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DESIGN OF PARALLEL COUPLED LINES BANDPASS FILTER USING DEFECTED GROUND STRUCTURE

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Bachelor of Engineering with Honours in Electronics (Telecommunication)
2020

UNIVERSITI MALAYSIA SARAWAK

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DESIGN OF PARALLEL COUPLED LINES BANDPASS FILTER USING DEFECTED GROUND STRUCTURE

SYAZA SYAFIQAH BINTI ZAIDAN

A final year project report submitted in partial fulfilment of
the requirement for the degree of
Bachelor of Engineering (Hons)
Electronics (Telecommunications) Engineering

Faculty of Engineering

Universiti Malaysia Sarawak

2020

ACKNOWLEDGEMENT

Alhamdulillah, all praise to Allah SWT for His blessings and giving me the strength to complete the thesis successfully. Without His righteousness, I would not be able to achieve what I currently have. First and foremost, I would like to express my sincere gratitude to my beloved supervisor, Dr Dyg Azra binti Awang Mat as I am deeply thankful for her endless support, insightful assistance and constructive criticisms for the completion of this research. Thank you for always giving me the opportunity to learn and grow throughout the process.

I would also like to extend my appreciation to my dearest family members for their never ending support especially my parents and my brother who are always present in giving constant moral support and encouragement. Moreover, I would like to take this opportunity to thank my support system throughout my alma mater years who have been there through my thick and thin, you know who you are. The love and attentiveness that I have received are overwhelming yet I am forever grateful.

ABSTRACT

Filter is a prominent component due to its ability to remove unwanted signal components with the specified frequency range in a signal transmission. The parameters of a filter which includes the gain and the efficiency have to be sufficiently optimised in order to produce the best signal outcome. A range of spurious frequency can cause the operating frequency in the signal for the transmission to undergo distortion thus causing inaccuracy in the filter. Therefore, to overcome this problem, an improvement on a Parallel Coupled Lines Bandpass Filter is designed with the implementation of Defected Ground Structure (DGS) design on the ground plane of the filter to elevate the performance. Parallel Coupled lines Bandpass Filter is proposed in order to achieve optimum results such as the attenuation and the reduction of losses abilities in the filter. The filter is simulated by using Rogers RO4003C and RO4350B substrate materials with a dielectric material of 3.38 and 3.66 and substrate thickness of 0.813mm and 0.762mm respectively. An operational frequency of 5.8GHz based on the ISM band is targeted. Multiple DGS structures are proposed and the most ideal among the etched designs is selected as the resonant structure in the ground plane of the filter. By properly adjusting the dimensions and position of the DGS shape, the H-shaped DGS filter design is selected as the losses the selectivity of the designed filter is significantly improved from the conventional design. The result of the filter's losses are simulated by using the simulation software, Advanced Design Software (ADS) and the H-shaped DGS filter design with the insertion loss (S_{21}) of -1.412dB and the return loss (S_{11}) of -20.24dB are measured by using Vector Network Analyzer (VNA) after the fabrication process.

ABSTRAK

Penapis adalah komponen yang penting kerana kemampuannya untuk membuang komponen isyarat yang tidak diingini dengan julat frekuensi yang ditentukan dalam penghantaran isyarat. Parameter filter yang merangkumi keuntungan dan kecekapan harus dioptimumkan dengan cukup untuk menghasilkan hasil isyarat terbaik. Julat frekuensi palsu boleh menyebabkan frekuensi operasi dalam isyarat agar transmisi mengalami distorsi sehingga menyebabkan ketidaktepatan pada penapis. Oleh itu, untuk mengatasi masalah ini, penambahbaikan pada *Parallel Coupled Lines Bandpass Filter* dirancang dengan pelaksanaan reka bentuk *Defected Ground Structure (DGS)* pada permukaan tanah penapis untuk meningkatkan prestasi. *Parallel Coupled lines Bandpass Filter* dicadangkan untuk mencapai hasil yang optimum seperti pelemahan dan pengurangan keupayaan kerugian dalam saringan. Penapis disimulasikan dengan menggunakan bahan substrat *Rogers RO4003C* dan *Rogers RO4350B* dengan bahan dielektrik 3.38 dan 3.66 dan ketebalan substrat masing-masing 0.813mm dan 0.762mm. Kekerapan operasi 5.8GHz berdasarkan jalur ISM disasarkan. Sebilangan struktur DGS dicadangkan dan yang paling ideal di antara reka bentuk terukir dipilih sebagai struktur resonan pada bidang tanah penapis. Dengan menyesuaikan dimensi dan kedudukan bentuk DGS dengan betul, lebar jalur dan selektiviti penapis yang dirancang dapat ditingkatkan dengan ketara. Hasil kerugian penapis ini adalah simulasi dengan menggunakan perisian simulasi, *Advanced Design Software (ADS)* dan reka bentuk DGS penapis H dengan *insertion loss* (S_{21}) yang berjumlah -1.412dB dan *return loss* (S_{21})yang berjumlah -20.21dB diukur dengan menggunakan *Vector Network Analyzer (VNA)* setelah proses fabrikasi.

