DISSERTATION

DESIGN OF GENERALIZED CHEBYSHEV MICROWAVE FILTER WITH PRESCRIBED TRANSMISSION ZEROES

By

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13943

Dissertation submitted in partial fulfilment of
the requirements for the
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CERTIFICATION OF APPROVAL

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Approved by,

____

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May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(TEE WEE LIANG)

ABSTRACT

This paper presents a better prototype approximation which is generalized Chebyshev where its transmission zeroes can be located arbitrarily and have high selectivity. The purpose of selecting generalized Chebyshev is because it can be designed in low loss and small size for prototype which such requirements are hardly achieved by other filter prototype. The scope of this project include microwave low pass generalized Chebyshev filter design using distributed elements particularly microstrip. Methodology of carrying out practical design work will be presented through different stages from design to fabrication. Results will be recorded and observed. In conclusion, generalized Chebyshev filter gives customer advantages for their requirement of filter devices due to its low impedance variance and flexibility locating zeroes.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank Universiti Teknologi PETRONAS (UTP) for structuring this Final Year Project course allowing me to equip myself on how to conduct research, design and/or development work on real-world problems.

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Last but not least, I wish to thank my parents for their unparalleled contribution and support both morally and financially throughout my life. They are my pillar of strength and I shall do my utmost to ensure their happiness and fulfilment as a filial son.

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ABBREVIATIONS AND NOMENCLATURES

CAD	Computer Aided Design
ADS	Advanced Design System
MATLAB	Matrix Laboratory
RF	Radio Frequency
UMTS	Universal Mobile Telecommunications System
LTE	Long Term Evolution
Wi-Fi	Wireless Fidelity
Q-factor	Quality factor
S-parameter	Scattering parameters

CHAPTER 1
INTRODUCTION

1.1 Background

In modern days, technology keeps developing and advancing in every single moment, people around the world seek for higher performance in terms of processor speed of the laptops, smartphone, tablet etc. Besides that, internet is world widely used and of course higher data rate is on demand in order to access the internet among consumers to acquire information faster and conveniently in this information age. With that, higher specifications particularly high frequency is required to transmit data as well as more time and money to be invested on research to improve existing or new technology.

Radio frequency and microwave have played a major role to provide faster data rate and low noise technology in the communication industry due to its high frequency. Basically, filter has played an important role to discard unwanted band, in another word, to extract desired frequency band for particular technology apart from the others. However, what we have studied about lumped elements like capacitor and inductor no longer support microwave filter design in higher frequency due to shorter wavelength, results of parasitic inductance and capacitance [1]. The interesting part of pursuing this filter designing project is using distributed elements such as microstrip and coaxial to design microwave filter by applying certain transformation concept instead of using inductors and capacitors. Furthermore, designing microwave filter using distributed elements is different from what we did by analysing the lumped electronic components during practical lab session [2].

The project involves analytical analysis, theoretical modelling, CAD tools design & simulation and finally prototype fabrication as well as measurement for verification throughout these two semesters of final year.

1.2 Problem Statement

Conventional Chebyshev function filter is not sufficiently selective to meet the modern mobile base station requirements. Compared with Elliptic filter, it is hard to be realized with many transmission zeroes due to high impedance variation in physical structure [3].

With the following issues stated above, generalized Chebyshev prototype in which transmission zeroes can be placed at the finite frequencies is needed and proposed in order to meet the demands of providing better telecommunication services for consumers by mobile operators.

Poor telecommunication services offered by mobile operators to customers may bring inconvenience to customers in case they have emergency matters, also to corporate customers as this may affect their business. More thorough research studies shall be conducted for improvement and advancement.

1.3 Objectives

1. To design a high selectivity 9^{th} order generalized Chebyshev low pass filter.
2. To fabricate the microstrip filter and measure the prototype using network analyser.

1.4 Scope of Study

The scope of study for this final year project will be microwave filters design using distributed elements especially microstrip transmission lines. Different kind of prototype of the filters such as maximally-flat, Chebyshev, elliptic and generalized Chebyshev shall be studied and compared. Besides that, running simulation software must be grasped well for ease of circuit design and mathematical computation purposes using Advanced Design System by Agilent, Maple 16 by Maplesoft and MATLAB by MathWorks. In addition, fundamental mathematical skills as well as knowledge of utilizing hardware such as network analyser are essential to carry out the final year project.

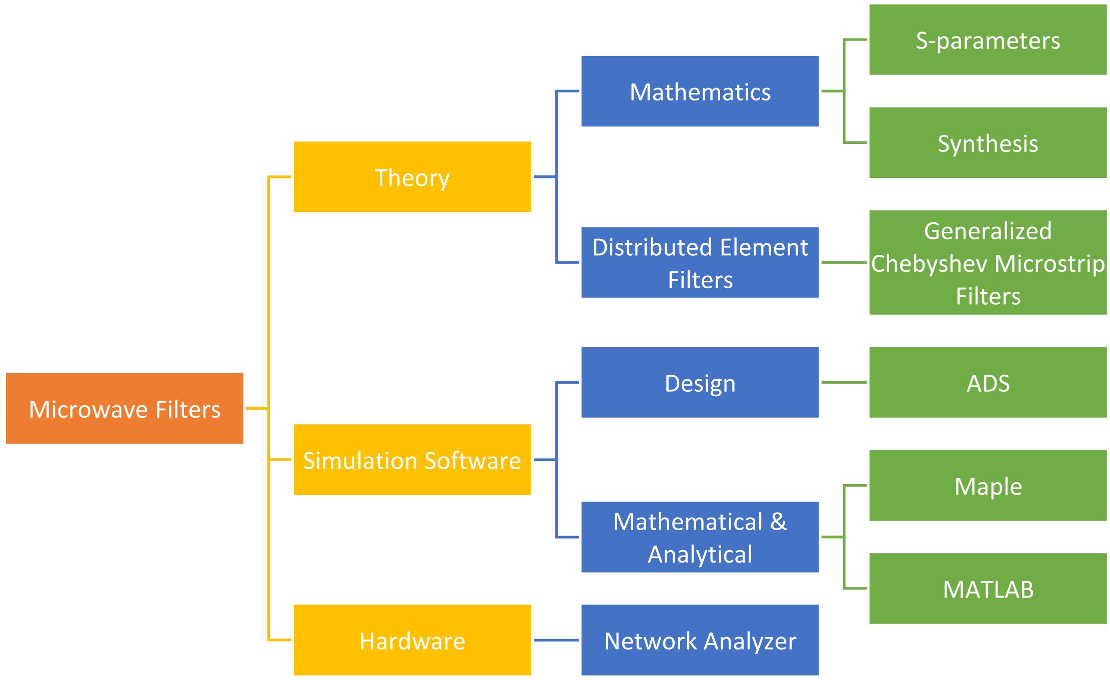

Figure 1.1: Scope of study for generalized Chebyshev filter design

CHAPTER 2

LITERATURE REVIEW

2.1 RF and Microwave Filters Design

RF (Radio Frequency) and microwave filters are widely used in many fields such as cellular networks (UMTS, LTE), satellite communication, and other applications as well. In general, the function of filters is to extract one particular operating frequency band from the unwanted one, for instance, noise or harmonics in both transmitter and received ends [4]. It is crucial to extract one particular frequency band as the frequencies are regulated by the government communication commission and the purchase of license of utilizing that particular frequency band for researches or providing service purposes is required unless it is a free band for example Wi-Fi operating at 2.4GHz or 5GHz [5].

The reason of not using lumped elements to design microwave filters is because when it comes to higher frequency, the wavelength becomes shorten, physical dimension of the circuit become more significant in design. Thus, the lumped elements become more parasitic [6]. There are many kinds of distributed element such as coaxial, microstrip, planner, and other filter technologies that are being used to fabricate the filter. Each of them possesses different specifications based on demand of the Q-factor.

2.2 Scattering Parameter

The scattering parameter which is known as S-parameter is a two port network for analysis of microwave design.

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$\boldsymbol{b_1 = S_{11}a_1 + S_{12}a_2}$$

$$\boldsymbol{b_2 = S_{21}a_2 + S_{22}a_2}$$

Where

$S_{11} = b_1/a_1|_{a_2=0}$: Input reflection coefficient

$S_{12} = b_1/a_2|_{a_1=0}$: Reverse gain

$S_{21} = b_2/a_1|_{a_2=0}$: Forward gain

$S_{22} = b_2/a_2|_{a_1=0}$: Output reflection coefficient

A two-port network can be said as reciprocal or passive if the forward gain and the reverse gain are equal for example $S_{12} = S_{21}$. It is symmetrical if the input reflection coefficient is the same with the output reflection coefficient. Furthermore, $|S_{11}|^2 + |S_{12}|^2 = 1$ implies the two port network is a lossless system.

$-10\log_{10}|S_{12}(\omega)|^2$ is known as insertion loss L_A which is derived from S-parameters (scattering parameters). $|S_{12}(\omega)|^2$ is solely defined as the squared magnitude of the transfer function of the response itself. Another important parameter that should be taken into account is $-10\log_{10}|S_{11}(\omega)|^2$ which is known as return loss, L_R. From that, the insertion loss and the return loss will be zero and infinity respectively for an ideal filter response [6].

2.3 Types of Filters

Table 2.1: Various kinds of filters with its characteristics

Filters	Characteristics
Low-pass filter	It allows signals of low frequency to pass through. Otherwise, signals with frequency higher than cut-off frequency will be either attenuated or eliminated.
High-pass filter	It allows signals of higher frequency to pass through. Otherwise, signals with frequency lower than cut-off frequency will be either attenuated or eliminated.
Band-pass filter	Allows certain range of frequencies to pass through while attenuate or eliminated the rest other than both lower and higher cut-off frequencies
Band-stop filter (Notch filter)	Remove one particular unwanted frequency, leaving the rest of frequencies of the signal remain unchanged.

2.3.1 Butterworth Function Prototype

Comparing to maximally flat filter which is also known as Butterworth filter, Chebyshev and Elliptic approximation has more selectivity and faster roll-off rate [1]. However, the advantage of the maximally-flat filter is that the behaviour of its gain is maximally flat at $\omega = 0$ and $\omega = \infty$ instead of having ripples. Given

$$|S_{12}(j\omega)|^2 = \frac{1}{1 + \omega^{2N}}$$

The poles of maximally flat approximation lies on the unit circle in the left half plane at equally spaced angular frequencies. The location of the zeroes is illustrated as below [7]:

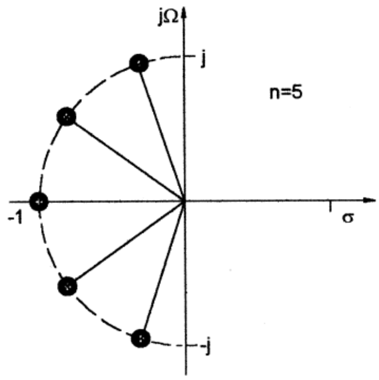

Figure 2.1: Pole distribution for Butterworth response when N=5

2.3.2 Chebyshev Function Prototype

Chebyshev approximation has the characteristics of having equiripple where it can be controlled in the passband and has transmission zeroes when the frequency approaches infinity. Also, the Chebyshev is very selective due to its equiripple characteristics. This can be explained based on the following equation:

$$|S_{12}(\omega)|^2 = \frac{1}{1 + \varepsilon^2 T_N^2(\omega)}$$

Where

$$T_{N+1}(\omega) = 2\omega T_N(\omega) - T_{N-1}(\omega), \qquad T_0(\omega) = 1, \qquad T_1(\omega) = \omega$$

Given that $T_N^2(\omega)$ is Chebyshev polynomial which is recursive [8]. As ω of function $T_N^2(\omega)$ approaches to infinity, $|S_{12}(\omega)|^2$ will become zero. Also, the pole distribution of Chebyshev approximation is shown below.

