UNIVERSITI PUTRA MALAYSIA

COMPACT BANDPASS FILTERS USING DUAL-MODE MICROSTRIP CLOSED-LOOP RING RESONATORS FOR WIRELESS COMMUNICATION SYSTEMS

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By

BABAK KAZEMI ESFEH

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

August 2009

DEDICATION

TO

MY BELOVED PARENTS

ABSTRACT

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

COMPACT BANDPASS FILTERS USING DUAL-MODE MICROSTRIP CLOSED-LOOP RING RESONATORS FOR WIRELESS COMMUNICATION SYSTEMS

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Chairman: Alyani Ismail, PhD

Faculty: Engineering

Microwave filters have important role in many wireless and communication systems such as satellite and cellular mobile organizations. In such kind of systems, factors such as compact size, low cost, light weight, high performance, and low loss in designing of microwave filters are of primary importance. In comparison with waveguide filters, microstrip filters are smaller and in such applications mentioned before there are needs to have smaller microstrip filters.

In this thesis, filters using dual-mode ring resonators is proposed, because they can be designed easier than the other kind of microwave filters and are more compact. In this thesis, a new compact form of dual-mode microstrip octagonal loop resonator filter is proposed in two forms; conventional and compact. These structures are designed to operate at WiMax frequency of 2.3 GHz with a 5% fractional bandwidth. The new dual-mode resonator will be produced by adding a rectangular patch inside the loop resonator. The experimental results and simulated values are presented and show good agreement.

The filter is fabricated on CER-10 substrate having a relative dielectric constant of 10 and 0.64 mm thickness. The primary dimension of the filter is 15.8 mm×15.8 mm and the measured minimum insertion loss is 1.68 dB and return loss is better than -20 dB. After minimization and compressing the filter structure, the final dimension is reduced to 9.1 mm×9.1 mm. The minimum insertion loss in this structure is 1.52 dB and the return loss is better than -20 dB. In the final design in addition to size reduction (about 42%), feed lines structure is changed from orthogonal to straight line form, which are more desirable in microwave networks. This new design is reduced in size by approximately 25% compared to the conventional square loop dual-mode filter. By using meander square loop structure more reduction in size (about 27%) can be achieved but this filter configuration has a weak frequency response including high passband insertion loss (more than 2.6 dB) and return loss less than -12dB at the same center frequency. Therefore its performance is less than the dual-mode filter proposed in this thesis.

Apart from WiMax, this model of filters is also useful for WLAN and mobile communication applications, because it is compact in size, low loss and has good performance due to its elliptic response with sharp rejection and adequate fractional bandwidth.

ABSTRAK

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

PENURAS LULUS JALUR KOMPAK MENGGUNAKAN PENYALUN MIKROSTRIP GELUNG PUSINGAN TERTUTUP DUA MOD UNTUK SISTEM KOMUNIKASI TANPA WAYAR

Oleh

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Penapis mikrogelombang mempunyai banyak peranan dalam sistem wayarles dan sistem komunikasi seperti satelit dan sistem telefon mudah alih. Dalam sistem tersebut, faktor dalam sesuatu rekaan penapis mikrogelombang adalah sangat penting dan perlu diambilkira. Saiz yang bersesuaian, harga yang berpatutan, ringan, kualiti yang tinggi, dan hingar yang rendah adalah antara faktor yang diperlukan untuk meningkatkan mutu produk dan mengurangkan kos perlaksanaannya. Saiz penapis mikrogelombang adalah lebih kecil berbanding penapis waveguide. Tetapi, untuk aplikasi tersebut, penggunaan penapis mikrogelombang yang bersaiz kecil sangat bersesuaian. Terdapat banyak permintaan terhadap penapis yang menggunakan penyalun gelang dua mod. Rekaannya adalah lebih ringkas berbanding penapis mikrogelombang yang lain. Dalam tesis ini, satu bentuk penapis dual mode mikrostrip penyalun gelung berbentuk oktagon yang padat dicadangkan dalam dua bentuk iaitu; piawai biasa dan kompak. Struktur ini direka untuk beroperasi pada frekuensi 2.3 GHz sebagai frekuensi WiMax dengan 5% pecahan lebar jalur.

