UNIVERSITI PUTRA MALAYSIA

DESIGN OF PHOTONIC BAND GAP APERTURE COUPLED FRACTAL SHAPE TRI-BAND ACTIVE ANTENNA

TALE SAEIDI

DESIGN OF PHOTONIC BAND GAP APERTURE COUPLED FRACTAL SHAPE TRI-BAND ACTIVE ANTENNA

By

TALE SAEIDI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

October 2014

DEDICATION

This thesis is dedicated to my parents

For their endless love, support and encouragement

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

DESIGN OF PHOTONIC BAND GAP APERTURE COUPLED FRACTAL SHAPE TRI-BAND ACTIVE ANTENNA

By

TALE SAEIDI

October 2014

Chairman: Adam Reda Hassan Alhawari, PhD
Faculty: Engineering

Microwavefrequencies have a rangeof 300MHz to 300GHz, while according toFederal Communications commission (FCC) and Industrial, Scintific, Medical (ISM) band only some specific frequencies can be used for industrial applications; for instance 0.915 GHz, 1.8 GHz and 2.45 GHz were selected. Based on these three different frequencies, an antenna can be developed to resonate at these three frequencies with high performances like high gain and being applicable for the application related to this band (ISM).

In this thesis, a new fractal shape has been used by mixing the Koch fractal shape and square loop to design more compact antenna resonating at three differentfrequencies. Then, a new Photonic Band Gap structure is exploited to either remove the undesired harmonic frequencies or pass the wanted harmonics. Besides, to suppress the surface current and fringing fields which cause the gain decrement some vias has been used. For integrating the amplifier as an active element to the antenna a matching circuit is needed, thus a n-section transmission line transformer (TLT) plays this role. After investigation of the four methods for finding the optimized value for each part of the TLT, the Genetic Algorithm (GA) showed the most advantageous result among the others.

The maximum gain is delivered to the load (antenna) when a good matching between the amplifier and the antenna achieved. The antenna has the ability to resonate at three frequencies 0.915, 1.8 and 2.45 GHz, which can cover the ISM bandand its relating applications. Moreover, the antenna has a miniaturized size compared to the previous works by almost55% and the gain of the antenna for every each resonant frequency is 20.9, 19.85 and 20.88dBirespectively. Furthermore, there is a good agreement between the simulated and measuredresults approximately.

Abstraktesis yang dikemukakankepadaSenatUniversiti Putra Malaysia sebagaimemenuhikeperluanuntukijazahMaster Sains

PERANCANGAN FOTONIK BAND GAP APERTURE COUPLED SHAPE FRACTAL TRI-BAND ANTENNA AKTIF

Oleh

TALE SAEIDI

October 2014

Pengersui: Adam Reza Hassan Alhawari, PhD

Fakulti: Kejuruteraan

Frekuensi-frekuensigelombangmikromempunyaipelbagaivarianseperti 300 MHz ke 300 GHz, manakalamengikutSuruhanjayaKomunikasi Persekutuan (FCC) dan ISM (Industri, Saintifik, Perubatan) hanyabeberapafrekuensitertentusahaja yang bolehdigunakan di dalambidangperindustrian; sebagaicontoh 0.915 GHz, 1.8 GHz dan 2.45 GHz telahdipilih. Berdasarkanperbezaan di antaraketiga-tigafrekuensiini, sebuahantenabolehdibangunkanuntukbergema / berfungsibersamadenganketiga-tigafrekuensidanmemberikeuntungan yang tinggisertabolehdigunapakaidalamkaedahini.

Dalamtesisini, bentukFraktal yang barutelahdigunakandenganmencampurkan Koch dalambentukFraktaldangelungpersegiuntukrekabentukantena yang lebihkompaksupayaiadapatbergemapadatigafrekuensi yang berbeza. Struktur Photonic Band jurang yang barutelahdibangunkansamaadauntukmenolakfrekuensi-frekuensiharmonik yang tidakdiinginiataumenerimafrekuensi-frekuensiharmonik yang dikehendaki. Selainitu, untukmenyekatpermukaansemasadanpinggiranmedan yang menyebabkanpengurangan beberapakeuntunganmelaluilubang-lubangtelahdigunakan.
Bagimengintegrasikanpenguatsebagaielemenaktifkepadaantena, litar yang sepadanadalahdiperlukan. Olehitu transformer talianpenghantaran n-Seksyen (TLT) telahmemainkanperananini. Setelahkajianterhadapempatkaedahuntukmencarinilai optimum bagisetiapbahagiandalam TLT, algoritmagenetik (GA) telahmenunjukkanhasil / kaedahTempahanterbaikdanberfaedahantara yang lain.

Selepaskesepadanansempurna di antarapenguatdanantenadicapai, keuntunganmaksimumakandihantarkepadabeban (antena). Antenamempunyaikeupayaanbergema di kekerapantigafrekuensiiaitu 0.915, 1.8 dan 2.45 GHz, yang bolehmelindungijalur ISM terutamanya di dalamsektorpertanian (pengawalanseranggaperosak). Selainitu, antenajugamempunyaisaiz yang kompakberbandingdengan model sebelumnyaiaitukurangdaripadahampir 55% dangandaankekerapanantenapadasetiap resonant adalah di antaradBi 20.9, 19.85 dan

20.88 masing-masing. Tambahan pula, terdapatsatuperjanjian yang baik di antarakeputusansimulasidandiukur.

