FREQUENCY RECONFIGURABLE TAPERED SLOT ANTENNAS FOR WIDEBAND NARROWBAND AND MULTIBAND APPLICATIONS

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To my beloved parents: “Shamsedin Chagharvand & Farah Heidari” and my beloved brothers “Ali & Amin and Farshad”

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ABSTRACT

Presented in this thesis are reconfigurable tapered slot antennas for wideband-narrowband and wideband-multiband reconfigurations. The presented approaches give benefits in reducing the interference level at the receiver. These reconfigurations enable RF front end to have better flexibility in wireless communication systems. After compiling considerable research on previous similar schemes in the literature, five new reconfigurable tapered slot antennas are presented and discussed, in order to contribute to the present state of knowledge in the field. Firstly, a wideband to narrowband reconfiguration is proposed by using a switched feed technique. The second design integrates wideband and multiband operations using a resonator technique. This antenna is capable of wideband, dual-band and triple-band functionalities. In the third design, a wide to multiband operation is achieved by using an internal loading technique. This is done by feeding the tapered slot antenna with a coplanar waveguide (CPW) to slot-line transition feed incorporating matching stub. The fourth design is a wide and a multiband antenna using dual port technique. The advantage of using this technique enables it to operate wideband and multiband function simultaneously. The fifth and final approach is the best proposed design. The design shows an improved structure of wideband tapered slot antenna that can switch to multiband slot dipole antenna using single port. The main advantage of this design is that multiband (single, dual and triple) operations are easily obtained and have shown to be more flexible in obtaining different operating frequency bands. The design has adopted in and out part of the antenna technique to achieve the frequency reconfiguration. The superiority of the proposed design over the other designs is stable radiation pattern in almost all different operating modes. The wideband frequency range is from 1-3.7 GHz. The resonance frequency of the single-band is at 2.4 GHz. In the dual-band, the resonance frequency of the first band is at 2.1 GHz, while the second resonance frequency is at 3.2 GHz. The low, mid and high resonance frequencies of the triple-band are at 1.5 GHz, 2.5 GHz, and 3.3 GHz, respectively. This design supports applications such as Global System for Mobile Communication (GSM), Universal Mobile Telecommunications System (UMTS), Wireless Fidelity (WiFi), Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX) and Long-Term Evolution (LTE) bands.

ABSTRAK

Tesis ini membentangkan konfigurasi antena untuk konfigurasi semula jalur lebar-jalur sempit dan jalur lebar-berbilang jalur. Pendekatan yang dibentangkan memberikan manfaat di dalam mengurangkan kadar gangguan di penerima. Implikasi ini membantu RF bahagian hadapan untuk mempunyai lebih banyak boleh ubah di dalam sistem komunikasi tanpa wayar. Selepas mengumpul kajian yang mencukupi untuk skim yang serupa di dalam penulisan sebelum ini, lima antena boleh konfigurasi semula baharu dibentangkan dan dibincangkan, supaya dapat memberikan sumbangan kepada bidang pengetahuan semasa. Yang pertama, antena slot tirus jalur lebar kepada jalur sempit dengan menggunakan teknik penukaran suapan dicadangkan. Reka bentuk yang kedua diintegrasikan daripada operasi jalur lebar kepada jalur sempit dengan menggunakan penyalun. Antena yang dicadangkan berupaya menyediakan jalur lebar, dwi jalur dan tiga jalur. Bagi reka bentuk yang ketiga, operasi jalur lebar kepada berbilang jalur dicapai dengan menggunakan teknik muatan dalaman. Hal ini dilakukan dengan menggunakan peralihan suapan pandu gelombang sesatah (CPW) kepada garis slot menggunakan puntung sepadan. Reka bentuk yang keempat ialah antena berjalur lebar dan berbilang dengan menggunakan teknik dwi pangkalan. Kelebihan menggunakan teknik ini adalah untuk mengendalikan fungsi operasi jalur lebar dan berbilang secara serentak. Reka bentuk kelima dan terakhir adalah reka bentuk yang terbaik dicadangkan. Reka bentuk ini menunjukkan tambah nilai kepada struktur antena jalur lebar slot tirus yang boleh bertukar kepada antena slot dwi kutub pelbagai jalur menggunakan port tunggal. Kelebihan utama reka bentuk ini adalah bahawa operasi pelbagai jalur (satu, dua dan tiga) mudah dijalankan dan menunjukkan ianya lebih fleksibel dalam mendapatkan jalur frekuensi operasi yang berbeza. Reka bentuk ini mengguna pakai teknik masuk dan keluar sebahagian antena untuk mencapai konfigurasi semula frekuensi. Kelebihan reka bentuk yang dicadangkan berbanding reka bentuk yang lain adalah corak sinaran stabil dalam hampir semua mod pengendalian yang berbeza. Julat frekuensi jalur lebar ialah 1-3.7 GHz. Jalur tunggal pula pada 2.4 GHz. Dalam dwi-jalur, jalur yang pertama adalah pada 2.1 GHz, manakala jalur yang kedua ialah pada 3.2 GHz. Jalur rendah, pertengahan dan tinggi untuk tiga jalur adalah pada 1.5 GHz, 2.5 GHz dan 3.3 GHz, masing-masing. Reka bentuk ini menyokong aplikasi seperti Sistem Global untuk Komunikasi Mudah Alih (GSM), Sistem Telekomunikasi Mudah Alih Universal (UMTS), Fideliti Tanpa Wayar (WiFi), Rangkaian Setempat Tanpa Wayar (WLAN), Saling Kendali Rangkaian Satelit Sedunia untuk Capaian Gelombang Mikro (WiMAX) dan jalur Evolusi Jangka Masa Panjang (LTE).

