Experiment-06-Bandpass Filter using Sallen-Key Second-Order Filters

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1 Objective

1. To design and implement a bandpass filter using separate Sallen-Key Low Pass Filter (LPF) and High Pass Filter (HPF).
2. To analyze and compare the frequency response of LPF, HPF, and the final bandpass filter.
3. To plot the magnitude response (gain vs. frequency) of all three filters.

2 Theory

A bandpass filter (BPF) allows frequencies within a specified range while attenuating those outside it. It is constructed using:

- A High Pass Filter (HPF) to remove low-frequency components.
- A Low Pass Filter (LPF) to remove high-frequency components.
- The combined response results in a bandpass characteristic.

Sallen-Key Second-Order Filters use operational amplifiers to provide different responses such as Butterworth, Bessel, or Chebyshev depending on component selection. The transfer function is:

$$H(s) = \frac{A}{s^2 + \frac{\omega_c}{Q}s + \omega_c^2} \tag{1}$$

where:

- ω_c is the cutoff frequency.
- Q is the quality factor.

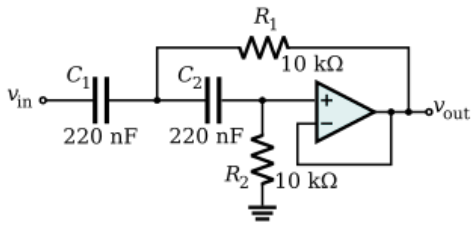
3 Circuit Design

3.1 High Pass Filter (HPF) Design

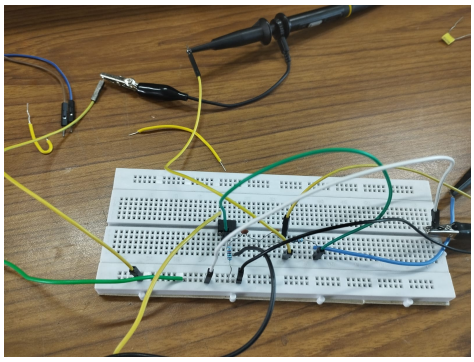
A high pass filter allows signals with frequencies higher than a certain cutoff frequency to pass while attenuating lower frequencies. The cutoff frequency f_{c1} is given by:

$$f_{c1} = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \tag{2}$$

This filter is used to eliminate unwanted low-frequency noise, such as DC offsets, and isolate higher-frequency components.
The values of Resistors are: 14.8kohm, 14.8kohm
The values of Capacitors are: 1nF, 1.2nF



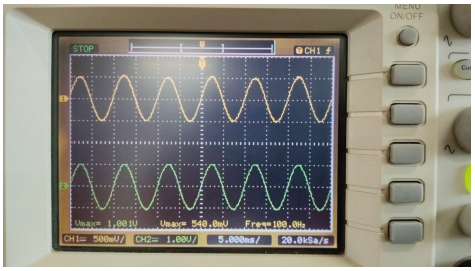
(a)



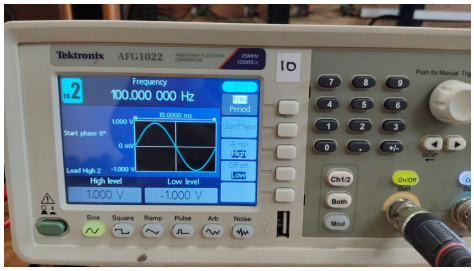
(b)

S. No.	Input Frequency (Hz)	Output Voltage (V)
1	100	0.54
2	500	0.56
3	1000	0.56
4	5000	0.56
5	10000	0.66
6	25000	0.8
7	50000	0.96
8	100000	0.96

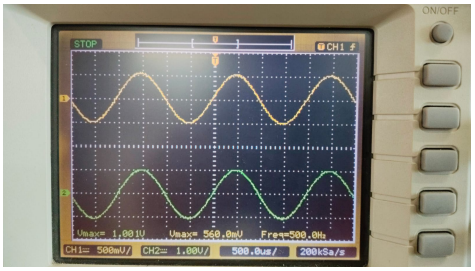
Table 1: Observation Table for Frequency Response for HPF



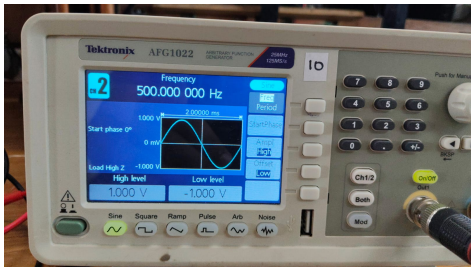
(c)



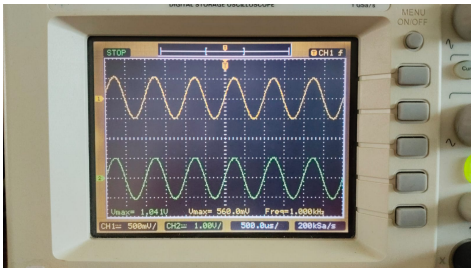
(d)



