# X-BAND FILTER USING PARALLEL COUPLED-LINE TECHNIQUE WITH DGS

**MIOR AZLAN BIN MIOR HAMDAN**

**This Report Is Submitted In Partial Fulfillment of Requirements for the Bachelor Degree of Electronic Engineering (Wireless Communication)**

**Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer**
**Universiti Teknikal Malaysia Melaka**

**JUNE 2013**

**UNIVERSTI TEKNIKAL MALAYSIA MELAKA**

FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

**BORANG PENGESAHAN STATUS LAPORAN**

**PROJEK SARJANA MUDA II**

**Tajuk Projek** : X-BAND BANDPASS FILTER USING PARALLEL COUPLED-LINE TECHNIQUE WITH DGS

**Sesi Pengajian** :

| | | | | |
|---|---|---|---|---|
| 1 | 2 | / | 1 | 3 |

Saya MIOR AZLAN BIN MIOR HAMDAN

mengaku membenarkan Laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan ( √ ) :

☐ **SULIT*** *(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

☐ **TERHAD**** **(Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

☐ **TIDAK TERHAD**

Disahkan oleh:

___________________________ ___________________________

(TANDATANGAN PENULIS) (COP DAN TANDATANGAN PENYELIA)

"I hereby declare that this report is the result of my own work except fot quotes as cites in the references."

Signature :…………………………………...

Name :MIOR AZLAN BIN MIOR HAMDAN

Date : JUNE 14, 2013

"I hereby declare that I have read this report and in my opinion this is sufficient in terms of the scope and quality for the award of Bachelor of Electronic Engineering (Wireless Communication) With Honours."

| | |
|---|---|
| Signature | :………………………………. |
| Supervisor's Name | :MOHD AZLISHAH BIN OTHMAN |
| Date | : JUNE 14, 2013 |

*Specially dedicated to my beloved parents*

*Mior Hamdan Bin Zakaria and Hadiah Binti Idris,*

*Brother, sisters and all my fellow friends*

*Who have encouraged, guided and inspired me throughout my journey of education*

**ACKNOWLEDGEMENT**

All gratitude is due to " ALLAH " who guides me to bring forth to light this thesis.

First of all, millions thanks to En. Mohd Azlishah Bin Othman for enduring my severe and prolonged indecisiveness and doubtfulness about this project by providing me a good supervision, good concern, support and encouragement. All the advices and guidance during completing this project enable me to be in the right direction and finish the project before the deadline. Given me this project really gives me the opportunity to explore and has a deeper understanding of filter operation.

Deepest appreciation to my project examiner, En. Mohd Shahril Izuan Bin Mohd Zin and En. Chairulsyah Wasli for his imperative questions and thought, which have broaden my mind and inspire me more ideas and considerations in solving the problems that occurs in the project implementation.

Not forgotten to En. Imran, thank you very much, for his advice and knowledge during the fabrication process.

Lastly, to my family members and not forgotten to my friends for their priceless contribution and encouragement, thank you vey much. Furthermore, many thanks to those that have directly or indirectly contributed in finalizing this project.

**ABSTRACT**

This report describes the design of filter using the parallel coupled-line technique with the defected ground structure. This project has three main phases, which are designing phase, fabricating phase and the measuring phase. This filters is required to operate at 10G Hz frequency. The filter's design and structure is base on the chebyshev prototype characteristic. The characteristics can be visualized through the responses of reflection coefficient and transmission coefficient, which later will be noted as $S_{11}$ and $S_{21}$ respectively.

In this report there will be an overview on how to design, fabricate and measure designs that meet the specification for the filter. The applications and software that will be used in designing the filter will be described. There will be an introduction to the filter concept and filters designs. Detailed theoretical calculations that have been performed will be shown in the following sections. The schematic diagrams together with the simulations result of filter is presented with all the parameters that have been introduced. All the parameters are related to the equations of the design phase, and other constraints that might be involved in the design process are given.

Finally, the measured results of the fabricated filters are discussed. Additionally, the operations of the filter and the approaches taken in finalizing the final design are described. The responses and the characteristics of the filter are observed by using a network analyzer. Furthermore, future work and improvements to the accuracy and the performance of the filters are discussed.

