DEPARTMENT OF COMPUTER &
SOFTWARE ENGINEERING

COLLEGE OF E&ME, NUST, RAWALPINDI

Electrical Network Analysis

Project Report

SUBMITTED TO:
Ma'am Umaimma
Dr Mahrukh Liaquat

SUBMITTED BY:

Hania Syed	**405339**
Shaheer Mukhtiar	
Fatima Tul Zohra	**405985**
Faiqa Ummarah Ahmad	**405052**

DE- 44-A Dept CE

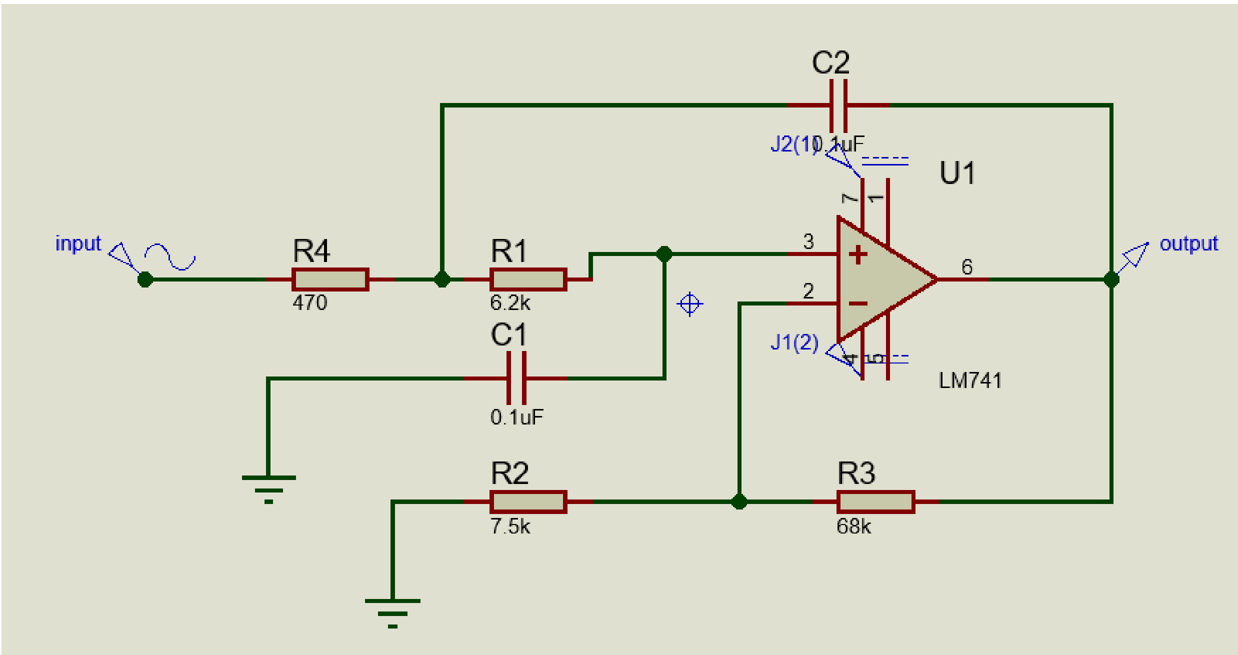
Submission Date:

7-6-2023

Description:

This project aimed to design a low-pass active filter circuit that meets specific requirements in terms of frequency attenuation and passband gain control. The filter required to attenuate frequency components at 13.5 kHz or higher by more than 15 dB, while maintaining a positive passband gain of 20 dB with a maximum deviation of 3 db, with desired passband frequency is 900 Hz and below.

This was achieved with the help of a second-order active low-pass filter shown in the diagram below. The order of the circuit was chosen to be 2 as the stop band roll-off will be twice the 1st order filters and would assist to attenuate the frequency quickly.



Feasibility studies:

+Butterworth Filter:

We chose the Butterworth filter for our design, due to its low-pass applications because of its maximally flat frequency response in the passband.

The order of the circuit was chosen to be two so that quick frequency attenuation can be achieved at a desired instant in contrast to a first-order filter that takes a longer period of time.

1) Steep roll-off: This filter design allows for a steep roll-off characteristic, which is crucial for attenuating frequencies above 13.5 kHz by more than 15 db. It ensures the effective suppression of unwanted high-frequency components.

b) Passband gain control: It also allows precise control over the passband gain. By carefully selecting the component values, the filter can maintain a positive passband gain of 20 dB, with a maximum deviation of 3 dB. This ensures the desired amplification of desired low-frequency signals while minimizing gain variations.

c) Flexibility: This circuit design provides the flexibility to select suitable operational amplifiers, resistors, and capacitors based on their availability and performance characteristics. This allows for customization and adaptation to specific design requirements.

Choosing the corner frequencies and passband gain:

Corner frequency:

The cutoff frequency, also known as the corner frequency, is the frequency at which the filter begins to attenuate the signal. In this case, the desired cutoff frequency is 13.5 kHz. This frequency will be the -3 dB point on the filter's frequency response curve.