(e)



(f)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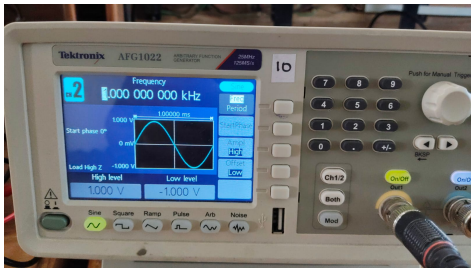
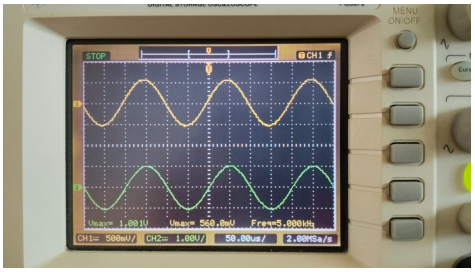
CH1
MENU
ON/OFF

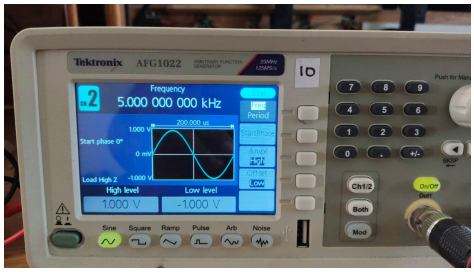
(g)


Tektronix
AFG1022
Frequency
1.000 000 000 kHz
High level
1.000 V
Low level
-1.000 V

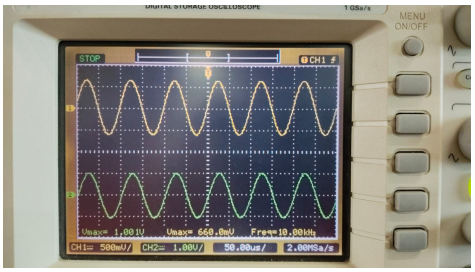
(h)


STOP
CH1
MENU
ON/OFF

(i)


Tektronix
AFG1022
Frequency
5.000 000 000 kHz
High level
1.000 V
Low level
-1.000 V

(j)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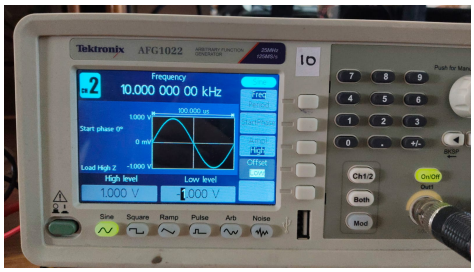
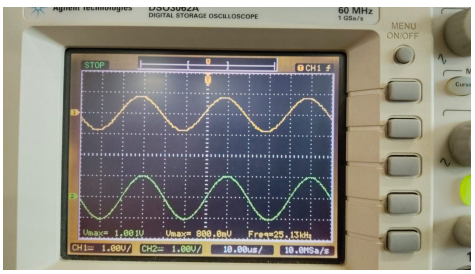
CH1
MENU
ON/OFF

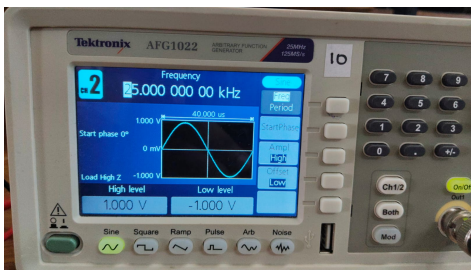
(k)


Tektronix
AFG1022
Frequency
10.000 000 00 kHz
High level
1.000 V
Low level
-1.000 V

(l)


STOP
CH1
MENU
ON/OFF

(m)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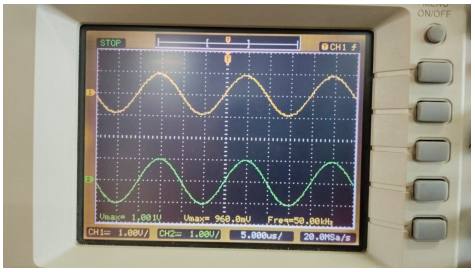
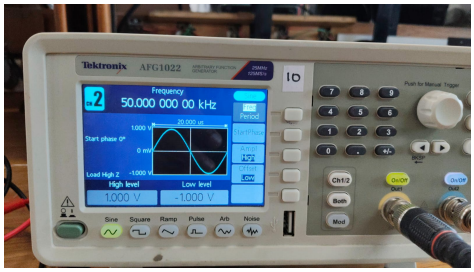
AFG1022
Frequency
25.000 000 00 kHz
High level
1.000 V
Low level
-1.000 V

