



# **Design of Higher Order Active Filter using Sallen and Key Biquad Circuit**

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## 1 Objectives

- To be familiar with the design of higher order active filters using cascaded biquad.
- To be familiar with design of filter using Sallen and Key biquad circuit.
- To be familiar with RC-CR transformation.

## 2 Exercises

### Problem 1

**What are the different techniques to design higher order active filters? Explain.**

Higher order active filters are a necessary part of telecommunication and instrumentation systems to satisfy the need of selectivity. The design of higher order active filters can be performed by two methods,

1. Cascade of biquad circuits
2. Active simulation of passive filters
  - (a) Elemental simulation
    - Ladder design with simulated inductors
    - Ladder design with Frequency-Dependent Negative Resistor (FDNR)
  - (b) Functional simulation
    - Leapfrog simulation of ladders

Since this lab experiment is based on the design of higher order active filters using cascade of biquad circuits, it is explained in detail. However, the active simulation of passive circuits is only introduced in this report.

### 2.1.1 Cascade of biquad circuits

For a higher order active filter with transfer function  $T(s)$ , the realization is possible as the ratio of the output voltage to input voltage of a cascade connection of lower order stages that don't cause load effect. For this to be possible, the output impedance of each stage needs to be lower than the input impedance of the following stage at all interested frequencies.

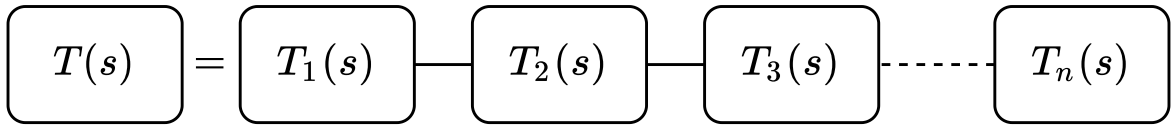


Figure 1: Cascade of biquad circuits

While designing a circuit with transfer function  $T(s)$  using biquadratic terms  $T_i(s)$  in a cascaded system, we have the following degree of freedom,

1. Pole-zero pairing i.e. which pole with zero of  $T(s)$  will be paired to form each  $T_i(s)$ .
2. Physical position of each biquad in the cascade system.
3. Distribution of the overall gain in the various biquad circuits.

This method of designing higher order active filters is made possible due to the use of operational amplifiers in designs of active filters. Since op-amp offers high input impedance and low output impedance, loading effect is nullified, which we use as an advantage to cascade different stages of active filters to get the desired transfer function for a final filter circuit.

If  $T(s)$  is the required transfer function given as,

$$T(s) = \frac{a_m s^m + a_{m-1} s^{m-1} + \dots + a_0}{s^n + b_{n-1} s^{n-1} + \dots + b_0}$$

For  $n$  as even,  $T(s)$  is expressed as,

$$T(s) = \prod_{i=1}^{\frac{n}{2}} \frac{a_{2i} s^2 + a_{1i} s + a_{0i}}{s^2 + b_{1i} s + b_{0i}} = \prod_{i=1}^{\frac{n}{2}} T_i(s)$$

For  $n$  as odd,  $T(s)$  is expressed as,

$$T(s) = \frac{a_{11}s + a_{01}}{s + b_{01}} \prod_{i=2}^{\frac{n-1}{2}} \frac{a_{2i}s^2 + a_{1i}s + a_{0i}}{s^2 + b_{1i}s + b_{0i}} = T_1(s) \prod_{i=2}^{\frac{n-1}{2}} T_i(s)$$

### 2.1.2 Active simulation of passive filters

Since the design of higher order active filters are limited due to the value of inductance, a way to design higher order active filters is by simulating the inductance behavior in the circuit using elemental simulation. This can be done by using a Generalized Impedance Converter (GIC), a two port network that is used primarily to convert one form of impedance into another. A grounded inductor in a passive circuit is replaced with a GIC to convert the passive circuit into active. Another way of performing elemental simulation is by using a magnitude scaling factor of  $K_m = \frac{1}{s}$ , which ultimately converts the resistor to a capacitor  $\left(\frac{R}{s}\right)$ , an inductor to a resistor  $(L)$ , and the capacitor to a Frequency Dependent Negative Resistor (FDNR)  $\left(\frac{1}{s^2C}\right)$  which is also realized using a GIC.

Similarly, functional simulation (leapfrog simulation) is another way to get active simulation of passive filters. Each component in the passive circuit is first replaced by their equivalent impedance or admittance and admittance or impedance groups are created based on same current (series) or same voltage (parallel) configuration giving rise to a block diagram equivalent to the original circuit. Each block is then implemented either by using an inverting summer (for summing blocks) or active circuits (for admittance and impedance blocks) to complete the active simulation of the passive filter.

**Problem 2**

From the circuit given in Figure 2 derive the transfer function  $\frac{V_2(s)}{V_1(s)}$ .

