

Physics laboratory 3

Task 7. Operational amplifier

Introduction

An operational amplifier (OA) is an electrical circuit widely used in almost all areas of analogue electronics. OA can be essentially described as a high gain differential voltage amplifier. In other words, OA provides an output voltage that is many times higher than the difference of the potentials between the two OA inputs (i.e. the input voltage). An ideal OA has an infinite amplification, infinite input resistance (thus there are no current losses at the OA inputs), zero output resistance and an infinite bandwidth (i.e. OA amplifies all frequencies equally). A real OA electrical circuit delivers varying amplifications — sometimes less than 1 000 and sometimes more than 10^6 . The input resistance is usually at least $1\text{ M}\Omega$ and the output resistance is usually around $50\ \Omega$. The bandwidth of a real OA is in the range of few kHz to hundreds of MHz, however, the amplification decreases and a phase difference between the input and the output increases for higher frequencies.

An electronic schematic of an OA is shown in Fig. 1. This electrical component typically has two inputs (an inverting input and a non-inverting input) and one output. If the non-inverting input potential is higher than the inverting input potential, the output voltage polarity is the same as the input voltage polarity. If the inverting input potential is higher than the non-inverting input potential, the output voltage polarity is opposite the polarity of the input voltage polarity. Besides the input and output pins, an OA has also power-in pins for positive as well as negative voltage.

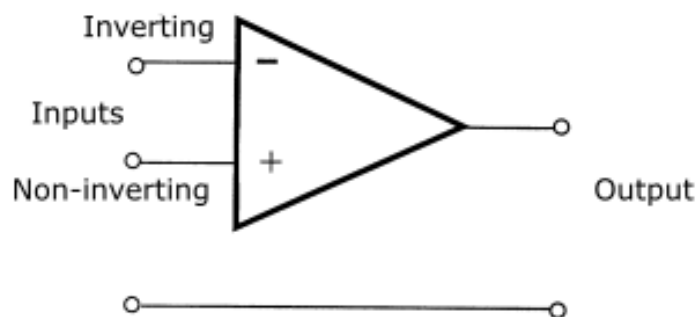


Figure 1: An electronic schematic of an operational amplifier.

In this laboratory you will work with some typical OA applications. A circuit board with an OA and all the necessary components (resistors, capacitors, diodes, leads) easily connectible to the circuit board are available. The OA has its own dedicated 15 V power supply. Moreover, two direct current (DC) and one alternating current (AC) power supplies are available. The frequency

of the AC power supply is tunable from 10 Hz to several MHz. Several multimeters are used for the measurement of the DC voltage; an oscilloscope is used to measure the AC voltage. Avoid saturating the output voltage in all measurements (except for the comparator measurement no. 5). Choose correct safe input voltage to achieve the output voltage not higher than 10 V.

