Operational amplifier

Introduction

An operational amplifier (op-amp) is a differentional high-gain electronic voltage amplifier which is widely used in numerous electronic circuits. In other words, an operational amplifier produces on its output voltage that is typically 10^6-times larger than the difference between voltages on its inputs. An ideal op-amp has infinite gain, infinite input impedance (i.e. zero currents flowing to the inputs) and zero output impedance. Real op-amps usually have voltage gain over 10 000, input resistivity at least 50 kΩ and output impedance approx. 50 Ω.

Usually, op-amps have two inputs (inverting and non-inverting) and one output. When the potential of the non-inverting input is higher than the potential of the inverting input, the output voltage is positive and vice-versa.

Tasks

1. Operational amplifier connected in the inverting amplifier configuration

The inverting amplifier configuration (see fig. 1) well demonstrates the behaviour of op-amps. Since the output voltage cannot reach infinite, the voltage between the inputs must be approx. zero. The non-inverting input is grounded in this configuration. Therefore, the potential of the inverting input (point A) must be zero as well. Further, the current flowing through the resistor R_1 must be identical with current flowing through the resistor R_2 since the input impedance of the operational amplifier is high. Consequently, $U_1/R_1 = -U_O/R_2$ and the configuration amplifies the input voltage according to the relation

$$U_O = -\frac{R_2}{R_1}U_1 \tag{1}$$

In this task, you will

- connect the operational amplifier in the inverting configuration. Choose such resistors that the configuration amplifies the input signal by ca 2 and verify whether the circuitry works well. Several pairs of the input and output DC voltages should be measured and the slope of the measured dependence should agree with the calculated gain.

- determine the bandwidth of the particular operational amplifier. Bandwidth is the frequency range where the op-amp amplifies the signal, conventionally range where the gain does not drop below $A_{u,max}/\sqrt{2}$. $A_{u,max}$ is the maximum gain for low frequencies

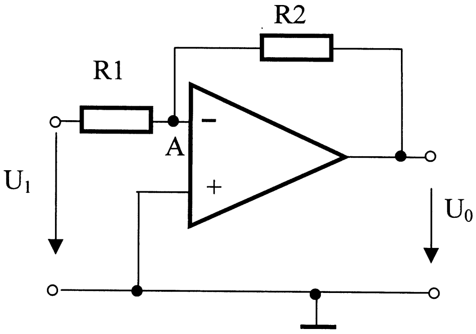

Figure 1: *Operational amplifier connected in the inverting amplifier configuration.*

given by eq. (1). Connect AC signal to the circuitry and measure the dependence of the gain on the frequency by means of an oscilloscope. From a graph showing this dependence define the op-amp bandwidth.

2. Low-pass filter

The configuration in the fig. 2 is similar to the inverting amplifier configuration (fig. 1). However, the capacitor decreases the impedance of the feedback branch for high frequencies leading to the gain

$$A_u = -\frac{R_F}{R_A}\frac{1}{1 + \mathrm{i}\omega C_F R_F} \tag{2}$$

In this task, measure the dependence of the gain of the low-pass filter depicted in the fig. 2 on frequency and define its bandwidth.

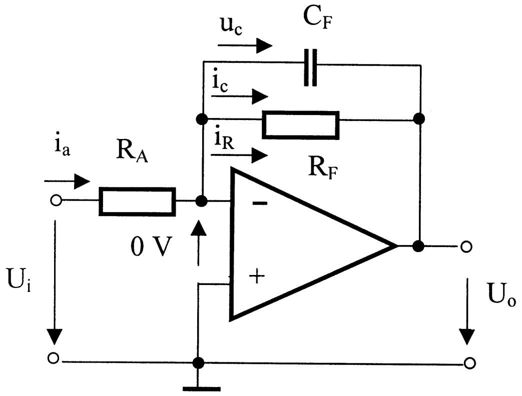

Figure 2: *Low-pass filter configuration.*

3. Non-inverting amplifier configuration

Take a look at the configuration in the fig. 3. The input voltage is connected to the non-inverting input whereas the inverting input is connected to ground through the resistor

R$_1$. The feedback is connected to the inverting input through the resistor R$_2$. By means of a procedure analogical to the procedure used in the task 1 you should calculate what makes the configuration in the fig. 3. During the practicum, you will verify whether your calculation was right.

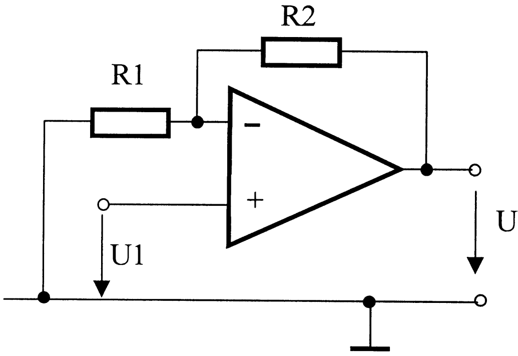

Figure 3: *Operational amplifier connected in the non-inverting amplifier configuration.*

4. Differential amplifier

Verify whether the configuration in the fig. 4 amplifies the difference between two input voltages in accordance with the equation

$$U_0 = U_2 \frac{R_4(R_1 + R_2)}{R_1(R_3 + R_4)} - U_1 \frac{R_2}{R_1} \tag{3}$$

