COMPACT AND MULTIBAND METAMATERIAL HAIRPIN-LINE BANDPASS FILTERS

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To my parents, for their endless love and support

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ABSTRACT

In RF and microwave field, the bandpass filters are very important in communication systems. Bandpass filters are used as frequency selective devices in many RF and microwave applications such as transmitter and receiver. In recent years, a new type of artificial materials called as metamaterials have attracted the attention of many researchers. Metamaterials have a wide range of potential uses in communication areas such as optical and RF design. The metamaterial is a material engineered to have an electromagnetic property that is not found in nature. Thanks to the presence of these properties many researchers have using the metamaterial to produce the high performance and compact devices. The rapid development of microwave and millimeter wave in communication systems greatly stimulates the demand for high-performance bandpass filters with compact dimensions, low insertion loss, high attenuation in the stopband, low cost and multiband responses. In this project, the compact and multiband metamaterial hairpin bandpass filters have been proposed to reduce the size of the filter and to provide a multiband filter with less complex structure. The proposed bandpass filters were designed by using the complementary split ring resonator (CSRR) structure. The compact size was achieved with size reduction of 10% from the conventional hairpin filter. For the proposed multiband bandpass filter, two-band frequency responses were obtained at 3.5 and 5.5 GHz. Moreover, both of them have an insertion loss less than 1 dB and high attenuation at stopband.

ABSTRAK

Dalam bidang RF dan gelombang mikro, penapis laluan jalur sangat penting dalam sistem komunikasi. Penapis laluan jalur digunakan sebagai alat pemilih kekerapan dalam banyak aplikasi RF dan gelombang mikro seperti pemancar dan penerima. Dalam beberapa tahun kebelakangan ini, sejenis bahan buatan baru yang dipanggil sebagai bahan metamaterial telah menarik perhatian ramai penyelidik. Bahan metamaterial mempunyai pelbagai potensi penggunaan dalam bidang komunikasi seperti reka bentuk optik dan RF. Bahan metamaterial adalah bahan kejuruteraan yang mempunyai sifat elektromagnetik yang tidak terdapat dalam alam semula jadi. Terima kasih kepada kehadiran sifat-sifat ini ramai penyelidik telah menggunakan metamaterial untuk menghasilkan prestasi tinggi dan peranti padat. Perkembangan pesat gelombang mikro dan gelombang milimeter dalam sistem komunikasi sangat merangsang permintaan untuk penapis bandpass berprestasi tinggi dengan dimensi padat, kehilangan sisipan yang rendah, pengecilan yang tinggi di perhentian, kos rendah dan pelbagai jalur tindak balas. Dalam projek ini, penapis laluan jalur padat dan pelbagai jalur metamaterial telah dicadangkan untuk mengurangkan saiz penapis dan menyediakan penapis pelbagai jalur dengan struktur yang kurang kompleks. Penapis laluan jalur yang dicadangkan telah direka dengan menggunakan struktur resonator cincin berpisah (CSRR). Saiz padat dicapai dengan pengurangan saiz sebanyak 10% dari penapis rambut konvensional. Untuk penapisan bandpass pelbagai jalur yang dicadangkan, respons kekerapan dua jalur diperoleh pada 3.5 dan 5.5 GHz. Lebih-lebih lagi, kedua-duanya mempunyai kehilangan penyisipan kurang dari 1 dB dan pengecilan tinggi pada hentian.

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LIST OF ABBREVIATIONS

RF	-	Radio Frequency
CSRR	-	Complementary Split Ring Resonator
SRR	-	Split Ring Resonator
CPW	-	Coplanar Waveguide
BPF	-	Bandpass Filter
CST	-	Computer Simulation Technology
DGS	-	Defected Ground Structure
UWB	-	Ultra Wideband
LPF	-	Low Pass Filter
SSRR	-	Symmetrical Split Ring Resonator
CRLH	-	Composite Right/Legth Handed
TL	-	Transmission Line
LH	-	Left Handed
RH	-	Right Handed
WLAN	-	Wireless Local Access Network
WiMAX	-	Worldwide Interoperability for Microwave Access
FBW	-	Fractional Bandwidth

LIST OF SYMBOLS

λ	-	wavelength
δ	-	conductivity
μ	-	permeability
ε	-	permittivity

CHAPTER 1

INTRODUCTION

1.1 Research Background

A bandpass filter (BPF) is a two-port network used to control the frequency response at a certain point in an RF or microwave system by providing transmission at frequencies within the passband of the filter and attenuation in the stopband of the filter [9]. Band-pass filters are used as frequency selective devices in many RF and microwave applications such as transmitters and receivers [10–12]. The advance of telecommunication system has enhanced the need for more sophisticated devices in order to support the variety of the applications. In order to meet the consumers need, some designing factors of microwave filters such as compactness, steepness, low cost, lightweight, small size, good performance, and low loss are important parameters that are desirable to have for enhanced system performance and to reduce the fabrication cost [1].

The implementation of the microstrip band-pass filters has various topologies such as end-coupled, parallel-coupled, hairpin-line, interdigital and combline filters. This project represents the design of a hairpin-line band-pass filter. The hairpin-line band-pass filter is one of the most popular microstrip filter configurations used for the compact structure. This design is easy to fabricate because it has open-circuited ends that require no grounding. This design is obtained by folding the resonators of parallel-coupled into a "U" shape. This configuration will reduce the length of the parallel-coupled band-pass filter.

