FREQUENCY-RECONFIGURABLE ANTENNA USING ELLIPSE-SHAPED PATCH WITH DEFECTED GROUND STRUCTURE

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JANUARY 2018

To my beloved wife, CHONG OI LING
and my daughter, TIFFANY LIM SHU YIN

ACKNOWLEDGEMENT

I would like to sincere gratitude to my supervisor, Professor Ir Dr Sharul Kamal bin Abdul Rahim for his encouragement, knowledgeable guidance, advice and supportive in completing my master project. I would also heartfelt gratitude to my co-supervisor, Dr Mohamad Rijal bin Hamid for his guidance, great technical advice and assistance me to complete this master project. Besides, I would like special thanks to Dr Ping Jack Soh, Dr Mohd Faizal Jamlos and Dr Fareq Malek from UniMAP provide technical guidance and never say no for lab facility support.

I would also like to thank all WCC staffs for their valuable support and discussion during my master. A special thanks to Mr. Sharul Shari and Mr. Norhafizul Ismail for their help in order to use the facilities to measure the performance of the antenna. A greatest appreciation to my entire friends for all the help and assistance during my project, especially to my WCC friends, Mursyidul Idzam Sabran, Akaa Agbaeze Eteng, Mohd Subri Abd Rani, Siti Fatimah Ausordin, Ridduan Ramli and UniMAP friends, Nazri and Toufiq.

I want to give special appreciation to my family, especially my lovely wife Chong Oi Ling and my adorable daughter Tiffany Lim Shu Yin for sacrifice in family good moments to allow me to complete my part-time study. Besides, my father Lim Yong Song, my mother Kuek Hoai Kiang, my brothers Lim Meng Chye and Lim Meng Hai for their love, morale support and prayer along my study. Their fully support has given me enough strength and inspiration in pursuing my ambition as well as to complete this project.

Last but not least, special thanks to my company (INTEL) sponsor my scholarship and my manager support throughout the study.

ABSTRACT

Recently, there has been an increased demand for single systems that can handle different wireless communication applications simultaneously. Often, it is impractical to allocate multiple antennas to the same system, so multifunctional antennas are a critical necessity. Also, most existing frequency-reconfigurable antennas (FRA) are made from non-transparent materials, but a transparent antenna may be useful in scenarios where the antenna should not impair visibility. Furthermore, wideband-to-narrowband reconfigurability has potential for use in future cognitive radio systems. This thesis focuses on FRAs with wideband-to-narrowband reconfigurability that use transparent and non-transparent materials. The ultra-wideband antenna design uses an ellipse-shaped patch, thereby yielding a 7.77 GHz impedance bandwidth from 2.83 GHz to 10.66 GHz. The first FRA is obtained by introducing a pair of annular ring slots defected ground structure (DGS) resonator with metal switches. Its initial wideband operation mode from 3 GHz to 6 GHz can be reconfigured into six additional bandwidth modes with a dual-band operation centred at 3.7 GHz and 5.8 GHz and five single-band modes resonating at 4.2 GHz, 4.58 GHz, 4.86 GHz, 5.7 GHz and 6 GHz. Meanwhile, a FRA for the Wireless Local-Area Network applications is reconfigured from a pair of rectangular DGS resonators integrated with PIN diodes. The antenna is able to switch between a narrowband operation centred at 5.8 GHz and a wideband operation in the range of 3.5 - 5.97 GHz. Finally, a semi-transparent antenna with a wideband-to-narrowband frequency mode is achieved by integrating an E-shaped DGS resonator and PIN diodes to disrupt the current flow. The antenna exhibits an impedance bandwidth from 3 GHz to 6 GHz in the wideband mode and a resonance at 4.75 GHz when operated in the narrowband mode. All prototypes are fabricated and measured to verify the simulated results. The gain of antenna fabricated using the AgHT-4 transparent material is about 59% lower compared to FR-4 due to the electrical loss of the transparent film.

