# A Project Report

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# Designing and Implementing a 3rd order Chebyshev low pass microstrip filter with a cut-off of 2.3 GHz and characteristic impedance of 50 ohm.

Submitted in partial fulfillment of the Requirements of

ECE F314, EM Fields and Microwave Engineering


**DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING**

**BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE HYDERABAD CAMPUS**

**Submitted to:** **Submitted by:**

**Dr. Harish V Dixit** **Group 49**

ECE F 314 Course Project

# Third order Chebyshev low pass microstrip filter with a cut-off of 2.3 GHz and characteristic impedance of 50 ohm.


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Project Report

# A third order Chebyshev low pass microstrip filter with a cut-off of 2.3 GHz and characteristic impedance of 50 ohm using Sonnet Software

Submitted in partial
fulfilment of
the requirements of the degree of

Bachelor of Engineering (Electronics and Communication)

By
Group 49
(145 146 147)

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Electrical and Electronics Engineering Department
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# Abstract

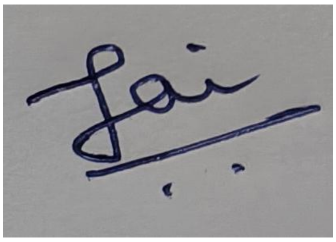
This paper reports the design and simulation of the 3rd-order Chebyshev low-pass filter. The prototype filter with a cut-off frequency of 2.3 GHz and characteristic impedance of 50 Ω is designed using standard formulas. The layout is designed in Sonnet Software. Simulation results of the filter are presented. After validating the design, the final structure is then fabricated using an FR4 substrate with $\varepsilon_r$ =4.4 and thickness d = 0.8 mm. Simulated and measured results of the obtained filter are reported. Low Pass filters, such as Chebyshev filters, have ripples either in the pass bands or in the stop bands. In the stop band, ripples can be detected as Type-I filters, while in the pass band, ripples can be detected as Type-II filters. A Chebyshev filter of type I is called a Chebyshev filter, while a Chebyshev filter of type II is known as an inverse Chebyshev filter. As well, the roll-off is steeper than that of a Butterworth filter.

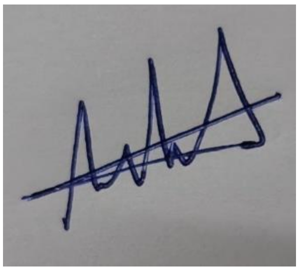
# Declaration of the Students

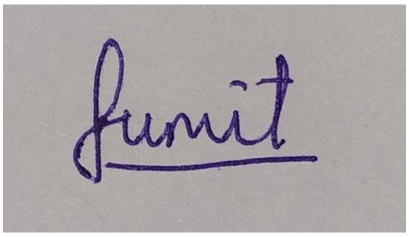
I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources.

I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea / data / fact / source in my submission.

I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.



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# Table of Contents

# List of Tables



# List of Figures

# Abbreviations and Nomenclature

**Symbols, Prefixes and Abbreviations**

*f* Frequency

F Farads

I current

A Amperes

H Henry

*V* Voltage

*L* Inductance

L Inductance/unit length

*C* Capacitance

*R* Resistance

R Resistance/unit length

*G* Conductance

*G* Conductance/unit length

L length m

ln natural logarithm (base e)

*N* number (integer)

*X* Reactance

*X* Reactance/unit length

$Z_0$ Characteristic Impedance

$Z_x$ *Impedance of the Component X*

m milli

G Giga

T Terra

Hz Hertz

$v_p$ Velocity in medium

β Phase Constant

W Width of Microstrip

d Thickness of Substrate

Ω Ohms

**Constants**

pi = $\boldsymbol{\pi}$ = 3.1416

Permittivity of free-space = $\varepsilon_0$ = 8.854 × $10^{-12}$ F/m

Permeability of free-space = $\mu_0 = 4\pi \times 10^{-7}$ H/m

Impedance of free-space = $\eta_0$= 376.7

Velocity of light in free-space = $c$ = 2.998 × $10^8$ m/s

# Chapter 1

# Introduction

## 1.1. Motivation

A filter is a two-port network that regulates the frequency response at a specific point in an RF or microwave system by giving transmission at frequencies within the filter's passband and attenuation in the filter's stopband. Analog filter design is one of the oldest subjects of interest in System Theory (with its branches: Control and Circuit Theory) and Signal Processing but is still a topical issue. New challenges are still arising. In Radio Frequency (RF) electronics applications, analog filters are especially appreciated as they do not need an external energy supply and tend to be more robust to uncertainties than digital filters. However, a big increase in filter complexity is expected due to the substantial growth in frequency bands and standards in the near future (Hashimoto et al., 2015). As a result, new filter design methods are required to replace outdated methods in order to tackle this challenge.

