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Experiment 1: Basic Filter Design

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1 Introduction

We can design a low pass filter, a high pass filter, a band pass filter using passive components, namely, a resistor and a capacitor. However since these are passive component, the signals filtered will be attenuated and won't be amplified. We calculate the threshold when the power in the signal has attenuated by half or about 3dB.

We can design an active first order filter which amplifies the signal using an op-amp.

In the third task, we will add two signals using an op-amp.

2 Objectives

Note: $G=12 \Rightarrow (G-1) \bmod 4 = 3$

2.1 Task 1

Design a 1st order passive filter with following corner frequencies:

1. Low pass filter with cut-off frequency of $f_H = 4(G-1) \bmod 4 + 12 = 24\text{KHz}$
2. High pass filter with cut-off frequency of $f_L = 4(G-1) \bmod 4 + 4 = 16\text{KHz}$
3. Band pass filter with cut-off frequencies of $f_L = 16\text{KHz}$ and $f_H = 24\text{KHz}$
4. Find out the 3dB frequency from both time and frequency domain representation of signal on Digital Signal Oscilloscope
5. Find out the amplitude of signal at $\frac{f_L}{2}, 2f_H$

2.2 Task 2

Implement a 1st order active low-pass filter using an op-amp with the above specifications and gain of 2. Observe the output on the DSO.

2.3 Task 3

Take two voltage signals $x_1(t)$ and $x_2(t)$ and add them using Op- Amp with following formula:

$$y(t) = (-1)^G \{x_1(t) + ((G-1) \bmod 4)x_2(t)\} = x_1(t) + 3x_2(t)$$

3 Instruments and Materials required

- RIGOL Signal Generator
- ScientiFIC SMO10C Digital Signal Oscilloscope
- +12V, -12V DC source and ground
- Resistors
- Capacitors
- Breadboard
- Connecting wires

4 Theory

A low-pass filter lets a signal below a certain frequency f_H pass. For a first order passive filter, we define f_H to be the point at which the power of the signal gets attenuated by 3dB from the maximum power.

In a passive filter with a resistor R and capacitor C, the f_H is:

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

A high-pass filter lets a signal above a certain frequency f_L pass. For a first order passive filter, we define f_L to be the point at which the power of the signal gets attenuated by 3dB from the maximum power.

In a passive filter with a resistor R and capacitor C, the f_H is:

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

For an active low pass filter using an op-amp, the gain is:

$$Gain = \left(1 + \frac{R_f}{R_2}\right)$$

and the f_H is:

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

5 Calculations and Circuit Design

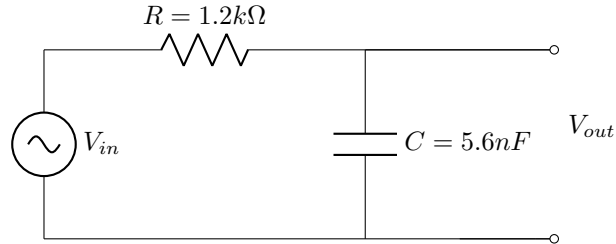
5.1 Task 1

5.1.1 Task 1.1

The closest we could get to $f_H = 24kHz$ was using $R = 1.2k\Omega$ and $C = 5.6nF$ to get $f_H = 23.683kHz$

The circuit is shown below

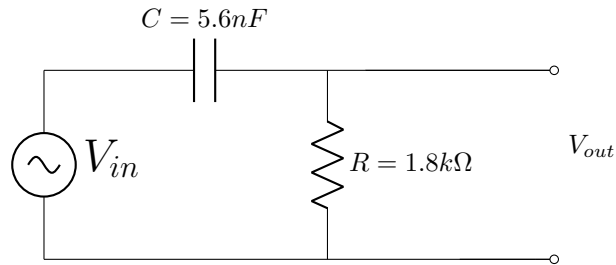
Figure 1: Required diagram for Task 1.1



5.1.2 Task 1.2

The closest we could get to $f_L = 16kHz$ was using $R = 1.8k\Omega$ and $C = 5.6nF$ to get $f_H = 15.789kHz$

