COMPACT MICROSTRIP BANDPASS FILTER

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This hard work of master's project is dedicated to my family especially to my husband, Mr. Mohd Zamil Ashraf bin Abdul Manan and our daughters, Naurah Nabilah and Amna Mu'izzah, thank you for the support, encouragement and sacrifices, also thanks to my supervisor, Dr. Samsul Haimi bin Dahlan for the guidance, opinions and advices.

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ABSTRACT

In microwave communication systems, the bandpass filter is an essential component, which is usually used in both transmitter and receiver. Parallel-coupled microstrip bandpass filter is one of the most popular filters in communication systems. However, this arrangement of parallel-coupled microstrip bandpass filter gives disadvantage in terms of size where the arrangement of this topology results in an electrically large in size of the filter. Therefore, this project focuses on designing a compact microstrip bandpass filter by using Sonnet Lite software software at centre frequency of 3.2GHz with the bandwidth of 400MHz. Besides, the design of the compact microstrip bandpass filter has achieved the objective when it successfully reduced the overall size to about 70% as compared to the size of conventional filter, which is parallel-coupled microstrip bandpass filter. Both filters give the same performance based on their frequency responses. The design also has successfully fabricated and measured by using network analyzer software to verify the simulated results obtained earlier. Although there is slightly mismatch between the simulated and measured frequency response due to some fabrication errors and variation of material properties, the design of filter is not affected since the results obtained from the designing process by using Sonnet Lite software are still valid and can be used in future improvement of the design.

ABSTRAK

Dalam sistem komunikasi gelombang mikro, penapis lulus jalur (*bandpass filter*) merupakan komponen penting, yang biasanya digunakan dalam pemancar dan penerima. Penapis lulus jalur mikrostrip *parallel-coupled* adalah salah satu penapis paling popular dalam sistem komunikasi. Walau bagaimanapun, susunan bagi penapis lulus jalur mikrostrip *parallel-coupled* memberikan kelemahan dari segi saiz di mana susunan topologi ini mengakibatkan saiz besar secara elektriknya. Oleh itu, projek ini memberi tumpuan kepada merekabentuk penapis lulus jalur mikrostrip yang bersaiz kompak menggunakan perisian Sonnet Lite di pusat frekuensi 3.2GHz dengan lebar jalur 400MHz. Selain itu, rekabentuk ini telah mencapai objektif apabila ia berjaya mengurangkan saiz keseluruhan kepada kira-kira 70% berbanding saiz penapis yang konvensional, iaitu penapis lulus jalur mikrostrip *parallel-coupled*. Kedua-dua jenis penapis memberi prestasi yang sama berdasarkan respon frekuensi mereka. Rekabentuk penapis juga telah berjaya difabrikasi dan diukur menggunakan perisian network analyzer untuk mengesahkan keputusan simulasi yang diperolehi sebelumnya. Walaupun terdapat sedikit perbezaan pada respon frekuensi diantara simulasi dan pengiraan, rekabentuk penapis tidak terjejas kerana keputusan yang diperolehi daripada proses merekabentuk menggunakan perisian Sonnet Lite masih sah dan boleh digunakan untuk penambahbaikan rekaan pada masa akan datang.

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CHAPTER 1

INTRODUCTION

This chapter introduces the idea and concept of the project. It consists of project background and the overview of the project.

1.1 Project Overview

Filters play important roles in many RF/microwave applications. They are used to separate or combine different frequencies. The electromagnetic spectrum is limited and has to be shared; filters are used to select or confine the RF/microwave signals within assigned spectral limits. Emerging applications such as wireless communications continue to challenge RF/microwave filters with ever more stringent requirement which are higher performance, smaller size, lighter weight, and lower cost. Depending on the requirements and specifications, RF/microwave filters may be designed as lumped element or distributed element circuits; they may be realized in various transmission line structures, such as waveguide, coaxial line, and microstrip.

A filter is an AC circuit that separates some frequencies from others within mixed-frequency signals [1]. A common need for filter circuits is in high-performance stereo systems, where certain ranges of audio frequencies need to be amplified or suppressed for best sound quality and power efficiency.

The design of filters' circuit may be very simple, consisting of a single capacitor or inductor whose addition to given network leads to improved performance. They may also be fairly sophisticated, consisting of many resistors, capacitors, inductors and op amps in order to obtain the precise response curve required for a given application. Filters are used in modern electronics to obtain dc voltages in power supplies, eliminate noise in communication channels, separate radio and television channels from the multiplexed signal provided by antennas and boost the bass signal in a car stereo as for example.