Analog Filters can be designed using Trivial Resistors, Inductors, and Capacitors. Still, they fail to perform at High-Frequency Ranges, hence the need for microstrip design which enables functionality at higher frequency ranges (in GHz and THz). Microstrip elements will help create line elements without power reflection or loss.

## 1.2. Objectives

The Primary Objectives of the project are

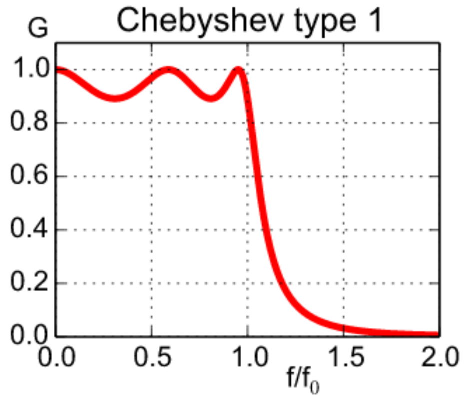
- To design a Low Pass 3rd Order Chebyshev Filter with a cut-off Frequency of 2.3 GHz by using FR-4 substrate and characteristic impedance of 50 ohm using Sonnet Software
- Fabrication of the designed filter in the RF Lab and testing its various parameters

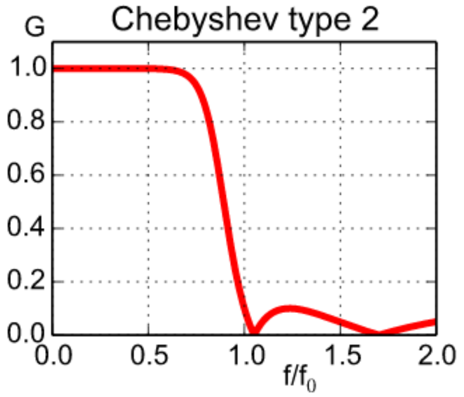
# Chapter 2

# Background

## 2.1. Filter Specifics

The Chebyshev filter is a Low Pass filter which has ripples either in the pass band or the stop band. If the ripples are present in the pass band, then the filter is a Type-I filter and if the ripples are present in the stop band then it is a Type-II filter. Type I Chebyshev filters are typically referred to as "Chebyshev filters", while type II filters are usually called "Inverse Chebyshev filters".  It also has a steeper roll-off than a Butterworth Filter of the same order.