**ABSTRAK**

Laporan ini menerangkan reka bentuk penapis menggunakan teknik "Parallel Coupled-Line" dengan "Defected Ground Structure". Projek ini mempunyai tiga fasa utama iaitu fasa mereka bentuk, fasa fabrikasi, dan fasa mengukur. Penapis ini diperlukan untuk beroperasi pada frekuensi 10G Hz. Struktur dan reka bentuk penapis ini adalah berdasarkan prototaip ciri "chebyshev". Ciri-ciri yang boleh dilihat melalui tindak balas pekali pantulan dan pekali penghantaran, yang kemudiannya akan dicatatkan sebagai $S_{11}$ dan $S_{21}$.

Dalam laporan ini, akan digambarkan mengenai bagaimana untuk mereka bentuk, fabrikasi dan mengukur reka bentuk yang memenuhi spesifikasi untuk penapis. Aplikasi dan perisian yang akan digunakan untuk mereka bentuk penapis akan diterangkan.Di dalam laporan ini juga, akan ada pengenalan mengenai konsep penapis dan mereka bentuk penapis. Pengiraan secara teori terperinci yang telah dilakukan akan ditunjukkan di dalam bahagian-bahagian berikut. Skema litar bersama dengan hasil simulasi penapis akan dibentangkan dengan semua parameter-parameter yang telah ditetapkan. Semua parameter yang berkaitan dengan persamaan fasa mereka bentuk, dan kekangan lain yang mungkin terlibat dalam proses reka bentuk akan di bentangkan.

Akhir sekali, hasil pengukuran fabrikasi penapis akan dibincangkan. Selain itu, operasi penapis dan pendekatan yang diambil dalam memuktamadkan reka bentuk akhir penapis ini akan diterangkan. Maklum balas dan ciri-ciri penapis akan dinilai menggunakan "network analyzer". Tambahan pula, kerja-kerja dimasa hadapan dan penambahbaikkan terhadap ketepatan dan prestasi penapis dibincangkan.

# TABLE OF CONTENTS


| CHAPTER | SUBJECT | PAGE |
|---|---|---|
| | **PROJECT TITLE** | **i** |
| | **DECLARATION** | **iii** |
| | **DEDICATION** | **v** |
| | **ACKNOWLEDGEMENT** | **vi** |
| | **ABSTRACT** | **vii** |
| | **ABSTRAK** | **viii** |
| | **TABLE OF CONTENTS** | **ix** |
| | **LIST OF TABLES** | **xii** |
| | **LIST OF FIGURES** | **xiii** |
| | **LIST OF ABBREVIATIONS** | **xv** |
| | **LIST OF APPENDIX** | **xvi** |
| **I** | **INTRODUCTION** | |
| | 1.1Project Overview | 1 |
| | 1.2Problem Statement | 2 |
| | 1.3Objective | 2 |
| | 1.4Scope | 3 |
| | 1.5 Project Outline | 4 |
| **II** | **LITERATURE REVIEW** | |
| | 2.1 Introduction | 5 |
| | 2.2 Filter Parameters and Prototype | 8 |

2.3Substrate Materials 9
2.4 Applications 10
2.5Summary of Transmission Lines and Waveguides 11
2.6 Distributed Element Filter 12
2.6.1 Coupled Microstrip Line 14
2.7 Defected Ground Structure (DGS) 16
2.7.1 Application in Microwave Circuit 19

**III DESIGN AND METHODOLOGY**

3.1 Design and Methodology of Distributed Filter 22
3.1.1 Design Parameters 24
3.1.2 Design Calculations 27
3.1.3 Schematic Layout 30
3.1.4 Simulation Result 31
3.1.5 Comments and Discussion 31
3.1.6 DGS BSF Design 31
3.1.7 Parallel Coupled-Line with DGS BSF Design 39
3.1.8 Simulation Result Parallel Coupled-Line withDGS 40
3.1.9 Comments and Discussions 40

**IV RESULT, ANALYSIS AND DISCUSSION**

4.1 Measurement of Parallel Coupled-Line Filter with DGS 41
4.1.1 Reflection ($S_{11}$) and Transmission ($S_{21}$) Testing 41
4.1.2 Comments and Discussions 43
4.1.3 Comparison Response 44

