DEVELOPMENT OF MULTIBAND FRACTAL PLANAR INVERTED F ANTENNA (F-PIFA) FOR MOBILE APPLICATIONS

by

SAIDATUL NORLYANA BINTI AZEMI
(0730810155)

A thesis submitted
In fulfillment of the requirements for the degree of
Master of Science (Communication Engineering)

School of Computer and Communication Engineering
UNIVERSITI MALAYSIA PERLIS

2009

UNIVERSITI MALAYSIA PERLIS

DECLARATION OF THESIS

Author's full name	:	SAIDATUL NORLYANA BINTI AZEMI
Date of birth	:	5th OCTOBER 1984
Title	:	DEVELOPMENT OF MULTIBAND FRACTAL PLANAR INVERTED F ANTENNA (F-PIFA) FOR MOBILE APPLICATIONS
Academic Session	:	2008 / 2009

I hereby declare that the thesis becomes the property of Universiti Malaysia Perlis (UniMAP) and to be placed at the library of UniMAP. This thesis is classified as :

[ ]	**CONFIDENTIAL**	(Contains confidential information under the Official Secret Act 1972)*
[ ]	**RESTICTED**	(Contains restricted information as specified by the organization where research was done)*
[X]	**OPEN ACCESS**	I agree that my thesis is to be made immediately available as hard copy or on-line open access (full text)

I, the author, give permission to the UniMAP to reproduce this thesis in whole or in part for the purpose of research or academic exchange only (except during a period of _____ years, if so requested above).

Certified by:

SIGNATURE	**SIGNATURE OF SUPERVISOR**
841005 - 14 - 5214	ASSOC. PROFESSOR DR. R BADLISHAH BIN AHMAD
(NEW IC NO. / PASSPORT NO.)	**NAME OF SUPERVISOR**
Date :_______________	Date : _______________

NOTES : * If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentially or restriction.

ACKNOWLEDGMENTS

I am indebted and grateful to many people, who have helped me during the course of this research project in one way or another. In particular I would like to acknowledge and express my deepest gratitude to my supervisor, Assoc. Professor Dr. R Badlishah to whom I am greatly indebted, for giving me the opportunity to undertake the research in UniMAP, for his supervision and for his encouragement throughout the course of the research.

I also would like to express my deep and sincere thanks to my co-supervisors, Mr Azremi Abdullah Al-Hadi and Mr Soh Ping Jack for their guidance, support and encouragement. Their door has always been opened and I could always talk to them no matter how busy they were. I can only feel flattered for the confidence that always show in me. Fortunately, I have benefited from his extraordinary motivation, great intuition and technical insight.

A special gratitude to Dr Fareq Malek for many useful discussion and suggestions during the course of my research, Mr Por Chee Seong and the rest of the RnD Department staff at Amphenol, for their precious contribution and guidance during my attachment, in manufacturing the prototype antenna and for their assistance during my measurement.

Last but not least I would like to thank my only sister Saidatul Norazihan Azemi and my parents for their patience, understanding, love and constant encouragement. Finally, I would like to thank everyone that has been involved in this project directly or indirectly for their help and contribution. Thank you very much!

TABLE OF CONTENTS

		Page
APPROVAL AND DECLARATION SHEET		ii
ACKNOWLEDGMENT		iii
TABLE OF CONTENTS		iv-vi
LIST OF TABLES		vii
LIST OF FIGURES		viii-xi
LIST OF SYMBOLS		xii-xiv
LIST OF ABBREVIATIONS		xv-xvi
ABSTRAK (BAHASA MELAYU)		xvii
ABSTRACT (ENGLISH)		xviii
CHAPTER 1 INTRODUCTION		
1.1	Overview	1-3
1.2	Problem Statement	3
1.3	Research Objective	3-4
1.4	Research Scope	4
1.5	Thesis Outline	5
CHAPTER 2 LITERATURE REVIEW		
2.1	Antenna Fundamentals	6
2.2	Antennas for Mobile Phone	7-8
	2.2.1 Whip Antenna	8-9
	2.2.2 Helical Antenna	9-10