The Chebyshev polynomials are obtained from the recurrence relation

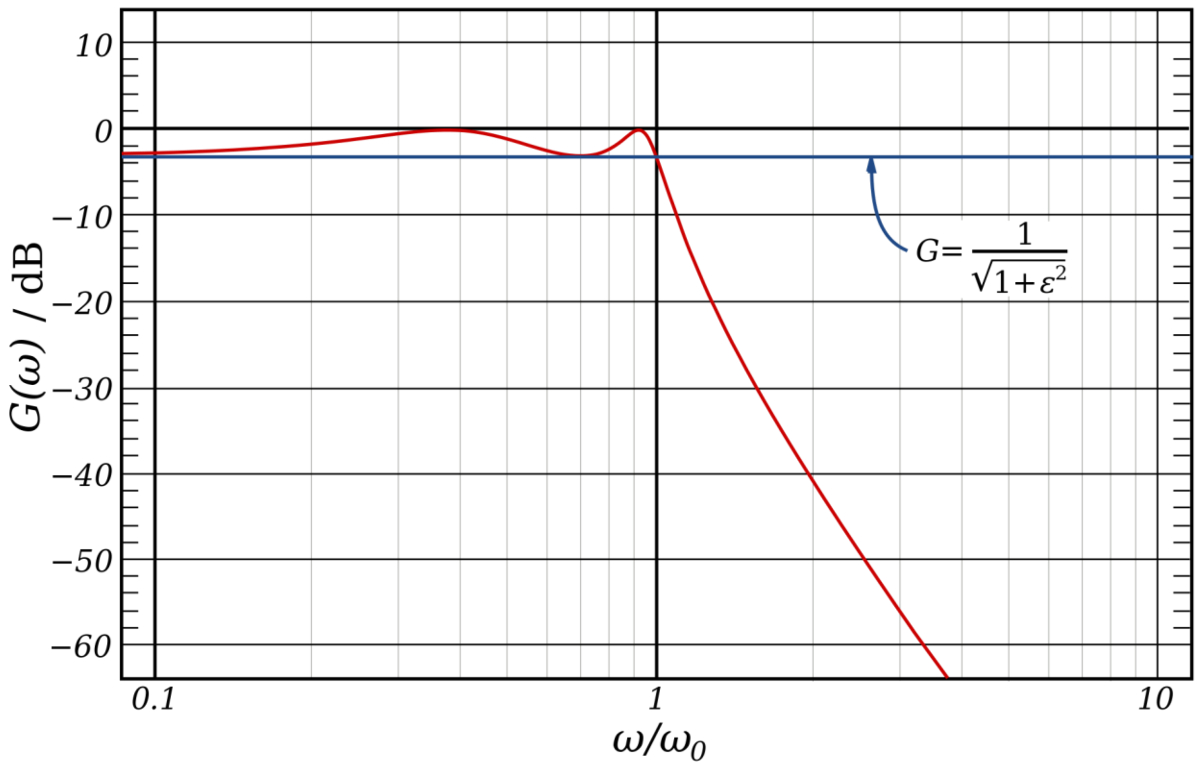
$$T_0(x) = 1$$
$$T_1(x) = x$$
$$T_{n+1}(x) = 2x\,T_n(x) - T_{n-1}(x)$$

## 2.2. Filter Prototype

The General Formula for a Transfer Function of a Chebyshev Filter is given by

$$|H(j\omega)|^2 = \frac{1}{1+\varepsilon^2 C_n^2(\omega)}$$

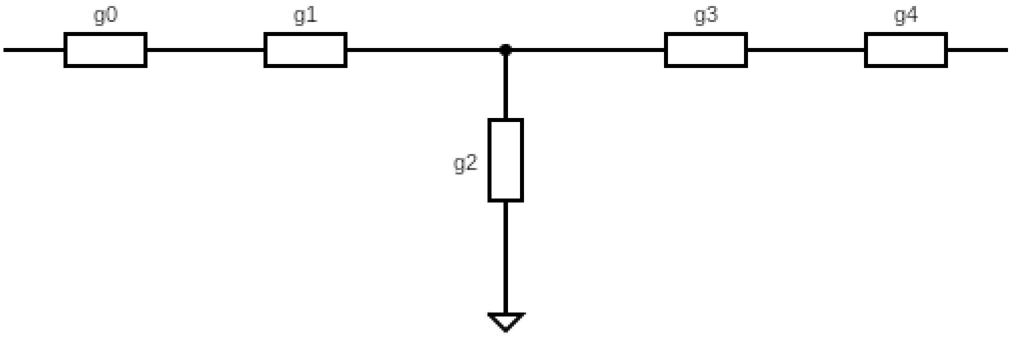
where ε is the ripple factor, $\omega_0$ is the cut-off frequency and $C_n$ is a Chebyshev polynomial of the $N^{th}$ order.




For the given Project, we will be using the following parameters.

Order , N=3 ; W0 = 2.3 GHz ;Ripple factor 3dB;

The prototype circuit would be as




The microstrip elements would be designed using this layout.

# Chapter 3

# Methodology

## 3.1. Resources and tools

The Project was implemented using Sonnet® - 18.53- Lite Software to design the microstrip elements of the filter. It was later used to generate the DXF file which is utilized by the cutter to fabricate the filter.

Sonnet is a commercial high-frequency planar electromagnetic (EM) analysis tool suite for single and multi-layer planar circuits and antennas. It provides very precise layout-based electrical model extraction of passive circuits and planar transmission lines from kHz through THz frequencies.