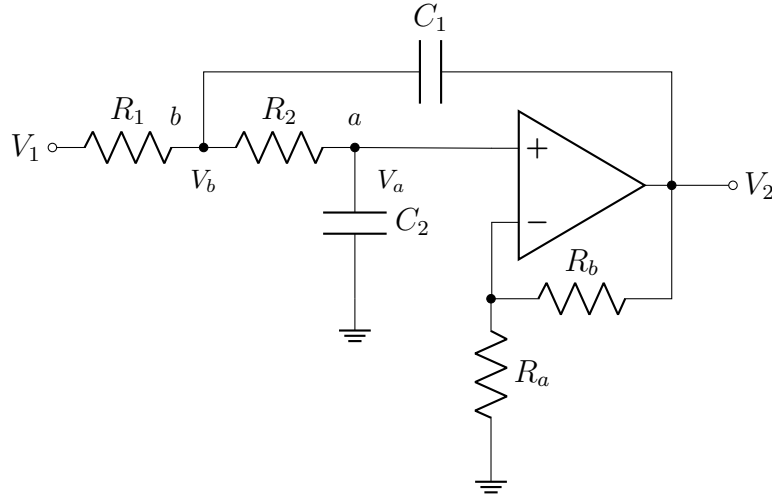


Figure 2: Sallen-Key lowpass filter

Let us consider the voltage at nodes  $a$  and  $b$  as  $V_a$  and  $V_b$  respectively. The circuit is in an non-inverting configuration, so the gain of the circuit has the following relationship,

$$\begin{aligned} \frac{V_2}{V_a} &= \left(1 + \frac{R_b}{R_a}\right) \\ \therefore V_a &= \frac{V_2}{K} \end{aligned} \quad (1)$$

where,  $K = \left(1 + \frac{R_b}{R_a}\right)$  is the gain.

Applying nodal analysis at node  $a$ , we get,

$$\begin{aligned} \Rightarrow \frac{V_a - V_b}{R_2} + \frac{V_a}{\frac{1}{sC_2}} &= 0 \\ \Rightarrow \frac{V_a}{R_2} - \frac{V_b}{R_2} + sV_aC_2 &= 0 \\ \Rightarrow V_a \left( \frac{1}{R_2} + sC_2 \right) &= \frac{V_b}{R_2} \\ \therefore V_b &= V_a R_2 \left( \frac{1}{R_2} + sC_2 \right) \end{aligned} \quad (2)$$

Substituting the value for  $V_a$  from Equation 1 into Equation 2, we get,

$$\begin{aligned}\Rightarrow V_b &= \frac{V_2 R_2}{K} \left( \frac{1}{R_2} + sC_2 \right) \\ \therefore V_b &= \frac{V_2}{K} (1 + sC_2 R_2)\end{aligned}\quad (3)$$

Applying nodal analysis at node  $b$ , we get,

$$\begin{aligned}\Rightarrow \frac{V_b - V_a}{R_2} + \frac{V_b - V_1}{R_1} + \frac{V_b - V_2}{\frac{1}{sC_1}} &= 0 \\ \therefore V_b \left( \frac{1}{R_2} + \frac{1}{R_1} + sC_1 \right) - \frac{V_a}{R_2} &= \frac{V_1}{R_1} + sV_2 C_1\end{aligned}\quad (4)$$

Substituting the values for  $V_a$  and  $V_b$  from Equation 1 and Equation 3 into Equation 4, we get,

$$\begin{aligned}\Rightarrow \frac{V_2}{K} (1 + sC_2 R_2) \left( \frac{1}{R_2} + \frac{1}{R_1} + sC_1 \right) - \frac{V_2}{KR_2} &= \frac{V_1}{R_1} + sV_2 C_1 \\ \Rightarrow \frac{V_2}{K} (1 + sC_2 R_2) \left( \frac{R_1 + R_2 + sC_1 R_1 R_2}{R_1 R_2} \right) - \frac{V_2}{KR_2} - sV_2 C_1 &= \frac{V_1}{R_1} \\ \Rightarrow \frac{V_2 [(1 + sC_2 R_2) (R_1 + R_2 + sC_1 R_1 R_2) - R_1 - sKC_1 R_1 R_2]}{KR_1 R_2} &= \frac{V_1}{R_1} \\ \Rightarrow \frac{V_2}{V_1} &= \frac{KR_2}{R_2 + sC_1 R_1 R_2 + sC_2 R_1 R_2 + sC_2 R_2^2 + s^2 C_1 C_2 R_1 R_2^2 - sKC_1 R_1 R_2} \\ \Rightarrow \frac{V_2}{V_1} &= \frac{KR_2}{s^2 C_1 C_2 R_1 R_2^2 + s(C_1 R_1 R_2 + C_2 R_1 R_2 + C_2 R_2^2 - KC_1 R_1 R_2) + R_2} \\ \Rightarrow \frac{V_2}{V_1} &= \frac{\frac{KR_2}{C_1 C_2 R_1 R_2^2}}{s^2 + s \left( \frac{C_1 R_1 R_2 + C_2 R_1 R_2 + C_2 R_2^2 - KC_1 R_1 R_2}{C_1 C_2 R_1 R_2^2} \right) + \frac{R_2}{C_1 C_2 R_1 R_2^2}} \\ \therefore T_{LP}(s) = \frac{V_2}{V_1} &= \frac{K \frac{1}{C_1 C_2 R_1 R_2}}{s^2 + s \left( \frac{1}{C_1 R_1} + \frac{1}{C_1 R_2} + \frac{1}{C_2 R_2} - \frac{K}{C_2 R_2} \right) + \frac{1}{C_1 C_2 R_1 R_2}}\end{aligned}\quad (5)$$



### Problem 3

**Realize the fourth order Butterworth filter (refer Table 1) using Sallen-Key circuit. Perform gain compensation if necessary.**