Figure 2: Required diagram for Task 1.2



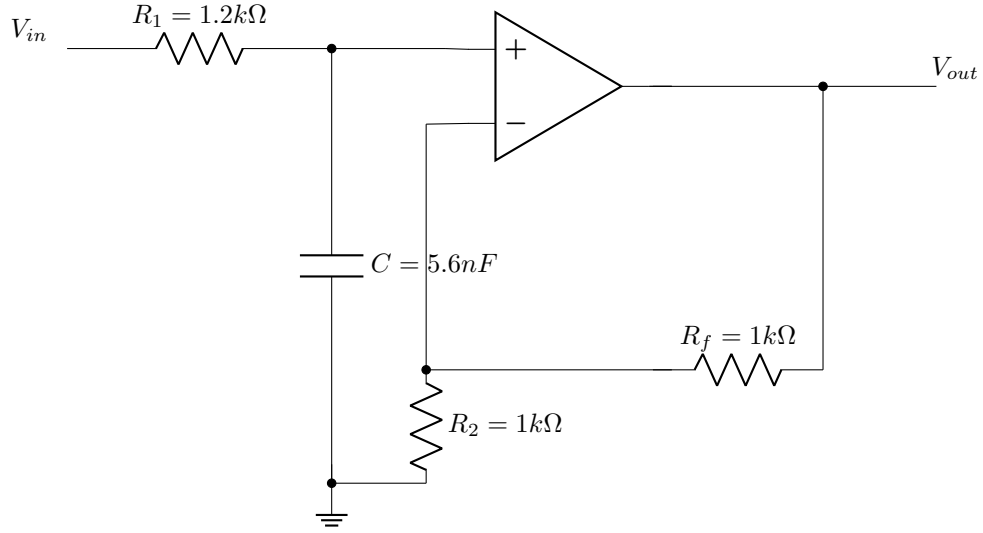
5.2 Task 2

Since the gain required is 2:

$$\Rightarrow 1 + \frac{R_f}{R_2} = 2 \Rightarrow R_f = R_2$$

We use the same LPF as before ($f_H = 24kHz$), and $R_f = R_2 = 1k\Omega$ in the circuit.

Figure 3: Required diagram for Task 2



5.3 Task 3

Seeing the R_f, R_3 configuration as a voltage divider, we equalise the voltage in the inverting and non-inverting input at $V_i = \frac{V_{out}R_3}{R_3 + R_f}$.

Also, since the input resistance is infinite, there is no current in the input.

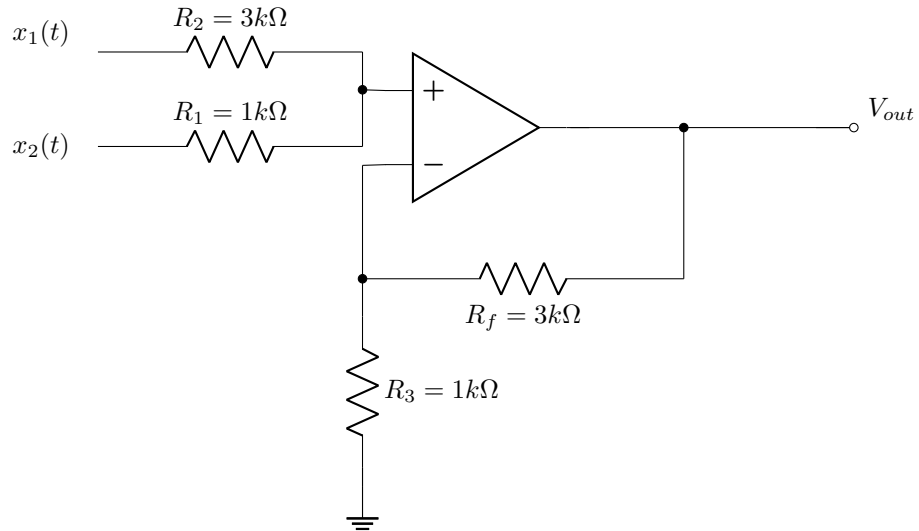
$$\Rightarrow \frac{x_1 - V_i}{R_2} + \frac{x_2 - V_i}{R_1} = 0$$

$$\Rightarrow R_1x_1 + R_2x_2 = (R_1 + R_2)V_i = \frac{(R_1 + R_2)R_3}{R_3 + R_f}V_{out}$$