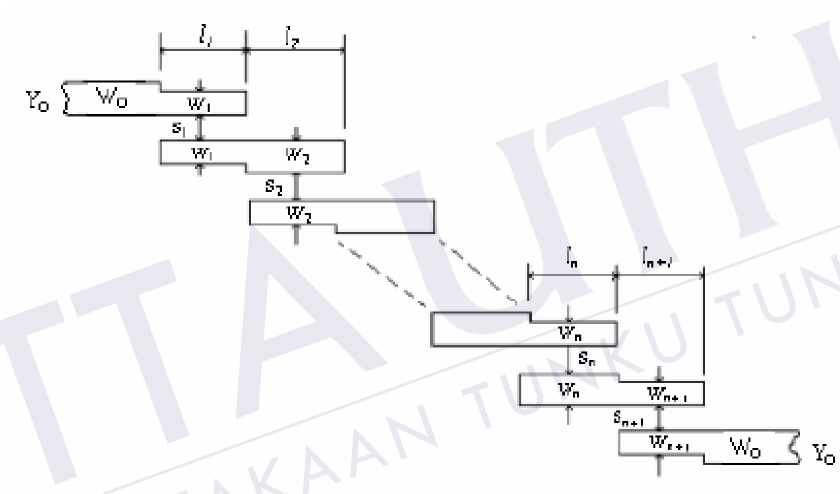
Basically, the concept of filter is that it selects the frequencies that may pass through a network. There are several varieties, depending on the needs of a particular application.

A low-pass filter passes frequencies below a cutoff frequency, while significantly damping frequencies above the cutoff. A high-pass filter, on the other hand, does just the opposite. The chief figure of merit of a filter is the sharpness of the cutoff, or the steepness of the curve in the vicinity of the corner frequency.

Combining a low-pass and a high-pass filter can lead to a band pass filter. In this type of filter, the region between the two corner frequencies is referred to as the passband; the region outside the passband is referred to as the stopband. By swapping the cutoff frequencies of the two filters, a band stop filter can be created, which allows both high and low frequencies to pass but attenuates any signal with a frequency between the two corner frequencies.

Microstrip filters are always preferred over the lumped filters at higher frequencies. For designing of a bandpass filter with minimum ripples in the passband and with sharp rejections the most widely used filters are coupled line, hairpin, and end coupled and cascaded quadruplet (CQ) filters. For the requirements at around 1.243 GHz the end coupled may be avoided because of size constrains and CQ filters have two attenuation poles which is difficult to design to have these poles at the desired frequencies. Coupled and hairpin filters can be used at this frequency to have the desired response in the passband, but the coupled line filter occupies large size where as in the hairpin second harmonics and the other harmonics were very prominent and not desirable for a filter required at the output of multiplier.

Parallel-coupled microstrip bandpass filter is one of the most popular bandpass filter and can be applied in many application of microwave communication systems. General layout of this bandpass filter is shown in figure 1.



$$Y_0=1/Z_0$$

Figure 1.1: General structure of parallel-coupled microstrip bandpass filter [1]

The filter structure is of open circuited coupled microstrip lines. The components are positioned so that adjacent resonators are parallel to each other along half of their length. This parallel arrangement gives relatively large coupling for a given spacing between resonators, and making this filter structure particularly convenient for constructing filters having a wider bandwidth as compared to other type of bandpass filter.

This paper will concentrate on the design of a compact size microstrip bandpass filter. This filter will be developed and then will be compared with existing structures.

Two existing filters were designed which are the conventional parallel coupled microstrip bandpass filter, and the other one is the existing compact microstrip bandpass filter with multispurious suppression. The selected frequency used for the design is based on the current applications in communication systems. The design process is done by using the Sonnet Lite software and then followed by the fabrication of the designed filter. The analysis of the designed filter will be presented and discussed briefly in further chapters.

1.2 Problem Statement

In microwave communication systems, the bandpass filter is an essential component, which is usually used in both transmitter and receiver. Parallel-coupled microstrip bandpass filter is one of the most popular filters in communication systems due to its advantages of ease in manufacture, ease of synthesis method, low cost and high practicality.

