Electrical Network Analysis

Filter Design Project Report

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Submitted To:

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Problem Statement:

Perform detailed analysis of a low-pass active filter circuit such that its roll off attenuates frequency components at **7.5 kHz** or more by more than **15 dB.** Also, it is desired to have the passband gain positive that does not deviate from 20 dB by more than **3 dB.** The passband frequency needed is 500 Hz and below.

Description of Design Problem:

The requirement of this project is to design an active low pass filter. A filter is something which allows a specific thing to pass through and restricts the other ones. A low pass active filter is that circuit which allows the input signal to pass through; that is, the output is obtained only at low frequencies while the output appearance decreases with the increase of frequencies.

The major needs of this project are:

- Type: **Active low-pass filter** using op-amps
- Passband frequency: **0–500 Hz**
- Gain in passband: **20 dB ±3 dB**
- Attenuation: **≥15 dB at 7.5 kHz and above**
- Use precise **resistors and capacitors**
- Select high-performance **op-amp**
- Assemble circuit on **breadboard and PCB**
- Test with **function generator** and **oscilloscope**
- Measure real-world frequency response
- Simulate circuit in **LTSpice/Multisim/Proteus**
- Provide Full Detailed Documentation

Theory and Background:

An **active low-pass filter** is a type of electronic filter that allows low-frequency signals to pass while attenuating high-frequency signals beyond a specified cutoff frequency, using both passive components (resistors and capacitors) and an active component—typically an **operational amplifier (op-amp)**. Unlike passive filters, active filters can provide **gain**, which means they can amplify the signal in the passband, as well as offer **better control over the frequency response**, **high input impedance**, and **low output impedance**. The cutoff frequency of an active low-pass filter is determined by the values of the resistors and capacitors used in the circuit.

Actual Calculations:

Element	Value	Qty
Resistors	(4.7,27,320,36)k	1 each
Capacitors	(0.1)uF	3 each
Op-Amps	LM-741/LF-353	1

ENA Project
(Calculations)

→ 20dB at 500Hz passband.

Desired gain = 20dB

$20 = 20\log G$

$\boxed{G = 10}$

Desired cutoff frequency = 500Hz

$\omega = 2\pi f_c \Rightarrow 2\pi \times 500 \Rightarrow 3141.5$

$\boxed{\omega = 3141.5\,rad/s}$

x —— x

For 2nd order

$$\frac{V_o}{V_i} = \frac{G}{s^2 + 1.414s + 1}$$

RC = 1 Corner frequency

$$\frac{3-G}{RC} = 1.414$$

$3 - G = 1.414 \times 1$

$\boxed{G = 1.586}$

$$G = 1 + \frac{R_A}{R_B} = 1.586$$

$\frac{R_A}{R_B} = 0.586$ Let $R_B = 1K\Omega$, $R_A = 586\Omega$

As $RC = 1$

$R = 1\Omega$ $C = 1F$

instead we select

$C = 1\mu F = 10^{-6}F$.

RC = 1 Corner frequency 3141.5 rad/s

$\boxed{RC \times K_f = RC'}$ $1 \times K_f = 3141.5$

$K_f = 3141.5$

frequency Scaling factor = $K_f = 3141.5$

So from table of Scaling

$$C'' = \frac{C}{K_m K_f}$$

$$10^{-6} = \frac{1}{K_m \times 3141.5}$$

$$K_m = \frac{1}{10^{-6} \times 3141.5} = \boxed{318.3\,K}$$

Consequently

$R'' = K_m R$

$R'' = 318 \times 1 = 318k\Omega$

$R_A = 586\Omega$

$R_B = 1K\Omega$

$C'' = 1\mu F$

$R'' = 318\Omega$

But design is not done yet

as $G = 1.586$ but we want

$G = 10$

$1 + \frac{R_f}{R_1} = 10$

$\frac{R_f}{R_1} = 9$

$R_f = 9R_1$

let $R_1 = 4.7K\Omega$ so $R_f = 27K\Omega$

$$\boxed{\begin{array}{ll} R_1 = 4.7K\Omega, & R_3 = 320K\Omega \\ R_2 = 27K\Omega, & R_4 = 32K\Omega \end{array}}$$