Penyalun dua mod akan dihasilkan dengan menambahkan bahagian berbentuk segi empat tepat di dalam gelung penyalun. Penapis ini telah direka , CER-10 menggunakan substrat yang mempunyai pekali dielektric 10 dan ketebalan 0.64 mm. Struktur asal penapis ialah 15.8 mm x 15.8 mm dan nilai kehilangan sisipan ialah 1.68 dB dan nilai kehilangan pulangan ialah 20 dB. Selepas proses pemadatan dan pengurangan struktur penapis, dimensi penapis dikurangkan kepada 9.1mm x 9.1 mm. Jumlah minimum kehilangan sisipan dalam struktur ini adalah 2.6dB dan kehilangan pulangan lebih tinggi dari 22 dB. Dalam rekabentuk pengurangan saiz di peringkat akhir (dalam 42%), struktur garis masukan ditukar dari bentuk paksi yang bersudut tepat ke bentuk garis lurus, yang lebih diperlukan dalam rangkaian mikrogelombang. Rekabentuk ini juga dibandingkan dengan bentuk penapis piawai biasa gelung segiempat dua mod yang mempunyai pengurangan saiz sebanyak 25%.

Dengan menggunakan struktur segiempat gegelung kekelokan , pengurangan saiz (dalam 27%) boleh dicapai. Tetapi penapis jenis ini mempunyai kelemahan dari segi sambutan frekuensi termasuklah kehilangan sisipan jalur lalu yang tinggi (lebih daripada 2.6 dB) dan return loss kurang daripada -12dB di frekuensi tengah yang sama. Oleh yang demikian, persembahannya adalah kurang memuaskan daripada penapis dual mode yang dicadangkan dalam tesis ini.

Model penapis ini sangat berguna untuk aplikasi WLAN dan sistem komunikasi, kerana saiz yang padat, kehilangan yang rendah, mempunyai keputusan yang baik dalam menapis dan pecahan lebar jalur yang memadai. Keputusan eksperimen dan simulasi yang dicadangkan telah menunjukkan mutu persembahan yang baik.

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Finally, I wish to thank to all my friends especially, Adam, Helmi, Aris and Ayub for their help and support.

APROVAL

I certify that a Thesis Examination Committee has met on (August 7, 2009**)** to conduct the final examination of (Babak Kazemi Esfeh) on his thesis entitled "**Compact Bandpass Filters Using Dual-Mode Microstrip Closed-Loop Ring Resonators for Wireless Communication Systems**" 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 degree).

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

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BABAK KAZEMI ESFEH

Date:

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LIST OF ABBREVIATIONS AND SYMBOL

BPF	Bandpass Filter
CAD	Computer-Aided Design
CPW	Coplanar Waveguide
DBS	Direct Broadcast Satellite
DGS	Defected Ground Structure
EM	Electromagnetic Simulator
FBW	Fractional Bandwidth
GPS	Global Positioning Satellite
HTS	High Temperature Superconductor
LTCC	Low-Temperature Cofired Ceramic
MIC	Microwave Integrated Circuit
MEMS	Microelectromechanic Systems
MMIC	Monolithic Microwave Integrated Circuits
TEM	Transverse Electromagnetic Mode
VNA	Vector Network Analyzer
WLAN	Wireless Local Area Network

LIST OF SYMBOLS

e_0	Permittivity of vacuum
e_r	Relative dielectric constant
e_{eff}	Effective dielectric constant
h	Impedance of free space
m_0	Permeability of vacuum
c	Speed of light in vacuum
S_{11}	Reflection coefficient
S_{21}	Transmission coefficient
l_g	Guided wavelength
Z_0	Characteristic impedance
v_p	Phase velocity
b	Propagation constant
a	Attenuation constant
q	Electrical length
w	Angular frequency
s	Conductivity
g	Complex propagation constant
Q_u	Unloaded quality factor
Q_L	Loaded quality factor

CHAPTER 1

INTRODUCTION

1.1 Background

The majority of applications of today's microwave technology are in communication, radar, environmental remote sensing, military and medical systems. The most universal use of microwave technology is in cellular telephone systems proposed in the 1970s. Global Positioning Satellite (GPS) system and Direct Broadcast Satellite (DBS) system are such successful satellite systems.

