Electronics Laboratory

Winter semester 2025

Lab 4 – Op Amps

Name ______________________ Reg. Nr. ____________

Name ______________________ Reg. Nr. ____________

Score and comments (only for tutors, please leave blank)

Please fill out this cover sheet and submit it with your lab report.

4 Lab 4 – Op Amps

Introduction

This lab considers the operational amplifier, and three important basic op amp circuits will be analyzed, simulated and measured: the basic non-inverting amplifier; the voltage-to-current converter; and the transimpedance amplifier. The last two for the basis for an optical transceiver (the “Optokoppler”), in which a signal is transmitted optically from a light source (an LED) to a light detector (a photodiode). We will see that op amps are important components in realizing such a transceiver.

Notes

- Download the SPICE op amp model `TL074.txt`.

4.1 Preparation

Please answer the following questions *before* beginning with the simulations or experiments. Then complete the preparation quiz "Preparation 4.1 – Op Amps" on Ilias using your results. The points for this preparation section will only be awarded via Ilias.

4.1.1 The ideal op amp

Think about the parameters which define an ideal op amp.

4.1.2 Non-inverting amplifier

For a non-inverting amplifier, such as that shown in Figure 4.2.1, what would the gain be if $R_1 = 220\,\Omega$ and $R_2 = 470\,\Omega$?

4.1.3 Maximum output voltage

What are the absolute minimum and maximum limits for the output voltage of an op amp circuit?

4.1.4 Mysterious amplifier

What kind of circuit results if, for a non-inverting amplifier, $R_1 \to \infty$ and $R_2 \to 0$? What are its characteristics?

4.1.5 Transimpedance amplifier

For a transimpedance amplifier, such as that shown in Figure 4.4.1, let's take $R_f = 10\,\mathrm{M\Omega}$. What is the value of the ratio V_o/I_{pd}? Ignore R_o.

4.1.6 Voltage-to-current converter

In a voltage-to-current converter, such as that shown in Figure 4.3.1, we set $R_1 = 470\,\Omega$. What voltage needs to be applied to the input to generate a current of $1\,\mathrm{mA}$?

4.2 Non-inverting amplifier

To introduce the op amp lab, we will simulate and measure the frequency response of a simple non-inverting amplifier, as shown in Figure 4.2.1.

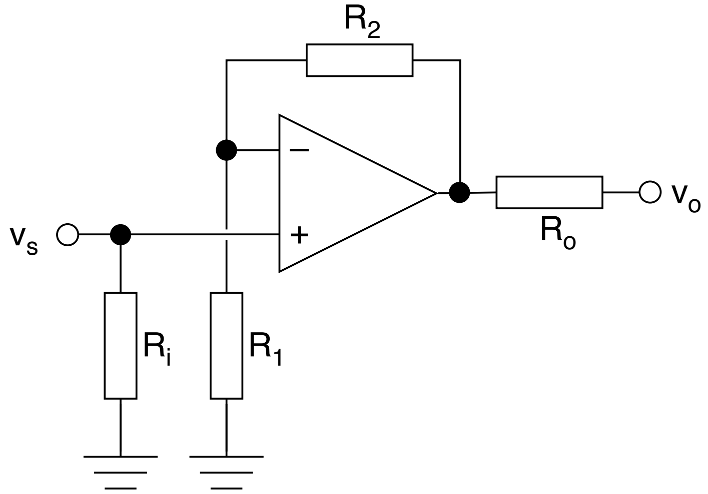

Figure 4.2.1

4.2.1 Simulation

(a) Set up a SPICE simulation of the circuit shown in Figure 4.2.1. Use $R_i = 10\,\mathrm{k}\Omega$, $R_1 = 2\,\mathrm{k}\Omega$, $R_2 = 18\,\mathrm{k}\Omega$ and $R_o = 10\,\mathrm{k}\Omega$. Use the TL074 op amp model[1] via the `.inc` directive and don't forget the $\pm 15\,\mathrm{V}$ power supply.

(b) Using the SPICE directive `.ac`, perform a frequency analysis from 5 kHz to 5 MHz with 500 measurement points per decade. Save your data.

(c) Now remove R_1 (essentially setting $R_1 \to \infty$).

