Department of theoretical physics and astrophysics of Faculty of Science,
Masaryk University

PHYSICS LABORATORY

Physics laboratory 3

Zpracoval: Tomáš Plšek **Measured:** 4. května 2018

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Task **7: Operational amplifier**

1. Introduction

An operational amplifier is a widely used electrical circuit. It can work as a high gain differential voltage amplifier, that provides voltage many times higher than the difference between input voltages. Real OA can deliver varying amplifications - less than 1000 and also over 10^6.

The bandwidth of OA is in the range of few kHz to hundreds of MHz. For higher frequencies the amplification decreases and the phase shift between the input and output arises. Therefore wide bandwidth is necessary for high-frequency systems and also feedback circuits, where the lag between input and output can lead to system instability.

The schematic of OA is shown in figure no. 1. It typically has two inputs (the inverting and the non-inverting one) a one output. If non-inverting input voltage is higher than the inverting input, the output voltage is positive and vice versa.

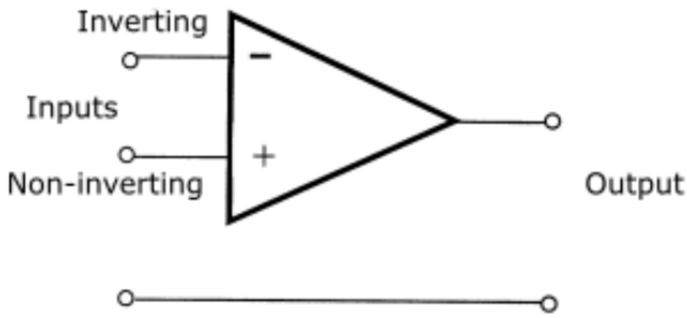


Figure 1: Operational amplifier scheme.

2. Measurment

2.1. Comparator

First of all we used the operational amplifier as a comparator. The comparator compares two input voltages and distinguishes, which one is higher. We connected the circuit acording to diagram on figure no. 2.

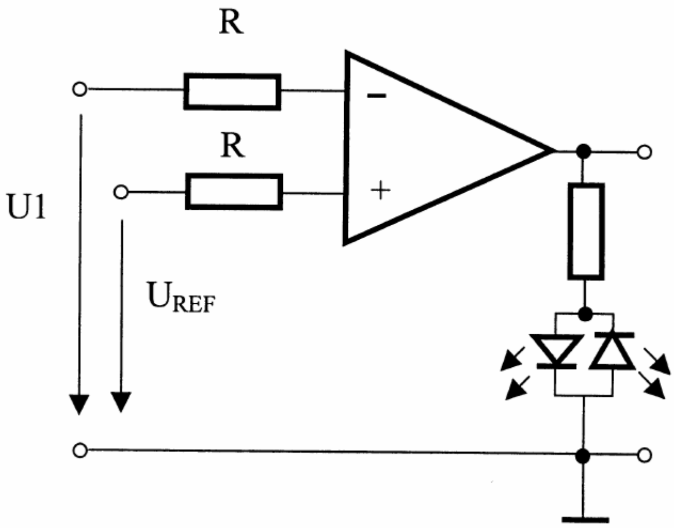


Figure 2: Diagram of OA connected as comparator.

The result is that if the voltage on the non-inverting input is higher than the voltage on the inverting input, one of the diods is connected in reverse direction and there is no current flowing. The second one is connected in forward direction and therefore shines. When we change the voltages so the one on the inverting input is higher, the direction of the current on the diods changes and now shines the second diod.