But since it's required that $V_{out} = x_1 + 3x_2$, we can solve the system as:

$$R_1 = 1k\Omega; R_2 = 3k\Omega; R_3 = 1k\Omega; R_f = 3k\Omega$$

Figure 4: Required diagram for Task 3



6 Observation Tables and Figures

6.1 Task 1

6.1.1 Task 1.1

Figure 5: Frequency response graph for Low-pass filter

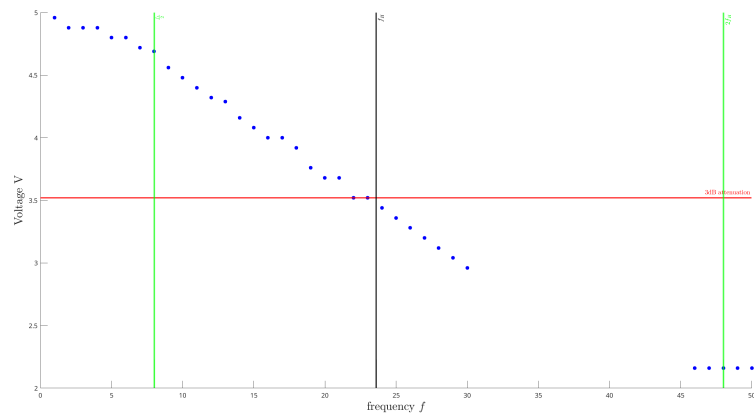


Table 1: Frequency response observation table for Low-pass filter

	Signal frequency (kHz)	Output Voltage(V)
	1	4.96
	2	4.88
	3	4.88
	4	4.88
	5	4.80
	6	4.80
	7	4.72
	8	4.69
	9	4.56
	10	4.48
	11	4.40
	12	4.32
	13	4.29
	14	4.16
	15	4.08
	16	4.00
c	17	4.00
	18	3.92
	19	3.76
	20	3.68
	21	3.68
	22	3.52
	23	3.52
	24	3.44
	25	3.36
	26	3.28
	27	3.20
	28	3.12
	29	3.04
	30	2.96
	46	2.16
	47	2.16
	48	2.16
	49	2.16
	50	2.16

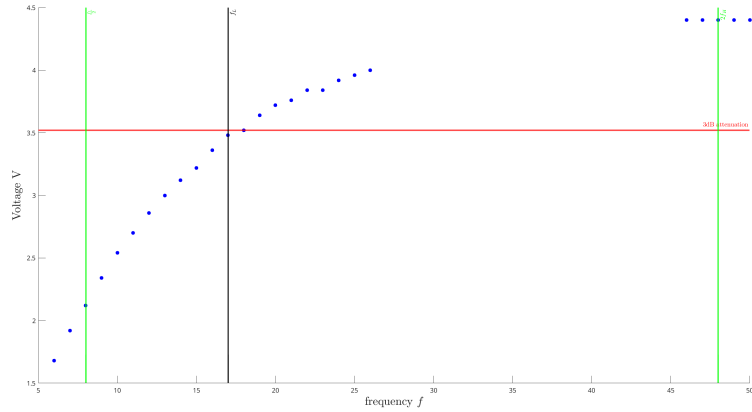
Results:

1. The 3dB frequency is 23KHz(The voltage decreases by $\sqrt{2}$, and the power by $2 \approx 3dB$)
2. The amplitude at $\frac{f_L}{2} = 8kHz$ is 4.56V

