V51 Circuits with operational amplifiers

Abstract

In this experiment, basic circuits with operational amplifiers are set up and their characteristics are determined. The differences between a real and an ideal operational amplifier, as well as some possible applications and limitations, are to be clarified.

References

[1] Horowitz and Hill, *The art of electronics* Cambridge

[2] Joachim Frederau, *Operationsverstärker*, Springer (2017)

[3] Ludwig Brabetz, *Gleichstromnetze, Operationsverstärkerschaltungen, elektrische und magnetische Felder*, DeGruyter (2015)

[4] Jerald G. Graeme, *Operational amplifiers*, McGraw-Hill (1971)

Preparation

Hundreds of different types of **OP**erational **Amp**lifiers (OP-Amp) are available. So it is absolutely necessary to know the pin configuration of the LM741 from the data sheet.[1] If you can answer the following questions and calculate the values from the preparation you are ready to do the experiment.

- What is the pin configuration of a LM741 in a DIL8 housing?
- Why are the two supply voltages used symmetrically around 0*V in most cases? What happens if the two voltages are not exactly opposite and equal?
- What differences between ideal and real operational amplifier excists?
- Illustrate how to set up a circuit on a breadboard (use Figure 1) by sketching a circuit of an *inverting amplifier*.
- What is common mode suppression?
- How are amplification and output bandwidth related?
- What is meant by the term positive and negative feedback?
- Show by calculation that an operation amplifier can be used to integrate and differentiate a voltage. What is the frequency behaviour in each case?

[1] The company of the data sheet is not relevant.

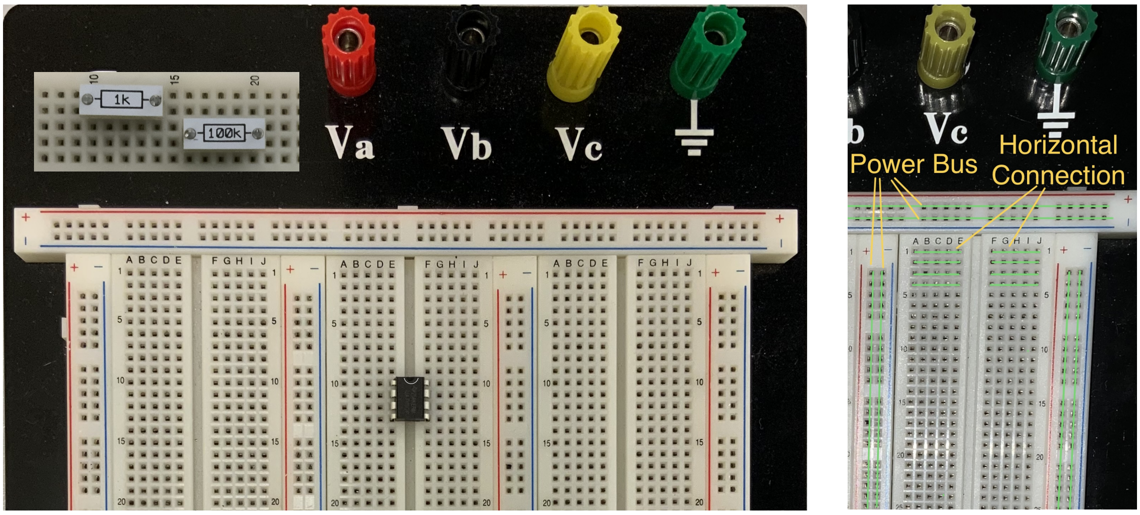

Figure 1: left: Breadboard with a LM741. The inset shows the dimension of the resistors used in the experiment. right: Detail of the breadboard. The green lines display the connected contacts of the breadboard.

- How does the characteristic of a Schmitt trigger with positive feedback look like? Evaluate the switching point and the threshold value.
- What signal curve results when the feedback of the Schmitt trigger is an integrator?
- What is the theoretical value of the oscillation frequency generated in the circuit in Fig. 7?
- Which DGL describes the voltage curve at the output of the oscillation generator in Fig. 8 at the point U_a?