2.2.3 Folded J Antenna 10-11

2.2.4 Planar Inverted F (PIFA) 11-16

2.2.4.1 Previous work on PIFA 16-21

2.3. The Fractal Theory 21-27

2.3.1 Iterated Function System 27-32

2.3.2 Characteristic of Fractal Antenna 32

2.3.3 Previous work on Fractal Antenna 33-36

2.4 Specific Absorption Rate (SAR) 36-38

2.5 Summary 38-39

CHAPTER 3 METHODOLOGY

3.1 Introduction 40-41

3.2 F-PIFA Development Procedure 42

3.3.1 Square Patch PIFA 42-45

3.3.2 Patch PIFA Fractal's Design 45-49

3.3.3 F-PIFA Feeding Structure 50-52

3.3.4 F-PIFA Ground Plane 53-54

3.3.5 F-PIFA Shorting Plate 55-56

3.3.6 F-PIFA Substrate 56-61

3.3 F-PIFA Dimension 61-62

3.4 Fabrication Process 62

3.4.1 Film Processing 63

3.4.2 UV Expose 63-64

3.4.3 Etching 64

3.4.4 Cutting and Drilling 65

3.5 Measurement Process 66-71

3.6 Summary 72

CHAPTER 4 RESULT AND DISCUSSION

4.1	Introduction	73
4.2	The Antenna S_{11} Result	73-78
4.3	Far Field Patterns	78-79
	4.3.1 Simulated Radiation Pattern	79-81
	4.3.2 Measured Radiation Patterns in Free Space	82-84
	4.3.3 Measured Radiation Patterns in Anechoic Chamber	84-86
4.4	Gain and Efficiency	87-92
4.5	Current Distribution	93-97
4.6	PIFA as internal antenna for mobile phone	97-109
4.7	Human Absorption of Radiation	109-112
4.8	Antenna Comparison	113-116
4.9	Summary	117

CHAPTER 5 SUMMARY AND FUTURE WORK

5.1	Conclusion	118-119
5.2	Contributions	119
5.3	Future Work	120

REFERENCES 121-128

Appendix A

Antennas Measurement Setup 129-140

Appendix B

Workflow using CST Microwave Studio 141-146

Appendix C

Antenna Publications and Accomplishment 147-151

LIST OF TABLES

Table		Page
1.1	Frequency Bands for a Few Wireless Applications	2
2.1	Advantages and Disadvantage of Fractal Antenna	32
3.1	Calculation of Fractal Design for Each Iteration of F-PIFA	47
3.2	Result summary on different feed locations	51
3.3	F-PIFA's bandwidth of with varying ground plane sizes	54
3.4	Bandwidth's Result of the Folded and Unfolded F – PIFA	60
4.1	Bandwidth for Measured of F – PIFA	78
4.2	Total Length of Current Paths for each Resonant Frequency	96
4.3	Measured Efficiency with and without Phone Model	100
4.4	Measured Gain with and without Phone Model	101
4.5	Summary of the Simulated and Measured Radiation Pattern Result of E-Plane F-PIFA	108
4.6	Summary of the Simulated and Measured Radiation Pattern Result of F-PIFA's H-Plane	109
4.7	Material Parameters of the SAM phantom	110
4.8	SAR Result at Different Operating Frequency	112
4.9	Bandwidth result of the F - PIFA, PIFA 1 and PIFA 2	114
4.10	Antenna Comparison between F-PIFA and Antennas that Available in Market	116