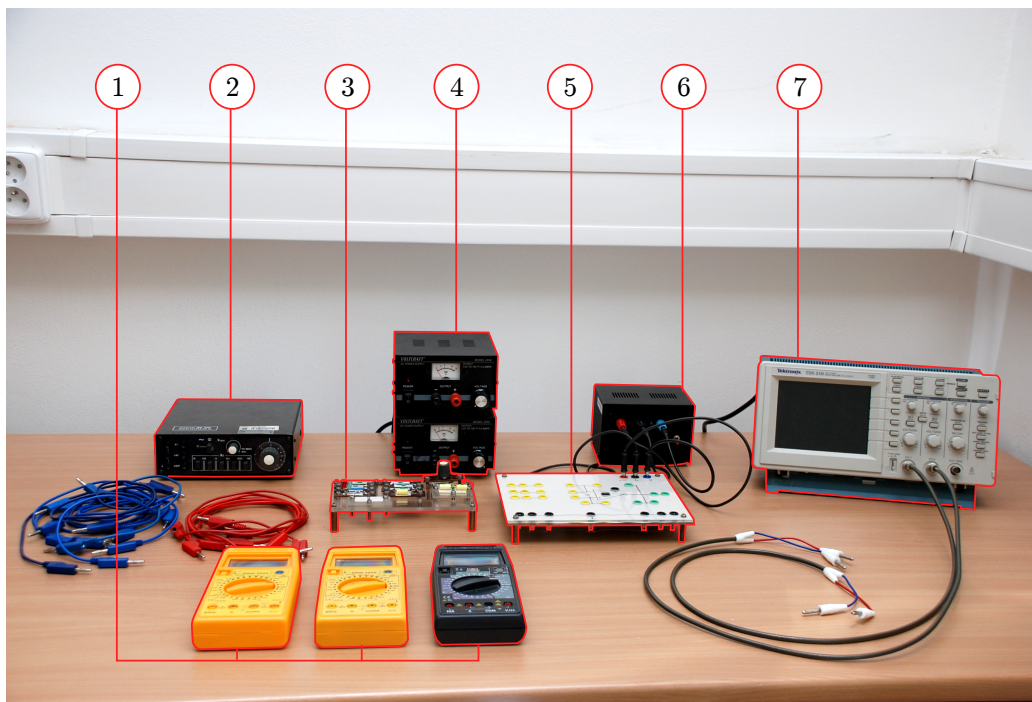


Figure 2: Operational amplifier setup: 1. Multimeters. 2. AC power supply. 3. Electrical components. 4. DC power supplies. 5. Circuit board with the operational amplifier. 6. Power supply. 7. Oscilloscope.

Comparator

To understand the principle of an OA it is good to try its simple application in comparing two voltages. Because the OA multiplies the difference of the input voltages by a large number, it can compare two input signals with a high sensitivity (i.e. distinguish, which one is even slightly higher). An example of a comparator is shown in Fig. 3. This type of a circuit well demonstrates the function of an OA, however, much faster components are nowadays used in practice.

Task

Try how this circuit behaves and how does the OA output voltage react to the difference between the input voltages.

Connection of the OA with inverting input

An electrical circuit diagram of an inverting amplifier is shown in Fig. 4. The input voltage is connected to the inverting input via resistor R_1 , the second input is grounded. The input voltage is amplified and a voltage of opposite polarity appears at the output. The output voltage is looped back onto the input voltage via a feedback resistor and this output voltage of opposite polarity decreases the voltage in the point A. Because of the high OA amplification, the circuit is stabilized at the point, where the voltage between the inputs is near zero. The non-inverting input is grounded, therefore the inverting input potential (in the point A) is also zero. As the OA input

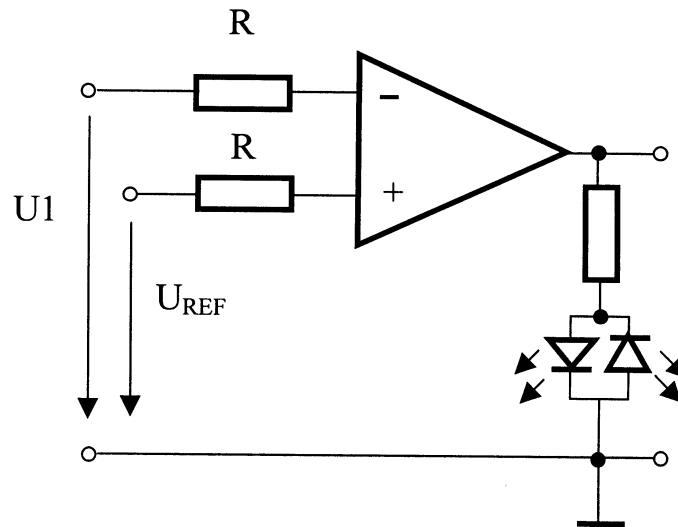


Figure 3: Comparator.

resistance is high, the current through the resistor R_1 must be identical to the current through the feedback resistor R_2 . Therefore $U_1/R_1 = -U_0/R_2$ and this OA circuit system amplifies the voltage according to

$$U_0 = -\frac{R_2}{R_1} U_1 \quad (1)$$

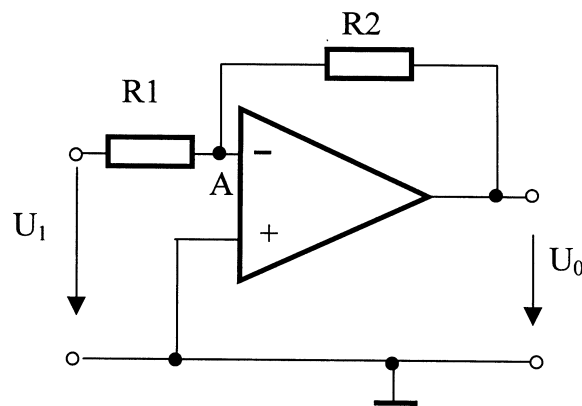


Figure 4: Electrical circuit of OA connected with the inverting input.

