Physical section, Faculty of science, Masaryk Univerzity

PHYSICAL LABORATORY

Physical laboratory 3

Student: Jan Beran **Date of measurement:** 25. April 2019

Course of study: UF **Group:** F4210/04 **Tested:**

Task . **5:** **Operational amplifier**

1. Preface

An operational amplifier is an electronic circuit that provides voltage at it's output much greater than the potential difference betweeen it's two outputs. Schema of this circuit is shown nín Figure 1 One of the important The characteristics of the ideal op amp is infinite input resistance, so do not in any it does not lose current from its inputs, which is a fact that we will use in the theoretical determination of gain voltage. Another characteristic is the dependence of gain on frequency, while at high frequencies there is a significant decrease in gain (with specific connections). This characterizes the width bands, which is the frequency at which gain decreases from the maximum theoretical value of $A_{u_{max}}$, to value $A_{u_{max}}/\sqrt{2}$.

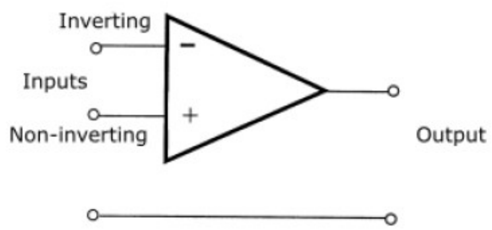

Figure 1: An electronic schematic of an operational amplifier.

2. Comparator

2.1. Task:

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

2.2. Theory

A simple use of the operational amplifier is to compare two input voltages. Engagement according to the diagram in Figure 2 it is called a comparator.

2.3. Measurement

Two voltages of opposite polarity were applied to the amplifier. The output voltage polarity was represented by two diodes of different colors (green and red). Always the diode that was in the forward direction of the greater of the supplied voltages. When the reference and supply voltage the same values both diodes went out because the output voltage was zero.

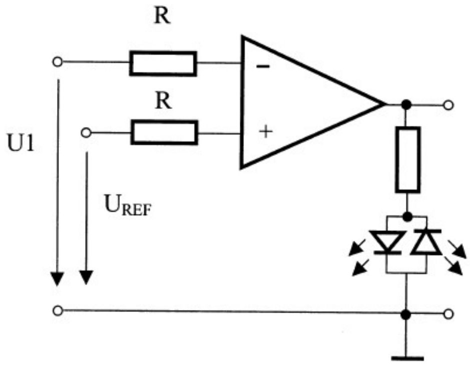

Figure 2: Comparator

3. Connection of the OA with inverting ipnut

3.1. Task:

- Connect such resistors, so that the whole circuit amplifies 2 times. Verify that the circuit connection of the inverting amplifier works according to equation (1) for several different input DC voltages.
- Measure the bandwidth of the OA with inverting amplifier.

3.2. Theory

The wiring diagram is shown in Figure 3. The input voltage is applied to the inverting input before the resistor R_1, the non-inverting input is grounded. The output voltage is fed back to the input via the feedback resistor R_2. This voltage, by its opposite polarity, decreases the voltage at point A. Since the second input is grounded, the circuit becomes steady when it has zero electrical potential at point A. Since the amplifier has a large input resistance, the current flowing through both resistors R_1, R_2 must be the same.

Using Kichoff's law, we get a relationship for amplification of voltage:

$$U_0 = -\frac{R_2}{R_1} U_1 \tag{1}$$

For AC voltage, the gain depends on its frequency. The maximum frequency at which an opamp operates in a given circuit is called the operational amplifier bandwidth. The boundary is the frequency at which A_u gain decreases to $A_{u_{max}}/\sqrt{2}$ where $A_{u_{max}}$ is the maximum gain given by equation (1).