ACKNOWLEDGEMENTS

The deepest gratitude is to ALLAH (Subhanahuwata'ala) who guided and aided me to make this work possible and to his mercy that enabled me to conduct my studies with patience.

I feel deeply indebted to my supervisor, Dr.Adam Reda Hassan Alhawari, for his patience, guidance, constant supervision, creative advising and personal involvement throughout the progression of this work. He has been, for me, not only a source of inspiration and encouragement, but also a model of ideal academic relations. Much of what I have learned during the progress of this thesis, I owe, in fact, to Dr Adam. Working under the supervision of a very great investigator of the highest academic and human caliber like Dr Adam has formed me and will continue to be an unforgettable and a unique experience of my life.I would like to express my great appreciation and gratitude to my co-supervisor Ass. Prof.Dr.Alyani Ismail for her guidance, advice and moral support.

I am grateful as well to my parents NaserSaeedi and TayebehSaeedifor encouraging me and supporting me in every possible way to continue my studies. I am really thankful to ALLAHfor having such great parents. And my gratitude also goes to my best friendand brother Rebaz Jamal Ahmad for all his understanding and patience throughout the period of study.

I am extremely grateful as well to Dr.Dhiadeen Mohammed Salih and Dr.MahirFaikIsmaile, MojtabaAhadi and Dr Ahmad Mohamadifor their help with the modeling part and their constant guidance, suggestion and valuable input to this work. In addition to that, their existence with me whenever i needed them 24/7 for the overall period of my studies and being there at my hardest times when my best friend and brother passed away is highly appreciated. A part from all what I mentioned about them, the lessons that they taught me for life and sharing their great experience's with me are that enabled me to be totally a new person and become who I am today. I am really more than proud of having them as my best friends and brothers for the rest of my life.

I would like to acknowledge the other people who have helped and encouraged me. I want to thank SerdashtSerdar, Irine Wong, MohammadRezaRanjbari, Amin Saberian, FarahnazBarahuie, Samer Adnan Ali BaniAwwad, AbdelmonaimEdrag, Sani Buba, Suleiman Moosa, Mohammed KazemChamran, Nurahmed Omar and all those whom have ever supported me or helped me throughout my studies.

Last but not least, I am deeply indebted, My thanks go to all my lectures at Universiti Putra Malaysia who taught me during my graduate study at the University. I am thankful to the Department of Electrical and Electronic Engineering, Univsersiti Putra Malaysia for offering all facilities and the academic environments that made this work possible.

I certify that a Thesis Examination Committee has met on (date of Viva) to conduct the final examination of Rebaz Jamal Ahmed on his thesis entitled “DESIGN OF HIGH GAIN TRIPLE-BAND ACTIVE ANTENNA FOR AGRICULTURE APPLICATIONS” in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Uneversiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

xxxxxx, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

xxxxxx, PhD
Senior lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal examiner)

xxxxxx, PhD
Senior lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

xxxxxx, PhD
Professor Eng.
UniversitiKebangsaan Malaysia
Malaysia
(External Examiner)

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Adam Reda Hassan Alhawari, PhD
Senior Lecturer
Department of Computer and Communication Engineering
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

AlyaniIsmail, PhD
Associate Professor
Department of Computer and Communication Engineering
Faculty of Engineering
Universiti Putra Malaysia
(Member)

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- This thesis is my original work;
- Quotations, illustrations and citations have been duly referenced;
- This thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- Intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- Written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- There is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ________________________ Date:

Name and Matric No: Tale Saeidi ,GS32772

Declaration by Members of Supervisory Committee

This is to confirm that:

- The research conducted and the writing of this thesis was under our supervision;
- Supervision responsibilities as stated in the university Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2012) are adhered to.

Signature	___________________	Signature	___________________
Nameof	Adam Reda Hasan Alhawari	Nameof	Alyani Ismail
Chairmanof	, PhD	Memberof	, PhD
Supervisory		Supervisory	
Committee:	___________________	Committee:	___________________

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figures Page

LIST OF ABBERVIATIONS

SYMBOL	DEFINITION
DDT	Dichlorodiphenyltrichlorethane
IPM	Integrated pest management
MW	Microwave
GHz	Gigahertz
mm	Mili-meter
MHz	Megahertz
ISM	Industrial, scientific and medical
FCC	Federal Communication Commission
LIMR	Low-intensity microwave radiation
TL	Transmission Line
VSWR	Voltage Standing Wave Ratio
3D	Three dimensional
2D	Two dimensional
dB	Deci-Bell
AR	Axial Ratio
BW	Bandwidth
FDTD	Finite Difference Time- Domain
Q	Quality factor
MSA	Microstrip Slot Antennas
PBG	Photonic Bandgap
DGS	Defected Ground Structure