$n = 2$	$n = 3$	$n = 4$	$n = 5$
$-0.7071068 \pm j0.7071068$	$-0.50 \pm j0.86603$	$-0.3826834 \pm j0.9238795$	$-0.809017 \pm j0.5877852$
	$-1.0$	$-0.9238795 \pm j0.3826834$	$-0.309017 \pm j0.9510565$
			$-1.0$

Table 1: Pole location for butterworth response

For a lowpass filter with poles at  $s = -\alpha \pm j\beta$  and  $s = -\alpha' \pm j\beta'$  the denominator polynomial is calculated as,

$$\begin{aligned}
 f_{den}(s) &= (s + \alpha + j\beta)(s + \alpha - j\beta)(s + \alpha' + j\beta')(s + \alpha' - j\beta') \\
 &= ((s + \alpha)^2 - j^2\beta^2) ((s + \alpha')^2 - j^2\beta'^2) \\
 &= (s^2 + 2\alpha s + \alpha^2 + \beta^2) (s^2 + 2\alpha' s + \alpha'^2 + \beta'^2)
 \end{aligned}$$

For given pole locations at  $s = -0.3826834 \pm j0.9238795$  and  $s = -0.9238795 \pm j0.3826834$ , i.e.  $\alpha = -0.3826834$ ,  $\beta = 0.9238795$ ,  $\alpha' = -0.9238795$ ,  $\beta' = 0.3826834$  the denominator function is,

$$f_{den}(s) = (s^2 + 0.7653s + 1)(s^2 + 1.8478s + 1) \quad (6)$$

The denominator function for a general 2<sup>nd</sup> order lowpass filter can be written as,

$$f_{den}^g(s) = s^2 + s \left( \frac{\omega_o}{Q} \right) + \omega_o^2 \quad (7)$$

We need to cascade two such 2<sup>nd</sup> order lowpass filters to get the desired form of denominator equation as,

$$f_{den}^c(s) = \left( s^2 + s \left( \frac{\omega_o}{Q} \right) + \omega_o^2 \right) \left( s^2 + s \left( \frac{\omega'_o}{Q'} \right) + \omega_o'^2 \right) \quad (8)$$

Comparing Equation 6 and Equation 8, we get,

$$\begin{aligned}\omega_o^2 &= 1 \Rightarrow \omega_o = \sqrt{1} = 1 \text{ rad/s} \\ \frac{\omega_o}{Q} &= 0.7653 \Rightarrow Q = \frac{\omega_o}{0.7653} = \frac{1}{0.7653} = 1.3067 \\ \omega_o'^2 &= 1 \Rightarrow \omega_o' = \sqrt{1} = 1 \text{ rad/s} \\ \frac{\omega_o'}{Q'} &= 1.8478 \Rightarrow Q' = \frac{\omega_o'}{1.8478} = \frac{1}{1.8478} = 0.5412\end{aligned}$$

Hence the filter parameters for the two stages of filters are,  $\omega_o = 1$ ,  $Q = 1.3067$ ,  $H = 1$ ,  $\omega_o' = 1$ ,  $Q' = 0.5412$ ,  $H' = 1$ .

### Stage I

Let us design the first stage with the parameters  $\omega_o = 1 \text{ rad/s}$ ,  $Q = 1.3067$  and  $H = 1$  using the default (equal element values) technique with elemental values  $C_1 = C_2 = 1 \text{ F}$  and  $R_1 = R_2 = R$  as,

$$\begin{aligned}R &= \frac{1}{\omega_o} \Rightarrow R = \frac{1}{1} = 1 \Omega \\ K &= 3 - \frac{1}{Q} \Rightarrow K = 3 - \frac{1}{1.3067} = 2.2347\end{aligned}$$

We have, the relation for gain,

$$K = 1 + \frac{R_b}{R_a} \Rightarrow \frac{R_b}{R_a} = K - 1 = 2.2347 - 1 = 1.2347$$

For  $R_a = 1 \Omega$ ,  $R_b = 1.2347 \Omega$ . Since the calculated gain is  $K = 2.2347$ , but we require a gain of  $H = 1$ , we need to perform gain compensation, i.e. reduction in this case. For gain reduction, we have to replace  $R_1$  in Figure 2 with an equivalent parallel circuit as,

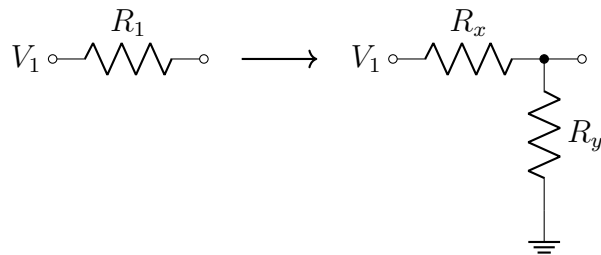


Figure 3:  $R_1 = R_x || R_y$  equivalence circuit

From Figure 3, we have,

$$\begin{aligned}
 R_1 &= R_x || R_y \\
 \Rightarrow R_1 &= \frac{R_x R_y}{R_x + R_y} \\
 \Rightarrow R_x + R_y &= R_x R_y
 \end{aligned} \tag{9}$$