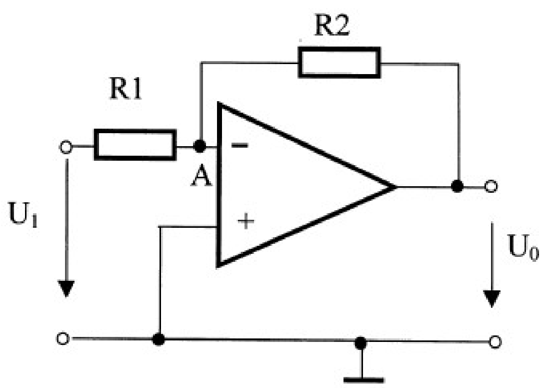

Figure 3: Electrical circuit of OA connected with the inverting input.

3.3. Measurement

I connect circuit as shown in Figure 3. I chose resistors $R_1 = 10\,\mathrm{k\Omega}$ and $R_2 = 20\,\mathrm{k\Omega}$. That's why $A_{u,\max} = -2$. I measured the dependece of the output voltage on the input voltage. I wrote the measured values in table 1. I graph these values in the graph in figure 4. Through linear regresion and slope of a line I found amplification A_u.

$$A_u = (-2.02 \pm 0.01) \tag{2}$$

Table 1: Measured data for OA with inverting input.

U_{IN} [V]	U_{OUT} [V]
1.42	-2.90
1.60	-3.25
1.82	-3.70
1.93	-3.93
2.00	-4.05
2.23	-4.53
2.43	-4.93
2.54	-5.16
2.68	-5.45
2.84	-5.76

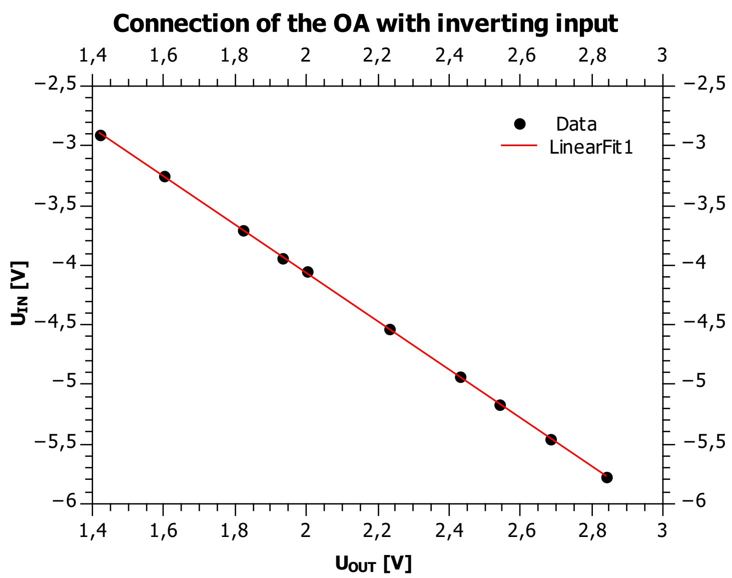

Figure 4: Graph of measured data for OA with inverting input with linear fit.

I measured the bandwidth of the inverting OA. I measured the gain dependence as the ratio of the output voltage U_0 and the input voltage U_1 to input volage frequency. I wrote the measured values in the table 2 and plot the dependence of the gain on the logarithm of the measured frequency and the line corresponing to the value

$$A_{u,\max}/\sqrt{2} \doteq 1.41 \tag{3}$$

Table 2: Measured data for bandwidth of OA with inverting input.