(d) Again perform a frequency analysis from 5 kHz to 5 MHz with 500 measurement points per decade. Save your data again.

(e) Plot the gain (in dB) and the phase of both variants in a single graph with a logarithmic abscissa.

(f) Determine the maximum gain of both variants.

(g) Determine the gain-bandwidth product for both variants at the point $A = 0\,\mathrm{dB}$.

(h) Describe and give reasons for the shape of this characteristic curve, and pay particular attention to prominent points and correlations or deviations from what you expect.

[1] Insert the op amp component `opamp2`, and then specify "X" for `Prefix` and "TL074" for `Value`.

4.2.2 Measurement

In the "OP-AMPLIFIER" section of the electronics board, we will use the *non-inverting amplifier* circuit, shown in Figure 4.2.2.

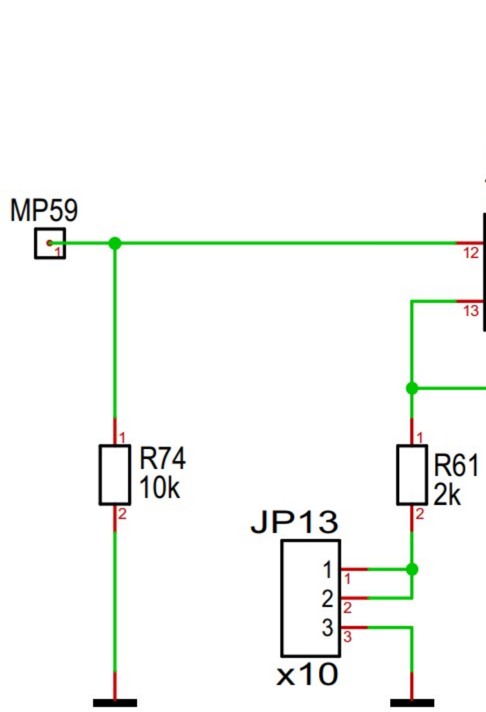

Figure 4.2.2: Schematic of the *non-inverting amplifier* circuit

(a) Apply the voltage generator input signal *W1* to *MP59* and also attach it to the oscilloscope *CH1*.

(b) Connect the output voltage at measurement point *MP51* to the oscilloscope *CH2*.

(c) Close the jumper *JP13*.

(d) In *WaveForms - Network*, set a proper input voltage value (amplitude 15 mV) and perform a frequency analysis from 5 kHz to 5 MHz by making a single recording of the output signal with a total of 500 measurement points. Save your data.

(e) Open the jumper *JP13*.

(f) In *WaveForms - Network*, again perform a frequency analysis from 5 kHz to 5 MHz, with a total of 500 measuring points.

(g) Plot the gain (in dB) and phase for both variants and determine the maximum gain values.

(h) Determine the gain-bandwidth product for both variants at the point $A = 0\,\text{dB}$.

4.3 Voltage-to-current converter

We will now consider a voltage-to-current converter which, as we saw in lecture, can be used to operate a current-driven LED.

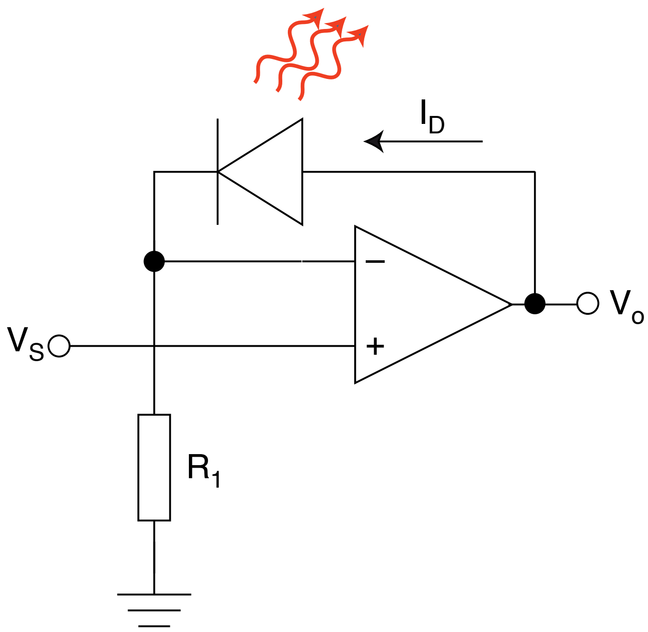

Figure 4.3.1

4.3.1 Simulation

(a) Set up a SPICE simulation of the voltage-to-current converter circuit shown in Figure 4.3.1. Use the same op amp as in the previous simulation (Section 4.2.1).