(n)



(o)



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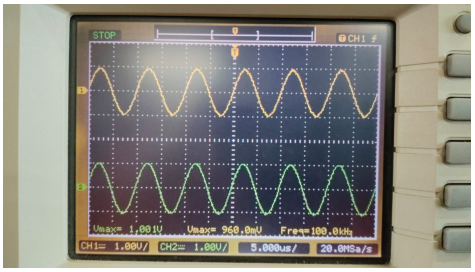

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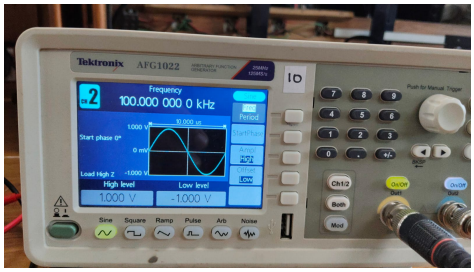


(r)

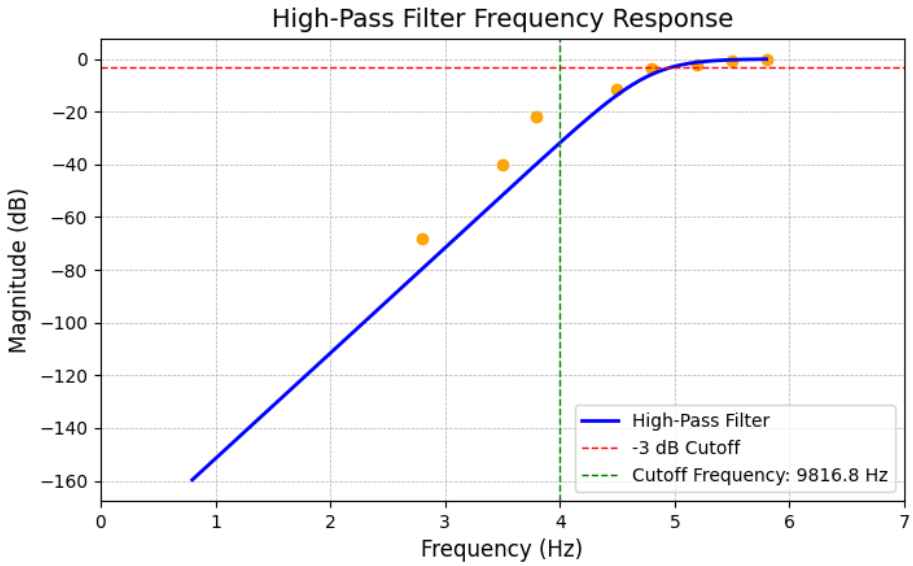


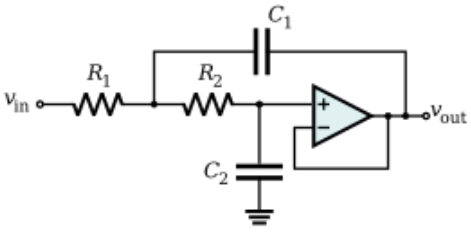
Figure 1: Bode plot for HPF

3.2 Low Pass Filter (LPF) Design

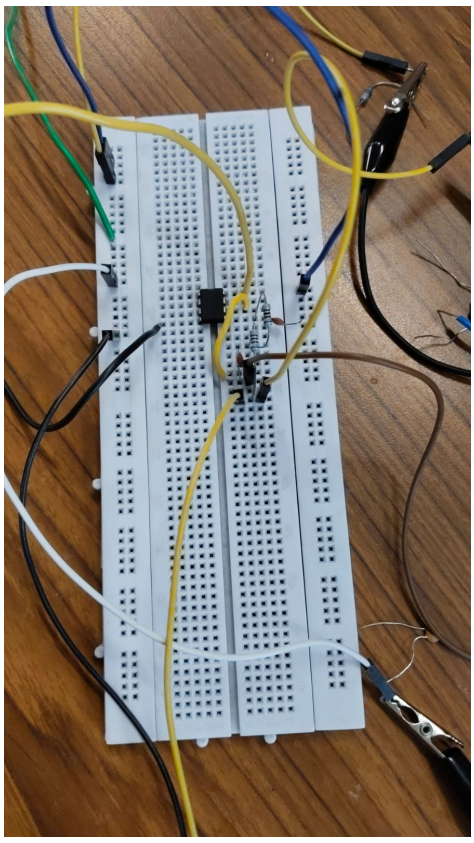
A low pass filter allows signals with frequencies lower than a certain cutoff frequency to pass while attenuating higher frequencies. The cutoff frequency f_{c2} is given by:

$$f_{c2} = \frac{1}{2\pi\sqrt{R_3 R_4 C_3 C_4}} \tag{3}$$

This filter is useful in applications where high-frequency noise needs to be removed, such as in audio processing and communication systems.
The values of Resistors are: 8.2kohm, 8.2kohm
The values of Capacitors in LPF part are: 1nF, 1nF



