# Experiment 6-Band Pass Sallen-Key Filter

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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 only the frequencies within a specific range and does not allow outside it.

- 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.

### 2.1 Sallen-Key Second-Order Filters:

- It is an active filter topology using operational amplifiers.
- Provides a Butterworth, Bessel, or Chebyshev response based on component selection.
- The transfer function is given by:

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

where:
$\omega_c$ is the cutoff frequency

$$\omega_c = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}} \tag{2}$$

$Q$ is the quality factor

$$Q = \frac{\sqrt{R_1 R_2 C_1 C_2}}{C_2(R_1 + R_2)} \tag{3}$$

### 2.2 Components and Equipment Required:

- Operational Amplifiers (e.g., TL074, TL081, or LM358)
- Resistors: $R_1$, $R_2$, $R_3$, $R_4$ (in k$\Omega$)
- Capacitors: $C_1$,$C_2$, $C_3$, $C_4$ (in nF)
- Function Generator
- Oscilloscope or Spectrum Analyzer
- DC Power Supply ($\pm$12V)
- Breadboard and connecting wires

## 3 Circuit design:

### 3.1 High pass Sallen-Key filter design:

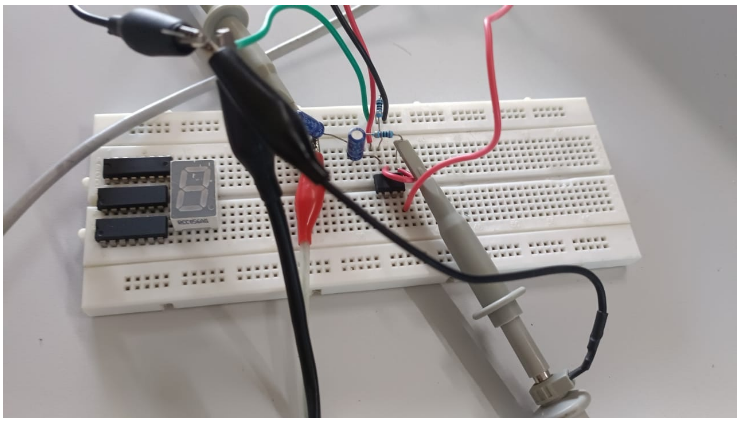


Figure 1: High Pass Sallen-Key Filter-Circuit design

- Here $R_1$=$R_2$=1000$\Omega$ and $C_1$=$C_2$=1$\mu$F
- Cutoff frequency $f_{c_1}$ (also lower cutoff frequency of the bandpass filter)

- Standard Sallen-Key HPF formula:

$$f_c = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \tag{4}$$

  Substituting values:

$$f_c = \frac{1}{2\pi\sqrt{(1000)(1000)(1\times10^{-6})(1\times10^{-6})}} \tag{5}$$

$$f_c = 159.15 \text{ Hz} \tag{6}$$

- Angular cutoff frequency:

$$\omega_c = 2\pi f_c = 2\pi \times 159.15 = 1000 \text{ rad/sec} \tag{7}$$

- Quality factor:

$$Q = \frac{1}{2} = 0.5 \tag{8}$$

- Transfer function of the High Pass Filter:

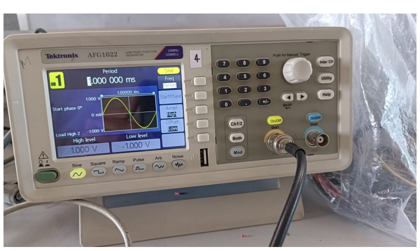
$$H(s) = \frac{s^2}{s^2 + \frac{\omega_c}{Q}s + \omega_c^2} \tag{9}$$

  where:
  $s$ is the complex frequency variable, $s = j\omega$
  $\omega_c = 1000$ rad/sec
  $Q = 0.5$

