WIDEBAND AND MULTIBAND ANTENNAS FOR MULTI-CONFIGURATION MODE APPLICATIONS

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DEDICATION

Dedicated to my parents, Idris bin Ismail, Sulaihah Ab. Rashid,
my only sister with brother-in-law, Sakinah Idris, Mohd Zaidi Zuraini,
my in-law families, my nieces,
my beloved husband, Muhammad Ubaidullah Ramlan and
my daughter, Hana Humaira' Muhammad Ubaidullah,
with love for their prays, support and encouragement.

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ABSTRACT

A combination of a simultaneous band of operations is needed to fulfill customers' requirements such as having a cost-effective and better service in the wireless communication system applications. Integration of many antennas in one single device requires a lot of space. Therefore, a reconfigurable antenna is proposed to combine multiple antennas' operations into one antenna, allowing simultaneous bands to operate at one time. This thesis presents three proposed antenna designs equipped with the switching ability between narrowband, multiband and wideband reconfigurations using Positive-Intrinsic-Negative (PIN) diodes as switching techniques. The first proposed antenna (Antenna A) is a combination of elliptical monopole and slot-dipole Coplanar Waveguide (CPW)-fed antenna that can operate in three modes known as narrowband (2.4 GHz / 3.5 GHz / 5.2 GHz), multiband (2.4 GHz, 3.5 GHz and 5.2 GHz), and wideband (2.0 GHz to 6.0 GHz). The second proposed antenna (Antenna B) operates at different operating frequency ranges such as dual-band at 1.57 GHz and 2.4 GHz and wideband from 3.5 GHz to 9.0 GHz. Additionally, it can achieve a single narrowband mode if additional switches are added. The second antenna concept is extended to the third and final proposed antenna (Antenna C) but with additional functionality. Unlike the second antenna, the third antenna resonates in multiband and wideband modes simultaneously. It is achieved by incorporating the slot-dipole arm into a bowtie shape with a CPW-fed antenna. The antenna provides a simultaneous multi-wideband mode operation (1.57 GHz, 2.4 GHz and 3.3 GHz to 9.0 GHz) and is switched to a multiband mode (1.57 GHz, 2.6 GHz, 3.5 GHz, 7.0 GHz) and a wideband mode (3.5 GHz to 9.0 GHz). The proposed antennas were designed using Computer Simulation Technology (CST) software, fabricated on Flame Retardant 4 (FR4) substrate and tested in terms of S_{11}, radiation pattern and gain performances. The proposed antennas are applicable in the telecommunication industry, such as multimode wireless communication systems that offer multiple standards and applications, for instance, Global Positioning System (GPS), Wireless Local Area Network (WLAN), Fourth Generation Long-Term Evolution (4G LTE), Bluetooth, and others through a wide range of frequencies. Multiple wireless communication services in a single antenna will optimize the antenna functionality and increase the flexibility of the antenna towards the system applications. In addition, less space is required as compared to the system which employed a conventional antenna. The proposed antennas provide more applications in a single antenna as compared to other previously reported works on frequency reconfigurable antenna.