V CONCLUSION AND FURTHER WORK

5.1 Conclusion 48
5.2 Further Work 49

REFERENCES

APPENDIX A
APPENDIX B
APPENDIX C

# LIST OF TABLES


| NO. | TITLE | PAGE |
|---|---|---|
| 2.5 | Comparison of Common Tranmission Lines and Waveguides | 11 |
| 3.1.1(a) | Element Values | 25 |
| 3.1.2(a) | Parallel-coupled Strip-line Resonator Filter Dimension | 30 |
| 3.1.6(a) | Summarized of investigation parameters | 33 |
| 4.1.3(a) | Measured and Simulated Results | 44 |

# LIST OF FIGURE


| NO. | TITLE | PAGE |
|---|---|---|
| 2.1(a) | A Cellular Base Station RF Front End | 5 |
| 2.1(b) | Four Common Type of Filter Characteristic | 7 |
| 2.6(a) | Single Layer Microstrip Line Structure | 12 |
| 2.6.1(a) | Structure of Coupled Microstrip Line | 14 |
| 2.6.1(b) | Quasi-TEM modes of a pair of coupled microstrip lines (a) even-mode and (b) odd-mode | 15 |
| 2.6.1(c) | MCLIN (Microstrip Coupled Line) | 16 |
| 2.7(a) | Various DGSs (a) Spiral head, (b) arrowhead-slot, (c) “H” shape slots, (d) a square open-loop with a slot in middle section, (e) open-loop dumbbell and (f) interdigital DGS | 17 |
| 2.7(b) | DGS dumbbell shape (g) equivalent circuit and (h) response | 18 |
| 2.7.1(a) | M-Shaped DGS bandpass filter (a) Square resonator (b) M-shaped Defected Ground Structure and (c) Simulation and Measurement results | 19 |
| 2.7.1(b) | Comparison of the whole circuit size of DDA and CDA | 20 |
| 2.7.1(c) | Photo of the fabricated 1:6 Wilkinson divider with DGS | 21 |
| 3.1(a) | Diagram of conventional Bandpass Filter with DGS | 22 |
| 3.1(b) | Design process Flow Chart | 23 |
| 3.1.1(a) | Element Definition of Filter Prototype | 25 |
| 3.1.1(b) | Attenuation VS Normalized Frequency for Chebyshev Filter Response | 26 |
| 3.1.1(c) | Element Values for Chebyshev Response | 26 |
| 3.1.2(a) | Layout of Parallel Line Filter | 27 |

| | | |
|---|---|---|
| 3.1.3(a) | Schematic Layout of Distributed Filter | 30 |
| 3.1.4(a) | Simulation Response of Distributed Filter | 31 |
| 3.1.6(a) | Layout of DGS with dumbbell shape | 32 |
| 3.1.6(b) | Investigate parameter *a* (varies *a*, *b* = 1 mm and *g* = 0.5 mm) | 32 |
| 3.16(c) | Investigate parameter *b* (*a* = 3 mm, varies *b* and *g* = 0.5 mm) | 33 |
| 3.1.6(d) | Investigate parameter *g* ( *a* = 3 mm, *b* = 1 mm and varies *g* ) | 33 |
| 3.1.6(e) | Simulation response of DGS BSF | 34 |
| 3.1.6(f) | Equivalent circuit of DGS | 34 |
| 3.1.6(g) | Butterworth prototype lowpass filter circuit | 35 |
| 3.1.6(h) | Simulation of DGS Bandstop Filter by Advance Design System | 36 |
| 3.1.6(i) | Simulation response of DGS Bandstop Filter | 36 |
| 3.1.6(j) | Simulation of one-pole parallel coupled-line bandpass filter by Advanced Design System | 37 |
| 3.1.6(k) | Simulation response of one-pole parallel coupled-line bandpass filter | 38 |
| 3.1.6(l) | Equivalent circuit of parallel coupled-line bandpass filter with DGS | 38 |
| 3.1.6(m) | Simulation response of parallel coupled-line bandpass filter with DGS | 39 |
| 3.1.7(a) | Layout of parallel coupled-line with DGS | 39 |
| 3.1.8 | Simulation Response of Filter with DGS | 40 |
| 4.1.1(a) | The Set-up for the Coupled paralle-line filter with DGS Test | 42 |
| 4.1.1(b) | Graph of $S_{21}$ and $S_{11}$ against Frequency | 43 |
| 4.1.3(a) | Comparison result between measurement and simulation (a) response $S_{21}$ of filter (b) response $S_{11}$ of filter | 45-46 |
| 4.1.3(b) | Comparison result between measurement and simulation (a) response of $S_{21}$ of filter with DGS (b) response $S_{11}$ of filter with DGS | 46 |

# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| ADS | - | Advanced Design System |
| BSF | - | Band-Stop Filter |
| BPF | - | Band-Pass Filter |
| DC | - | Direct Current |
| DGS | - | Defected Ground Structure |
| ICI | - | Inter-Channel Interference |
| RF | - | Radio Frequency |
| VSWR | - | Voltage Standing Wave Ratio |

# LIST OF APPENDIX


| NO | TITLE | PAGE |
|---|---|---|
| | | |
| A | Example of Undercutting Effect | 54 |
| B | Fabricated Parallel Coupled-Line | 54 |
| C | Fabricated Parallel Coupled-Line with DGS | 54 |

# CHAPTER 1

# INTRODUCTION

## 1.1 Project Overview

The primary idea is to design and fabricate a 10G Hz Distributed Bandpass Filter. Later, its performance will be measured and demonstrate. The filter's design and structure is based on the chebyshev prototype characteristic. The characteristics can be visualized through the responses of reflection coefficient and transmission coefficient, which later will be noted as $S_{11}$ and $S_{21}$ respectively. Theoretically, with correct calculation and proper fabrication processes, the performance of the filter can be clearly identified since the filter characteristic will only allow the desired frequency band to operate.

Formation of the distributed filter will adopt the Parallel-Coupled Strip Line Resonators technique and will be fabricated using microstrip line that will be etched on the top of blank printed circuit board. Simulation package named Advanced Design Package (ADS) will be used to design and simulate the filer.

All the principles and the detailed operatios will be discussed and elaborated in the subsequent chapter.

## 1.2 Problem Statement

Microstrip is a cheaper, reliable and easy to connect with other planar devices. Compare to waveguide, microstrip is thus much less expensive than traditional waveguide technology, as well as being far lighter, has high Q factor and is more compact. Most present day, systems demand for small size, lightweight and low cost. The employment of microstrip technology arises extensively over the years. So microstrip are particularly suited to those applications where low profile.

## 1.3 Objective

The main objective of doing this project is to observe the performance of Band Pass filterwith Defected Ground Sturcture operating at a frequency of 10G Hz. It is also to gain better understanding on the operability of the intended filter by allowing good transmission of desired signal and at the same time reject the undesirable signal at 10G Hz. On the other hand, to design, fabricated and analyze the Band Pass Filter with DGS and lastly to achieve size minimization of the design.

In addition, with the specific operating frequency accurate design and filter characteristic selection is crucial to produce the correct filter performance.

## 1.4 Scope

The headline is Parallel Coupled-Line Technique with Defected Ground Structure for Bandpass Filter at 10G Hz. This project is personally new for me. Consequently, in the beginning of the project the basic information on how the filter works was brought together to have an overview of filter opertion. The aspects that need full attention in designing an accurate filter to produce best performance have been studied to implement this project in the early stage.

A book titled *"Microwave Filters, Impedance-Matching Networks, and Coupling Structures"*, written by G. Matthaei, L. Young and E. M. T. Jones was used as guidance indesign technique for filters with parallel-coupled strip line resonators that I am going to produce for this project for the distributed filter.

Therefore, as part of performing research on these types of filters, I also need to get familiar with the basic filter concepts in order to make a filter as required to complete this project.

The most important aspect that need to be aware for this project, to what type of work that need more time to be designed, fabricated and tested where required high accuracy of designing and calculations method. Then simulations and optimizations testing need to be done using ADS simulation package.