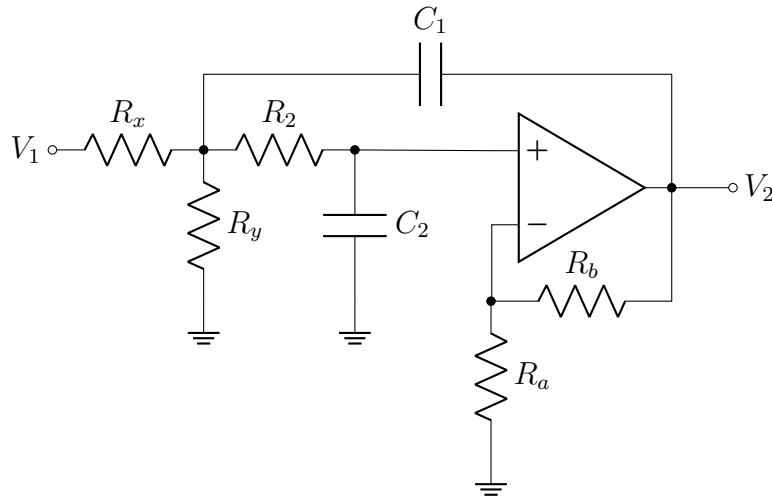


Figure 4: Sallen-Key gain reduction circuit

Performing gain compensation as,

$$\begin{aligned}
 \frac{R_y}{R_x + R_y} &= \frac{H}{K} = \frac{1}{2.2347} = 0.4474 \\
 \Rightarrow 0.4474 R_x + 0.4474 R_y &= R_y \\
 \Rightarrow 0.5526 R_y &= 0.4474 R_x \\
 \Rightarrow R_y &= 0.8096 R_x
 \end{aligned} \tag{10}$$

Solving for  $R_x$  and  $R_y$  using Equation 9 and Equation 10, we get,  $R_x = 2.2351 \Omega$  and  $R_y = 1.8095 \Omega$

## Stage II

Let us design the second stage with the parameters  $\omega'_o = 1 \text{ rad/s}$ ,  $Q' = 0.5412$  and  $H' = 1$  using the default (equal element values) technique with elemental values  $C'_1 = C'_2 = 1 \text{ F}$  and

$R'_1 = R'_2 = R'$  as,

$$R' = \frac{1}{\omega'_o} \Rightarrow R' = \frac{1}{1} = 1 \Omega$$

$$K' = 3 - \frac{1}{Q'} \Rightarrow K' = 3 - \frac{1}{0.5412} = 1.1522$$

We have, the relation for gain,

$$K' = 1 + \frac{R'_b}{R'_a} \Rightarrow \frac{R'_b}{R'_a} = K' - 1 = 1.1522 - 1 = 0.1522$$

For  $R'_a = 1 \Omega$ ,  $R'_b = 0.1522 \Omega$ . Since the calculated gain is  $K' = 1.1522$ , but we require a gain of  $H' = 1$ , we need to perform gain compensation, i.e. reduction in this case. For gain reduction, we have to replace  $R'_1$  in the original Sallen-Key circuit with an equivalent parallel circuit as,

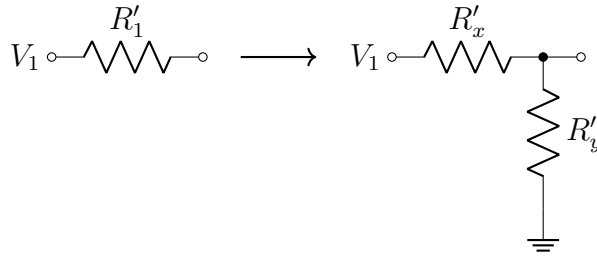


Figure 5:  $R'_1 = R'_x || R'_y$  equivalence circuit

From Figure 5, we have,

$$\begin{aligned} R'_1 &= R'_x || R'_y \\ \Rightarrow R'_1 &= \frac{R'_x R'_y}{R'_x + R'_y} \\ \Rightarrow R'_x + R'_y &= R'_x R'_y \end{aligned} \tag{11}$$

Performing gain compensation as,

$$\begin{aligned} \frac{R'_y}{R'_x + R'_y} &= \frac{H'}{K'} = \frac{1}{1.1522} = 0.8679 \\ \Rightarrow 0.8679 R'_x + 0.8679 R'_y &= R'_y \\ \Rightarrow 0.1321 R'_y &= 0.8679 R'_x \\ \Rightarrow R'_y &= 6.57 R'_x \end{aligned} \tag{12}$$

Solving for  $R'_x$  and  $R'_y$  using Equation 11 and Equation 12, we get,  $R'_x = 1.1522 \Omega$  and  $R'_y = 7.57 \Omega$

