CMPE 460 Laboratory Exercise 7

OPAMP Circuits and Filter Design

Gloria Mbaka
Performed: 03/27/24
Submitted: 04/05/24

Lab Section: L1

Instructor: Prof. Ketout

TA: Jack Sipley
Andrew
Tevebaugh Colin
Vo

Lecture Section: 01
Professor: Prof. Ketout

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Your Signature: ______________________________

1. Lab Description

In this Lab exercise, the operational parameters and performance of different operational amplifier (Op-Amp) configurations were explored. Using both DC and sinusoidal input signals, the inverting and non-inverting amplifier behaviors, as well as Op-Amp utility as an adder were examined. Moreover, the lab covered the design and characterization of active filters, specifically Low-Pass (LPF), High-Pass (HPF), and Bandpass filters. These components were tested for their frequency response and phase angle at a spectrum of frequencies, providing practical insights into their application in signal processing and conditioning. The objective was to characterize these filters based on their frequency response and phase angles across multiple frequencies. The comparison of calculated theoretical values with actual measured data was integral to the lab, providing a practical understanding of Op-Amp applications and filter designs.

2. Op Amp as DC Inverting Amplifier

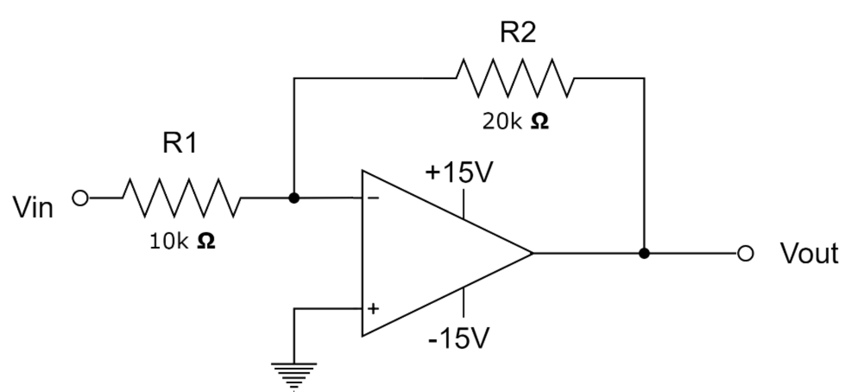


Figure 1: Schematic Diagram of Op amp as DC Inverting amplifier

2.1 Steps and values for the calculated components

$A_V = -\frac{R_2}{R_1}$

Given that $R_2 = 2R_1$,

$A_V = -2$

Selecting,

$R_2 = 20k\Omega$

$R_1 = 10k\Omega$

$\frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}$

$V_{out} = A_V \times V_{in} = -2V_{in}$

2.2 The record of Vout calculated and measured are shown in Table-1.

Table-1: Inverting amplifier(DC input signal)		
Vin (V)	Calculated Vout (V)	Measured Vout (V)
0.1	-0.2	-0.2
1.5	-3	-3.04
2	-4	-4.055
2.5	-4	-4.055
2.5	-5	-5.068
3	-6	-5.068
4	-8	-8.1
5	-10	-10.12

3. Op Amp as Dc Non- Inverting Amplifier

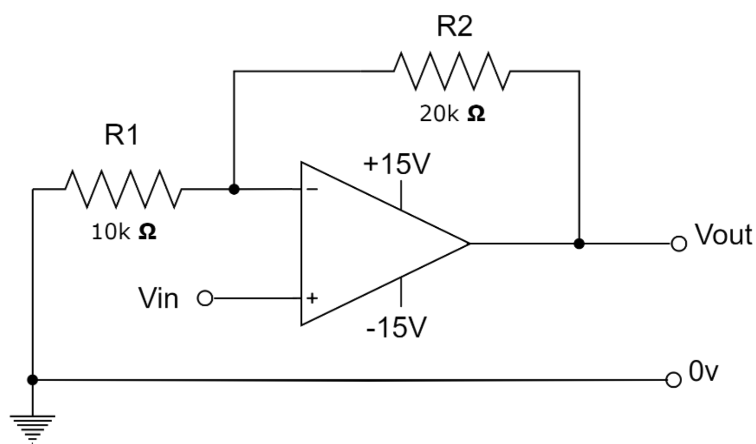


Figure 2: Schematic Diagram of Op amp as DC Non- Inverting amplifier

3.1 Steps and values for the calculated components

$$A_V = 1 + \frac{R_2}{R_1}$$

Selecting,

$R_2 = 20k\Omega$

$R_1 = 10k\Omega$

$$A_V = 1 + \frac{20k\Omega}{10k\Omega} = 3$$

$$V_{out} = A_V \times V_{in} = 3V_{in}$$

3.2 The record of Vout calculated and measured are shown in Table-2.

Table-2: Non-Inverting amplifier (DC input signal)		
Vin (V)	Calculated Vout (V)	Measured Vout (V)
0.1	0.3	0.308
1.5	4.5	4.472
2	6	5.96
2.5	7.5	7.45
3	9	8.93
4	12	11.91
5	15	14.21

