Semester Project Report

For the Course
EE-211 Electrical Network Analysis

Wide Band Pass Filter

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Introduction

A band pass filter is an RC or RL circuit arrangement formulated by cascading a high pass and a low pass filter. As a result, the circuit only allows a certain range of frequencies to pass through, based upon the values of components in the circuit; resistors and capacitors ,or in the case of RL circuit, resistors and inductors. There are mainly two main types of Band Pass filters:

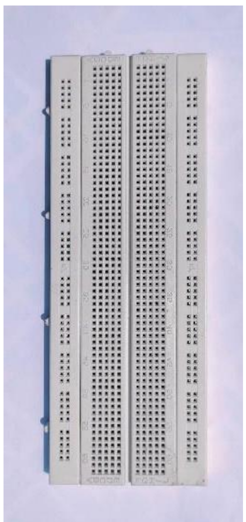
- Active Band Pass Filter
- Passive Band Pass Filter

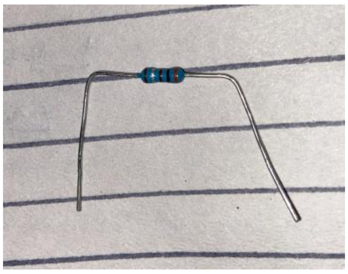
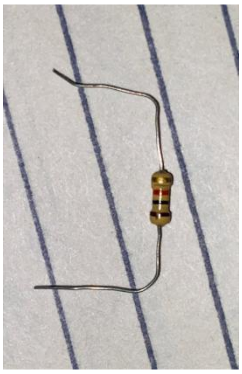
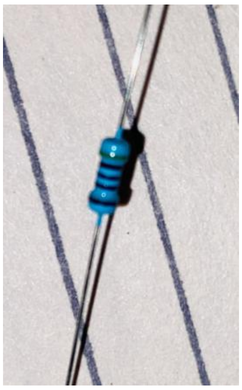
The project was relevant to the active band pass filter. It is created in a manner similar to passive band pass filter. The only difference is that an active component; an op-amp is added to the circuit arrangement.

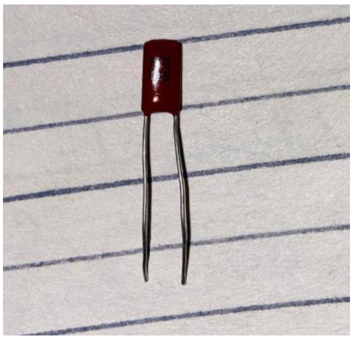
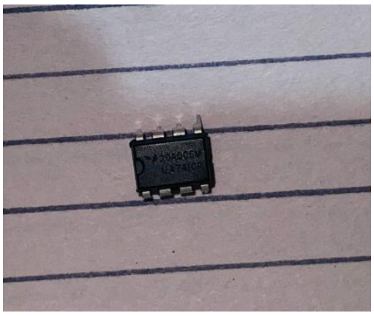
Requirements of the Project

- Mid band Gain is 12 db and 3 db Bandwidth extends from 500 Hz to 10 kHz.
- Implement the circuit using PSpice/Multisim.
- Build the circuit using breadboard.
- Acquire the voltage transfer function using function generator and oscilloscope.
- Plot the measured frequency response.
- Compare the theoretical, simulated and measured results by plotting then on same graph.
- Modify circuit by a scaling factor of 2 and implement circuit using PSpice/Multisim.

Equipment Used

S.No	Component	Specifications	Quantity	Picture
1	Breadboard	N/A	2	

2	Resistor	3.2 kohm	1	
3	Resistor	10 kohm	1	
4	Resistor	5 kohm	4	
5	Capacitor	0.1 uF	1	

6	Capacitor	1.6 nF	1	
7	Op-Amp LM 741	N/A	2	

Calculations

- **Value of Gain Formula:**

A_{v1}= 1 + R3/R2 **[Gain Filter One]**

Av2= 1+ R6/R5 **[Gain Filter Two]**

- **Formula for High and Low Frequency Range:**

f_h= 1/2 π R_1 C_1 **[Capacitor and Resistor Values High Pass Filter]**

f_l= 1/2 π R4 C_2 **[Capacitor and Resistor Values Low Pass Filter]**

FNA Project
(Wide Band pass Filter)