LIST OF FIGURES

Figure		Page
2.1	Mobile phone size variation until present	8
2.2	Illustration of whip Antenna	10
2.3	Typical helical Antenna that commonly use in cellular communication device	10
2.4	(a) Folded J Antenna during process prototyping, (b) Folded J antenna ready to manufacture	11
2.5	Planar Inverted-F Antenna from view side	13
2.6	Development of PIFA from monopole, planar monopole, and microstrip antenna	13
2.7	The internal antenna is installed on the back side of mobile phone	14
2.8	3D view on geometry of the quad band antenna	17
2.9	Geometry and dimension of the proposed low-profile planar monopole antenna for GSM, DCS, PCS, UMTS operation Construction algorithm for the Triangular PIFA antenna	18
2.10	The Frequency Selective Surface FSS – Strips Multiband PIFA antenna design and (b) the mounted on extra ground plane (right)	19
2.11	The Geometry of the proposed wideband PIFA antenna	20
2.12	Fractal used to symbolize in nature, its exhibit self similarity	22
2.13	Iterative generation process of fractal	22
2.14	Dipole antenna and qualities bandwidth	25
2.15	Biconical Antenna	25
2.16	Benoit Mandelbrot process	27
2.17	Gaston Julia sets for different values ċ	28
2.18	Benoit Mandelbrot set	28
2.19	An illustration iteration of Sierpinski Gasket	29
2.20	Block diagram of the Iterated Function System (IFS)	30
2.21	Dimension for Fractal PIFA. (a) 0 Iteration (b) 1st Iteration (c) 2nd Iteration (d) 3rd Iteration.	31

2.22	Geometry of the tree shaped antenna	33
2.23	The proposed Sierpinski fractal antenna for broadband operation	34
2.24	Development of a multiband Conical Monopole Antenna derived from a Sierpinski Gasket	36
2.25	Illustration of human's head absorption of radiation	37
3.1	Research methodology flow chart	41
3.2	Initial design of the proposed PIFA	43
3.3	First iteration of Fractal PIFA	48
3.4	Second iteration of Fractal PIFA	49
3.5	Third iteration of Fractal PIFA	49
3.6	F-PIFA simulated return loss against frequency with different feed point locations	51
3.7	F-PIFA simulated of return loss against frequency with a variation of ground plane sizes: 25 x 50 mm, 27 x 60 mm and 29 x 70 mm	53
3.8	Simulated return loss against frequency for F-PIFA with various parameter of shorting plate, (*ws*). a) S_{11} result for F-PIFA with and without shorting pins. b) Simulated return loss of F-PIFA with shorting pin's width variation	56
3.9	Simulated of return loss against frequency of F-PIFA with different value of dielectric constant, ε_r	57
3.10	Simulated of return loss against frequency of F-PIFA with a different height (*h*), 4 mm, 6 mm, 8 mm and 10 mm	58
3.11	Configuration and S_{11} of F-PIFA a) Configuration of F-PIFA with parasitic element, b) Return loss against frequency of F-PIFA with and without parasitic plane.	59
3.12	Design and configuration of F-PIFA with, a) variation on *a*, b) Return loss against F-PIFA with different folded size and height	60
3.13	Fractal PIFA from front and side view	62
3.14	Flowchart of the fabrication process	62

3.15	Fractal pattern design printed on a transparency	63
3.16	Photo of exposure machine	64
3.17	Developer solution machine	64
3.18	Etching machine	65
3.19	Photoresist stripper tank	65
3.20	Simulated and fabricated of Fractal PIFA	66
3.21	Antenna propagation measurement setup for return loss measurement	67
3.22	Radiation pattern measurement setup	69
3.23	Antenna illustration arrangement for radiation pattern measurement	69
3.24	STARGATE 64 Anechoic Chamber	70
4.1	Simulated and measured return loss against frequency of the designed antennas for different iterations	74-76
4.2	Simulated 3-D radiation pattern for the F - PIFA at (a) 2GHz – 0 iteration (b) 2GHz – 1st Iteration (c) 2GHz – 2nd Iteration (d) 5GHz – 2nd Iteration	80-81
4.3	Simulated and measured F - PIFA taken in open space laboratory	82-84
4.4	Simulated and measured 2-D radiation pattern for E-Plane and H-Plane using STARGATE 64 Anechoic Chamber SG-64	85-86
4.5	Simulated and measured Gain for F-PIFA at (a) 2GHz – 0 iteration (b)2GHz – 1st Iteration (c) 2GHz – 2nd Iteration (d) 5GHz – 2nd Iteration.	88-89
4.6	Simulated and measured efficiency for the F-PIFA at (a) 2GHz – 0 iteration (b) 2GHz – 1st Iteration (c) 2GHz – 2nd Iteration (d) 5GHz – 2nd Iteration.	91-92
4.7	Simulated current distributions for the F-PIFA, (a) Current Flow at 0 iteration, (b) Current Flow at 1st iteration, (c) Current Flow at 2nd iteration (2GHz), (d) Current Flow at 2nd iteration (5GHz	94-95
4.8	Simulated surface current distributions on the radiating elements	96