Experimental setup and Measurements

The different circuits you have to built are set up on a breadboard shown in Figure 2. The electronic components as resistors, OP-Amps plug directly in the sockets of the bread board and thus no soldering is necessary. As shown in Figure 2 there are vertical connections which are used for power and ground. Divided by a centering line there are horizontal connected sockets marked with a - e and f - j, respectivly. Components which are in the same row will be connected. For further connections use the breadboard jumper wires. To run the different circuits a function generator, a power supply, a multimeter, an oscilloscope and several other electronic components are supplied. Note

Figure 2: Devices used in the experiment.

the direction of the notch on the OP-Amp in order to correctly assign the contacts. The OP-Amp can be destroyed if the connections are incorrect!!!

Inverting amplifier

Set up the circuit of an inverting amplifier shown in Figure 3. Measure with $R_1 = 1\ k\Omega$ and $R_2 = 100\ k\Omega$ the frequency dependence of the amplitude (Gain) and the phase over several decades. Plot the results in a double logarithmic diagram (Bode plot). Extract with a fit the amplification, Cutoff frequency and bandwidth from the plot.
Repeat the measurements for at least two more amplifications.

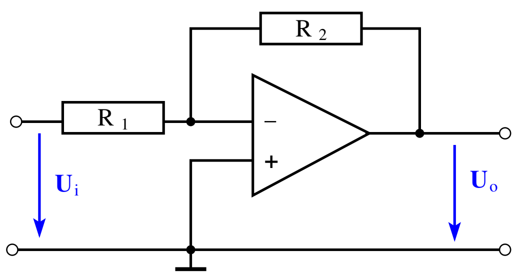

Figure 3: Circuit of an inverting OP-Amp

Integrator

Set up the reverse integrator shown in Figure 4 with $R = 10\ k\Omega$ and $C = 100\ nF$. Check whether the chosen time constant is reasonable. Measure the input voltage and the output voltage as a function of the frequency and plot the data in a double logarithmic diagram. Compare the result with your calculation (preparation).
Display the output signals for an initial triangular and rectangular input signal. Make sure that the input voltage does not contain any DC voltage components.

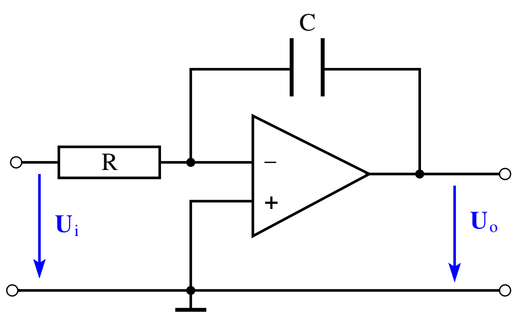

Figure 4: Circuit of an Integrator

Differentiator

Set up a differentiator with $R = 100\ k\Omega$ and $C = 22\ nF$ as shown in Figure 5. Proceed with the measurements analogously to the analysis of the integrator.

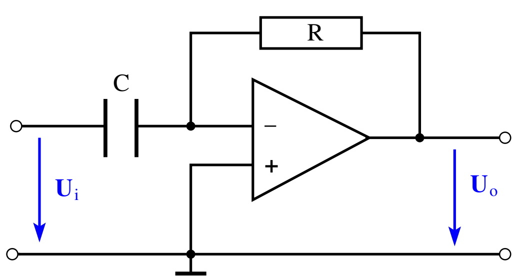

Figure 5: Circuit of an Differentiator

Schmitt Trigger

Set up the circuit of a Schmitt Trigger with $R_1 = 10\ k\Omega$ and $R_2 = 100\ k\Omega$ shown in Figure 6. Starting from 0 V, increase the amplitude in steps of a few mV. Use the oscilloscope to determine the peak value at which the circuit just begins to tilt. An alternative method to determine the peak value is to use a triangle input signal with a higher amplitude than the threshold. Measure with this method several points where the circuit starts to tilt and average over them.

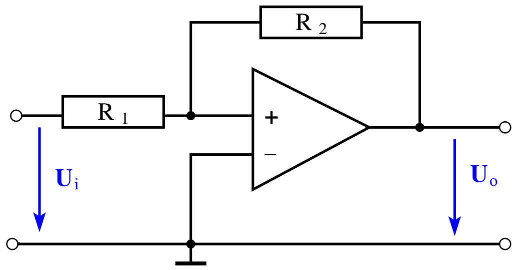

Figure 6: Circuit of a Schmitt Trigger

Note there is a hysteresis curve between input and output voltage. Store synchrononously data of input and output voltage on the oscilloscope. Compare the breakdown voltage /peak voltage with the theoretical predicted value (preparation).

