FREQUENCY AGILE ANTENNA INTEGRATED WITH BAND PASS FILTER

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To my beloved parents Mohamad Dahlan Omar and Norlida Nordin,
my lovely wife and daughter
and finally my cherished siblings.

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In the Name of ALLAH The Most Benevolent, The Most Merciful

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ABSTRACT

In the era of wireless communication, new problem arises when user's attention increases together with new development of wireless applications. The limited frequency spectrum, which allows only one application to operate at the same time and frequency, has created resource issue for the wireless communication industry. Hence, new frequency agile technologies such as Software Define Radio and Cognitive Radio systems are being developed. One of the requirements of this type of application is an antenna system that is able to change its operating frequency as instructed by the back end system. This research explores the possibility of integrating band pass filters to manipulate the operating frequency of a broadband antenna. RF diode, inductors and capacitors are used as switching mechanism to actively change the operating frequency. Based on the spectrum allocation in Malaysia, frequency range from 1GHz to 6GHz was chosen due to the allocation of many types of communication applications such as mobile applications, unlicensed band and satellite communication. A proof of concept was done for active switching at 1.3GHz and 2GHz of the antenna prototype. Another structure was fabricated to implement frequency reconfigurability operation at 1.3GHz, 2GHz, 3GHz, 4GHz, 5GHz and 6GHz using copper strips instead of active elements. Simulated and measured results showed good agreement for 1.3GHz – 2GHz active switching prototype while 1.3GHz – 6GHz copper strip prototype shows minor shifts and degradation at high frequencies in measured result. From the data collected in this research, band pass filter integrated antenna shows high potential to be used as frequency agile antenna with active switching capability. The results from simulation and measurement of fabricated structures are analyzed and discussed in detail in this thesis. This research contributes to the development of frequency agile antenna design for future frequency agile application.

ABSTRAK

Pada zaman perhubungan tanpa wayar, wujud permasalahan baru apabila teknologi tanpa wayar terus mendapat perhatian pengguna dan pelbagai aplikasi baru yang sedang dibangunkan. Jalur frekuensi yang terhad membolehkan hanya satu aplikasi beroperasi pada waktu dan frekuensi yang sama telah menghasilkan isu sumber dalam industri perhubungan tanpa wayar. Maka, teknologi frekuensi tangkas baru sedang dibangunkan contohnya *Software Defined Radio* dan juga *Cognitive Radio*. Salah satu keperluan teknologi seperti ini adalah sistem antena yang mampu mengubah frekuensi operasinya seperti yang diarahkan oleh sistem belakang. Penyelidikan ini meneroka kebarangkalian untuk mengawal frekuensi operasi sebuah antena jalur lebar dengan mengintegrasikan penapis lulus jalur. Diod frekuensi radio (RF), peraruh dan kapasitor digunakan untuk mengawal frekuensi operasi secara aktif. Berdasarkan peruntukan spektrum di Malaysia, julat frekuensi dari 1GHz hingga 6GHz telah dipilih kerana kebanyakan aplikasi komunikasi berada dalam julat ini seperti komunikasi bergerak, jalur tanpa lesen dan komunikasi satelit. Satu bukti konsep telah dijalankan bagi membuktikan keupayaan suis aktif pada operasi 1.3GHz dan 2GHz. Sebuah struktur prototaip lain telah difabrikasi untuk operasi 1.3GHz, 2GHz, 3GHz, 4GHz, 5GHz dan 6GHz dengan menggunakan jalur tembaga berbanding penggunaan unsur-unsur aktif. Keputusan dari simulasi dan yang diukur menunjukkan persetujuan yang baik bagi prototaip operasi 1.3GHz – 2GHz manakala bagi operasi 1.3GHz – 6GHz, perubahan kecil dan kemerosotan dapat diperhatikan di frekuensi tinggi pada keputusan yang diukur. Dari data yang dikumpul dalam penyelidikan ini, antena yang diintegrasi dengan penapis lulus jalur menunjukkan potensi yang tinggi untuk digunakan sebagai antena tangkas jalur dengan keupayaan pensuisan aktif. Keputusan yang diperoleh dari simulasi dan pengukuran struktur yang telah difabrikasi dianalisa dan dibincangkan dengan terperinci di dalam tesis ini. Penyelidikan ini menyumbang dalam perkembangan rekaan antena tangkas frekuensi untuk aplikasi tangkas frekuensi masa hadapan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