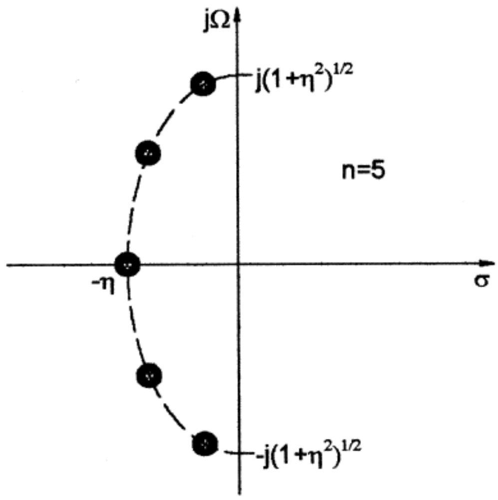

Figure 2.2: Pole distribution for Chebyshev response when N=5

The major axis of the ellipse is on the imaginary axis of the p-plane while the minor axis is on the real axis with the size of η [7].

2.3.3 Elliptic Function Prototype

Elliptic function has equiripple in both passband and stopband. Instead of having transmission zeroes at infinity, it has fixed zeroes at certain finite frequencies. In other words, It does not have the flexibility of prescribing the transmission zeroes at desired frequencies [1]. The response is given equation as shown below:

$$|S_{12}(\omega)|^2 = \frac{1}{1 + \varepsilon^2 F_N^2(j\omega)}$$

where $F_N^2(\omega)$ is an Elliptic rational function.

2.3.4 Generalized Chebyshev Function Prototype

Generalized Chebyshev which is known as pseudo-elliptic [9] has equiripple at both passband and stopband together with the advantage of having the flexibility of prescribing the transmission zeroes. In addition, it can have the option of generating symmetric and asymmetric frequency response.

The major difference between Chebyshev function prototype and generalized Chebyshev function prototype is that the latter provides more flexibility in terms of having the option to prescribe the location of the transmission zeroes. Likewise, it allows customization of the generalized Chebyshev function to yield symmetrical or asymmetrical results [1]. Compared to elliptic prototype, the selectivity of generalized Chebyshev is very close with each other, however, in terms of realization, the latter are more approachable. Furthermore, generalized Chebyshev filter prototype has lower impedance variations than that of elliptic with the ratio of 2:1 [3].

The approximation function of generalized Chebyshev is given by

$$|S_{12}(j\omega)|^2 = \frac{1}{1 + \varepsilon^2 F_N^2(j\omega)}$$

With

$$-1 < F_N(\omega) < 1 \; for -1 < \omega < 1$$

Where

$$F_N(\omega) = \cos[N \cos^{-1}(\omega)]$$

And

$$F_N(\omega) = \frac{j}{2}\left(\prod_{r=1}^{N}\left\{\frac{1 + pp_r + [(1+p^2)(1+p_r^2)]^{1/2}}{p - p_r}\right\} + \prod_{r=1}^{N}\left\{\frac{1 + pp_r - [(1+p^2)(1+p_r^2)]^{1/2}}{p - p_r}\right\}\right)$$

And the ε can be obtained based on given minimum return loss level in dB [3]:

$$\varepsilon = [10^{(LR/10)} - 1]^{-1/2}$$

2.3.4.1 Synthesis of generalized Chebyshev prototype

There are various techniques of synthesis for generalized Chebyshev filters and most of them depend on many conditions for example the even or odd degree of the filters, considering whether the zero are symmetrically or asymmetrically located as well as the location of the zeroes in the complex plane. Unfortunately, generalized Chebyshev filter cannot be synthesised using ladder networks. There are few types of synthesis techniques and they are explained below:

A. ***Synthesis of generalized Chebyshev prototypes with symmetrically located transmission zeroes***

This synthesis method is simplified by using even-mode and odd-mode admittances. Its ladder network is cross-coupled. It is suitable for narrowband applications.

B. ***Synthesis of generalized Chebyshev prototypes with ladder-type networks with conditions***

The Nth degree of the filter prototype must be odd. The elements connected in series are parallel resonant circuit. The symmetrically located real frequency transmission zeroes can be realized using the circuit shown below:

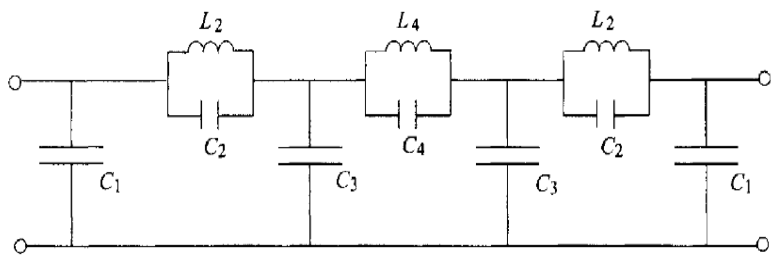

Figure 2.3: The generalized Chebyshev with ladder-type realization

C. ***Asymmetrically located transmission zeroes***

Certain requirements such as having one side of the passband to be more selective. Therefore, that is where the asymmetrically located transmission zeroes synthesis method coming in.

2.4 Microstrip

As mentioned before, microstrip is one of the transmission line for filter design. It is classified as planar transmission line which is similar to coplanar waveguide and strip line. It can be fabricated using PCB (printed circuit board) technology [10]. Microstrip is light and less expensive to be fabricated. It consists of a strip that is conductive separated from a ground plane by a substrate. The most important parameters for microstrip design is the width of the strip, the height which is equivalent to the thickness of the substrate and the relative permittivity of the substrate [11]. However, the microstrip has the advantage of lower power handling capacity and also induces greater losses. Unintentional radiation and cross-talk is likely to happen as microstrip is not entirely enclosed.

To realize this microstrip filter from filters designed from lumped elements, derived synthesis formulas are required to obtain the physical width and length of the microstrip.

Given the characteristic impedance and the cut-off frequency, the synthesis formula is as shown as below:

For narrow strips when $Z_o > (44 - \varepsilon_r)\Omega$:

$$\frac{w}{h} = \left(\frac{e^{H'}}{8} - \frac{1}{4e^{H'}}\right)^{-1}$$

Where

$$H' = \frac{Z_o\sqrt{2(\varepsilon_r + 1)}}{119.9} + \frac{1}{2}\left(\frac{\varepsilon_r - 1}{\varepsilon_r + 1}\right)\left(ln\frac{\pi}{2} + \frac{1}{\varepsilon_r}ln\frac{4}{\pi}\right)$$

For wide strips, when $Z_o > (60 - \varepsilon_r)\Omega$ and ${}^{w}/_{h} > 1.3$:

$$\frac{w}{h} = \frac{2}{\pi}\left[(d_\varepsilon - 1) - \ln(2d_{\varepsilon_1} - 1)\right] + \frac{(\varepsilon_r - 1)}{\pi\varepsilon_r}\left[\ln d_{\varepsilon_r} - 1 + 0.293 - \frac{0.517}{\varepsilon_r}\right]$$

Where

$$d_\varepsilon = \frac{59.95\pi^2}{Z_o\sqrt{\varepsilon_r}}$$

However, we can see that the formulas given above is too sophisticated to solve. Instead, ADS is use for synthesize the parameters to physical width and length of the microstrip. The tools that will be used in ADS is called LineCalc.

Furthermore, given the strip width and length, we can actually analyse the characteristics impedance based on the formulas.

For narrow strips $\left({}^{w}/_{h} < 3.3\right)$:

$$Z_o = \frac{119.9}{\sqrt{2(\varepsilon_r + 1)}} ln\left[4\frac{w}{h} + \sqrt{16\left(\frac{h}{w}\right)^2 + 2}\right]$$

For wide strips $\left({}^{w}/_{h} > 3.3\right)$:

$$Z_o = \frac{119.9}{\sqrt{2\varepsilon_r}}\left\{\frac{w}{2h} + \frac{ln\,4}{\pi} + \frac{\ln(e\pi^2/16)}{2\pi}\left(\frac{\varepsilon_r - 1}{{\varepsilon_r}^2}\right) + \frac{\varepsilon_r + 1}{2\pi\varepsilon_r}\left[\ln\frac{\pi e}{2} + \ln\left(\frac{w}{2h} + 0.94\right)\right]\right\}$$

CHAPTER 3
METHODOLOGY/PROJECT WORK

3.1 Project Work

The project work will be divided into four phases, mainly theory understanding, filter prototype synthesis, simulation design as well as fabrication and measurement.

First and foremost, the project will begin by literature reviewing. A thorough understanding of microwave filter technology and design will be discussed with supervisor, Dr. Wong by have appointment with him on weekly basis. Also, supervisor will assist in providing guidelines of doing the microwave filter design project so that the progress will be on the right track. Besides that, self-studying will be self-conducted prior consultation by referring to internet, online journals, and reference books. Prior to have a real practical design given the specifications, having references and guidelines of how to design a generalized Chebyshev filter will be studied through several journals and reference books in order to get familiar with the design approach in final year project 2 which falls on upcoming semester.

Secondly, after mastering the theories, circuit will be designed given specific requirement for example the location of transmission zeroes and cut-off frequencies. With that, a prototype network will be designed given formula yielding the values of lumped elements for the microwave filter before transforming into transmission line prototype.

Thirdly, circuit will be further designed in ADS for simulation. Circuit transformation of lumped element network prototype will be applied in order to transform into distributed element filter network by using the simulation software once the parameters of the lumped element circuit prototype has been successfully identified. Moving on, the electrical length from ideal distributed elements will be synthesized into physical length of microstrip for realization of low pass filter. Next, a design layout will be generated and produced by the simulation software.

Last but not least, the design layout will be sent out for fabrication. Once the prototype has been done fabricating, network analyser plays an important role to test and measure the essential parameters of the prototype for verification purposes.