2.2. Inverting input amplifier connection

Next we focused on the inverting input of the operational amplifier (fig no. 3). We verified that the connection of the inverting input works according to eq. (1) and also measured the bandwidth, which is the maximal frequency, where the operational amplifier works well. It is the frequency, at which amplification value decreases to $A_{u,max}/\sqrt{2}$. Rezistances of the rezistors are $R_1 = 10\,\Omega$ and $R_2 = 20\,\Omega$. The circuit amplifies the output voltage according to:

$$U_{\text{out}} = -\frac{R_2}{R_1}U_1. \tag{1}$$

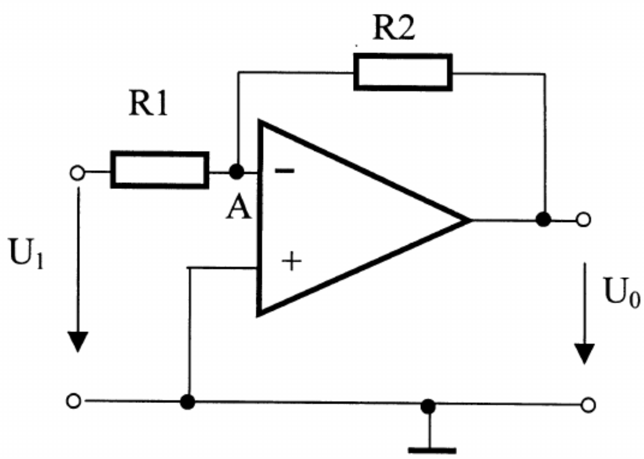
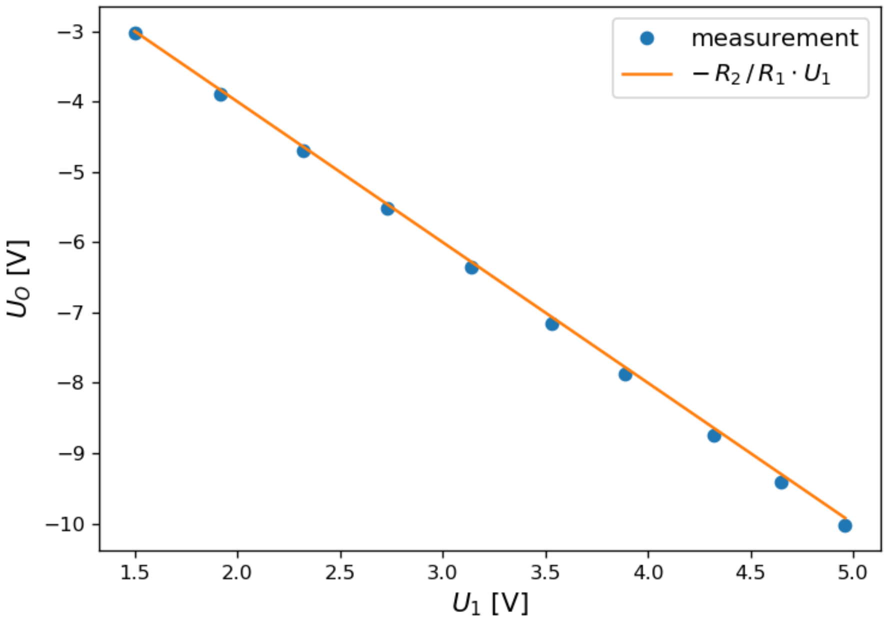


Figure 3: Circuit of OA with inverting input.

Table 1: Output voltage dependence on voltage U_1.

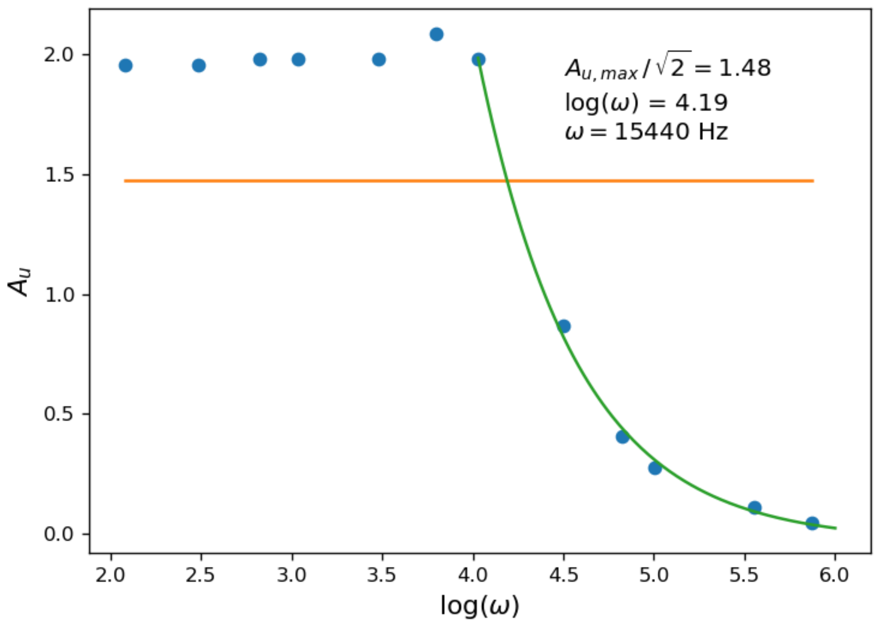
U_1 [V]	U_{out} [V]
1.50	-3.03
1.92	-3.89
2.32	-4.69
2.73	-5.52
3.14	-6.36
3.53	-7.15
3.89	-7.87
4.32	-8.74
4.65	-9.40
4.96	-10.03