ε_{eff}	-	Effective Dielectric Constant
ε_r	-	Dielectric Constant
h	-	Substrate Thickness
W	-	Width
L	-	Length
f_r	-	Resonant Frequency
υ_0	-	Free-space Velocity of Light; 3 x 10^8
ΔL	-	Length extension
λ_o	-	Wavelength
f_H	-	Higher Operating Frequency
f_L	-	Lower Operating Frequency
a	-	Radius of sphere
ηa	-	Efficiency of ESA
Rr	-	Radiation Resistance
Rm	-	Material Loss Resistance
η_s	-	efficiency of system
η_m	-	efficiency of matching network
Tx	-	Transmitter
Rx	-	Receiver

LIST OF ABBREVIATIONS

CR	-	Cognitive Radio
SDR	-	Software Defined Radio
GHz	-	Giga Hertz
ISM	-	Industrial Scientific Medical
GSM	-	Global System for Mobile Communications
TV	-	Television
FR4	-	Flame Retardant 4
MHz	-	Mega Hertz
RF	-	Radio Frequency
BW	-	Bandwidth
3D	-	Three Dimensional
CPW	-	Co-planar Waveguide
SMA	-	SubMiniature version A
IF	-	Interdigital Filter
UWB	-	Ultra Wide Band
dB	-	Decibel
LPF	-	Low Pass Filter
BPF	-	Band Pass Filter
HPF	-	High Pass Filter
BSF	-	Band Stop Filter
CST	-	Computer Simulation Technology
VNA	-	Vector Network Analyzer
MEMs	-	Microelectromechanical Systems
UMTS	-	Universal Mobile Telecommunications System
LTE	-	Long Term Evolution

LIST OF APPENDIX

CHAPTER 1

INTRODUCTION

Research background, problem statement, objective of the research, scopes of the project and thesis outline is presented in this chapter.

1.1 Background

The emergence of reconfigurable antennas has enabled wireless communication industry to expand wireless technology and system complexity. Reconfigurability in frequency has enable multi operating frequency while antenna with beam steering capability able to focus the antenna coverage towards desired location. Cognitive Radio (CR) and Software Defined Radio (SDR) are two examples that uses multiple operating frequency [1-2]. The purpose of these technologies is to increase the utilization of the available frequency spectrum hence enabling the network to have larger capacity.

Generally, the spectrum can be classified into two categories, the license and unlicensed band. The unlicensed band or the ISM band (Industrial, Science and

Medical) which is 2.4 GHz and 5.8 GHz are usually used by various short range wireless consumer products such as WiFi, Bluetooth, wireless mouse, keyboard and other wireless user interface [3]. The free ISM band suffers from high spectrum occupancy due to the number of users that would create interference even though various techniques such as frequency hopping and code division multiple access have been applied.

On the other hand, the licensed band could only be use by the company that pays for the certain frequency range. Example of such band is the GSM band, TV band, armature radio band and Satellite bands [3]. These bands are not usually being utilized all time. In some cases, the bands would be used periodically and in some scenario, the band would be occupied only once a year in a small area.

Currently, CR has gained attention from researchers around the world to develop the system as it is hoped to be the solution to spectrum insufficiency problem. There are no standards presently set for CR but some of the researchers are focusing on the TV band while others set their own operating frequency range [4]. In Malaysia, the Multimedia and Communication Commission (MCMC) has allocated 1GHz to 6GHz of the spectrum to applications such as mobile communication, satellite communication and ISM [3]. Some of these applications will not always use the frequency allocated for them or their coverage are small. It is suitable for unlicensed applications such as SDR and CR to temporary occupy the licensed band. Hence, the frequency range from 1GHz to 6GHz was chosen as the frequency range for this research.