Passband gain:

The passband gain is the gain within the desired frequency range, which in this case is 900 Hz and below. The passband gain should be positive and should not deviate from 20 dB by more than 3 dB.

Determined the component (or parameter) values of the filter circuit:

$$\omega_C = 2\cdot\pi\cdot F_C \qquad C \cong 10/F_C\ (\text{uF})$$

$$C1 < \frac{[\,a^2 + 4\cdot b\cdot(K-1)]\cdot C}{4\cdot b}$$

$$R1 = \frac{2}{(a\cdot C + \{[\,a^2 + 4\cdot b\cdot(K-1)\,]\cdot C^2 - 4\cdot b\cdot C\cdot C1\}^{1/2})W_C}$$

$$R2 = \frac{1}{b\cdot C\cdot C1\cdot R1\cdot W_C{}^2}$$

$$R3 = \frac{K\cdot(R1 + R2)}{(K-1)},\ \ R4 = K\cdot(R1 + R2)\,, \qquad \text{For } K \neq 1$$

-The above formulas were used to calculate the values of C1, C2, R1, and R4.

-C1= 10/Cutoff frequency

= 10/900 = approx. 0.1 microfarad

C1 was chosen to be equal to C2.

- The values of R1 and R4 came out to be 6.2k and 470ohm respectively.

- The following formula was used to calculate values of feedback resistances for the active filter design.

$G = 10$ ∵ Given in Question

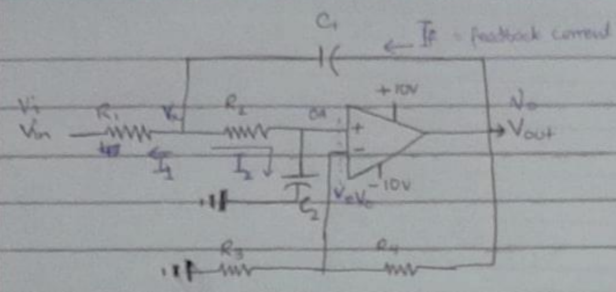
$$G = \frac{R_4}{R_3} + 1$$

$$\frac{R_4}{R_3} = 9$$

hence $\dfrac{R_4}{R_3} = \dfrac{68k}{7.5k} \approx 9$

Transfer function:

op-amps have virtual short between +ve and -ve nodes and OA current due to high resistance



$R_1 = 47\,\Omega$

$R_2 = 620\,\Omega$

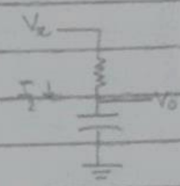
$R_3 = 750\,\Omega$

$R_4 = 6.8\,k\Omega$

$C_1 = C_2 = 1.0\,\mu F$

→ KCL : $I_f = I_1 + I_2$

$$\frac{v_o - v_x}{1/sC_1} = \frac{v_x - v_i}{R_1} + \frac{v_o - 0}{1/sC_2}$$



$$(v_o - v_x)sC_1 = (v_x - v_i)/R_1 + v_o s C_2$$

→ Potential divider: $v_o = v_x \left(\frac{1/sC_2}{1/sC_2 + R_2} \right) = \frac{v_x}{1 + sC_2R_2}$

$$v_x = v_o(1 + sC_2R_2) = v_o + v_o s C_2 R_2$$

→ Substituting into KCL equation:

$$(\cancel{v_o} - \cancel{v_o} - v_o s C_2 R_2) s C_1 = (v_o + v_o s C_2 R_2 - v_i)/R_1 + v_o s C_2 \quad \times R_1$$

$$- R_1 v_o s^2 R_2 C_1 C_2 = v_o + v_o s C_2 R_2 - v_i + R_1 v_o s C_2$$

$$- v_o (s^2 C_1 C_2 R_1 R_2 + 1 + s C_2 R_2 + s R_1 C_2) = - v_i$$

$$\frac{v_o}{v_i} = \frac{1}{s^2 C_1 C_2 R_1 R_2 + s C_2 (R_1 + R_2) + 1} \quad \div C_1 C_2 R_1 R_2$$

→ $\boxed{H(s) = \frac{v_o}{v_i} = \frac{\frac{1}{C_1 C_2 R_1 R_2}}{s^2 + s\left(\frac{R_1 + R_2}{C_1 R_1 R_2}\right) + \frac{1}{C_1 C_2 R_1 R_2}}}$

inputting values: $H(s) = \frac{34.32 \times 10^6}{s^2 + 22.89 \times 10^3 s + 34.32 \times 10^6}$

poles = -1613 and 21277

cut-off frequency = $\frac{1}{2\pi \sqrt{R_1 R_2 C_1 C_2}} = \frac{1}{2\pi \sqrt{47 \times 620 \times 10^{-12}}} = \boxed{932 \approx 900\ Hz}$