RFID	Radio Frequency Identification
SAW	Surface Acoustic Wave
AIA	Active Integrated Antenna
MMIC	Monolithic Microwave Integrated Circuit
LNA	Low Noise Amplifier
TLT	Transmission Line Transformer
WLAN	Wireless Local-Area Network
WiMAX	Worldwide Interoperability for Microwave Access
CPW	Coplanar Waveguide
PSO	Particle Swarm Optimization
GA	Genetic Algorithm

CHAPTER 1

INTRODUCTION

1.1 Introduction

Communication can be broadly defined as the transfer of information from one point to another. A communication system is usually required when the information is to be conveyed over a distance. Over the years, sophisticated techniques have been developed for this process using electromagnetic carrier waves operating at radio frequencies as well as microwave and millimeter wave frequencies. In today's modern communication industry, antennas are the most important components required to create a communication link. Through the years, microstrip antenna structures are the most common option used to realize millimeter wave monolithic integrated circuits for microwave, radar and communication purposes. Due to many advantages over the conventional antenna, the microstrip antenna have achieved importance and generated interest to antenna designers for many years.

The microstrip patch antenna is the best selection for the researcher because of many advantages such as low cost material, lightweight and also easy to fabricate. Many researchers had improved the parameter result with to give better performance and efficiency of the patch antenna design. The parameters that can be considered to improve are return loss, gain, directivity and bandwidth [1]. In the case of decreasing the dimensions of antenna when the dimensions of antenna and the transmission lines have been enhanced due to the lower operating frequencies, there are some techniques to solve this problem and fractal shaped structure antenna is one of these solutions.

In modern wireless communication systems and increasing of other wireless applications, wider bandwidth, multiband and low profile antennas are in great demand for both commercial and military applications. This has initiated antenna research in various directions; one of them is using fractal shaped antenna elements. Fractal shape antennas have already been proved to have some unique characteristics that are linked to the geometry properties of fractal. Fractals were first defined by Benoit Mandelbrot [2,3] in 1975. Plus, fractal geometry has unique geometrical features occurring in nature. Fractals have some benefits such as fine structure with details on arbitrarily small scales, too irregular to be described by traditional geometry, having some form of self similarity, can be described in a simple way.

Nowadays, active microstrip antenna arrays and active apertures are increasingly present in phased array radar applications. In addition, these devices also serve as potentially efficient power combiners. Hence, active microstrip antennas arrays are often used in spatial or “quasi-optical” combining schemes for creating high-power and high-frequency components. Furthermore, microstrip antennas are often used in military aircraft, missiles, rockets and satellites [5]. Active antennas have received great attention because they offer many advantages such as low level of noise, low cost, and compactness. In active integrated antenna (AIA) approach, circuit and antenna units are combined into a single unit [6]. In transmitting AIAs, antenna is placed at the output port of the active unit. The impedance matching of the amplifier is done with respect to the antenna unit [7]. The active device loading technique can be applied for the gain enhancement and bandwidth improvement of the circular polarized antenna design [8].

1.2 Problem Statement and Motivation

According to Federal Communications Commission (FCC) and ISM (Industrial, Scientific and Medical) band, there are three frequency bands that can be applied tothe application related to ISM and they are 915 MHz, 1.8 GHz and 2.45 GHz.

Based on the operating frequency (0.915 GHz), the size of the antenna will be determined. But the size is large and it can resonate at one frequency only.Another problem that should be encountered with is the low gain of the microstrip antennas.To integrate an active element to the passive antenna in the case of gain enhancement, mismatching between the active element and the load (antenna) which decrease the gain and the radiation properties of the antenna should be kept in mind as well.

1.3 Research Objectives

The main aim of this thesis is to design a high gain active antenna resonating at three frequencies as follows 915 MHz, 1.8 GHz and 2.45 GHz ISM applications. The specific objectives of the current research are:

1. To develop a novel fractal shape antenna by compounding the modified second iteration of Koch fractal and square loop with the Photonic Band Gap (PBG) as an aperture part. Then, introduce anew approach of coupled feeding to easily integrate the antenna to the active element.
2. To design and analyzea transmission line transformer (TLT) using the Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Analytical method as well as aChebyshev filter method in order to achieve a perfect matching between the active element and the antenna.
3. To develop a high gain active antenna operating at three different frequencies and investigate its capability to be utilized as an insect repellent at compact size and low cost.

1.4 Research Questions

In order to carry out the mentioned objectives above, the following questions come to mind:

1. Which type of fractal is better to make a multiband antenna?
2. What kind of feeding is more matched with active antenna and can be integrated with them?
3. Which shape is better as an aperture?
4. Which type of optimizing technique is better for TLT matching circuit?
5. Which type of the amplifier can be applied to be integrated with the antenna?

