DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING

FACULTY OF ENGINEERING
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<u>EE5207: ELECTRONIC CIRCUIT DESIGN</u>

Project Report

Designing a 9th Order Chebyshev Low Pass Filter with a 9 kHz cut–off frequency

GROUP NO. 07

PREFACE

Filters are used in modern electronic systems to control the frequency of signals. Chebyshev filters are preferred because they can provide sharp frequency transitions with a limited ripple in the passband.

This project aims at designing a 9th-order Chebyshev low-pass filter with a cut-off frequency of 9 kHz and a passband ripple of 3 dB. The purpose is to put theoretical ideas of filter design into practice through simulation of filter performance.

Throughout this project, we obtained practical expertise with filter design and signal processing applications. We believe this study is beneficial to people interested in filter design and related fields.

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1 INTRODUCTION

The development of efficient and accurate filters is a key part of modern signal processing and electronic systems. Among many filter types, the Chebyshev filter is distinguished by its ability to create a quick roll-off at the cut-off frequency while maintaining controlled ripples throughout the passband, making it excellent for applications needing high selectivity and low distortion.

This project focuses on developing a 9th-order Chebyshev low-pass filter with a 9 kHz cut-off frequency and a 3 dB passband ripple. The 9th-order design enables a very precise and steep transition from the passband to the stopband, thus meeting the strict requirements for filtering low-frequency signals. A specification of 3 dB passband ripple achieves an equilibrium between flatness and general performance of the filter, which enhances its applicability in real-world scenarios.

The key objectives of this project are to derive the mathematical parameters for the filter design, simulate the circuit to evaluate its behavior, and validate its performance against theoretical expectations. The results of the project find useful applications in several industry sectors, specifically telecommunications, audio engineering, and instrumentation, where high-performance filtering solutions are a must.

Through this project, we hope to gain a better understanding of advanced filter design, hone our skills in the analysis and implementation of circuits, and contribute something useful to the development of accurate signal processing solutions.

2 CALCULATIONS

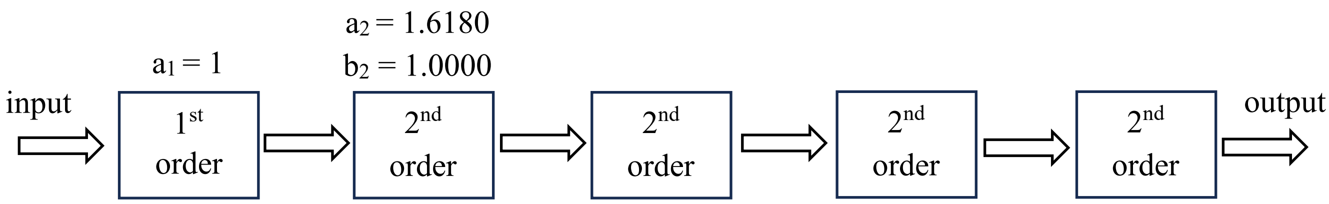

Figure 1: Block Diagram of 9th Order Chebyshev Filter Design

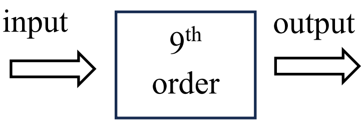

Figure 2: Final output of the filter

For the 9th order chebyshev filter with 9 kHz cutoff frequency (f_c) and 3dB passband ripple.

2.1Calculating the C_A, C_B, and a, b parameters

For 1st order

$$H(s) = \frac{A_0}{(1 + as)} = \frac{1}{1 + as} \;;since, unity\ gain\ A_0 = 1$$

$$a = \omega C_1 R_1$$

$$a = 2\pi f_c C_1 R_1$$

$$R_1 = \frac{a}{2\pi f_c C_1}$$

; Assume C_1 = 47 nF , a = 10.175 according to the 3dB passband ripple chebysheff table. (for 9th order)

$$R_1 = \frac{10.1759}{2\pi \times 9 \times 1000 \times 47 \times 10^{-9}}$$

$$R_1 = 3828.3724\ \Omega = 3.9\ \text{k}\Omega$$

2nd order (1st)

$$C_B = 330pF$$

$$C_A \geq C_B \times \frac{4b_2}{a_2^2}$$

$$C_A \geq 330 \times 10^{-12} \times \frac{4 \times 7.8971}{(1.4585)^2}$$

$$C_A \geq \ 4.9\ nF$$

$$C_A = 10\ nF$$
$$C_B = 330\ pF$$
$$a_2 = 1.4585$$
$$b_2 = 7.8971$$

2nd order (2nd)

$$C_B \ = \ 330pF$$

$$C_A \geq \ C_B \times \frac{4b_3}{a_3^2}$$

$$C_A \geq \ 330 \times 10^{-12} \times \frac{4 \times 2.3651}{(0.3561)^2}$$

$$C_A \geq 24.62\ nF$$

$$C_A = 27\ nF$$
$$C_B = 330\ pF$$
$$a_3 = 0.3561$$
$$b_3 = 2.3651$$

2nd order (3rd)

