UNIVERSITI PUTRA MALAYSIA

COMPACT MICROSTRIP BANDPASS FILTERS USING COUPLED SPIRAL RESONATOR AT 2.3 GHz

ADAM REDA HASAN ALHAWARI

FK 2009 15

COMPACT MICROSTRIP BANDPASS FILTERS USING COUPLED SPIRAL RESONATOR AT 2.3 GHz

By

ADAM REDA HASAN ALHAWARI

Thesis Submitted to the School Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

August 2009

DEDICATION

إلى من قال الله تعالى فيهم: "**وَقَضَى رَبُّكَ أَلاَّ تَعْبُدُوا إِلاَّ إِيَّاهُ وَبِالْوَالِدَيْنِ إِحْسَاناً إِمَّا يَبْلُغَنَّ عِنْدَكَ الْكِبَرَ أَحَدُهُمَا أَوْ كِلاهُمَا فَلا تَقُلْ لَهُمَا أُفٍّ وَلا تَنْهَرْهُمَا وَقُلْ لَهُمَا قَوْلاً كَرِيماً * وَاخْفِضْ لَهُمَا جَنَاحَ الذُّلِّ مِنَ الرَّحْمَةِ وَقُلْ رَّبِّ ارْحَمْهُمَا كَمَا رَبَّيَانِي صَغِيراً " الاسراء 23-24**

To my ever-loving parents…

To my beloved wife…

To my dearest siblings…

To my caring parents in laws…

To every kind pious person who loves universal peace and prosperity…

To those who are patient towards tyranny and oppression…

To those who love knowledge and are pursuing it for world positive change…

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

COMPACT MICROSTRIP BANDPASS FILTERS USING COUPLED SPIRAL RESONATOR AT 2.3 GHz

By

ADAM REDA HASAN ALHAWARI

August 2009

Chairman: Dr. Alyani Binti Ismail, PhD

Faculty: Engineering

Microstrip filters are essential components utilized in the RF/Microwave applications because of their low loss and simple structure. Moreover, it can be fabricated using simple printed circuit technology and characterize main advantages in RF/Microwave filters like high performance, light weight and low cost which the fast track of continuous evolution in wireless communication systems highly demands.

This thesis presents design and development of three different microstrip bandpass filters (BPFs) for high selectivity applications. A fourth order microstrip BPF was designed using Chebychev lowpass prototype with passband ripple of 0.05 dB and bandwidth of 120 MHz, which operates at center frequency of 2.3 GHz. This filter is designed by using coupled spiral resonator, where these types of resonator structures simplify the design method for microstrip BPF and yet more efficient. This filter

design is then rearranged and modified by using square spiral resonator structures and embedded-resonator topology with the same fundamental frequency to make it more compact; furthermore, it has high quality performance in terms of the frequency responses.

All the microstrip BPF designs were developed and analyzed by a 3-D electromagnetic simulator. To confirm the simulation results, the three proposed filters are fabricated on R/T Duroid 5880 with dielectric constant of 2.2. The Experimental measurements are carried out using an Agilent N5230A network analyzer. The simulated and measured results are presented, compared and discussed. The analysis indicates a fairly good agreement between simulation and measurment. Finally, compact microstrip BPFs which could demonstrate high quality performance are thoroughly investigated.

In this design, the minimum measured insertion loss is 2.65 dB, and the measured return loss is greater than 11 dB in the passband operating at 2.3 GHz, with a fractional bandwidth of 5.2% with two transmission zeros on both sides of the passband. The total size of this layout is 24.74 x 21.2 mm^2. This new filter provides a significant size reduction of more than 30% and 18%, with respect to the conventional microstrip BPFs and the recently reported bandpass filter by Wang and others in 2008, respectively, at the same center frequency.

Later, multilayer technology is used to reduce more than 25% of the filter size; which is much smaller compared to the microstrip filters using single layer structure. The new filter structure consists of four spiral resonators placed on two stacked layers where the metallic ground plane is deposited onto bottom surface of the dielectric. The measured minimum passband insertion loss is 5.2 dB with measured return loss is no more than -17 dB in the passband. The overall filter size is 380 mm^2, which is approximately 10% smaller compared to the multilayer filter reported by Denidni and Djaiz in 2005. It is also reduced more than 25% and 41% compared to our proposed single layer microstrip filter and bandpass filter reported by Wang and others in 2008, respectively, at the same center frequency.