4. Op amp as AC Inverting amplifier:

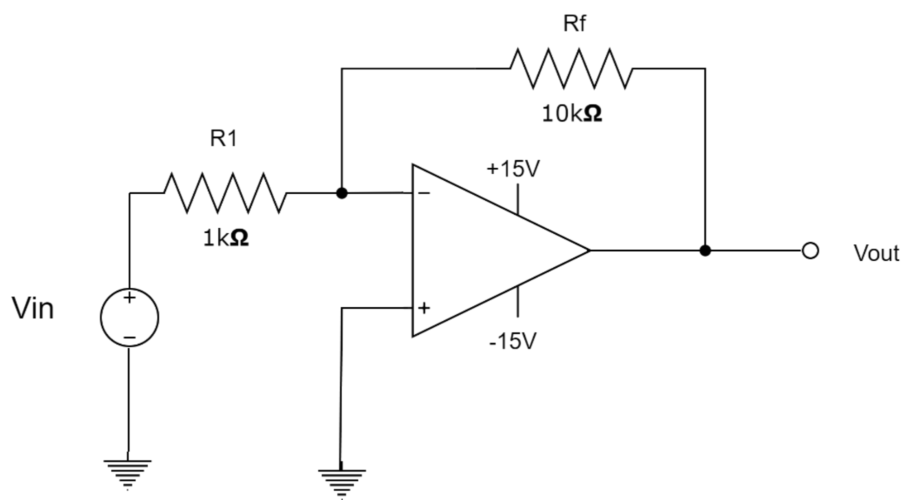


Figure 3: Schematic Diagram of Op amp as AC Inverting amplifier

4.1 Steps and values for the calculated components

Given $R_1 = 1k\Omega$ and $R_f = 10k\Omega$

$A_V = -\frac{R_f}{R_1}$

$A_V = -10$

$V_{out} = A_V \times V_{in} = -10V_{in}$

4.2 Answers to Questions:

a. At low frequencies (10 Hz, 100 Hz), the output maintains a consistent gain and inversion relative to the input. At higher frequencies (10 kHz), some reduction in gain was observed as shown in figure 4 but the phase remains consistent.

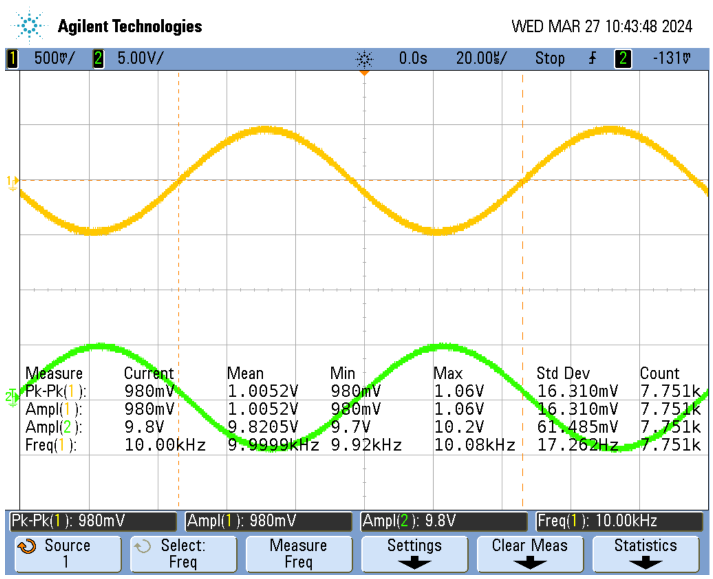


Figure 4: Screenshoot of Output of AC Inverting Amplifier at 10kHz

b. At very high frequencies (100 kHz), the gain decrease and a significant phase shift occur due to the op-amp's bandwidth limitations.