Make these measurements for the aforementioned electrical circuit:

- Connect such resistors, so that the whole circuit amplifies 2 times. Verify that the circuit connection of the inverting amplifier works according to eq. (1) for several different input DC voltages. Fit the measured data with a line that should cross the zero point and its slope should give the theoretical amplification.
- Measure the bandwidth of the OA with inverting amplifier. The bandwidth is the maximal frequency, where the operational amplifier works well at a given electrical circuit. This limit is usually taken as the frequency at which the amplification decreases by 3 dB over the amplification of low-frequency signals $A_{u,max}$ theoretically described by eq. (1). The

decrease of 3 dB corresponds to the decrease of the amplification to the value of $A_{u,max}/\sqrt{2}$. As you will measure a wide range of frequencies, it is convenient to plot the graph of the amplification dependent on the frequency logarithm.

Low-pass filter

By a simple change in the electrical circuit with inverting amplifier (Fig. 4) you can get a circuit that allows only the low frequencies from the input signal (see Fig. 5) to pass through. The added capacitor reduces the impedance of the feedback loop for high frequencies, which leads to the amplification (gain) of

$$A_u = -\frac{R_F}{R_A} \frac{1}{1 + i\omega C_F R_F} \quad (2)$$

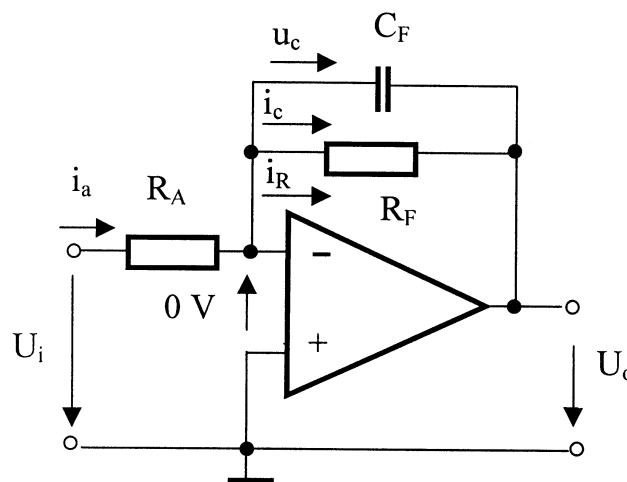


Figure 5: Low-pass filter.

Task

Measure the gain dependence on the frequency and determine the bandwidth from the graph. Plot the theoretical dependence of the gain on the frequency in the graph as well. Besides the gain, include also a commentary for the behaviour of the phase difference between the input and the output signal.

Non-inverting input amplifier connection

Look at the electrical circuit with the non-inverting amplifier diagram in Fig. 6. The input voltage is applied to the non-inverting input. The inverting input is grounded through resistor R_1 and the feedback loop is connected to the same input via resistor R_2 . Think about what this circuit will do before the laboratory. The relation between the input and the output voltage can be easily deduced using the same line of thought as to the one leading to equation (1).

Task

Verify the validity of your equation during the laboratory.

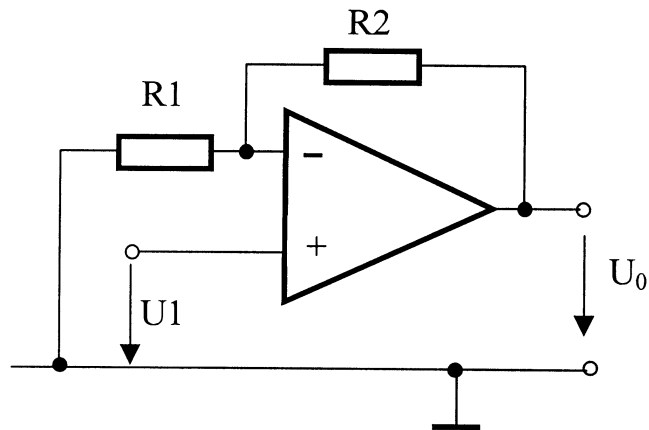


Figure 6: Electrical circuit with non-inverting amplifier.