Generator

Set up the circuit of a generator shown in Figure 7. Use the following components for the

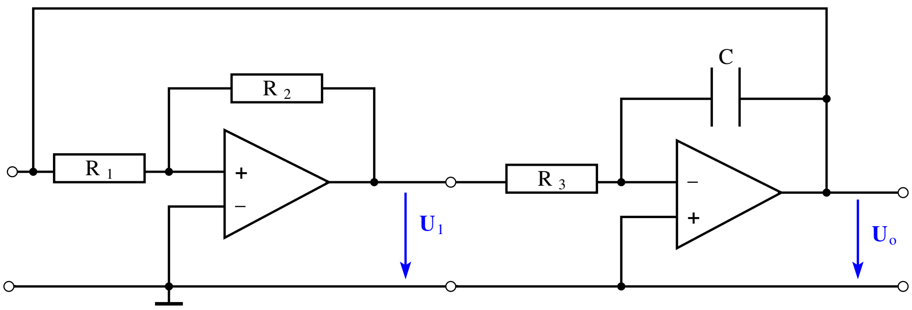

Figure 7: Circuit of an Generator

generator: $R_1 = 10\ k\Omega$, $R_2 = 100\ k\Omega$, $R_3 = 1\ k\Omega$ and $C = 1\ \mu F$. The system starts spontaneously to oscillate and generates a triangular signal U_a with frequency

$$\nu_a = \frac{R_2}{4\,C\,R_1\,R_3} \tag{1}$$

and amplitude

$$U_0 = U_{max}\frac{R_1}{R_2} \tag{2}$$

Using the oscilloscope, measure the signals U_1 and U_a and compare the frequency and the amplitudes with the theoretical values.

Generator with varying amplitudes

Set up the circuit of a generator with varying amplitude shown in Figure 8. A good choice

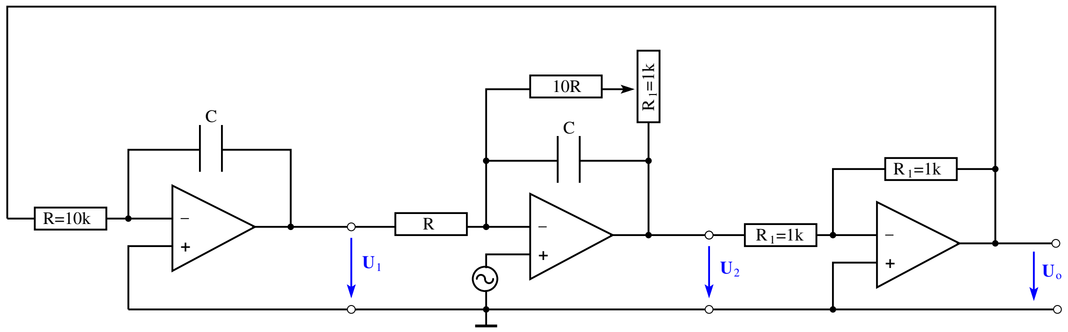

Figure 8: Circuit of an Generator for varying amplitudes

for the capacitor C are the values $C = 22\ nF$ or $C = 100\ nF$. Show experimentally that the following holds

$$T = 2\,\pi\,R\,C \tag{3}$$

$$\tau = \frac{20\,R\,C}{|\eta|} \tag{4}$$

for the period of oscillation T and the decay-time τ. The damping factor η represents the fraction of the output voltage U_a which is applied to the input of the second op-amp. Its value can be varied by the potentiometer P between -1 and 1.

In case of $\eta < 0$, a damped oscillation is to be recorded with an oscilloscope. Due to the damping, you must feed a square wave voltage into the non-inverting input of the second op-amp, as the system does not start to oscillates on its own.

Measure the damping of the oscillation, plot the result in a semi-logarithmic diagram and determine τ. Compare it with the theoretical value.

In case of $\eta > 0$ the circuit will oscillate. Measure the period of oscillation and compare it with the theoretical value.