Graph 1: Verification of equation (1).

Table 2: Dependence of amplification on frequency.

U_{in} [V]	U_{out} [V]	$\log(\omega)$	A_u
9.0	-17.6	2.08	1.96
9.0	-17.6	2.49	1.96
9.0	-17.8	2.83	1.98
9.6	-19.0	3.04	1.98
9.0	-17.8	3.48	1.98
9.2	-19.2	3.80	2.09
10.0	-19.8	4.03	1.98
9.4	-8.16	4.50	0.87
10.0	-4.08	4.83	0.41
10.2	-2.80	5.00	0.27
9.2	-1.04	5.55	0.11
8.6	-0.40	5.87	0.05



Graph 2: The bandwidth of the inverting amplifier.

As we can see in the graph no. 1 the connection works according to eq. (1). I also determined the bandwidth of OA (graph no. 2) - I found the value $A_{u,max}/\sqrt{2}$ and using exponencial decay fit I also found the corresponding value of frequency (frequency logarithm). The bandwidth is about 15 kHz.

2.3. Low-pass filter

By simple change in circuit with inverting amplifier (figure no. 3) we can get a circuit that allows only low frequencies to pass trough - low-pass filter (figure no. 4). The added capacitator reduces the impendance of the feedback line for high frequencies. This leads to the amplification:

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

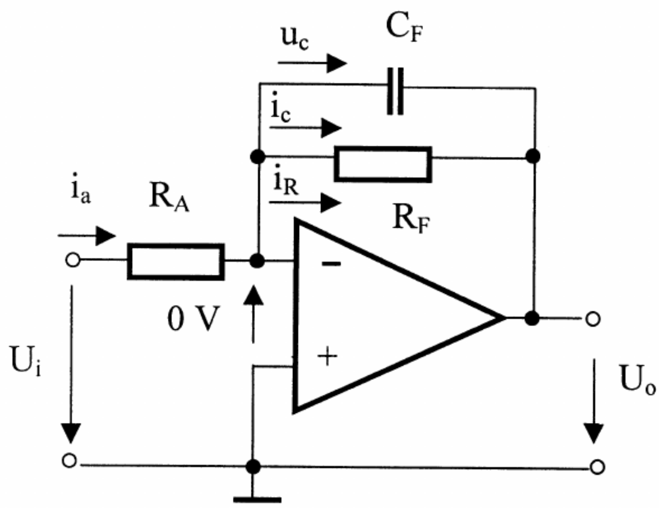
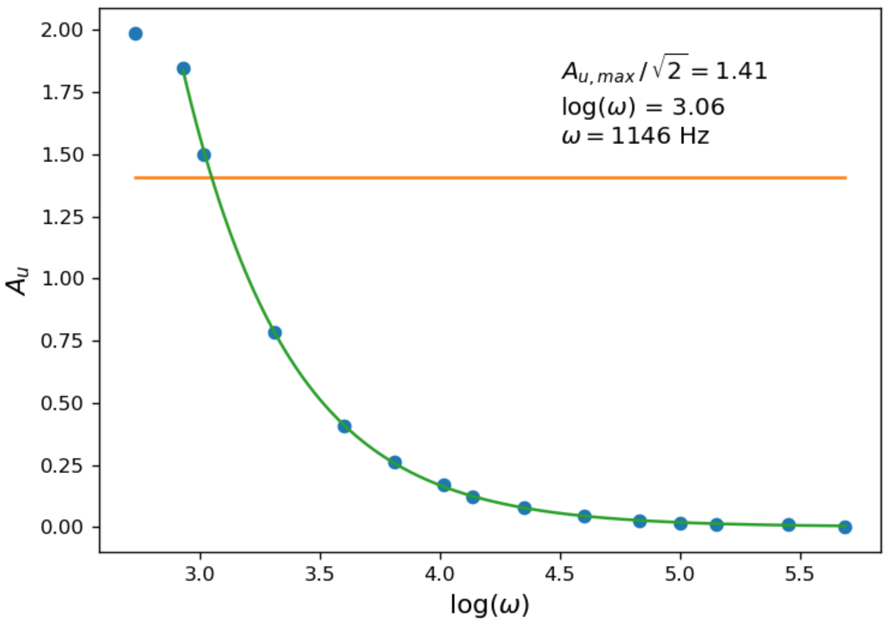