$$C_B \ = \ 330pF$$

$$C_A \geq \ C_B \times \frac{4b_4}{a_4^2}$$

$$C_A \geq \ 330 \times 10^{-12} \times \frac{4 \times 1.3165}{(0.1294)^2}$$

$$C_A \geq 103.78\ \mu F$$

$$C_A = 120\ nF$$
$$C_B = 330\ pF$$
$$a_4 = 0.1294$$
$$b_4 = 1.3165$$

2[nd] order (4[th])

$$C_B \ = \ 330pF$$
$$C_A \geq \ C_B \times \frac{4b_5}{a_5^2}$$

$$C_A \geq \ 330 \times 10^{-12} \times \frac{4 \times 1.0210}{(0.0348)^2}$$

$$C_A \geq 1.113 \ \mu F$$

$$C_A = 1.5 \ \mu F$$
$$C_B = 330 \ pF$$
$$a_5 = 0.0348$$
$$b_5 = 1.0210$$

2.2 Calculating the resistor values and capacitor values

For 1[st] order

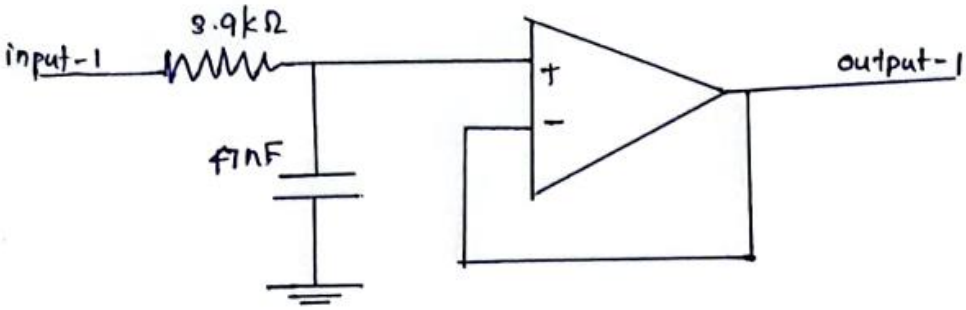

Figure 3 : Circuit diagram for first order

2[nd] order (1[st])

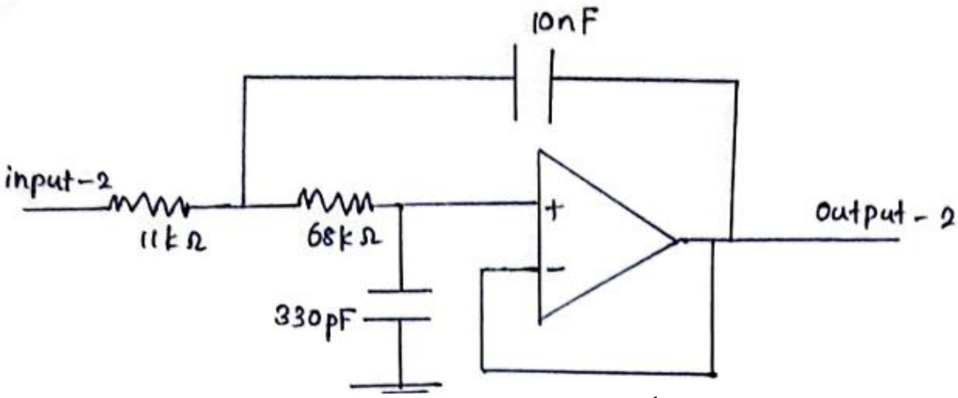

Figure 4: Circuit diagram for 2[nd] order (1[st])

$$R_{A,B} = \frac{a_2 C_A \pm \sqrt{a_2^2 C_A^2 - 4b_2 C_A C_B}}{4\pi f_c C_A C_B}$$

$$R_{A,B} = \frac{1.4585 \pm \sqrt{1.4585^2 \times (10 \times 10^{-9})^2 - 4 \times 7.8971 \times 10 \times 10^{-9} \times 330 \times 10^{-12}}}{4\pi \times 9000 \times 10 \times 10^{-9} \times 330 \times 10^{-12}}$$

$$R_{A,B} = 66985.4687\ \Omega, 11171.933\Omega$$

$$R_A = 11\ k\Omega$$
$$R_B = 68\ k\Omega$$
$$C_A = 10\ nF$$
$$C_B = 330\ pF$$

2nd order (2nd)