By dividing the project into two stages, it will significantly reduce the duration applied to complete this project. in the first stage, the distributed filter is designed, calculated and simulated. Then in the second stage, the performace of the filter is tested and measured. This allows any problems that arise during each stage to be tackled carefully and correct consideration can be made.

## 1.5 Project Outline

This thesis comprises of six chapters. The first chapter briefly discusses project overviewthat is the introduction, objectives, problem statements and scope.

Chapter 2 describes research findingsand information about the project from selected references. This literature review has been explained about the coupled microstrip lines.

Chapter 3 will discuss about the project methodology and design such as calculation, simulation, fabrication and testing. All of these should be followed for a better performance. I will also discuss project findings and analysis in this chapter. All the initial simulation results of coupled microstrip lines and collected data are documented using table and discussed. This is including the graphs that have been obtained during the simulation.

Chapter 4 describes my hypothesis regarding the expected result and the comparison between simulation and measurement.

Finally I will share my project conclusion together with recommendation for possiblefuture works. The recommendation is added to give an opinion and guidance for future improvements.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

The operating RF filters in the microwave spectrum have many applications including wireless handset and base stations, as well as satellite receivers and military applications. All of these famous systems that been used in RF and microwave filters is in order to allow good transmission of wanted signal simultaneously rejects the unwanted signal frequencies. Recently published papers investigating RF filter design reveal a need for ongoing development. These filters operate in an increasingly crowded signal spectrum. They may operate in harsh environments subject to shock, vibration, and extreme temperatures. The industry experiences continuous pressure to improve performance while reducing the size and cost of the filters and their associated systems. The RF front end of a cellular radio base station block diagram shown in Figure 2.1(a) is the application of typical filtering [1].

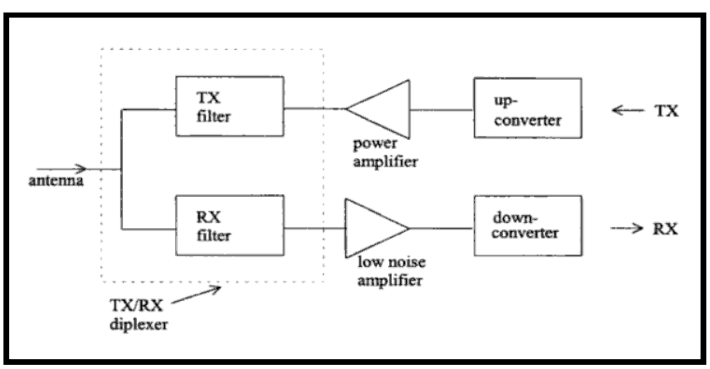


Figure 2.1(a): A Cellular Base Station RF Front End

The most obvious application of filter structures, of course is for the rejection of unwanted signal frequencies while permitting good transmission of wanted frequencies. In microwave communications, the most common filters are used, which are briefly described in the following [2]:

Low-Pass Filter

Low-pass filter networks transmit all signals between DC and some upper limit $\omega_c$, and attenuate all signals with frequencies above $\omega_c$. They are realized by using a cascade of series inductors and shunt capacitors. The frequency range of the filter specification has been divided into three areas. The passband extends from zero frequency to the passband edge frequency $f_{pass}$and the stop-band extends from the stop-band edge frequency $f_{stop}$ to infinity. These two bands are separated by the transition band that extends from $f_{pass}$ to $f_{stop}$.

High-Pass Filter

High-pass filter pass all signals with frequencies above the cut-off value $\omega_c$, to the load with minimum loss and reject signal with frequencies below $\omega_c$. High-pass filter networks are realized by using cascade of series capacitors and shunt inductors. In this case the passband extends from $f_{pass}$ to infinity and is located at a higher frequency than the stop-band, which extends from zero to $f_{stop}$. High-pass filter are used to eliminate low frequencies from a signal.

Band-Pass Filter

The band-pass filter shows the signal is transferred to the load in a band of frequencies between the lower cut-off frequency $\omega_{c1}$, and the upper cut-off frequency $\omega_{c2}$. Between the lower and upper cut-off frequency is the center frequency $\omega_o$, defined by the geometric mean of $\omega_{c1}$ and $\omega_{c2}$ [3]. A band-pass filter will pass a band of frequencies while attenuating frequencies below or above that band. In this case, the passband exists between the lower passband edge frequency $f_{pass1}$ and the upper passband edge frequency $f_{pass2}$. A band-pass filter has two stop-bands. The lower stop-band extends from zero to $f_{stop1}$, while the upper stop-band extends from $f_{stop2}$ to infinity.

