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

by

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TABLE OF CONTENTS

CHAPTER 3 METHODOLOGY

CHAPTER 4 RESULT AND DISCUSSION

CHAPTER 5 SUMMARY AND FUTURE WORK

LIST OF TABLES

LIST OF FIGURES

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, 1st iteration, 2nd iteration and 3rd 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.