f [Hz]	U_1 [V]	U_o [V]	$\log f$	A_u
10.5	8.8	17.6	1.021189299	2.000000
20.42	8.8	17.6	1.310055738	2.000000
31.85	8.6	17.2	1.503109437	2.000000
40.74	8.8	17.8	1.610021025	2.022727
52.52	9	17.6	1.720324717	1.955556
63.22	8.6	17	1.800854492	1.976744
73.53	8.6	17	1.866464566	1.976744
91.52	8.6	17.4	1.961516011	2.023256
102.3	8.6	17.4	2.009875634	2.023256
200.3	8.6	17.4	2.301680949	2.023256
310	8.4	16.6	2.491361694	1.976190
434.8	8.8	17.6	2.638289535	2.000000
559.8	9	17.6	2.748032894	1.955556
830.6	8.6	17.2	2.919391927	2.000000
919.3	8.8	17.6	2.96345726	2.000000
1684	8.6	16.8	3.226342087	1.953488
4167	9	18	3.6198235	2.000000
5379	8.8	17.8	3.730701544	2.022727
8187	8.6	17	3.91312479	1.976744
9640	9.4	18.6	3.984077034	1.978723
10040	9	17.8	4.001733713	1.977778
16010	8.8	16.4	4.204391332	1.863636
25000	9.2	10.6	4.397940009	1.152174
64270	9.6	4.2	4.8080083	0.437500
78130	9.4	3.5	4.892817824	0.372340
206900	9.4	1.2	5.315760491	0.127660
340700	8.8	0.8	5.532372134	0.090909
499300	9.4	0.5	5.698361566	0.053191
655700	8.6	0.4	5.816705184	0.046512
781700	8	0.3	5.893040112	0.037500

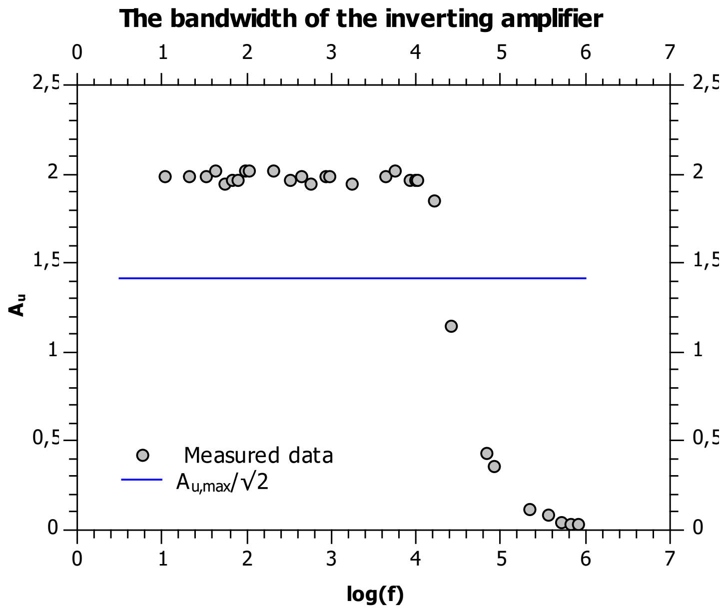

Figure 5: Dependency A_u on $log(f)$ with value $A_{u,\max}/\sqrt{2}$.

4. Low-pass filter

4.1. 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.

4.2. Theory

The wiring diagram of Low-pass filter connecting is shown in figure 6. Amplification of Low-pass filter is

$$A_u = -\frac{R_f}{R_A} \cdot \frac{1}{1 + i\omega C_F R_F} \tag{4}$$

If we use modulus of complex number we get

$$A_u = -\frac{R_f}{R_A} \cdot \frac{1}{\sqrt{1 + \omega^2 C_F^2 R_F^2}}, \tag{5}$$

where $\omega = 2\pi f$.

4.3. Measurements

I used electronic component with parametr:

$$R_A = 10\,\mathrm{k\Omega} \tag{6}$$

$$R_F = 100\,\mathrm{k\Omega} \tag{7}$$

$$C_F = 10\,\mathrm{nF} \tag{8}$$

With this parametr the value of amplification should be -10.

Measured data are in table 3 and at figure 7.