The parallel-coupled microstrip bandpass filter structure is of open circuited coupled microstrip lines. The components are positioned so that adjacent resonators are parallel to each other along half of their length. This parallel arrangement gives relatively large coupling for a given spacing between resonators, and making this filter structure particularly convenient for constructing filters having a wider bandwidth as compared to other type of bandpass filter.

However, this arrangement of parallel-coupled microstrip bandpass filter gives disadvantage in terms of size. The arrangement of this topology results in an electrically large in size of the filter. Thus, this problem of size limit the application for this type of filter in certain communication systems and it became less favourable as compared to other filters.

A compact, low insertion loss and wide rejection band bandpass filter has come to be one of the recent trend in global system for mobile communication (GSM), wireless code-division multiple-access (WCDMA), and wireless local area network (WLANs).

It is clear that there is a need to design a compact filter to fulfil the recent need in microwave communication system. Microstrip line is a good candidate for filter design due to its advantages of low cost, compact size, light weight, planar structure and easy integration with other components in single board. Thus, a compact microstrip bandpass filter is proposed to be designed.

1.3 Objectives

The objectives of this project are:

i. To design a compact microstrip bandpass filter for a selected frequency using Sonnet Lite software
ii. To analyze the performance of the designed filter in terms of its S parameters, physical size of the filter and bandwidth.
iii. To compare the designed compact microstrip bandpass filter with the conventional bandpass filter.
iv. To fabricate and measure the frequency response of the designed filter for the frequency used.

1.4 Scope

i. This project is aimed to design a compact microstrip bandpass filter at centre frequency (f_0) of 3.2Ghz. This centre frequency is selected as it is widely used in many microwave application such as Wi-fi, Bluetooth, WiMax etc.

ii. The designed filter also aimed to be smaller in overall size as compared to the conventional parallel-coupled microstrip bandpass filter.

iii. The designed filter also will be analysed in terms of its S-parameter such as the return loss (S11) and insertion loss (S21). Besides, the size of the designed filter will be observed and compared with the conventional microstrip parallel-coupled bandpass filter. In addition, the size of bandwidth of the designed filter also will be observed.

iv. Finally, the designed filter will be fabricated and tested for the selected frequency by using network analyzer.

CHAPTER 2

THEORETICAL BACKGROUND

2.1 Filter Definition

Basically, an electrical filter is a circuit that can be designed to modify, reshape or reject all unwanted frequencies of an electrical signal and accept or pass only those signals wanted by the circuits' designer [2]. In other words they "filter-out" unwanted signals and an ideal filter will separate and pass sinusoidal input signals based upon their frequency.

In low frequency applications (up to 100kHz), passive filters are generally constructed using simple RC (Resistor-Capacitor) networks, while higher frequency filters (above 100kHz) are usually made from RLC (Resistor-Inductor-Capacitor) components. Passive filters are made up of passive components such as resistors, capacitors and inductors and have no amplifying elements, so have no signal gain, therefore their output level is always less than the input.

Filters are so named according to the frequency range of signals that they allow to pass through them, while blocking or "attenuating" the rest. The most commonly used filter designs are the:

i. The Low Pass Filter – the low pass filter only allows low frequency signals from 0Hz to its cut-off frequency, ƒc point to pass while blocking those any higher.

ii. The High Pass Filter – the high pass filter only allows high frequency signals from its cut-off frequency, ƒc point and higher to infinity to pass through while blocking those any lower.

iii. The Band Pass Filter – the band pass filter allows signals falling within a certain frequency band setup between two points to pass through while blocking both the lower and higher frequencies either side of this frequency band.

A low-pass filter passes frequencies below a cutoff frequency, while significantly damping frequencies above the cutoff. A high-pass filter, on the other hand, does just the opposite. The chief figure of merit of a filter is the sharpness of the cutoff, or the steepness of the curve in the vicinity of the corner frequency.

Combining a low-pass and a high-pass filter can lead to a band pass filter. In this type of filter, the region between the two corner frequencies is referred to as the passband; the region outside the passband is referred to as the stopband. By swapping the cutoff frequencies of the two filters, a band stop filter can be created, which allows both high and low frequencies to pass but attenuates any signal with a frequency between the two corner frequencies.

2.2 Different Types of Filter

Filter can be classified into two types which are passive and active filters [1].