	for 2nd iteration F - PIFA at: (a) 2000 MHz, (b) 5000 MHz	
4.9	F - PIFA mounted on a candy bar phone	98
4.10	(a) Actual PCB size for a candy bar phone, (b) the antenna feed and ground plane location	98
4.11	Full phone model a) Front view, b) Rear view	98
4.12	F - PIFA S_{11} result with and without phone model	100
4.13	Position of the antenna during measurement in anechoic chamber	103
4.14	Simulated and measured 2D and 3D Radiation pattern of F - PIFA. a) 3D radiation pattern without phantom head, b) 3D radiation pattern with phantom head	104-108
4.15	Simulated SAR with SAM Phantom Head using CST simulation tools	112
4.16	Geometry and dimension of Sierpinski Carpet antenna, F-PIFA, PIFA-1 and PIFA-2 along with a simulated return loss result for these four antennas	115

LIST OF SYMBOLS

ε	electric permittivity (farads/meter)
μ	magnetic permeability (henrys/meter)
η_{total}	Total efficiency
σ	electric conductivity (Siemens/meter)
σ^*	magnetic resistivity (ohms/meter)
μ	the magnetic permeability
δ	Loss tangent of dielectric material
ε_r	Relative Permittivity
ε_{eff}	Effective Relative Permittivity
χ	wavelength
ρ	density of body tissues [kg/m3]
Γ	reflection coefficient
A_n	The scale factor
B	The magnetic flux density
BW	Bandwidth
C	maximum transmit data rate,
c	Velocity of light waves in free space
D	The electric flux density,
D	Directivity
E	The electric field intensity,
f	Frequency

fU	Upper frequency
fL	Lower frequency
fC	Center frequency
G	Gain
Gt	Antenna receiver gain
Gs	Antenna transmitter gain
h	The height of the radiating plate
H	The magnetic field intensity,
H(ω)	Frequency response
h(τ)	Impulse response
I	Terminal current
J	The electric current density
L	The geometric shape of the radiating plat (length)
L1	Patch Width
L2	Patch Length
L_g,	The size and shape of the ground plane (length)
L_n	The scale factor for length of a side of white boxes
M	The magnetic conductive current density
N_n	Number of black boxes
Pt	Received power on antenna receiver
Ps	Received power on antenna transmitter
P_{rad}	Total radiated power
Rin	The location and structure of the feeding stem

$R_{radiated}$	Radiation resistance
R_L	Loss resistance
U	Radiation intensity
V	Voltage
V_0	Source region of the antenna
V_∞	Big region which enclose the antenna
W	The geometric shape of the radiating plat (width)
W_g	The size and shape of the ground plane (width)
$\bar{W}e$	stored electric energy
$\bar{W}m$	stored magnetic energy
Wm	total average energy the region $V_0 - V_\infty$
We	electric energy stored the region $V_0 - V_\infty$
ws	Shorting Plate width
Z_0	characteristic impedance
Z_L	arbitrary load

LIST OF ABBREVIATIONS

3G	Third generations
ABS	Acrylonitrile Butadiene Styrene
ADS	Advanced Design System
AMPS	Advanced Mobile Phone System
AUT	Antenna Under Test
CDMA	Code Division Multiple Access
DCS	Digital Communication System
DECT	Digital Enhanced Cordless Telecommunications
EM	Electromagnetic
F-PIFA	Fractal Planar Inverted F Antenna
FCC	Federal Communications Commission
FE	Finite Element
FDTD	Finite-Difference Time-Domain
FIT	Finite Integration Technique
FNBW	First Null Beamwidth
FDMA	Frequency Division Multiple Access
FR-4	Flame Retardant 4
FSS	Frequency Selective Surface
GSM	Global System for Mobile Communications
GPRS	General Packet Radio Service
HiperLAN	High Performance Radio LAN
HPBW	Half Power Bandwidth