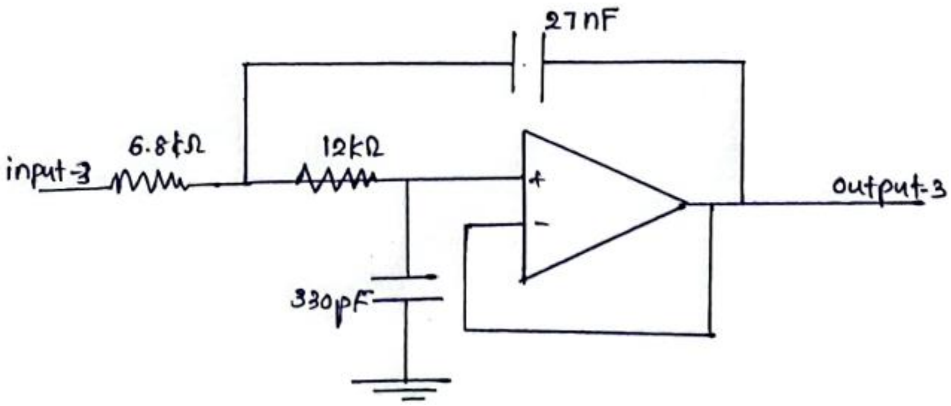

Figure 5 : Circuit diagram for 2nd order (2nd)

$$R_{A,B} = \frac{a_3 C_A \pm \sqrt{a_3^2 C_A^2 - 4 b_3 C_A C_B}}{4\pi f_c C_A C_B}$$

$$R_{A,B} = \frac{0.3561 \times 27 \times 10^{-9} \pm \sqrt{0.3561^2 \times (27 \times 10^{-9})^2 - 4 \times 2.3651 \times 27 \times 10^{-9} \times 330 \times 10^{-12}}}{4\pi \times 9000 \times 27 \times 10^{-9} \times 330 \times 10^{-12}}$$

$$R_A = 6708.1937\ \Omega = 6.8\ \mathrm{k}\Omega$$
$$R_B = 12374.3233\ \Omega = 12\ k\Omega$$
$$C_A = 27\ nF$$
$$C_B = 330\ pF$$

2nd order (3rd)

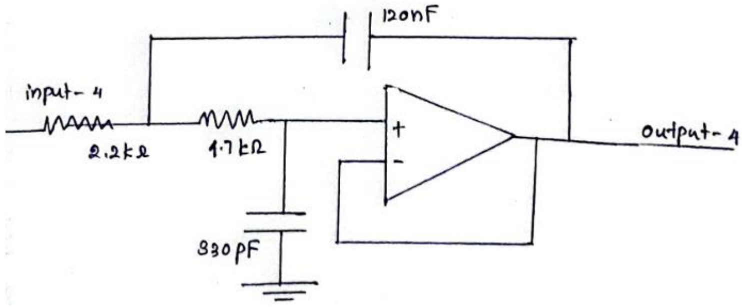

Figure 6 : Circuit diagram for 2nd order (3rd)

$$R_{A,B} = \frac{a_4 C_A \pm \sqrt{a_4^2 C_A^2 - 4 b_4 C_A C_B}}{4\pi f_c C_A C_B}$$

$$R_{A,B} = \frac{0.1294 \times 120 \times 10^{-9} \pm \sqrt{(0.1294 \times 120 \times 10^{-9})^2 - 4 \times 1.3165 \times 120 \times 10^{-9} \times 330 \times 10^{-12}}}{4\pi \times 9000 \times 120 \times 10^{-9} \times 330 \times 10^{-12}}$$

$$R_A = 4741.68\ \Omega = 4.7\ \text{k}\Omega$$
$$R_B = 2192.546\ \Omega = 2.2\ k\Omega$$
$$C_A = 120\ nF$$
$$C_B = 330\ pF$$

2nd order (4th)

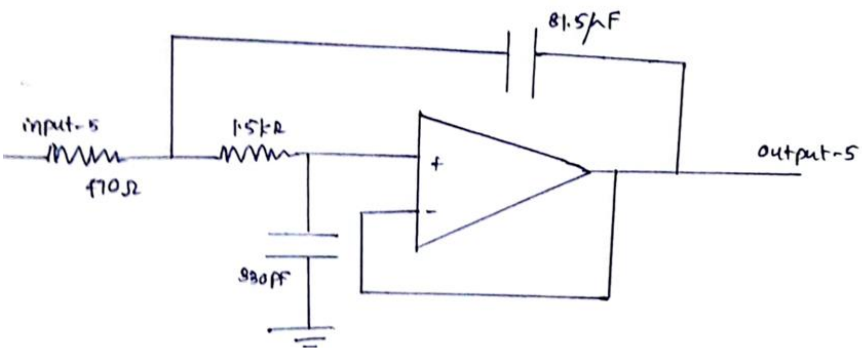

Figure 7 :Circuit diagram for 2nd order (4th)

$$R_{A,B} = \frac{a_5 C_A \pm \sqrt{a_5^2 C_A^2 - 4 b_5 C_A C_B}}{4\pi f_c C_A C_B}$$

$$R_{A,B} = \frac{0.0348 \times 1.5 \times 10^{-6} \pm \sqrt{(0.0348 \times 1.5 \times 10^{-6})^2 - 4 \times 1.021 \times 1.5 \times 10^{-6} \times 330 \times 10^{-12}}}{4\pi \times 9000 \times 1.5 \times 10^{-6} \times 330 \times 10^{-12}}$$

$$R_A = 1406.12\ \Omega = 1.5\ \text{k}\Omega$$
$$R_B = 458.726\ \Omega = 470\ k\Omega$$
$$C_A = 1.5\ \mu F$$
$$C_B = 330\ pF$$