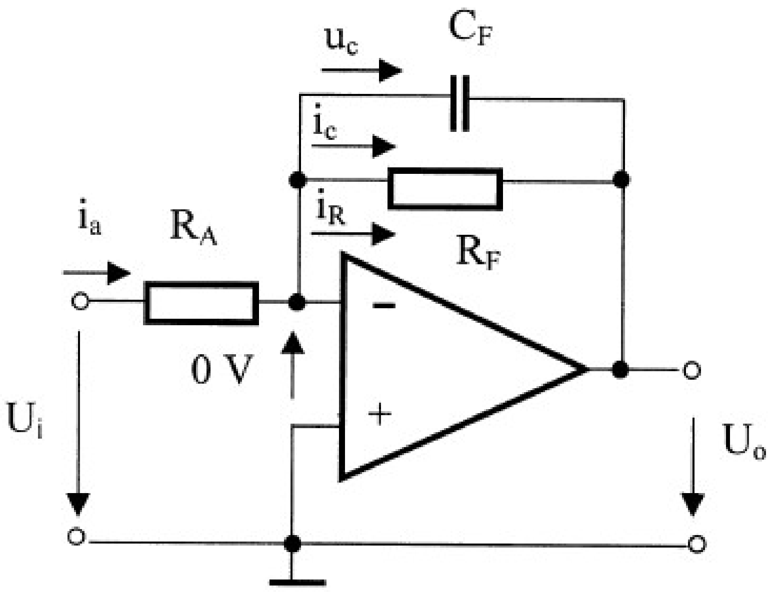

Figure 6: Low-pass filter.

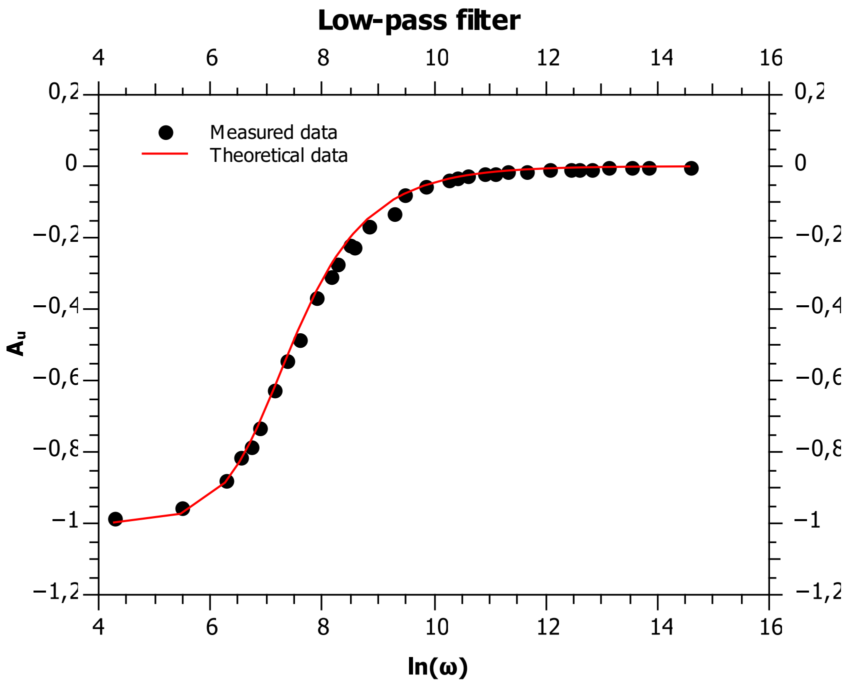

Figure 7: Measured data and theoretical data for Low-pass filter.

Table 3: Measured data fot Low-pass filter.