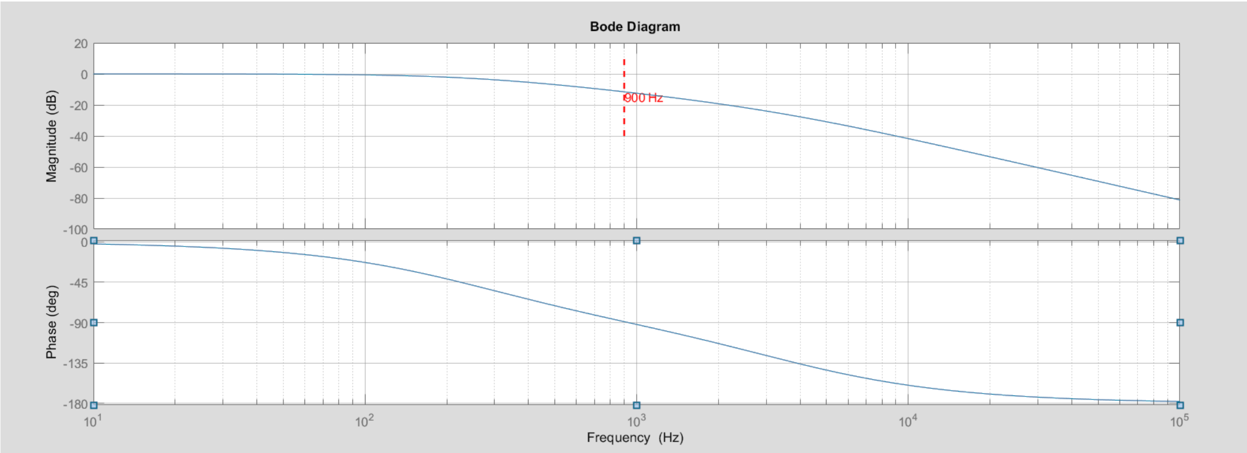
Frequency Response Characteristic:

MATLAB code:

```
R1 = 47;
R2 = 620;
C1 = 1e-6;
C2 = 1e-6;
a = 1;
b = (R1+R2)/(C1*R1*R2);
c = 1 / (C1*C2*R1*R2);

h = tf(c, [a b c]);
bode(h);
grid on;
```

Graphs:

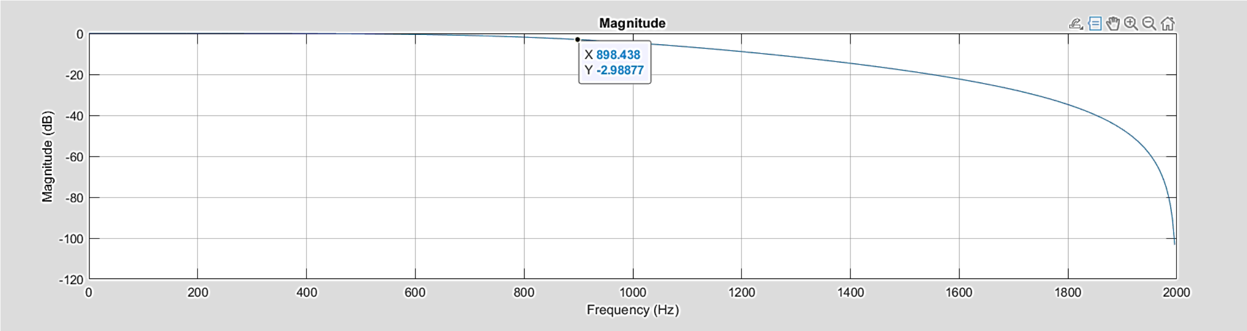


Butterworth plot:

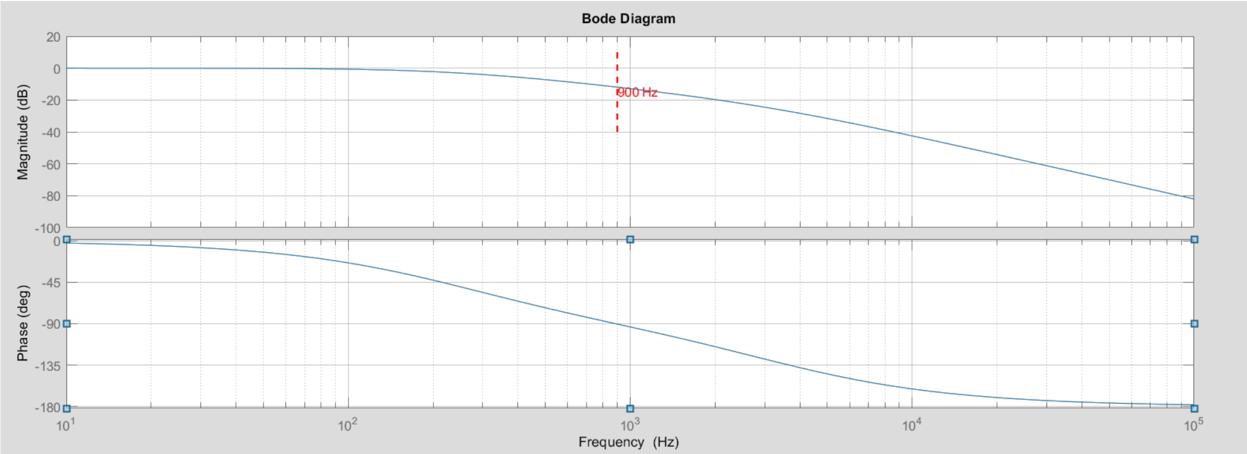
```
order = 2;              % Filter order
cutoff_freq = 900;      % Cutoff frequency in Hz
sampling_freq = 4000;   % Sampling frequency in Hz

% Design Butterworth filter
[b, a] = butter(order, cutoff_freq/(0.5*sampling_freq), 'low');
freqz(b,a,[],sampling_freq)
grid on;
```