Differential amplifier

A differential amplifier can be connected by a combination of the inverting and the non-inverting amplifier as is shown in Fig. 7. The following equation is valid for its output voltage:

$$U_O = U_2 \cdot \frac{R_4(R_1 + R_2)}{R_1(R_3 + R_4)} - U_1 \cdot \frac{R_2}{R_1}. \quad (3)$$

When we choose resistors $R_1 = R_3 = 10 \text{ k}\Omega$ and $R_2 = R_4 = 20 \text{ k}\Omega$, we can simplify this equation to:

$$U_O = 2(U_2 - U_1) \quad (4)$$

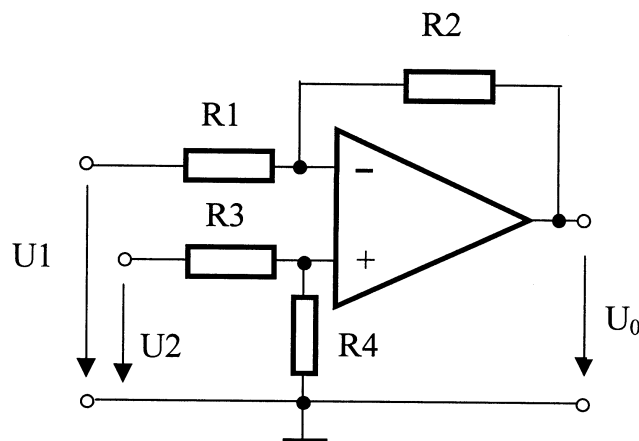


Figure 7: Differential amplifier.

Task

Connect the differential amplifier and verify equation (4).

Differentiator

Task

There are 4 different OA circuit diagrams in Fig. 8. Consider which one works as a differentiator before the laboratory. A differentiator is a circuit that is designed in such a way that the output of the circuit is directly proportional to the rate of change (the time derivative) of the input. Verify your chosen circuit during the laboratory.

You will need to solder one component to make the differentiator circuit.

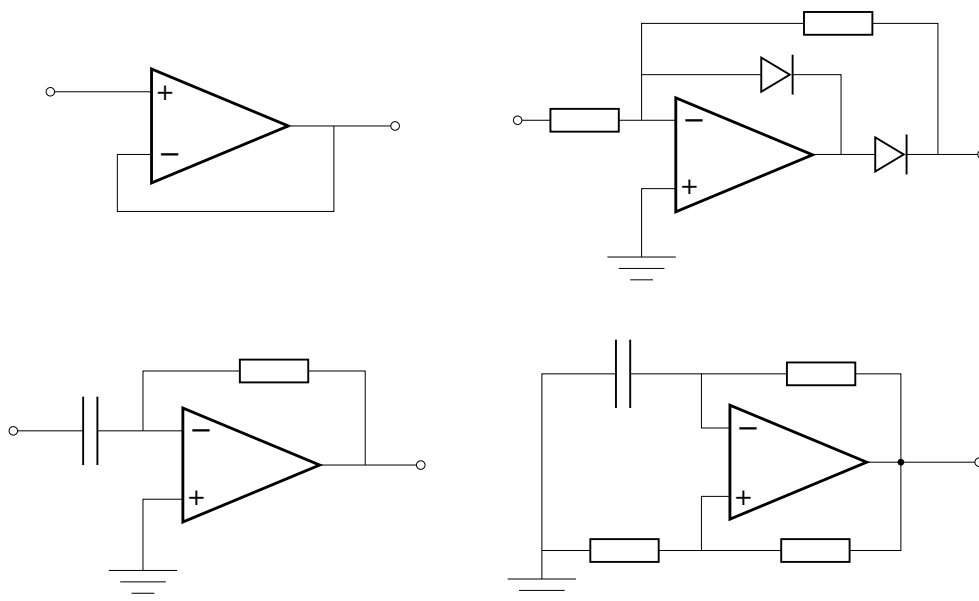


Figure 8: Circuit diagrams of an operational amplifier.

Puzzle lovers can also figure out what the other circuit diagrams in Fig. 8 do. Can you find out how to build a summing amplifier or a device behaving as a negative resistance using an operational amplifier? However, this is above the basic scope of this laboratory.