Formula Sheet:

Gain in dB:

$A_{db}=20\log10(A_v)$

Linear gain from dB:

$Av=10^{A_{db}/20}$

Cut Off Frequency:

$F_c=1/2\pi\sqrt{R_1R_2C_1C_2}$

If $R_1=R_2=R$ and $C_1=C_2=C$

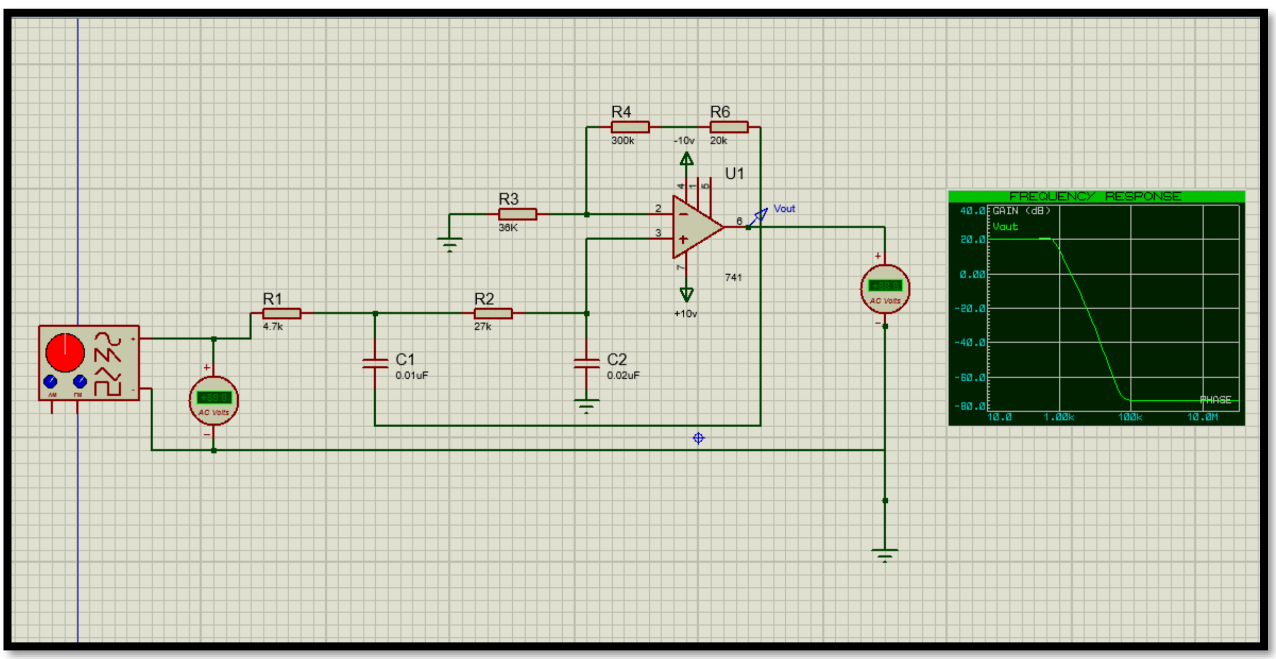
$F_c=1/2\pi RC$

$$\text{Attenuation (dB)} = 20\log_{10}\left(\frac{V_{out}}{V_{in}}\right)$$

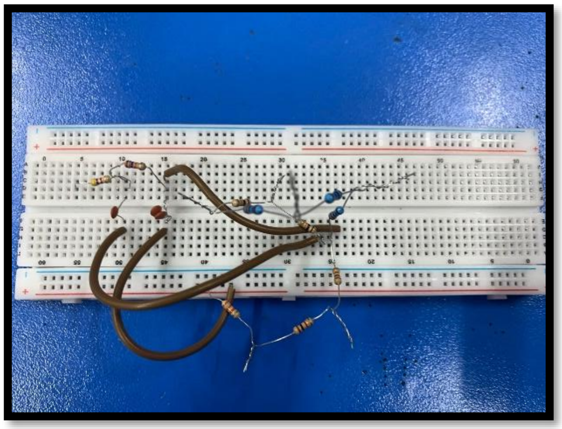
$$H(s) = \frac{A_v \cdot \omega_c^2}{s^2 + \frac{\omega_c}{Q}s + \omega_c^2}$$