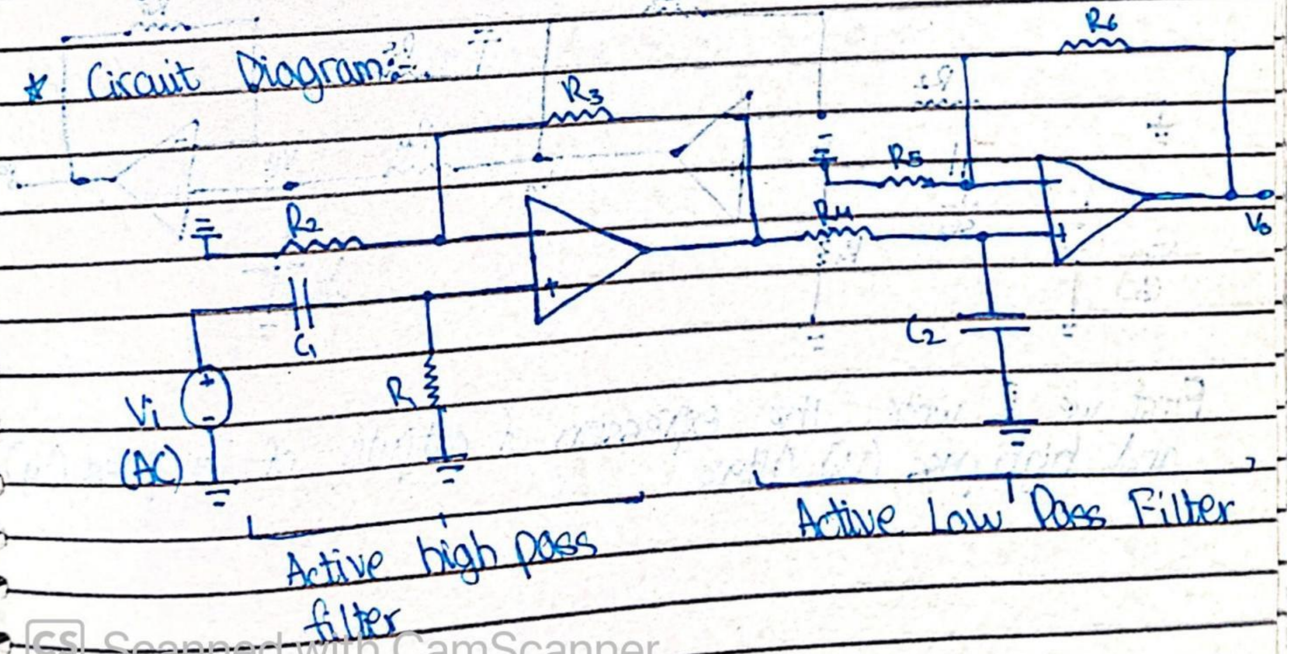
*** Block Diagram (Step by Step)**

Voltage Source → CR Circuit → +ve terminal of OP Amp → RC Circuit → +ve terminal of 2nd OP Amp → Output Voltage

*** Block Diagram (Simplified):**

Input Voltage → Active High Pass Filter → Active Low Pass Filter → Output

*** Circuit Diagram:**



* Note:-

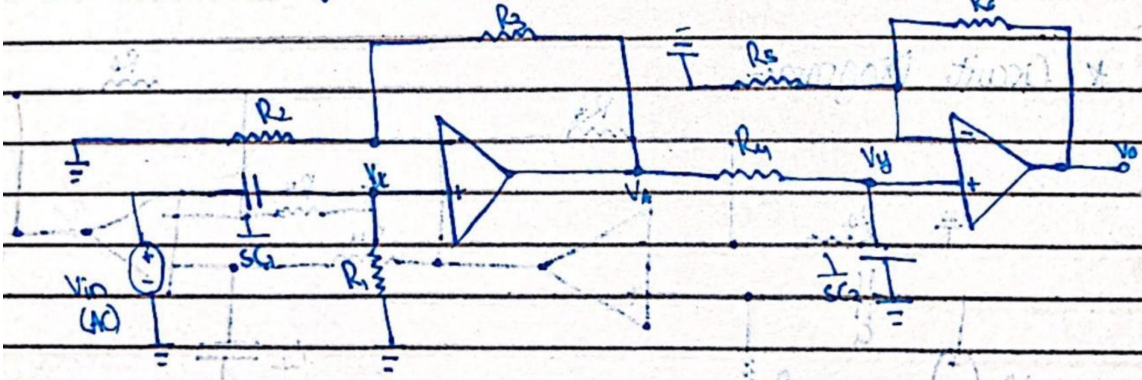
→ The values of R_2, R_3, R_5 and R_6 will decide the values of gain only. These values will not affect the cut-off frequencies (f_L and f_H)

→ Values of f_L and f_H will be decided by R_1, C_1 and R_4, C_2 respectively

- No current enters through the -ve terminal of OP-Amp. (Non-inverting case)

* Derivation of Transfer function:-

The s-domain equivalent circuit would be



First we write the expression of outputs of low pass (V_y) and high pass (V_x) filters.

Thus, using voltage divider rule

$$V_x = \left(\frac{R_1}{R_1 + \frac{1}{sC_1}}\right) V_{in} \longrightarrow V_x = \left(\frac{sC_1R_1}{sC_1R_1 + 1}\right) V_{in}$$

The expression for the output of the first OP Amp (V_A) would be,

$$V_A = \left(1 + \frac{R_3}{R_2}\right) V_x \longrightarrow V_A = \left(1 + \frac{R_3}{R_2}\right)\left(\frac{sC_1R_1}{sC_1R_1 + 1}\right) V_{in} - (i)$$

Now we derive expression for V_y, considering V_A as input voltage for second OP Amp. Using voltage divider rule,

$$V_y = \left(\frac{1/sC_2}{R_4 + 1/sC_2}\right) V_A \Longrightarrow V_y = \left(\frac{1}{sC_2R_4 + 1}\right)\left(1 + \frac{R_3}{R_2}\right)\left(\frac{sC_1R_1}{sC_1R_1 + 1}\right) V_{in}$$

Finally we derive expression for V_o, using the expression of V_y. As,

$$V_o = \left(1 + \frac{R_6}{R_5}\right) V_y \Longrightarrow V_o = \left(1 + \frac{R_6}{R_5}\right)\left(\frac{1}{sC_2R_4 + 1}\right)\left(1 + \frac{R_3}{R_2}\right)\left(\frac{sC_1R_1}{sC_1R_1 + 1}\right) V_{in}.$$

Put $s = j\omega$ and simplify;

$$\frac{V_o}{V_{in}} = H(j\omega) = \frac{(1 + R_6/R_5)(1 + R_3/R_2)}{(1 + j\omega C_2R_4)\left(1 + \frac{1}{j\omega C_1R_1}\right)}.$$

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$$= H(j\omega) = \frac{(1+R_6/R_5)(1+R_3/R_2)}{(1+j\omega C_2 R_4)\left(1+\frac{1}{j\omega C_1 R_1}\right)}$$

[redacted] $\therefore R_2 = R_3 = R_5 = R_6 = 5k\Omega$

[redacted] $\cancel{= (1+1)(1+1)}$

[redacted] Values of R and C: (for cut-off frequencies)

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$f_L = \frac{1}{2\pi C_1 R_1}$ Since we need to find both R_1 and C_1, therefore we will have to assume any one of these.

