Lab 5: Analogue Filter Design

1 Objectives

The objective of this lab is to implement and analyse two analogue low pass filters.

2 Equipments

1. A signal generator
2. An oscilloscope
3. Breadboard (**bring your own one**)
4. Resistors and capacitors
5. One op-amp (e.g., LM741)

3 First order lowpass filter

In the first part of the lab we implement and measure the frequency response of a first order lowpass filter.

Task 1 Construct the circuit shown in Fig. 1 with $R = 10$ kΩ and $C = 10$ nF. This is in fact the integrator that we considered in Lab 4 but we now analyse it in the view of a low pass filter. The signal generator will be providing the input signal. Let $\boxed{f_c = \frac{1}{2\pi RC}}$ which is called the 3-dB cut-off frequency. You need to calculate f_c before moving on the next tasks.

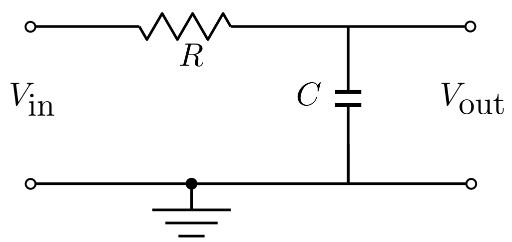

Figure 1: First-order lowpass filter.

Task 2 Apply the **sine wave** of 10 V (peak-to-peak) at the frequency $f = f_c$. Measure **the ratio** of the output voltage magnitude (i.e., V_{out}) to the input voltage magnitude (i.e., V_{in}) and the **phase shift** between the output and input voltages. Explain why f_c is called 3dB cutoff frequency.

Task 3 Repeat Task 2 for $f = 100$ Hz, $f = 1$ kHz, $f = 10$ kHz, and $f = 100$ kHz. You may write down the measured results into the following table which will be included in your report.

Input Frequency (kHz)	Gain $\frac{V_{\text{out}}}{V_{\text{in}}}$ (V/V)	Gain $20\log_{10}\frac{V_{\text{out}}}{V_{\text{in}}}$ (dB)	Phase $\angle\frac{V_{\text{out}}}{V_{\text{in}}}$ (°)
0.1			
1			
10			
100			

Table 1: Measured results for the first order lowpass filter shown in Fig. 1.

Task 4 Apply the **square wave** of 10 V and set the input frequency $f = 4f_c$. Observe and plot the output. If you take a picture of the output from the oscilloscope, make sure it is visible and the size is reduced before including in the report. Give your comments on the output. (is the output what you expect?)

Task 5 Repeat Task 4 for the **triangle wave**.

4 Second-order Low pass Filter

In the second part of the lab we implement and measure the frequency response of a second order low pass filter.

Task 6 Construct the circuit shown in Fig. 2, which is called a (second order) Sallen-Key low pass filter with $R_1 = R_2 = R = 10$ kΩ and $C_1 = C_2 = C = 10.$ nF. **Remember to connect the power supply ($\pm 15V$) to the operational amplifier**.

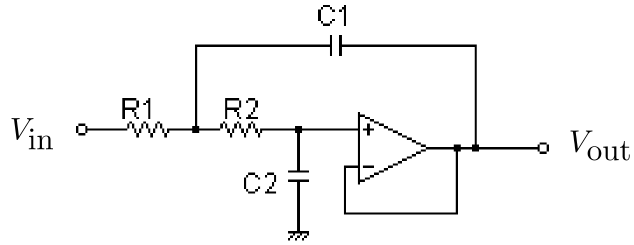

Figure 2: Sallen-Key lowpass filter.

The transfer function of the considered second order filter is given by

$$H(s) = \frac{\frac{1}{R_1C_1R_2C_2}}{s^2 + \left(\frac{1}{R_1C_1} + \frac{1}{R_2C_1}\right)s + \frac{1}{R_1C_1R_2C_2}} \tag{1}$$

If $R_1 = R_2 = R$ and $C_1 = C_2 = C$, then 3-dB cut-off frequency is $f_c = \frac{1}{2\pi RC}$.

Task 7 Repeat Tasks 2 to 5 for the Sallen-Key lowpass filter. You may record the obtained results into the following table. Based on the obtained results, you should comments on the quality of the second order lowpass filter, compared to that of the first order filter investigated in the previous section.

Input Frequency (kHz)	Gain $\frac{V_{\text{out}}}{V_{\text{in}}}$ (V/V)	Gain $20\log_{10}\frac{V_{\text{out}}}{V_{\text{in}}}$ (dB)	Phase $\angle\frac{V_{\text{out}}}{V_{\text{in}}}$ (°)
0.1			d
1			
10			
100			

Table 2: Measured results for the second order lowpass filter shown in Fig. 2.

5 Reports

Your report should have the following structure

- All the plots you obtained during the lab and the your comments and opinions on the results.

- Your detailed workings to arrive at the transfer function of the Sallen-Key lowpass filter given in equation (1).
- Your theoretical analysis showing that the obtained results in Task 3 match with the theory.
- A summary of what you gained in the lab.

5.1 Submission

- Each group submits a **single report**.
- To be uploaded via moodle **before the next Friday**.
- A penalty 10% of each day will be applied to late submission.
- Poorly written report is subject to deduction.