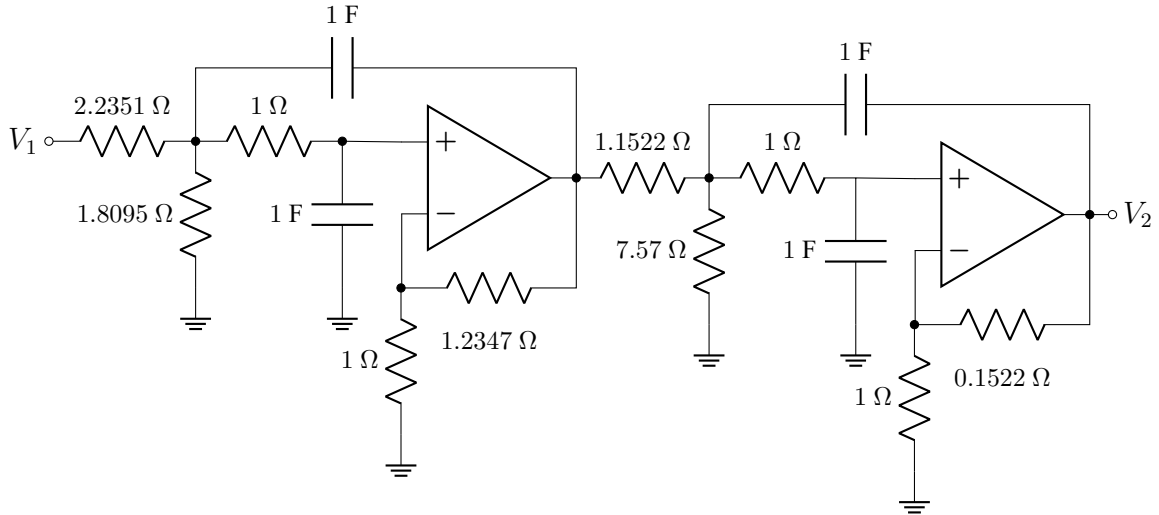


Figure 6: Fourth order butterworth normalized lowpass filter using Sallen-Key circuit

#### Problem 4

**Obtain the final design of lowpass filter having half power frequency of 3.1831 KHz and practically realizable elements. Realize it in circuit and observe the magnitude response. Also note down the gain in passband and half power frequency.**

Here,

Half power frequency of designed normalized filter ( $\omega_o$ ) = 1 rad/s

Required half power frequency ( $\Omega$ ) = 3.1831 KHz =  $2\pi \times 3.1831 \times 10^3$  rad/s

Frequency scaling factor ( $K_f$ ) =  $\frac{\Omega}{\omega_o} = \frac{2\pi \times 3.1831 \times 10^3}{1} \approx 20 \times 10^3$

Since the values of resistance is unchanged with this scaling factor, let us use the magnitude scaling factor  $K_m = 10^3$  to make the values practically realizable. The scaled elemental values are,

$$R_a = 1 \times 10^3 = 1 \text{ K}\Omega$$

$$R'_a = 1 \times 10^3 = 1 \text{ K}\Omega$$

$$R_b = 1.2347 \times 10^3 = 1.2347 \text{ K}\Omega$$

$$R'_b = 0.1522 \times 10^4 = 152.2 \Omega$$

$$R_x = 2.2351 \times 10^3 = 2.2351 \text{ K}\Omega$$

$$R'_x = 1.1522 \times 10^3 = 1.1522 \text{ K}\Omega$$

$$R_y = 1.8095 \times 10^3 = 1.8095 \text{ K}\Omega$$

$$R'_y = 7.57 \times 10^3 = 7.57 \text{ K}\Omega$$

$$R_2 = 1 \times 10^3 = 1 \text{ K}\Omega$$

$$R'_2 = 1 \times 10^3 = 1 \text{ K}\Omega$$

$$C_1 = \frac{1}{10^3 \times 20 \times 10^3} = 50 \text{ nF}$$

$$C'_1 = \frac{1}{10^3 \times 20 \times 10^3} = 50 \text{ nF}$$

$$C_2 = \frac{1}{10^3 \times 20 \times 10^3} = 50 \text{ nF}$$

$$C'_2 = \frac{1}{10^3 \times 20 \times 10^3} = 50 \text{ nF}$$

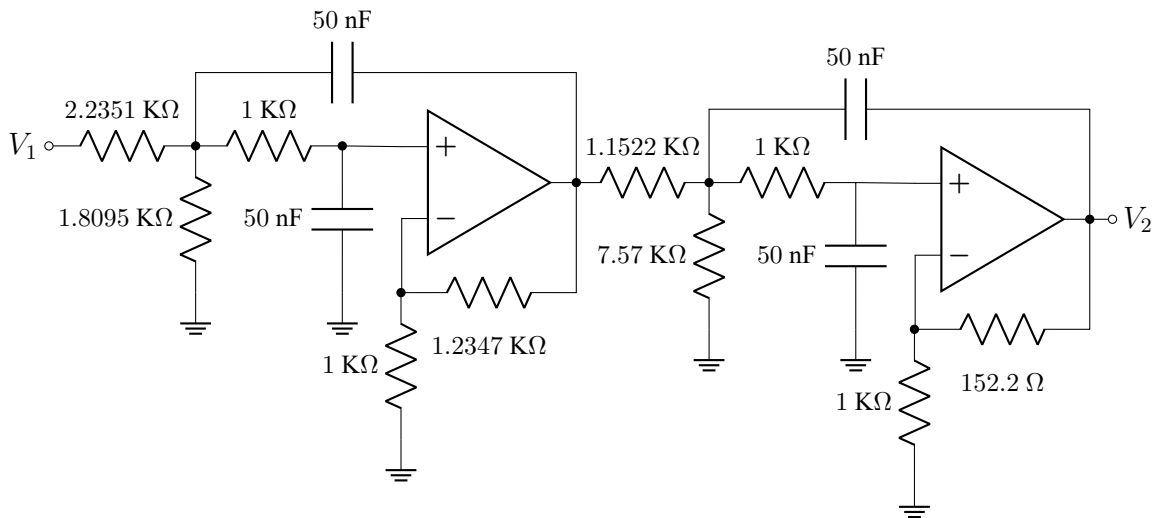


Figure 7: Fourth order butterworth lowpass filter at half power frequency 3.1831 KHz