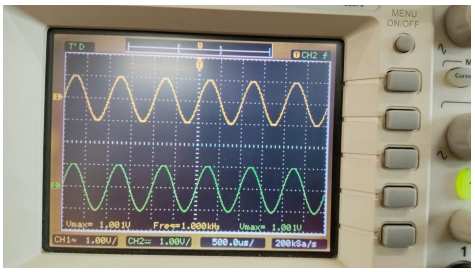
(a)



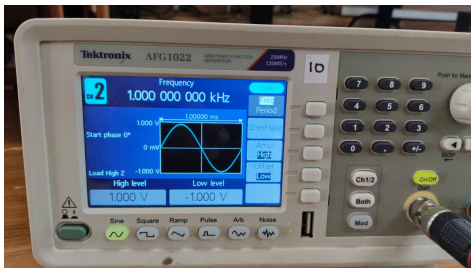
(b)

S. No.	Input Frequency (Hz)	Output Voltage (V)
1	1000	1
2	5000	0.88
3	10000	0.8
4	19000	0.64
5	20000	0.64
6	50000	0.52
7	100000	0.48

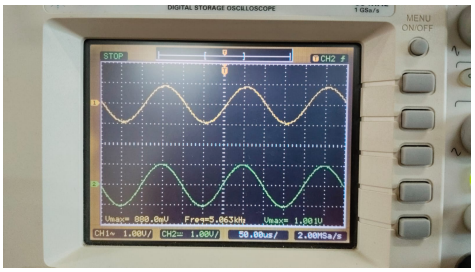
Table 2: Observation Table for Frequency Response for LPF



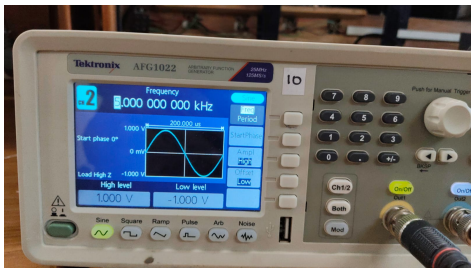
(c)



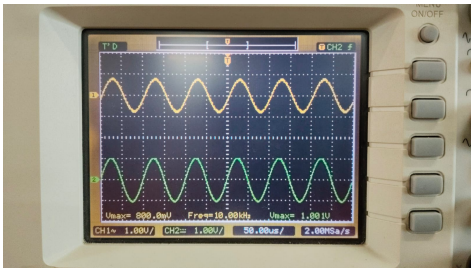
(d)



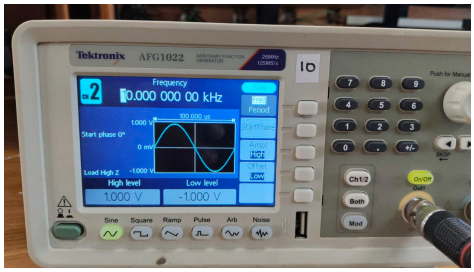
(e)



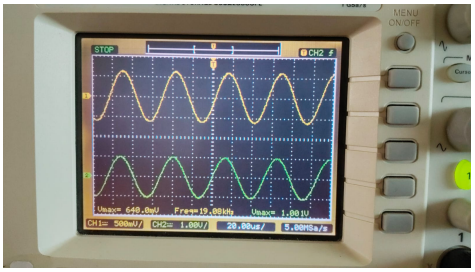
(f)



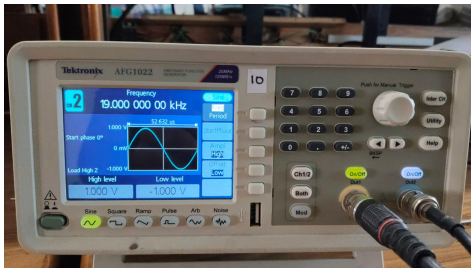
(g)


Tektronix AFG1022
Frequency
0.000 000 00 kHz
High level
1.000 V
Low level
-1.000 V

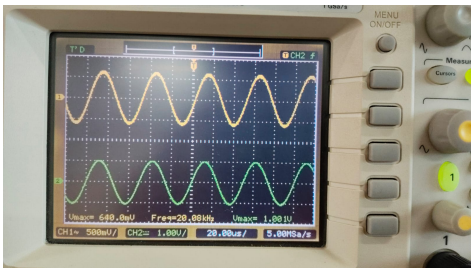
(h)



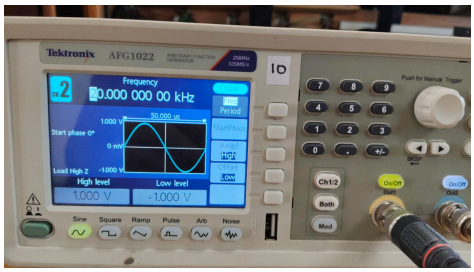
(i)