Thus assuming $C_1 = 0.1\,\mu F = 0.1\times10^{-6} F$

Therefore,

$f_L = \frac{1}{2\pi \times 0.1\times10^{-6}\times R_1}$ $f_L = 500\,Hz$

$R_1 = \frac{1}{2\pi \times 0.1\times10^{-6}\times 500} \approx 3.2k\Omega$

· Similarly, for higher cut-off frequency we have the following formula.

$f_H = \frac{1}{2\pi C_2 R_4}$

Assuming value of $R_4 = 10k\Omega$.

$f_H = \frac{1}{2\pi \times C_2 \times 10 \times 10^3}$ ∴ $f_H = 10 \times 10^3 Hz$

$10 \times 10^3 = \frac{1}{2\pi \times C_2 \times 10 \times 10^3}$

$C_2 = \frac{1}{2\pi \times 10 \times 10^3 \times 10 \times 10^3}$

$C_2 = 1.6 \times 10^{-9} F$

Hence the value of R and C for filters,

$R_1 = 3.2k\Omega$, $C_1 = 0.1\mu F$, $R_4 = 10k\Omega$ and $C_2 = 1.6nF$

* Values of R: (for 12dB gain)
We have the gain in decibel form so we first need to convert to linear form

$$\text{Linear Gain} = 10^{(\text{Gain in dB}/20)}$$

$$= 10^{(12/20)}$$

$$= 3.98 \approx 4$$

So we need a total gain of 4 at the output terminal. We have two OP Amps. So we can choose any configuration.

1+3 (or) 0+4 (or) 2+2 (or) 3+1 (or) 4+0 ⇒ for gain (OPAmp1 + OpAmp2)

For our simplicity, we choose 2+2 = 4 gain configuration. so

⇒ Gain from high pass filter $= 1 + \frac{R_3}{R_2} = 2$

$$\frac{R_3}{R_2} = 2 - 1 = 1$$

$$\Rightarrow \boxed{R_3 = R_2}$$

We assume $R_3 = 5k\Omega$ then $R_2 = 5k\Omega$.

⇒ Gain from low pass filter $= 1 + \frac{R_6}{R_5} = 2$

$$\frac{R_6}{R_5} = 2 - 1$$

$\frac{R_6}{R_5} = 1$

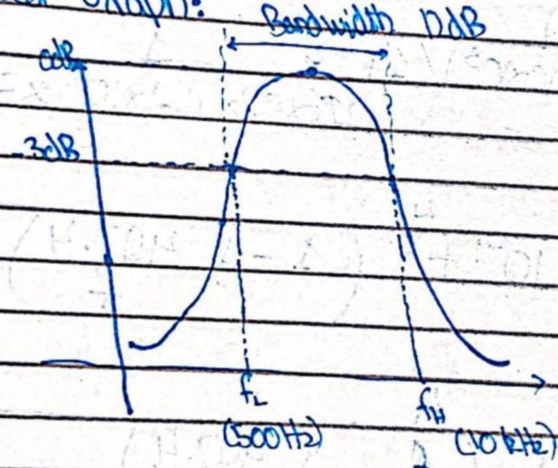
$\boxed{R_6 = R_5}$

We assume $R_6 = 5k\Omega$ and $R_5 = 5k\Omega$

Hence, to summarize

$\boxed{R_2 = 5k\Omega}$ $\boxed{R_3 = 5k\Omega}$ $\boxed{R_5 = 5k\Omega}$ $\boxed{R_6 = 5k\Omega}$

* Expected Graph:



$\boxed{\text{Note}}$ Put the chosen values of R and C into expression of transfer function H(s) and write in terms of linear frequency [Hint. $\omega = 2\pi f$]. Put different values (20-25) in the formula of H(f) and plot gain [H] vs frequency (f).

* Verification of transfer function:

$$\frac{V_o}{V_{IN}} = H(j\omega) = \frac{\left(1+R_3/R_2\right)\left(1+R_6/R_5\right)}{\left(1+j\omega C_2 R_4\right)\left(1+\frac{1}{j\omega C_1 R_1}\right)}$$

$$\left(f_c = \frac{1}{2\pi C_1 R_1}\right)$$

Put values into transfer function.