3 CIRCUIT SIMULATION

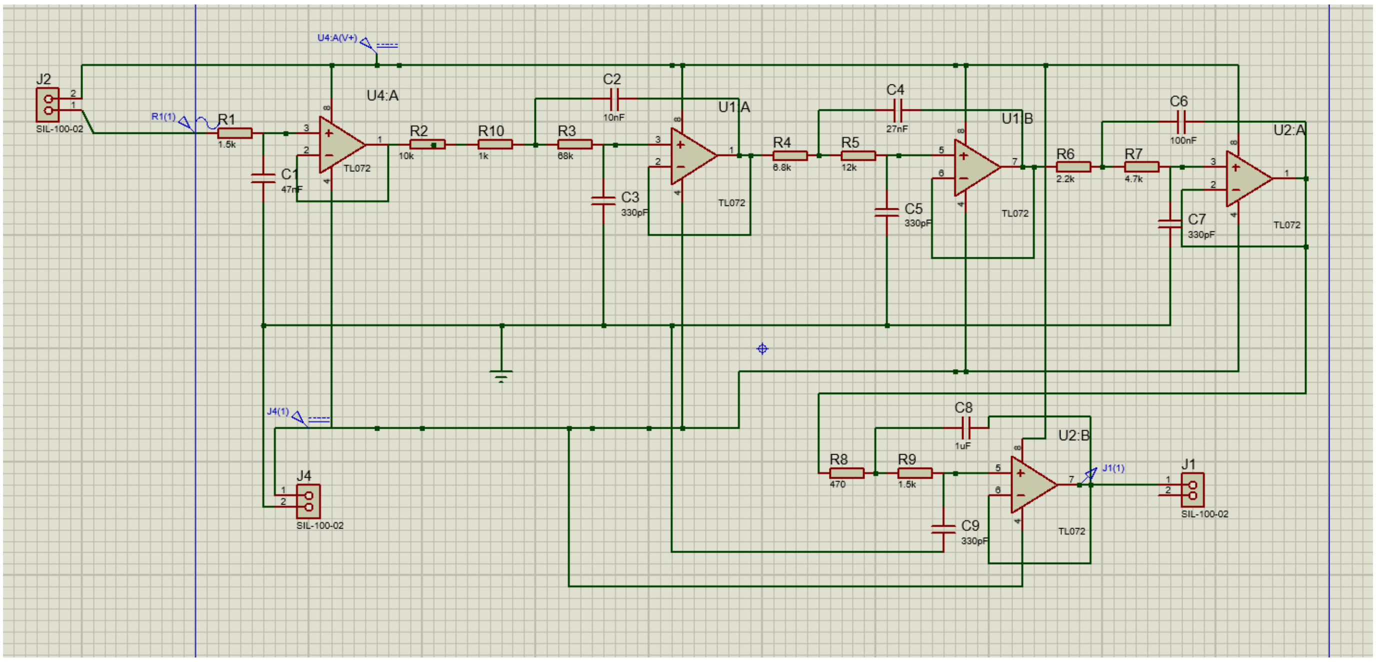

Figure 8 : Proteus implementation of the circuit

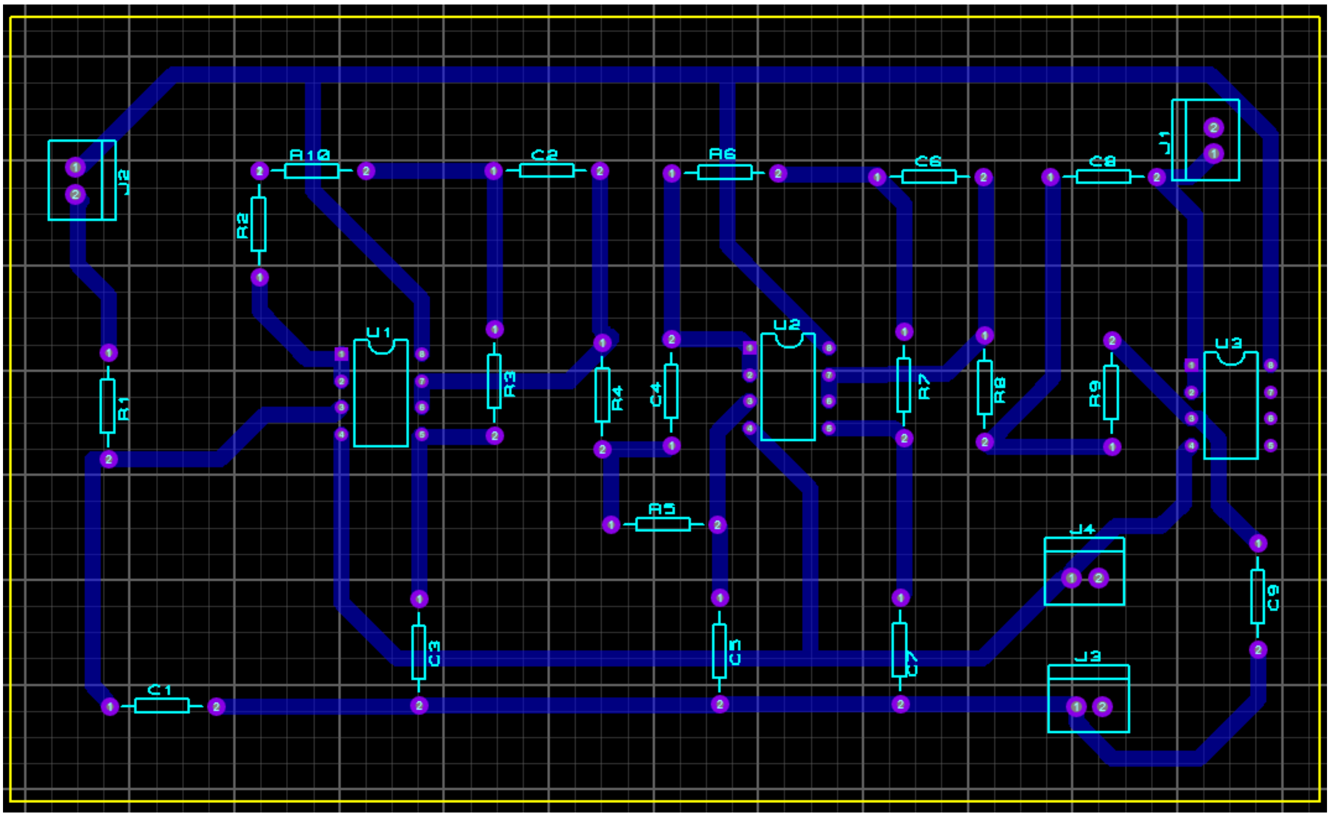

Figure 9: The PCB Layout Using Proteus software

*Here, we used resistors to increase the clearance and path with instead of for capacitors(Just to show the pcb desiging). But actually capacitors are named as C1, C2, C3,…..etc.