After the birth of radar, communication systems using microwave technology began to be developed. Some advantages offered by microwave organizations, including wide bandwidths and line-of-sight propagation, have proved to be important for both satellite and terrestrial communications systems and also have provided the development of low-cost miniaturized microwave components (Pozar, 2005).

Since the electromagnetic spectrum is limited and has to be shared, filters attract so much concern due to their important roles in using the available spectrum efficiently. The main filter functions are to select or limit the RF/microwave signals within assigned spectral limits and to combine or separate different frequencies. Some applications of microwave filters are in wireless and communication systems such as satellite and cellular mobile systems. In these systems more stringent requirements such as higher performance, lighter weight, smaller size and lower cost are desirable. Depending on the requirements and applications, microwave filters may be designed in various transmission line structures such as waveguide, coaxial line and microstrip. In addition, they may be realized as distributed element or lumped element circuits.

1.2 Problem Statement and Motivation

Microwave filters have important role in many wireless and communication systems such as satellite and cellular mobile organizations. In such kind of systems some factors in designing of microwave filters are of primary importance. Compact size, low cost, light weight, high performance, and low loss are some of these factors that are essentially required to enhance the system performance and to reduce the fabrication cost (Pozar, 2005), (Hong, 2001). Parallel-coupled microstrip filters first proposed by Cohn have been used for many years since 1958 (Hasan, 2008). Although they have many advantages such as a wide range of filter fractional bandwidth (FBW) of 5% to 50 %, and simple design procedure, there are still some issues on this type of filters. Major disadvantages of this type of filter include the length of parallel coupled filter that is too long and it further increases with the order of filter. Some techniques have been developed to solve this problem. One of these techniques was using hairpin-line filters including folded $l/2$ resonator structures (Hasan, 2008). Afterwards, microstrip ring resonators in any shape were considered as the building blocks of microstrip bandpass filters and in which they are widely used, because they satisfy the mentioned demands that are essential for microwave filters.

On the other hand, microstrip ring resonators have many interesting characteristics including small size, low fabrication cost, and narrowband (Hsieh, 2000). In 1969, one technique for measuring wavelengths and dispersion characteristics of the relative permittivity of a microstrip line has been done by Troughton (Wolff, 1971) with the help of ring resonators. Microstrip ring resonators are also used for the measurement of phase velocity, and effective dielectric constant. Since no open-end

effects need to be considered in microstrip ring resonators, using them instead of the linear resonator for dispersion measurements is more desirable (Wolff, 1971 and Chang, 1987). In 1970 the theory of the ring resonator has been introduced by Wolff and Knoppik. In this theory, the ring resonator has been considered as a cavity resonator with electric walls on the top and bottom and magnetic walls on the side border. The curvature of the ring affects the resonance frequencies and this effect become larger by using lines with small impedances and substrate materials with small relative permittivity. Therefore, wider resonators are more affected in the higher-order resonances by the curvature, and as the width increases, this influence become larger. For resonators with impedances higher than 20 Ω (for example 50, 90, and 110 Ω) the effective relative permittivity is almost independent of the length of the resonator (Wolff, 1971). Another factor that affects the resonant frequency is the coupling gap. To calculate the coupling gap effects on the resonant frequency, the equivalent circuit of coupling gap that is modeled by a p - network is included in the equivalent circuit of the ring resonator (Chang, 1987). By using this model it can be found that as the coupling gap decreases, the resonant frequency become lower, but for most ranges of the coupling gap size, the influences on resonant frequency are small and negligible (Chang, 1987). The main discussing concept in this thesis is on dual-mode ring resonators. During recent years, they have been more considered and greatly used for microwave bandpass filter in wireless local area network (WLAN) applications and mobile communication systems (Chen, 2007).