A passive filter can be constructed by simply using a single capacitor and a single resistor as shown in figure 2.1

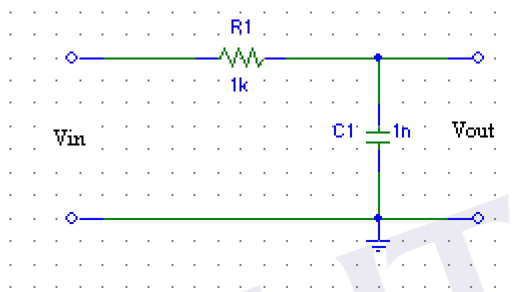


Figure 2.1: A simple low-pass filter constructed from a resistor-capacitor combination

The transfer function for this low-pass filter circuit is

$$H(s) = \frac{V_{out}}{V_{in}} = \frac{1}{1 + RCs} \qquad (1)$$

H(s) has a single corner frequency, which occurs at ω=1/RC, and a zero at s equal infinity, leading to its “low-pass” filtering behavior. Low frequencies (s approaching zero) result in |H(s)| near its maximum value (unity, or 0dB), and high frequencies (s approaching zero) result in |H(s)| approaching zero. This behavior can be understood qualitatively by considering the impedance of the capacitor: as the frequency increases, the capacitor begins to act like a short-circuit to ac signals, leading to a reduction in the output voltage. The sharpness of the response curve in the vicinity of the cutoff frequency can be improved by moving to a circuit containing additional reactive (i.e. capacitive and/or inductive) elements.

The use of an active element such as the op amp in filter design can overcome many of the shortcomings of passive filters. The op amp circuits can be designed to provide gain. Op amp circuit can also exhibit inductor-like behavior through the strategic location of capacitors.

The internal circuitry of an op amp contains very small capacitance (typically on the order of 100pF), and these limit the maximum frequency at which the op amp will function properly. Thus, any op amp circuit will behave as low-pass filter with a cutoff frequency usually on the order of 10-100 kHz. If a smaller frequency is desired, an external filter can be added at the input or output of the op amp.

Active filters contain amplifying devices to increase signal strength while passive do not contain amplifying devices to strengthen the signal. As there are two passive components within a passive filter design the output signal has smaller amplitude than its corresponding input signal, therefore passive RC filters attenuate the signal and have a gain of less than one, (unity).

2.3 Microstrip Filter

Microstrip transmission line is the most used planar transmission line in Radio frequency (RF) applications [2]. The planar configuration can be achieved by several ways, for example with the photolithography process or thin-film and thick film technology. As other transmission line in RF applications, microstrip can also be exploited for designing certain components, like filter, coupler, transformer or power divider.

If a microstrip transmission line is used for transport of wave with relative low frequency, the wave type propagating in this transmission line is a quasi-TEM wave. This is the fundamental mode in the microstrip transmission line.

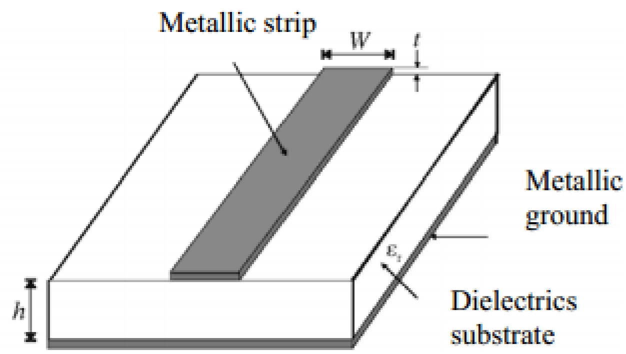


Figure 2.2: Microstrip transmission line [2]

Microstrip filters are always preferred over the lumped filters at higher frequencies. For designing of a bandpass filter with minimum ripples in the passband and with sharp rejections the most widely used filters are coupled line, hairpin, and end coupled and cascaded quadruplet (CQ) filters. For the requirements at around 1.243 GHz the end coupled may be avoided because of size constrains and CQ filters have two attenuation poles which is difficult to design to have these poles at the desired frequencies. Coupled and hairpin filters can be used at this frequency to have the desired response in the passband, but the coupled line filter occupies large size where as in the hairpin second harmonics and the other harmonics were very prominent and not desirable for a filter required at the output of multiplier.