ABSTRAK

Gabungan jalur beroperasi secara serentak diperlukan untuk memenuhi kehendak pelanggan seperti mempunyai perkhidmatan yang menjimatkan kos dan lebih baik di dalam aplikasi sistem komunikasi tanpa wayar. Penyatuan pelbagai antena di dalam satu peranti memerlukan banyak ruang. Oleh itu, antena yang dapat dikonfigurasi semula dicadangkan untuk menggabungkan jalur beroperasi secara serentak pada satu masa. Tesis ini memperkenalkan tiga rekabentuk antenna dilengkapi dengan kebolehan untuk menukar konfigurasi di antara jalur sempit, berbilang dan lebar dengan menggunakan suis Positif-Intrinsik-Negatif (PIN) diod. Antena pertama yang dicadangkan (Antena A) ialah kombinasi antara antena elips ekakutub dan lubang alur-dwikutub suapan-Pandu Gelombang Sesatah (CPW), yang mampu untuk beroperasi di dalam tiga mod yang dikenali sebagai, jalur sempit (2.4 GHz / 3.5 GHz / 5.2 GHz), jalur berbilang (2.4 GHz, 3.5 GHz dan 5.2 GHz), dan jalur lebar (2.0 GHz sehingga 6.0 GHz). Antena kedua yang dicadangkan (Antena B) beroperasi pada julat operasi frekuensi yang berbeza seperti jalur dual pada 1.57 GHz dan 2.4 GHz dan jalur lebar antara 3.5 GHz sehingga 9.0 GHz. Selain itu, antena ini mampu mencapai mod jalur sempit yang tunggal jika suis tambahan ditambah. Konsep antena kedua dilanjutkan kepada cadangan antena ketiga (Antena C) dengan kefungsian tambahan. Tidak seperti antena kedua, antena ketiga mempunyai kebolehan untuk menyalun di mod jalur berbilang dan jalur lebar secara serentak. Ini dapat dicapai dengan menggabungkan lengan lubang alur-dwikutub kepada bentuk tali leher dengan antena suapan-CPW. Antena ini menyediakan mod serentak jalur berbilang-lebar (1.57 GHz, 2.4 GHz dan 3.3 GHz sehingga 9.0 GHz), dan bertukar ke mod jalur berbilang (1.57 GHz, 2.6 GHz, 3.5 GHz, 7.0 GHz) dan mod jalur lebar (3.5 GHz sehingga 9.0 GHz). Antena yang dicadangkan direka menggunakan perisian Computer Simulation Technology (CST), difabrikasi pada Flame Retardant 4 (FR4) substrat dan prestasinya diuji dari segi S_{11}, pola radiasi dan gandaan. Antena yang dicadangkan boleh digunakan di industri telekomunikasi seperti sistem komunikasi berbilang mod tanpa wayar yang menawarkan pelbagai piawaian dan aplikasi seperti Sistem Penentu Sejagat (GPS), Rangkaian Wayarles Kawasan Setempat (WLAN), Generasi Evolusi Jangka Panjang Ke-empat (4G LTE), Bluetooth dan sebagainya melalui jarak frekuensi yang lebar. Perkhidmatan berbilang komunikasi tanpa wayar dalam satu antena akan mengoptimumkan fungsi sesebuah antena dan meningkatkan kebolehlenturan antena terhadap aplikasi sistem. Di samping itu, ruang yang sedikit diperlukan berbanding dengan sistem yang menggunakan antenna konvensional. Antena yang dicadangkan menyediakan lebih banyak aplikasi dalam satu antena tunggal berbanding dengan kerja-kerja sebelumnya pada antena boleh konfigurasi semula frekuensi.

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LIST OF ABBREVIATIONS

CST	-	Computer Simulation Technology
GSM	-	Global System for Mobile Communications
UMTS	-	Universal Mobile Telecommunications System
4G-LTE	-	4^{th} Generation Long-Term Evolution
UWB	-	Ultrawideband
GPS	-	Global Positioning System
WLAN	-	Wireless Local Area Network
MB-OFDM	-	Multiband Orthogonal Frequency Division Multiplexing
ME	-	Magneto-Electric
RF-MEMS	-	Radio Frequency-Micro Electro-Mechanical System
BST	-	Barium Strontium Titanate
FB	-	Fabry-Perot
SSRR	-	Single Split-Ring Resonators
PIFA	-	Planar Inverted-F antenna
RSR	-	Rectangular Slot Resonator
WiMAX	-	Worldwide Interoperability for Microwave Access
SPDT	-	Single Pole Double Throw
CPW	-	Coplanar Waveguide
CdS-PCSS	-	Cadmium Sulphide Photoconductive Semiconductor Switch
PBG	-	Photonic Bandgap
GHz	-	Giga Hertz
MHz	-	MegaHertz
SNR	-	Signal-to-Noise Ratio
FCC	-	Federal Communications Commission
MCMC	-	Malaysian Communications and Multimedia Commission
ITU	-	International Telecommunication Union
5G	-	5^{th} Generation

LIST OF SYMBOLS

ε_r	-	Relative permittivity
$\tan\delta$	-	Loss tangent
GHz	-	Giga Hertz
MHz	-	MegaHertz
dB	-	Decibels
η	-	The efficiency of the antenna
G	-	The gain of the antenna
D	-	Directivity of the antenna

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Nowadays, different types of applications in wireless communication systems have multiplied the usage of frequency bands (Anguera *et al.*, 2013). For example, in mobile communication, many frequency bands have been used and utilized by many systems such as Global System for Mobile Communications (GSM), Universal Mobile Telecommunications System (UMTS), and Long-Term Evolution (LTE) bands.