Band-Reject (Stop) Filter

The band-reject filter is a complement of the band-pass filter. The signal experiences high loss between $\omega_{c1}$ to $\omega_{c2}$, hence the name band-stop or band-reject. In this case the band of frequencies being rejected is located between the two pass-bands. The stop-band exists between the lower stop-band edge frequency $f_{stop1}$ and the upper stop-band edge frequency $f_{stop2}$. The band-stop filter has two pass-bands, the lower passband extends from zero to $f_{pass1}$, while the upper passband extends from $f_{pass2}$ to infinity.

All-Pass Filter

The all-pass filter allows the signal amplitude for all frequencies to pass through the network without any signigficant loss. This network has no frequency selective pass-band of stop-band.

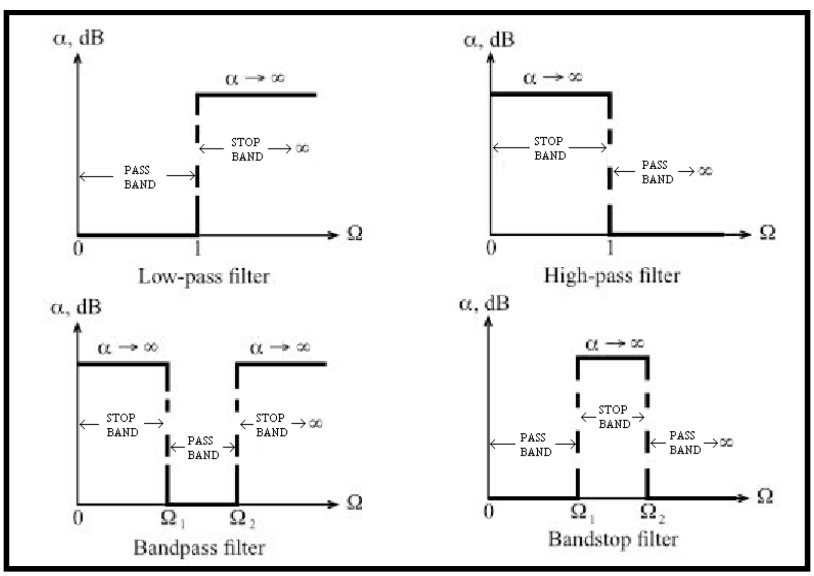


Figure 2.1(b):Four Common Type of Filter Characteristic [4]

A review of some filter design basics will be helpful. Ludwig and Bretchko [5] provide a textbook overview of filter basics. Filter types, theory and design are reviewed. Filter types include Butterworth, Chebyshev and Linear filters. Chebyshev filters are seen to have an advantage of fast transition between midband and out of band signal spectrum. This transition is relatively slow for linear filters, which are favored for their relatively linear phase across the filter's spectrum. Higher phase linearity implies less variation in signal (group) delay with frequency and therefore less potential distortion across a filter's passband [5-6].

## 2.2 Filter Parameters and Prototype

The primary function played by filters in today modern wireless communication is to prevent inter-channel interference (ICI). The key aspect and parameters for filter design are the operating frequency, input and output impedance levels, 3dB bandwidth, insertion loss, return loss, roll-off, voltage standing-wave ratio (VSWR), temperature range, group delay, and transient response [7]. Two main prototypes of filter are Butterworth and Chebyshev with maximally flat and equal-ripple respectively.

Butterworth

The Butterworth response is known as the maximally flat response. The response has a smooth roll-off with no ripple. The transition-band is medium in width. The cutoff of the filter is not sharp and the phase response is not too bad for low order filters. This is the easiest filter type to compute pole or zero locations as they fall exactly on a circle whose radius in the s-plane is the cutoff frequency. The phase response is fair and there is moderate overshoot and ringing to a step function. This filter is a good compromise when the time domain response is of medium importance relative to the frequency domain response.