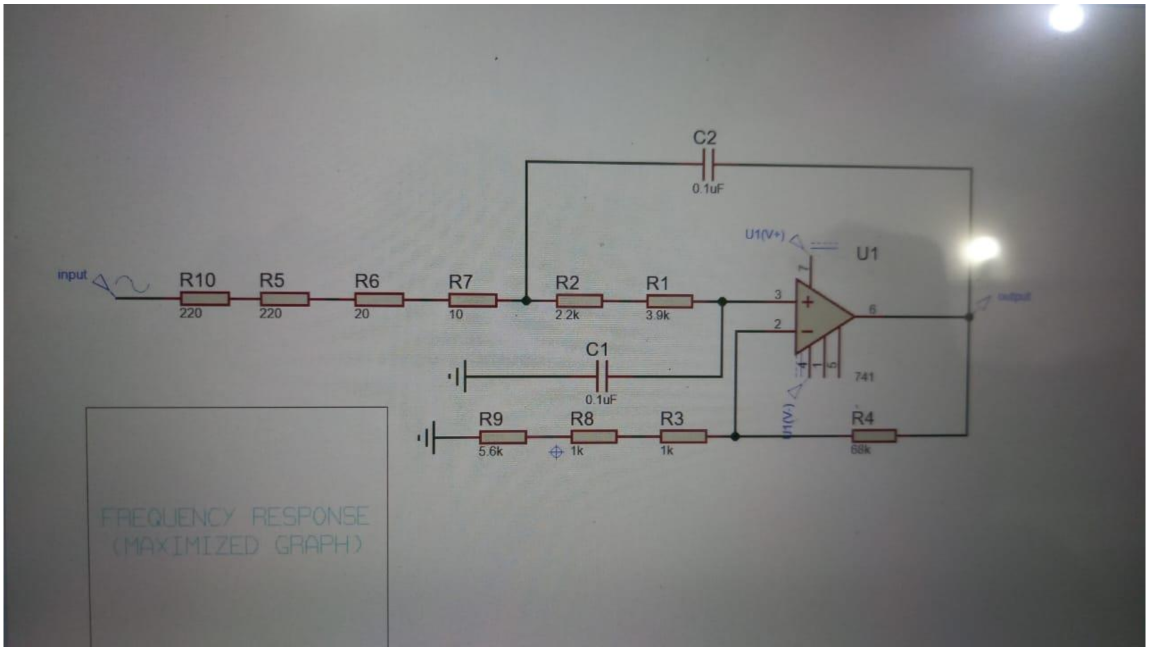
Butterworth plot:



Frequency response magnitude characteristic when values of two components (one resistance and another capacitance) deviate 5% from their nominal values. (Via MATLAB)



Constructed low pass circuit:



As required value resistors were not available, combinations of different resistors were used. The value of resistance was further scaled by a factor of ***'10'*** to achieve the available value of resistance.

The following combinations were used:

$\boxed{K_m = 10}$ $C_2 = C_1 = 1M = 0.1M$

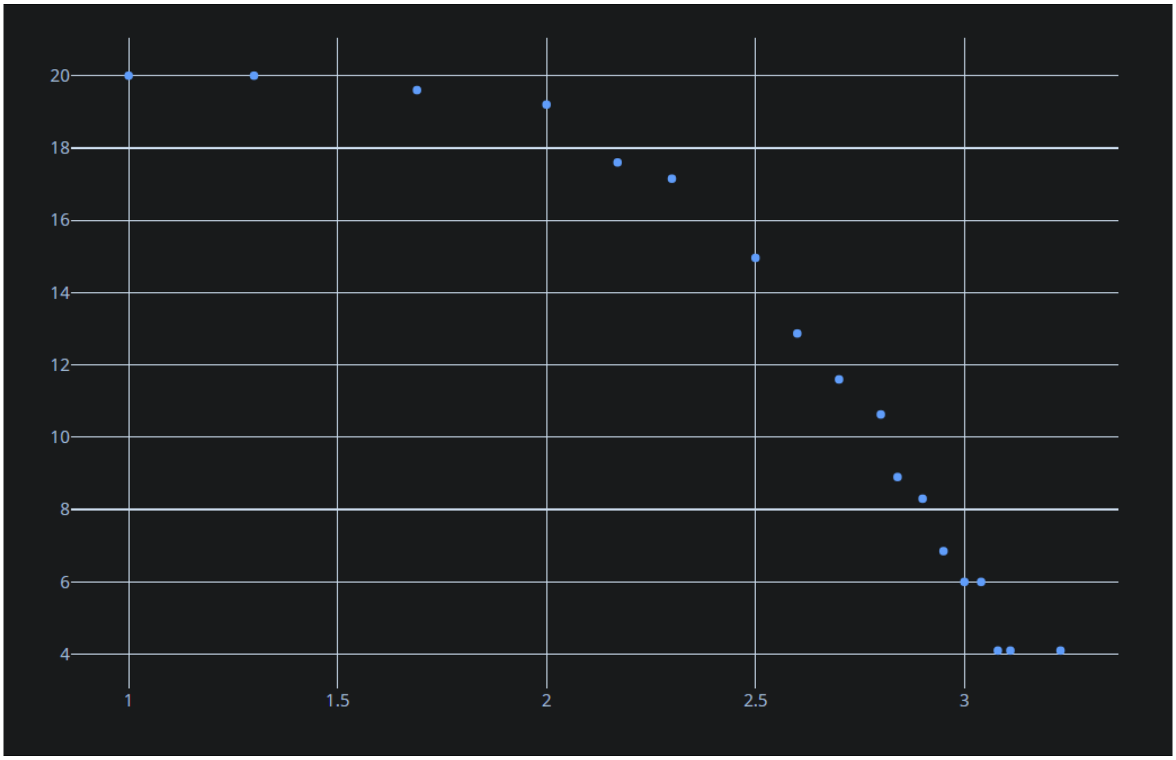
$R_1 = 47 = 470 = 220 + 220 + 10 + 20$

$R_2 = 620 = 6.2k = 2.2k + 3.9k$

$R_3 = 750 = 7.5k = 5.6k + 1k + 1k$

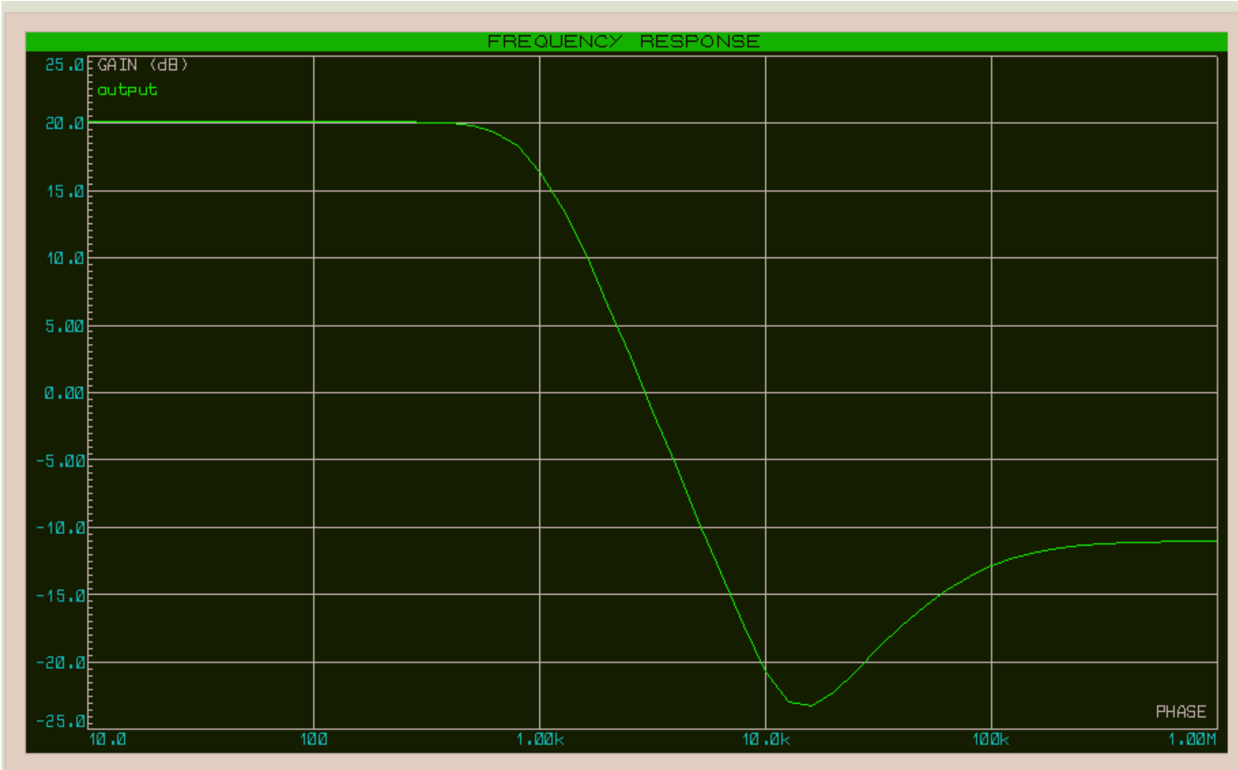
$R_4 = 6.8k = 68k = 68k$

Experimentally measured frequency response magnitude characteristic:

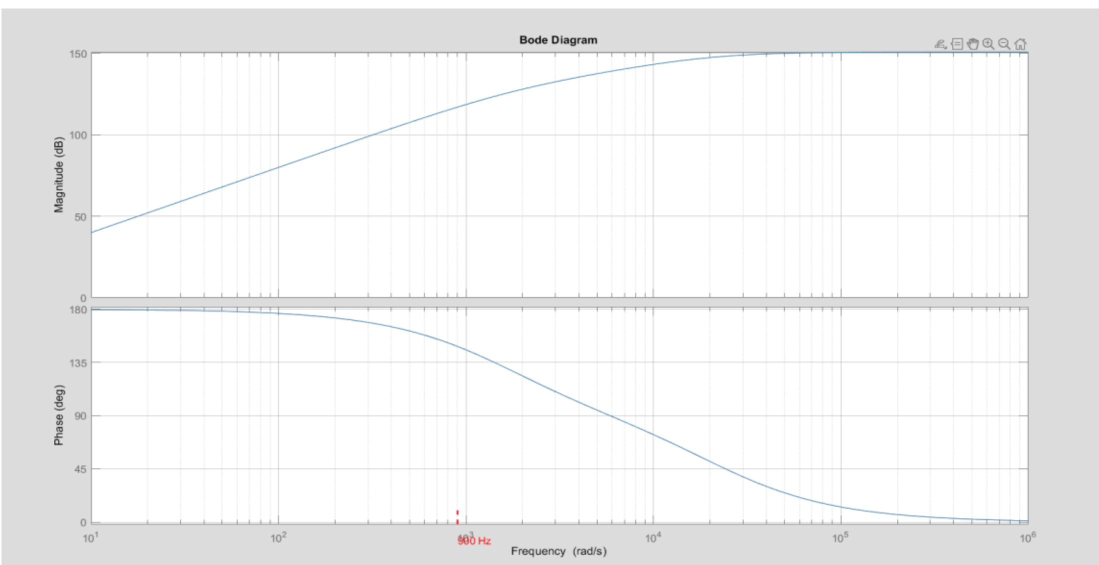


	A	B
0	20	1
1	20	1.3
2	19.6	1.69
3	19.2	2
4	17.6	2.17
5	17.15	2.3
6	14.96	2.5
7	12.87	2.6
8	11.6	2.7
9	10.63	2.8
10	8.9	2.84
11	8.3	2.9
12	6.85	2.95
13	6	3
14	6	3.04
15	4.1	3.08
16	4.1	3.11
17	4.1	3.23
18	2.9	

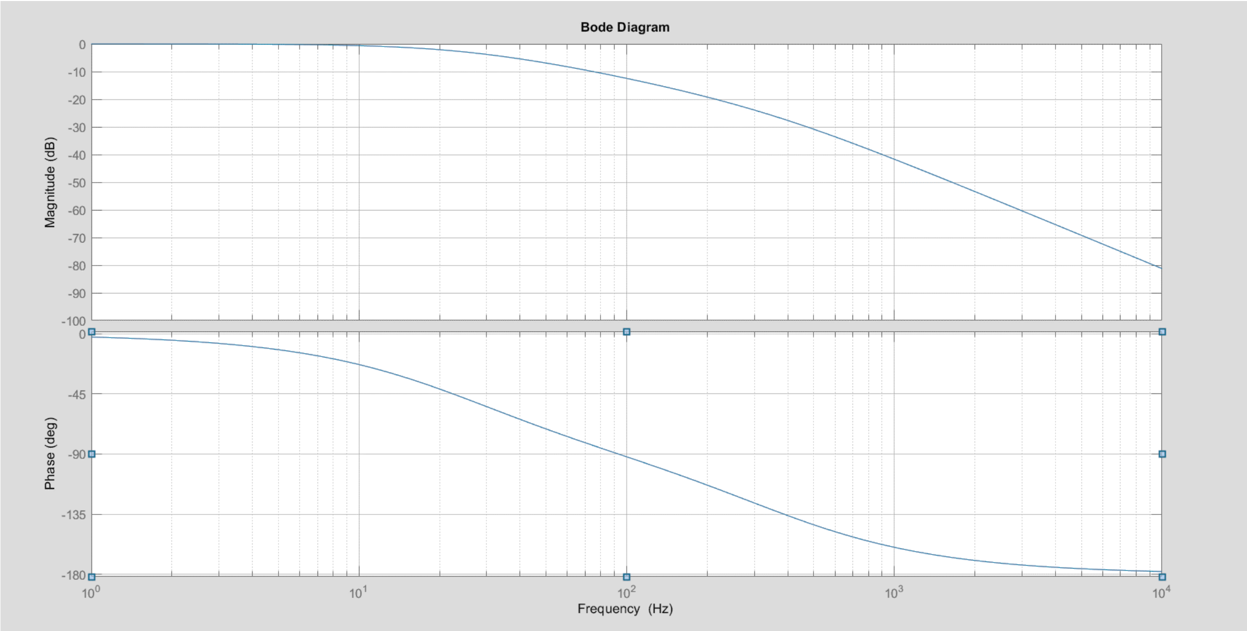
Simulations via proteus:



Conversion of a low-pass filter to a high-pass filter:



Conversion of a low-pass filter you designed to another low-pass filter with a different 3 dB frequency:



PCB design software & etching process:

PCB Layout:

The PCB design software allows for creating a schematic representation of the circuit and then translating it into a physical layout. This was done with the help of proteus software. The PCB layout included various factors, such as component placement, signal integrity, ground plane design, routing techniques, and clearances between traces and pads.

Gerber Files Generation:

Once the PCB layout is finalized, the design needs to be exported in the Gerber file format. Gerber files contain the necessary information for manufacturing the PCB, including the copper traces, solder mask, and drill holes. The PCB design software typically has the option to generate Gerber files, which can be sent to a PCB fabrication service for production.

PCB Fabrication and Etching Process:

The Gerber files are used by PCB fabrication services to manufacture the PCBs. The fabrication process generally involves the following steps:

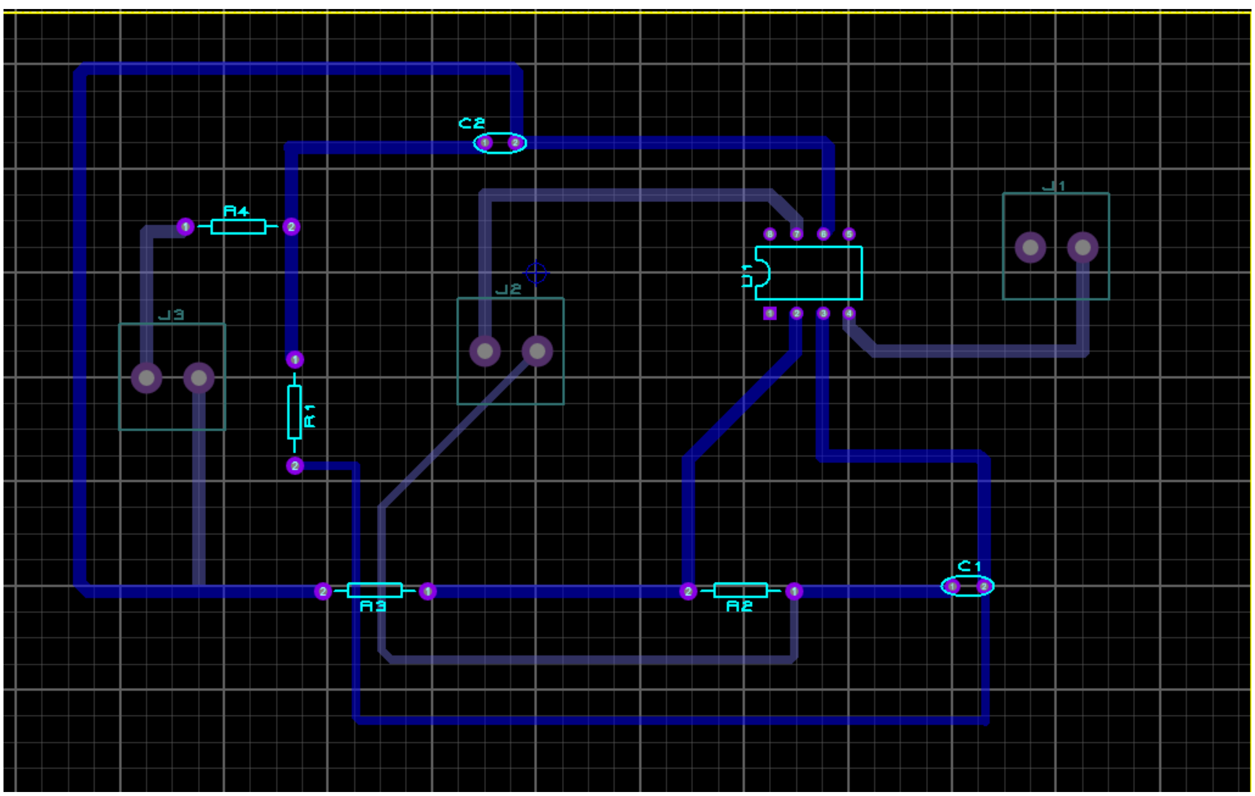
a) Substrate Preparation: A copper-clad substrate, typically made of fiberglass-reinforced epoxy, was prepared.