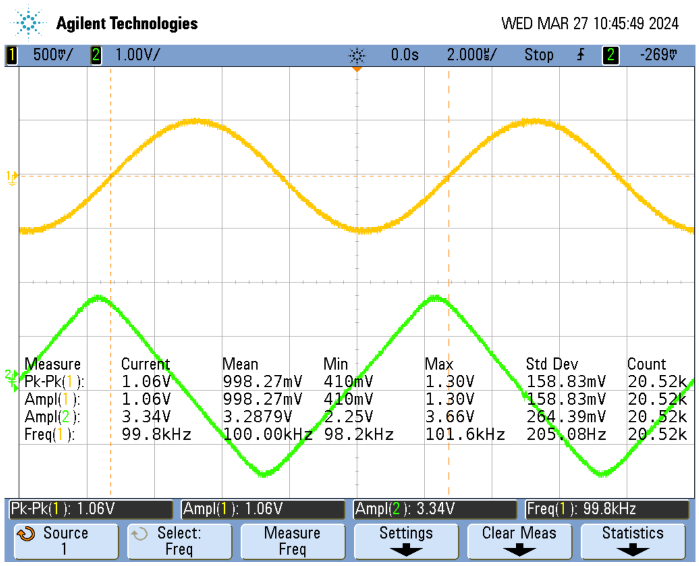


Figure 5: Screenshoot of Output of AC Inverting Amplifier at 100kHz

4.3 The record of Vout calculated and measured are shown in Table-3.

Table-3: Inverting amplifier (Sinusoidal inputs)		
Vin (V)	Calculated Vout (V)	Measured Vout (V)
0.1 Vpp	1	1.1
0.2 Vpp	2	1.9
0.3 Vpp	3	2.8
0.5 Vpp	5	4.8
1.0 Vpp	10	10

5. Op Amp As AC Non-Inverting Amplifier

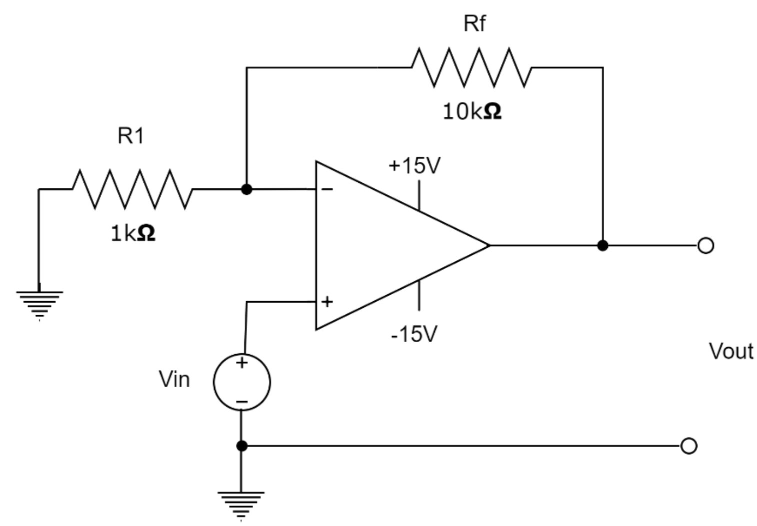


Figure 6: Schematic Diagram of Op amp as AC NON-Inverting amplifier

5.1 Steps and values for the calculated components

Given $R_1 = 1k\Omega$ and $R_f = 10k\Omega$

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

$A_V = 11$

$V_{out} = A_V \times V_{in} = 11V_{in}$

5.2 The record of Vout calculated and measured are shown in Table-4.

Table-4: Non-Inverting amplifier (Sinusoidal inputs)

Vin (V)	Calculated Vout (V)	Measured Vout (V)
0.1 Vpp	1.1	1.1
0.2 Vpp	2.2	2.3
0.3 Vpp	3.3	3.4
0.5 Vpp	5.5	5.6
1.0 Vpp	11	11.1