The team utilized the standard tables for 3dB ripples to obtain critical values and coefficients.

The formulas used are listed above.

## 3.2 Calculation of target variables

The Chebyshev Filter is characterized by the factors

1. Order
2. Ripple Band
3. Cut-off Frequency

The Order and were pre-set to 3 as we are designing a $3^{rd}$ Order Low-Pass Filter. The Cut-off frequency was set to 2.3 GHz. The team used the table below with N=3 to determine the Normalized Impedances of the circuit elements.

**3.0 dB Ripple**

| $N$ | $g_1$ | $g_2$ | $g_3$ | $g_4$ | $g_5$ | $g_6$ | $g_7$ | $g_8$ | $g_9$ | $g_{10}$ | $g_{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.9953 | 1.0000 | | | | | | | | | |
| 2 | 3.1013 | 0.5339 | 5.8095 | | | | | | | | |
| 3 | 3.3487 | 0.7117 | 3.3487 | 1.0000 | | | | | | | |
| 4 | 3.4389 | 0.7483 | 4.3471 | 0.5920 | 5.8095 | | | | | | |
| 5 | 3.4817 | 0.7618 | 4.5381 | 0.7618 | 3.4817 | 1.0000 | | | | | |
| 6 | 3.5045 | 0.7685 | 4.6061 | 0.7929 | 4.4641 | 0.6033 | 5.8095 | | | | |
| 7 | 3.5182 | 0.7723 | 4.6386 | 0.8039 | 4.6386 | 0.7723 | 3.5182 | 1.0000 | | | |
| 8 | 3.5277 | 0.7745 | 4.6575 | 0.8089 | 4.6990 | 0.8018 | 4.4990 | 0.6073 | 5.8095 | | |
| 9 | 3.5340 | 0.7760 | 4.6692 | 0.8118 | 4.7272 | 0.8118 | 4.6692 | 0.7760 | 3.5340 | 1.0000 | |
| 10 | 3.5384 | 0.7771 | 4.6768 | 0.8136 | 4.7425 | 0.8164 | 4.7260 | 0.8051 | 4.5142 | 0.6091 | 5.8095 |

Source: G. L. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance-Matching Networks, and Coupling Structures*, Artech House, Dedham, Mass.,1980