IFFT	Inverse Fast Fourier Transform
IFS	Iterated Function System
MoM	Method of Moments
PCS	Personal Communications System
PIFA	Planar Inverted F Antenna
RF `	Radio Frequency
PCB	Printed Circuit Board
PNA	Portable Network Analyzer
RL	Return Loss
SAM	Specific Anthropomorphic Mannequin
SAR	Specific Absorption Rate
SMS	Short Message Service
SMA connector	Sub Miniature version A connector
SNR	SIGNAL TO NOISE RATIO
TDMA	Time Division Multiple Access
UMTS	Universal Mobile Telecommunications System
UWB	Ultra Wideband
VSWR	Voltage Standing Wave Ratio
WLAN	Wireless Local Area Network

Pembangunan dan Analisis Antena Satah Fractal Songsang F (F-PIFA) Pelbagai Jalur untuk Aplikasi Mudah Alih

ABSTRAK

Beberapa tahun kebelakangan ini, permintaan terhadap pegabungan frekuensi jalur bebas di dalam satu peralatan telah meningkatkan daya usaha untuk membangunkan antena baru. Dengan adanya kemajuan terhadap teknologi antena, ia telah menjadi tarikan untuk meningkatkan keupayaan antena di dalam pelbagai cabang aplikasi seperti komunikasi mudah alih dan jalur bebas. Permintaan terhadap kebiasaan antena adalah seperti, bersaiz kecil, tidak rumit, tahan lasak, terlindung dari radiasi, mempunyai kepelbagaian sistem dan berjalur lebar. Ini adalah kerana, sekarang ini, terdapat lebih dari lima isyarat gelombang yang ditetapkan untuk aplikasi komunikasi mudah alih. Oleh itu, "Fractal Planar Inverted F Antenna" (F-PIFA) telah dihasilkan serta dianalisa. Kajian yang dijalankan ini adalah bertujuan membangunkan antena dengan kos yang rendah, bersaiz kecil, mempunyai keupayaan yang tinggi, dan mampu beroperasi dalam pelbagai jalur frekuensi. Proses penghasilan antenna F-PIFA bermula dengan penetapan spesifikasi antena, pemilihan bahan dan disimulasi menggunakan perisian CST. Dalam kajian ini, penghasilan produk terbahagi kepada tiga peringkat. Peringkat pertama adalah menghasilkan tiga jenis antena lanjutan dan mentafsir keupayaannya. Peringkat kedua adalah proses fabrikasi dan mengukur antena untuk diaplikasikan untuk perkakasan WLAN dan alat komunikasi. Akhir sekali, adalah untuk menganalisa dan menyelidik antena tersebut untuk penambah baikan antena tersebut dimasa hadapan. Kajian ini telah berjaya menghasilkan antena yang kecil molek, dapat beroperasi dengan baiknya tanpa penyusutan nilai gandaan serta jalur lebar, dimana ini adalah keunikan F-PIFA. Antena ini bersaiz 27 x 27 mm telah dihasilkan dan dioptimumkan untuk menerima isyarat rangkaian frekuensi GSM (Global System for Mobile Communication), UMTS (Universal Mobile Telecommunication System) dan HiperLAN (HigH Performance Radio LAN dengan setiap jalur lebar frekuensi adalah dari 850-960 MHz, 1900 MHz - 2100 MHz, 1885 - 2200 MHz untuk rangakaian 3G dan 4800MHz - 5800MHz untuk rangkaian HiperLAN. Antena yang telah dihasilkan ini menghasilkan corak radiasi berbentuk bulatan dengan nilai kuasa gandaannya adalah 3.57 dB dan dapat beroperasi dengan kecekapan sebanyak 65 – 90% serta meghasilkan nilai SAR kurang dari 2W/kg.