6. Op Amp Applications as Adder or Summing Amplifier

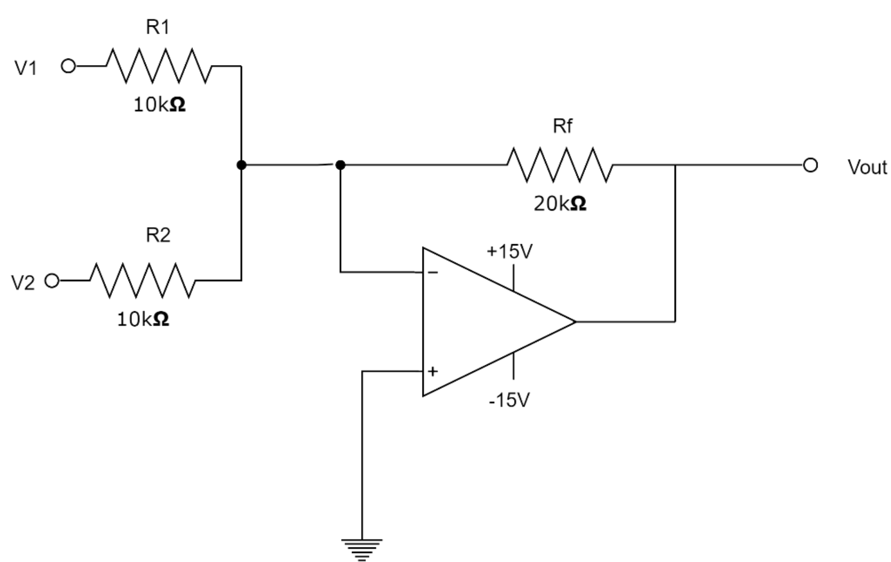


Figure 7: Schematic Diagram of Op Amp as Adder or Summing Amplifier

6.1 Steps and values for the calculated components

Selecting $R_1 = R_2 = R = 10k\Omega$ and $R_f = 20k\Omega$

$A_V = -\frac{R_f}{R}$

$A_V = -2$

$V_{out} = A_V V_1 + A_V V_1 = -2V_1 - 2V_2$

6.2 Select different values for V_1 & V_2, the record of Vout calculated and measured are shown in Table-5.

Table-5: Op amp as an ADDER

V1	V2	Calculated Vout (V)	Measured Vout (V)
0.1	0.5	-1.2	-1.2
1.5	1	-5	-4.99
2	1.5	-7	-6.98
2.5	2	-9	-8.97
3	2.5	-11	-11.17
4	3	-14	-13.55
5	4	-18	-13.55

7. Second Order Sallen-Key Butterworth Low Pass Filter

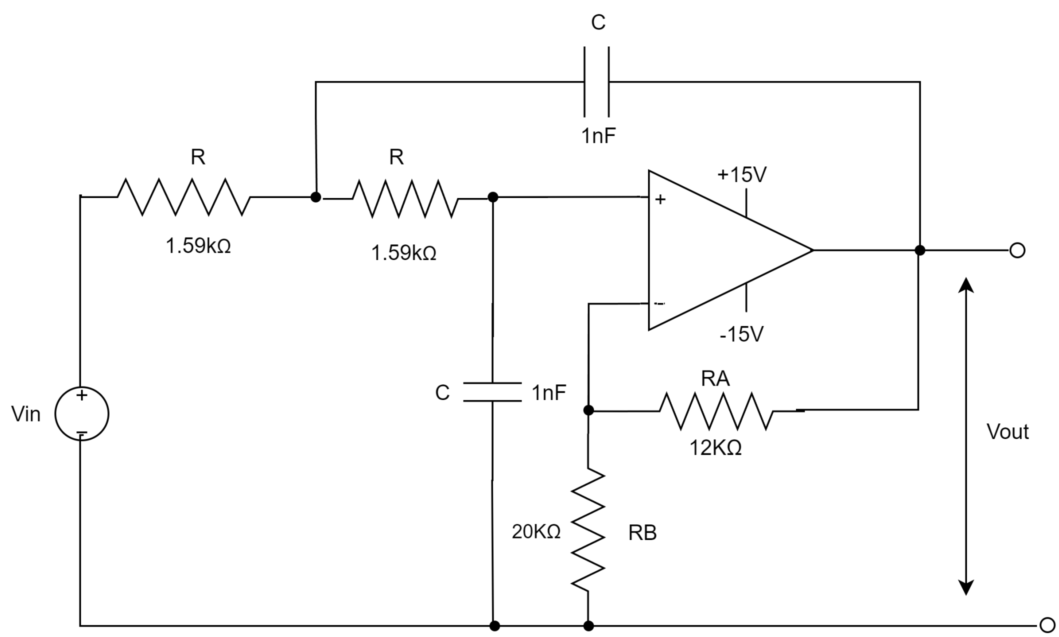


Figure 8: Schematic Diagram of Second Order Sallen-Key Butterworth Low Pass Filter

7.1 Steps and values for the calculated components

Given $R_1 = R_2 = R, C_1 = C_2 = C, R_B = 20k\Omega,\ f_c = 100\text{k}Hz,$
$A_V = 1 + \frac{R_A}{R_B}$

Since it is a Butterworth,
$Q = 0.707$

$Q = \frac{1}{3 - A_V}$

$A_V = 3 - \frac{1}{Q} = 3 - \frac{1}{0.707} = 1.586$

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

Substituting $R_B = 20k\Omega$

$1.586 = 1 + \frac{R_A}{20k\Omega}$

$$R_A = 11720 \approx 12k\Omega$$

Finding the value of the RC,

Selecting $C = 1nF$

$f_c = \frac{1}{2\pi RC}$

$R = \frac{1}{2\pi f_c C} = \frac{1}{2\pi \times 100kHz \times 1nF} = 1.59k\Omega$