It is a promising product to attract usage in modern wireless communication system applications which demand compact size bandpass filters at very low insertion loss but high selectivity, and good out-of-band rejection.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENURAS LOLOS LALUAN JALUR MIKRO PADAT MENGGUNAKAN PENYALUN PILIN BERPASANGAN PADA 2.3 GHz

Oleh

ADAM REDA HASAN ALHAWARI

Ogos 2009

Pengerusi: Dr. Alyani Binti Ismail, PhD

Fakulti: Kejuruteraan

Penuras jalur mikro adalah komponen yang sangat penting kepada aplikasi Frekuensi Radio/Gelombang Mikro kerana faktor natijah kehilangan kuasa yang rendah dan strukturnya yang ringkas. Malahan, ia boleh difabrikasi menggunakan teknologi litar bercetak yang menyumbang ciri – ciri kelebihan utama kepada penuras Frekuensi Radio/Gelombang Mikro seperti berprestasi tinggi, ringan, dan kos yang rendah untuk membuatnya yang menjadikannya dambaan arus deras aliran evolusi sistem komunikasi tanpa wayar.

Tesis ini membentangkan rekabentuk dan penghasilan tiga (3) penuras lolos laluan jalur mikro BPF yang berbeza untuk aplikasi pilihan tinggi. Satu penuras jalur mikro dengan empat (4) penyalun direka menggunakan prototaip laluan rendah Chebychev dengan riak lolos laluan 0.05 dB dan lebar lolos jalur 120 MHz, yang beroperasi

pada pusat frekuansi 2.3 GHz. Penuras ini direka menggunakan penyalun pilin berpasangan; struktur penyalun jenis ini meringkaskan kaedah menghasilkan rekaan penuras jalur mikro BPF tetapi ianya amat efisien. Rekaan penuras ini kemudiannya disusun atur semula dan diubahsuai menggunakan struktur penyalun pilin empat segi dan topologi penyalun terbenam dengan asas frekuensi yang sama untuk menjadikannya lebih padat. Jika dibandingkan dengan penuras jalur mikro BPF konvensional, penuras yang dicadangkan berupaya mengurangkan 30% daripada saiz keseluruhan struktur.

Kesemua rekaan jalur mikro dicipta dan dianalisa dengan bantuan simulasi elektromagnetik 3-dimensi. Untuk mengesahkan keputusan simulasi, ketiga – tiga penuras yang dicadangkan itu difabrikasi di atas substratum R/T Duroid 5880 dengan kemalaran dieletrik pada 2.2. Keputusan ujikaji diperolehi dengan menggunakan sebuah mesin penganalisa rangkaian jaringan Agilent N5230A. Natijah simulasi dan keputusan ujikaji dibentangkan, dibandingkan dan dibincangkan. Analisa menunjukkan keserasian yang agak bagus di antara simulasi dan natijah ujikaji. Hasilnya, penuras jalur mikro BPF yang mampu menonjolkan prestasi berkualiti tinggi telah dikaji dengan jayanya.

Dalam rekaan ini, kiraan minimum kehilangan insersi ialah 2.65 dB, dan nilai kehilangan kembali adalah 11 dB lebih besar berbanding jalur lolos yang beroperasi pada 2.3 GHz dengan nilai lebar 5.2% jalur fraksional dengan 2 transmisi sifar pada kedua-dua belah jalur lolos. Saiz keseluruhan tata letak ini ialah 24.74 x 21.2 mm^2. Penuras baru ini menjanjikan pengurangan saiz yang amat ketara sehingga lebih daripada 30% pada penuras jalur mikro konvensyenal dan 18% pada penuras jalur lolos yang dilaporkan baru-baru ini oleh Wang dan lain-lain pada tahun 2008, masing-masing pada pusat frekuensi yang sama.

Kemudian, teknologi pelbagai lapis digunakan bagi mengurangkan 25% lagi daripada saiz penuras agar lebih kecil daripada penuras jalur mikro yang menggunakan teknologi selapis. Struktur penuras baru ini terdiri daripada empat (4) penyalun pilin yang diletakkan pada dua lapisan berperekat di mana satah dasar metalik dilekatkan di bahagian bawah permukaan dielektrik. Kiraan minimum kehilangan insersi jalur lolos ialah 5.2 dB dengan kehilangan kembali tidak lebih daripada -17 dB pada jalur lolos. Saiz keseluruhan ialah 380 mm^2, iaitu lebih kurang 10% lebih kecil berbanding penuras pelbagai lapis yang dilaporkan oleh Denidni dan Djaiz pada tahun 2005. Ia juga berkurangan lebih daripada 25% dan 41% berbanding penuras mikro selapis kami dan penuras jalur lolos yang dilaporkan oleh Wang dan lain-lain pada tahun 2008, masing-masing pada pusat frequensi yang sama.