Development and Analysis of Multiband Fractal Planar Inverted F Antenna (F-PIFA) for Mobile Applications

ABSTRACT

In the past few years, demand in unification of wireless hardware has propelled new development of antenna. With the advances on antenna technology, it becomes attractive to enhance the capabilities of antenna in many areas such as mobile communication and wireless application. The requirements of ubiquitous antenna are small in size, simple, robust, have a shielding mechanism, multisystem and wide bandwidth. The reason is, currently, there are five bands that are assigned for world mobile services. Due to the aforementioned issues, a novel Fractal planar inverted F antenna (F-PIFA) based on the self affinity design is presented in this research. This research is conducted in order to develop an antenna with low cost, small in size, high performance, and capable to operate at multiple frequency bands. The F-PIFA development processes include specification definition, selection of the dielectric material and construction of prototype using CST software tools. In conducting this research, the production of prototypes is divided into three stages. The first stage is to develop three different iteration of F-PIFA and to evaluate its performance. The second stage is to fabricate, measure the antenna performance as well as the SAR value. Finally, the design is investigated and improved for future works. This research has successfully produced an antenna with good efficiency without degrading bandwidth and gain of the F-PIFA. The antenna has a total dimension of 27mm x 27mm is designed and optimized in order to receive GSM (Global System for Mobile Communication) and UMTS (Universal Mobile Telecommunication System) and HiperLAN (HigH Performance Radio LAN) with the frequency range from 850-960 MHz, 1900 MHz to 2100 MHz, 1885 to 2200 MHz for 3G and 4800 MHz to 5800 MHz for HiperLAN respectively. This omni-directional antenna invented here have 65-90% efficiency with peak gain value that is 3.57 dB, and be able to produce less than 2W/kg SAR value.

CHAPTER 1

INTRODUCTION

1.1 Overview

The rapid development of wireless communication systems is bringing a wave of new wireless devices and system to meet the demand of mobile phone. The creation of mobile phone has drastically changed the lifestyle of people through the widespread use of wireless personal terminals for both voice and data services. In the past ten years, mobile phone usage has increased up to 7.6 millions. Almost 84% of the 26 million people in Malaysia had a mobile telephone by March 2007 and had the second highest mobile penetration in South East Asia after Singapore (SAT Magazine, 2004).

In early years, the first generation mobile phone which is call as Advanced Mobile Phone System (AMPS) is designed to operate in the 800MHz frequency range. AMPS used analog technology with Frequency Division Multiple Access (FMDA) and carries voice only and it is lacked of security and capacity. In addressing these deficiencies, the second generation of mobile phone is introduced in early 90's and it is called the Personal Communications System (PCS). PCS is based on digital technology with Time Division Multiple Access (TDMA) or Code Division Multiple Access (CDMA). PCS operates within 1800 – 1900MHz frequency range and able to carry voice and low rate data.

The economics of manufacture makes it very desirable to produce mobile phone that cover several of the increasing number of world frequency bands. For high end products, both economics and user expectations require them to cover as many bands as possible. Currently at least five bands are assigned for world wide mobile services (850, 900, 1800, 1900 and 2100 MHz). In addition, it is very important that antenna's gain and efficiency are as high as possible whenever transmitting data using high order modulation schemes. Table 1.1 lists a few useful transmission technologies and their operating frequencies.

Table 1.1: Frequency Bands for a Few Wireless Applications.