(b) Set $R_1 = 470\,\Omega$.

(c) For the LED, use a generic LED model from the catalogue, name it "red" and then use the directive `.model red D (N=3.73)` (as you did in the LED simulation of Lab 1, Section 1.3.1).

(d) Define a dc source as the input voltage V_s. Using the `.dc` directive, define a voltage ramp from $-10\,\text{V}$ to $10\,\text{V}$ with $10\,\text{mV}$ steps.

(e) Measure the LED current and plot this as a function of V_s.

(f) Find a way to determine the power dissipated in the LED and plot this as a function of V_s. Compare with the previous plot.

(g) Describe the characteristics and explain why they look like they do. How do you expect the intensity of light emission from the LED to vary with V_s?

4.3.2 Measurement

In the "OP-AMPLIFIER" section of the electronics board, we will use the *voltage-to-current converter* circuit (the transmitter part of the optical transceiver), shown in Figure 4.3.2.

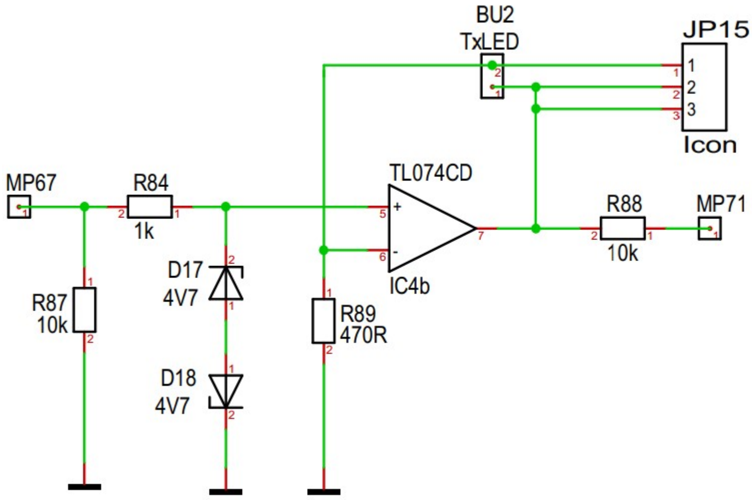

Figure 4.3.2: Schematic of the *voltage-to-current converter* circuit

(a) Define an input signal V_s varying from $-10\,\text{V}$ to $10\,\text{V}$ at $1\,\text{Hz}$ and connect it to the measurement point *MP67*. Tip: you might need the amplifier to double the voltage from the voltage generator *W1*. Tip 2: you might not be able to reach $-10\,\text{V}$ to $10\,\text{V}$, but rather $-8.9\,\text{V}$ to $8.9\,\text{V}$.

(b) Find a way to measure the LED current and plot this as a function of V_s. Tip: use the approach you came up with in Section 4.3.1(e). Tip 2: *pin 1* of jumper JP15 is connected to the inverting node of the opamp; *pin 2* and *pin 3* are connected to the output voltage V_o at the measurement point *MP71*.

(c) Determine a way to measure the voltage drop across the LED. Then use this voltage and the LED current to plot the LED power as a function of V_s. Tip: you might need more than two oscilloscopes to measure the signals, so do the measurement one by one and save the data.

(d) Describe and give reasons for the shape of the resulting characteristic curve. How do your measurement results compare with the simulation?

(e) Determine the maximum input voltage $V_{s(max)}$ up to which the output V_o is still linear.

4.4 Transimpedance Amplifier

Finally, we will look at the inverse of a voltage-to-current converter, namely a current-to-voltage converter, typically referred to as a transimpedance amplifier. In this example, the current will be generated by a photodiode exposed to light.