1.5 Thesis Scope

The scope of the thesis is on development and improvement of the patch antenna array both linear and circular polarization, investigation of the patch antenna array parameters such as bandwidth, feeding and gain. Moreover, studyhow these parameters effect on antenna design and optimizing process to obtain the requiremnts for the target applications. The active antennas, Active Integrated Antenna (AIA), multiband antennas using CST 2013 softwarecan be involved in this area. This software has been used in abundant cases such as what presented in [9]. As a limitation, the hardware of this project must be done by using chemical and etching process which can effect on the measuring result. The frequency band which the antenna works in it can coverthe ISM band and its applications, and operates in the range of 0 to 5 GHz. While the measurement processwas conducted in a normal room environment.

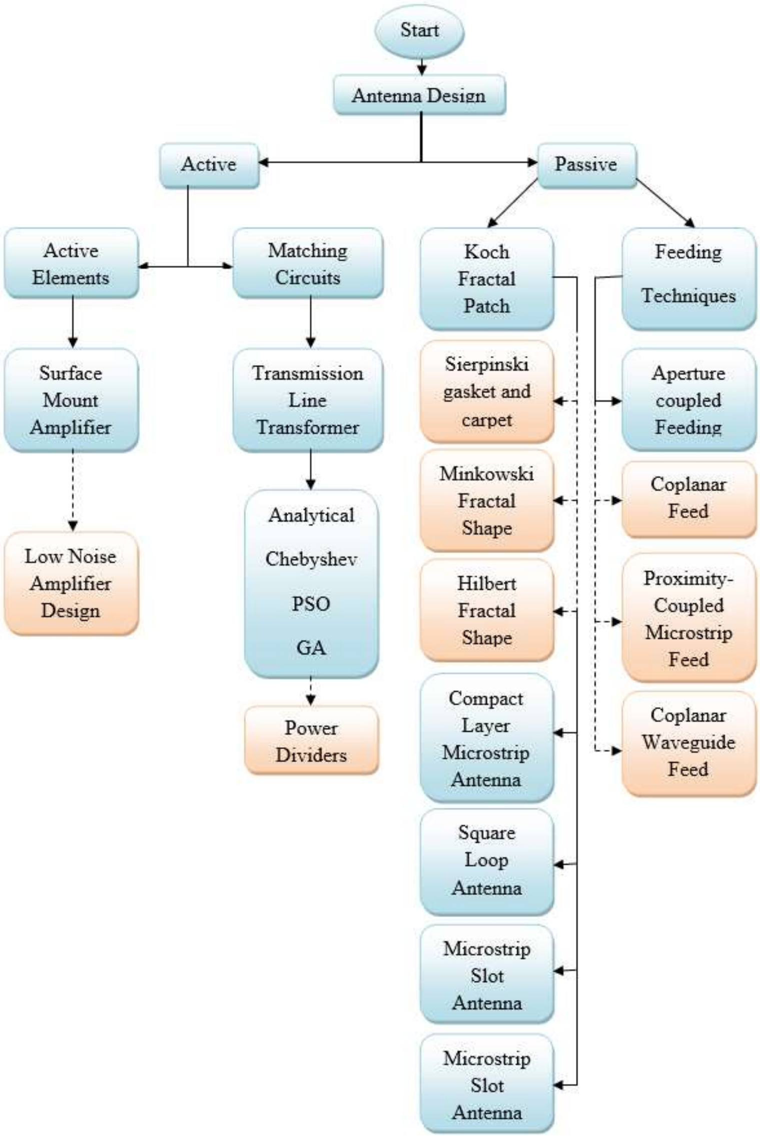

Figure 1-1 Thesis scope chart

1.6 Thesis Contributions

1. In this thesis a novel fractal shape by mixing the 2nd iteration of the Koch fractal and the square loop shape has been presented to first decrease the dimensions size of the antenna and second help the antenna to resonate at three resonant frequency. Then the new shape of the PBG structure applied as an aperture that antenna could be fed through it.
2. Furthermore, a new optimized matching technique asa transmission line transformer (TLT) have been designed and analyzed by exploiting the

analytical method, Chebyshev filter, PSO and GA which among all these techniques the Genetic Argorithm has the best and collaborated result for matching the amplifier to the antenna.

3. A high gain active antenna with compact size and low cost which has the capability of resonating at three frequencies with good performances in ISM has been designed and then presented here.

1.7 Thesis Outline

Chapter 1 begins with a review about the applicable frequency band for these problems and which type of antenna is better to solve this problem have been presented. Both the significance applications of the active microstrip antennas are given. Moreover, the objectives of this thesis are also listed. And finally, the scope and the limitations of the study have been shown. Chapter2 has been started with an overview aboutsome types of microstrip antennas, their characteristics and necessary parameters should be considered in designing, feeding techniques, Active Integrated Antennas, matching circuit process, Optimization methods and so on. The methodology of the thesis has been illustrated in chapter 3. Besides, chapter 4 demonstrates the results and discussion and finally the conclusion of this work and future work can be seen in chapter 5.

REFERENCES

[1] B. H. Ahmad, H. Nornikman, M. Z. a. Abd Aziz, M. a. Othman, and a. R. Othman, "Tri-band Minkowski Island Patch Antenna with Complementary Split Ring Resonator at the Ground Plane," *2013 Conf. Microw. Tech.*, pp. 46–51, Apr. 2013.

