



**RECONFIGURABLE TEXTILE ANTENNA FOR GPS
AND WiFi APPLICATIONS**

by

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Specially dedicated to my beloved mother, Hasina Bt Bidin, my father, Mat Salleh Bin Said, brother, sisters and friends with love and care.

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“Humans are a curious species. We wonder, we seek answers. Living in this vast world that is by turns kind and cruel, and gazing at the immense heavens above, people have always asked a multitude of questions: How can we understand the world in which we find ourselves? How does the universe behave?...” –*Stephen Hawking*

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LIST OF SYMBOLS

θ	Theta
Ω	Ohm
σ	Conductivity
ϵ	Permittivity
ϵ_r	Relative Permittivity
R_s	Surface Resistivity
dB	Decibel
dBm	Decibel of Measured power referenced to 1 mille watt (mW)
GHz	Giga Hertz
km	Kilometer
mm	Millimeter

ABBREVIATIONS

BAN	Body Area Network
CST	Computer Simulation Technology
GPS	Global Positioning System
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ISM	Industrial, Scientific and Medical
PAN	Personal Area Network
RF	Radio Frequency
SAR	Specific Absorption Rate
TSB	Touch Stone Block
VSWR	Voltage Standing Wave Ratio
WBAN	Wireless Body Area Network
WiFi	Wireless Fidelity
WiMAX	Wireless Interoperability for Microwave Access
WLAN	Wireless Local Area Network

Kebolehubahan Frekuensi Tekstil Antena Untuk Aplikasi GPS dan WiFi

ABSTRAK

Kerja kajian di dalam tesis ini menjurus kepada kebolehubahan frekuensi tekstil antena untuk aplikasi *GPS* dan *WiFi*. Idea kawalan frekuensi tekstil antena ini membantu untuk penghasilan antena yang lebih kecil, kos minima dan lebih fleksibiliti untuk kegunaan sistem perhubungan tanpa wayar di badan (*WBAN*). Kawalan frekuensi tekstil antena berkebolehan dalam mengelakkan masalah berkaitan gangguan saluran oleh sistem perhubungan tanpa wayar yang lain disamping dapat memaksimumkan penghantaran data. Tesis ini memperkenalkan satu kawalan frekuensi tekstil antena (*RFTA*) yang berkebolehan menukar dari satu operasi frekuensi (*GPS*) kepada dua operasi frekuensi (*GPS* and *WiFi*) dan sebaliknya. *RFTA* terdiri daripada elemen pengalir yang berbentuk segi empat yang diubah suai di bahagian bucunya bertujuan membolehkan antena menghasilkan “*circular polarization*”. Manakala, di bahagian permukaan belakang antena terdapat *slot*. Tiga PIN diod suis diintegrasikan ke dalam *slot* untuk mengawal panjang saiz *slot*. Dengan mengawal suis, antena dapat beroperasi pada frekuensi yang berbeza mengikut saiz *slot*. Selain daripada itu, antena ini menggunakan kaedah *slot* di bahagian permukaan belakang dapat mengekalkan fungsi “*circular polarization*” pada 1.575 GHz frekuensi untuk aplikasi *GPS*. Dengan dimensi 113 x 99 mm², ia adalah cukup kompak untuk disepadukan pada pakaian untuk aplikasi *WBAN*. Selain itu, *RFTA* dianalisa dalam keadaan melengkung memandangkan antena tekstil yang dipakai di bahagian lengan akan mudah melengkung mengikut bentuk badan manusia. Keputusan daripada simulasi menunjukkan antena dalam keadaan melengkung pada 20°, 30°, 40°, 50°, 60°, 70°, dan 80° berfungsi dengan baik dalam kebanyakan kes. Berdasarkan penilaian awal “*Specific Absorption Rate*” (*SAR*), penyelidikan ini mengesahkan bahawa *RFTA* adalah selamat digunakan pada tubuh manusia dengan hasil keputusan simulasi *SAR* kurang daripada 1.6 W/kg dan 2 W/kg untuk setiap 1 g and 10 g isipadu tisu berdasarkan peraturan “*International Commission on Non-Ionizing Radiation Protection*” *ICNIRP*. Dengan semua keupayaan ditunjukkan dan dibincangkan, *RFTA* yang diperbuat daripada kain *felt* dan *ShieldIt Super* mempunyai potensi besar untuk merealisasikan kawalan frekuensi tekstil antena pada pakaian pintar yang baru.