Figure 10 : 3D View of PCB

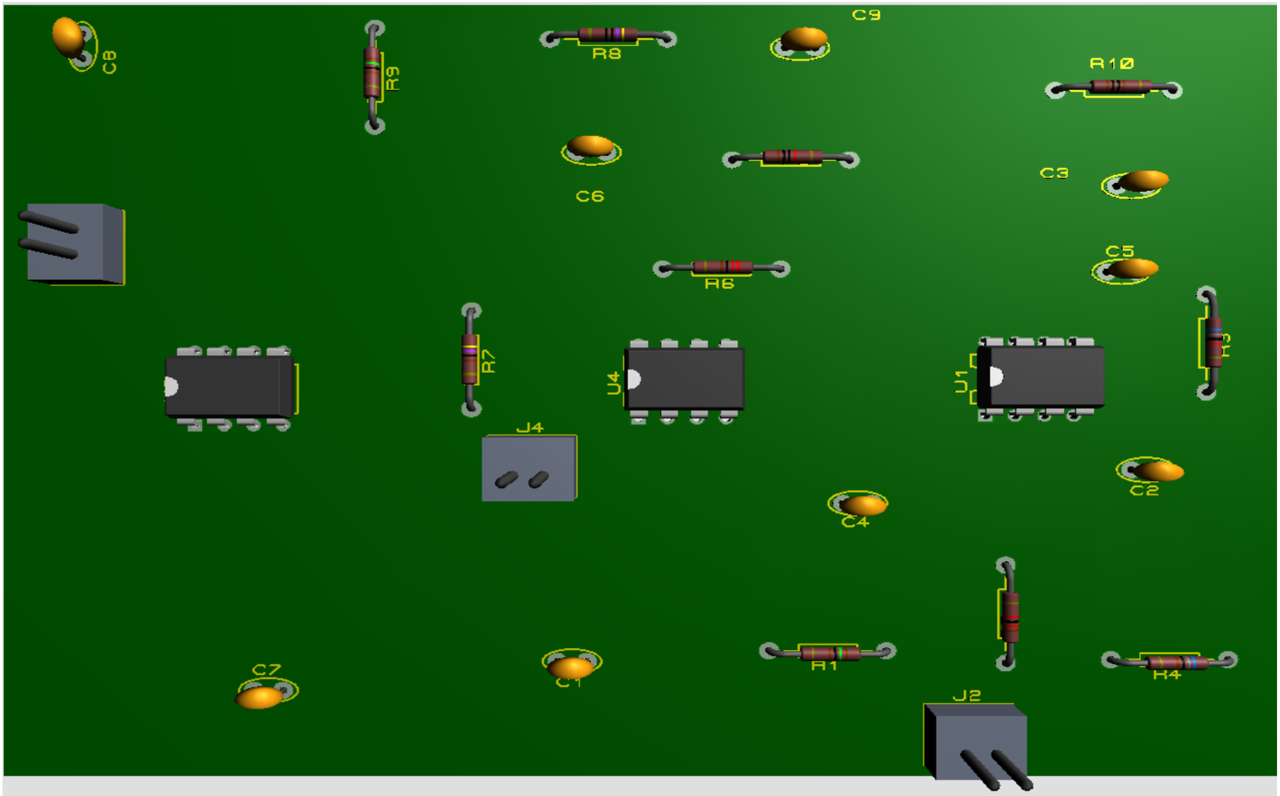

Figure 11 : Top View of PCB

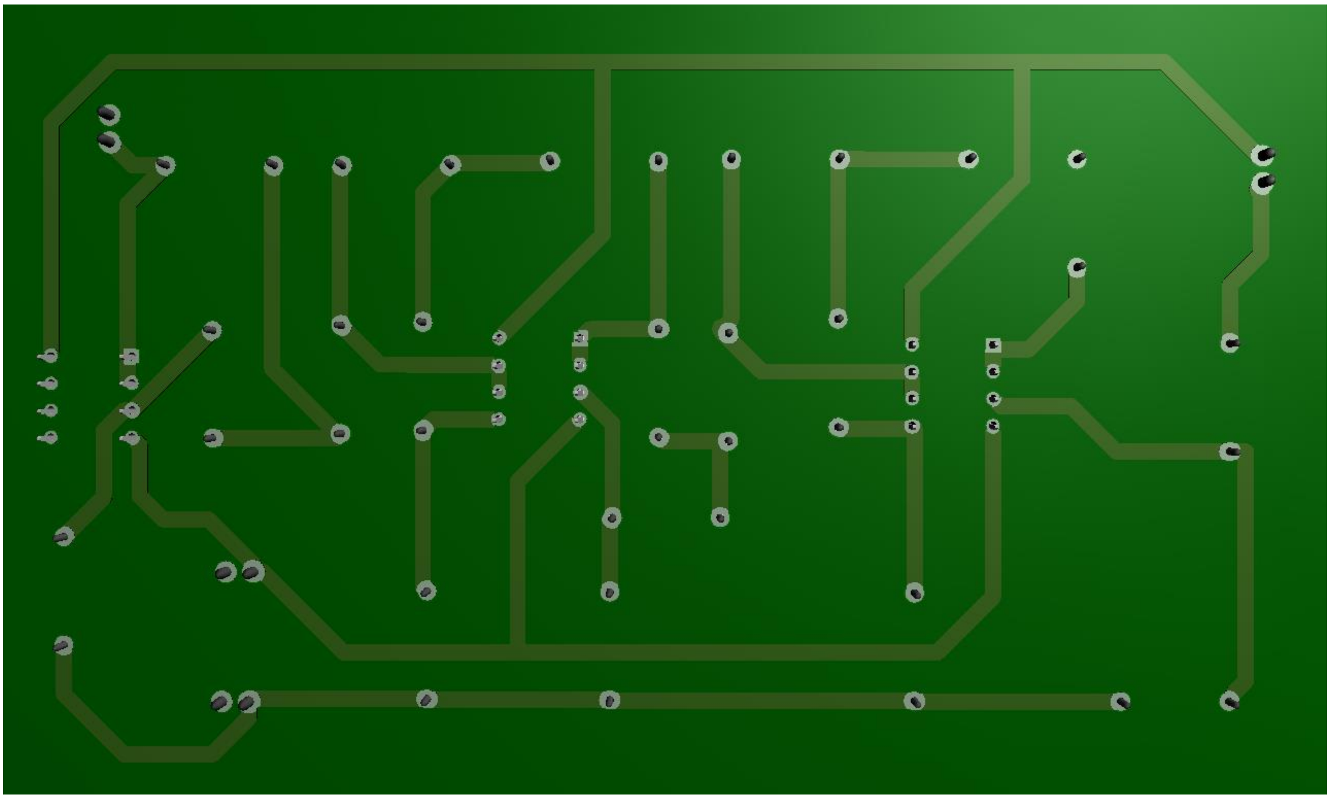

Figure 12: Bottom View of PCB

4 PRACTICAL IMPLEMENTATIONS

PCB Manufacturing Process

Figure 13: Image Transferring to the copper board

Figure 14: Etching Process

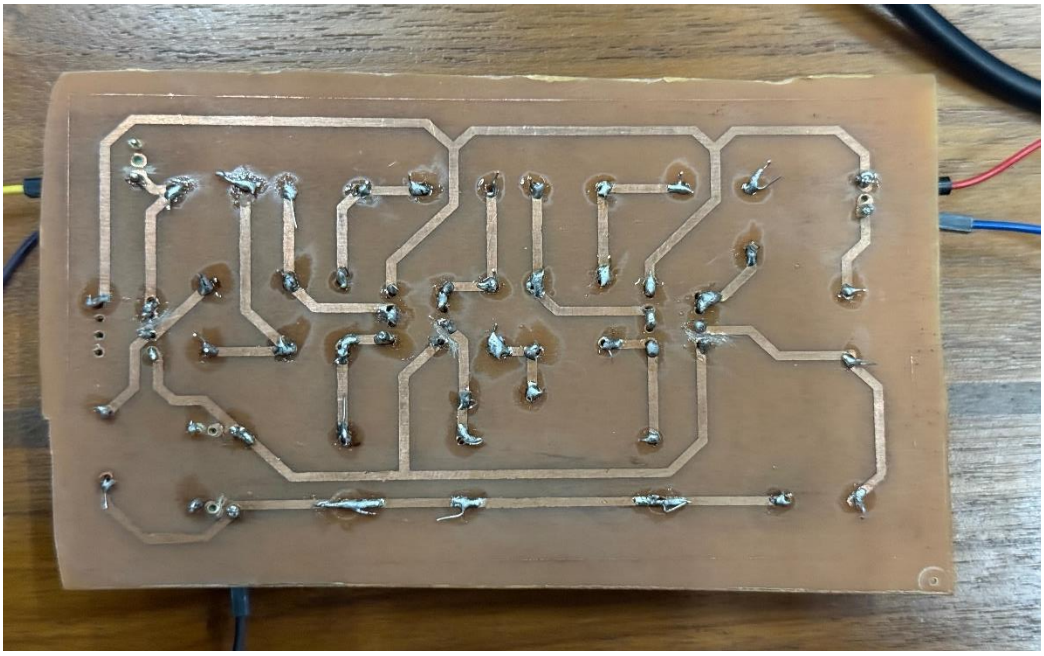