Tektronix AFG1022
Frequency
19.000 000 00 kHz
High level
1.000 V
Low level
-1.000 V

(j)



(k)


Tektronix AFG1022
Frequency
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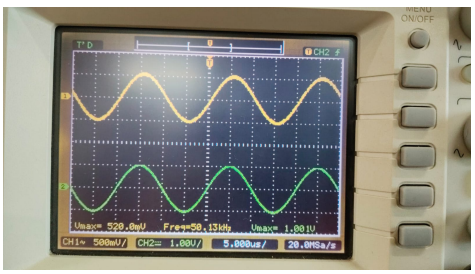
High level
1.000 V
Low level
-1.000 V

(l)



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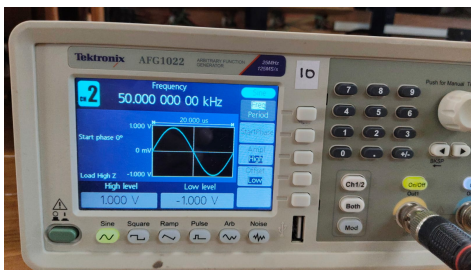
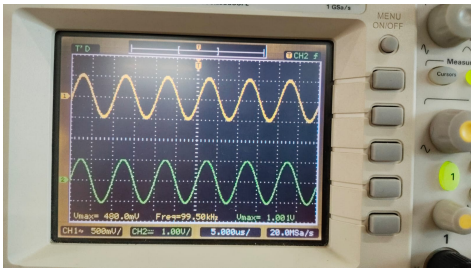

Tektronix AFG1022
Frequency
50.000 000 00 kHz
High level
1.000 V
Low level
-1.000 V

(n)



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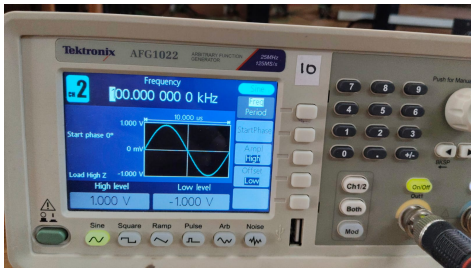

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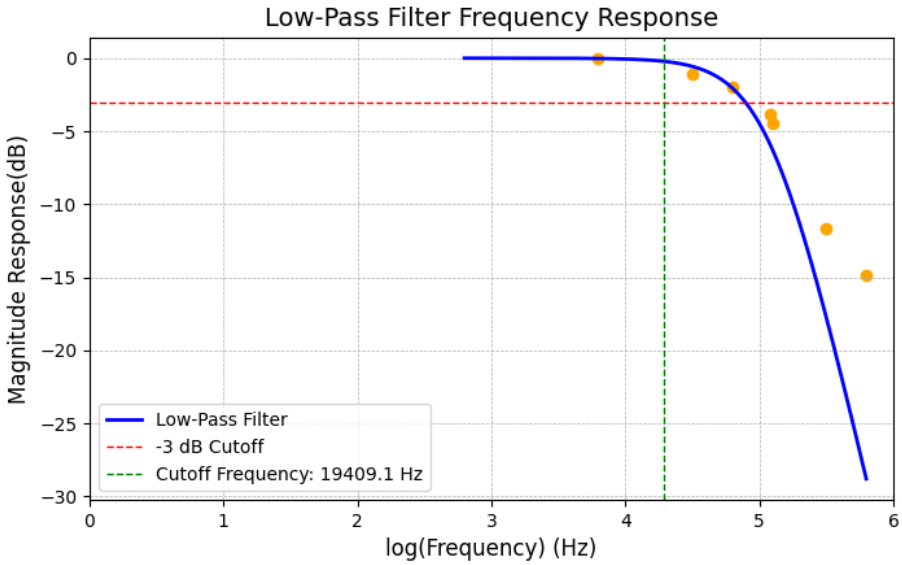


Figure 2: Bode plot for LPF

3.3 Bandpass Filter (BPF) Design

A bandpass filter is formed by cascading the HPF and LPF, allowing signals within a specific frequency range to pass while attenuating frequencies outside this range. The important parameters are:

- Bandwidth: $BW = f_{c2} - f_{c1}$
- Center Frequency: $f_0 = \sqrt{f_{c1} f_{c2}}$

Bandpass filters are widely used in wireless communication, biomedical signal processing, and audio applications to extract relevant signals within a desired frequency range.