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RF	-	Radio Frequency
SNR	-	Signal-to-Noise ratio
PBG	-	Photonic Band Gap
EBG	-	Electromagnetic Band Gap
DGS	-	Defected Ground Structure
EM	-	Electromagnetic
ADS	-	Advanced Design System
PCB	-	Printed Circuit Board
DSP	-	Digital Signal Processing
IPM	-	Image Parameter Method
ILM	-	Insertion Loss Method
VSWR	-	Voltage Standing Wave Ratio
RL	-	Return Loss
IL	-	Insertion Loss
NF	-	Noise Figure
BER	-	Bit Error Rate
TEM	-	Transverse Electromagnetic Waves
VNA	-	Vector Network Analyzer

CHAPTER 1

INTRODUCTION

1.1 Background

In the field of electronics, signal transmission is known to be a prominent propagating process of sending and transmitting information in the form of analog or digital signals. Analog signal processing indicated the conduct of analog signals that is represented as a set of continuous values whereas digital signal processing is the digital representations of discrete-time signals [1]. Generally, for a signal transmitter, the roles include choosing the preferred signal from several possibilities on a periodic basis thus translating it into a waveform that matches the transmitting medium. The efficiency of the information transfer depends on the waveforms of the transmission medium thus the signal waveforms must be curated in a way that could cause the least affect the propagation medium and making it easier to detect and reproduce signals with minimum probability of error [2]. Therefore, the function of the passive electronic device, filter is needed in every signal transmission-based application to achieve high-resolution outcomes. The function of a filter is to remove unwanted frequency components that are not applicable in the frequency range of the system. Depending on the applications, disturbances such as random noises or the extrication of important parts of the propagating signal are interchangeable features of a filter thus proving the containment or source of suppression of components [3]. Absorptive or reflective filters are mainly used to pass signals or currents at a specified range of frequencies to the circuit's load while rejecting unwanted components to the ground or sending them back to their initial source.

Bandpass filters are extensively used in various types of instruments in different industries such as the telecommunications field. Furthermore, this filter operates in a transmitter mainly to help limit the bandwidth range while preventing signals of unwanted frequency components from being accessible in a receiver. Bandpass filters help optimize the signal-to-noise (SNR) ratio thus affecting the sensitivity of a receiver. In any required signal transmission applications, it is important to choose the most suitable technology depending on the application's needs. The technologies that are usually used in this field of research consist of Photonic Band Gap (PBG), Electromagnetic Band Gap (EBG) and Defected Ground Structure (DGS). The comparison of PBG, EBG and DGS are shown in **Table 1.1.**

Table 1.1 : Comparison of structural design techniques [4]

	PBG	EBG	DGS
Definition	Based on periodical structures which are engraved on the ground plane and can control the propagation of electromagnetic (EM) waves	Based on periodical structures with a compact dimensions	A unit or several units of miniature geometrical slots etched on the ground plane of circuitries
Geometrical structure	Periodic-based etched structure	Periodic-based etched structure	Periodic etched structure
Parameter extraction	Very complex	Very complex	Easy to extract
Size	Large	Medium	Compact
Fabrication process	Complex	Complex	Simple

Defected Ground Structure (DGS) has been gaining recognition for enhancing a filter's parameters based on its relatively simple structures. Moreover, DGS is the prominent choice to improve the performance of the filter by increasing the gain and bandwidth, lowering the cross-polarization of the signal and coupling in the case of the applied filter [4]. For designing high performance and compact filters, DGS is a suitable technique to be implemented. These etched slots or defects on the ground plane of a filter known as DGS are used underneath the microstrip line to acquire band-stop characteristics and to halt higher mode of harmonics and mutual coupling [5]. This method causes interference on the distribution end of the current in the ground plane of the filter thus it will change the characteristics of the transmission line. This includes the capacitance and inductance of the filter.