ABSTRAK

Pada masa kini, terdapat permintaan yang tinggi untuk sistem tunggal yang boleh mengendalikan pelbagai aplikasi komunikasi tanpa wayar. Adalah tidak praktikal untuk menggunakan antena yang banyak dalam satu sistem, maka antena pelbagai fungsi adalah diperlukan. Selain itu, kebanyakan antena frekuensi boleh ubah (FRA) dihasil daripada bahan-bahan legap, antena lut sinar mungkin berguna dalam senario di mana antena seharusnya berprofil rendah dan lut sinar. Di samping itu, konfigurasi frekuensi boleh ubah dari jalur-lebar ke jalur-sempit mempunyai potensi besar untuk digunakan dalam sistem radio kognitif di masa hadapan. Penyelidikan di dalam tesis ini tertumpu kepada antena frekuensi boleh ubah dari jalur-lebar ke jalur-sempit dengan menggunakan bahan lut sinar dan legap. Reka bentuk antena jalur-lebar luas menggunakan tampalan berbentuk elips menghasilkan frekuensi pada 7.77 GHz lebar jalur galangan dari 2.83 GHz hingga 10.66 GHz. FRA pertama diperolehi dengan memperkenalkan teknik *annular ring slots defected ground structure* (DGS) menggunakan suis logam. Mod operasi jalur-lebar dari 3 GHz hingga 6 GHz boleh dikonfigurasi ke enam mod lebar jalur tambahan dengan dua jalur berpusat pada 3.7 GHz dan 5.8 GHz, lima mod satu jalur berpusat pada 4.2 GHz, 4.58 GHz, 4.86 GHz, 5.7 GHz dan 6 GHz. Di samping itu, FRA untuk aplikasi *Wireless Local-Area Network* dikonfigurasi dari sepasang DGS segi empat tepat dengan menggunakan diod PIN. Antena boleh beroperasi di jalur-sempit yang berpusat pada 5.8 GHz dan jalur-lebar dalam 3.5 - 5.97 GHz. Akhir sekali, antena separa lut sinar dengan mod jalur-lebar ke jalur-sempit dicapai dengan mengintegrasikan DGS berbentuk E dan diod PIN untuk mengganggu aliran arus. Antena ini menghasilkan lebar jalur galangan dari 3 GHz hingga 6 GHz di dalam mod jalur-lebar dan mod jalur-sempit pada 4.75 GHz. Semua rekabentuk yang dicadangkan telah direka dan diukur untuk mengesahkan hasil simulasi. Nilai capaian antena yang direka menggunakan AgHT-4 lut sinar didapati 59% lebih rendah berbanding dengan FR-4 kerana sifat kehilangan elektrik filem bahan lut sinar tersebut.

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LIST OF ABREVIATIONS

GHz	-	GigaHertz
MHz	-	MegaHertz
Gbps	-	Gigabits Per Second
Mbps	-	MegaBits Per Second
PIN	-	Positive Intrinsic Negative
DC	-	Direct Current
MEMS	-	Micro-Electro Mechanical System
FETs	-	Field-Effect Transistors
FR-4	-	Flame Resistant 4
UWB	-	Ultra-Wideband
CP	-	Circular Polarization
IVC	-	Inter-Vehicle Communication
DRSC	-	Dedicated Short Range Communications
DGS	-	Defected Ground Structure
AgHT	-	Conductive Silver Coated Thin Film
Cu	-	Copper
FCC	-	Federal Communication Commission
IEEE	-	Institute of Electrical and Electronics Engineers
Wi-Fi	-	Wireless Fidelity
NFC	-	Near Field Communication
UHF	-	Ultra High Frequency
SHF	-	Super High Frequency
TCF	-	Thin Conductive Film
OLED	-	Organic Light Emitting Diode
ITO	-	Indium Tin Oxide
AgGL	-	Silver Grid Layer

AgNw	-	Silver Nano Wire
PET	-	Polyethylene terephthalate
CPW	-	Co-planar Waveguide
DRA	-	Dielectric Resonator Antenna
RF	-	Radio Frequency
NASA	-	National Aeronautics and Space Administration
CST	-	Computer Simulation Technology
VNA	-	Vector Network Analyzer
RL	-	Return Loss
dB	-	Decibel
dBi	-	Isotropic Decibel
S_{11}	-	Reflection Coefficient
S_{21}	-	Insertion Loss
DC	-	Direct Current
PCB	-	Printed Circuit Board
UV	-	Ultra Violet
SMA	-	Sub Miniature version A
CR	-	Cognitive Radio
BW	-	Bandwidth
WLAN	-	Wireless Local Area Network
GUI	-	Graphical User Interface
FRA	-	Frequency Reconfigurable Antenna
N/A	-	Not Applicable