Microstrip dual-mode filters have many interesting characteristics, such as narrowband, high Q, easy-to-design, and compact size. The main advantage of these types of filters is that in dual-mode each resonator operates as a doubled tuned resonant circuit and therefore, an n-degree filter can be achieved in more compact

configurations due to the halved number of resonators (Hong, 2001 and Chen, 2007). In addition to using dual-mode filters, there are some other useful methods to achieve a compact size in filter design. One of these techniques is to have different parts of filter bent. This could be the best solution to get more compact sizes especially for filters with stubs and long straight transmission lines.

Ultra-wideband filter reported in (Razalli, 2008) and wideband filter reported in (El-Shaarawy, 2008) are among the structures making use of method of bending the lines. Although miniaturizing of microwave filters can be done by using substrates with high dielectric constant, or lumped element or different transmission lines such as coplanar waveguide (CPW), reduction in size with changing the geometry of the filters using microstrip transmission lines is more desirable. This is because high dielectric permittivity will often introduce more surface waves and losses, and while filters using coplanar waveguide (CPW) can be found in quite compact sizes, however they also introduce more insertion losses. Hence, microwave filters using coplanar waveguide are seldom used in the millimetre-wave range, despite their wide applicability in monolithic microwave integrated circuits (MMICs) due to their ability in easily integrating series and shunt elements and simplicity of fabrication (Ismail, 2008).

In this thesis, by applying dual-mode microstrip closed-loop resonator, a compact narrowband bandpass filter applicable for WiMax and WLAN applications is introduced, designed, fabricated and tested.

Table 1.1: Filter and Resonator specifications for WiMax Application

Parameters	Specification
Fractional Bandwidth, BW_{3dB}	5 %
Center Frequency, f_0	2.3 GHz

Passband Insertion Loss	Less than 3 dB
Passband Return Loss	Better than – 20 dB

The main specifications of this proposed filter is shown in Table 1.1. It is shown that by using proper substrate material and filter structure in octagonal meander closed-loop shape a compact filter with good performance as mentioned in Table 1.1 can be achieved.

1.3 Research Aim and Objectives

This thesis presents a miniaturization technique of microwave filters by using dual-mode microstrip resonators and investigates their performance comparing with other kinds of filter structures. Even though dual-mode filters are essentially small and compact in size, but in many applications such as cellular mobile communication systems, much smaller size is more desirable, therefore some useful techniques can be applied to make the dual-mode filter structure even more compact. The aim of this thesis is to introduce and design a new configuration of compact narrowband bandpass filter with good performance including low insertion loss and return loss, sharp rejection and adequate bandwidth.

To achieve the aim, the main objectives of the thesis are as follows:

1. To design a compact and high performance dual-mode microstrip filter for WiMax applications.
2. To simulate and investigate the frequency response of the filters using an Electromagnetic Simulator software.
3. To fabricate and measure the frequency response of the filter.

1.4 Thesis Scope

As stated earlier, microwave filters are one of the most important parts of the cellular mobile and satellite systems and in this kind of circuits, compactness and high

performance are of primary importance. Of course, some other parameters such as low cost, light weight and low loss have also important role in enhancing the system performance. In the mean time, simplicity of the designing and fabricating of the filter structure is one of the other parameters that can be of an advantage for a filter design.

In this thesis, the narrowband bandpass filter is designed using microstrip dual-mode resonator. The microstrip dual-mode resonator will be constructed of a meander closed-loop in octagonal form. The compactness will be obtained by using dual-mode resonator and by using the dual-mode closed-loop resonator in meander form in which more compact structure can be achieved. Using the microstrip line as the transmission line in this filter design can make design calculation easy. By choosing the closed-loop resonator in octagonal form the curvature effects is decreased, compare with that in similar filter structures designed in square loop shape. The substrate material used has good characteristics that can support the mentioned demands such as low loss, light weight and low cost. Its high dielectric constant also helps to have more compact size. Of course by using better materials with lower loss tangent, lower insertion loss in passband can be achieved.

The operating frequency range of this filter makes it suitable to be used for WiMax applications.

1.5 Scope of Research

Figure 1.1 shows an overview of the scope in this thesis to achieve the desired compact filter structure. The solid lines in the chart exhibit the instruction followed in this thesis to obtain our objective and the dash lines propose other directions that are considered as different methods to minimize the filters size and make their structure more compact