The values of Resistors in LPF part are: 15ohm, 15ohm
The values of Resistors in HPF part are: 150ohm, 150ohm
The values of Capacitors in LPF part are: 1nF, 1nF
The values of Capacitors in HPF part are: 1nF, 1nF

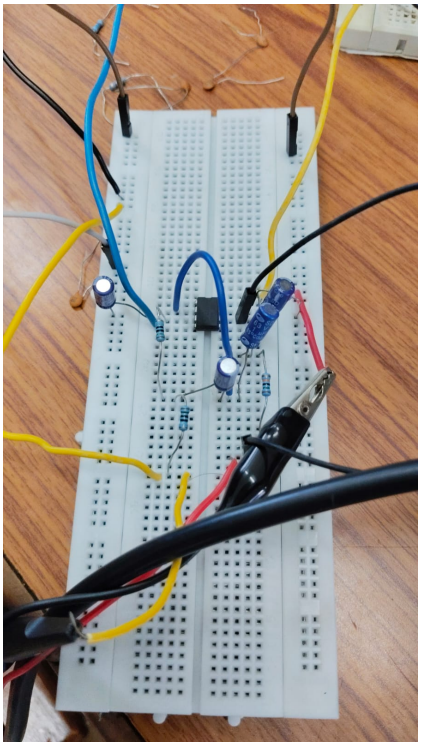
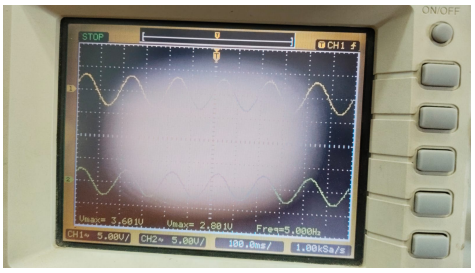


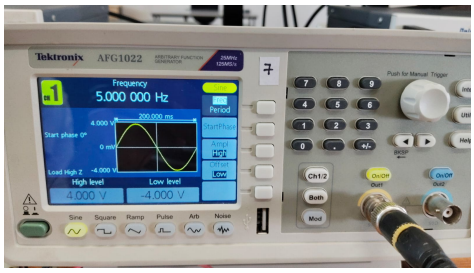
Figure 3: Circuit for BPF

S. No.	Input Frequency (Hz)	Output Voltage (V)
1	5	2.801
2	10	3.681
3	31.6	4
4	100	4
5	250	3.761
6	500	3.121
7	1000	2.481
8	10000	1.681
9	100000	0.76
10	1000000	0.38

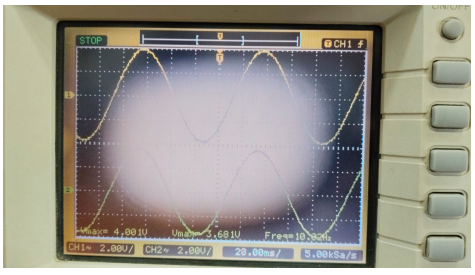
Table 3: Observation Table for Frequency Response for BPF



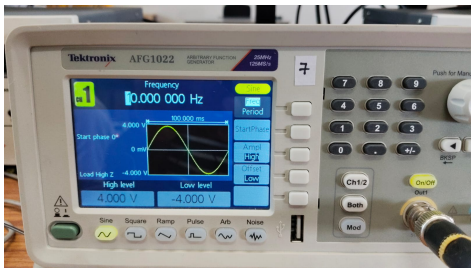
(a)



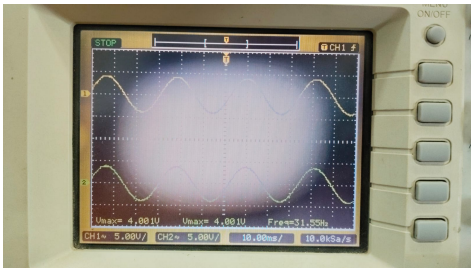
(b)



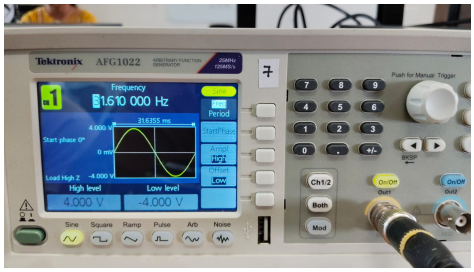
(c)



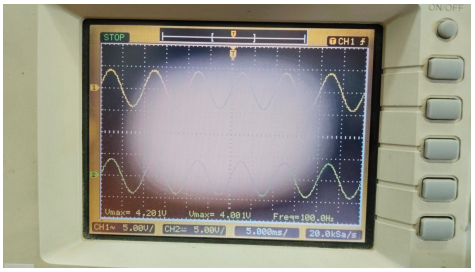
(d)


STOP
CH1 ƒ
Vmax= 4.00IV
Vmax= 4.00IV
Freq=31.55Hz
CH1~ 5.00V/
CH2~ 5.00V/
10.00ms/
10.0kSa/s