In this project, the DGS technique is chosen to enhance the performance and stabilize the signal of the microstrip path antenna used for signal-based applications. The analysis on the DGS performance is carried out by comparing between the filters with 2 substrate materials which are RO4350B and RO4003C respectively. The different locations and parameters of the slot DGS proposed under the parallel-coupled microstrip line affect the conventional result of the filter. However, due to the scarce of resources, RO4350B's output designs are solely carried out in the simulation depth whereas the simulation and the fabrication outcome of the design are made out of the best combination which includes the involvement of Rogers RO4003C as the filter's substrate by using the software Advanced Design System (ADS).

1.2 Problem Statement

Known for its ability to remove disturbances in a transmission, a filter's parameter such as the gain and efficiency must be fully optimized to produce the best outcome. A spurious range of frequency can affect the operating frequency of the signal involved in the transmission into inaccuracy. Finding the optimal frequency band in getting the desired resolution as well as ensuring the signals transmitted are able to overcome the measurement noise and uncertainties are the key problems of this matter. To overcome this problem, the design of a Parallel Coupled Bandpass Filter with DGS is proposed.

1.3 Objectives

The objectives of this project are stated as follows :

i. To investigate the basic principles of a Parallel-Coupled Lines Bandpass Filter for signal transmitting applications.
ii. To design a Parallel-Coupled Lines Bandpass Filter with an optimum microwave frequency.
iii. To analyse the effect of Defected Ground Structure (DGS) on the efficiency and performance of the Parallel-Coupled Lines Bandpass Filter

1.4 Scopes of the Project

The scope of work for this project is to design and analyse the operation of a Parallel-Coupled Lines Bandpass Filter with Defected Ground Structure (DGS) technique for signal transmission applications. The software used for this project is Advanced Design System (ADS) Version 2020 thus the software is used to simulate and monitor in-depth the effect of DGS on the bandpass filter for microwave imaging purposes. The basic functions and characteristics of a bandpass filter are explained and altered through the simulation result to achieve the targeted parameters by using 2 different materials of RO4350B and RO4003C for simulation. Moreover, the hardware of the filter design is carried out by fabricating the filter using Rogers RO4003C thus proceeding with the measurement. The measurement is carried out using R&S Vector Network Analyzer (VNA) equipment.

1.5 Thesis Outline

This thesis is divided into five chapters which comprise the overall details of the project. In Chapter 1, the introduction on the project is explained by clarifying the background, problem statements, objectives and scopes of research of the project.

Furthermore, Chapter 2 elaborates on the literature review of the project. In this chapter, concepts and findings of a particular field related to the project are clarified. The general concept of signal transmission is explained with an overview of electronic filters. The conceptual design of a bandpass filter with DGS is also included in this chapter as the project specifically focuses on the DGS technique to enhance the microwave circuit used in the proposed imaging system. The defect etched in the ground plane method is explained with findings on its basic characteristics and comparison made with other viable feeding techniques for a filter.

Chapter 3 focuses on the methodology of the whole project. The methodology part is briefly illustrated in a flowchart to explain on the planning and organizing process of executing the project. The procedures and techniques involved in the project are also included theoretically with the assistance of the expected simulation result done by using ADS. The calculations for the parameters of the filter are also included as to cover the detailed explanation on the design proposed.

Moreover, Chapter 4 showcases the result of the simulation and the fabricated filter itself. The result are illustrated in graphs and tabulated data. The comparison between the filter designs are also observed and analysed for further deduction. The most suitable DGS filter design is chosen based on its improving parameters in comparison with the conventional design. Relevant reasonings and statements on the selected design are also discussed for justification purposes.

Lastly, Chapter 5 provides the overall conclusion of the whole project. This section emphasizes on the outcomes thus provides constructive recommendations for further works in the recurring field of study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the main specifications of the filter design for signal transmission-based applications are reviewed in detail. The basic concept of filter and its parameters in the communications field is also presented in the chapter. Moreover, the fundamental concept and transmission characteristics on the band pass filter which includes the transmission line used is provided in this section. Besides that, the conceptual design of Defected Ground Structure (DGS) are further elaborated in this chapter.

2.2 Filter

According to [6], filters that are found in electronic circuits are useful in providing a range of signal processing applications. In signal processing, a filter is described as a device that is capable of passing certain frequencies while removing unwanted frequency components from the signal. High performance filters are required to remove disturbance in terms of signals transmitted at the receiving end such as the noises from incoming signals at the antenna's receiving end, unwanted signals at the frequency of an image, and harmonics after the mixing operation [7].