3. The amplitude at $2f_H = 48kHz$ is 2.16V

6.1.2 Task 1.2

Figure 6: Frequency response graph for High-pass filter



Results:

1. The 3dB frequency is 17KHz(The voltage decreases by $\sqrt{2}$, and the power by $2 \approx 3dB$)
2. The amplitude at $\frac{f_L}{2} = 8kHz$ is 2.12V
3. The amplitude at $2f_H = 48kHz$ is 4.40V

Table 2: Frequency response observation table for High-pass filter

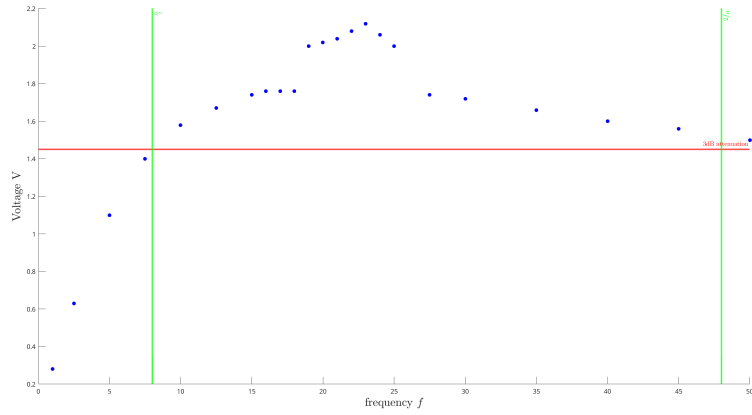
Signal frequency (kHz)	Output Voltage(V)
6	1.68
7	1.92
8	2.12
9	2.34
10	2.54
11	2.70
12	2.86
13	3.00
14	3.12
15	3.22
16	3.36
17	3.48
18	3.52
19	3.64
20	3.72
21	3.76
22	3.84
23	3.84
24	3.92
25	3.96
26	4.00
46	4.40
47	4.40
48	4.40
49	4.40
50	4.40

6.1.3 Task 1.3

Results:

1. The 3dB frequency is 8KHz at the lower end but we couldn't find the higher cutoff
2. The amplitude at $\frac{f_L}{2} = 8kHz$ is 3.52V
3. The amplitude at $2f_H = 48kHz$ is 3.6V

Figure 7: Frequency response graph for Band-pass filter



Signal frequency (kHz)	Output Voltage(V)
4	9.6
6	9.52
8	9.20
10	8.96
12	8.64
14	8.32
16	8.00
18	7.68
20	7.36
22	7.04
24	6.72
26	6.40
28	6.16
30	5.84
40	4.80
42	4.64
44	4.48
46	4.40
48	4.16
50	4.08

6.2 Task 2

Results:

1. The 3dB frequency is 22KHz

Figure 8: Frequency response graph for active low-pass filter

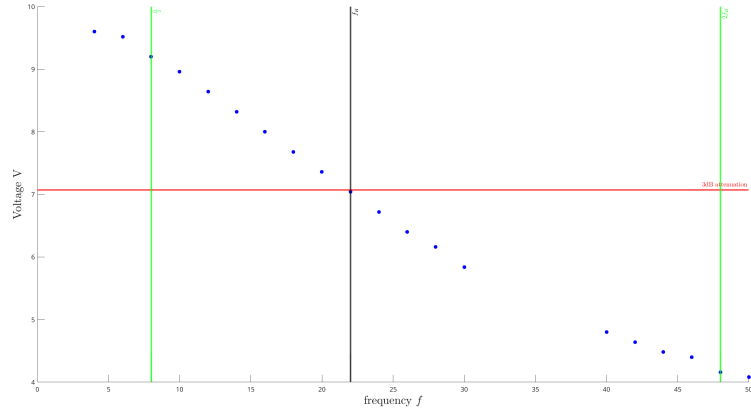


Table 3: Frequency response observation table for active low-pass filter with gain 2