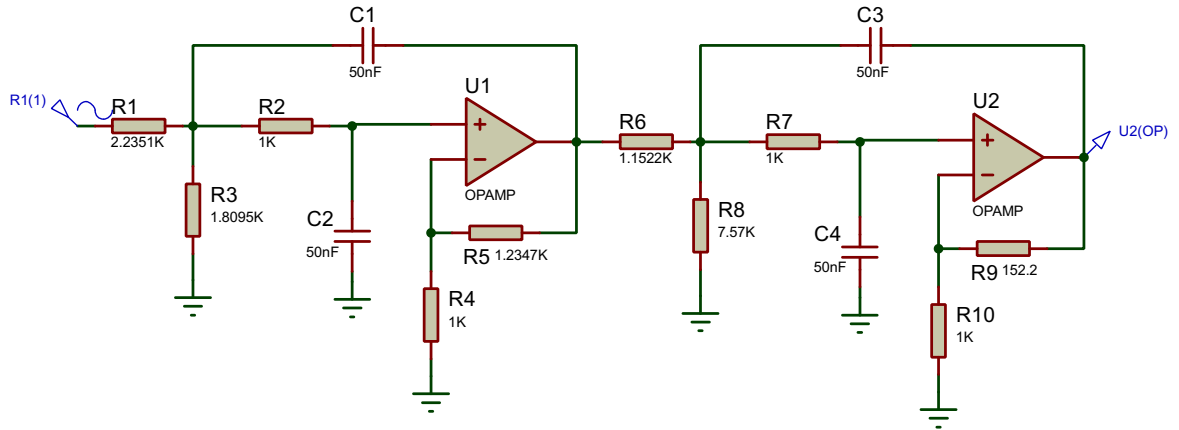
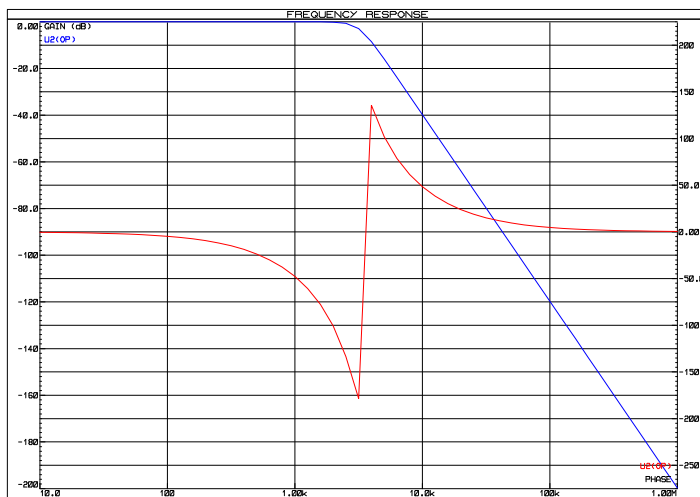


Figure 8: Proteus circuit for fourth order lowpass filter designed in Problem 4



Noted Values	
DC gain (in dB)	0
Half power frequency (in KHz)	3.177

Figure 9: Observation for lowpass filter designed in Problem 4

### Problem 5

**Apply RC-CR transformation in your filter circuit obtained in Problem 4, to obtain the highpass filter.**

RC-CR transformation is a technique used to convert lowpass filters to highpass filters, where each resistance is converted to a capacitor with capacitance  $\frac{1}{R}$  and each capacitor is converted to a resistance with value  $\frac{1}{C}$ . Converting the normalized filter in Figure 6 into an highpass

filter using RC-CR transformation, we need to perform gain compensation (reduction) for both stages as,

### Stage I

$$\begin{aligned}\frac{1}{s \times 1} &= Z_x || Z_y \\ \Rightarrow \frac{1}{s} &= \frac{\left(\frac{1}{sC_x}\right) \left(\frac{1}{sC_y}\right)}{\frac{1}{sC_x} + \frac{1}{sC_y}} \\ \Rightarrow \frac{1}{s} &= \frac{\frac{1}{s^2 C_x C_y}}{\frac{C_x + C_y}{s C_x C_y}} \\ \Rightarrow C_x + C_y &= 1\end{aligned}\tag{13}$$

Performing gain compensation as,

$$\begin{aligned}\frac{Z_y}{Z_x + Z_y} &= \frac{H}{K} = \frac{1}{2.2347} = 0.4474 \\ \Rightarrow 0.4474 Z_x + 0.4474 Z_y &= Z_y \\ \Rightarrow 0.5526 Z_y &= 0.4474 Z_x \\ \Rightarrow Z_y &= 0.8096 Z_x \\ \Rightarrow \frac{1}{sC_y} &= 0.8096 \frac{1}{sC_x} \\ \Rightarrow C_x &= 0.8096 C_y\end{aligned}\tag{14}$$

Solving for  $C_x$  and  $C_y$  using Equation 13 and Equation 14, we get,  $C_x = 0.4474$  F and  $C_y = 0.5526$  F.