Phase Shift was calculated for the given frequencies using the formula,

$$\varphi(\omega) = -\arctan\left(\left(\frac{1}{\alpha}\right) * \left(\left(\frac{2\omega}{\omega^0}\right) + \sqrt{4 - \alpha^2}\right)\right) - \arctan\left(\left(\frac{1}{\alpha}\right) * \left(\left(\frac{2\omega}{\omega^0}\right) - \sqrt{4 - \alpha^2}\right)\right)$$

Where:

Q = 0.707

$\alpha = 1/Q = 1/0.707 = 1.414$

$\omega = 2\pi f$ (current frequency in radians per second)

$\omega_0 = 2\pi fc$ (cut-off frequency in radians per second) = 628400 rad/s

7.2 The record of calculated Gain from measured values of Vo and Vi and calculated phase shift are shown in Table-6.

Table-6: Active LPF table

Freq	Gain (Vo/Vi)	Gain (dB)	Phase Angle
100 Hz	1.9	5.58	-1
500 Hz	1.9	5.58	-0.41
5 kHz	1.82	5.2	-4.05
10 kHz	1.78	5	-13.665
50kHz	1.6	4.08	-43.63
100kHz	0.84	-1.51	-89.99
200kHz	0.46	-6.74	-136.67
300kHz	0.34	-9.37	-152.04
500kHz	0.26	-11.7	-163.58

7.3 The frequency response (semi-log scale) and phase diagrams are as shown in figure 9.

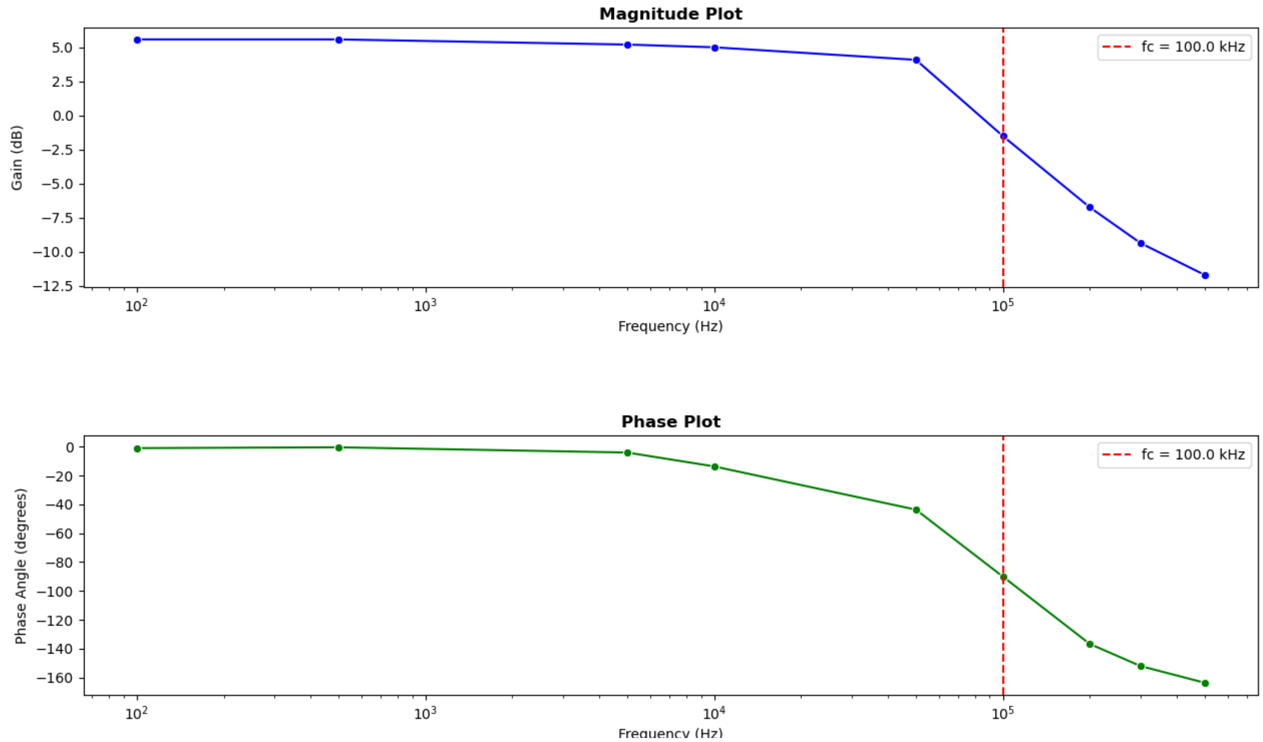


Figure 9: The frequency response (semi-log scale) and phase diagrams of Low Pass Filter