$$= \frac{(1+1)\,(1+1)}{\left(1+j2\pi f\times 1.6\times 10^{-9}\times 10\times 10^{3}\right)\left(1 \mp \frac{1}{2\pi f\times 0.1\times 0.1\times 10^{-6}\times 3.2\times 10^{3}}\right)}$$

$$= \frac{4}{\left(1+j1\times 10^{-4} f\right)\left(1-j\frac{497.4}{f}\right)}$$

$$= \frac{4}{\left(1+j1\times 10^{-4} f\right)\left(\frac{f - j497.4}{f}\right)}$$

$$= \frac{4f}{\left(1+j1\times 10^{-4}\cdot f\right)\left(f-j497.4\right)}$$

$$= \frac{4f}{(f - j497.4 + j1\times10^{-4}f^2 + 4.97\times10^{-2}f)}$$

$$= \frac{4f}{(1.0497f + j1\times10^{-4}f^2 - j497.4)}$$

Put in value of $f = 500 Hz$

$$= \frac{4f}{(1.0497f + j1\times10^{-4}f^2 - j497.4)}$$

$= 2.1 + j1.9 = 2.832 \angle 42^\circ$

Put in value of $f = 1\times10^3 Hz$

$$= \frac{4f}{(1.0497f + j1\times10^{-4}f^2 - j497.4)}$$

$= 3.33 + j1.26$

Put in value of $f = 2.5\times10^3 Hz$

$$= \frac{4f}{(1.0497f + j1\times10^{-4}f^2 - j497.4)}$$

$= 3.8 - j0.18$

At $f_2 = 5\times10^3$ Hz

$$= \frac{4 \times 5\times10^3}{(1.0497\times5\times10^3) + j(1\times10^{-4}\times(5\times10^3)^2) - j497.4}$$

$$= 3.3 - j\,1.26$$

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$$= \frac{4(7.5\times10^3)}{(1.0497\times7.5\times10^3) + j\left[1\times10^{-4}\times(7.5\times10^3)^2\right] - j497.4}$$

$$= 2.68 - j\,1.74$$

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$$= \frac{4(10\times10^3)}{(1.0497\times10\times10^3) + j\left[1\times10^{-4}\times(10\times10^3)^2\right] - j497.4}$$

$$= 2.1 - j1.9$$

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$$= \frac{4(250)}{(1.0497\times250) + j\left[1\times10^{-4}\times(250)^2\right] - j497.4}$$

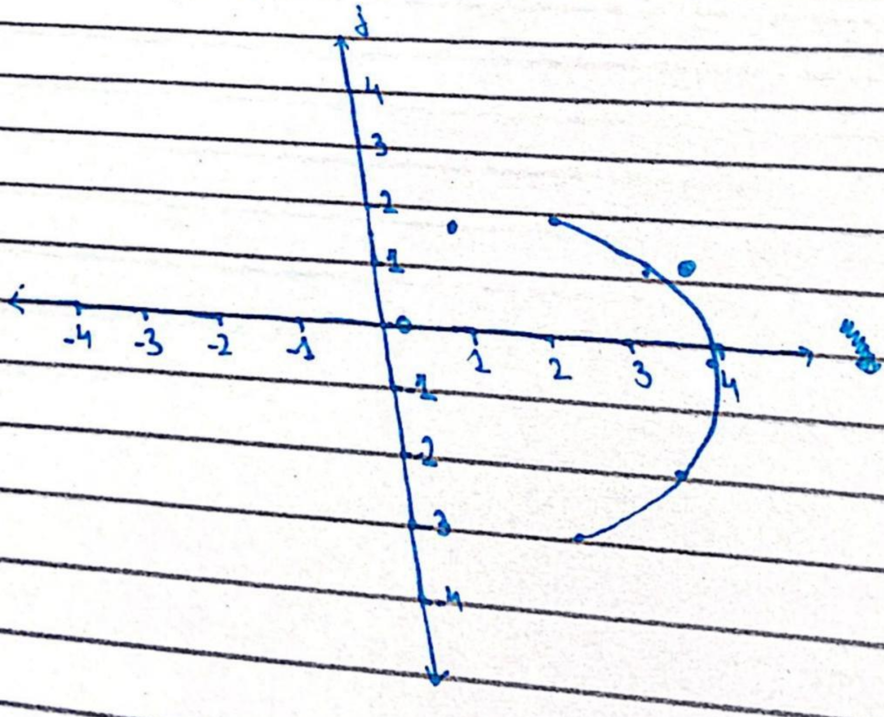
=

$= 0.85 + j1.58$

At $f = 12.5\times10^3$ Hz

$$= \frac{4(12.5\times10^3)}{(1.0497\times12.5\times10^3) + j\left[1\times10^{-4}\times(12.5\times10^3)^2\right] - j497.4}$$

$= 1.74 + j0.03$



The calculated resistor and capacitor values were available in the market.

Workings

- **For the Lower Cut-Off Value:**

Connect the circuit according to the hand-drawn circuit diagram. Connect input from frequency at the capacitor C1 and set up a common ground for the circuit. Set amplitude of input value at 1V, and then we will connect DMM at voltage setting. One wire of DMM will be connected at the pin 6 of the second Op-Amp and the other pin at the common ground. The desired ideal output voltage would be 2.8V.

- **For the Higher Cut-Off Value:**

We will set the frequency generator value at 10 kHz and the input amplitude at 1V. We will repeat the steps as for the Lower Cut-Off Value. The value of output should be 2.8V for the higher cut-off as well.