[2] Benoit B. Mandelbrot, "The Fractal Nature of Geometry," *New York, W. H. Freeman and Company.*, 1977.

[3] Mohamed Ismail et al, "Investigationson Novel Configurations of Triangular Fractal Microstrip Patch Antenna," NRSC conf, March 14-16 2006.

[4] Abd. Shukur, "Sierpinski Gasket Patchand Monopole Fractal Antenna," University Technology Malaysia, March 2005.

[5] N. P. Cummings, W. L. Stutzman, G. S. Brown, and W. A. Davis, "Active Antenna Bandwidth Control Using Reconfigurable Antenna Elements," Virginia Tech Antenna Group Bradley Department of Electrical & Computer Engineering Blacksburg, Virginia, 24061-0111,2003.

[6] M. I. Kontorovich and N. M. Lyapunova, "Active antennas," *Radio Eng,Electron. Phys*, vol. 19, pp. 126–127,, 1974.

[7] J. Lin, S. M. Ieee, and T. Itoh, "Active Integrated Antennas," vol. 12, no. 12, 1994.

[8] K. Chang, R. A. York, S. Member, P. S. Hall, and T. Itoh, "Active Integrated Antennas," vol. 50, no. 3, pp. 937–944, 2002.

[9] https://www.waset.org/journal/Electrical, "CST." .

[10] P. Mathur, "Miniaturization and Feeding Techniques of H-Shaped Antenna," no. 6, pp. 978–981, 2012.

[11] *Pozar - Microwave Engineering.pdf*.

[12] Http://www.antenna-theory.com/tutorial/txline/transmission4.php,"Antenna theory" .

[13] I. J. Bahl, *Lumped Elements for RF and Microwave Circuits*. London: Artech House, 2003.

[14] David M. Pozar, "Microwave Engineering," *Addison-Wesley Publ. Co.*, 1993.

[15] "Return Loss to VSWR Conversion Table," p. 95037.

[16] John D. Kraus, *antennas and wave propagation*, 4th ed.

[17] Constantine A. Balanis, *Antenna Theory*, Third Edition.

[18] S. S, “Microwave, Survey of Antenna, Design Problems Region.”

[19] C. Fung, “Basic Antenna Theory and Application,” 2011.

[20] Dean A. Frickey “Conversions Between S, Z, Y, h, ABCD, and T Parameters Which are Valid for Complex Source and Load Impedances,” *IEEE Trans. Microw. Theory Tech.,*, vol. 42, no. 2, pp. 205–211, 1994.

[21] Deschamps,G.A, “Microstrip Microwave Antennas,” 1953.

[22] J. Howell, “Microstrip Antennas,” *IEEE AP-S Int*, pp. 177–180, 1971.

[23] Http://www.intechopen.com/books/advancement-in-microstrip-antennas-with-recent-applications/axial-ratio-bandwidth-of-a-circularly-polarized-microstrip-antenna, “Microstrip Antenna.” .

[24] C. Gupta K, “Microstrip Lines and Slot Lines,” *Artech House, Norwood,MA*, 1996.

[25] P. B. Ramesh Garg, *Microstrip Antenna Design Handbook*. 2000.

[26] D. M. Pozar, “Considrations for Milimeter Wave Printed Antennas,” *IEEE Trans. Antennas Propag.*, pp. 740–747, 1983.

[27] K. . and E. . C. Carver, “Theoritical Investigation of the Microstrip Antenna,” *Phys. Sci. Lab. New Mex. State Univ. las Cruces*, 1979.

[28] Z. N. Chen, *Broadband Planar Antennas: Design and Applications*.

[29] V. Bernard, J. Paul, and I. Iloh, “Microstrip Antenna Design Using Transmission Line Model,” vol. 3, no. 11, 2013.

[30] K. Moussakhani and A. Ghorbani, “A Novel Transmission Line Model for Analyzing Bowtie Patch Antennas,” pp. 168–171, 2006.

[31] Y. H. Richards W.F., “An Improved Theory for Microstrip Antennas and Applications,” *IEEE Trans. Antennas Propag.*, pp. 38–46, 1981.

[32] Z. Hua and S. Hu, “Antennaswith Frequency Domain Controlfor Future Communication,” University of Birmingham, 2012.

[33] K. Kirschning, M, R. Jansen and N, “Accurate Model for Open-end Effect of Microstrip Line,” *Electron. Lett*, vol. 17, pp. 123–125, 1981.

[34] P. B. Ramesh Garg, *Microstrip Antenna Design Handbook*. 2000.

[35] Christophe Caloz and Tatsuo Itoh, "*Electromagnetic Metammaterials"*. Wiley, 2005.

[36] D. . Paulotto, S. Baccarelli, P. ; Frezza, F. ; Jackson, “Full-Wave Modal Dispersion Analysis and Broadside Optimization for a Class of Microstrip

CRLH Leaky-Wave Antennas," *IEEE Trans. Microw. Theory Tech.,*, pp. 2826 – 2837, 2008.