8. Second Order Sallen-Key Butterworth High Pass Filter

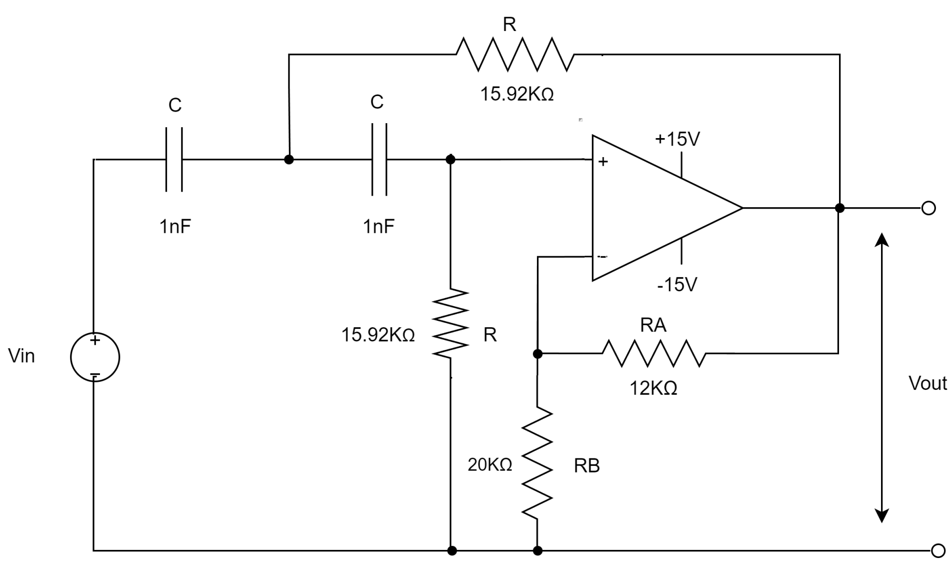


Figure 10: Schematic Diagram of Second Order Sallen-Key Butterworth High Pass Filter

8.1 Steps and values for the calculated components

Given $R_1 = R_2 = R, C_1 = C_2 = C, R_B = 20k\Omega,\ f_c = 10\text{k}Hz,$

$A_V = 1 + \frac{R_A}{R_B}$

Since it is a Butterworth,

$Q = 0.707$

$Q = \frac{1}{3 - A_V}$

$A_V = 3 - \frac{1}{Q} = 3 - \frac{1}{0.707} = 1.586$

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

Substituting $R_B = 20k\Omega$

$1.586 = 1 + \frac{R_A}{20k\Omega}$

$R_A = 11720 \approx 12k\Omega$

Finding the value of the RC,

Selecting $C = 1nF$

$f_c = \frac{1}{2\pi RC}$

$R = \frac{1}{2\pi f_c C} = \frac{1}{2\pi \times 10\text{kHz} \times 1\text{nF}} = 15.92k\Omega$

Phase Shift was calculated for the given frequencies using the formula,

$$\varphi(\omega) = \pi - \arctan\left(\left(\frac{1}{\alpha}\right) * \left(\left(\frac{2\omega}{\omega^0}\right) + \sqrt{4 - \alpha^2}\right)\right)$$
$$- \arctan\left(\left(\frac{1}{\alpha}\right) * \left(\left(\frac{2\omega}{\omega^0}\right) - \sqrt{4 - \alpha^2}\right)\right)$$

Where:

Q = 0.707

$\alpha = 1/Q = 1/0.707 = 1.414$

$\omega = 2\pi f$ (current frequency in radians per second)

$\omega_0 = 2\pi f_c$ (cut-off frequency in radians per second) = 62840 rad/s

8.2 The record of calculated Gain from measured values of Vo and Vi and calculated phase shift are shown in Table-7.

Table-7: Active HPF table

Freq	Gain (Vo/Vi)	Gain (db)	Phase Angle
100 Hz	0.13	-17.72	1.75
500 Hz	0.172	-15.28	-0.918
1kHz	0.334	-9.54	-0.813
5 kHz	1.5	3.52	-40.488
10 kHz	1.5	3.52	-86.848
50kHz	1.18	1.44	-160.433
100kHz	0.84	-1.51	-168.726
200kHz	0.5	-6.02	-172.7978
300kHz	0.34	-9.37	-174.154
500kHz	0.28	-11.06	-175.236