Figure 16: The Final PCB Circuit back view

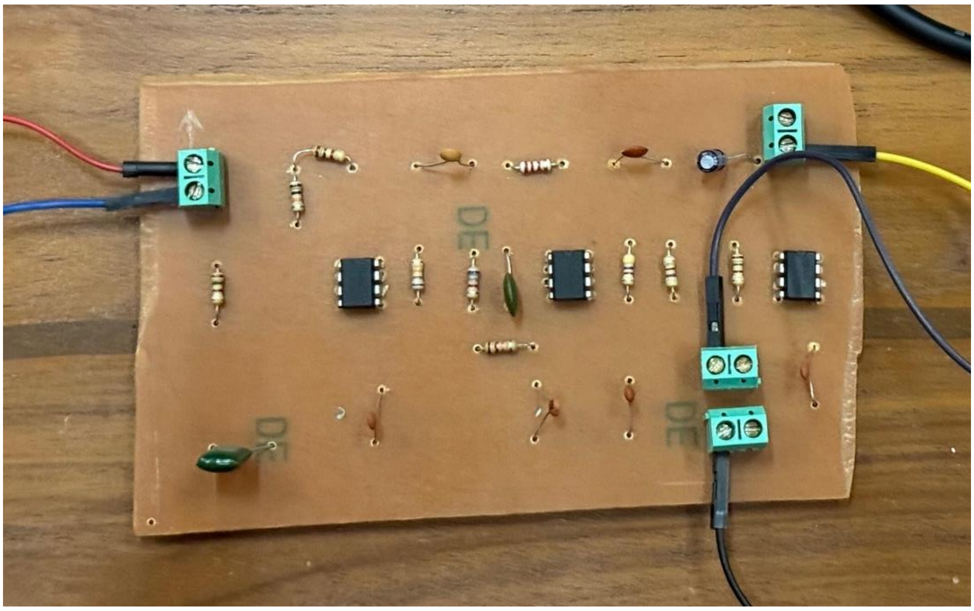

Figure 15: The Final PCB Circuit back view

5 RESULTS

- Simulations Results

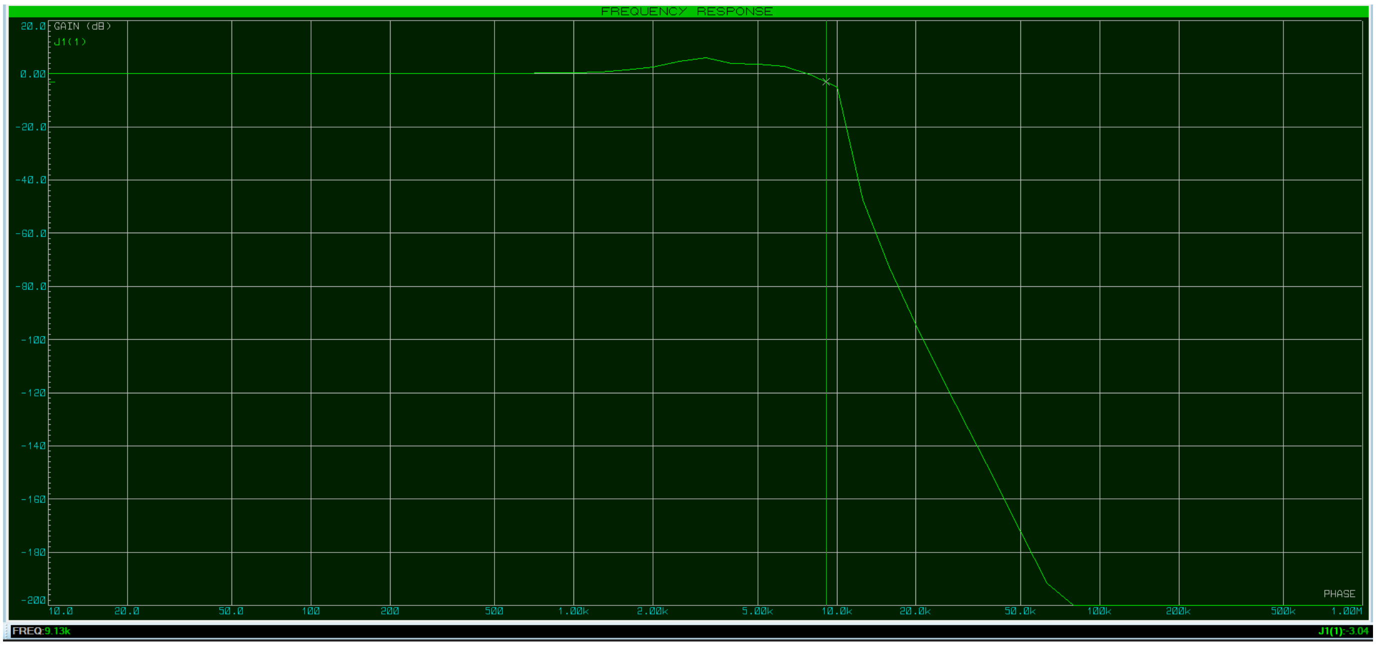

Figure 17: Frequency Response of the Circuit

At the cursor point frequency is 9.13 kHz

Gain in the y axis is -3.04 dB

