing the advantage of planar structures. In addition of that, the center feeding method is incompatible with the modern compact communication devices. Also, the existence of the balun and the impedance transformer in the feeding structure increase the size and the cost of the antenna. Furthermore, they put more constraints and difficulties in designing process of the antenna.

A lot of effort was done to make the conventional Archimedean spiral antenna structure completely planar and to eliminate the need for the balun and the impedance transformer network.Feeding the spiral antenna from the outer arms was proposed [6] to get a completely planar structure.This technique gives limited circular polarization bandwidth, while the balun and the impedance transformer are still needed.However, this technique helps to develop new forms of Archimedean spiral antennas one of these forms is the CPW fed Archimedean spiral slot antenna [4, 7, 8]. The CPW fed Archimedean spiral slot antenna eliminates the need for the balun and the impedance transformer while the axial ratio bandwidth still limited or is not investigated by the authors.

1.3 Objective

The objective of this project are to design, simulate and fabricate a CPW-fed Archimedean spiral slot antenna without the need for an impedance transformer circuit, which allows a completely planar structure. Also, to optimize the performance of the antenna, by minimizing the axial ratio and improving the radiation efficiency. Furthermore, to reduce the size of the antenna. The desired specifications of the antenna are, UWB impedance bandwidth with return loss better than 10 dB (decibel), wide band circularly polarized radiation pattern with an axial ratio less than 3 dB over a 1.5:1 bandwidth.

.

1.4 Project Scope

The project scopes are as follows: First of all, literature review of related antenna parameters, Archimedean spiral antenna, and CPW- fed spiral slot antennas. Then, Design CPW-fed two arms Archimedean spiral slot antenna. After that, studying and optimizing the designed antenna through simulation by using CST2010 microwave studio. Afterwards, a prototype is going to be fabricated to verify the simulation results. Later, analyze the performance of the designed antenna

1.5 Dissertation outlines

This dissertation is organized as follows.

Chapter 1 presents the project background, problem statement objective and scope of the work.

Chapter 2 covers the literature review of the project including related antenna parameters, brief introduction to the frequency independent antennas, theory of spiral antennas and a review on planar Archimedean spiral antennas.

Chapter 3 presents project methodology, the proposed CPW spiral slot antenna structure and a brief introduction to CST MWS and simulation and measurements procedures.

The simulation and measurement results are presented compared and discussed in Chapter 4.

Chapter 5 highlights the overall conclusion of the project with future work suggestions for improving the antenna performance.

REFERENCES

1. Thaysen, J., Jakobsen, K. and Appel-Hansen, J. Characterisation and optimisation of a coplanar waveguide fed logarithmic spiral antenna. *Antennas and Propagation for Wireless Communications, 2000 IEEE-APS Conference on*. 2000. 25–28.
2. Mayes, P. Frequency-independent antennas and broad-band derivatives thereof. *Proceedings of the IEEE*, 1992. 80(1): 103 –112.
3. Volakis, C.-C. C., J. and Fujimoto., K. *Small Antennas Miniaturization Techniques and Applications*. New York: McGraw Hill. 2010.
4. Muller, D. and Sarabandi, K. Design and Analysis of a 3-Arm Spiral Antenna. *Antennas and Propagation, IEEE Transactions*, 2007. 55(2): 258–266.
5. Chen, C. and Yung, E. Dual-Band Dual-Sense Circularly-Polarized CPW-Fed Slot Antenna With Two Spiral Slots Loaded. *Antennas and Propagation, IEEE Transactions on*, 2009. 57(6): 1829–1833.
6. Gschwendtner, E., Parlebas, J. and Wiesbeck, W. Spiral Antenna with Planar External Feeding. *Microwave Conference, 1999. 29th European*. 1999, vol. 1. 135 –138.
7. Wang, C.-J. and Wu, J.-W. CPW-fed two-arm spiral slot antenna. *TENCON 2007 - 2007 IEEE Region 10 Conference*. 2007.
8. Wang, C.-J. and Hsu, D.-F. Studies of the novel CPW-fed spiral slot antenna. *Antennas and Wireless Propagation Letters, IEEE*, 2004. 3: 186–188.
9. Stutzman., W. L. *Polarization in Electromagnetic Systems*. New York: Artech House. 1993.
10. Balanis., C. A. *Antenna Theory, Analysis and Design 3rd.ed.* New York: Wiley. 2005.
11. Yi Huang, K. B. *Antennas from Theory to Practice, 3rd.ed.* New York: Wiley. 2008.
12. L.Volakis, D. *Antenna Engineering Handbook, 4th.ed.* New York: McGraw Hill. 2007.

13. Turner, E. M. *Spiral Slot Antenna*. Technical Report Note WCLR-55-8 WADC. Wright-Patterson AFB,Ohio,Tech. 1955.

14. Bawer, R. and Wolfe, J. J. The spiral antenna. *IRE International Convention Record, PI. T.* 1960. 84–95.

15. Kaiser, J. The Archimedean two-wire spiral antenna. *Antennas and Propagation, IRE Transactions on*, 1960. 8(3): 312 –323.