Multiband antennas are used in mobile communications to operate at multiple-bands at one time. Potentially, the antenna can provide more functionality if the antenna's parameters can be reconfigured. Therefore, a reconfigurable antenna is an excellent candidate to replace conventional antennas (Mohanta *et al.*, 2019) with its ability to switch the antenna's properties to maximise the antenna performance according to the surrounding demands.

There are five types of reconfigurable antennas, depending on their property's reconfiguration. They were divided into frequency (Cao *et al.*, 2014), radiation pattern (Aboufoul *et al.*, 2013), bandwidth (Obadiah *et al.*, 2016), beam (Chaimool *et al.*, 2019) and polarisation (Pouyanfar and Rezaeieh, 2013) reconfigurable antennas. In this research, the work is solely focused on frequency reconfigurable antenna. The frequency reconfigurable antenna only changes its operating band, and generally, it will not affect the other antenna's electrical properties. There are many types of frequency reconfiguration such as 1) switching between narrowband, 2) switching between multiband, 3) switching between wideband, 4) switching between narrowband and wideband, 5) switching between narrowband and multiband, 6) switching between multiband and wideband, and 7) switching between narrowband, multiband and wideband. The combination of the reconfiguration types stated above provide extra flexibility and results in maximising the antenna functionality.

1.2 Problem Statements

Each of the non-reconfigurable antennas, such as narrowband antennas, multiband antennas, and wideband antennas, has its advantages and disadvantages. For example, the narrowband antenna offers reliable long-range communication and good out-of-band rejection (Deslise, 2014). Multiband antenna, on the other hand, provides the ability to operate multiple operations for communication systems (Secmen, 2011), while the wideband antenna supports broadband applications. However, the narrowband antenna can only support one operating frequency at one time compared to multi and wideband antennas. Meanwhile, both the multiband and wideband antennas suffer from poor out-of-band rejection.

Therefore, a frequency reconfigurable antenna that combines these bands into a single antenna and selects the bands when necessary is one option to mitigate the problems. Combining the wideband and multiband properties in a single antenna can support multiple services at a time and reduce the spacing requirement in the system (Yang *et al.*, 2009). However, this is not always true if multiple radiators are required in the configuration (Cleetus and Bala, 2019). Hence a lot of switches are required to enable the reconfiguration. The radiators' number also dictates the biasing line's complexity, such as in (Cherian and Das, 2015; Cleetus and Bala, 2019; Awan *et al.*, 2020). The operating frequency also limited and depended on the number of the radiators such as in (Cherian and Das, 2015; Abutarboush and Shamim, 2018; Awan *et al.*, 2020) where a small range of operating frequencies was demonstrated. In addition, when the operating band is switched to a low frequency, unneeded harmonics will be appeared within the upper interested band. Thus, it is necessary to filter them out. As far as the author’s concerns, only limited works have been done on narrowband-to-multiband-to-wideband configuration because of their design complexity and none of them has harmonic suppressions capability. Thus, for a simplicity and less complex biasing line, combining just a few radiating elements is necessary but yet still can provides a good number of operating bands. Besides, it is also required to provides the harmonic pre-filtering capability.

Besides switching between narrowband, multiband and wideband modes, simultaneous operation between two modes is preferable because it can serve more applications at one time. When two modes are served simultaneously, more applications are being served in one time than in the previous configuration, where only one mode is operated at a time. A review on reconfigurable antennas (Nafde and Pande, 2016; Heydari *et al.*, 2017; Thanh Tu *et al.*, 2019) reported that the simultaneous operation between two modes could be implemented. Unfortunately, the reported antennas can only cover the simultaneous operation of narrowband-and-wideband mode with a limited number of operating bands. Due to the complexity of the designs, the reviewed prototype was developed without using the real switch. It is believed the antennas will have a complicated biasing line if a real switch configuration was implemented. To serve more applications such as Global Positioning System (GPS), Wireless Local Area Network (WLAN), Long-Term Evolution (LTE), C-band and X-band, the antenna, which offers the simultaneous operation of multiband-and-wideband mode, is preferable and shall be demonstrated using real switches with a doable biasing line. In addition, the proposed work shall provide more operating bands compared to the existing antennas. By adding the switches, the antenna should switch to the simultaneous narrowband-and-wideband mode and another available mode. By increasing the antenna flexibility towards the system application, more benefits can be obtained as mentioned earlier.