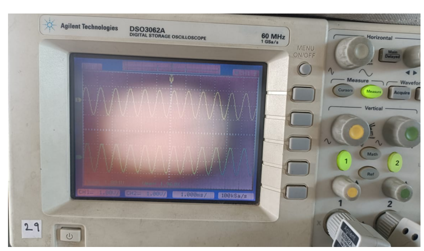
**Experimental Data**

| Frequency (Hz) | Input Voltage (V) | Output Voltage (V) | Experimental Gain | Theoretical Gain |
|---|---|---|---|---|
| 100 | 1.0 | 0.24 | -10.46 | -10.96 |
| 160 | 1.0 | 0.44 | -7.12 | -6.2 |
| 200 | 1.0 | 0.56 | -5.04 | -4.26 |
| 1000 | 1.0 | 0.76 | -0.238. | -0.217 |

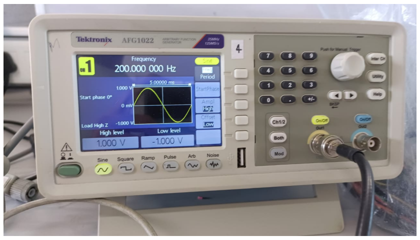
Table 1: Comparison of Experimental and Theoretical Gain for High Pass Filter




(a) Input

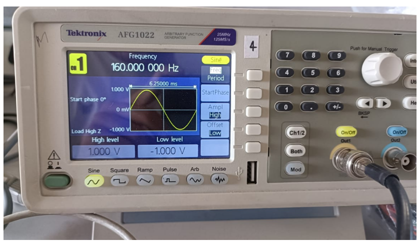



(b) Output

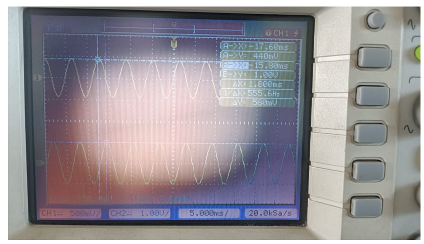



(c) Input

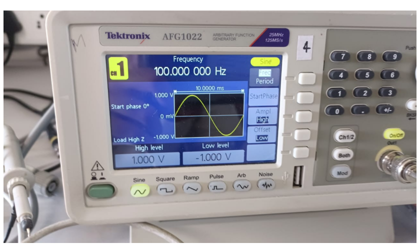
(d) Output




(e) Input



(f) Output




(g) Input

(h) Output

Figure 2: Experimental results for high pass filter

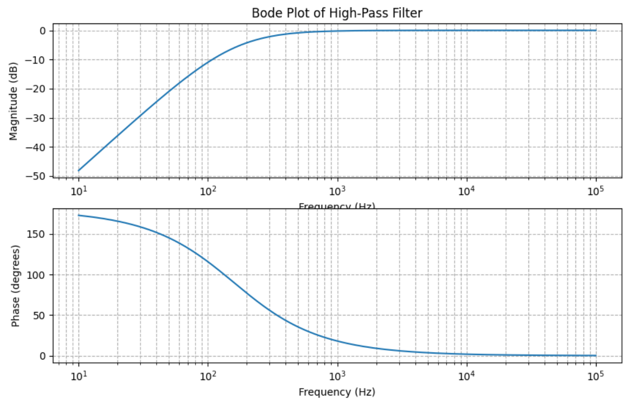



Figure 3: High Pass Filter Frequency Response

## 3.2 Low pass Sallen-Key filter design:

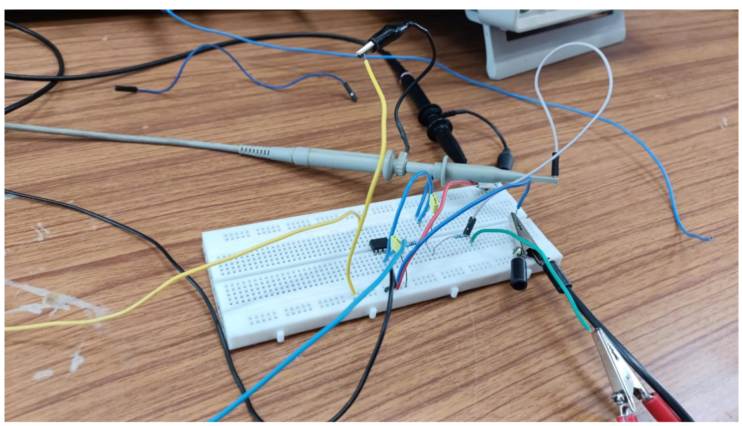


Figure 4: Low Pass Sallen-Key Filter-Circuit design

- Here $R_1$=$R_2$=1000Ω and $C_1$=$C_2$=1$\mu$F
- Cutoff frequency $f_{c_2}$ (also upper cutoff frequency of the bandpass filter)
- Standard Sallen-Key LPF formula:

$$f_c = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \tag{10}$$

Substituting values:

$$f_c = \frac{1}{2\pi\sqrt{(1000)(1000)(1 \times 10^{-6})(1 \times 10^{-6})}} \tag{11}$$

$$f_c = 159.15 \text{ Hz} \tag{12}$$

- Angular cutoff frequency:

$$\omega_c = 2\pi f_c = 2\pi \times 159.15 = 1000 \text{ rad/sec} \tag{13}$$

- Quality factor:

$$Q = \frac{1}{2} = 0.5 \tag{14}$$

- Transfer function of the Low Pass Filter:

$$H(s) = \frac{\omega_c^2}{s^2 + \frac{\omega_c}{Q}s + \omega_c^2} \tag{15}$$

where:
$s$ is the complex frequency variable, $s = j\omega$
$\omega_c = 1000$ rad/sec
$Q = 0.5$

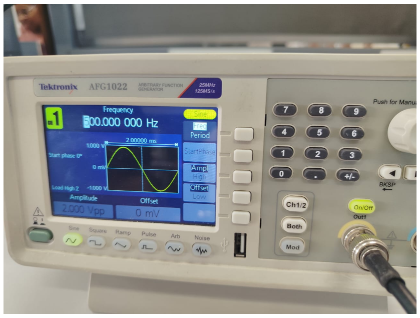
**Experimental Data**

| Frequency (Hz) | Input Voltage (V) | Output Voltage (V) | Experimental Gain | Theoretical Gain |
|---|---|---|---|---|
| 100 | 1.8 | 1.62 | -2.38 | -2.88 |
| 160 | 1.0 | 0.88 | -5.36 | -6.08 |
| 500 | 1.0 | 0.124 | -18.12 | -20.72 |
| 1000 | 1.0 | 0.48 | -28.2 | -31.5 |

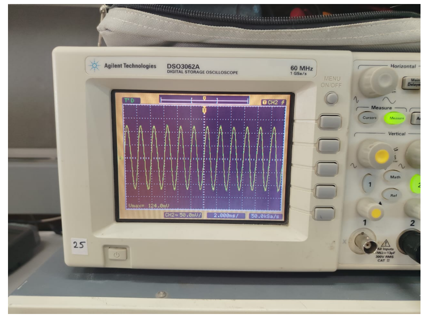
Table 2: Comparison of Experimental and Theoretical Gain for Low Pass Filter