U_i [V]	f [Hz]	U_0 [V]	ω [s^{-1}]	$\ln\omega$	A_u
5,04	11,44	-4,96	71,88	4,274998062	-0,9841
4,88	37,59	-4,64	236,18	5,464594226	-0,9508
5,12	83,3	-4,48	523,39	6,260326884	-0,875
5,12	107,5	-4,16	675,44	6,51536433	-0,8125
5,12	128,2	-4	805,5	6,691463203	-0,7813
5,04	148,9	-3,68	935,57	6,841155969	-0,7302
5,12	200	-3,2	1256,64	7,136196771	-0,625
5,04	250	-2,72	1570,8	7,359340323	-0,5397
4,96	306,2	-2,4	1923,91	7,562114853	-0,4839
5,28	425	-1,92	2670,35	7,889964829	-0,3636
5,28	553,1	-1,6	3475,23	8,153415943	-0,303
5,28	606,8	-1,44	3812,64	8,246077142	-0,2727
5,12	769,2	-1,12	4833,03	8,483228879	-0,2188
5,04	825,4	-1,12	5186,14	8,553744961	-0,2222
5,12	1062	-0,85	6672,74	8,805785849	-0,166
4,96	1701	-0,64	10687,7	9,276848827	-0,129
5,2	2041	-0,392	12823,98	9,459072135	-0,0754
4,96	2907	-0,264	18265,22	9,812753984	-0,0532
5,2	4503	-0,184	28293,18	10,25037607	-0,0354
5,28	5280	-0,168	33175,22	10,40955849	-0,0318
5,28	6329	-0,13	39766,28	10,5907746	-0,0246
5,04	8529	-0,092	53589,29	10,88910451	-0,0183
5,28	10360	-0,086	65093,8	11,08358459	-0,0163
5,12	12920	-0,068	81178,75	11,30440879	-0,0132
5,28	17810	-0,053	111903,53	11,62539244	-0,01
5,28	27600	-0,034	173415,91	12,06344809	-0,0065
5,52	40210	-0,024	252646,88	12,43974806	-0,0044
5,44	45770	-0,022	287581,39	12,56926119	-0,004
5,6	56920	-0,017	357638,91	12,78727913	-0,0031
5,12	78520	-0,014	493355,71	13,10898571	-0,0027
5,04	118300	-0,01	743300,82	13,51885611	-0,002
4,8	160000	-0,008	1005309,65	13,82080616	-0,0017
5,12	338700	-0,006	2128114,86	14,5707471	-0,0012

5. Non-inverting input amplifier connection

5.1. Task:

- Verify the validity od your equation during the laboratory.

5.2. Theory

The wiring diagram of Non-inverting input amplifier connectin is shown in figure 8.
With the same consideration as in the inverting input we can get equation (9):

$$I_1 = I_2$$
$$\frac{U_1 - 0}{R_1} = \frac{U_0 - U_1}{R_2}$$

$$U_0 = \left(\frac{R_2}{R_1} + 1\right) \cdot U_1 \tag{9}$$

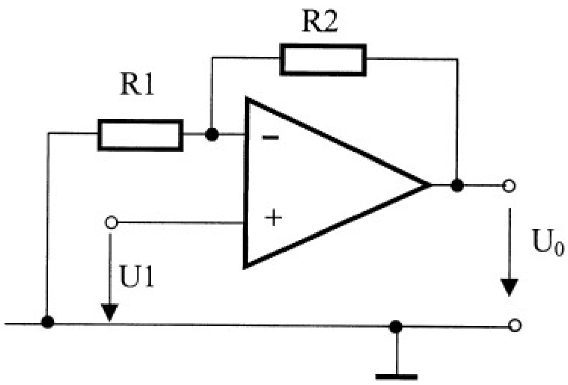

Figure 8: Electrical circuit with non-inverting amplifier.

5.3. Measurements

I used resistors:

$$R_1 = 10\,\mathrm{k\Omega} \tag{10}$$
$$R_2 = 20\,\mathrm{k\Omega} \tag{11}$$

Theoretical amplification is $A_{u,\max} = 3$.
Measured data is in table 4. I plot data at graph 9 and through linear regresion I found amplification A_u as

$$A_u = 3.016 \pm 0.004 \tag{12}$$

Table 4: Measured data for non-inverting input.