Filters can be classified into two categories which are passive or active. Passive filters are based on combinations of electronic components such as resistors, inductors and capacitors. The frequency band ranges from roughly 100Hz to 300MHz. These filters are capable of handling high-ranging frequencies as they are not dependent on external power supplies with the absence of active components such as transistor. Radio frequency circuits are often used to utilize passive filters. Active filters are implemented by merging the components of a passive and active device that requires external power source. Filters with active specifications have high quality factor (Q) that can achieve resonance with the absence of inductors. These filters are specialized in dealing with very low frequencies which are in the range of approaching 0Hz. Active filters are less-suited for high-frequency applications due to the amplifier bandwidth limitations. However, in terms of the costing and operating losses, the active filters are not convenient when compared to the current passive filters. Active filters that operates for the basis of power conditioning are also referred to as active power filters, active power line conditioners or active power quality conditioners

The example of four major types of filters are defined as shown in the following classification [8] :

i. Lowpass filters are filters that allow low frequencies up to the cut-off frequency f_c and attenuate frequencies higher than the f_c.
ii. High pass filters are filters that select frequencies higher than f_c and attenuate frequencies below f_c.
iii. Bandpass filters are filters that select frequencies within the range of a lower cut-off frequency f_{cl} and a higher cut-off frequency f_{ch}. Frequencies that are below the range of f_{cl} and frequencies higher than the range of f_{ch} are attenuated.
iv. Notch filters attenuate frequencies in a range of narrow bandwidth within the cut-off frequency f_c.

In designing filters, two types of design methods that are significantly used which are known to be the Image Parameter Method (IPM) and the Insertion Loss Method (ILM). For IPM, the method consists of a filter with cascaded two-port sections to provide desire cut off frequency and attenuation characteristics. This method does persist the requirements of a frequency response to pass over the completed operating range. For ILM, the method is based on a network synthesis technique and it allows a high notch of control over the amplitude and the phase characteristics of the pass band and stop band. If the attenuation rate were to be sacrificed, an enhanced phase response can be acquired with the use of a linear phase filter design. Therefore, the ILM method permits the filter performance to be improved with a direct approach, at the expense of a higher order or a more complex filter [9].

2.2.1 Bandpass Filter

In the wireless communications field, the usage of bandpass filters is widely utilized. Microstrip line band-pass filters are preferred in microwave-based systems due to their simplicity in designs, cost-efficient characteristics and easy integrability with other devices [10]. Bandpass filters are used in the audio frequency range of 0 kHz to 20 kHz especially for the applications of speech processing whereas for bandpass filters with high frequency of several hundred MHz, the filters are utilized for the selection of channels in the telephone central offices [11]. Several methods can be implemented in designing the proposed novel filters with advanced attributes that are based on specific structures for the optimum structural design of bandpass filters [12].

Bandpass filters are two-port devices which provide transmission at a specified range of frequencies within the band and attenuate other frequencies outside of the specified band. The combination of high pass and low pass characteristics obtained from the respective filters result in the production of a functional bandpass filter. Furthermore, bandpass filter is a passive component that is capable of selecting signals of a pre-defined bandwidth at a specified center frequency and rejects signals that are foreign and may cause interference towards

the information signals in the frequency spectrum [13]. Preventing signal interference and utilize frequencies that are suitable for the applied signal are the key points of using the band pass technology in a filter's design. Since the bandpass filter is a series combination of a high pass filter and a low pass filter, the overall gain will be a multiplication of the two gains of the series combination.

The gain of the following filter is given by the equation [14]:

$$\frac{v_o}{v_{in}} = \frac{A_{FT}\,(\frac{f}{f_L})}{\sqrt{\left[1+\left(\frac{f}{f_L}\right)^2\right][1+\left(\frac{f}{f_H}\right)^2\,]}} \tag{2.1}$$

Where A_{FT} is the total of gain obtained in the pass band, f is the frequency of the input signal, f_L is the lower cut off frequency and f_H is the higher cut off frequency.

2.3 Filter Parameters

In designing a filter, the design parameters need to be considered which consist of the filter's scattering parameters, the bandwidth, the insertion loss, the Quality Factor (Q-factor), the Voltage Standing Wave Ratio (VSWR), the return loss, the ripple and noise measurement.

2.3.1 Scattering Parameters (S-Parameters) of a Filter

The scattering parameters (S-parameters) for a filter design are usually utilized for operations at radio frequencies (RF) where the signal power and energy transmitted are easily identified within the currents and voltages. The S-parameters are obtained by using the relevant impedance parameters [15]. Besides that, S-parameters are one of the ways to describe the electrical characteristics of RF devices such as filter. There are four prominent parameters and each one of the parameters is the ratio obtained from the signal incident to the signal reflected by the device or transmitted through it which is illustrated in **Figure 2.1** [16].