(a) Input

(b) Output

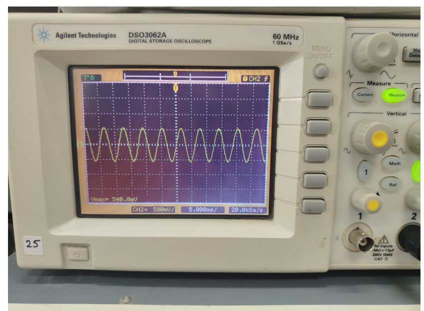



(c) Input



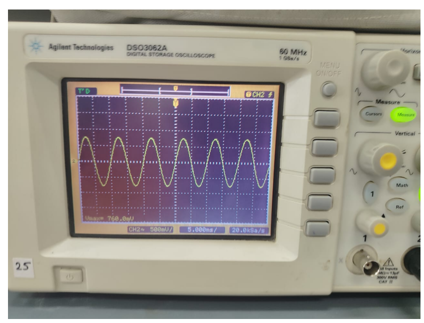

(d) Output


(e) Input




(f) Output


(g) Input




(h) Output

Figure 5: Experimental results for low pass filter

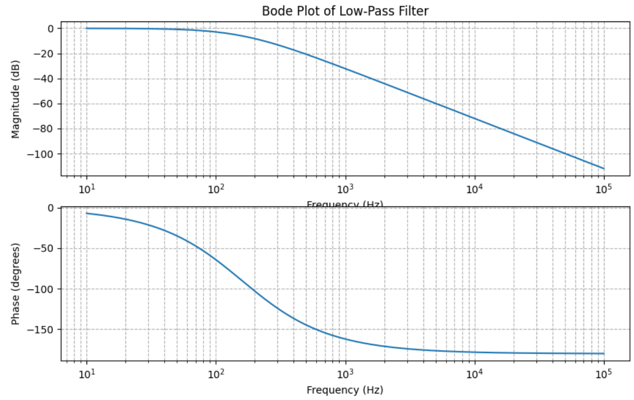



Figure 6: Low Pass Filter Frequency Response

### 3.3 Bandpass Sallen-Key Filter Design:

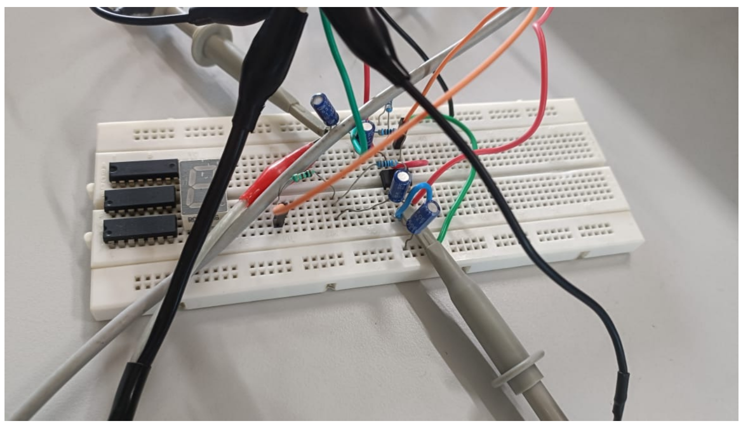


Figure 7: band Pass Sallen-Key Filter-Circuit design

- The bandpass filter is constructed by cascading a high-pass filter and a low-pass filter.
- Components in the high-pass filter: $R_1$=$R_2$=1000Ω and $C_1$=$C_2$=1$\mu$F.
- Components in the low-pass filter: $R_1$=$R_2$=100Ω and $C_1$=$C_2$=1$\mu$F.
- The output of the high-pass filter is connected to the input of the low-pass filter.

- The overall transfer function of the bandpass filter is the product of the individual transfer functions of the high-pass and low-pass filters:

$$H_{\text{BPF}}(s) = H_{\text{HPF}}(s) \cdot H_{\text{LPF}}(s) \tag{16}$$

where:

$$H_{\text{HPF}}(s) = \frac{s^2}{s^2 + \frac{\omega_{c1}}{Q_1}s + \omega_{c1}^2} \tag{17}$$

$$H_{\text{LPF}}(s) = \frac{\omega_{c2}^2}{s^2 + \frac{\omega_{c2}}{Q_2}s + \omega_{c2}^2} \tag{18}$$

- The cutoff frequencies for the high-pass and low-pass filters are:

$$f_{c1} = 159.15 \text{ Hz} \quad \text{(High Pass)} \tag{19}$$

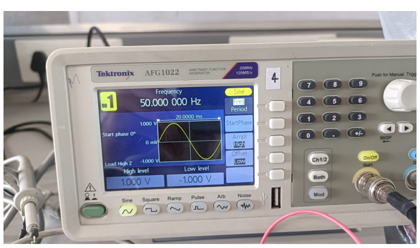
$$f_{c2} = 1591.5 \text{ Hz} \quad \text{(Low Pass)} \tag{20}$$

- The bandpass filter allows frequencies between $f_{c1}$ and $f_{c2}$.