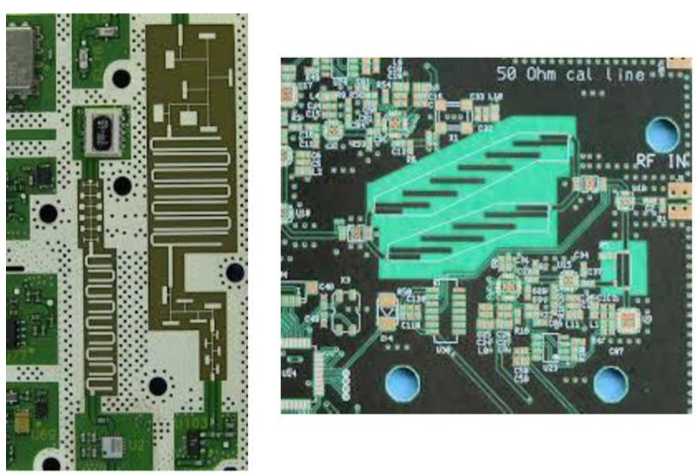


Figure 2.3: Example of Microstrip filter applications in industry

2.4 Parallel - Coupled Microstrip Filter (Conventional filter)

Parallel-coupled microstrip bandpass filter is one of the most popular bandpass filter and can be applied in many application of microwave communication systems [2].

The filter structure is of open circuited coupled microstrip lines. The components are positioned so that adjacent resonators are parallel to each other along half of their length. This parallel arrangement gives relatively large coupling for a given spacing between resonators, and making this filter structure particularly convenient for constructing filters having a wider bandwidth as compared to other type of bandpass filter. General layout of this bandpass filter is shown in figure 2.3

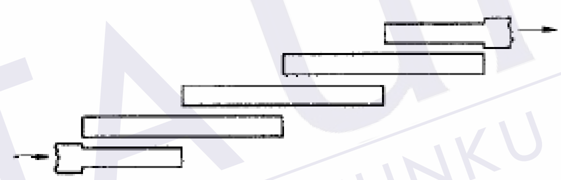


Figure 2.4: General stucture of Parallel-Coupled Microstrip Bandpass Filter [2]

The design equations involved in this type of filter are:

$J_{01} / Y_0 = (FBW\text{л} / 2g_0g_1)^{1/2}$ (1)

$J_{j,j+1} / Y_0 = (\text{л}FBW) / 2(g_jg_{j+1})^{1/2}$ j=1 to n-1 (2)

$J_{n,n+1} / Y_0 = (\text{л}FBW / 2g_ng_{n+1})^{1/2}$ (3)

Where g_0, g_1 …g_n are the element of a ladder-type lowpass prototype with a normalized cutoff Ω_c=1, and FBW is the fractional bandwidth of bandpass filter. $J_{j,j+1}$ are the characteristics admittances of J-inverters and Y_0 is the characteristics admittance of the terminating lines.

To obtain the *J*-inverters, the even- and odd-mode characteristic impedance of the coupled microstrip line resonators are determined by

$(Z_{0e})_{j,j+1} = [\ 1 + (J_{j,j+1} / Y_0) + (J_{j,j+1} / Y_0)^2] / Y_0$ j=0 to n (4)

$(Z_{0o})_{j,j+1} = [\ 1 + (J_{j,j+1} / Y_0) + (J_{j,j+1} / Y_0)^2] / Y_0$ j=0 to n (5)

The next step of the filter design is to find the dimensions of coupled microstrip lines that exhibit the desired even- and odd-mode impedances. For instance, referring to figure 3.1, w1 and s1 are determined such that the resultant even- and odd-mode impedances match to $(Z_{0e})_{0.1}$ and $(Z_{0o})_{0.1}$.

The actual lengths of each coupled line section are then determined by

$l_j = \{\lambda_0 / 4[\varepsilon_{re})_j \text{ x } (\varepsilon_{ro})_j]\} - \Delta l_j$ (6)

The software Sonnet lite used is the in the design process, therefore no need to calculate them manually because this software will automatically do it. Using this software, the value for the frequency and order should be inserted, and then it will display the values for width, length and separation for every substrate's value. This report will focus on the design at the center frequencies of 3.2 GHz.

This type of filter is designed in order to be compared with the compact microstrip bandpass filter. The new designed of compact filter should give the same frequency response, with a smaller size filter.

2.5 S-Parameters

The network representation of a two-port network at high RF/microwave frequencies is called "scattering parameters" (or "S-parameters" for short) [2]. The high frequency S-parameters are used to characterize high RF/Microwave two-port networks. These parameters are based on the concept of travelling waves and provide a complete characterization of any two-port network under analysis or test at RF/Microwave frequencies. In view of the linearity of the electromagnetic field equations and the linearity displayed by most microwave components and networks, the "scattered waves"

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