Signal frequency (kHz)	Output Voltage(V)
4	9.6
6	9.52
8	9.20
10	8.96
12	8.64
14	8.32
16	8.00
18	7.68
20	7.36
22	7.04
24	6.72
26	6.40
28	6.16
30	5.84
40	4.80
42	4.64
44	4.48
46	4.40
48	4.16
50	4.08

2. The amplitude at $\frac{f_L}{2} = 8kHz$ is 9.20V

3. The amplitude at $2f_H = 48kHz$ is $4.16V$

6.3 Task 3

All signals of frequency 1 kHz, All voltages peak to peak

1. $x_1 = 1V$, $x_2 = 1V$, $V_{out} = 4V$
2. $x_1 = 1V$, $x_2 = 2V$, $V_{out} = 7V$
3. $x_1 = 1V$, $x_2 = 3V$, $V_{out} = 10V$
4. $x_1 = 2V$, $x_2 = 1V$, $V_{out} = 5V$
5. $x_1 = 3V$, $x_2 = 1V$, $V_{out} = 6V$
6. $x_1 = 4V$, $x_2 = 1V$, $V_{out} = 7V$

Figure 9: Case 1

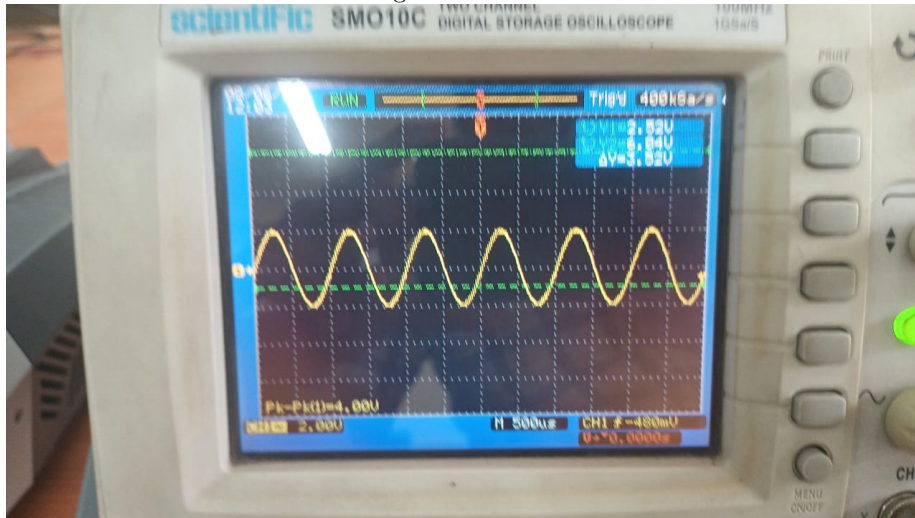


Figure 10: Case 2