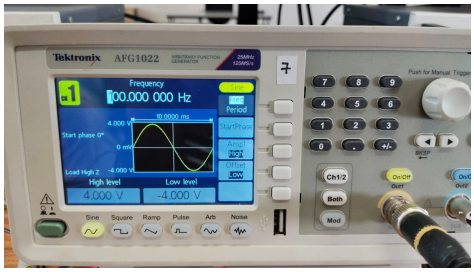
(e)


Tektronix
AFG1022
Frequency
1.610 000 Hz
316355 ms
High level
Low level
4.000 V
-4.000 V
Sine
Square
Ramp
Pulse
Arb
Noise
Ch1/2
Both
Mod

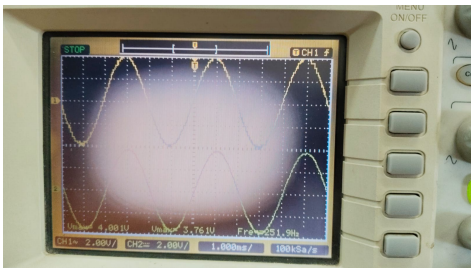
(f)


STOP
CH1 ƒ
Vmax= 4.20IV
Vmax= 4.00IV
Freq=100.0Hz
CH1~ 5.00V/
CH2~ 5.00V/
5.000ms/
20.0kSa/s

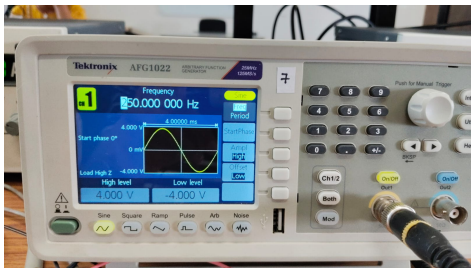
(g)


Tektronix
AFG1022
Frequency
00.000 000 Hz
10.0000 ms
High level
Low level
4.000 V
-4.000 V
Sine
Square
Ramp
Pulse
Arb
Noise
Ch1/2
Both
Mod

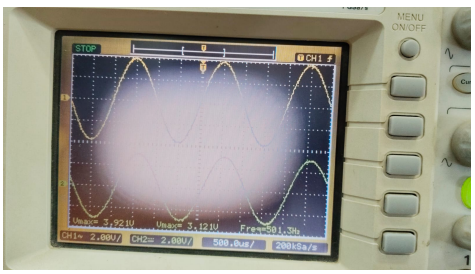
(h)


STOP
CH1 ƒ
Vmax= 4.00IV
Vmax= 3.76IV
Freq=251.9Hz
CH1~ 2.00V/
CH2~ 2.00V/
1.000ms/
100kSa/s

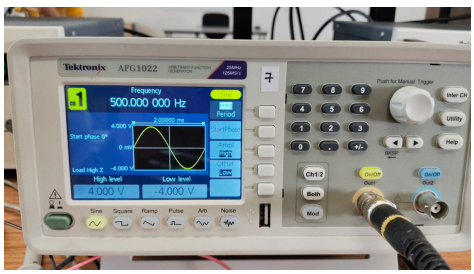
(i)


Tektronix
AFG1022
Frequency
50.000 000 Hz
4.00000 ms
High level
Low level
4.000 V
-4.000 V
Sine
Square
Ramp
Pulse
Arb
Noise
Ch1/2
Both
Mod

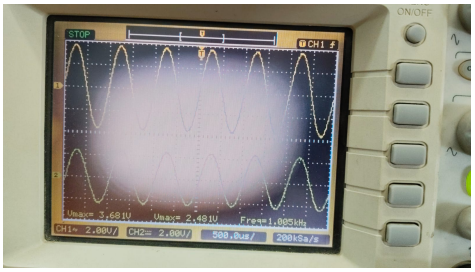
(j)


STOP
CH1 ƒ
Vmax= 3.92IV
Vmax= 3.12IV
Freq=501.3Hz
CH1~ 2.00V/
CH2~ 2.00V/
500.0us/
200kSa/s

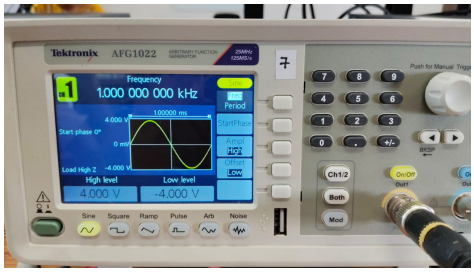
(k)


Tektronix
AFG1022
Frequency
500.000 000 Hz
2.00000 ms
High level
Low level
4.000 V
-4.000 V
Sine
Square
Ramp
Pulse
Arb
Noise
Ch1/2
Both
Mod

(l)