Thus the values for the prototype are

$g_0$ = 1.000 = $R_s$

$g_1$ = 3.3487 = $C_1$

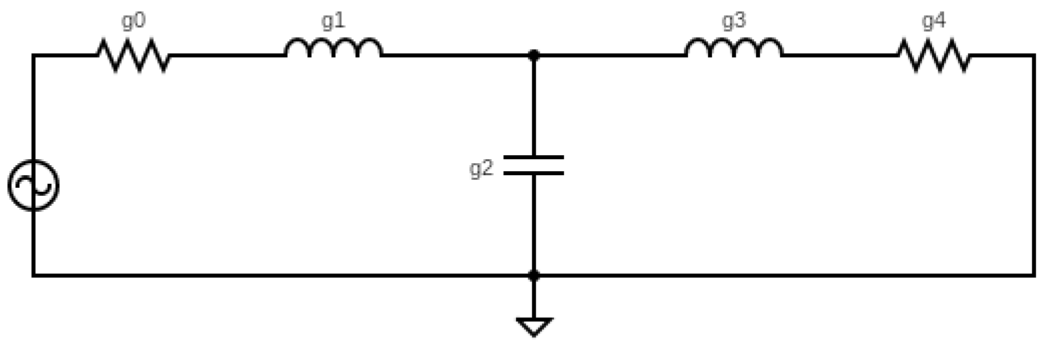
$g_2$ = 0.7117 = $L_2$

$g_3$ =3.3487 = $C_3$

$g_4$ = 1.000 = $R_L$

$Z_0$ = 50 Ω d= 0.8 mm $\varepsilon_r$ = 4.4

Frequency f = 2.3 GHz




*Prototype 3rd order Chebyshev Filter*

$$v_p = \frac{c}{\sqrt{\epsilon_e}},$$
$$\beta = k_0\sqrt{\epsilon_e},$$

$$\beta\ell = \frac{L R_0}{Z_h} \qquad \beta\ell = \frac{C Z_\ell}{R_0}$$

$Z_0 = 50\ \Omega$ $Z_h = 120\ \Omega$ $Z_l = 20\ \Omega$

The microstrip element values were calculated using the formulas below

$$Z_0 = \begin{cases} \dfrac{60}{\sqrt{\epsilon_e}} \ln\left(\dfrac{8d}{W} + \dfrac{W}{4d}\right) & \text{for } W/d \le 1 \\ \dfrac{120\pi}{\sqrt{\epsilon_e}\,[W/d + 1.393 + 0.667 \ln(W/d + 1.444)]} & \text{for } W/d \ge 1. \end{cases}$$

$$\frac{W}{d} = \begin{cases} \dfrac{8e^A}{e^{2A} - 2} \\ \dfrac{2}{\pi}\left[B - 1 - \ln(2B - 1) + \dfrac{\epsilon_r - 1}{2\epsilon_r}\left\{\ln(B - 1) + 0.39 - \dfrac{0.61}{\epsilon_r}\right\}\right] \end{cases}$$

Capacitor length = 4.8 mm

Capacitor width = 5.6mm

Inductor length = 12.1mm

Inductor width = 0.6mm

Resistor length = 5.0mm

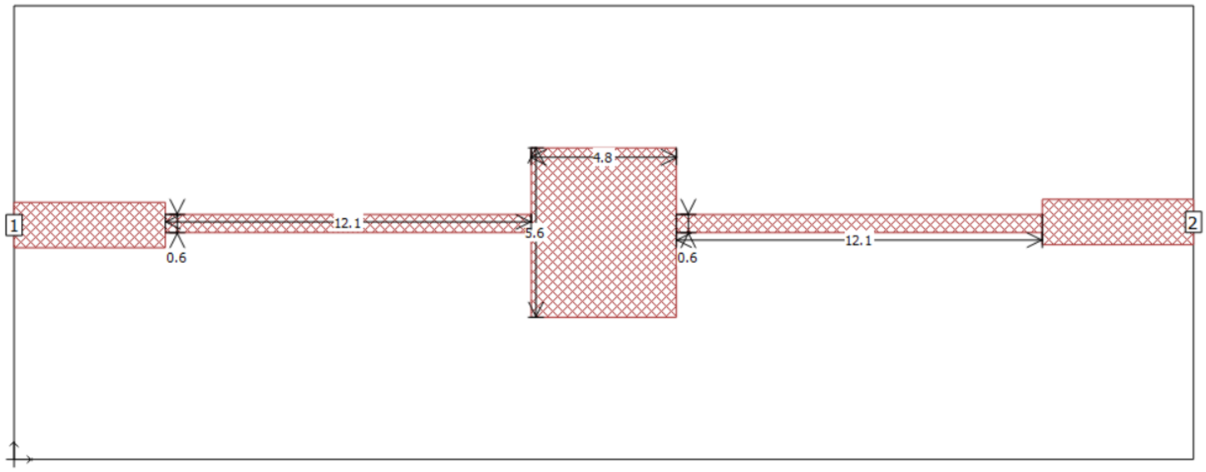
Resistor width = 1.5mm

| Element | Microstrip Length | Microstrip Width | Impedance |
|---|---|---|---|
| Inductor | 12.1 mm | 0.6 mm | 20 Ω |
| Resistor | 5.0 mm | 1.5 mm | 50 Ω |
| Capacitor | 4.8 mm | 5.6 mm | 120 Ω |