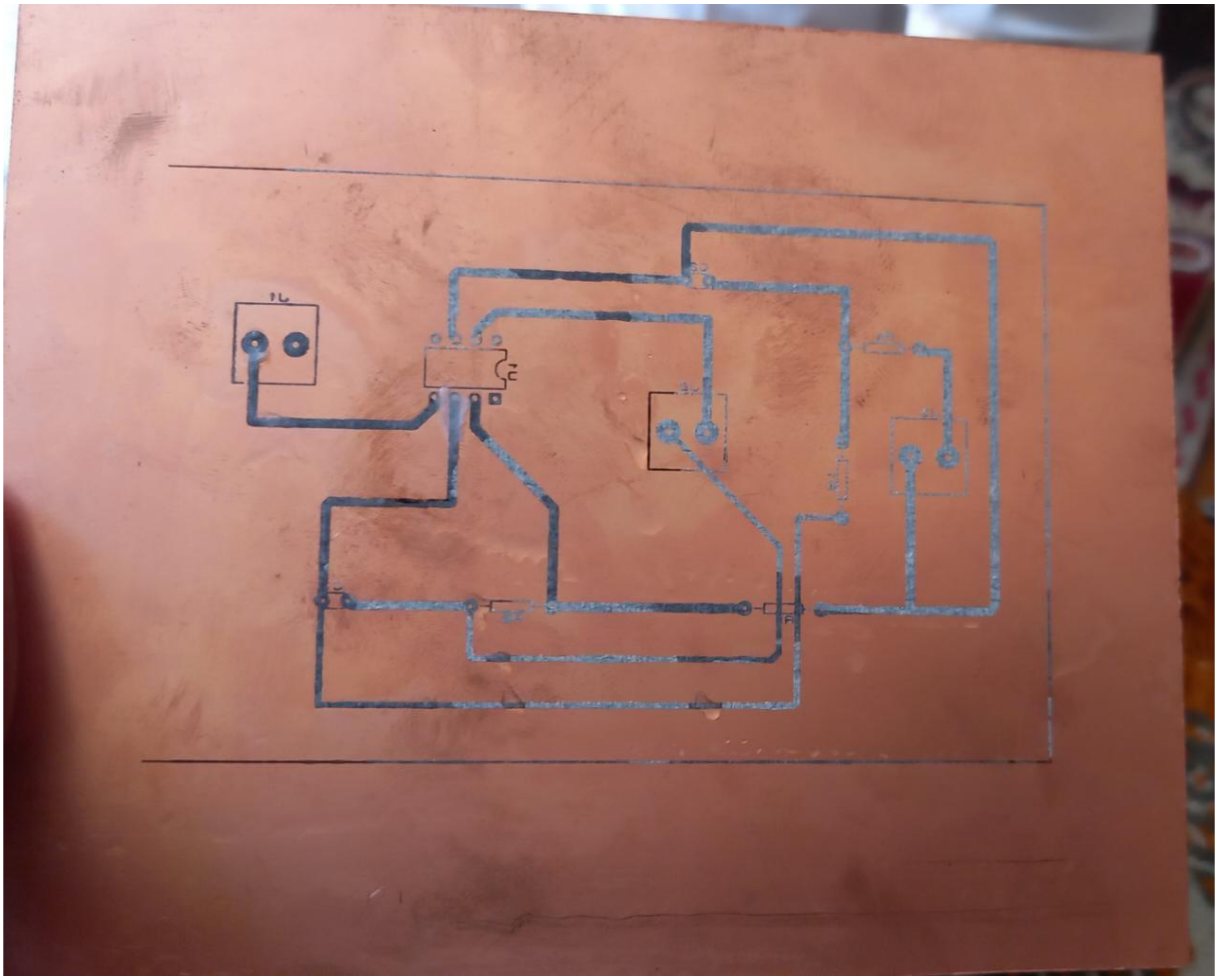
b) Photoresist Application: A layer of photosensitive material, known as the photoresist, was applied to the substrate. The photoresist protects the desired copper traces during the etching process.

c) UV Exposure and Development: The Gerber files are used to generate a photomask, which is placed over the photoresist-coated substrate. The substrate is exposed to UV light through the photomask, and the photoresist is developed, leaving behind the desired pattern.

d) Etching: The exposed copper areas not protected by the photoresist are etched away using an etching solution, typically a mixture of ferric chloride or ammonium persulfate. The etching process removes the unwanted copper, leaving only the desired copper traces.

e) Cleaning and Inspection: The PCB is thoroughly cleaned to remove any residual photoresist or etchant. Visual inspection and electrical testing are performed to ensure the quality and functionality of the fabricated PCB.





Conclusions & Design Experience:

In conclusion, the design of a low-pass active filter circuit to meet the given specifications has been successfully achieved. By following a systematic design process and considering the desired roll-off, passband gain, and cutoff frequency, appropriate resistor and capacitor values were determined. The design experience gained from this problem allowed for a deeper understanding of active filter design principles. The process involved analyzing transfer functions, selecting standard component values, and considering trade-offs to meet the desired specifications. The importance of simulations or prototyping to validate the design and account for real-world factors was also emphasized. Overall, this design exercise provided valuable insights into the practical application of active filter enhanced design skills.