LIST OF SYMBOLS

f_H	-	High frequency
f_L	-	Low frequency
f_c	-	Center frequency
σ	-	Electrical Conductivity
ε_r	-	Dielectric constant substrate
ε_{eff}	-	Effective permittivity of substrate
$\tan \delta$	-	Loss Tangent
c_0	-	Speed of light in free space
λ_0	-	Free space wavelength
λ_g	-	Guide wavelength
$\leq$	-	Less then
Ω	-	Ohm
%	-	Percentage

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Demand for wireless communication has progressively grown over the years. Antennas are crucial parts of transceiver systems of wireless devices. Some modern wireless systems are employed in multiple applications, requiring various operating frequencies and antenna polarizations. Often, it is impractical to integrate multiple antennas in a single transceiver system. Rather, a single antenna may be designed to provide coverage of a wide range of frequencies. Although an ultra-wideband UWB antenna can provide wide frequency coverage over the unlicensed 3.1 GHz to 10.6 GHz spectrum [1], it may not provide optimal signal to noise ratio performance, and may need additional filtering to suppress unwanted interference [2]. Alternatively, reconfigurable antennas have been proposed in recent years to provide coverage over a wide range of frequencies.

Typically, antenna reconfigurability can be categorized in terms of radiation pattern, polarization, and frequency. The frequency reconfigurable antenna is arguably the most practical option as it is capable of switching its operation to the desired frequency, instead of utilizing a number of antennas allocated for signal reception at different frequencies. Besides improved performance, the combined multi-frequency operation in a single antenna reduces space and cost [3]. Frequency reconfigurable antennas can be classified into two types, namely continuous and discrete. Typically, continuous tuning uses components like varactors, which apply electric bias to change the antenna impedance. Discrete tuning, on the other hand, employs switches that are controlled by DC biasing for ON and OFF state switching. Discrete tuning can be achieved through the integration of devices such as PIN diodes.

Tuning mechanisms can be categorized into three major groups: mechanical actuation, tunable materials and integrated devices. Mechanical actuation alters the radiator shape or dimension to tune the resonant frequency. The drawback of this method, which typically uses a motor, is that it takes longer time to actuate the motor, besides high maintenance due to wear and tear part. Next, tunable materials changes the inherent electrical properties such as permittivity, permeability and electrical conductivity. The electric, magnetic or optical properties can be generally influenced by using an external circuit. For instance, ferrites, ferroelectrics and liquid crystals are tuned in this way. The last method for frequency reconfigurable antenna using electronic devices in small packaging. The example of discrete tuning which includes PIN diode, micro-electromechanical systems (MEMS), field-effect transistors (FETs) whereas varactor can be used in continuous tuning by varying the bias voltage to control their impedance [4]. Currently, PIN diodes are the most practical and popular component for this technique [5]. Switching between different resonant frequencies can be further categorized into two types; wideband-to-multiband and multiband-to-multiband.

Presently, optically transparent antennas are uncommon in the market due to limitations in research and the complexity of fabrication, compared with well-known conventional antenna substrates such as FR4, Taconic and Rogers. To the best of author's knowledge, no frequency reconfigurable antenna implemented using transparent materials have been presented in literature. In this research, investigation of conventional and semi-transparent reconfigurable antennas capable of wideband and narrowband modes will be performed. .

1.2 Problem Statement

Electronic devices enabling multiple wireless applications in one system are widespread. The antenna is a crucial front-end device to radiate and receive radio frequency signals in the transceiver to support such systems. Ultra-wideband (UWB) antennas provide the advantage of covering wide bandwidths, from 3.1 GHz to 10.6 GHz, on a single antenna. However, within the UWB bandwidth there are various applications for which frequency spectra have been allocated. Thus, coexistence between the UWB transceiver and other applications within this bandwidth may become an issue, as these other applications may interfere with the UWB transceiver. Multiple antennas at specific frequencies can be used to overcome this problem, but at a price of cost and space utilization. In order to mitigate unwanted interference, a frequency reconfigurable antenna is a great candidate to use when antenna installation space is constrained. It also useful for cognitive radio applications.