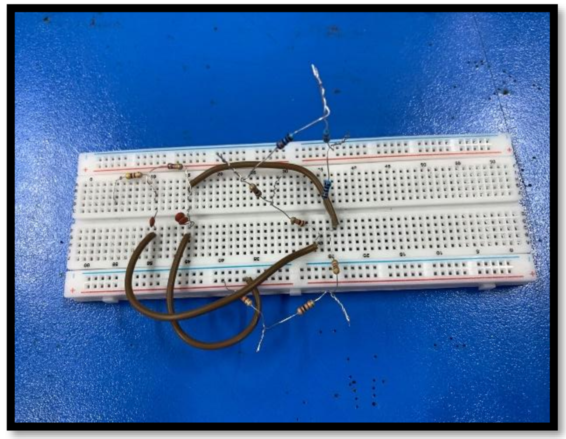
$$\text{Roll-off rate} = 40\ \text{dB/decade}$$

Circuit Simulation:

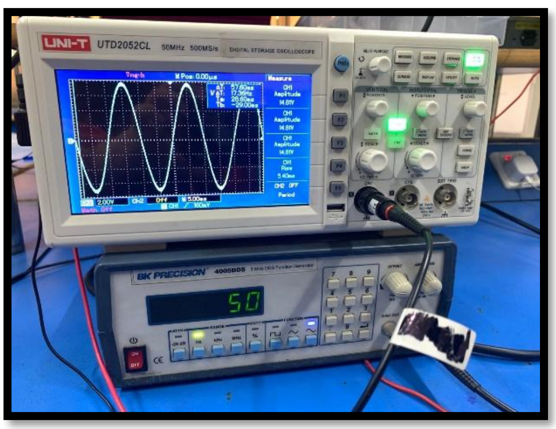


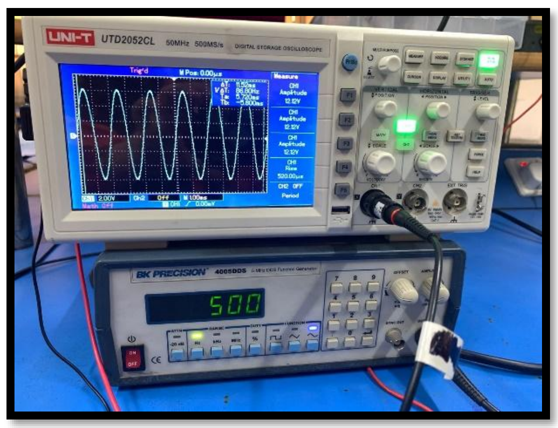
Final Practical Circuit Images:

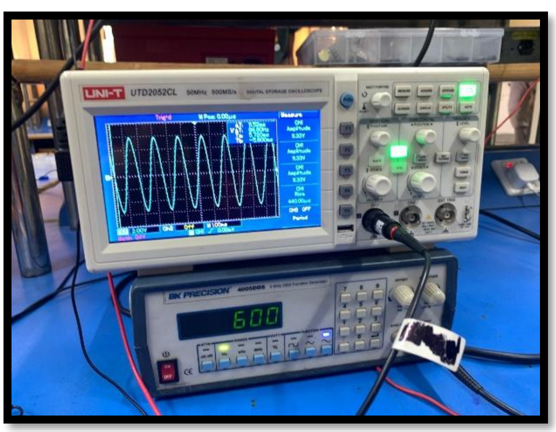


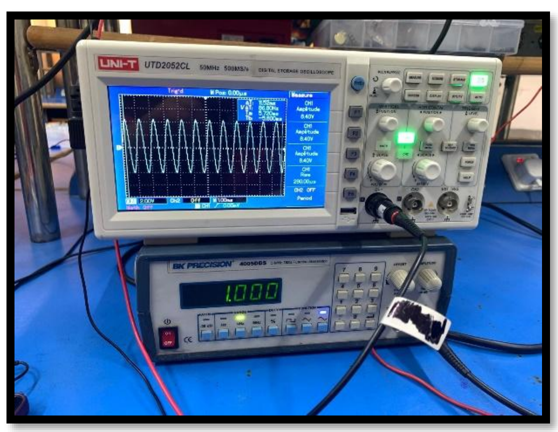


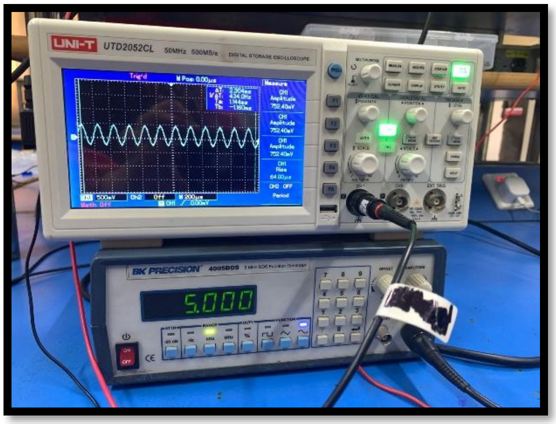
Measured Calculations:

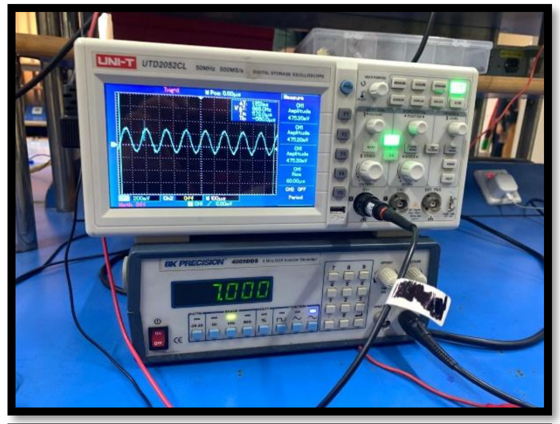


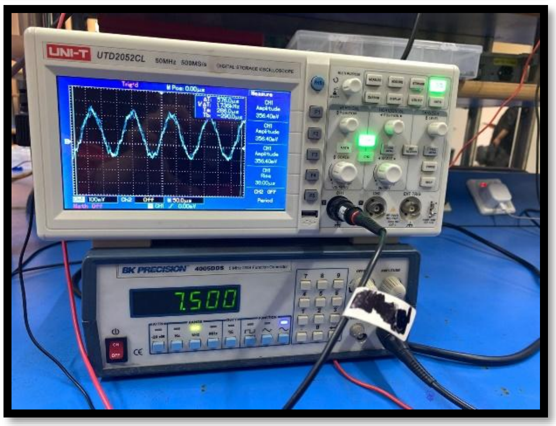


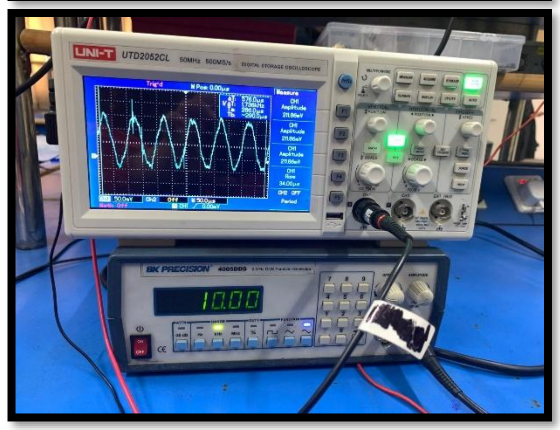








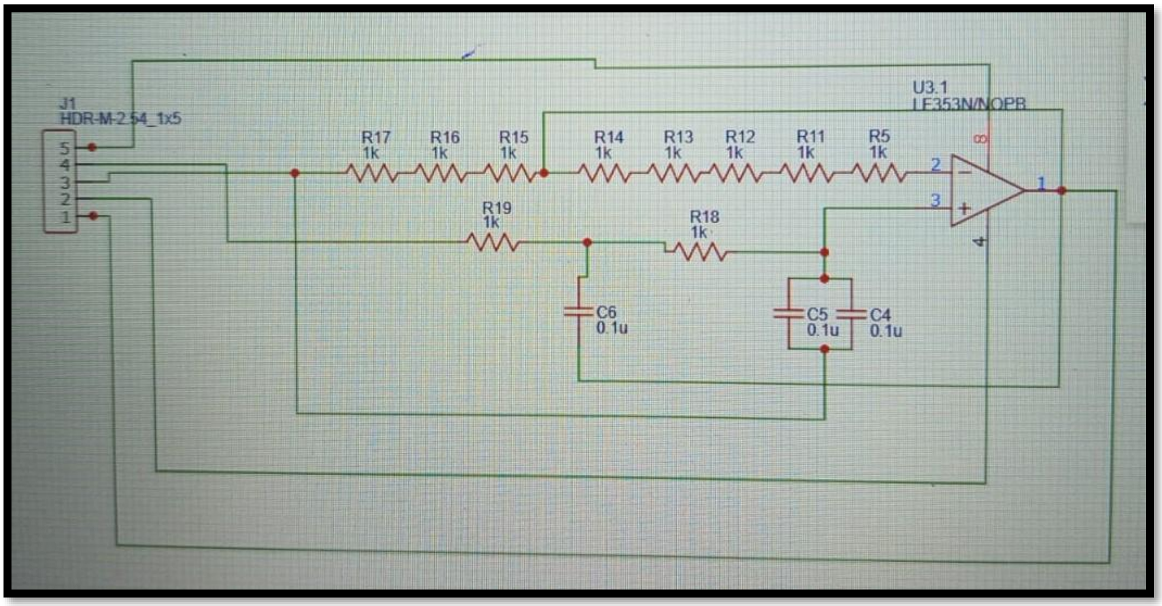


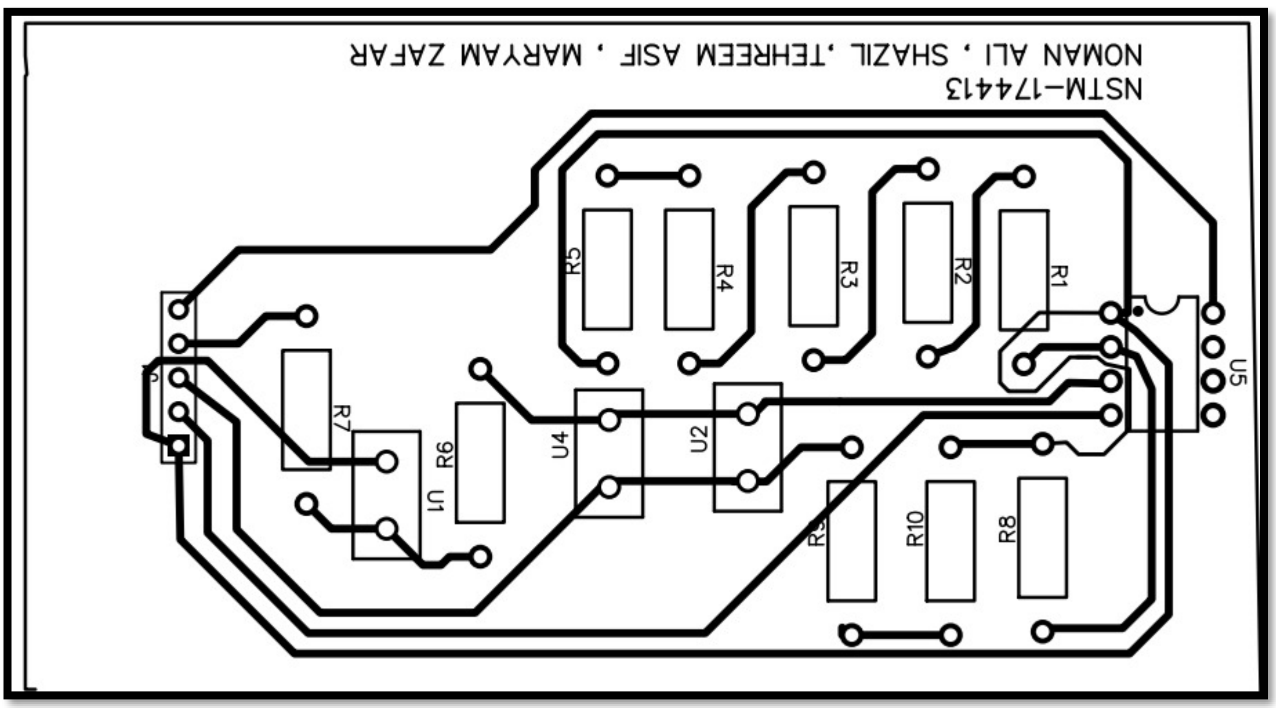


PCB:

A **Printed Circuit Board (PCB)** is a flat board used to physically support and electrically connect electronic components using conductive tracks, pads, and other features etched from copper sheets. It replaces traditional wiring and helps build compact, reliable, and professional electronic circuits. PCBs improve circuit stability, reduce noise, and make the assembly of complex designs easier. For designing the PCB in this project, we used **EasyEDA**, a free, cloud-based electronic design automation (EDA) tool. It allows for easy schematic capture, PCB layout design, and even simulation of electronic circuits. EasyEDA also provides access to a vast component library and supports exporting Gerber files for PCB manufacturing. Its user-friendly interface and online accessibility made it ideal for designing and testing our low-pass filter circuit.

PCB Circuit:


J1
HDR-M-2.54_1x5
R17 1k
R16 1k
R15 1k
R14 1k
R13 1k
R12 1k
R11 1k
R5 1k
R19 1k
R18 1k
C6 0.1u
C5 0.1u
C4 0.1u
U3.1
LF353N/NOPB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NSTM-174413
R5
R4
R3
R2
R1
U5
R7
R6
U1
U4
U2
R10
R8

Requirements/Apparatus:

- EasyEDA software for schematic design and PCB layout
- Copper-clad PCB board (single or double-sided)
- UV-sensitive photoresist film/Iron (for PCB etching process)
- Etching solution (Ferric Chloride or Ammonium Persulfate)
- Laser printer and glossy paper (for toner transfer method, if used)
- PCB drill machine for component hole drilling
- Soldering iron and solder wire for component mounting
- Multimeter for continuity testing
- Power supply for circuit testing
- Protective gloves and safety glasses during chemical handling
- Tweezers and wire cutters for component placement and trimming