Ia adalah satu prospek produk yang menarik untuk digunakan dalam aplikasi sistem komunikasi tanpa wayar moden yang membutuhkan saiz jalur lolos yang kompak pada kehilangan insersi yang lebih rendah tetapi berselektiviti tinggi dan rejeksi luar jalur yang baik.

ACKNOWLEDGMENTS

First and foremost, my greatest gratitude goes to the Most Merciful Allah S.W.T. who Granted me the opportunity to pursue my second degree study in Malaysia.

I am also so grateful to have a very supportive, helpful, encouraging and patient family members; which helps a lot to accomplish this completion of the assigned thesis. My special thanks are due to my beloved wife for being understanding and cooperative.

Last but not least, my due appreciation to my generous supervisor: Dr. Alyani binti Ismail for her objective guidance and firm support; which I am at lost without it. I am in a way indebted to my best friends and lab-mates for their kind assistance especially in sharing information, skills and experience.

I certify that an Examination Committee met on 14th August 2009 to conduct the final examination of Adam Reda Hasan Alhawari on his thesis entitled "Compact Microstrip Bandpass Filters Using Coupled Spiral Resonator at 2.3 GHz" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Examination Committee were as follows:

Sabira Khatun, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Ahmad Fauzi Abas, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Mohd Nizar Hamidon, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Mohamad Kamal A. Rahim, PhD
Associate Professor
Faculty of Electrical Engineering
Universiti Teknologi Malaysia
(External Examiner)

BUJANG KIM HUAT, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Alyani Binti Ismail, PhD
Senior Lecturer
Department of Computer and Communication System Engineering
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Raja Syamsul Azmir Bin Raja Abdullah, PhD
Senior Lecturer
Department of Computer and Communication System Engineering
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohd. Fadlee Bin A. Rasid, PhD
Senior Lecturer
Department of Computer and Communication System Engineering
Faculty of Engineering
Universiti Putra Malaysia
(Member)

HASANAH MOHD. GHAZALI, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 16 November 2009

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

ADAM REDA HASAN ALHAWARI

Date: 08 September 2009

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BPF	Bandpass Filter
CSR	Coupled Spiral Resonators
dB	Decibels
DUT	Device Under Test
EM	Electromagnetic Spectrum
FBW	Fractional Bandwidth
GHz	Gigahertz
GSM	Global System for Mobile Communications
HTS	High-Temperature Superconductivity
MEMS	Micro-Machining or Microelectromechanical Systems
MHz	Megahertz
mm	Millimetre
MMICs	Monolithic Microwave Integrated Circuits
PCB	Printed Circuit Board
RF	Radio Frequency
SIR	Stepped Impedance Resonator
S-parameters	Scattering parameters
SSR	Square Spiral Resonator
TEM	Transverse Electromagnetic Mode
UIR	Uniform Impedance Resonator
VNA	Vector Network Analyzer
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

CHAPTER 1

INTRODUCTION

1.1 Background

Current fast track technological advancement has turned gregarious human to rely on various microwave or RF devices and gadgets in daily communications. Devices like microwave filters, antenna, amplifiers, switches, etc. have become civil and military utter telecommunication necessity of contemporary lifestyle.

Recent progress witnesses strong demand from communications industry for creative innovation of more compact microwave devices which are capable to outperform previous technology. Among the most demanded in the microwave devices list is microwave filter which is used most in wireless communication technology to provide a more highly sought after telecommunication efficiency beyond typical imagination.

In wireless communication systems, microwave filters are vital components and play important roles in many RF/Microwave applications. Bandpass filters are essential components utilized in the RF/Microwave and wireless communication systems, which are usually found in both transmitters and receivers to discriminate between intended and unintended signal frequencies. In other words, they are used to select or reject RF/Microwave signals within assigned spectral limits. Evidently, the quality of bandpass filters is extremely important to acquire precise desired frequency.

As far filter technology went throughout history since its advent before the burst of world War II, it had produced various typical technologies like lumped-element LC filters, planar filters, coaxial filters, cavity filters, dielectric filters, and high-temperature superconductivity (HTS) filters. Among them, the planar technology is the most immensely used in improving the compactness of the filter size and has a more promising future ahead mainly because it is the easiest to fabricate especially ones using printed circuit technology at minimum cost production compared to other technologies mentioned but still could compromise quality performance.