One of the most important components in a wireless system is the antenna. A good antenna ensures the coverage area specification is met as well as the signal power and quality. For frequency agile application, new types of antenna need to be designed since the concept of dynamic operating frequency in this system requires the antenna to operate at broad bandwidth for scanning process as well as narrow bandwidth for the data transfer process [5].

In this research, a broadband antenna were designed from conventional circular patch antenna by implementing bandwidth enhancing techniques such as shorting pin, slot and steps. The designed broadband antenna will be integrated with filters to limit and control the operating frequency. A proof of concept was done by integrating the broadband antenna with a dual frequency band pass filter operating at 1.3GHz and 2GHz. RF diodes were used as switches to manipulate the filter stub length for narrow band operation. Another structure was also fabricated to incorporate four band pass filter for narrow band operation at 1.3GHz, 2GHz, 3GHz, 4GHz, 5GHz and 6GHz. Copper strips were used instead of RF diodes for the second structure. However, by integrating multiple filters to the antenna, the overall structure will be larger and the complexity in fabrication will also increase.

1.2 Problem Statement

Spectrum is a scarce recourse in wireless communication world. Nowadays, most of the available spectrum has been assigned to specific applications, the only free band to be used by general consumer is the ISM bands. A lot of application such as Bluetooth and WiFi that operates in small coverage areas share the ISM bands. In some areas such as highly populated cities, the number of ISM band users is high which would cause interference between the users. This fact calls for a solution to avoid further disturbance in the wireless service as more users will use the services each coming day.

Antennas need to be designed for each application so that it could deliver the signal to its best. Moreover, compact antenna is highly desirable in modern society where everything is preferred to be mobile, small and light weighted. For frequency agile applications, the antenna should not only meet the expectation of normal antennas, it should also be able to reconfigure its operating frequency on demand by the back end system. Additional requirement for CR system is the antenna should also be able to operate at broad bandwidth so that it could detect “holes” in the spectrum. The antenna and system development of Cognitive Radio (CR) are still in early stage. Some prototype antenna designs published in papers, conferences and journals can be use as reference in designing future antennas for CR.

1.3 Objective

- To design a frequency reconfigurable antenna for frequency agile applications.
- To design band pass filters to be integrated with a broadband antenna that will limit and determine the operating frequency of the antenna.
- To analyze the performance of the structure designed in terms of bandwidth, operating frequency, return loss and gain.

1.4 Scopes of Work

This research involves four scope of work, which begins with literature review, followed by structure design process, fabrication and measurement.

1.4.1 Literature Review

Some reviews from previous works that have been done on the design of reconfigurable antenna specifically for CR.

1.4.2 Structure Design, Modification, Simulation and Optimization

Several structures of antenna integrated with filters were designed which are reconfigurable, compact and suitable for frequency agile application. The structure of the antennas will be planar on the FR4 dielectric substrate. The design will include an antenna simulations and optimizations using CST Design Studio.

1.4.3 Antenna Fabrication

The designed and simulated antennas were fabricated on the dielectric material (FR4 substrate). Implementation of RF diodes and SMA connectors will be conducted in this stage.

1.4.4 Structure Testing and Measurement

The fabricated structures were measured at different frequencies ranging from 1GHz to 6GHz. The return loss of the reconfigurable antenna will be measured at all possible configuration. The measured and simulated results will be compared for further optimization purpose until a finalized design is obtained.

1.5 Thesis Outline

The thesis consists of seven chapters starting with introduction which explains the background, problem statement, scope of work and objectives of this research. In Chapter 2, fundamental theories on antenna and filter design are explained as well as review on previous researches that are related to this research. The methodology, considerations and limitations involved in this research are discussed in Chapter 3. Chapter 4 explains the design of the antenna and filter prototypes in detail which includes all measurements and functions. Results obtained from simulation and measurement for antenna and filter designed are also analyzed this chapter. Chapter 5 explains about the design of integrated structure. The simulated and measured results of the integrated structure are discussed as well as comparison on performance between stand alone structure and integrated structure. Discussions are focused on return loss as this affects the operating frequency. Conclusion of the research and recommendations on future research are stated in Chapter 6.

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