3.2 Design Methodology

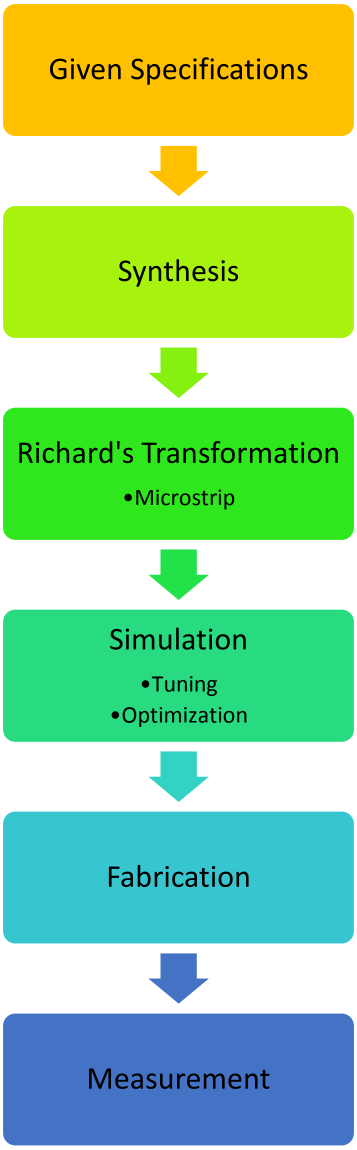

Figure 3.1: The methodology of designing the 9^{th} order generalized Chebyshev low pass filter

3.2.1 Given Specifications

The specification of the generalized Chebyshev low pass filter is listed as below:

Cut-off frequency: 2 GHz

Return loss: >20 dB

Number of elements: 9

3.2.2 Synthesis

Given the specification above, the value of the lumped elements can be obtained from the table in [3], and they are:

$$C_1 = 1.03487$$

$$L_2 = 1.123352$$

$$L_3 = 0.47688$$

$$C_3 = 1.19263$$

$$L_4 = 1.07413$$

$$L_5 = 0.42818$$

$$C_5 = 1.32834$$

And the lumped element circuit for the generalized Chebyshev filter as illustrated below:

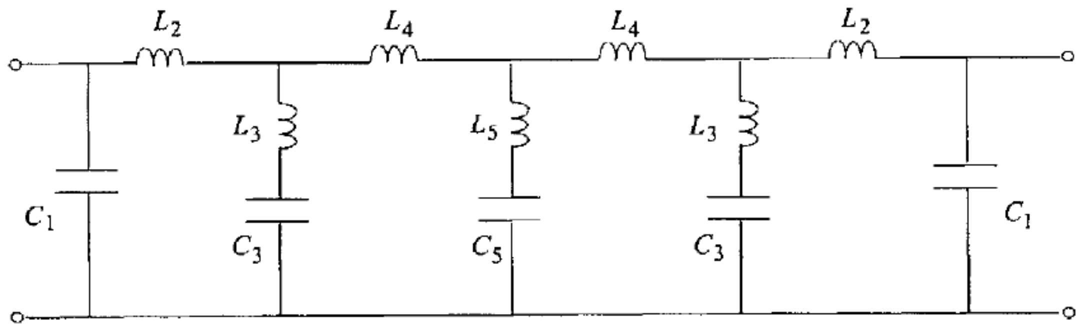

Figure 3.2: Lumped element circuits for generalized Chebyshev filter at N=9

3.2.3 Richard's Transformation

Next we use Richard's transformation to transform the lumped elements into distributed elements by finding its physical length and its characteristics impedance

$$p \rightarrow \alpha \tanh ap$$

Lumped low pass prototype circuit is converted into a distributed circuit of passband edge frequency, ω_c. Hence,

$$1 \Rightarrow \alpha \tan a\omega_c$$

$$a = \frac{1}{\omega_c} \tan^{-1} \frac{1}{\alpha}$$

where

$$\omega_c = 2\pi f_c \text{ and } f_c = 2\ GHz$$

$$\alpha = \omega_o = 1.32599\ rad/s$$

ω_o is obtained from [3] based on the design specification

$$a = \frac{1}{4\pi \times 10^9} \tan^{-1} \frac{1}{1.32599} = 5.14193 \times 10^{11}$$

Consequently, we use the value of a to find the admittance of the distributed value based on the value of lumped elements. The distributed circuit is shown as below [1]:

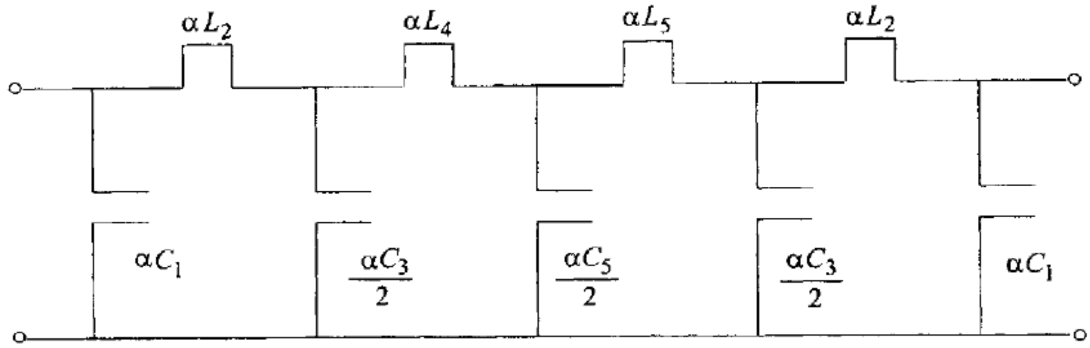

Figure 3.3: Distributed element circuit for generalized Chebyshev filter at N=9

$$Y_1 = \alpha C_1 = 1.37223$$

And its 50 ohm system impedance is 36.44Ω for first and last shunt open circuited stub. The length of the open circuit stub is given from

$$a = \frac{l}{v}$$

$$l = av = 5.14193 \times 10^{11} \times 3 \times 10^{8} = 15.42579\ mm$$

while Y_3 and Y_5 is calculated as

$$Y_3 = \frac{\alpha C_3}{2} = 0.79071$$

$$Y_5 = \frac{\alpha C_5}{2} = 0.88068$$

whereas the resonator stub length is the twice of first and last shunt open circuited stub

$$l_3 = l_5 = 2l = 30.85158\ mm$$

However, the design for series short circuited stub which contribute for third transmission zero at infinity is unrealisable. This is because at $2f_o$, infinite impedance is produced by series short circuited stub in quarter wavelength. Also, the two admittance of the shunt open circuited stub is infinity in quarter wavelength long. However, half of the quarter wavelength long for the shunt open circuited resonator stubs bring no response to the filter. Thus, we can find another alternative by equating the impedances of the series short circuited stubs to high impedance lines at the passband edge frequency [1, 3]. We have

$$l_r = \frac{v}{\omega_c} \sin^{-1}\left[\frac{L_r}{Z_o}\right]$$

Hence,

$$l_2 = \frac{3 \times 10^8}{\omega_c} \sin^{-1}\left[\frac{L_2}{Z_o}\right] = 11.6305\ mm$$

$$l_4 = \frac{3 \times 10^8}{\omega_c} \sin^{-1}\left[\frac{L_4}{Z_o}\right] = 11.07786\ mm$$

Important parameters and their values for the filter are tabulated for ease of reference

Table 3.1: The list of parameters of each distributed element

Lumped Elements	Stub Length (mm)	Characteristic Impedance (Ω)	Electrical Length (˚)
C1	15.4258	36.44	45.00
L2	11.6305	120.00	33.93
L3 & C3	30.8516	63.23	90.00
L4	11.0748	120.00	32.32
L5 & C5	30.8516	56.77	90.00

The values will be used in ADS software for simulation. The response of lumped and distributed element circuit will be observed and discussed in results and discussion section.

3.2.3.1 Microstrip

Given the characteristic impedance and the electrical length, we can synthesize these parameters to find the physical width and length of microstrip transmission line. The substrate that we are going to use for the filter fabrication. It has the following specifications:

Effective relative dielectric constant, Er	=2.2
Permittivity, Mur	=1
Thickness of the substrate, H	=787 um
Position of the cover, Hu	=3.9e+34
Thickness of the copper line, T	=17.5 um
Copper line conductivity, Cond	=2.88e+7

Using ADS, we can implement synthesis by using LineCalc as shown below:

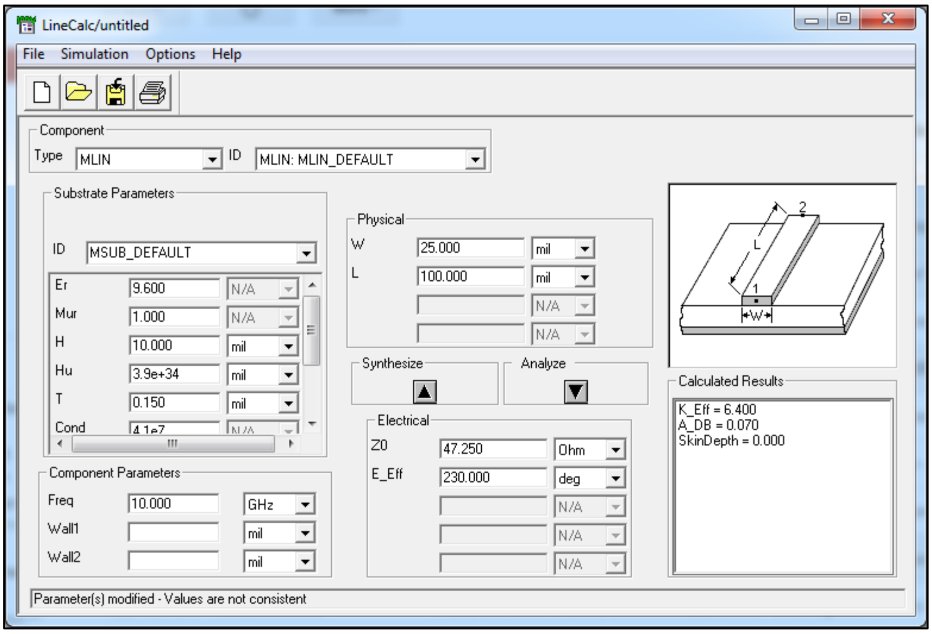

Figure 3.4: Synthesis using LineCalc through ADS

After synthesis, the obtained values will be inserted into the microstrip circuit for simulation. Further tuning and optimization of the width and length of the microstrip transmission line will be done in order to achieve the specification as requested.

3.2.4 Fabrication

Consequently, once the desired response has been obtained. A layout is generated from ADS in order to send for fabrication. Prior to that, the layout of the microstrip circuit must be flatten so that during the circuit printing, there is no other redundant strips that have been printed accidentally.

3.2.5 Measurement

After the prototype has been fabricated, the microstrip filter will be measured using network analyser to verify the network response.