Reconfigurable Textile Antenna For GPS And WiFi Applications

ABSTRACT

The research work in this dissertation describe the reconfigurable frequency textile antenna for GPS and WiFi applications. The idea of reconfigurable frequency textile antenna helps to reduce the antenna size, cost, and gives more flexibility for wireless body area network (WBAN) application. Reconfigurable frequency antenna is useful in the rapid growth of the wireless communication system. The advantages of reconfigurable frequency antenna are to minimize interference with other wireless system and maximizing throughput. This dissertation proposed a reconfigurable frequency textile antenna (RFTA) with reconfigurable ability to switch from a single band frequency (GPS) into dual-band frequency (GPS and WiFi) and vice versa. RFTA is composed of a truncated edges rectangular patch in order to perform circular polarization and incorporated with the slot structure at the ground plane. Three PIN diode switches are integrated at the slotted to varying the total size of the slot. By controlling the state of the switches, such antenna is able to perform at different operating frequencies. Besides, the antenna is using slotted method at the ground plane are capable to maintain the performances of circular polarization pattern at GPS operating frequency. With a dimension of $113 \times 99 \text{ mm}^2$, it is compact enough to be integrated in clothing for WBAN applications. On the other hand, RFTA is analyzed in term of bending conduction since the wearable antenna will be attached at arm will easily bend due to human body structure. The simulation results further indicated that the RFTA under the bending degree of 20° , 30° , 40° , 50° , 60° , 70° , and 80° are good in most cases. Based on a preliminary assessment of specific absorption rate (SAR) results, this research confirms that RFTA is safe to the human being where the simulation SAR results are less than 1.6 W/kg and 2 W/kg for 1g and 10g mass of tissues correspondingly at based on International Commision on Non-Ionizing Radiation Protection (ICNIRP) regulation. With all capabilities demonstrated and discussed, the RFTA antenna made of felt fabric and ShieldIt Super has big potential in realizing a new smart garment antenna.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Recently, the investigations on wearable antenna which is focusing on the body-worn communication are rapidly growth. The deployment of the wearable antenna designed for wireless communication systems have been widely used in various applications such as GPS, WiFi, WiMAX and WLAN. Consequently, the interest in integrating textile technology to wearable antenna for on body communication has gained huge attention since the fabric material does not constrain the wearer to abandon the comfort zone (M. A. R. Osman, Rahim, Samsuri, Elbasheer, & Ali, 2012). Moreover, the textile antenna has many advantages including light weight, easy to integrate with clothes, and low implementation cost as compared to the conventional microstrip antenna (Yahya, Kamarudin, & Seman, 2014).

Reconfigurable antenna can be categorized into four types based on the capability to dynamically amend various parameters. These parameters includes operating frequency (Ismail et al., 2012), polarization (M. N. Osman, Rahim, Yussof, Hamid, & Majid, 2013), radiation pattern (Muzammil Jusoh, Jamlos, Kamarudin, Sabapathy, & Jais, 2013) and two or more parameters in a single antenna. Recent works on frequency reconfigurable antenna are mainly focused on the conventional board such as FR4, which is not flexible for on body communication. In this kind of scenario, a reconfigurable textile antenna can be a good solution where, the antenna could attach on body and have potential to integrate with the switches.

The aim of this project is to design a wearable antenna with reconfigurable scheme. In order to enable reconfigurable ability, a switchable-frequency circuit is needed to be embedded on the textile antenna. Thus, utilization of silver loaded epoxy adhesive on the antenna design has given a solder less association between embedded switchable-frequency circuit and the conductive textile.

The proposed antenna is designed and simulated using Computer Simulation Technology (CST) Microwave Studio Suite software. The proposed frequency reconfigurable textile antenna is fabricated with a substrate made of Felt with permittivity and thickness of 1.22 and 1.7 mm respectively. While, the ShieldIt super with conductivity of 1.67×10^5 S/m and thickness of 0.17 mm is deployed as conductive textile (E-textile). The fabricated antenna is measured and compared with the simulation result to prove the novelty of the wearable antenna to switch its frequency through certain configuration of RF PIN diode.

The proposed of reconfigurable frequency textile antenna can be replace the conversional antenna especially the radio communication used by military. Generally, monopole antenna is used on radio communication devices where the physical length of the antenna is quite long. The user need to carry the devices with long antenna will constrain the uncomfortable zone and the movement of the user also will delimited. Hence, these kinds of problem can be solves by using a textile antenna that attached on the user jacket which is low profile and lightweight.

1.2 Problem Statement

The rising interest on reconfigurable antenna has gain huge attention among the researchers and the industry players. This is due to the fact that the reconfigurable antenna has the capability of combining multiple tasks in a single terminal if compared to a conventional antenna which is only capable to perform a single task in a single antenna platform. Therefore, the reconfigurable antenna offers compactness, flexibility and reduced cost.