[37] S. . Mohammad, A.A. ; Subhi, H. ; Ahmad, A.K. ; Juma, "Cavity Model Analysis of Rectangular Microstrip Antenna Operating in TM03mode," *Inf. Commun. Technol. 2006. ICTTA '06. 2nd*, pp. 2218 – 2223, 2006.

[38] K. M. L. Kai Lee Fong, "Microstrip Patch Antennas," The University of Mississippi, USA, 2011.

[39] Y.J. Zhang J. F. Y. S. Hu,"Equivalent Circuit Modelof Coaxial Probes," vol. 38, no. February, pp. 281–296, 2012.

[40] M. A. Saed, "Antenna Fedbya Coplanar Waveguide," pp. 227–239, 2005.

[41] A. Kumar, J. Kaur, and R. Singh, "Performance Analysis of Different Feeding Techniques," vol. 3, no. 3, pp. 884–890, 2013.

[42] D. M. Pozar, "A Review of Aperture Coupled Microstrip Antennas : History , Operation , Development , and Applications by," no. May, 1996.

[43] M. Civerolo, "Aperture Coupled Patch Antenna Design Methods," pp. 6–9, 2011.

[44] A. Majumder, "Rectangular Microstrip Patch Antenna Using Coaxial Probe Feeding Technique to Operate in S-Band," vol. 4, no. April, pp. 1206–1210, 2013.

[45] James and P. S. H. I, *Hand book of Microstrip Antennas*. London, UK, 1989.

[46] M. Ahamed and K. Bhowmik, "Rectangular Microstrip Patch Antenna at 2GHZ on Different Dielectric Constant for Pervasive Wireless Communication," vol. 2, no. 3, pp. 417–424, 2012.

[47] M. Ahamed, K. Bhowmik, and A. Al Suman, "Analysis And Design of Rectangular Microstrip Patch Antenna On Different Resonant Frequencies For Pervasive Wireless Communication," vol. 1, no. 5, pp. 2010–2013, 2012.

[48] M. Habibullah, M. T. Islam, M. R. Ahsan, J. S. Mandeep, and N. Misran, "A Dual Band Slotted Patch Antenna on Dielectric Material Substrate," *Int. J. Antennas Propag.*, vol. 2014, pp. 1–7, 2014.

[49] B. K. Gupta and S. Mishra, "Analysisof Circular Disc Antenna Using Defective Ground Plane," pp. 2319–2321, 2014.

[50] K. P. Raju, "Circular Disk Monopole Antenna for Broadband," vol. 2, no. 6, pp. 3–6, 2012.

[51] M. Samsuzzaman, M. T. Islam, J. S. Mandeep, and N. Misran, "Printed Wide-slot Antenna Design with Bandwidth and Gain Enhancement on Low-cost Substrate.," *ScientificWorldJournal.*, vol. 2014, p. 804068, Jan. 2014.

[52] M. T. Islam, N. Misran, and J. S. M. J. J. Tiang, “Progress In Electromagnetics Research, Vol. 120, 499–512, 2011,” vol. 120, no. September, pp. 499–512, 2011.

[53] Http://www.ceng.ec.saga-u.ac.jp/mwel2012/research/msa.html,“Microstrip Slot Antenna.” .

[54] D. Photonic, B. Structure, V. Radisic, S. Member, Y. Qian, T. Itoh, and L. Fellow, “Broad-Band Power Amplifier Using,” vol. 8, no. 1, pp. 1997–1998, 1998.

[55] C. Kim, S. Member, J. Park, A. Memeber, D. Ahn, and J. Lim, “A Novel 1-D Periodic Defected Ground Structure for Planar Circuits,” vol. 10, no. 4, pp. 131–133, 2000.

[56] S. Dig, J. Haidar, A. Vilcot, M. Bouthinon, J. Boussey, B. Cabon, and A. Illiadis, “1-D Photonic Bandgap Resonator Antenna,” vol. 29, no. 5, pp. 312–315, 2001.

[57] F. Yang, Y. Rahmat-samii, and L. Angeles, “A Low-profile Circularly Polarized Curl Antenna Overan Electromagnetic,” vol. 31, no. 4, pp. 264–267, 2001.

[58] T. Kim and C. Seo, “A Novel Photonic Bandgap Structure for Low-pass Filter of Wide Stopband,” *IEEE Microw. Guid. Wave Lett.*, vol. 10, no. 1, pp. 13–15, 2000.

[59] Y. Qian et al., “A Novel Approach for Gain and Bandwidth Enhancement of Patch Antenna,” *in Proc. RAWCON’98*, pp. 221–224, 1998.

[60] M. J. Cryan and P. S. Hall, “Spectral Control of Integrated Active Antennas,” *IEE Conf. Antenna Propag.*, vol. 1, no. 436, pp. 1518–1521, 1997.

[61] M. J. Cryan, and P. S. H. G. R. Buesnel, “Harmonic Control in Active Integrated Patch Oscillators,” *Electron. Lett*, vol. 34, no. 3, pp. 228–229, 1998.