Figure 4: Differential amplifier scheme.

Table 3: Dependence of amplification on frequency.

U_{in} [V]	U_{out} [V]	$\log(\omega)$	A_u
9.2	17.00	2.93	1.850
9.2	13.80	3.02	1.500
9.2	7.200	3.31	0.783
9.2	3.760	3.60	0.409
9.2	2.400	3.81	0.261
9.4	1.600	4.02	0.170
9.2	1.120	4.14	0.122
9.6	0.780	4.35	0.081
9.2	0.400	4.60	0.043
9.2	0.248	4.83	0.027
9.8	0.172	5.00	0.018
9.2	0.128	5.15	0.014
9.2	0.096	5.45	0.010



Graph 3: Low-pass filter amplification for high frequencies.

In the graph no. 3 we can see, that low-pass filter really amplifies well only low frequencies. For frequencies 1 kHz and higher we can see an exponencial decay in dependency of amplification on the frequency logarithm.

2.4. Differential amplifier

A differential amplifier is connected by combination of the inverting and non-iverting amplifier (figure no. 5). Used rezistors' rezistances are $R_1 = R_3 = 10\,\Omega$ and $R_2 = R_4 = 20\,\Omega$. The output voltage then should be equal to:

$$U_{\text{out}} = U_2 \cdot \frac{R_4(R_1 + R_2)}{R_1(R_3 + R_4)} - U_1 \cdot \frac{R_2}{R_1} = 2(U_2 - U_1). \tag{3}$$