(Sine wave generator , V_{pp} = 10V and f = 1 kHz)

+Vcc = 12V and -Vcc = -12V

*These values are taken in adjusting the cursor approximately

- Results After physical Implementation

Figure 18: Input sine wave parameters

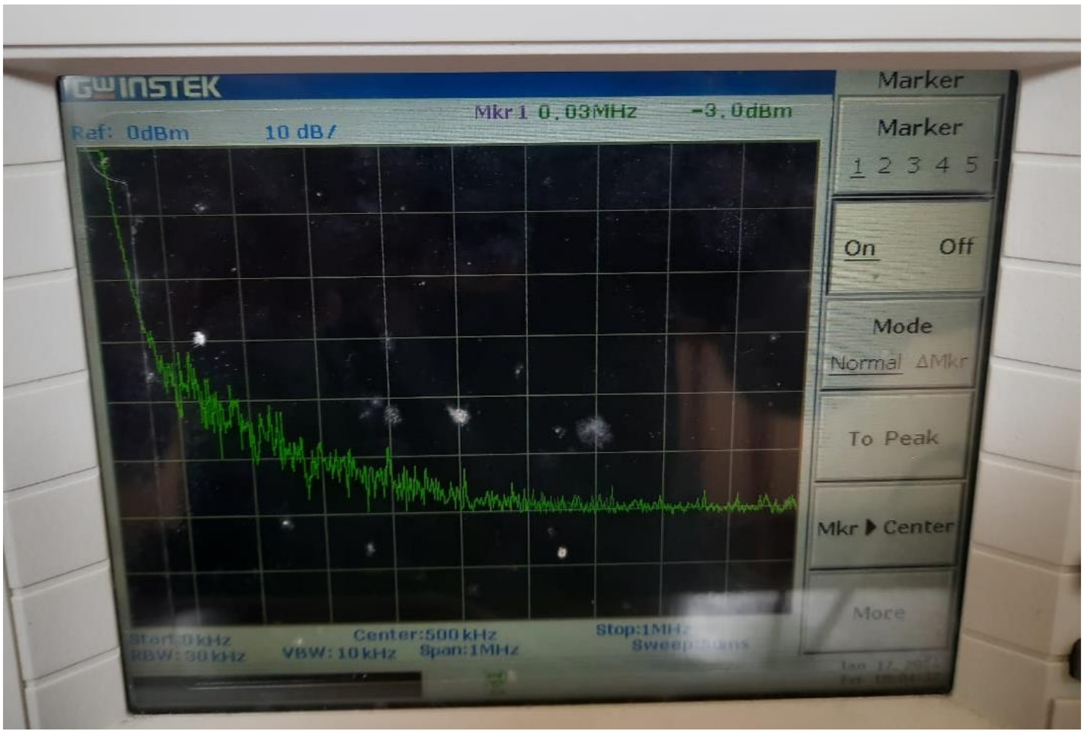

Figure 19: Output result on the spectrum analyzer

6. DISCUSSION

Even though we plugged the calculated values for the capacitor and the resistor values , we are getting around 30 kHz bandwidth. It may be the reason because of the clearance between the conducting path may increase the capacitance value of the line or may be the resistor values and the capacitor values may differ than that they have mentioned on there.