*Table of the obtained values*

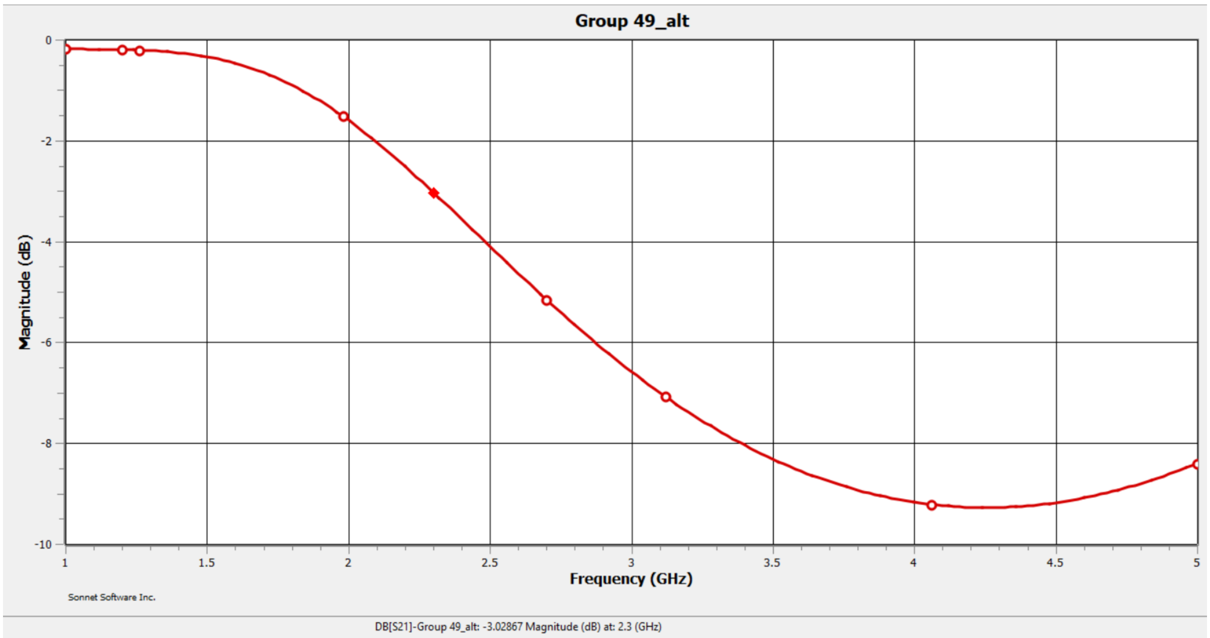
### 3.3. Circuit Design in Software and Simulation

The prototype with the obtained values was then designed in the Sonnet Software. Planar Rectangles of the Substrate with the aforementioned values were designed to create the filter.



The Magnitude v/s Frequency response across the ports was plotted.

The ‘s’ Parameters were set as: From Port 1, To Port 2




The -3dB Frequency was noted for the simulation.

## 3.4. Fabrication

After the simulation was verified by the Teaching Assistants and Lab Instructors of the course, the DXF file for the design was generated and submitted. This file was loaded and given as input to the machine which then cut our filter from a microstrip sheet.

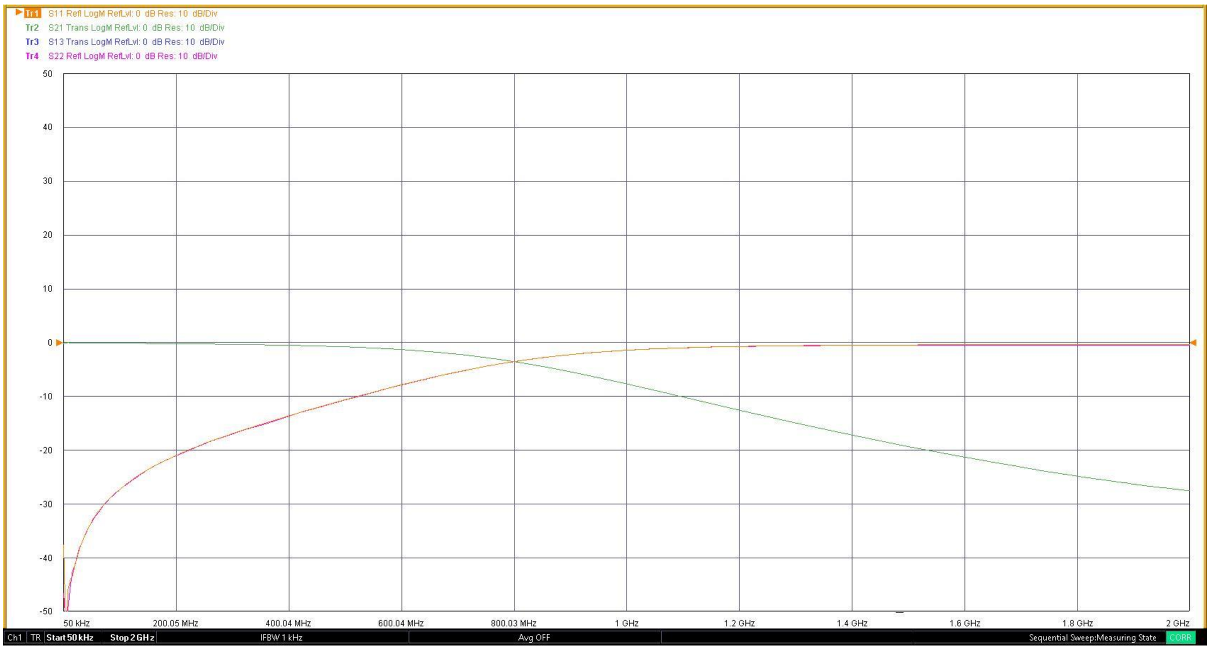
The body of the filter was obtained. 2 ports were soldered on the designated ends, and the filter was ready. A VNA was used to test the response of the filter . The VNA was calibrated and the ports of the Chebyshev filter were connected to the ports of VNA . The S parameters were tabulated and the output was recorded.