### Stage II

$$\begin{aligned}\frac{1}{s \times 1} &= Z'_x || Z'_y \\ \Rightarrow C'_x + C'_y &= 1\end{aligned}\tag{15}$$



Performing gain compensation as,

$$\begin{aligned}
 \frac{Z'_y}{Z'_x + Z'_y} &= \frac{H'}{K'} = \frac{1}{1.1522} = 0.8679 \\
 \Rightarrow 0.8679Z'_x + 0.8679Z'_y &= Z'_y \\
 \Rightarrow 0.1321Z'_y &= 0.8679Z'_x \\
 \Rightarrow Z'_y &= 6.57Z'_x \\
 \Rightarrow \frac{1}{sC'_y} &= 6.57 \frac{1}{sC'_x} \\
 \Rightarrow C'_x &= 6.57C'_y
 \end{aligned} \tag{16}$$

Solving for  $C'_x$  and  $C'_y$  using Equation 15 and Equation 16, we get,  $C'_x = 0.8679$  F and  $C'_y = 0.1321$  F.

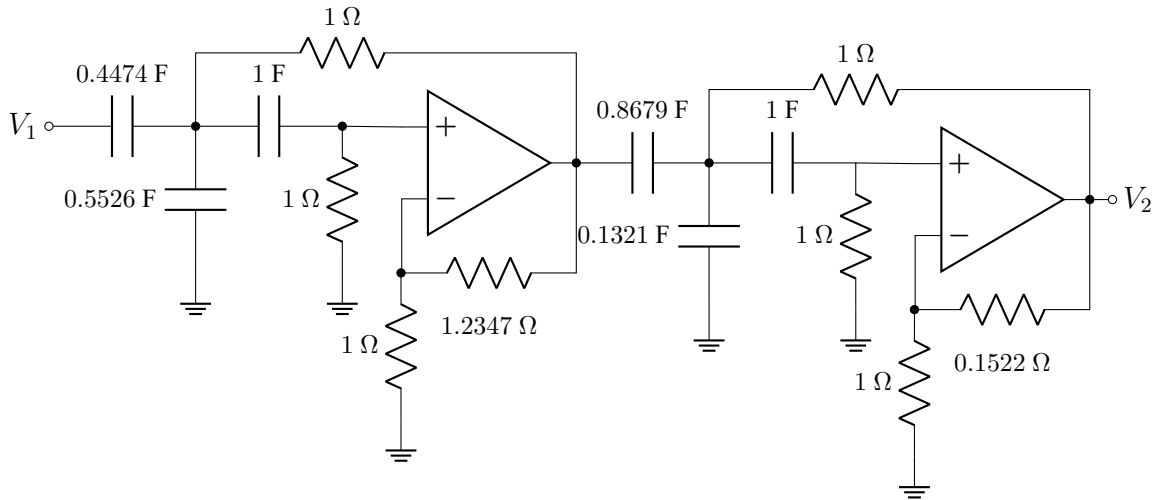


Figure 10: Fourth order butterworth normalized highpass filter using RC-CR transformation

### Problem 6

**Finally obtain a highpass filter (from Figure 10) having half power frequency of 4.775 kHz with practically realizable elements. Realize the network and observe the response and note down the gain in passband and half power frequency.**

Here,

Half power frequency of designed normalized filter ( $\omega_o$ ) = 1 rad/s

Required half power frequency ( $\Omega$ ) = 4.775 KHz =  $2\pi \times 4.775 \times 10^3$  rad/s

Frequency scaling factor ( $K_f$ ) =  $\frac{\Omega}{\omega_o} = \frac{2\pi \times 4.775 \times 10^3}{1} \approx 30 \times 10^3$

Since the values of resistance is unchanged with this scaling factor, let us use the magnitude scaling factor  $K_m = 10^3$  to make the values practically realizable. The scaled elemental values are,