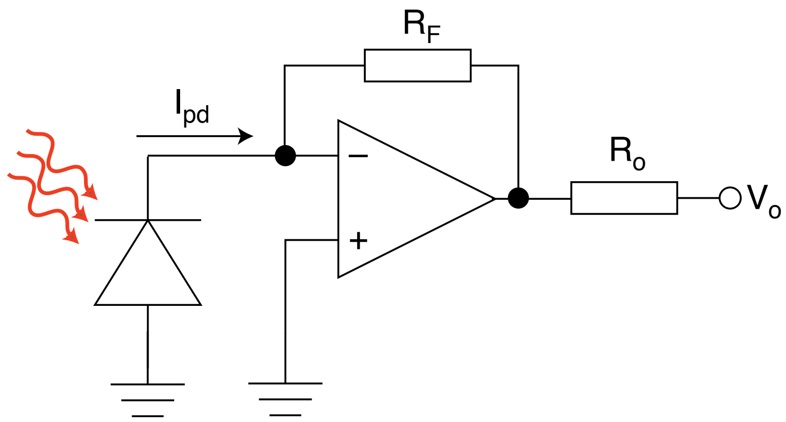

Figure 4.4.1

4.4.1 Simulation

(a) Set up a SPICE simulation of the transimpedance amplifier shown in Figure 4.4.1. Again use the same op amp as in the first simulation (Section 4.2.1).

(b) Take $R_f = 10\,\text{M}\Omega$ and $R_o = 10\,\text{k}\Omega$.

(c) Since a photodiode generates a current in response to light, replace the photodiode with a current source I_{pd}. Using the `.dc` directive, define a current ramp from $-500\,\text{nA}$ to $500\,\text{nA}$ with $10\,\text{nA}$ steps.

(d) Plot the output voltage V_o as a function of I_{pd}.

(e) Describe the characteristic and estimate the transimpedance factor (V_o/I_{pd}). What circuit parameter determines this value?

4.4.2 Measurement

In the "OP-AMPLIFIER" section of the electronics board, we will now use the entire optical transceiver, consisting of the *voltage-to-current converter* circuit, Figure 4.3.2 above, and the *transimpedance amplifier* circuit, shown in Figure 4.4.2 below. In this transceiver, the light emitted by the LED at BU2 (labeled *TxLED* on the board) is detected by the photodiode[2] at D16 (labeled *RxLED* on the board), which then provides

[2]Actually, an LED is used as a photodiode at D16. An LED emits light if a current is injected to it, but can also be operated "backwards" and generate a current if light is incident on it.

the input to the transimpedance amplifier.

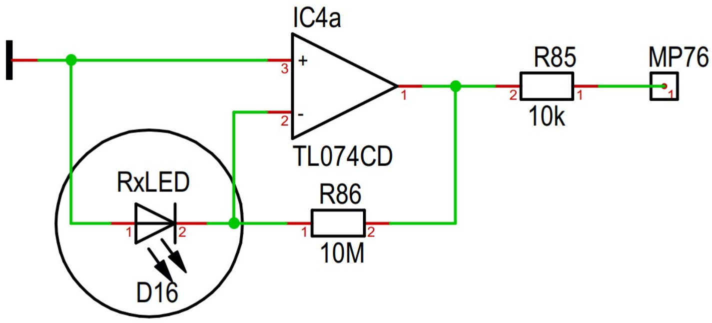

Figure 4.4.2: Schematic of the *transimpedance amplifier* circuit

(a) Using the same circuit as in Section 4.3.2, apply an input signal V_s ($-10\,\mathrm{V}$ to $10\,\mathrm{V}$ at $1\,\mathrm{Hz}$) to the measurement point *MP67*. This input voltage will generate light from LED *TxLED*.

(b) Now measure the output voltage V_o at the measurement point *MP76* of the circuit in Figure 4.4.2.

(c) From your analysis of the transimpedance amplifier circuit, estimate the current flowing through *D16* I_{pd}.

(d) Plot V_o as a function of I_{pd} in a diagram and compare it with your simulation. In which direction does the current flow and why?

(e) Plot $|I_{pd}|$ and V_o as a function of V_s in a single diagram.

(f) Explain the characteristics that you measure.