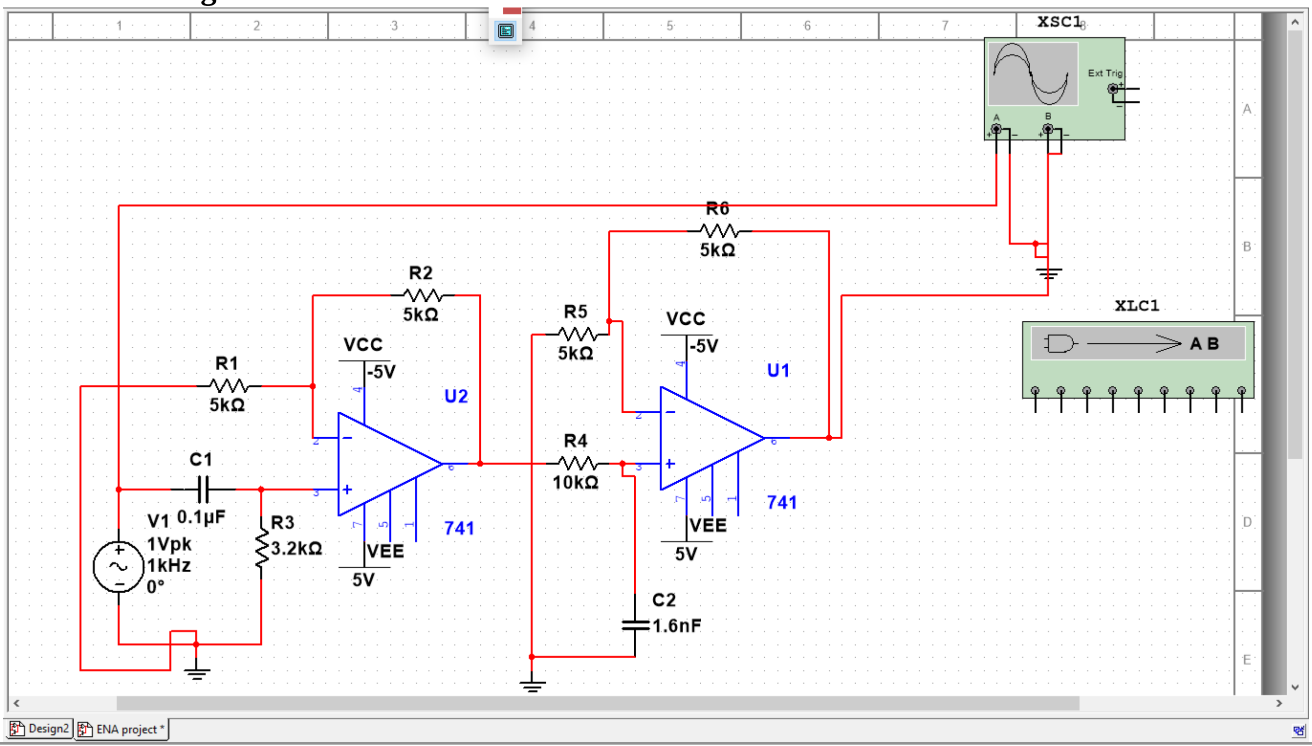
- **For the Maximum Gain:**

Maximum gain is achieved ideally at a frequency of 2.236 kHz from the frequency generator. The gain would be 4.

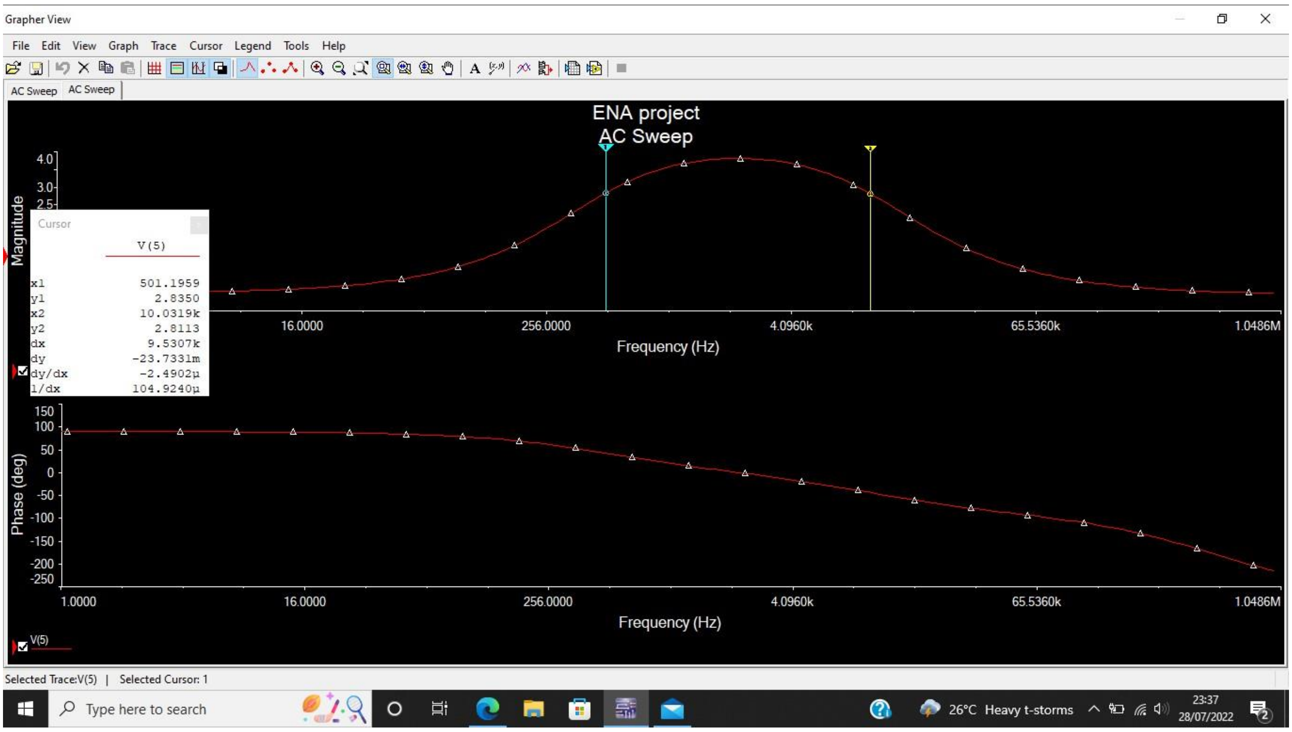
MultiSim Circuit Simulation Diagram and Graph