[62] Y. Qian, and T. I. V. Radisic, “Broadband Power Amplifier Integrated with Slot Antenna and Novel Harmonic Tuning Structure,” *1998 IEEE MTT-S Dig*, pp. 1895–1898., 1998.

[63] S. Deshmukh and H. Huang, “Wireless Interrogation of Passive Antenna Sensors,” *Meas. Sci. Technol.*, vol. 21, no. 3, p. 035201, Mar. 2010.

[64] H. José, M. João, and C. Peixeiro, “From Passive Microstrip Single Patch Antennas to Active Microstrip Patch Arrays,” 1949.

[65] Y. Horii and M. Tsutsumi, “Harmonic Control by Photonic Bandgap on Microstrip Patch Antenna,” *IEEE Microw. Guid. Wave Lett.*, vol. 9, no. 1, pp. 13–15, 1999.

[66] K. Swamy and M. Veluri, “Active Integrated Antenna (AIA) System for Wireless Communication,” vol. 3, no. 11, pp. 1–5, 2013.

[67] S.-H. C. Wan-Rone Liou, Mei-Ling Yeh, Chun-An Tsai, “Design and Implementation of a Low-voltage 2.4-GHz CMOS RF Receiver Front-end for Wireless Communication,” *J. Mar. Sci. Technol.*, pp. 170–175, 2005.

[68] Benoit B. Mandelbrot, “Fractal and the Geometry of the Nature.” 1975.

[69] F. Roudet and S. Tedjini, “Design of Compact Size Excitation Device for Antenna Pattern Using Fractal Architectures,” *2005 IEEE Antennas Propag. Soc. Int. Symp.*, vol. 1B, pp. 223–226.

[70] S. N. Shafie, I. Adam, and P. J. Soh, “Design and Simulation of a Modified Minkowski Fractal Antenna for Tri-Band Application,” *2010 Fourth Asia Int. Conf. Math. Model. Comput. Simul.*, no. 1, pp. 567–570, 2010.

[71] K.J. Vinoy, “Fractal Shaped Antenna Elementsfor Wideand Multi- band Wireless Applications,” The Pennsylvania State University The Graduate School College of Engineering Fractals, 2002.

[72] Hydeandrugg.wordpress.com/2013/06/22/verifier-voynich-and-accidental-complexity, “Fractal Geometry.”

[73] M. Salarrahimi, “Gain and Impedance Matching Improvement of Sierpinski Carpet Patch Antenna Using Dual Band EBG Structure,” pp. 681–684, 2011.

[74] T. Milligan, A. Editor, R. Ghatak, R. K. Mishra, and R. Poddar, “Design Formula for Sierpinski Gasket Pre-Fractal Planar-Monopole Antennas,” vol. 50, no. 3, pp. 104–107, 2008.

[75] S. H. H. Oraizi, “Wideband Monopole Fractal Antenna with Hilbert Fractal Slot Patterned Ground Plane,” *2011 41st Eur. Microw. Conf.*, pp. 242 – 245, 2010.

[76] R. Azaro, F. Viani, L. Lizzi, E. Zeni, and a. Massa, “A Monopolar Quad-Band Antenna Based on a Hilbert Self-Affine Prefractal Geometry,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 8, no. d, pp. 177–180, 2009.

[77] J. An, G. Wang, W. Zeng, and L. Ma, “Structureof Von KOCH Fractal Shape Slot,” vol. 6, pp. 61–66, 2009.

[78] J.-H. Kim, I.-K. Kim, J.-G. Yook, and H.-K. Park, “A Slow-wave Structure With Koch Fractal Slot Loops,” *Microw. Opt. Technol. Lett.*, vol. 34, no. 2, pp. 87–88, Jul. 2002.

[79] S. N. Shafie, “Design and Simulation of a Modified Minkowski Fractal Antenna for Tri-Band Application,” no. 1, pp. 2–5, 2010.

[80] W. Liu, “Design of a CPW-fed Notched Planar Monopole Antenna for Multiband Operations Using a Genetic Algorithm,” *IEE Proc.-Microw. Antennas Propag*, vol. 152, 2005.

[81] R. Khare and P. R. Nema, "Reflection Coefficient Analysis Of Chebyshev Impedance Matching Network Using Different Algorithms," vol. 1, no. 2, pp. 214–218, 2012.

[82] S. Srisathit, S. Virunphun, M. Chongcheawchamnan, A. Worapishet, and N. Pistrinct, "A Dual-Band 3-dB Three-Port Power Divider Based on a Two-Section Transmission Line Transformer," pp. 4–7, 2003.

[83] C. Tsai, C. Tsai, and S. Lee, "Nonsyncronous Alternating-Impedance Transformers," pp. 310–313, 2001.

[84] C. Monzon and S. Member, "Analytical Derivation of a Two-Section Impedance Transformer for a Frequency and Its First Harmonic," vol. 12, no. 10, pp. 381–382, 2002.

[85] C. Monzon and S. Member, "A Small Dual-Frequency Transformer in Two Sections," vol. 51, no. 4, pp. 1157–1161, 2003.