U_1 [V]	U_2 [V]
1.34	4.02
1.67	5.03
1.87	5.61
2.02	6.08
2.21	6.64
2.40	7.23
2.73	8.22
2.99	9.01
3.19	9.60
3.42	10.29
3.64	10.95

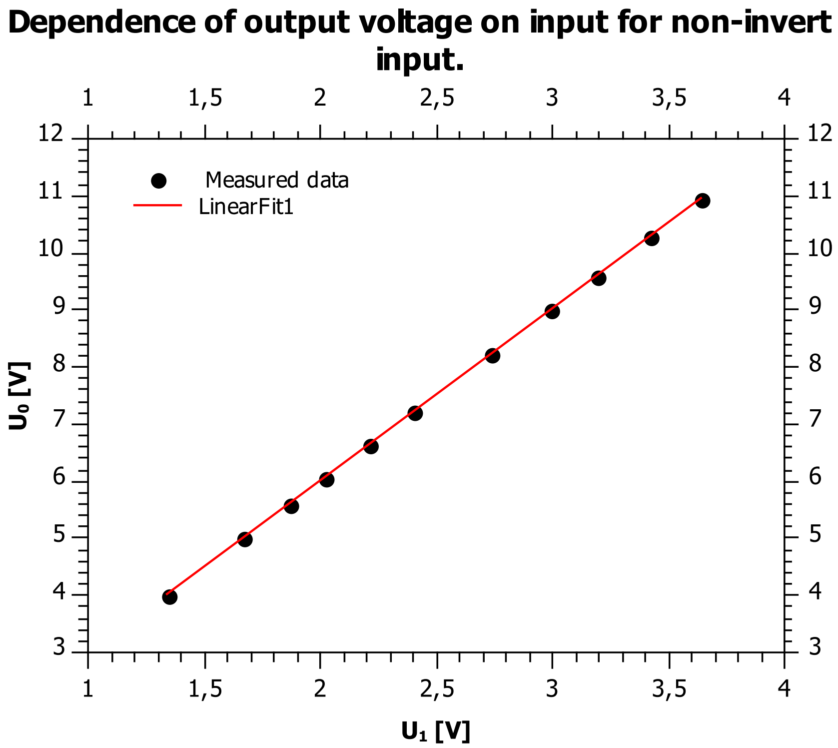

Figure 9: Measured data for dependence of output on input for non-invert input and linear fit of measured data.

6. Differential amplifier

6.1. Task:

- Connect the differential amplifier and varify equation (14).

6.2. Theory

A differential amplifier is created by combining an inverting and non-inverting amplifier. The wiring diagram is shown in figure 10.

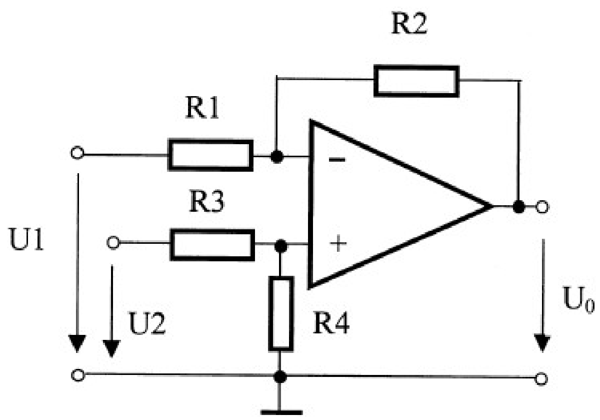

Figure 10: Differential amplifier.

The output voltage is described by equation:

$$U_0 = U_2 \cdot \frac{R_4(R_1 + R_2)}{R_1(R_3 + R_4)} - U_1 \cdot \frac{R_2}{R_1} \tag{13}$$

I chose resistors $R_1 = R_3 = 1\,\mathrm{k\Omega}$ and $R_2 = R_4 = 20\,\mathrm{k\Omega}$ and equation (13) are simplified to the equation:

$$U_0 = 2(U_2 - U_1) \tag{14}$$

6.3. Measurements

I used resistors

$$R_1 = 10\,\mathrm{k\Omega} \tag{15}$$

$$R_2 = 20\,\mathrm{k\Omega} \tag{16}$$

Measured data is in table 5. I plot data at graph 11 and through linear regresion I found amplification A_u (that I should get value of mplification $A_u = 2$):

$$A_u = 2.02 \pm 0.01 \tag{17}$$

Table 5: Measured voltages U_1, U_2, U_3 and calculated $U_1 - U_2$ and theory value of U_0 by equation 14.