Figure 3.5: Network analyser

3.3 Gantt Chart

The summary of the project work will be summarized as Gantt chart as below:

Table 3.2: Gantt chart and key milestones for final year project timeline

	FYP1														FYP2													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
selection of project topic	■	■																										
basic network theory			■																									
lumped element prototype networks			■																									
filter training workshop				■																								
generalized Chebyshev prototype					■																							
design of GC filter						■																						
extended proposal						■																						
circuit transformation on lumped prototype networks							■	■																				
simulation software							■	■	■	■	■																	
proposal defence								■																				
circuit design										■	■																	
draft report for FYP1												■																
final report for FYP1													■															
synthesis of the circuit														■	■	■	■											
simulation of the circuit															■	■	■											
fabrication																		■	■									
progress report																				■								
measurement																				■	■	■						
pre-SEDEX																							■					
draft final report																								■				
dissertation																									■			
technical paper																									■			
viva																										■		
project dissertation (hard bound)																											■	

Based on the Gantt chart, the progress of the project might be ahead of the schedule provided that if one-week semester break are willing to be spent. Certain tasks can be carried out concurrently for example literature review and circuit simulation in order to avoid time wastage and at the same time build up the strong understanding in relation of theory and application. Having weekly follow up and selfevaluation are essential in order to keep the progress of the project on the right track. Some weeks are expected to be left blank due to tight schedule during test period.

3.4 Key Milestones

Certain important tasks need to be taken as priority as they are they backbone of completing the project

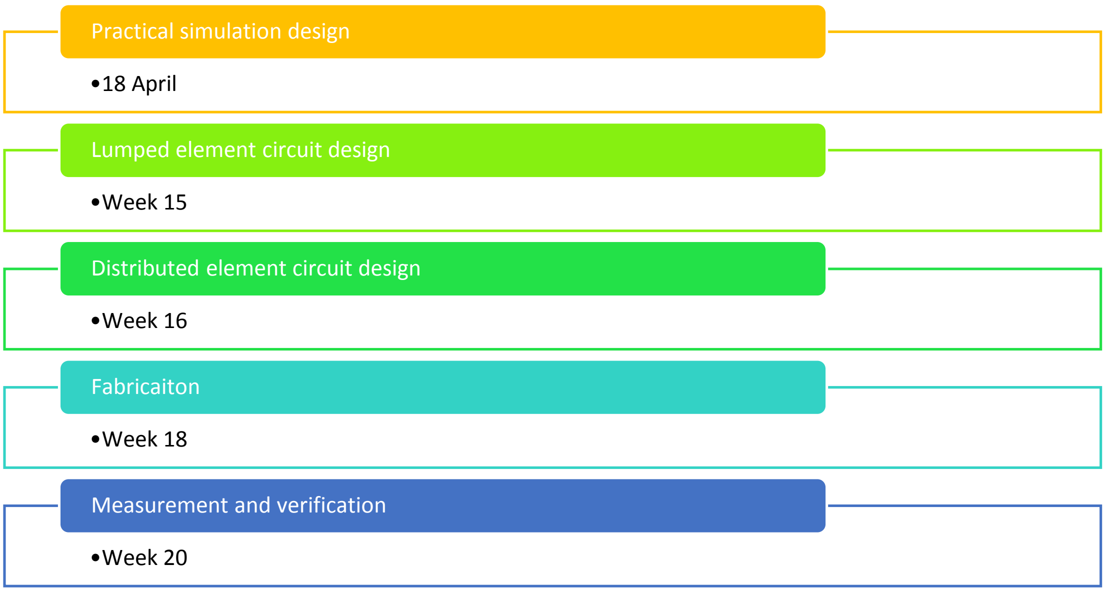

Figure 3.6: The key milestones of final year project

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Distributed Element Circuit Design

4.1.1 Ideal Transmission Line Circuit

The design would be ninth order of generalized Chebyshev low-pass filter circuit using short circuit stubs as unit elements and open circuit stubs.

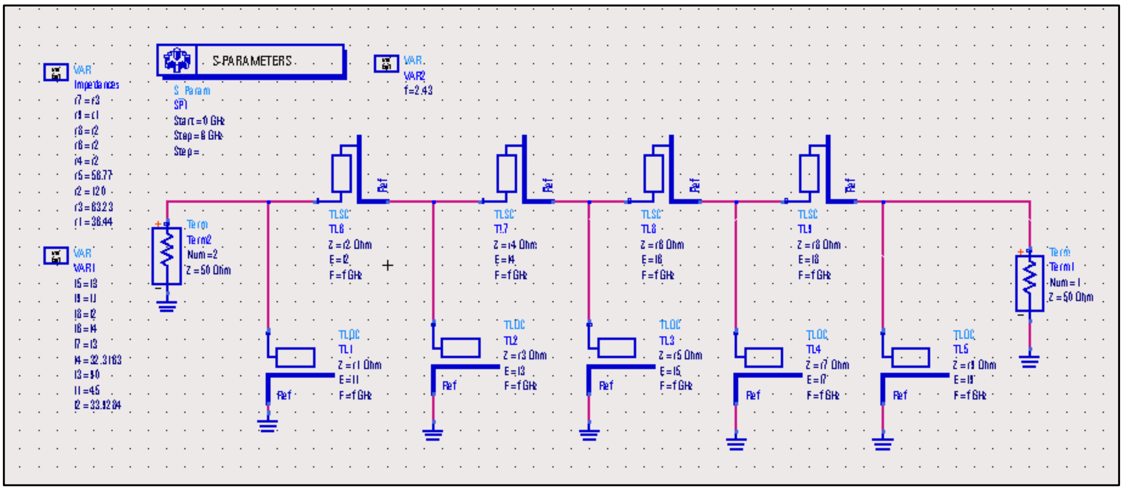

Figure 4.1: Schematic diagram of 9th order generalized Chebyshev low-pass filter prototype using ideal transmission lines.

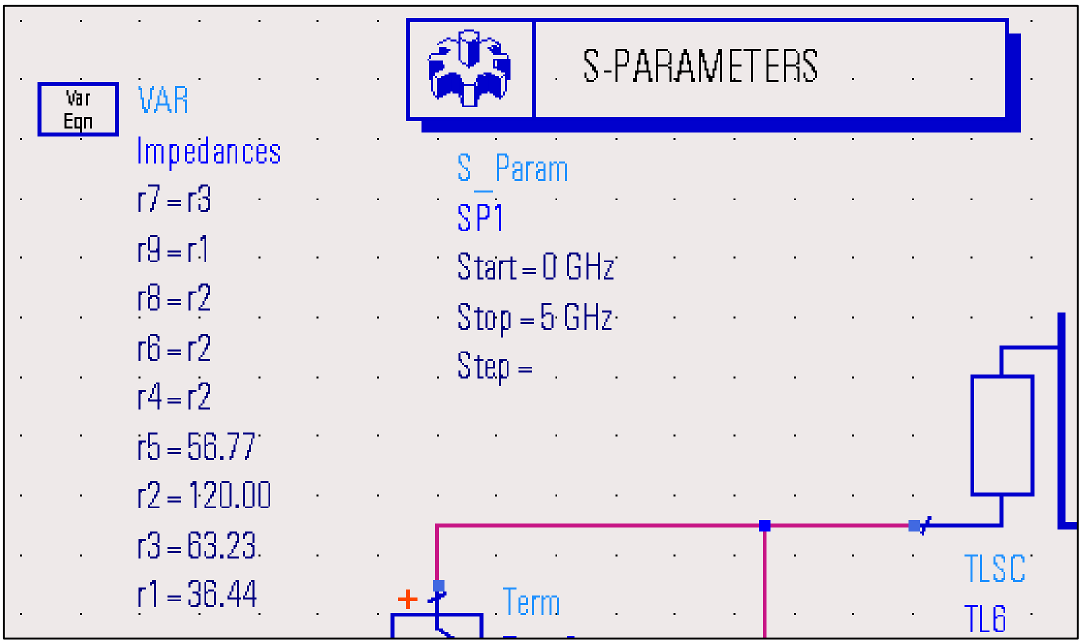

Figure 4.2: The characteristics impedances that have been set for simulation in ADS and also the frequency range for S-parameters simulation