- **<u>Actual Circuit:</u>**

- **Circuit Diagram:**

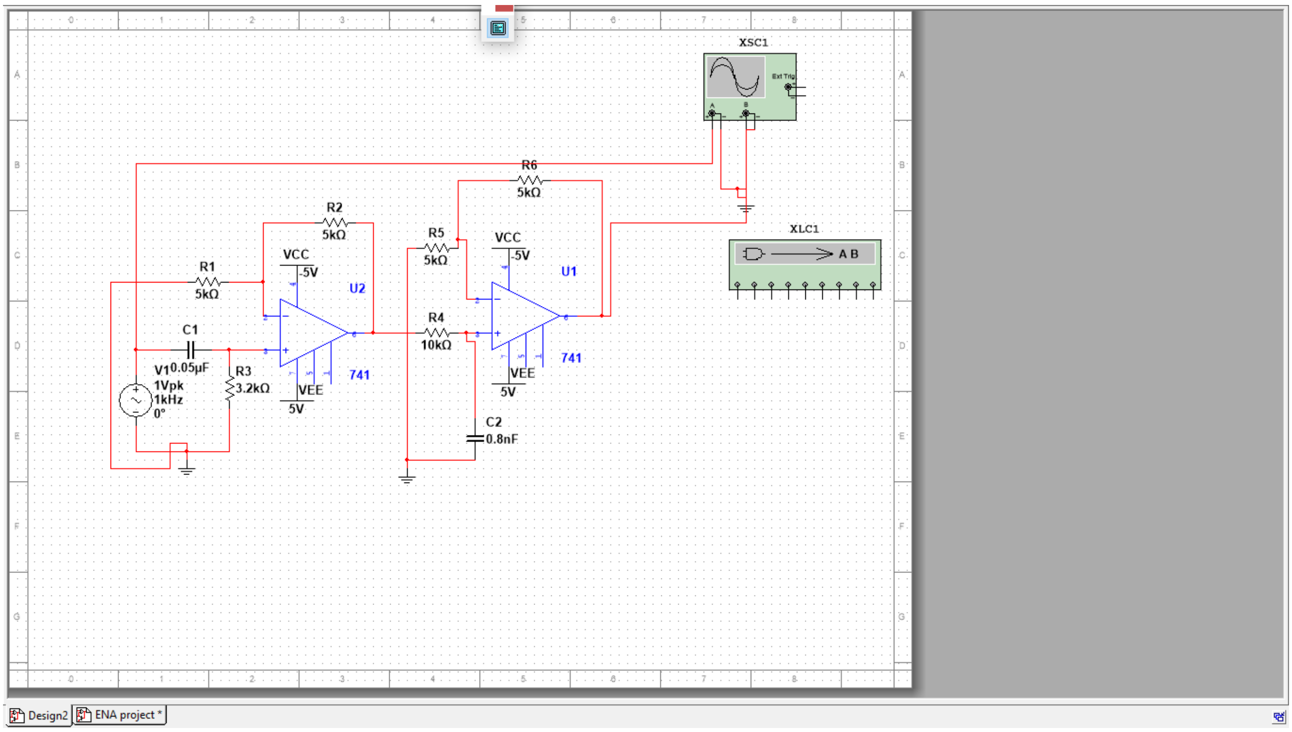


- **Graph:**

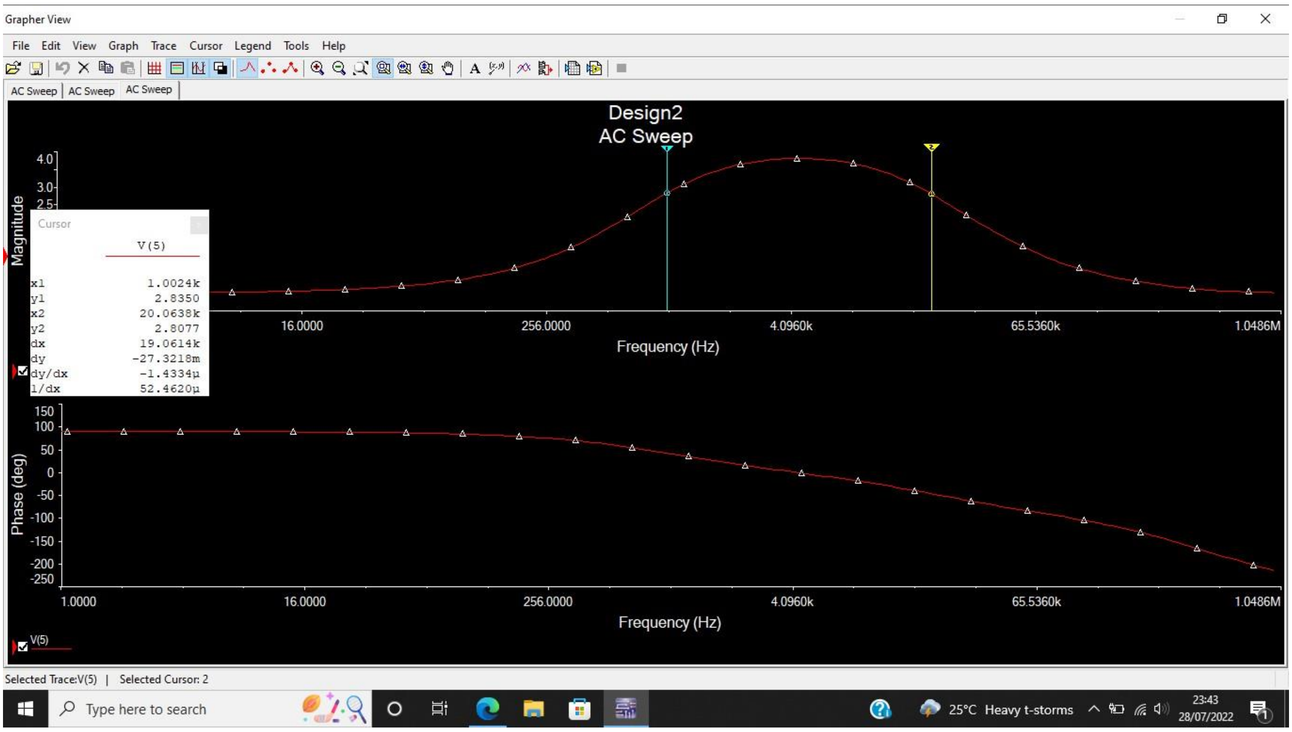


- **Frequency-Scaled Circuit:**

- **Circuit Diagram:**



- **Graph:**



Formula for Frequency Scaling:

Frequency Scaling