16. Rumsey, V. *Frequency Independent Antennas*. Academic Press. 1966.

17. Dyson., J. The equiangular spiral antenna. *IRE Trans. Antennas Propag*, 1959. 7(2): 181–187.

18. Fillpovic, D. S. *Multi-Functional Slot Spiral-Based Antenna For Airborne and Automotive Applications*. Dissertation. University of Michigan. 2002.

19. Wood, C. Curved microstrip lines as compact wideband circularly polarised antennas. *Microwaves, Optics and Acoustics, IEE Journal on*, 1979. 3(1): 5–13.

20. JR, D. Second-mode operation of the spiral antenna. *IRE Transactions on Antennas and Propagation*, 1960. 8: 637.

21. Donnellan, R., J.; Close. A spiral-grating array. *IEEE Transactions on Antennas and Propagation*, 1961. 9: 291–295.

22. Donnellan, J. A spiral-grating array. *Antennas and Propagation, IRE Transactions*, 1961. 9(3): 276–279.

23. Curtis, W. L. Spiral antennas. *IRE Trans. Antennas Propag*, 1960. AP-8(3): 298–306.

24. Yeh, Y. and Mei, K. Theory of Conical Equiangular Spiral Antennas,Part I - Numerical Techniques. *Antennas and Propagation, IEEE Transactions*, 1967. AP-15: 634–639.

25. Yeh, Y. and Mei, K. Theory of Conical Equiangular Spiral Antennas,Part II -Current distribution and input impedance. *Antennas and Propagation, IEEE Transactions*, 1968. AP-16: 14–21.

26. Penney, R., C.W.; Luebbers. Input impedance, radiation pattern, and radar cross section of spiral antennas using FDTD. *Antennas and Propagation, IEEE Transactions*, 1994. 42(9): 1328–1332.

27. Guangzheng, L. R. N. Numerical analysis of 4-arm Archimedian printed spiral antenna. *Magnetics, IEEE Transactions*, 1997. 33(2): 1512–1515.

28. R.G. Corzine, J. M. *Four-Arm Spiral Antennas*. USA: Norwood, MA: Artech

House. 1990.

29. Nakano, J., H.; Yamauchi. Characteristics of modified spiral and helical antennas. *Microwaves, Optics and Antennas, IEE Proceedings H*, 1982. 129(5): 232–237.

30. J. Wang, V. T. Design of Multioctave Spiral-Mode. Microstrip Antennas. *IEEE Transactions on Antennas and Propagation*, 1991. 39(3): 332–335.

31. Iwasaki, A. I. K., T.; Freundorfer. A unidirectional semi-circle spiral antenna for subsurface radars. *Electromagnetic Compatibility, IEEE Transactions*, 1994. 36(1): 1–6.

32. Nurnberger, M. W. and Volalasi, J. L. A unidirectional semi-circle spiral antenna for subsurface radars. *IEEE Transactions on Antennas and Propagation*, 1996. 44(1): 130–131.

33. Stutzman, G. A., Warren L.; Thiele. *Antenna Theory and Design 2nd.ed.* New York: Wiley. 1998.

34. Werntz, P. and Stutzman, W. Design, Analysis and Construction of an Archimedean Spiral Antenna and Feed Structure. *Southeastcon '89. Proceedings. Energy and Information Technologies in the Southeast., IEEE.* 1989, vol. 1. 308–313.

35. Caswell, E. D. *Design and Analysis of Star Spiral with Application to Wideband Arrays with Variable Element Sizes*. Dissertation. Virginia Polytechnic Institute and State University. 1998.

36. Thaysen, J., Jakobsen, K. B. and Appel-Hansen, J. Ultra wideband coplanar waveguide fed spiral antenna for humanitarian demining. *Microwave Conference, 2000. 30th European*. 2000.

37. Tu, W.-H., yi Li, M. and Chang, K. Broadband Microstrip-Coplanar Stripline-Fed Circularly Polarized Spiral Antenna. *Antennas and Propagation Society International Symposium 2006, IEEE.* 2006. 3669–3672.

38. Fu, W., Lopez, E., Rowe, W. and Ghorbani, K. A Planar Dual-Arm Equiangular Spiral Antenna. *Antennas and Propagation, IEEE Transactions*, 2010. 58(5): 1775–1779.

39. Gustafson, C. and Johansson, A. J. Archimedean spiral antenna for underground soil measurements in Greenland. *Antennas and Propagation (EuCAP), 2010 Proceedings of the Fourth European Conference on*. 2010. 1–5.

40. J. R. James, C. W., P. S. Hall. *Microstrip Antenna Theory and Design*. London:

Peter Peregrinus Ltd. 1981.

41. Demming-Janssen, F. and Koch, W. 3D Field simulation of sparse arrays using various solver techniques within CST MICROWAVE STUDIO . *Radar Conference, 2006. EuRAD 2006. 3rd European*. 2006. 80–83.

42. Chevalier, C., Kory, C., Wilson, J., Wintucky, E. and Dayton, J., J.A. Traveling-wave tube cold-test circuit optimization using CST MICROWAVE STUDIO. *Electron Devices, IEEE Transactions on*, 2003. 50(10): 2179–2180.

43. Hirtenfelder, F. Effective Antenna Simulations using CST MICROWAVE STUDIOA. *Antennas, 2007. INICA '07. 2nd International ITG Conference on*. 2007. 239 –239.