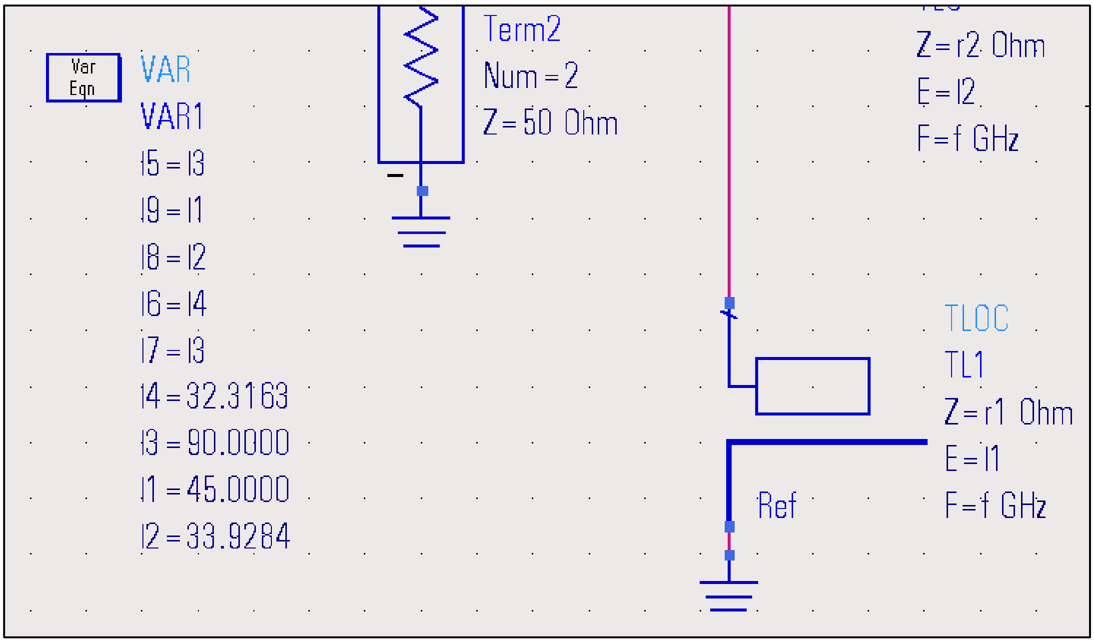

Figure 4.3: The electrical length that have been set for ADS simulation

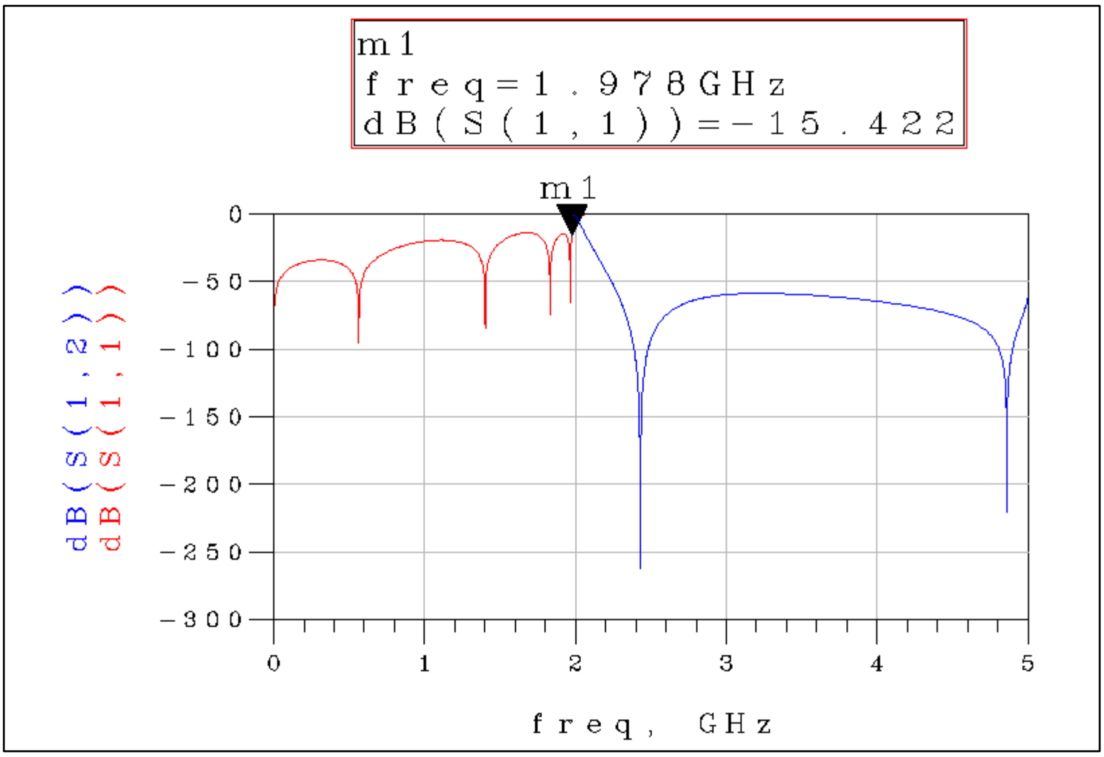

Figure 4.4: The simulated filter response of circuit from Figure 4.2 shows the passband cut-off frequency almost at 2 GHz with return loss of -15 dB

Based on the response above, we can see that the cut-off frequency is 2 GHz right at -15 dB, which mean that the simulation from ideal transmission line is accurate. The f_o can actually be calculated by using the formula as shown:

$$2af_o = 90^{\circ}$$

$$f_o = \frac{90}{2(18.51095)} = 2.431\ GHz$$

From the graph, a ninth degree order of low-pass filter can be identified by observing the ripples from the input reflection coefficient, S_{11}.

Furthermore, we can inspect that there is another transmission zeroes occur at another frequency which is the twice of the f_o.

Hence, the location of the transmission zeroes are at 2.43 GHz and 4.86 GHz.

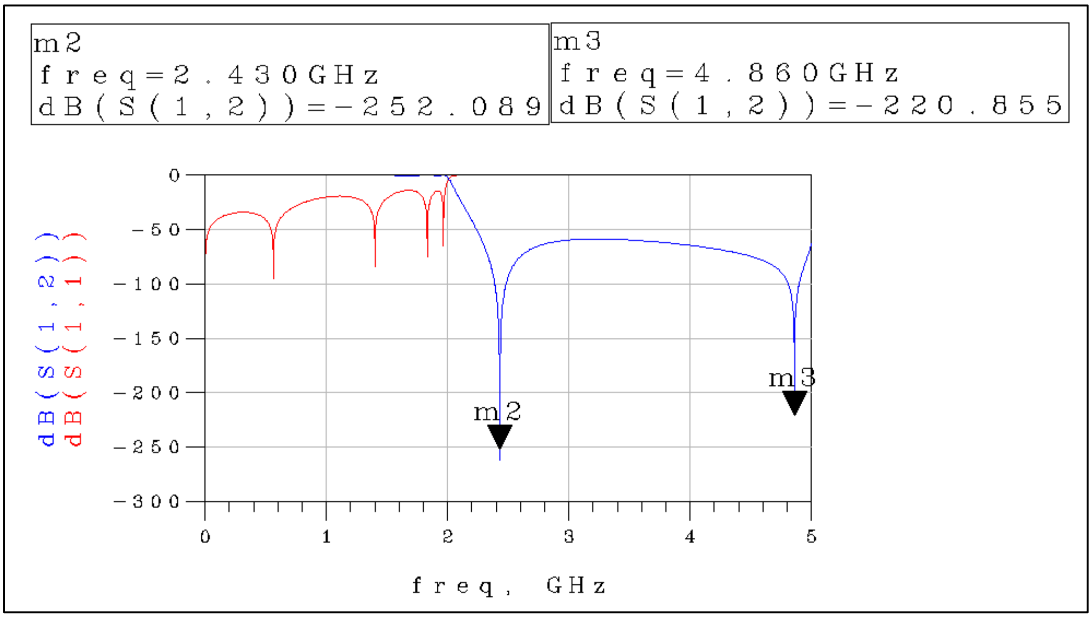

Figure 4.5: The location of the transmission zeroes from ninth order of generalized Chebyshev low-pass filter

4.1.2 Microstrip Transmission Line Circuit

To design microstrip line circuit, we need to use LineCalc tool from ADS to synthesis the characteristics impedance into the width and the length of the microstrip line.

Table 4.1: The parameters need before and after synthesis for microstrip line circuit design.

	Before Synthesis			After Synthesis			
Lumped Elements	Stub Length	Characteristics Impedance (Ω)	Electrical Length	Width (um)	Label	Length (um)	Label
R		50.00	61.75	2397.82	ws1	15436.10	l1
C1	15.4258	36.44	45.00	3767.31	wsh1	11089.50	l2
L2	11.6305	120.00	33.93	427.36	ws2	8865.47	l3
L3 & C3	30.8516	63.23	90.00	1650.89	wsh2	22759.40	l4
L4	11.0748	120.00	32.32	427.36	ws3	8444.23	l5
L5 & C5	30.8516	56.77	90.00	1969.23	wsh3	22638.10	l6

It is ninth order of generalized Chebyshev low-pass filter circuit using microstrip line (MLIN), microstrip T-junction (MTEE) and microstrip open-circuited stub (MLOC).

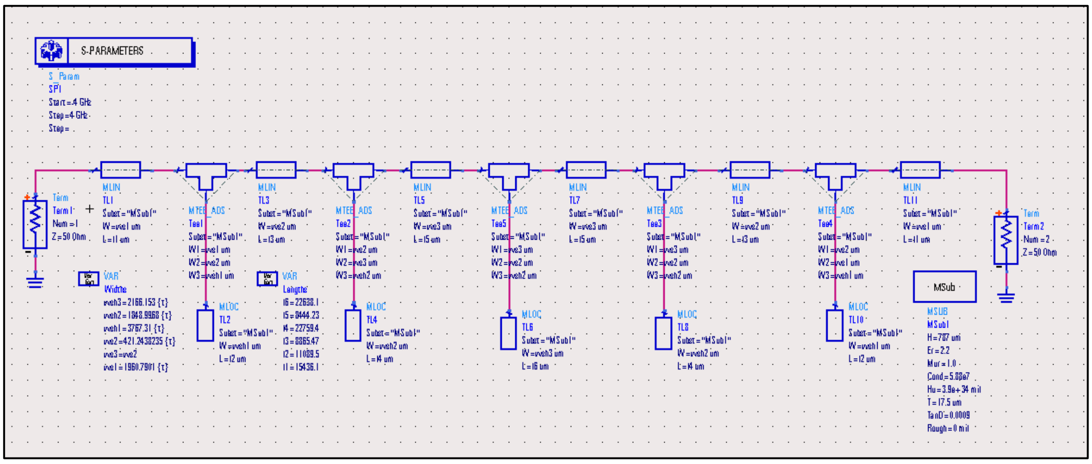

Figure 4.6: Schematic diagram of 9^{th} order generalized Chebyshev low-pass filter prototype using microstrip transmission lines

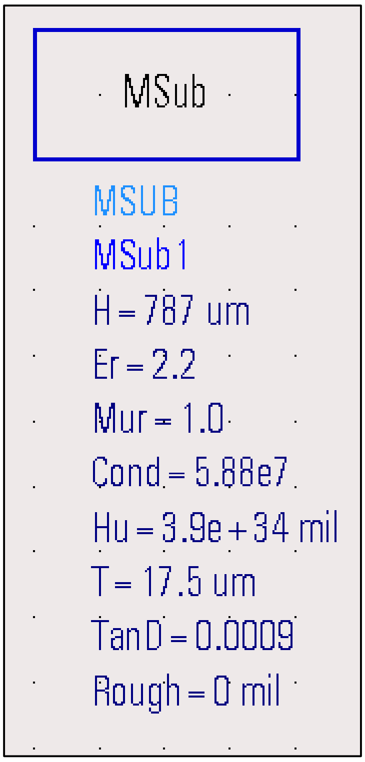

Figure 4.7: The specification and properties of the substrate

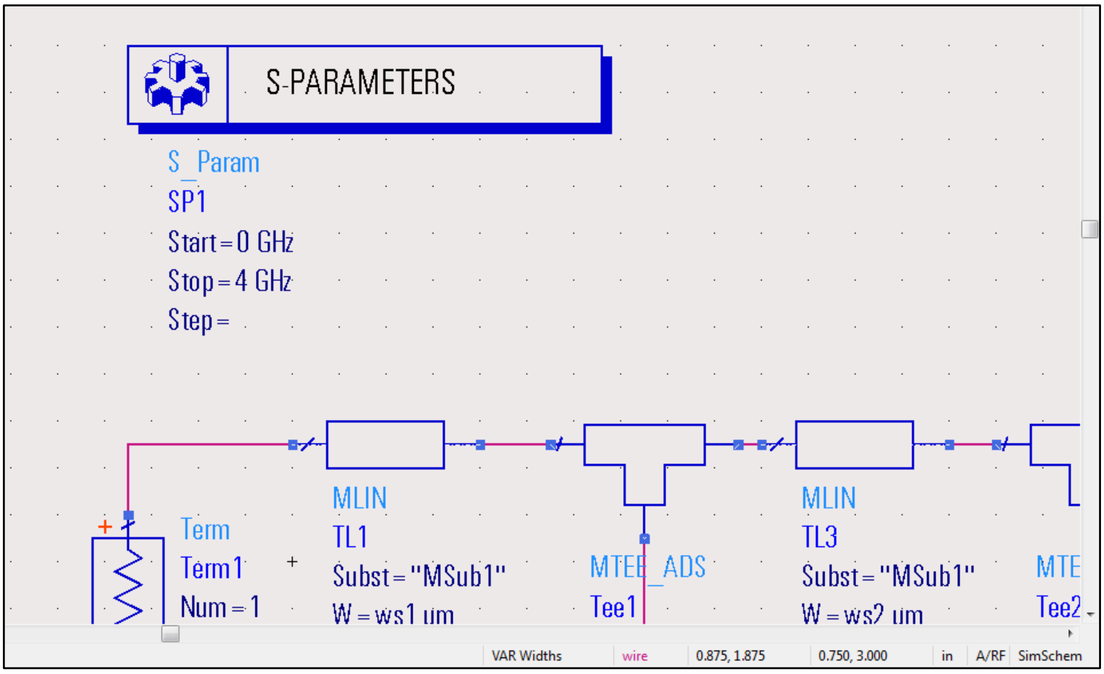

Figure 4.8: The range of frequencies to be simulated for inspecting S-parameters response