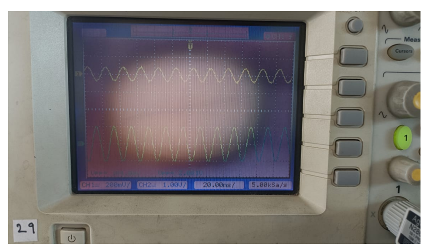
**Experimental Data**

| Frequency (Hz) | Input Voltage (V) | Output Voltage (V) | Experimental Gain | Theoretical Gain |
|---|---|---|---|---|
| 50 | 1.0 | 0.80 | -21.94 | -20.84 |
| 160 | 1.0 | 0.44 | -7.14 | -6.02 |
| 1000 | 1.0 | 0.90 | -3.56 | -3.8 |
| 1600 | 1.0 | 0. | -6.66 | -6.12 |

Table 3: Comparison of Experimental and Theoretical Gain for Bandpass Filter

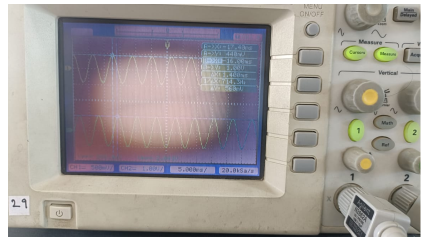



(a) Input

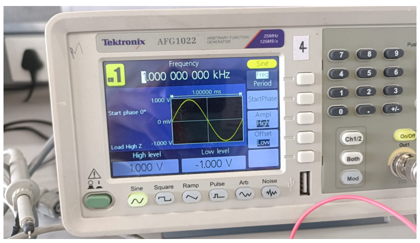


(b) Output

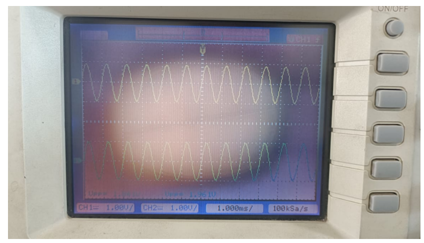
(c) Input



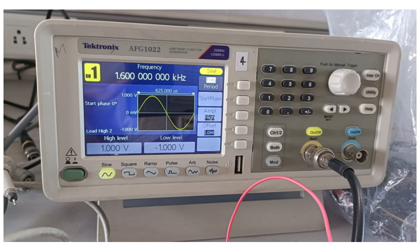
(d) Output



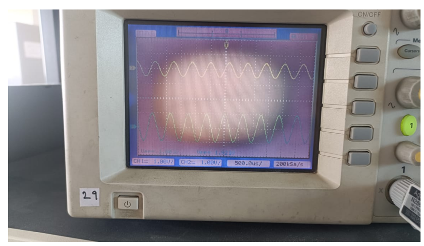
(e) Input



(f) Output



(g) Input



(h) Output

Figure 8: Experimental results for bandpass filter

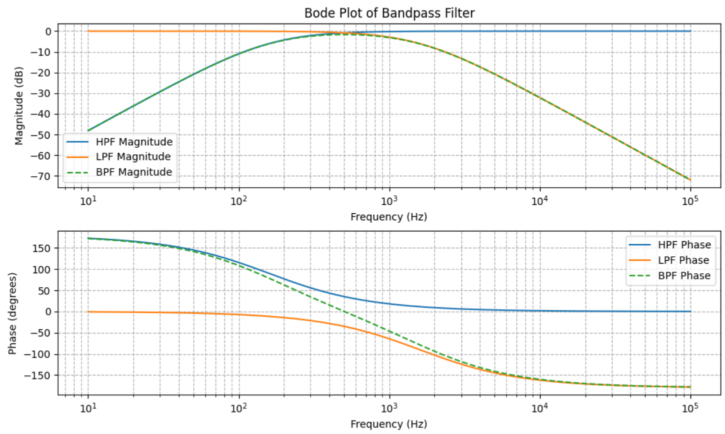



Figure 9: Bandpass Filter Frequency Response

# 4 Conclusion

- From the above observation we can say that cascading the low pass and high pass filter provides a good stability and response