Transmission Technology	**Frequency Bands (MHz)**	**Bandwidth (MHz)**
GSM-900	*890-960*	*70(7.6%)*
GSM-1800	*1710-1880*	*170(10.6%)*
3G-(UMTS2000)	*1885-2200*	*315(17.5%)*
(WLAN)	*2400-2483*	*83(3.4%)*
Bluetooth	*2400-2500*	*100(4.1%)*

Due to the affirmation issues, the demands placed on mobile communications antenna have increased remarkably. However, the antenna for mobile phone devices has been the largest component in addition to the battery and display. Thus, antenna designers face many demands and challenges such as low or ultra low profile feature, wide or ultra wide operating bandwidth, multiple functions, pure polarization, low cost, less radiation, small or tiny size, and many more. Primarily, antennas need to be high gain, small physical size, broad bandwidth, versatility and embedded installation. In particular, the bandwidth for impedance, polarization or axial ratio, radiation pattern and gain are becoming the most important factors that determine the usability of antennas in contemporary and future wireless communications systems. In order to achieve a multiple band frequencies, a fractal planar inverted F antenna is proposed.

1.2 Problem Statement

The problem statements of this research are:

1. Developing a small-size and light in weight antenna with minimal effect on performance.
2. Developing a simple antenna thus it can be easy to manufacture but robust in strength.
3. Ensure the antenna radiates away from user body and meets a safety specification which is SAR.
4. Developing an antenna for many applications since many different wireless standards are available for mobile communication; therefore it requires an antenna can work for different frequency bands.

1.3 Research objective

The objectives of this research are:

1. To develop and fabricate an efficient, low profile and realizable antenna that is capable to operate at GSM frequency band (900 MHz, 1800 MHz, 1900 MHz and

2000 MHz), adding in the capability of the third generation (3G), Wireless LAN, and HiperLAN frequency band, and

2. To measure and evaluate the antenna performances in term of return loss, bandwidth, radiation pattern, gain, efficiency as well as SAR.

1.4 Research Scope

This research is intended to develop and analyze a multiband Fractal Planar Inverted F Antenna (F-PIFA) that is capable to cover third generation (3G), Wireless LAN, HiperLAN and GSM frequency band (900MHz, 1800 MHz, 1900 MHz and 2000 MHz) in a single device. The antenna development and analysis includes 0 iteration, 1^{st} iteration, 2^{nd} iteration and 3^{rd} iteration of the F-PIFA using CST MWS simulation software. This simulation tool is used to evaluate the operation of the antenna at the prescribed frequencies in terms of input impedance, radiation patterns of the electric field (E - field) and magnetic field (H - field) and return loss values for the S11 parameters. The final stage is to measure and analyze the integrated F-PIFA in a mobile communication device as internal antenna and evaluates the gain, efficiency, field pattern and SAR,

1.5 Thesis Organization

In this dissertation, several topics are covered and they are organized into five chapters. This first chapter, the introduction to the project, gives an explanation of the objective, problem statement and scope of project. Chapter 2 begins with the description of

Antennas for Mobile Communication. This is followed by discussion of relevant theory and literature review on the PIFA and fractal antenna. Chapter 3 presents the antenna design procedure and the fabrication of the designed antennas. This chapter discusses the development of Fractal Planar Inverted F Antenna (F-PIFA). Chapter 4 presents some results and analysis that obtained from simulation and measurement. Chapter 5 presents the conclusions for this thesis. Some ideas for future works of this project are suggested.

CHAPTER 2

LITERATURE REVIEW

1.6 Antenna Fundamentals

The word antenna is derived from Latin word *antenna* which is in Greek means *stretched.* According to Schantz, 2003, an antenna is defined as a transducer that converts guided electromagnetic energy in a transmission line into radiated electromagnetic energy in free space. In the other words, antennas convert electromagnetic waves into electrical currents and vice versa. According to Balanis (2005), antenna types can be classified as wire, aperture, microstrip, array and reflector types. Antennas are used in systems such as mobile phone, radio and television broadcasting, point-to-point radio communication, wireless LAN, radar, and space exploration. Antennas usually work in air or outer space, but can also be operated under water or even through soil and rock at certain frequencies for short distances. In the last few years, the demand of multiband and compact antenna has been rising due to the rapid advancement in wireless communication. As a result, intensive researches are toward Planar Inverted F Antenna (PIFA) and fractal theory due to the need to invent compact and multiband novel antenna for cellular communication. A brief discussion on theoretical of PIFA and Fractal theory is presented in the following sections.