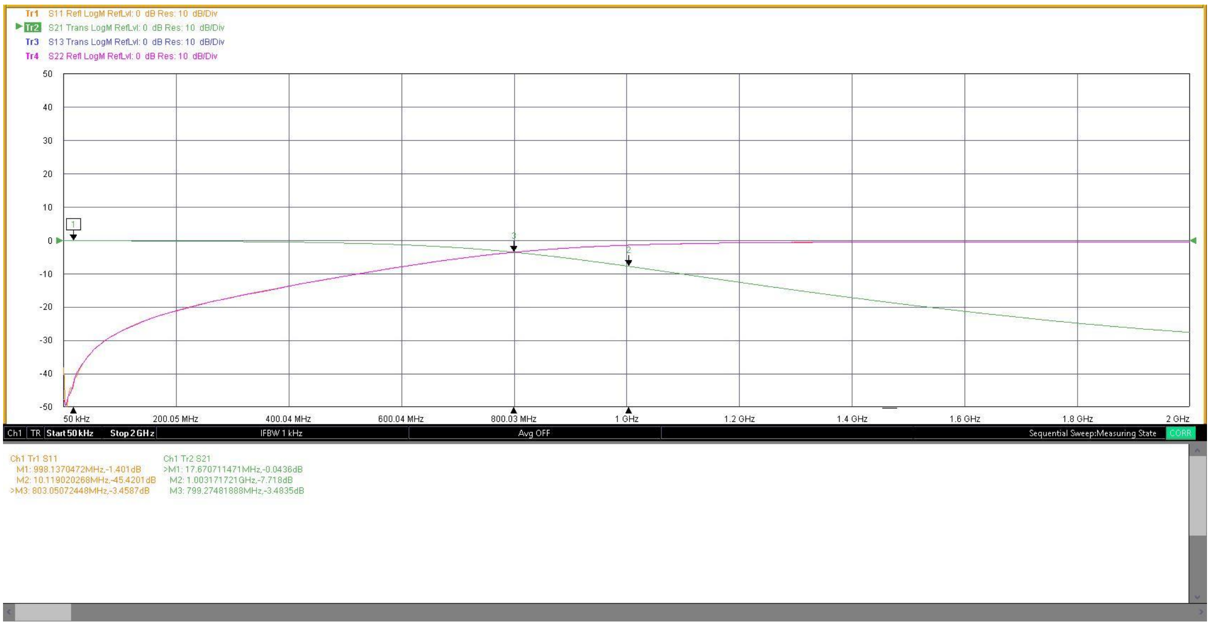
# Chapter 4

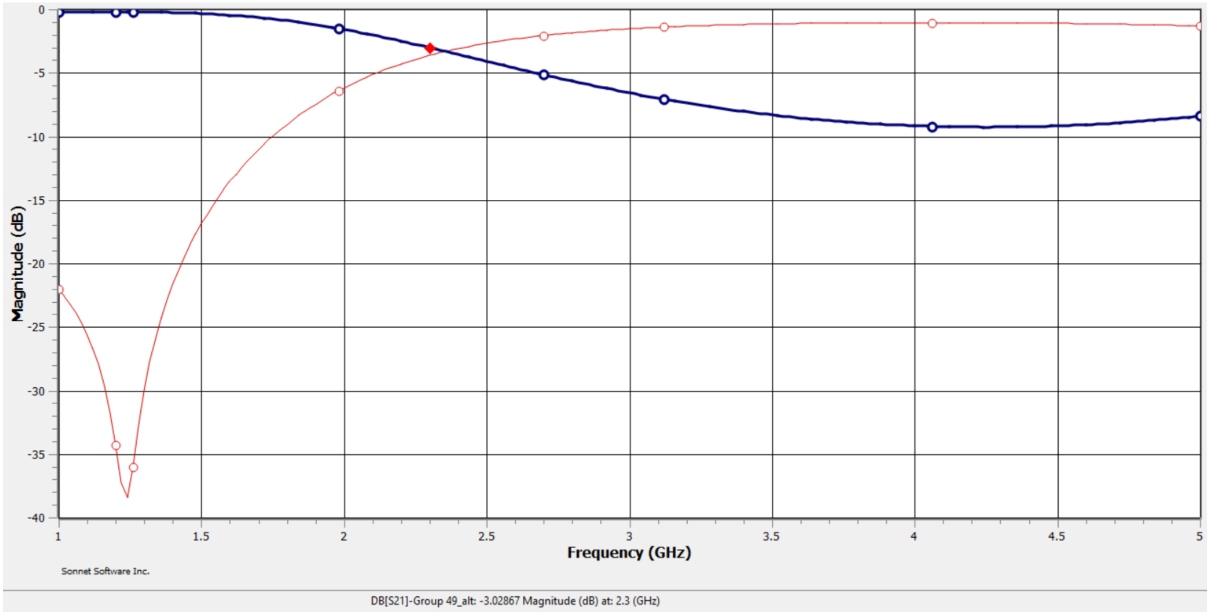
# Results

The team sent the obtained filter to the RF and Microwave Engineering Lab, wherein the Lab Instructors tested it.

The following Graphs were obtained from the fabricated microstrip filter that the Lab Instructors shared.






*Sonnet Simulation*

We find that the measured cut-off frequency is **2.29701 GHz**.

The measured cut-off frequency showed a deviation of **0.0997%**, which lies within the tolerable range of 2.3 ± 1% GHz.

The results have been tabulated and stored here: https://drive.google.com/file/d/1mz9As3JM57gzmzwLs30KS3bVuUcko2pV/view?usp=share_link

Link to .s2p file: https://drive.google.com/file/d/1WCg24fW4fmFfEaW3Iqzr259uIbGjys5M/view?usp=share_link