For example if your choose $R_1 = R_3 = 10$ kΩ and $R_2 = R_4 = 22$ kΩ, you get:

$$U_O = 2{,}2\,(U_2 - U_1) \tag{4}$$

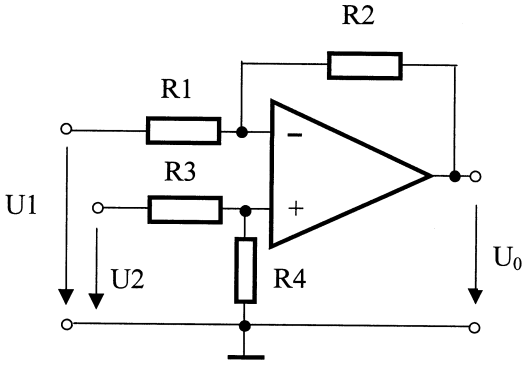

Figure 4: *Operational amplifier connected in the differential amplifier configuration.*

5. Voltage comparator

Since operational amplifier multiplies the difference between the input potential by a very high number, it is very sensitive tool to compare two signals. Fig. 5 shows an example of the comparator configuration. Explore behaviour of this comparator.

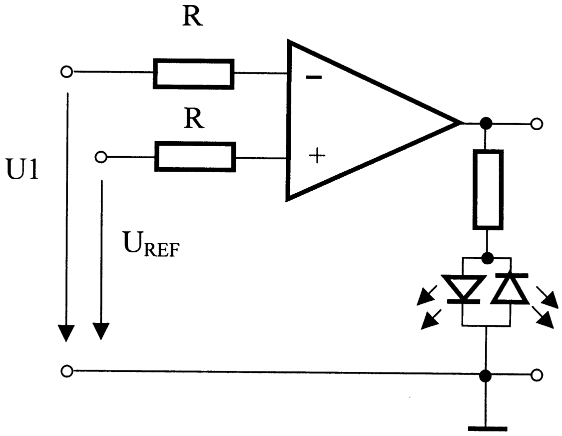

Figure 5: *Comparator configuration.*

6. Differentiator

There are four various configurations with an op-amp in the fig. 6. One of them is a differentiator, it means that its output voltage is directly proportional to the derivative of the input voltage. Verify whether this configuration works according to the mentioned statement. During this task you will have to solder one component to the network.

Who likes brain-teasers, can try to guess, what are the other configurations in the fig. 6. In addition, you can try to think out how to make a network with an op-amp which behaves as a summing amplifier of as a negative resistivity. But these tasks are outside of the scope of an usual practicum.

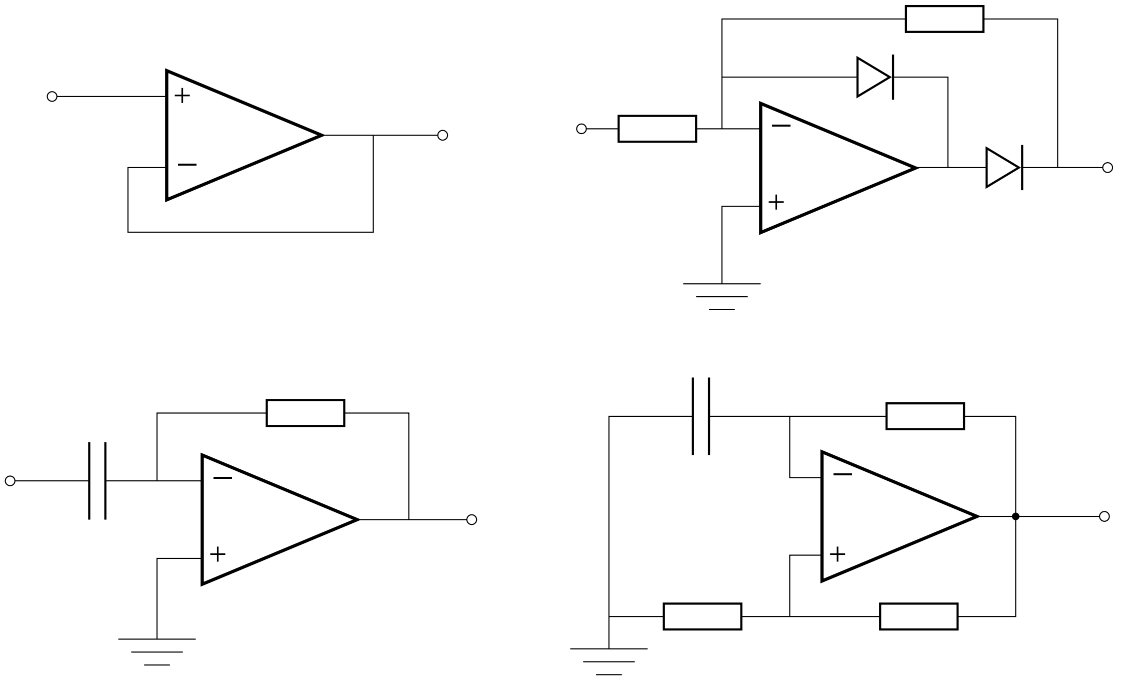

Figure 6: *Several examples of op-amp configurations.*