STOP
CH1
ON/OFF

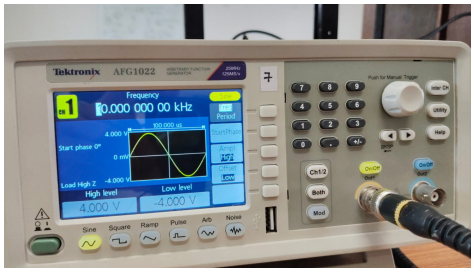
(m)


Tektronix
AFG1022
Frequency
1.000 000 000 kHz
High level
4.000 V
Low level
-4.000 V

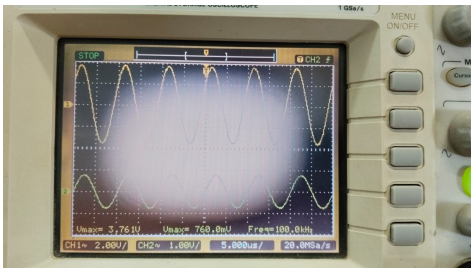
(n)


STOP
CH2
MENU
ON/OFF

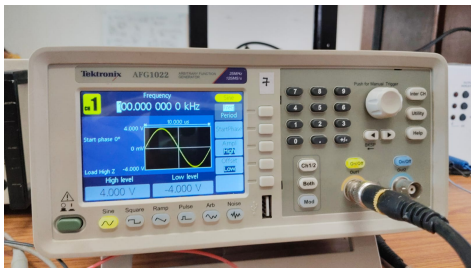
(o)


Tektronix
AFG1022
Frequency
High level
4.000 V
Low level
-4.000 V

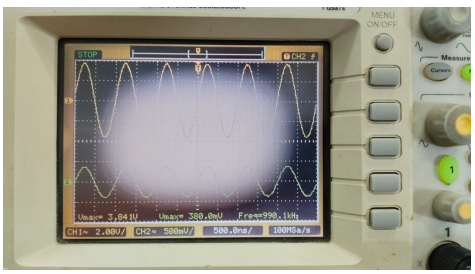
(p)


STOP
CH2
MENU
ON/OFF

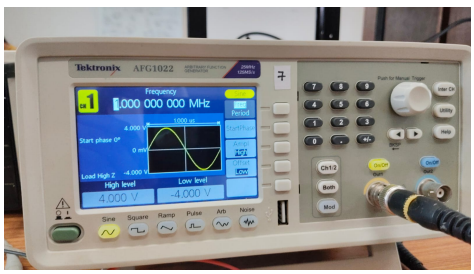
(q)


Tektronix
AFG1022
Frequency
High level
4.000 V
Low level
-4.000 V

(r)


STOP
CH2
MENU
ON/OFF

(s)


Tektronix
AFG1022
Frequency
1.000 000 000 MHz
High level
4.000 V
Low level
-4.000 V

(t)

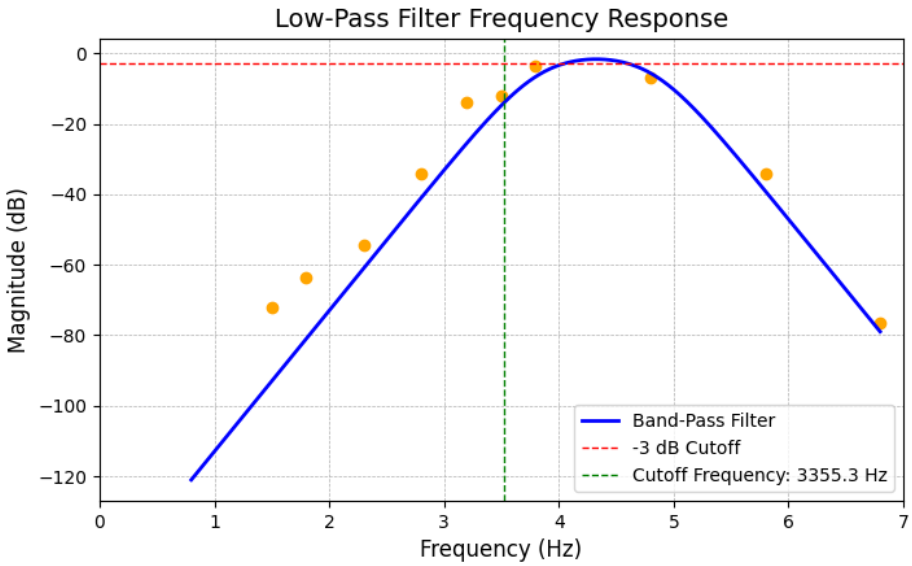


Figure 4: Bode plot for BPF

4 Observations and Results

- Plot the frequency response of HPF, LPF, and BPF.
- Compare the experimental and theoretical cutoff frequencies.
- Verify if the BPF passes the expected frequency range.

5 Conclusion

- The experiment verifies the cascading method to form a bandpass filter.
- The experimental results should match the theoretical calculations.
- Sallen-Key topology provides good stability and response.