"Frequency scaling is the process of shifting the frequency response of a network up or down the frequency axis while leaving the impedance the same"

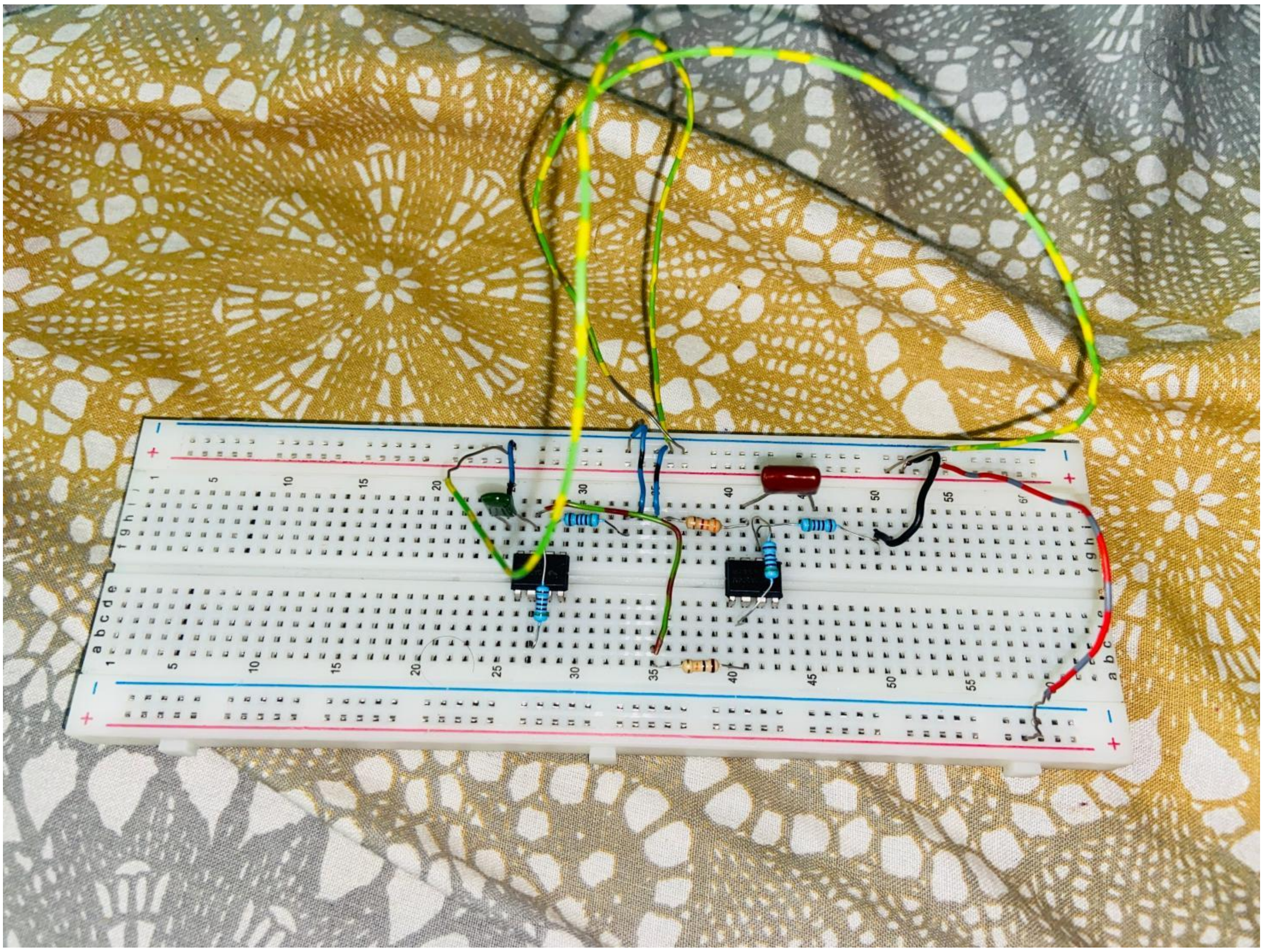
- We achieve frequency scaling by multiplying the frequency by a factor K_f while keeping the impedance the same. The scaling factor for basic circuit elements is as under:

- For Resistors: $$R_1 = R \times \frac{\text{Normalized frequency}}{\text{Desired frequency}}$$

- For Capacitors: $$\mathbf{Z}_C = \frac{1}{j(\omega K_f)C'} = \frac{1}{j\omega C} \quad \Rightarrow \quad C' = \frac{C}{K_f}$$

- For Inductors: $$\mathbf{Z}_L = j(\omega K_f)L' = j\omega L \quad \Rightarrow \quad L' = \frac{L}{K_f}$$

Circuit Hardware



Practical Value of Lower Cut-Off= 2.85

Practical Value of Gain at Maximum Value= 3.83

Practical Value of Higher Cut-Off= 2.885

Percentage Error in Circuit

- **<u>Percentage Errors of Lower and Higher Cut-Off and Gain:</u>**

Theoretical Value of Lower and Higher Cut-Off= 2.83

Practical Value of Lower Cut-Off= 2.85

% Error of Lower Cut-Off= $\frac{2.85 - 2.83}{2.83}$ x 100= 0.707%

Practical Value of Higher Cut-Off= 2.885

% Error of Higher Cut-Off= $\frac{2.885 - 2.83}{2.83}$ x 100= 1.943%

Theoretical Value of Gain= 3.73

Practical Value of Gain= 3.83

% Error of Gain= $\frac{3.83 - 3.73}{3.73}$ x 100= 2.68%

- **Percentage Error in Circuit Elements:**

- **Capacitors:**

Theoretical Value of C_1= 0.1 µF

Practical Value of C_1= 0.106 µF

% Error in Value of C_1= $\frac{0.106 - 0.1}{0.1}$ x100= 6%

Theoretical Value of C_2= 1.6 nF

Practical Value of C_2= 1.66 nF

% Error of Value of C_2= $\frac{1.66 - 1.6}{1.6}$ x 100= 3.75%

- **Resistors:**

Theoretical Value of R_1= 3.3.05 kΩ

Practical Value of R_1= 3.2 kΩ

% Error of R_1= $\dfrac{3.3.05 - 3.2}{3.2}$ x 100= 3.28125%

Theoretical Value of R_2= 10 kΩ

Practical Value of R_2= 10 kΩ

% Error in Value of R_2= $\dfrac{10 - 10}{10}$ x 100= 0%

Modification in Transfer Function due to Practical Values

$$\frac{4}{\left(1+j2\pi f \times 1.66\times10^{-9} \times 10\times10^{3}\right)\left(1+\dfrac{1}{j2\pi f \times 0.106\times10^{-6} \times 3.303\times10^{3}}\right)}$$

$$= \frac{4}{\left(1+j1.04\times10^{-4} f\right)\left(1-\dfrac{j454.3}{f}\right)}$$

$$= \frac{4f}{\left(1+j1.04\times10^{-4} f\right)\left(f-j454.3\right)}$$

$$= \frac{4f}{f - j454.3 + j1.04\times10^{-4}f^2 + 4.724\times10^{-2}f}$$

$$= \frac{4f}{j1.04\times10^{-4}f^2 + 1.04724f - j454.3}$$

At 500 Hz,

$$= \frac{4(500)}{j1.04\times10^{-4}(500)^2 + 1.04724(500) - j454.3}$$

$$= 2.29 + j1.87 = 2.957 \angle 39.23°$$

At 2.236 kHz,

$$\frac{4(2.236\times10^3)}{j1.04\times10^{-4}(2.236\times10^3)^2 + 1.04724(2.236\times10^3) - j454.3}$$

$$= 3.817 - j0.107$$

$$= 3.82 \angle 1.606°$$

At 10 kHz,

$$= \frac{4(10\times10^3)}{j1.04\times10^{-4}(10\times10^3)^2 + 1.04724(10\times10^3) - j454.3}$$

$$= 2 - j.9 = 2.759 \angle -43.53°$$

% Error at Lower Cut-Off= $\frac{2.85-2.957}{2.957}$ x 100= -3.619% = 3.619%

% Error at Higher Cut-Off= $\frac{2.885-2.759}{2.759}$ x 100= 4.567%

% Error of Maximum Gain= $\frac{3.83-3.82}{3.82}$ x 100= 0.261%

Conclusion

This circuit is a band pass circuit. AC input from source enters the high pass RC filter and is amplified by the Op-Amp. This amplified value is then furthered filter by a low pass filter and then amplified a second time to give us our required gain. The range of the band pass filter was maintained by using the formula of **f=** $\frac{1}{2\pi RC}$**.** We will assume the value of either the resistor or capacitor and find the value of the other unknown component. Our circuit is working correctly as the percentage error between the practical and theoretical values is minute. The common ground established for the circuit is correct. All the components are of correct value and the arrangement is correct. The only error, although minute, is that the values that we have for the resistors and the capacitors are slightly different than their theoretical values which causes a slight deviation in the answers.