The earliest frequency reconfigurable antenna was patented in 1983 [6]. Since then most research has focused on the use of conventional, non-transparent materials for antennas. Lately, several systems require transparent parts to integrate with other structures in the environment in order to reduce visual obstruction [7], for instance, in energy harvesting applications [8]. Other examples are the Inter-Vehicle Communication (IVC) and solar powered vehicle applications. IVC will be the next generation vehicle communication system, and it employs dedicated short range communications (DRSC). It provides inter-vehicle communication, and is beneficial as a vehicle safety mechanism in road scenarios as depicted in Figure 1.1 [9]. There is the possibility that cognitive radio technology can be applied to IVC in sensing and spectrum allocation scheme for information sharing between vehicles [10]. In addition, these vehicles could be solar powered, where energy is obtained through photovoltaic cells installed on top of vehicle shown as Figure 1.2 [11]. Such vehicles would benefit from the use of transparent antennas to facilitate IVC, so as not to interfere with the solar irradiation on the photovoltaic cells.

Previous researches on transparent antennas have addressed the scopes of UWB, dual-band, circular polarized (CP), and band notched antenna designs. Currently, there is a gap in literature on the development of frequency reconfigurable antennas using transparent materials. Therefore, this thesis addresses the design of frequency reconfigurable antenna by utilizing FR-4 and AgHT-4 which provides wideband-to-narrowband reconfigurability. Such antenna can be potentially applied in future IVC scenarios involving solar vehicles.

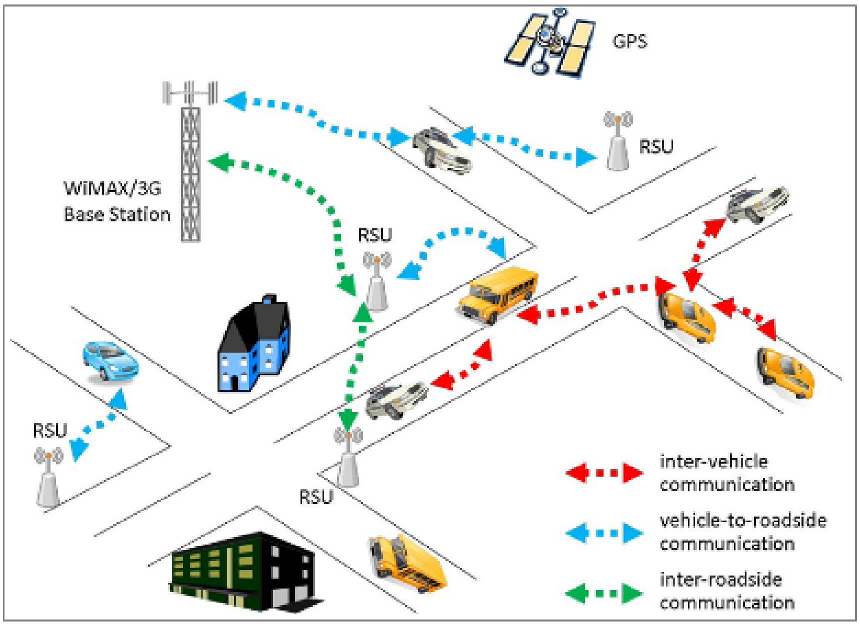

Figure 1.1: Vehicular ad-hoc Network [9]