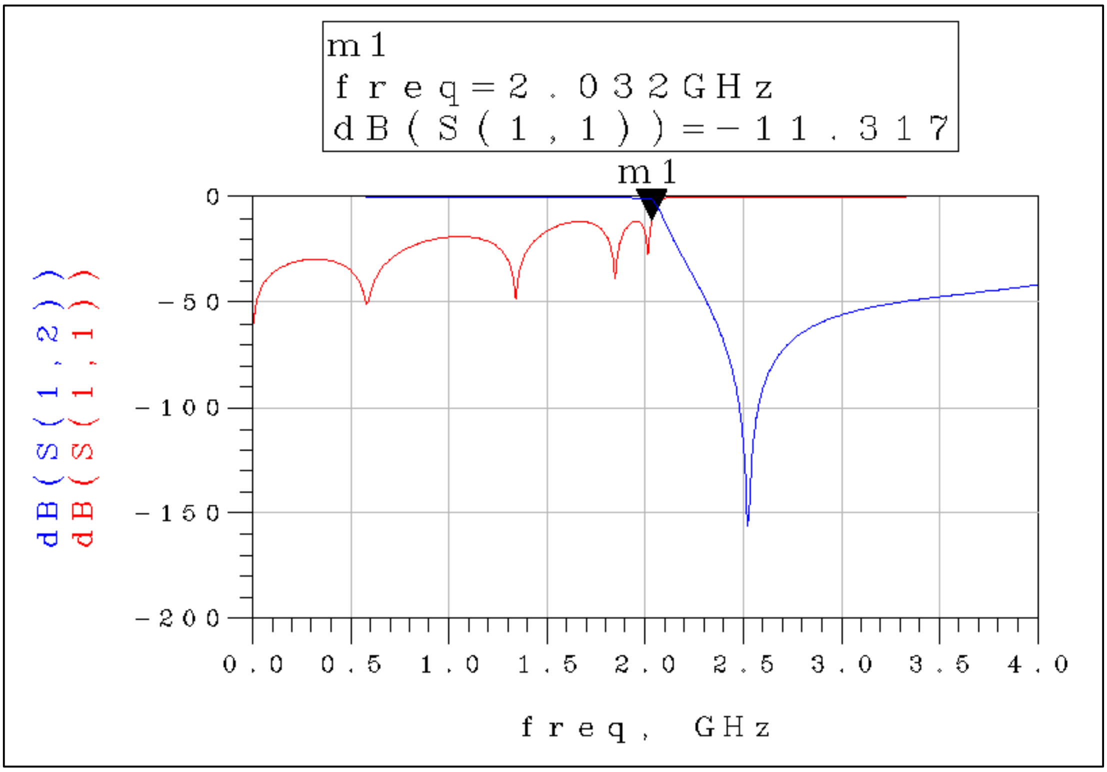

Figure 4.9: The simulated filter response of circuit from Figure 4.6 shows the cut-off frequency almost at 2 GHz with the return loss of -11 dB

Based on the response after synthesizing the ideal transmission line circuit into microstrip by using a LineCal, its graph is almost the same from what we expect according to the ideal response from the ideal transmission line circuit. Both passband cut-off frequency is 2 GHz. Also, the input reflection coefficient response show that the low pass filter is in the order of nine. However the location of the transmission zeroes are at 2.5 GHz and 5.1 GHz which has the difference percentage of 2.9% and 4.9% respectively. The calculation are as follows:

Percentage difference for first transmission zeroes:

$$\frac{2.5 - 2.43}{2.43} \times 100\% = 2.9\%$$

Percentage difference for second transmission zeroes:

$$\frac{5.1 - 4.86}{4.86} \times 100\% = 4.9\%$$

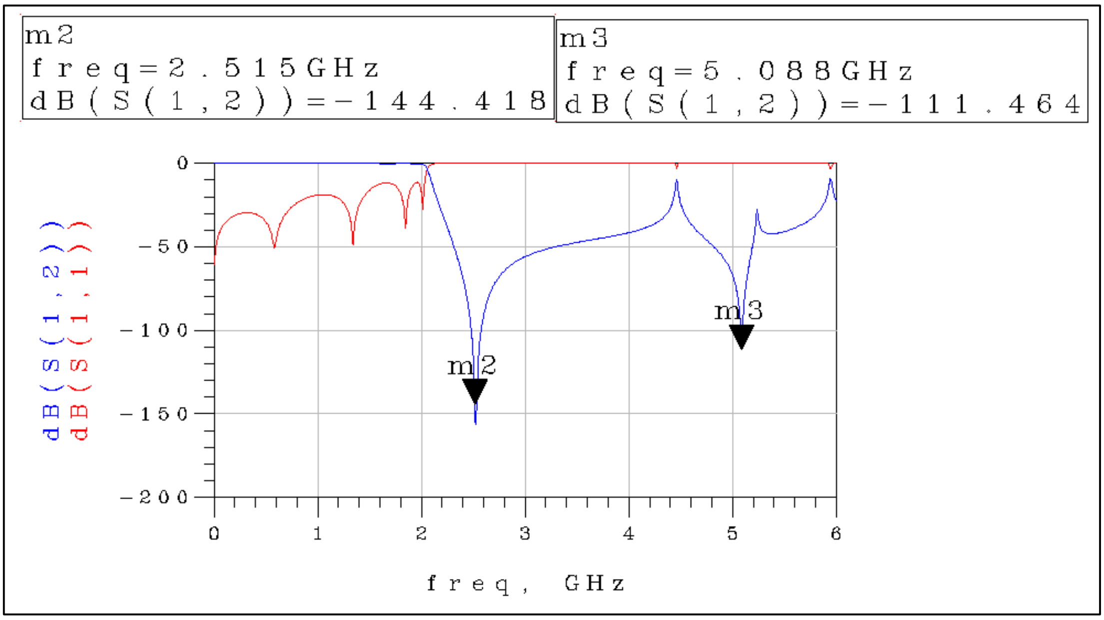

Figure 4.10: The location of the transmission zeroes simulated filter response of circuit from Figure 4.9

However, there is one specification that haven't been achieved yet that is the return loss which is supposed to be less than -20 dB but the simulated response manages to achieve -11 dB. Therefore, the width and the length of the microstrip transmission lines must be tuned in order to achieve the desired specifications. Noted that the width of unit elements namely TLIN will be the same with each other in order to avoid fabrication difficulty

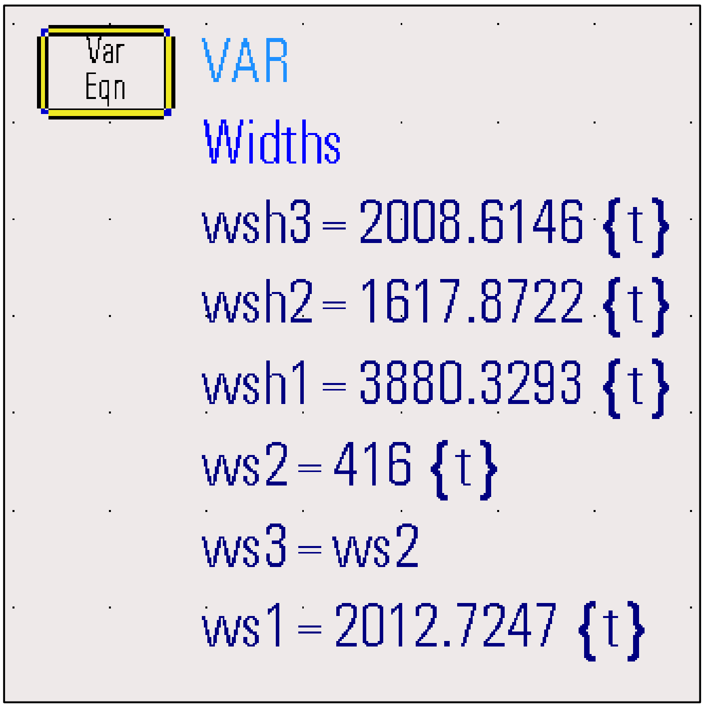

Figure 4.11: The physical width parameters of microstrip transmission lines are configured for tuning to achieve desired response

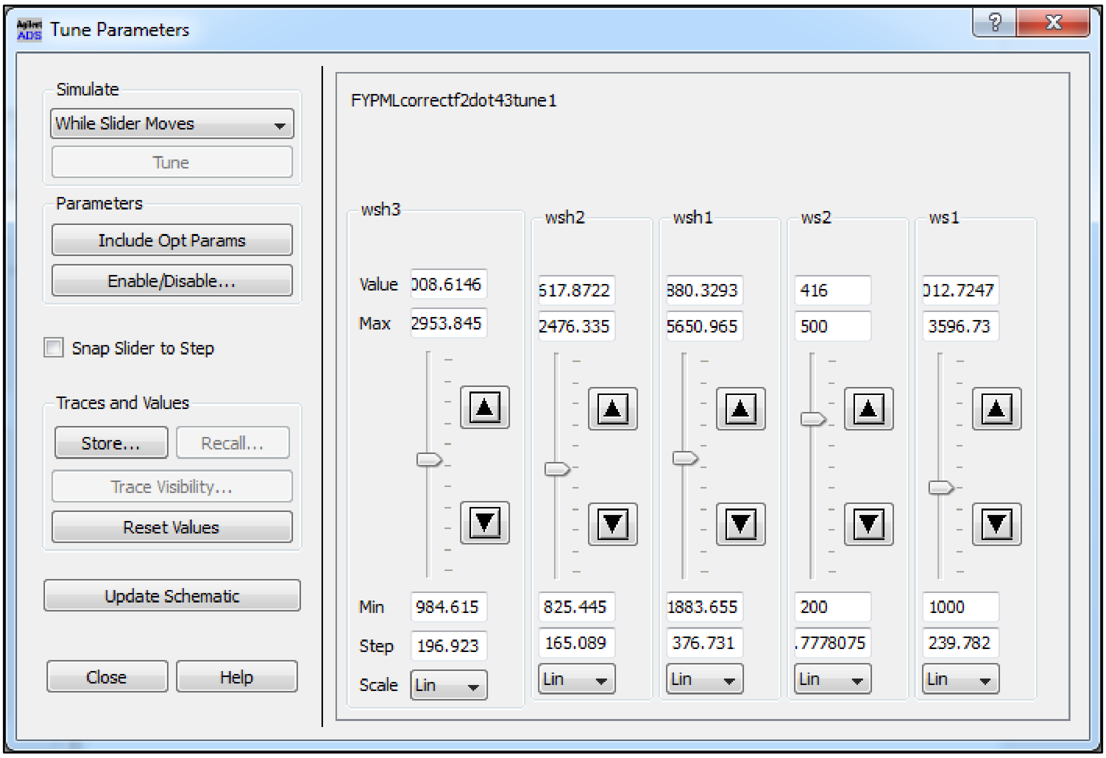

Figure 4.12: Tune parameters

Once the requirement of the insertion loss has been achieved, click the "Update Schematic" to update the latest tuned parameters for the microstrip transmission line circuit.