Frequency reconfigurable antenna are very important for a terminal that needs to operate in a multi-function mode such as WiFi, WiMAX, 4G, GPS and Bluetooth in one system. Up to date, there are a number of reconfigurable frequency antenna reported in the past research (Aboufoul, Member, Alomainy, & Parini, 2012; Li, Xiong, Yu, & He, 2010; Qin, Weily, Guo, & Bird, 2010). However, these antennas suffer from complex biasing circuit. For instance, by utilizing too many lumped elements such as inductors, capacitors, and bias lines may reduce the performance of the antenna and increase the

fabrication cost. To overcome this, a reconfigurable frequency slot antenna with biasing circuit embeded in the ground plane is proposed.

The growth of on-body reconfigurable textile antenna application is still in its preliminary stages which currently delimited by a single antenna with a single application. Furthermore, the majorities of published papers on reconfigurable antenna has focused on rigid microstrip (Ismail et al., 2012; M Jusoh, 2011; Majid, Rahim, Hamid, & Ismail, 2012). This kind of the antenna is not flexible and not suitable for wearable application. Hence, the implementation of frequency reconfigurable technique into textile antenna is considered new with more advantages and flexibility to users.

In addition, the application of GPS to communicate with satellite requires the antenna to be operated in circular polarization. Hence, a reconfigurable frequency antenna which is covers the GPS operating frequency need to consider the polarization scheme. The main challenges in this work is to achieve single switchable-frequency wearable antenna with circular polarization for GPS and WiFi applications.

1.3 Objectives

This project involves studies on the reconfigurable wearable antenna inclusive of design, fabrication, measurement and test in order to establish optimum antenna. The objectives can be summarized as follows:

- i. To design a circular polarization (CP) textile antenna for GPS application.
- ii. To embed WiFi application by integrating RF PIN diode and switches components using the varying slot size method.

- iii. To configure frequency from single band frequency (GPS) to dual-band frequency (GPS and WiFi) and vice versa.
- iv. To evaluate reconfigurable frequency of GPS and WiFi textile antenna performances.

1.4 Scope of work

The scope of this research consists of several stages to achieve the objectives of this work. The stages are partitioned into five stages presently:

Stage 1: Literature Review

Study and analysing of previous research work related to wearable textile antenna and reconfigurable textile antenna. An inventive antenna design with the capability of wearable, circular polarization and reconfigurable frequency design are prioritized.

Stage 2: Analytical Calculation

In order to determine dimension of patch wearable antenna, analytical calculations are carried out based on the basic equations of microstrip patch antenna and concept of designing a circular polarization antenna.

Stage 3: Simulation antenna design and optimization

The initial project is started by identifying suitable material and measuring the properties of fabric material. Then, a square patch antenna with both opposite edge truncated is designed followed by reconfigurable frequency textile antenna. All simulation is assisted by CST software. In this stage, switchable frequency is integrated with DC biasing circuit through simulation using PIN diode. The antenna is capable to configure frequency by varying the slot size at ground plane. Optimization has been conducted to obtain antenna performance results such as reflection coefficient S_{11} , axial ratio and gain.

Stage 4: Fabrication and Measurement

Fabrication of prototype wearable antenna using ShieldIt Super as electronic textile and Felt as substrate is carried out at this stage. The DC biasing circuit is attached on wearable antenna using silver loaded epoxy adhesive. Meanwhile, the external switching circuit is made to control the configuration of the antenna. The antenna prototypes were measured in Antenna & Microwave lab (Amrellab) in Universiti Malaysia Perlis (UniMAP) and Advanced Microwave & Antenna Laboratory in Universiti Teknologi Malaysia (UTM).

Stage 5: Assessment of antenna in bending condition and SAR analysis

Wearable antenna will be placed at any part of the body like shoulder, chest and leg. Those parts require antenna to be bent easily and follow human body shape and

movement. Hence, a study to investigate the antenna performance in bending condition is carried out at this stage which considering reflection coefficient, axial ratio and gain. The proposed antenna then analyse in term of Specific Absorption Rate (SAR). The purpose of SAR analysis is to ensure the electromagnetic radiation produce by the antenna did not suppress the guideline limit and safe to use on human body.

1.5 List of Contributions

The main contributions of the research work include:

- i. Inventing a reconfigurable frequency textile antenna for GPS and WIFI applications.
- ii. Propose a new switchable-frequency textile antenna with circular polarization ability for GPS application.
- iii. Providing analysis of reconfigurable frequency textile antenna with PIN diode in bending condition.
- iv. Providing SAR value of reconfigurable frequency textile antenna.

1.6 Thesis Outline

This thesis is organized into five chapters. The current chapter consists of introduction, problem statements, objective, scope of work, thesis outline and contributions.