[86] L. Wu, H. Yilmaz, T. Bitzer, A. P. M. Berroth, and S. Member, "A Dual-Frequency Wilkinson Power Divider : For a Frequency and Its First Harmonic," vol. 15, no. 2, pp. 2004–2006, 2005.

[87] P. Guo, X. Wang, and Y. Han, "The Enhanced Genetic Algorithms for the Optimization Design," no. Bmei, pp. 2990–2994, 2010.

[88] C. Ming, "Novel Design Method of a Multi-section Transmission-line Transformer Using Genetic Algorithm Techniques," *Sch. Opt. Electron. Eng. Chong Qing Univ. Posts Telecommun. Chong,* pp. 3793–3796, 2006.

[89] D. M. Pozar, "Microwave Enginnering," *Addison-Wesley Publ. Co.*, 1993.

[90] S. J. Orfanidis, "A Two-Section Dual-Band Chebyshev," vol. 13, no. 9, pp. 382–384, 2003.

[91] R. Khare and P. R. Nema, "Reflection Coefficient Analysis Of Chebyshev Impedance Matching Network Using Different Algorithms," vol. 1, no. 2, pp. 214–218, 2012.

[92] E. R. Kennedy J, "Particle Swarm Optimization," *IV, Perth, Aust.*, pp. 1942–1948, 1995.

[93] D. Gies, and Y. Rahmat-samii, "Particle Swarm Optimization for Reconfigurable Phase-Differentiated Array Design," vol. 38, no. 3, pp. 168–175, 2003.

[94] M. Khodier, N. Dib, and J. Ababneh, "Design of Multi-band Multi-section Transmission Line Transformer Using Particle Swarm Optimization," pp. 293–300, 2008.

[95] Y. Dong, J. Gu, N. Li, X. Hou, and W. Yan, "Combination of Genetic Algorithm and Ant Colony Algorithm for Distribution Network Planning," August, pp. 19–22, 2007.

[96] B. Liu and P. Meng, “Hybrid Algorithm Combining Ant Colony Algorithm with Genetic Algorithm for Continuous Domain,” pp. 1819–1824, 2008.

[97] K.M. and K. W. LeungLuk, “Dielectric Resonator Antennas,” *Res. Stud. Press. Hert- fordshire, UK*, 2003.

[98] Y. X. Sun, K. W. Leung, and A. D. D. C. Dra, “Dual-Band and Wideband Dual-Polarized Cylindrical Dielectric Resonator Antennas,” vol. 12, pp. 384–387, 2013.

[99] M. F. Ain, Y. M. Qasaymeh, Z. A. Ahmad, M. A. Zakariya, and U. Ullah, “An Equivalent Circuit of Microstrip Slot Coupled Rectangular Dielectric Resonator Antenna,” pp. 1837–1840, 2012.

[100] R. Waterhouse, “Printed Antennas for Wireless Communications,” *John Wiley Sons Inc*, 2007.

[101] S. Raje, S. Kazemi, and H. R. Hassani, “Wideband Stacked Koch Fractal Antenna With H-Shape Aperture Coupled Feed,” *2007 Asia-Pacific Microw. Conf.*, pp. 1–4, Dec. 2007.

[102] R. S. Aziz, M. A. S. Alkanhal, and A. F. A. Sheta, “Triple Band Fractal-Like Antennas,” pp. 886–889, 2011.

[103] http://chemandy.com/calculators/microstrip-transmission-line-calculator-hartley27.htm, “Transmission line.” .

[104] “CST Microwave Studio.” 2013.

[105] T.Peter, M.K.A. Rahim, J.Din, T.Masri, “Active Integrated Antennawith Low Noise Amplifier Designat 5 GHz,” vol. 5780, pp. 5–10.

[106] B. Compound and E. Cyanoacrylate, “Technical Data Sheet Super Glue Part"no. 49403.

[107] C. A. Balanis, *Antenna Theory Analysis and Design*, 2 ed. New York: Wiley, 1997.

[108] R. E. Collin, "*Foundations for Microwave Engineering"*, 2 ed. New York: McGraw-Hill, 1996.

[109] M. L. Filters, N. C. Karmakar, S. Member, and M. N. Mollah, “Investigations Into Nonuniform Photonic-Bandgap,” vol. 51, no. 2, pp. 564–572, 2003.

[110] Roberto Coccioli, “Aperture-Coupled Patch Antenna,” *IEEE Trans. Microw. Theory Tech.*, vol. 47, no. 11, pp. 2123–2130, 1999.

[111] D. M. POZAR, “Microstrip Antenna Aperture-Coupledtoa Microstrip line Fault Detectionand Identificationfor Reliable Large-Scale Computing,” *Electron. Lett.*, vol. 21, pp. 49–50, 1985.

[112] S. Mount, “Monolithic Amplifier.”, 'www. minicircuit. com'

[113] C. Ming, “Novel Design Method of a Multi-section Transmission-line Transformer Using Genetic Algorithm Techniques,” pp. 3793–3796.

[114] D. Coupler, “Antenna Measurements,” pp. 120–129.