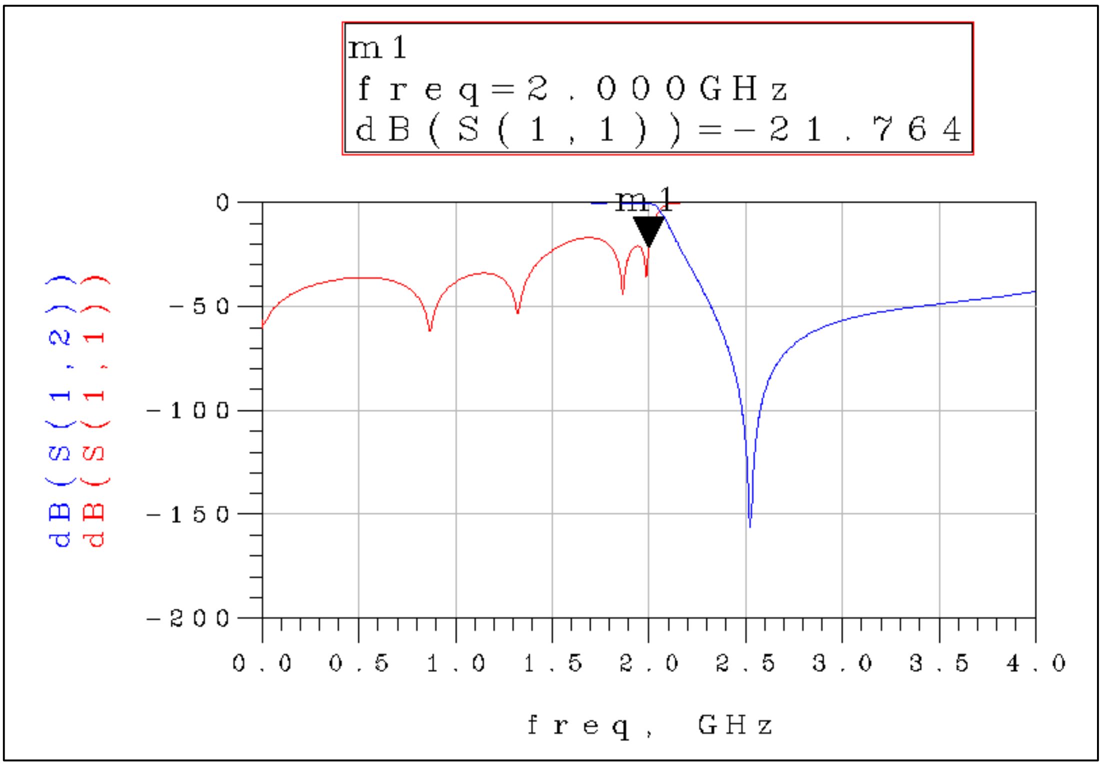

Figure 4.13: The filter response after tuning the width and the length of the microstrip transmission lines

Based on the graph above, we can see that the simulated response is improved by having the insertion loss less than -20 dB. Also, the passband cut-off frequency remains the same at 2 GHz. The advantage of tuning is that the simulated response can be observed spontaneously once you tune the parameters that have been configured. In addition, it is easy to be corrected if the response is false.

4.2 Generating Layout

Layout is generated using ADS based on the specified characteristics of the substrate as shown:

Figure 4.14: The layout of the microstrip filter

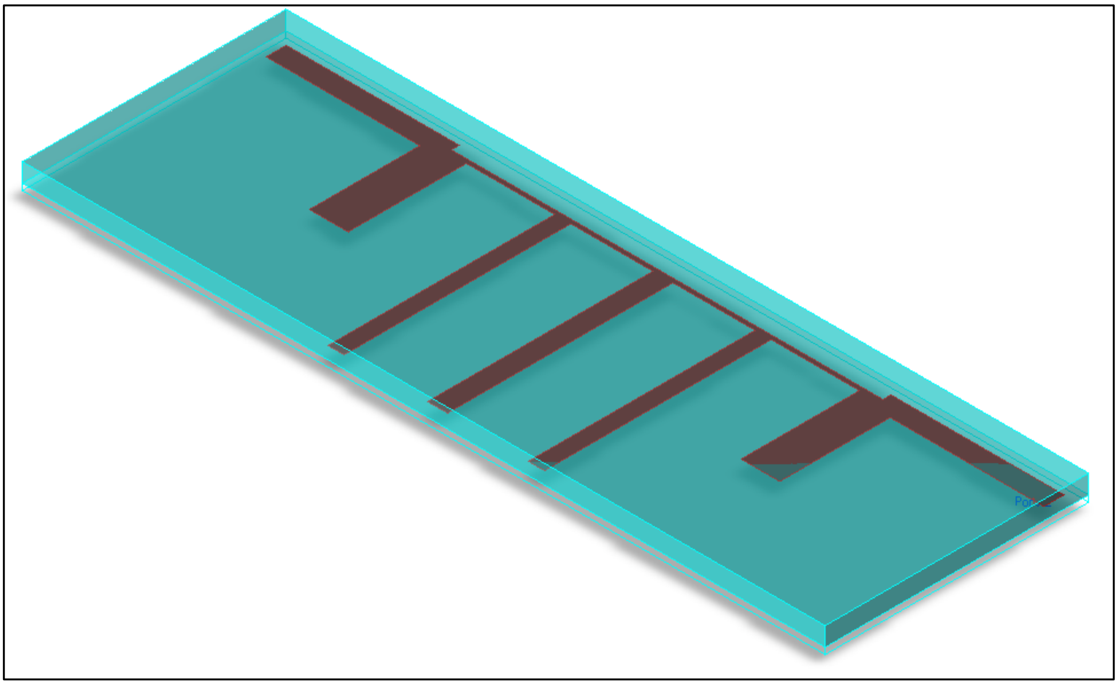

Figure 4.15: The 3D view of the generalized Chebyshev low pass ninth order microstrip filter

4.3 Fabricated Prototype

The ninth order generalized Chebyshev lowpass filter is fabricated and will be sent for measurement using network analyzer

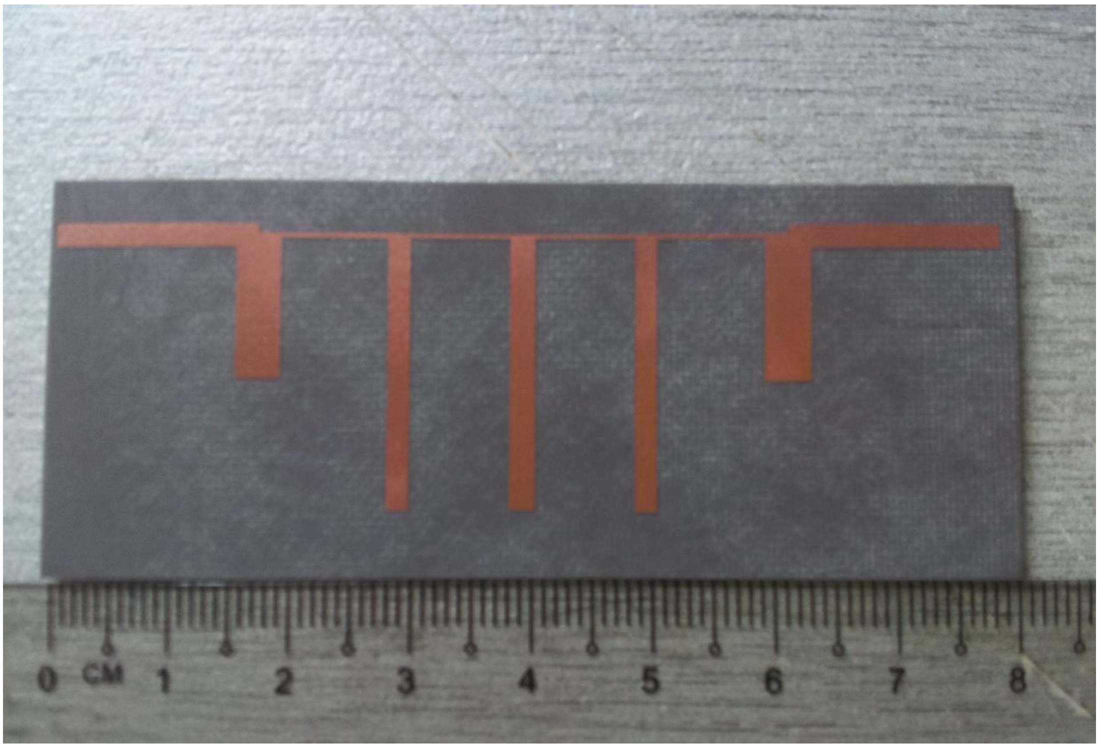

Figure 4.16: Fabricated prototype of generalized Chebyshev lowpass filter

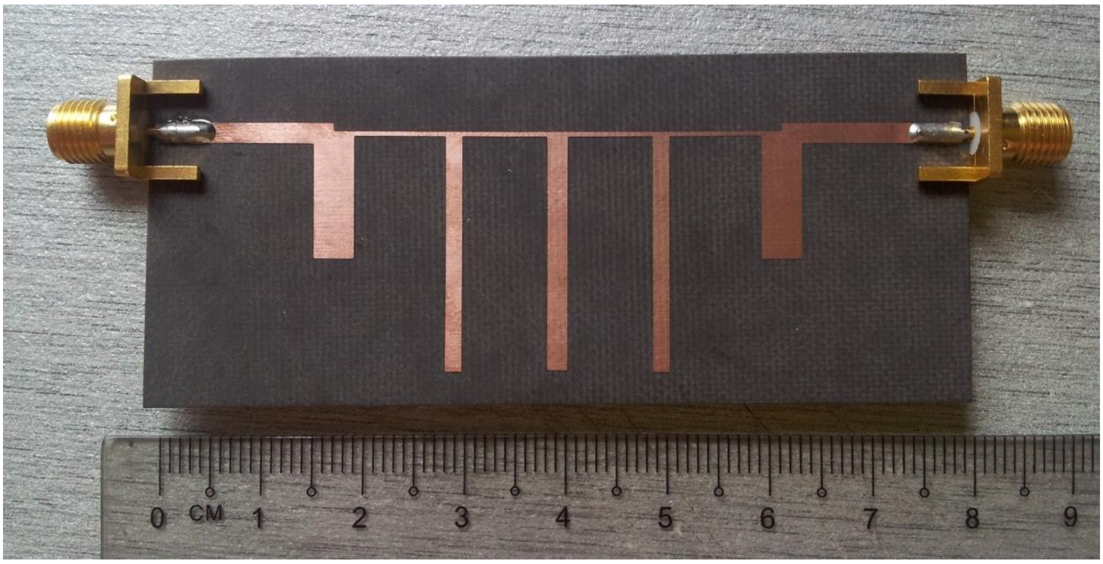

Figure 4.17: Soldered prototype of generalized Chebyshev lowpass filter with two ports