There are many types of planar filter designs had been created like parallel-couple line topology proposed by Cohn, which is the most commonly used filter (Cohn, 1958). Several configurations were then introduced to make the filters more compact like hairpin resonator filters and open-loop resonator filters, and are widely used in many wireless communication applications due to their smaller size compared to the conventional coupled-line resonator filters.

1.2 Statement of Problem and Motivation

Modern microwave communication systems demand low cost, high performance narrowband bandpass filters which characterize low insertion loss, high selectivity and out-of-band rejection together with optimized size reduction especially in wireless communication system applications such as worldwide interoperability for microwave access (WiMAX), wireless local area network (WLAN) and global system for mobile communications (GSM). Recent advancement in materials and technologies such as high-temperature superconductors (HTS), micro-machining or microelectromechanical systems (MEMS) and hybrid or monolithic microwave integrated circuits (MMICs) has stimulated the development of new compact microstrip filters (Hong and Lancaster, 2001).

Miniaturization of microwave filters is one of the fundamental requirements in communication systems. Therefore, small-size and high performance filters are always necessary to reduce cost and enhance system performance. To meet these demands, intensive research efforts have been focused on achieving compact low loss bandpass filters for wireless system applications using parallel coupled-line resonator filters (Fok et al., 2005; Lin et al., 2005; Chen and Wang, 2009), hairpin resonator filters (Kuo et al., 2004; Denidni and Djaiz, 2005; Hasan and Nadeem, 2008; Liu and Li, 2008), open-loop resonator filters (Hong and Lancaster, 1999 and 2000; Romani et al., 2007; Zhang et al., 2007), and coplanar waveguide (CPW) filter (Ismail et al., 2008). However, the size of planar filters with parallel coupled-line resonators, hairpin resonators, open-loop resonators or coplanar waveguide (CPW) filters design is obviously still too large to adapt the demand of modern systems, moreover, would add complexity to some designs and therefore, very difficult to be tuned into the right operating frequency (Clavet et al., 2007; Militaru et al., 2007).

In addition to compact size, less weight, high selectivity, and low losses, other desirable features of microstrip bandpass filters are low cost and narrowband. So, in this thesis, the inspired design is to utilize the microstrip spiral resonators instead of its frequent usage in HTS technology; due to its cost and fabrication problems (Huang, 2001; Huang and Xiong, 2003; Zhang et al., 2005a and 2005b; Ono et al., 2007; Abu-Hudrouss et al., 2008).

Thus, the need for size reduction and lower fabrication cost are critical issues in RF/Microwave filters development. Consequently, more creative researches are needed to find effective designs to achieve the above mentioned demanded characteristics of modern filters and to get precise measurement as closest as possible to the ideal accuracy in the whole design process.

These ideals were found in one of the literature review referred (Wang et al., 2008), which had ignited interest to investigate similar design specifications e.g. four-pole bandpass filter design using embedded–resonator topology which is more compact than other designs existed. Motivated by their creative design, this study reaches out for a wider exploration on various design possibilities in order to achieve better modifications especially in terms of frequency responses, losses and selectivity performance. Their filter topology with Chebychev response could not respond at par with elliptic response, since in comparison it does not produce skirts as sharp as the elliptic one.

Most of the present wireless communication system applications screened are below 3 GHz (Bahl, 2003). In this spectrum, achieving narrowband bandpass filters (BPFs) that yield high quality performance at smaller size and lower cost is a challenging task. Hence, this research specifically aims to design a lower loss microstrip four-pole BPFs which is capable to meet the required specifications of wireless communication systems. Compact novel microstrip BPFs designs using coupled spiral resonator principle with Chebychev and elliptic responses are developed to achieve a prospect practical solution for pre-select filters in a base station of wireless communication systems with sharp rejection and adequate fractional bandwidth.

1.3 Research Objectives

The aim of this research is to study and develop new filter designs that could avoid size and precision problems but tackling them to perform well at a very low cost which is useful prospect for wireless communication system applications. Research objective is to produce and develop four-pole microstrip BPFs using coupled spiral resonator structures for high selectivity applications.

The thesis is built around three main objectives:

1. To design a novel compact microstrip BPFs using single layer structure at center frequency of 2.3 GHz.
2. To design a novel compact microstrip BPF using multilayer technology at center frequency of 2.3 GHz.
3. To simulate, fabricate and measure the filters responses.

Finally, the synthesis and design of new compact microstrip BPFs is conducted. The resulting BPFs should be easier to design with excellent performance.