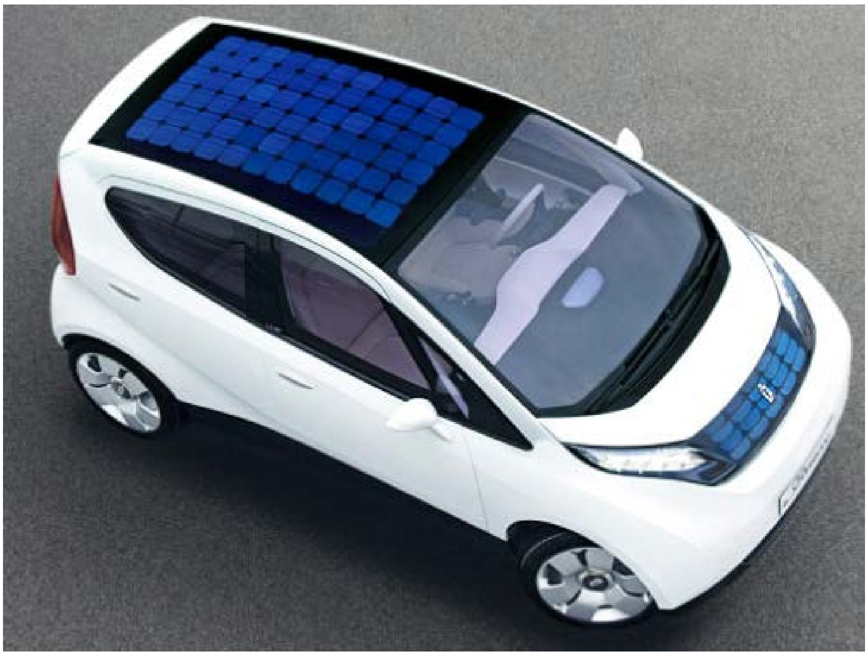

Figure 1.2: Solar power vehicle [11]

1.3 Objectives of the Research

The objectives for this study are stated as follows:

i. To design, fabricate, and analysis the wideband-to-narrowband frequency reconfigurable antenna by implementing defected ground structure (DGS) resonator.

ii. To investigate the performance of frequency reconfigurable antenna by applying transparent materials that is potential implement in future wireless communication.

1.4 Scope of Work

This study is focused on frequency reconfigurable antenna with wideband-to-narrowband reconfigurability. Two different antenna designs are implemented in this work, namely non-transparent antenna and a semi-transparent antenna. The non-transparent antenna utilizes FR-4 material for the antenna design, while the semi-transparent antenna employs AgHT-4, copper and glass.

In the first stage, a non-transparent antenna design for UWB is developed. The basic geometry of the UWB antenna is used for subsequent antenna designs. This is followed by the design of frequency reconfigurable antennas with single-, dual- and wideband reconfigurablity by adding defected ground structure (DGS) annular ring slots, with ideal switches in between the slots. Next, the DGS square slots with stubs are used with the implemented PIN diodes, and the effect of the stubs and switches are investigated. In the second stage, a semi-transparent antenna is developed by employing DGS with E-shaped slot. Various configuration of materials and parametric studies are analysed.

The CST© Microwave Studio is the main design simulation software used prior to antenna fabrication and measurement. The antenna parameters of the wideband-to-narrowband mode are analyzed in terms of reflection coefficient, gain, radiation pattern, and bandwidth of the antenna. Lastly, all the simulated and measured results are plotted to validate the actual performances.

1.5 Thesis Outline

This thesis contains a total of six chapters which discuss various aspects of this research project. The thesis outline is briefly described as follows:

Chapter 1 presents an introduction and the basis of the frequency reconfigurable antenna, problem statement, research objective and scope of work.

Chapter 2 discusses types of non-transparent antenna substrates as well as an emerging transparent material – silver coated conductive film (AgHT). Literature review of previous related works is important in this section for knowledge absorption to apply in this research project. There are few types of antennas discussed, which include UWB antennas, frequency reconfigurable antennas and transparent antennas.

Chapter 3 divides into a few sub-chapters to explain the methods of antenna designs, starting with literature review until data analysis. Additionally, some experiments carried out to define material properties for uncertain materials are described. The material properties of note include the dielectric constant and resistance sheet of material. The Chapter also discusses the fabrication technique for FR-4 and semi-transparent antenna substrates.

Chapter 4 presents the steps to design a UWB antenna, leading to frequency reconfigurable antenna and prior to the development of semi-transparent antenna. This chapter discusses three antennas which are the UWB, frequency reconfigurable antenna integrated with metal switches (ideal switch) proof-of-concept, and the frequency reconfigurable antenna with wideband-to-narrowband 5.8 GHz reconfigurability. In this chapter, performance of antennas will be discussed in terms of parameters like s-parameters, radiation pattern and gain.

Chapter 5 focuses on the development of semi-transparent frequency reconfigurable antenna using AgHT-4 thin film, copper and glass. There is the final step in the evolution of the proposed antenna, from UWB to frequency reconfigurable antenna integrated with PIN diodes (Chapter 4). The E-Shape DGS is introduced into the CPW ground-plane for pre-filtering circuit at 4.75 GHz narrowband and switchable to wideband mode from 2 GHz to 6 GHz. Different material configurations and parametric studies are discussed and analysed. The simulation and measurement results for s-parameters and radiation pattern are presented.

Chapter 6 is the last chapter, and presents a conclusion and recommendation for future works.

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