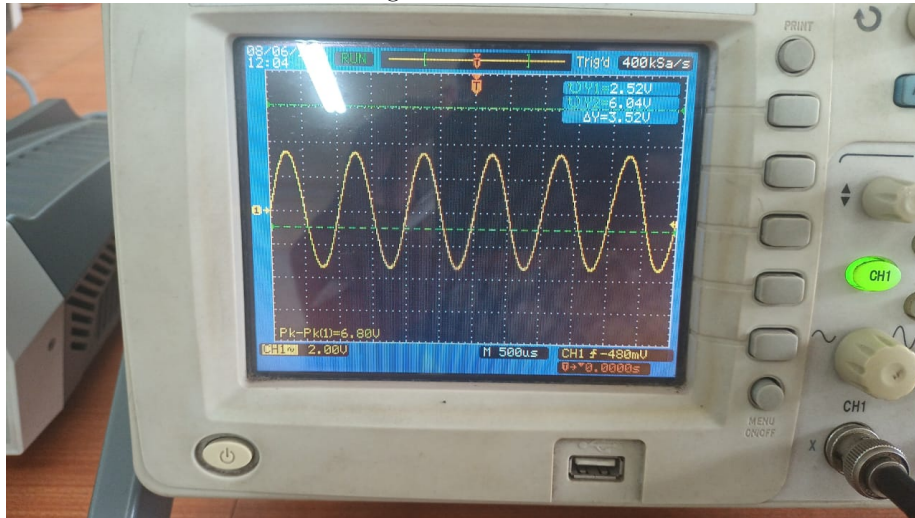


Figure 11: Case 3

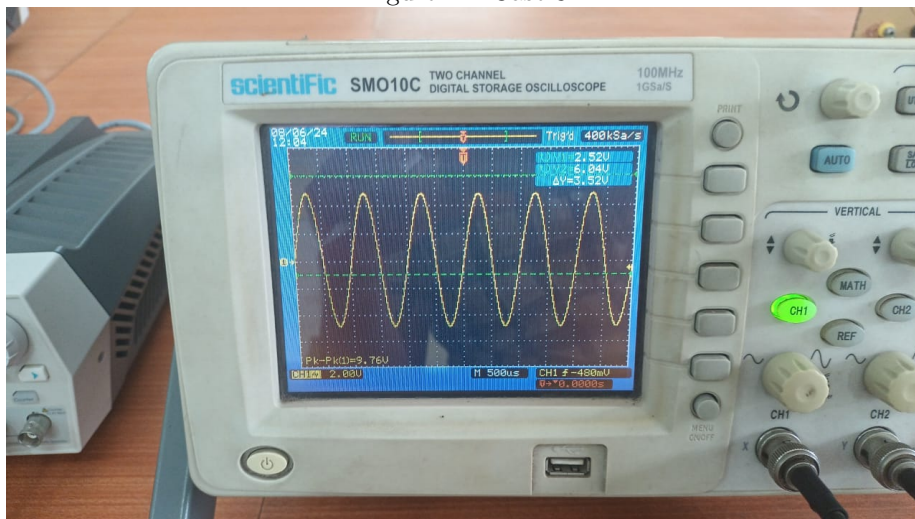


Figure 12: Case 4

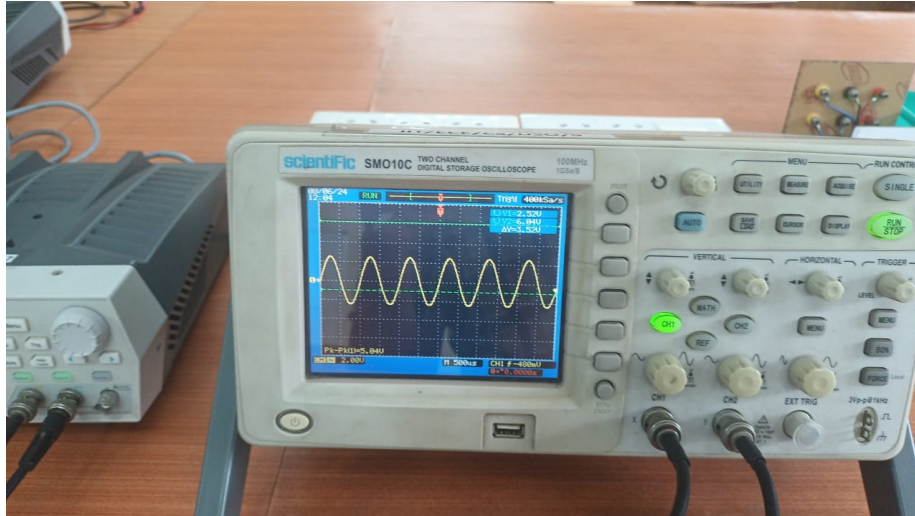


Figure 13: Case 5

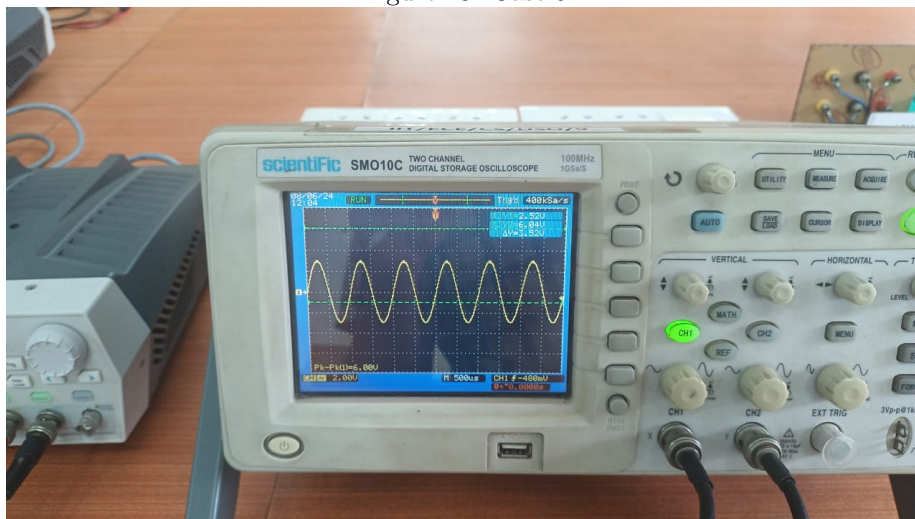
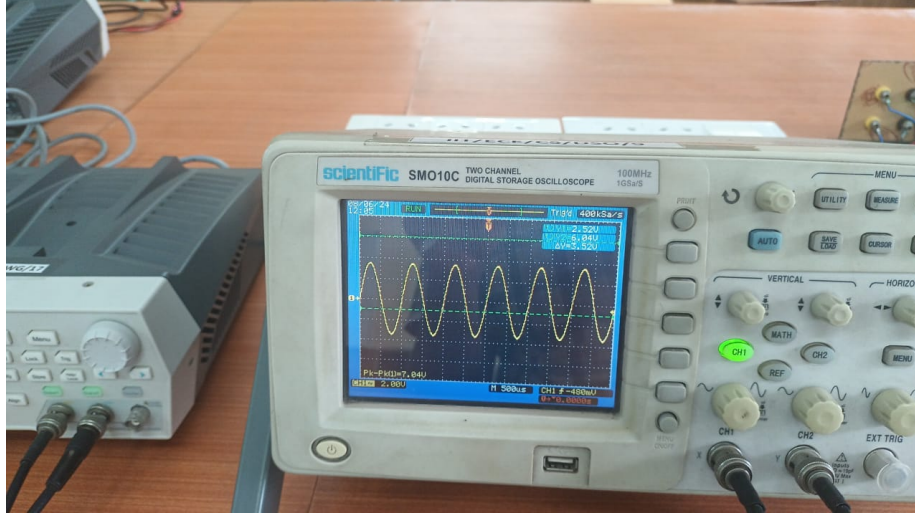


Figure 14: Case 6



7 Discussion

7.1 Samyak Sheersh, 22EC30045

1. We observed that the bandwidth of the band pass filter increased than the expected $f_H - f_L$. We believe this is because the effective resistances seen by the LPF capacitor is increased which leads to $\frac{1}{RC}$ decreasing, which makes f_L go down, and the HPF capacitor sees less resistance which leads to $\frac{1}{RC}$ increasing, which makes f_H go up.
2. We also saw that the active filter gave out a smoother graph, which we think is because the amplification was able to mitigate the loss due to stray resistances and other losses.
3. Taking the FFT spectrum also showed us that for frequencies within the allowed range, almost all the energy was in a single frequency, the one which we were spending. However for the frequencies which landed outside the acceptable range, the base of the spectrum grew wider. We don't know what the exact mechanism behind this is, and we can't rule out the DSO's precision

8 Conclusion

In conclusion, we learned how to design and test the behaviours of passive and active, low-pass, high-pass and band-pass filters.