U_1 [V]	U_2 [V]	U_0 [V]	$U_2 - U_1$ [V]	U_{0T} [V]
1.80	1.88	0.16	0.08	0.16
1.94	2.14	1.41	0.20	0.40
1.94	2.44	1.99	0.50	1.00
1.94	2.55	1.24	0.61	1.22
1.94	2.70	1.57	0.76	1.52
1.94	2.68	1.92	0.74	1.48
1.77	3.00	2.51	1.23	2.46
1.65	3.05	2.83	1.40	2.80
1.37	3.25	3.82	1.88	3.76
1.37	2.41	4.14	1.04	2.08

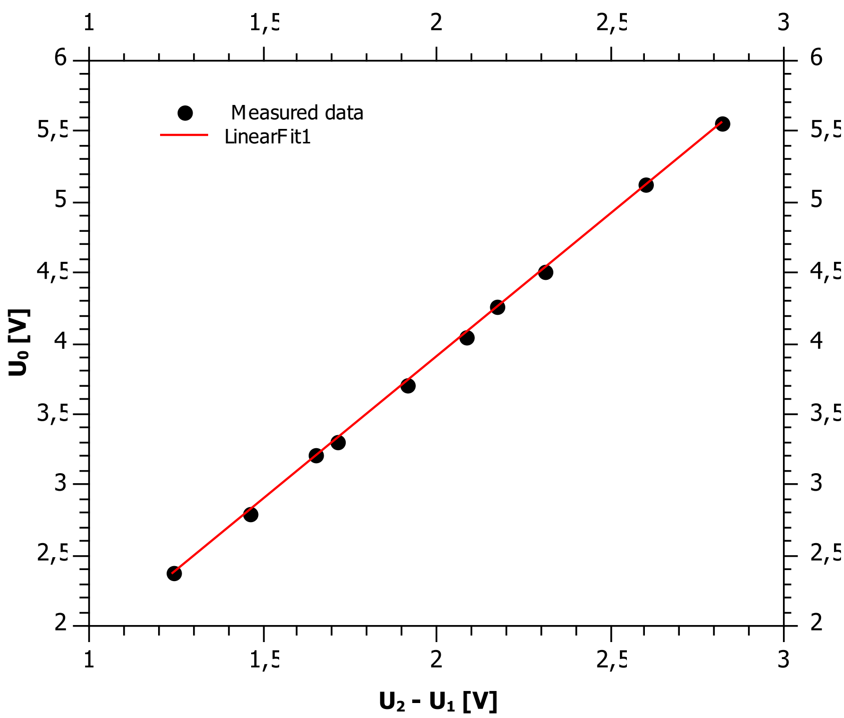

Figure 11: Dependence output voltage on Input voltage for differential amplifier.

7. Differentiator

7.1. Task

- Verify your chosen circuit during the laboratory.

7.2. Theory

The differentiator is a circuit that gives a voltage at it's output that is proportional to the time derivative of the input voltage. The differentiator connection is shown in figure 12.

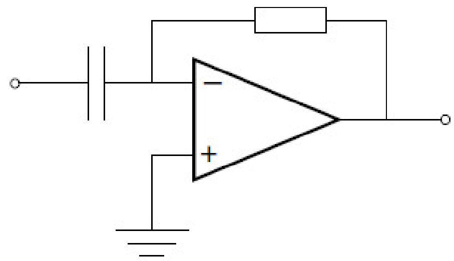

Figure 12: Scheme of differentiarot.

7.3. Measurement

I measured in a circuit connected as shown in the figure (12). I input the sinusoidal AC voltage to the input. I observed the input voltage waveform using an oscilloscope. Finally, I checked the voltage on the derivative of the input voltage.

8. Conclusion

In this laboratory I verified predicated effect of OA many different kinds. Exactly i verified predicated effect on Comparator, inverting input of OA, Low-pass filter, non-inverting input OA, differential amplifier and differentiator.