1.3 Research Objectives

The research objectives are as follow:

(i) To design frequency reconfigurable antenna, switched from wideband to multiband or vice versa, by employing PIN diode switches.

(ii) To design frequency reconfigurable antenna with harmonics suppression characteristics.

(iii) To develop a frequency reconfigurable antenna with the flexibility of switching between single-mode and simultaneous two modes of operations.

1.4 Scope of Research

The research focuses on three types of antennas, which can switch their operating frequency from multiband to wideband modes, either simultaneously or one mode at a time. Increasing the number of the frequency bands will increase the flexibility of the antenna towards the system application. All the antennas will be based on slotted antenna design since it is easy to do the biasing later on. PIN diode switches will be employed on the antenna structure to achieve the frequency reconfigurability. The first antenna will be designed to have a wideband with operating bandwidth (2.0 GHz to 6.0 GHz) and switched to a triple-band operating frequency (i.e., 2.4 GHz, 3.5 GHz, and 5.2 GHz). The second antenna will have a single wideband operating frequency from 3.3 GHz to 9.0 GHz and can be switched to a dual-band operating mode (1.57 GHz and 2.4 GHz). Note that the multiband mode is not within the wideband operating frequency range as in the first antenna design. The third antenna will be designed to have multiband and wideband modes to operate either simultaneously or individually. All of the antennas are designed and simulated using the Computer Simulation Technology (CST) Studio Suite software.

All the antennas will be fabricated into two sets of switches which are ideal and real switches set. Ideal switch using copper strips is used as a first approximation to prove that the antenna can be reconfigured. Meanwhile, real switch using PIN diode is used as the real implementation of antenna in the future. After the fabrication process, the antennas will be tested and measured using appropriate equipment. Both simulated and measured results in terms of S_{11}, radiation pattern and gain performances will be analysed. It is to ensure that the antenna can be used in the multimode communication system applications i.e., small base station that required the applications such as in GPS, WLAN, Bluetooth, LTE, WiMAX, as well as S-band and C-band applications.

1.5 Thesis Outline

The thesis is composed of seven chapters. As an overview, the first chapter describes the introduction to the research project. A brief introduction of a reconfigurable antenna, the project's problem statement, and the research project's objectives and scope are presented.

A literature review of non-reconfigurable and reconfigurable antennas is discussed thoroughly in the second chapter. Previous works on both types of antennas are presented and reviewed. The discussions are mainly focusing on how the antennas work to achieve narrowband, multiband or wideband modes. Also, the reviews of band-pass filters are included to realise harmonic rejection functionality to the designed antenna

The methodology of the research project is discussed in the third chapter. In this chapter, the flow chart shows the method or process to conduct the research project with a detailed explanation of the simulation, fabrication and measurement process.

The fourth chapter presents the first frequency reconfigurable antenna design known as Antenna A. The proposed antenna is capable of operating either in multiband or wideband mode through switches. The switchable multiband mode is set within the wideband mode frequency range. The designed antenna can cleverly combine two radiating elements without increasing the original size. Potentially, the antenna can also have six additional reconfiguration modes by placing the switches at specific parts of the antenna structure.

Chapter five presents the second design of a switchable multi-to-wideband antenna known as Antenna B. As opposed to the first design, the multiband mode is now designed at 1.57 GHz and 2.4 GHz, which is outside the wideband mode operating frequency ranging from 3.5 GHz to 9.0 GHz. Besides, a band-pass filter is also incorporated to suppress the harmonic frequency of the multiband mode operation.

Chapter six presents the third design of the frequency reconfigurable antenna, called as Antenna C, where the multi-and-wideband modes can operate either simultaneously or just one mode at a time. A new single bowtie structure is designed to achieve the new modes of operation. The method employed in this design is opposite to the combination method used and employed in Chapters 4 and 5, respectively.

The final chapter discusses the conclusions of the research project. Limitations of this research are addressed. Potential future work to improve all the shortcomings encountered in this research project is mentioned.

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LIST OF PUBLICATIONS

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