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LIST OF ABBREVIATIONS

CPW	-	Coplanar Waveguide
CST	-	Computer Simulation Technology
DC	-	Direct Current
EM	-	Electromagnetic
FR4	-	Fire Retardant Type 4
FIT	-	Finite Integration Technique
GPS	-	Global Positioning System
GSM	-	Global System for Mobile Communication
Gas FET	-	Gallium Arsenide Field Effect Transistor
LTE	-	Long-Term Evolution
MEMS	-	Micro Electro Mechanical System
PIN Diode	-	Positive Intrinsic Negative Diode
PIFA	-	Planar Inverted F Antenna
Q-factor	-	Quality factor
RMTSA	-	Reconfigurable Multiband Tapered Slot Antenna
SMA	-	Sub Miniture Version A
SMD	-	Surface Mounted Devices
TSA	-	Tapered Slot Antenna
UV	-	Ultra Violet
UMTS	-	Universal Mobile Telecommunications System
VNA	-	Vector Network Analyzer
WiFi	-	Wireless Fidelity
WiMAX	-	Worldwide Interoperability for Microwave Access
WLAN	-	Wireless Local Area Network

LIST OF SYMBOLS

BW	-	Bandwidth
f_r	-	Reference frequency
Q	-	Q-factor
C	-	Capacitance
ε_0	-	Permittivity of free space
A	-	Surface area
d	-	Distance between the capacitance plates
λ_g	-	Guide wavelength
λ_0	-	Free space wavelength
ε_r	-	Relative permittivity
θ_u	-	Upper angular width
θ_l	-	Lower angular width
HPBW	-	Half power beam width
L	-	Total length of slot arm
f	-	Frequency
K	-	Ratio
j_i	-	Bessel
N_i	-	Neumann

APPENDICES

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The rapid expansion of electronics and wireless communication systems has created multiple wireless applications and standards. Reconfigurable antenna is proposed in order to provide multi-functionality for wireless communication systems. The fundamental characteristics such as operating frequency, radiation pattern and polarization are reconfigured to accommodate modifications in the operating arrangement. The most important advantages of reconfigurable antenna over typical antenna are: a) the ability to tune the antenna operating frequency over a band, b) filtering capability to remove interfering signals and c) their ability to tune the antenna in a new operating environment [1].

After the introduction of cognitive radio systems, interest in reconfigurable antennas, wideband and multiband antennas has considerably increased. Two types of architecture have been proposed in cognitive radio systems. The first one uses a single wideband antenna for both sensing of the spectrum and communication link. The second uses a wideband antenna for spectrum sensing and a reconfigurable antenna for the communication link [2]. Reconfigurable antennas offer significant advantages for wireless communication systems compared to wideband and multiband antennas, such as compactness and flexibility. A considerable number of reconfigurable antennas with narrowband switching capabilities have been discussed in [3-15]. Wideband-to-narrowband reconfigurable antennas [16-18], providing multi-functionality, have great potential to be used in cognitive radio systems. In [19-21], wideband-to-multiband reconfigurable antennas were presented. In cognitive radio systems, a reconfigurable antenna is required for the communication link [22-24].

1.2 Problem Statement

Recently, there has been an increasing demand to have a wide bandwidth antenna for wireless application. To suit this demand, Tapered Slot Antenna is considered since it represents a highly potential technology for wideband operations. TSA has some advantages compared with other type of antenna such as it is a surface wave antenna, has a wideband characteristic, high directivity and very low profile. However, since interference from different resonance frequencies is always associated in wideband antenna, frequency reconfigurable antennas are highly vital for pre-filtering capability of the interference level at the receiver. Current TSAs have low flexibility to suit the demand of the system. Most of them are fixed in frequency and some of them capable to provide wideband to narrowband operations by incorporating band-pass resonator technique. Narrowband functions confine one operation at a time which not suitable for current communications trend. This has to be solved and new techniques rather than band-pass resonator technique shall be introduced. The drawback of band-pass resonator technique is that only narrowband operation can be provided. Currently there is no frequency reconfigurable TSA that can switch frequency from wideband to multiband operation. The work in this thesis describes five techniques to fill this gap.