In recent years, a new type of artificial materials called as metamaterials have attracted the attention of many researchers. The presence of such material with effective negative permittivity (ε) and negative permeability (μ) was theoretically investigated by a Russian scientist Vaselago in [13]. The metamaterial is a material engineered to have an electromagnetic property that is not found in nature [3]. That means, in the normal material, they have positive permittivity and permeability. For metamaterial, they can produce negative permittivity or negative permeability or negative index of refraction. Metamaterials derive their properties not from the properties of the base materials, but from their newly designed structures. In RF and microwave engineering, in order to obtain properties not present in the conventional material, the transmission line is loaded with reactive elements and it called metamaterial transmission lines. Metamaterial transmission line is an artificial line consisting of a host line such as microstrip and coplanar waveguide (CPW) loaded with reactive elements such as inductances, capacitance or resonator [14]. Thanks to the presence of these reactive elements in the line we have more degree of freedom for design as compared to conventional lines so it means that we have more design flexibility so that we can make device design based on dispersion and impedance engineering. The example of an application for wireless communication by using metamaterial transmission line is filter [4–8] and sensor [15–17]. There are two ways for the implementation of metamaterial transmission lines. First, the CL-loaded approach, where the host line is loaded with series capacitances and shunt inductances. Second, the resonant-type approach, where the line is loaded with electrically small resonators, such as split ring resonator (SRR) and complementary split ring resonator (CSRR) [18]. SRR and CSRR are the most widely used planar structure for exhibiting left-handed property. At resonance, these resonators exhibit sharp stopband and are smaller in size compared to the wavelength, hence known as sub-wavelength resonators.

This project is about designing of compact and multiband metamaterial hairpin-line bandpass filters by using CSRR structure. By applying this technique, the proposed filter can reduce size more than the conventional hairpin filter. Moreover, a structure for design multiband filter is not complex and provide high attenuation at stopband.

1.2 Problem Statement

With the rapid development of microwave and millimeter wave communication systems, it greatly stimulates the demand for high-performance microwave filters with compact dimensions, low insertion loss, high attenuation in stopband and low cost. Miniaturization of microwave filters is one of the fundamental requirements in communication systems. In order to reduce cost and enhance system performance, the small-size and high-performance filters are always necessary. Usually, the size of microwave filter is large at low frequency. Therefore, many researchers have been proposed to reduce the filter size by using a parallel-coupled resonator, hairpin-line resonator, interdigital resonator and combline resonator. However, the size of planar filters with parallel-coupled resonators, hairpin resonators, interdigital resonators or combline resonators design is obviously still too large to accept the demand for modern communication and electronic systems. To solve this problem, the metamaterial is used to reduce more size and improve the performance of the filter. In this project, a compact metamaterial hairpin-line bandpass filter by using CSRR structure has been proposed.

In addition, with the rapid evolution of multiband and multiservice communication systems, filters with a multiband response are in high demand. In the field of advanced multiband wireless systems, filters with the two-through seven-band operation for RF devices have become indispensable. The challenges to circuit designers designing a multi-band bandpass filter are to achieve a compact size and low insertion loss simultaneously. The previous works are usually too many components inside have caused large circuit size and structure design very complex. Besides of the ability to support various wireless communication applications, also need to satisfy the specifications of a bandpass filter which are size reduction, high stability, high selectivity simultaneously. In this project, a multiband metamaterial hairpin-line bandpass filter by using CSRR structure has been proposed

1.3 Objectives

The following objectives of this project are;

1. To design a unit cell of CSRR at frequency 2.4 GHz.
2. To design a compact metamaterial hairpin-line bandpass filter by using CSRR structure.
3. To design a multiband metamaterial hairpin-line bandpass filter by using CSRR structure.

1.4 Scope of The Work

The scope of this project is to design and simulate of compact and multiband metamaterial hairpin-line bandpass filter by using CSRR structure. The proposed bandpass filter using Rogers RT6006 as a substrate of BPF with a thickness (h) of 1.27 mm, a relative permittivity (ε_r) of 6.15 and a loss tangent δ of 0.025.Other material use is copper with the thickness of 0.035 mm as transmission line and ground plane.The proposed of compact bandpass filter needs to operate at operating frequency 2.2 GHz with the fractional bandwidth of 20%, while for the proposed of multiband bandpass filter needs to operate at operating frequency 3.3 and 5.5 GHz with the fractional bandwidth of 40% and 20%. Bandpass filter design, simulation and optimize process using the Computer System Technologies (CST) simulator. The performances of bandpass filter are determined by analysis of S-parameter.

1.5 Chapter Outline

This report consists five chapters, which provide information and the concept of designing for compact and multiband metamaterial hairpin-line bandpass filters by using CSRR structure. Chapter 1 gives a brief introduction to the research background, problem statement, objectives of project and scope of the work was done.

Chapter 2 describes some review of works previous researcher about compact and multiband bandpass filter, metamaterial transmission line, and metamaterial bandpass filter. Chapter 3 describes the methodology, the procedures of design, simulation, and analysis of the proposed bandpass filter have been discussed in details. Chapter 4 shows the simulation results of the conventional hairpin-line bandpass filter, the proposed compact bandpass filter, and the proposed bandpass filter. The comparison simulation results between conventional hairpin-line filter and metamaterial hairpin-line filter have been discussed in chapter 4. Chapter 5 gives a brief conclusion for this project and the problems encountered have been explained in this chapter.

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