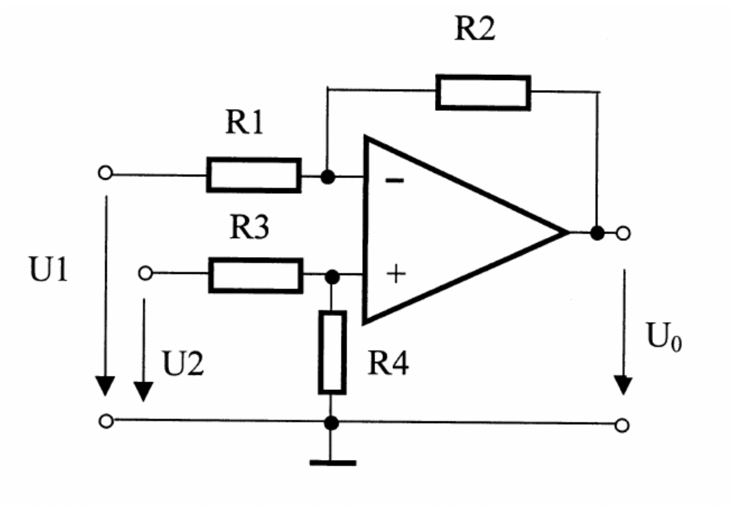
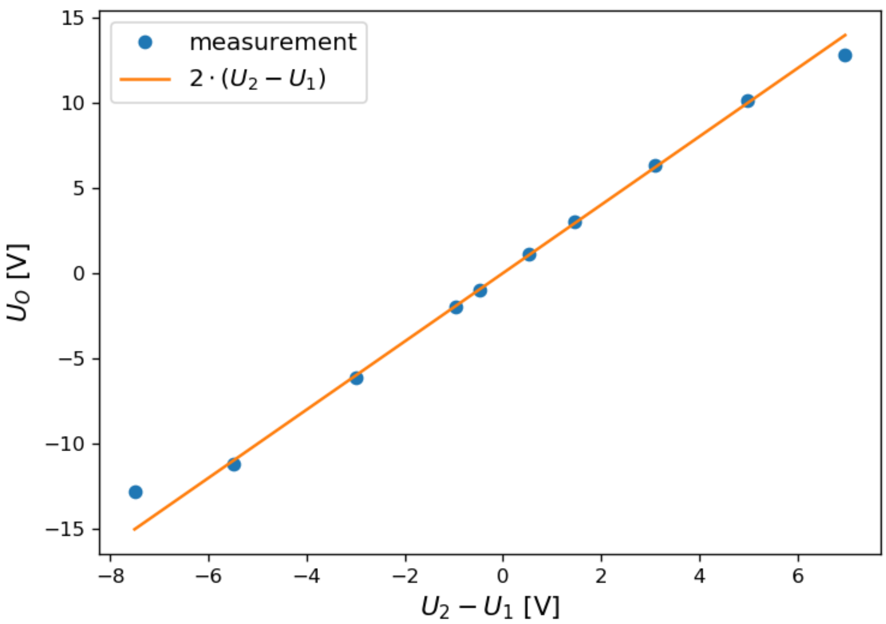


Figure 5: Differential amplifier scheme.

Table 4: Dependence of output voltage on input voltages.

U_1 [V]	U_2 [V]	U_{out} [V]
2.52	2.05	-0.99
3.01	2.05	-1.99
5.04	2.05	-6.10
7.54	2.05	-11.16
9.55	2.05	-12.78
3.01	3.53	1.10
3.01	4.47	3.00
3.01	6.11	6.31
3.01	7.99	10.13
3.01	9.98	12.78



Graph 4: Differential amplifier's function veryfication.

In the graph no. 4 we can see that the measurement corresponds well to theoretical prediction.

2.5. Differentiator amplifier

Our last task was to consider which connection (figure no. 6) works as a differentiator a then verify the correctness of the circuit function. The output of the differentiator is the derivative of the input, that means the output is proportional to the change of the input.

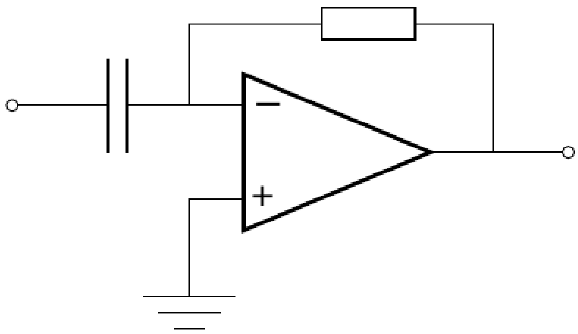


Figure 6: Differentiator amplifier scheme.

Using osciloscope we made the input function sinusoidal and the output function was cosinusoidal, which is the derivative of sinus.

3. Conclusion

In this task, we analyzed various uses of operational amplifier. At first we connected the electrical circuit so the OA worked as a comparator. When the reference voltage was higher the green diod was shinning and vice versa.

Next we connected the OA as a inverting input amplifier. We verified if this amplifier works according to equation (1) and we measured the bandwidth of the frequencies in which the amplifier works well. The bandwidth is about 15 kHz.

By a simple change we connected the electrical circuit to work as a low-pass filter. We measured the dependence of amplification on frequency and determined the bandwidth to approx. 1.1 kHz.

Then we connected the electrical circuit to work as a differential amplifier. We measured the dependence of output voltage on difference between two input voltages a verified the equation (3) After that we connected the circuit to work as differentiator amplifier a verified its functionality.