8.3 The frequency response (semi-log scale) and phase diagrams are as shown in figure 11.

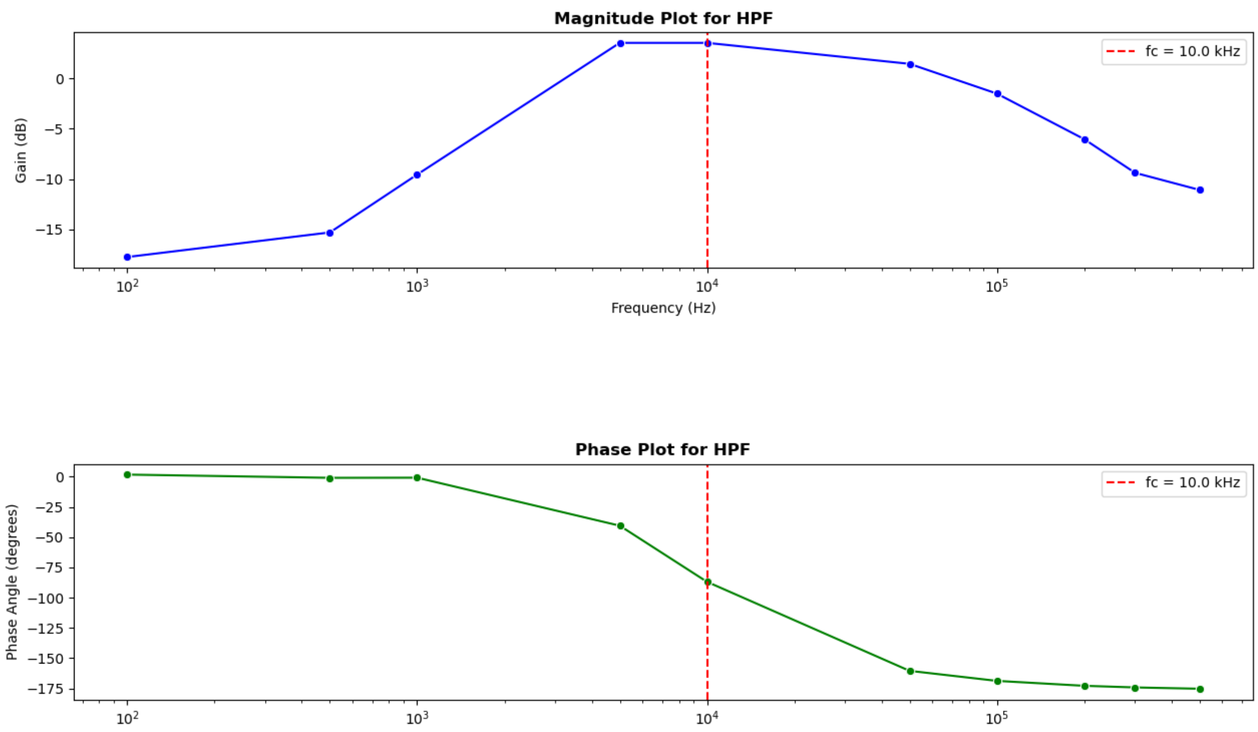


Figure 11: The frequency response (semi-log scale) and phase diagrams of High Pass Filter

9. Band Pass Infinite Gain (MFB) Multiple Feedback Active Filter

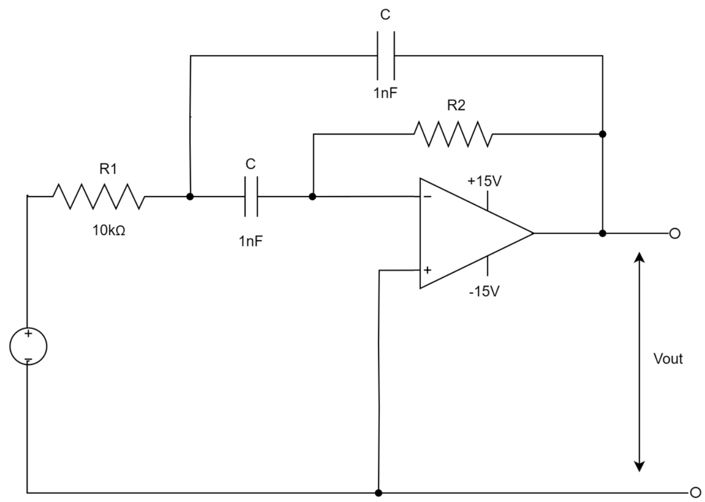


Figure 12: Schematic Diagram of Band Pass Infinite Gain (MFB) Multiple Feedback Active Filter

9.1 Steps and values for the calculated components

Given, $A_V = -1$, $f_r = 10kHz$

$$A_V = -\frac{R_2}{R_1} = -2Q^2$$

$$1 = -\frac{R_2}{R_1} = -2Q^2$$

$$Q = 0.7071 = \frac{1}{2}\sqrt{\frac{R_2}{R_1}}$$

$$R_2 = 2R_1$$

$$f_r = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}$$

Letting $C_1 = C_2$ and selecting $R_1 = 10k\Omega$ and $R_2 = 20k\Omega$

$C = 1\text{nF}$

Phase Shift was calculated for the given frequencies using the formula,

$$\varphi(\omega) = \frac{\pi}{2} - \arctan\left(\frac{2Q\omega}{\omega^0} + \sqrt{4Q^2 - 1}\right) - \arctan\left(\frac{2Q\omega}{\omega^0} + \sqrt{4Q^2 - 1}\right)$$

