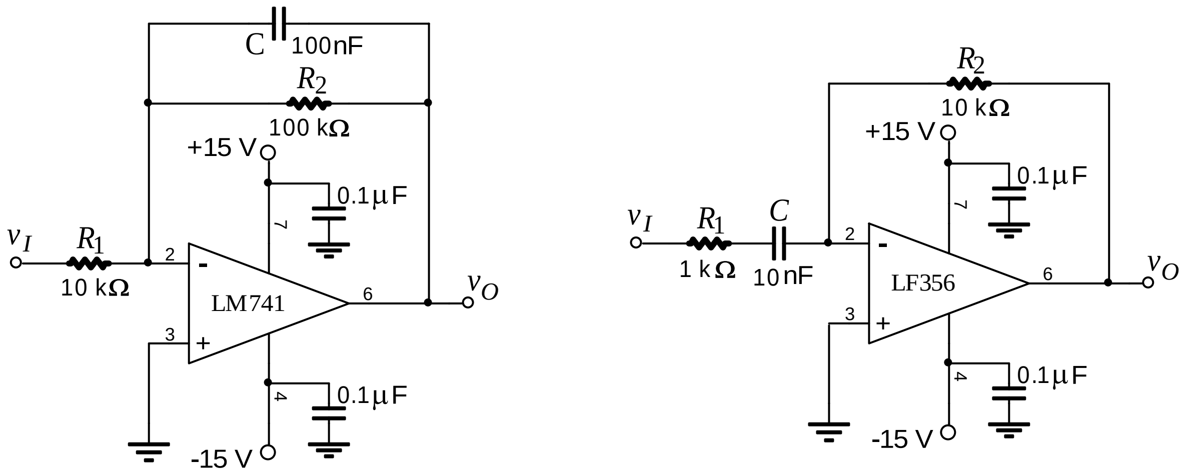
Lab 3: **Integrator and Differentiator with Op-Amps**

In this experiment you will use capacitors as well as resistors in the feedback circuits of your operational amplifier. All of these circuits can be thought of either in time domain terms [differential equations] or frequency domain terms [transfer functions], depending upon the application.

The circuits are shown in figure 1 and the board is presented in Annex 1.



a) Integrator / Low Pass Filter

b) Differentiator/ HighPass Filter

Figure 1: Circuits for op-amp integrator and differentiator

The low-pass filter

Figure 1.a) shows the integrator configuration; in the frequency domain, this circuit corresponds to a low-pass filter.

To determine the dc and low frequency gain (A_{v0}) apply at the circuit input a dc voltage, from $-V_D$ source, measure the dc output voltage and complete the first column of table 1 (consider the magnitude of the gain – without sign). To complete the rest of the table, apply a sine wave at the input with a magnitude of about 0.7 V rms.

Determine the break frequency (or bandwidth) and write the result in the last column of table 1. The output voltage at this point is the voltage at low frequency (dc, A_{v0}) divided by $\sqrt{2}$. Modify the frequency until the desired voltage (and gain) is obtained.

Table 1. The gain-frequency characteristic of the low-pass filter

f (Hz)	0	10	20	50	100	200	1 k	2 k	f_{B_Exp}=
V_i (V)									
V_o (V)									
A_v									
A_v (dB)									

Compare the experimental bandwidth with the theoretical one:

$$f_{B\_Th} = \frac{1}{2\pi \cdot R_2 C}.$$

Plot the magnitude of the transfer function (in dB) as a function of frequency. Consider a logarithmic scale for the frequency (from 1 Hz to 10 kHz) and consider the dc gain as the gain at 1 Hz. On the same plot, draw the asymptotes for this transfer function that you would expect based upon the calculated transfer function.

The ac integrator

Analyze the same circuit as an ac integrator. Apply at its input a square wave with amplitude of few volts and a frequency of few hundred Hz (e.g. 500 Hz, at least ten times greater than the break frequency).

Plot the input and output waves (one under the other) determine the input and output amplitude (peak-to-peak values) and complete table 2.

Table 2. The ac integrator

f (Hz)	V_{i_pp} (V)	$V_{o\_pp(Exp)}$ (V)	$V_{o\_pp(Th)}$ (V)	ε (%)

Compare the experimental output amplitude with the theoretical one.

The low-frequency differentiator

Figure 1.b) shows the circuit configuration for a low-frequency differentiator.

Apply to this circuit a triangular wave with amplitude of few volts and a frequency of about 1 kHz. The signal generator is connected to the lines 22 (active) and 23 (ground) – as represented in Annex 1.

Plot the input and output waves (one under the other) determine the input and output amplitude (peak-to-peak values) and complete table 3.

Table 3. The low-frequency differentiator

f (Hz)	V_{i_pp} (V)	$V_{o\_pp(Exp)}$ (V)	$V_{o\_pp(Th)}$ (V)	ε (%)

Compare the experimental output amplitude with the theoretical one.

Observe the output as a function of frequency. Verify that this circuit does indeed operate as a differentiator. Notice that at higher frequencies you will see that the slew-rate limit of the amplifier dominates the circuit performance as the input amplitude is increased. At what frequency does the performance of your differentiator begin to deteriorate?

The high-pass filter

In the frequency domain, the low-frequency differentiator can be thought of a high-pass filter. Apply a sine wave with a magnitude of about 0.7 V rms.; modify the frequency and complete table 3. Measure the input voltage at higher frequencies and readjust it if it is necessary. Determine the break frequency in the last column of table 3.

Table 3. The gain-frequency characteristic of the high-pass filter

f (Hz)	200	500	1 k	2 k	5 k	10 k	20 k	50 k	100k	200k	f_{B_Exp}=
V_i (V)											
V_o (V)											
A_v											
A_v (dB)											

Compare the experimental bandwidth with the theoretical one: $f_{B\_Th} = \dfrac{1}{2\pi \cdot R_1 C}$.

Plot the sine-wave frequency response. On the same plot, draw the asymptotes for the transfer function that you would expect (based upon the calculated transfer function).

Annex 1: The board with the fig.1.a) circuit.