4.4 Measured Results

The prototype is measure using network analyser and the results are shown as below:

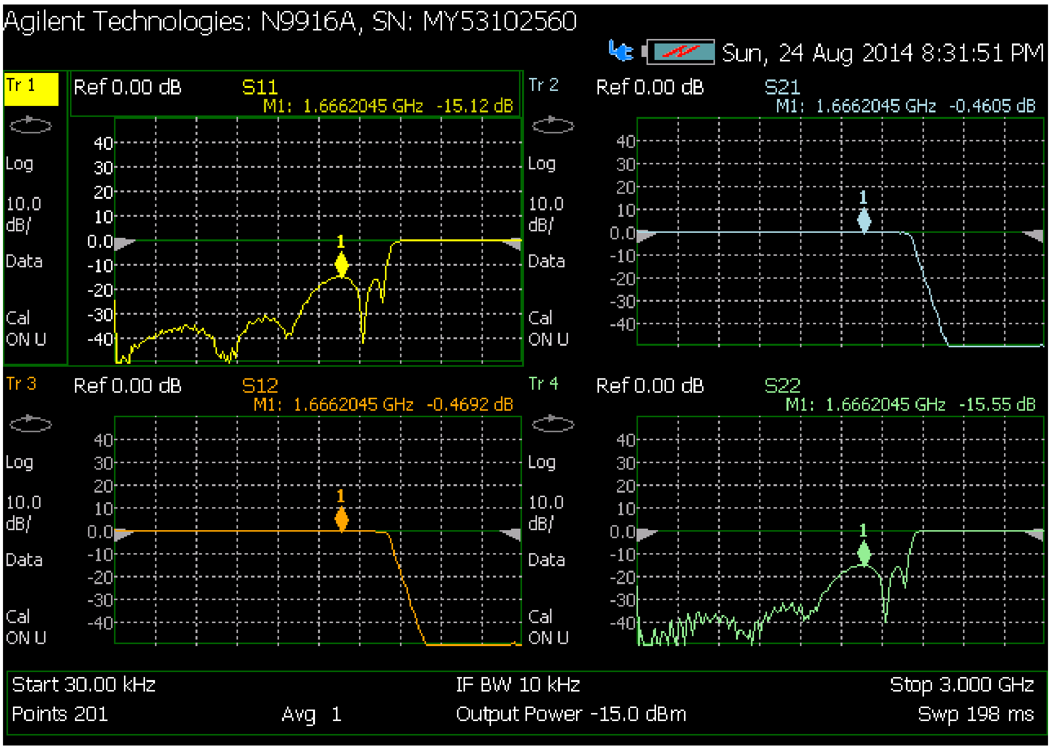

Figure 4.18: Measure response from network analyser

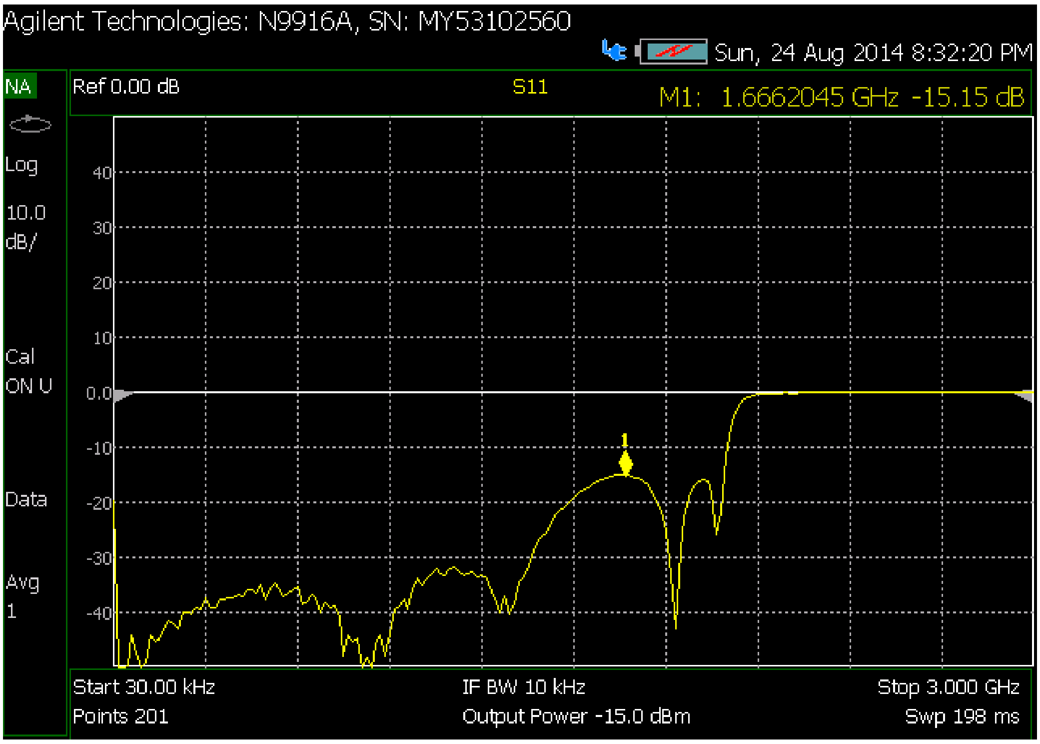

Figure 4.19: Return loss for the filter prototype

Table 4.2: The step values for S11 and S12 parameters

Frequency (Hz)	S11 (dB)	Frequency (Hz)	S12 (dB)
1950010500	-18.4819	1950010500	-0.72823
1965010350	-25.8832	1965010350	-0.7629
1980010200	-22.0263	1980010200	-0.93504
1995010050	-12.1431	1995010050	-1.38963
2010009900	-6.75934	2010009900	-2.39971
2025009750	-3.79691	2025009750	-4.19947
2040009600	-2.24148	2040009600	-6.6788
2055009450	-1.40977	2055009450	-9.47875
2070009300	-0.8969	2070009300	-12.3554
2085009150	-0.68874	2085009150	-15.2531

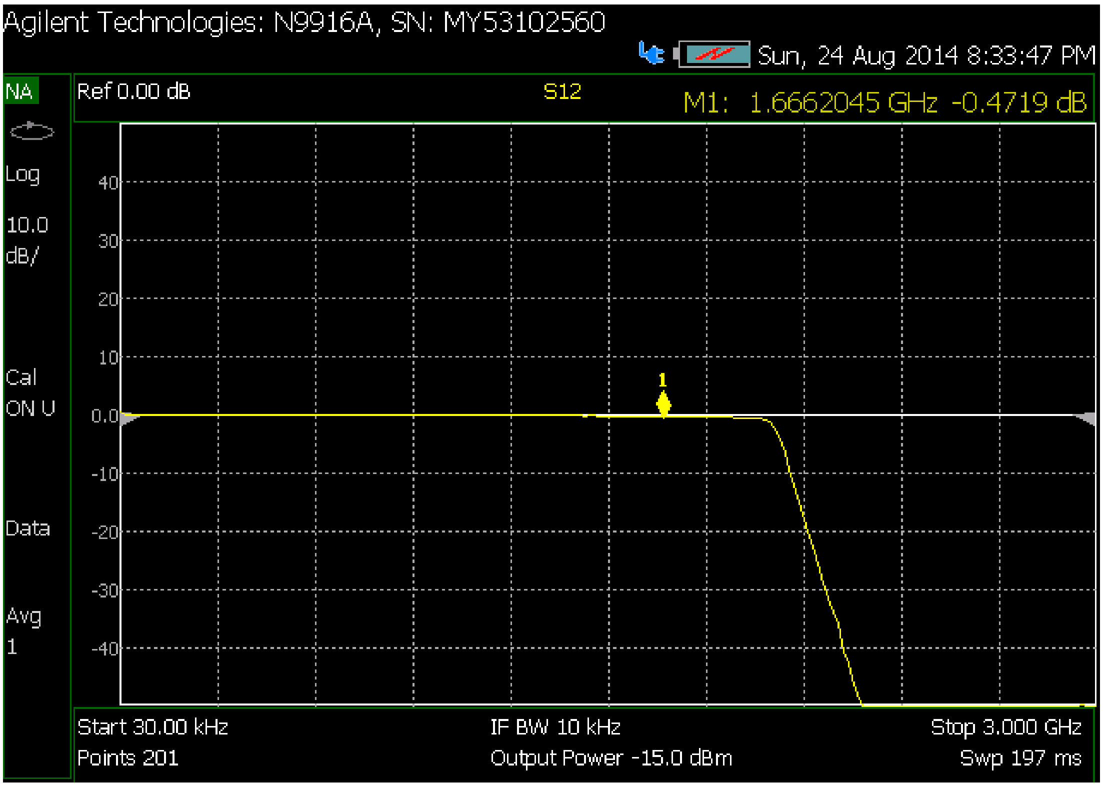

Figure 4.20: Insertion loss for the filter prototype

Based on the Figure 4.19, the return loss of the response is accurate where the passband cutoff frequency is located around 2 GHz. The ripples for the return loss in the passband section shows the order of the filter is in ninth order. However, for the return loss, we are unable to achieve the desired results as we obtain the return loss of around -12 dB based on Table 4.1. The reason of having this issue is because in practical measurement, several external factors like unintentional radiation or the air resistance will affect the measurement of the response while simulation response is simulated without considering the loss factor.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The Generalized Chebyshev microwave filter helps to improve the performance of the telecommunication equipment found in base station such as transceiver, antenna etc. Technically, it helps to filter out unwanted frequency band, in another words, prevent interference from harmonics or addictive noises from other equipment.

Comparing to other function of filter prototype, Generalized Chebyshev is better than other approximations such as Butterworth, Chebyshev and Elliptic. This is because it provides customization of prescribing transmission zeroes at desired frequencies. In addition, it also can be customized to be either symmetrical or asymmetrical response. In comparison to Elliptic filter, generalized Chebyshev is easily realizable because the variation of the impedance is much smaller.

In future, a higher order of the filter should be designed to achieve higher selectivity and more transmission zeroes should be added to observe its flexibility.

With that, mobile operators will be able to provide better telecommunication services for example better data throughput to the customers for them to have better experience of utilizing the service.

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APPENDICES