Where:

Q = 0.707

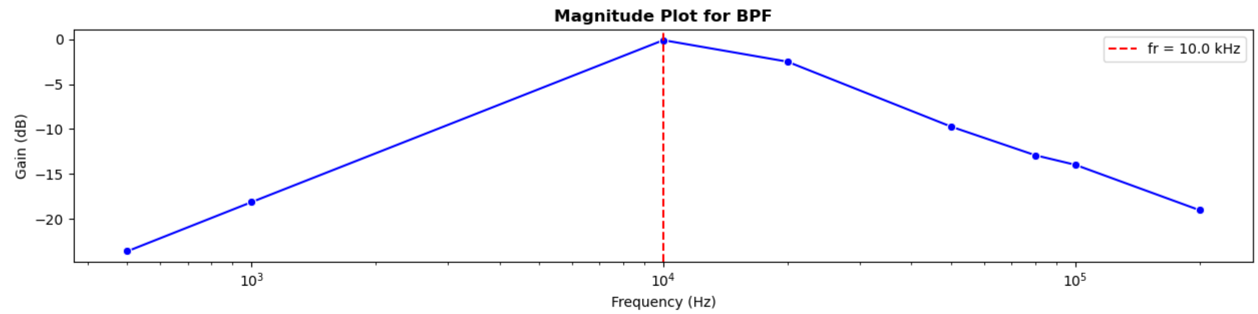
ω = 2πf (current frequency in radians per second)

ω_0 = 2πfc (cut-off frequency in radians per second) = 62840 rad/s

9.2 The record of calculated Gain from measured values of Vo and Vi and calculated phase shift are shown in Table-8.

Table-8: Active Band table			
Freq	Gain (Vo/Vi)	Gain (db)	Phase Angle
500 Hz	0.066	-23.6	-2.484
1kHz	0.1238	-18.14	-6.551
10 kHz	0.988	-0.105	-88.428
20 kHz	0.75	-2.498	-135.089
50kHz	0.326	-9.74	-162.015
80kHz	0.226	-12.92	-168.249
100kHz	0.2	-13.98	-170.297
200kHz	0.112	-19.02	-174.373

9.3 The frequency response (semi-log scale) and phase diagrams are as shown in figure 13.



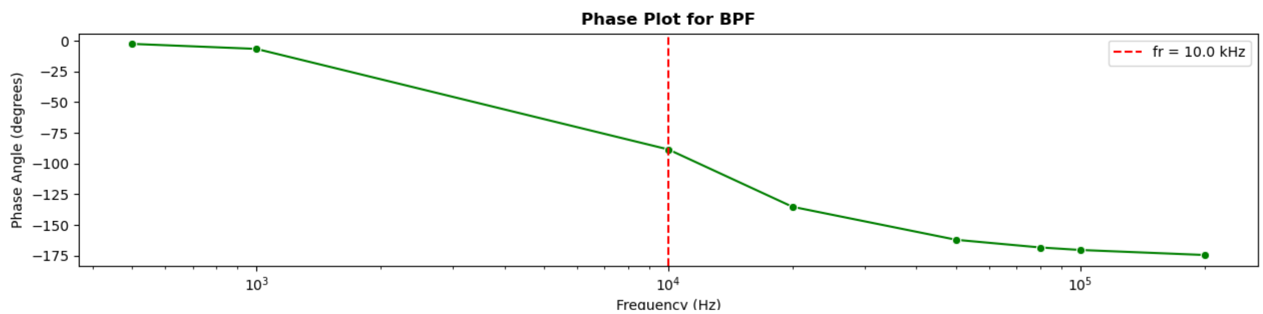


Figure 13: The frequency response (semi-log scale) and phase diagrams of Band Pass Filter

Exercise 7: Op amp and Filter Design

Student's Name: Glori Mbaka Section: 1

Demo		Point Value	Points Earned	Date
Demo	Inverting op amp (DC & AC)	10	10	Mar 27
	Non-Inverting op amp (DC & AC)	10	10	Mar 27
	Summing Amplifier	10	10	Mar 27
	second order Butterworth low pass filter	10	10	AJT 4/3
	second order Butterworth high pass filter	10	10	AJT 4/3
	Band pass Infinite Gain (MFB) Filter	10	10	4/3

Report	Point Value	Points Earned	Comments
Exercise Description	5		
Circuit Schematics/Wiring diagrams	10		
Calculated and measured values	5		
Magnitude and phase plot with f_c identified	10		