1.3 Research Objectives

The main objectives of this research are as follows:

i. To incorporate a narrowband function and control the bandwidth of a wideband tapered slot antenna
ii. To add the multiband function into a wideband tapered slot antenna
iii. To employ several reconfiguration techniques; namely switched feed, band-stop resonator, internal loading, and switching in and out part of the antenna
iv. To combine wideband tapered slot antenna and slot dipole antenna using single and dual ports

1.4 Scope of Research

The scope for each objective is presented below, within anticipated border lines to support the aim of this research.

The aim of this work is to incorporate narrowband and multiband functions into a wideband tapered slot antenna. Therefore, it is necessary to study and understand the fundamental behavior of the tapered slot antenna. There are several types of tapered slot antenna which are categorized based on their feeding technique: namely microstrip to slot-line transition feed, CPW to slot-line transition feed incorporating delay line, CPW to slot-line transition feed incorporating matching stub and antipodal feed network**.** However, this work will only focus on CPW to slot-line transition feeding structures due to the ease of fabrication and simple manipulation of the delay line and matching stub so that wideband to multiband operation is achieved.

There are several techniques which can be adopted to achieve frequency reconfigurability. However, the most common technique (and possibly the only technique used so far in a tapered slot antenna) employs band-pass resonators. To fill this gap therefore, various techniques will be proposed and used as follows: switched feed, band-stop resonator, internal loading, dual port and switching in and out part of the antenna. In addition, a dual ports structure - with a combination of slot dipole and tapered slot antennas - will also be developed. Therefore, it is also necessary to study and understand the fundamental behavior of the slot dipole antenna.

To achieve frequency reconfiguration electronically, RF switches are used. There are various types of RF switches; such as PIN diodes, MEMS and FETs. In this work, all proposed antennas were developed using PIN diode switches, since they have strategic advantages over MEMS and FETs - such as fast switching speeds, and are easy to fabricate. Moreover, they are readily available on the market. Since the PIN diode switches used in this work cover the range of frequencies up to 6 GHz, all the proposed antennas operating frequencies are therefore designed within this limit. All numerical solutions are obtained using CST's 3D simulator.

1.5 Outline of Thesis

In Chapter 1, a brief introduction is given on frequency reconfigurable antenna. This is followed by motivation for the work, the scope of the research and the research objectives.

Chapter 2 presents the backgrounds of the frequency reconfigurable antenna and tapered slot antenna. Previous studies on frequency reconfigurable antennas, including narrowband-to-narrowband, wideband-to-narrowband and wideband-to-multiband are then discussed and summarized.

Chapter 3 describes the methodology of the research. The flow of the studies is presented, and the main two phases of the study are reported. The designs and simulations are explained in the first phase of study in detail. The fabrication and measurement of the antenna are fully discussed in the second phase of the study.

Chapter 4 presents a wide-to-narrowband frequency reconfigurable antenna. A frequency reconfigurable tapered slot antenna, with a bandwidth control and a switchable frequency band characteristic, is discussed. A switched feed technique is then introduced, and the placement of switches on the delay line is discussed.

Chapter 5 presents a reconfigurable multiband tapered slot antenna using a band-stop resonator technique. The antenna consists of a T and C-shaped resonator to produce frequency reconfiguration. Switches are placed on the edge of the V opening slot to produce three different operations. The designed antenna is suitable to be used as a base station antenna for cognitive radio systems.

Chapter 6 describes a wide-to-multiband frequency reconfigurable slot-line feed tapered slot antenna. The proposed antenna consists of two rectangular slits and a cone shaped matching stub. An internal loading technique is used in designing this antenna.

Chapter 7 initiates the combination of two antennas into a single antenna, in order to improve the system space. A dual port antenna for both wide and narrowband applications is discussed. The proposed antenna system consists of two antennas; a tapered slot and a dipole antenna. The tapered slot antenna has a wideband width, while the dipole antenna is able to reconfigure multibands. The dual port technique is used in this design to obtain the wide and narrowband operations. In the final design, the two configurations discussed above are merged to produce a single port design. Wide-to-multiband operation is achieved by using switching in and out part of the antenna technique. This design is a merger of the previous design using single port, and possesses strong potential for applications in reconfigurable mobile terminals and base stations.

Chapter 8 concludes the thesis and suggests areas for future work. It includes the achievements accomplished and reviews the basic objectives of this work. Moreover, the challenges those are still to be addressed in the future are highlighted in this chapter. These could be potential areas of research for the upcoming wireless technologies.

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