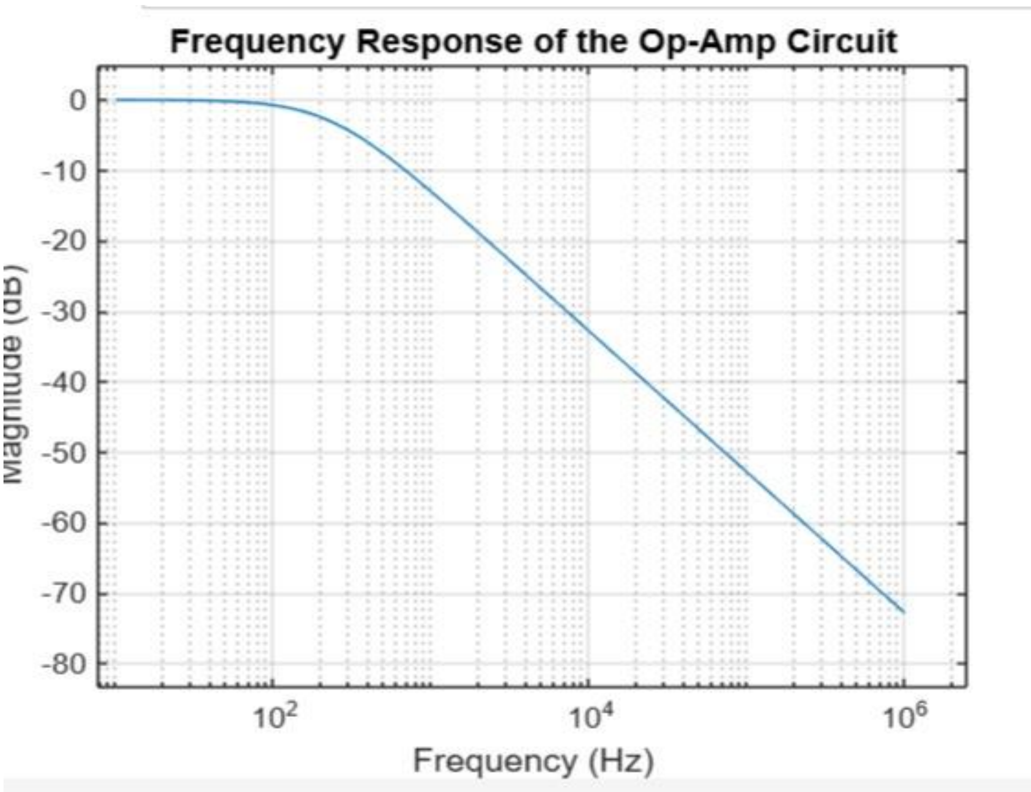
Procedure of PCB Designing:

- ➢ Design the circuit schematic using EasyEDA.
- ➢ Convert the schematic into a PCB layout and place components.
- ➢ Route the traces and finalize the board dimensions.
- ➢ Perform Design Rule Check (DRC) to detect errors.
- ➢ Generate Gerber files and export them for fabrication.
- ➢ Print the PCB layout (for DIY) or send Gerber files to a PCB manufacturer.
- ➢ Transfer the layout to a copper-clad board using UV exposure or toner transfer or Iron and we use Iron.
- ➢ Etch the board using an etching solution to remove unwanted copper.
- ➢ Drill holes for through-hole components using a PCB drill.
- ➢ Clean and dry the board, then apply a solder mask if required.
- ➢ Place the electronic components onto the PCB.
- ➢ Solder the components using a soldering iron and wire.
- ➢ Inspect all connections and test the circuit functionality with a multimeter and power supply

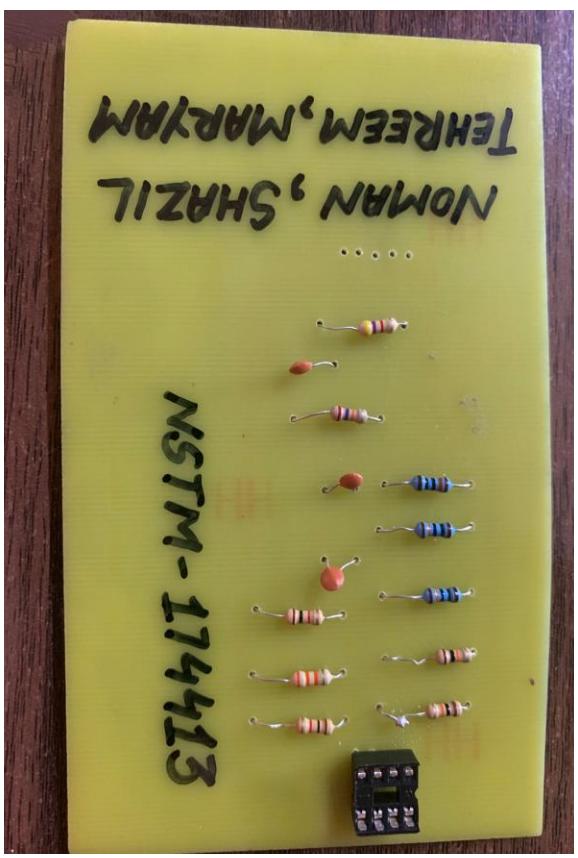
CODE:

% MATLAB Code for Simulating the Given Op-Amp Circuit

```
clc;
clear;
close all;
% Component Values
R = 1000; % Resistance in Ohms (1k Ohm)
C = 0.1e-6; % Capacitance in Farads (0.1 uF)
% Frequency Range
f = logspace(1, 6, 1000); % Frequency range from 10 Hz to 1 MHz
w = 2 * pi * f; % Angular frequency
% Calculating Impedances
Zc = 1 ./ (1j * w * C); % Impedance of capacitors
% Voltage Divider Network (Considering the Resistor Chain)
Z_total = R * 7; % 7 resistors of 1k Ohm each
% Transfer Function Calculation
H = (1 ./ Z_total) ./ (1 ./ Z_total + 1 ./ Zc); % Simplified transfer function
% Plotting
figure;
semilogx(f, 20 * log10(abs(H)));
grid on;
title('Frequency Response of the Op-Amp Circuit');
xlabel('Frequency (Hz)');
ylabel('Magnitude (dB)');
```



Frequency Response of the Op-Amp Circuit
Magnitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
-80
10^2
10^4
10^6
Frequency (Hz)



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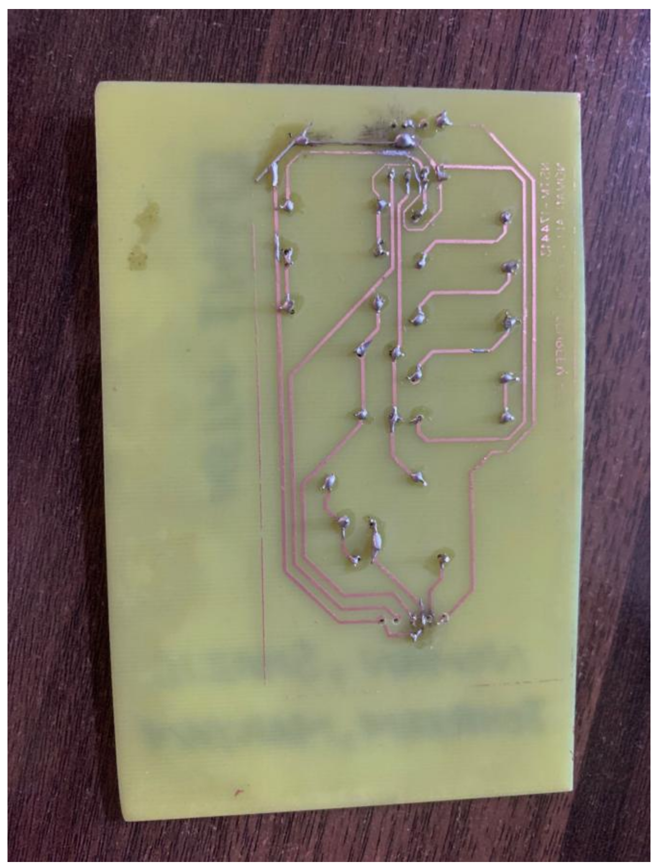

Conclusion:

In this project, an active low-pass filter was successfully designed, simulated, and implemented. The theoretical design calculations were based on the specified requirements of a passband gain of 20 dB ±3 dB, a cutoff frequency of 500 Hz, and an attenuation of at least 15 dB at 7.5 kHz. These calculations guided the selection of appropriate resistor and capacitor values, ensuring that the circuit met the desired specifications.

The filter circuit was first simulated using Proteus, where its frequency response was analyzed and found to align closely with theoretical predictions. The practical implementation was then achieved using a breadboard and later transferred to a PCB designed in EasyEDA. The measured frequency response from the practical circuit was consistent with both theoretical and simulated results, with minor deviations attributed to component tolerances and parasitic effects.

This project provided valuable insights into the design and implementation of active filters, including the impact of component selection, the importance of precise calculations, and the challenges of practical circuit assembly. Overall, the project objectives were met, demonstrating a strong understanding of filter design principles