# Chapter 5

# Conclusion

The 3rd order Chebyshev Low Pass Microstrip Filter using an FR4 Substrate of 0.8mm thickness has been premeditated in this project. Its simulation and analysis are performed using Sonnet software. Several iterations make further improvements in the design of end correction. The final structure was then fabricated and tested.

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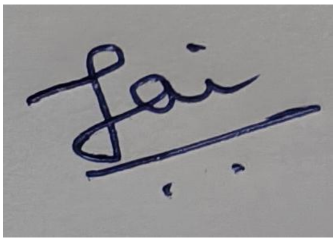
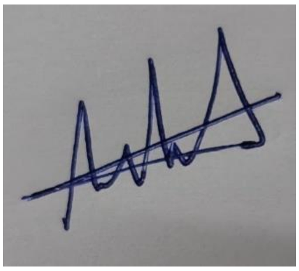
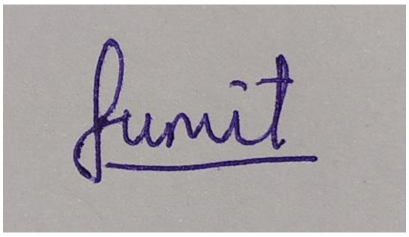
We  would like to express our special thanks to our Mentors and Lab instructors for their time and efforts they provided throughout the duration of the project . Their useful advice and suggestions were really helpful to the team during the project's completion. In this aspect, we are eternally grateful to them.







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