$$R_a = 1 \times 10^3 = 1 \text{ K}\Omega$$

$$R'_a = 1 \times 10^3 = 1 \text{ K}\Omega$$

$$R_b = 1.2347 \times 10^3 = 1.2347 \text{ K}\Omega$$

$$R'_b = 0.1522 \times 10^4 = 152.2 \text{ }\Omega$$

$$R_1 = 1 \times 10^3 = 1 \text{ K}\Omega$$

$$R'_1 = 1 \times 10^3 = 1 \text{ K}\Omega$$

$$R_2 = 1 \times 10^3 = 1 \text{ K}\Omega$$

$$R'_2 = 1 \times 10^3 = 1 \text{ K}\Omega$$

$$C_x = \frac{0.4474}{10^3 \times 30 \times 10^3} = 14.913 \text{ nF}$$

$$C'_x = \frac{0.8679}{10^3 \times 30 \times 10^3} = 28.93 \text{ nF}$$

$$C_y = \frac{0.5526}{10^3 \times 30 \times 10^3} = 18.42 \text{ nF}$$

$$C'_y = \frac{0.1321}{10^3 \times 30 \times 10^3} = 4.4 \text{ nF}$$

$$C_2 = \frac{1}{10^3 \times 30 \times 10^3} = 33.33 \text{ nF}$$

$$C'_2 = \frac{1}{10^3 \times 30 \times 10^3} = 33.33 \text{ nF}$$

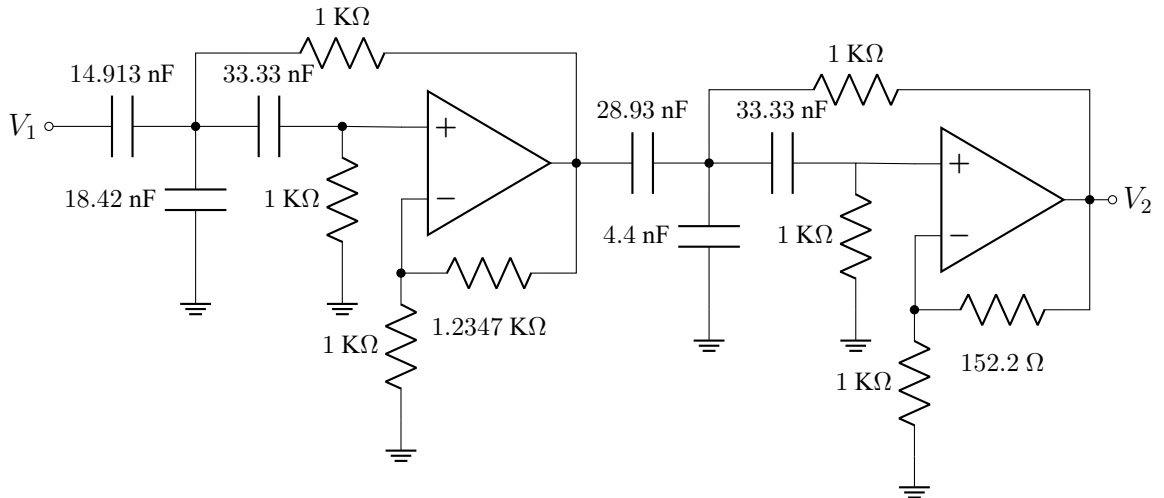


Figure 11: Fourth order butterworth highpass filter at half power frequency 4.775 KHz

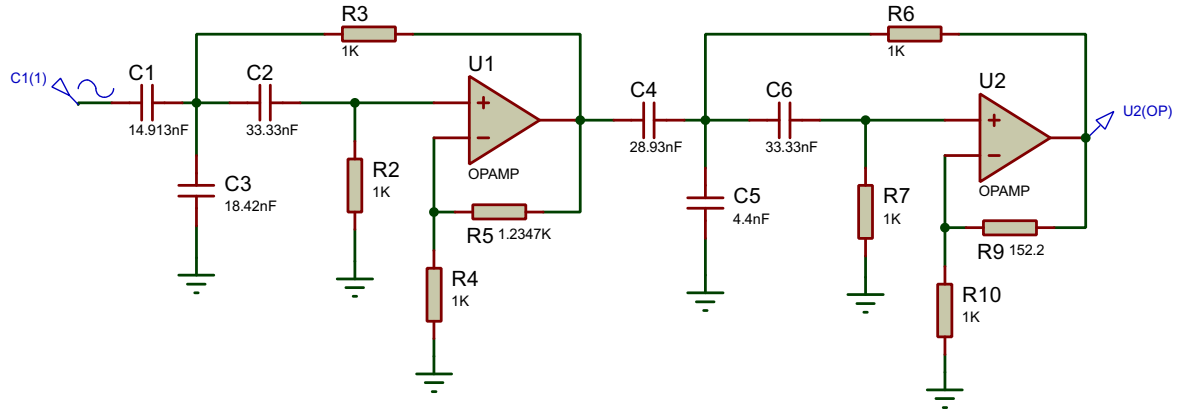
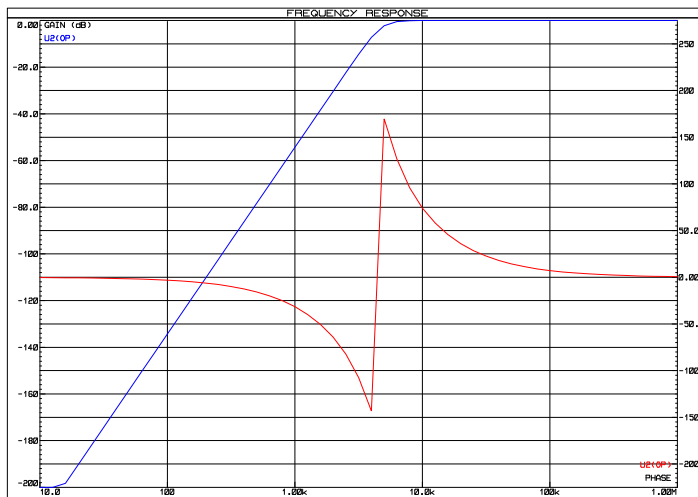


Figure 12: Proteus circuit for fourth order highpass filter designed in Problem 6



Noted Values	
DC gain (in dB)	0
Half power frequency (in KHz)	4.79

Figure 13: Observation for highpass filter designed in Problem 6

### 3 Discussion and Conclusion

In this lab experiment, we dealt with cascading of biquad circuits to design higher order filters using Sallen-Key biquad circuit shown in Figure 2. The derivation for the transfer function of a Sallen-Key circuit was understood as a part of the experiment. Then using the transfer function, a set of design-rules can be established, out of which the report uses the default (equal element values) rule to calculate the elemental values for the different stages of the

cascade network. Once the values are calculated, gain compensation (in the case of this lab report, gain reduction) was performed to get the desired gain. Once the normalized lowpass filter is obtained, it is scaled using the scaling formulae to get the desired response at required half power frequency. Next, RC-CR transformation is performed to convert the normalized lowpass filter to a normalized highpass filter. Once the normalized high pass filter is obtained, similar scaling is applied to get the desired response at desired half power frequency. Hence, the objectives of the lab were fulfilled with the understanding of the mentioned topics.