Experiment W

Operational Amplifier

Before you start to perform an experiment you are obliged to have mastered to the following theoretical subjects:

1. Types and mode of action of the feedback. [1], [3], [4].
2. Structure, operation and properties of the differential amplifier. [1÷5].
3. Properties of the ideal operational amplifier. [1÷5].
4. Properties and applications of the practical operational amplifier. [1÷5].

Purpose

To understand and analyze the operations of practical operational amplifiers.

Theoretical basis

A typical operational amplifier (Op-Amp) is made up of three types of amplifier circuit: a differential amplifier, a voltage amplifier, and a push-pull amplifier. The parameters of op-amp is presented in Table 1.

Table 1 – Parameters of Op-Amp.

Parameters	The ideal Op-Amp	The practical Op-Amp
Open-loop voltage gain	∞	$10^5 \div 10^6$
Input impedance [Ω]	∞	$10^5 \div 10^8$
Output impedance [Ω]	0	$10 \div 100$
Common-mode rejection ratio (CMRR)	$1: \infty$	$1: 10^3 \div 1: 10^6$ (60 ÷120 dB)
Bandwidth [MHz]	$0 \div \infty$	$0 \div 200$
Output voltage [V]	$0 \div \pm \infty$	Limited by supply voltages

Description of measurement method

The Op-Amp is investigated in systems with negative feedback as inverting and noninverting amplifier.

Measurements are performed both for DC and AC input voltages. The Adjustable Voltage Source and Function Generator provide the DC an AC signals to the Op-Amp. The kit of DMM's voltmeters shows the DC input and output voltages. For AC voltages the input and output signals are presented on the screen of Oscilloscope, which works in the DUAL mode.

The Power Supply (DF1731SB3A or MPS-3003L-3) with serial operating mode is adjusted to the symmetrical voltage ±20V and supplies the Op-Amp.

Experimental procedure

A. The inverting amplifier

(Connection diagrams are presented on Figures M1a, M1b, and M1c).

Switch on the Power Supply in serial mode, adjust the symmetrical voltage to ±20V and then switch it off.

I. The transfer characteristic of amplifier

1. Connect the circuit according to the diagrams presented in Figs. M1a and M1c. Set the switches R_3 and R_L to the "∞" position. Set the rotary function switch on DMM's voltmeters to the 20 DC V.
2. Set the switches Z_1 and Z_2 to the "2" position (Fig. M1c).
3. Set the rotary function switch on the Adjustable Power Supply to the "2" position (Fig. M1a).
4. Switch on the Power Supply.
5. Increasing the input voltage from –12V to +12V determine the dependence of input voltage on output voltage.
6. Record the obtained result on the data sheet in the Data Table A1.
7. Set the switches Z_1 and Z_2 according to the supervisor's order and repeat the procedure described in previous steps.

Data Table A1 / (A1$^{\#}$) – Inverting amplifier.

Z_1 / ($R_{S1}^{\#}$)	Z_2 / ($R_L^{\#}$)	Input voltage		Output voltage	
[Ω]	[Ω]	U_{IN} [V]	ΔU_{IN} [V]	U_{OUT} [V]	ΔU_{OUT} [V]

II. Measurement of the input impedance of the amplifier

1. Set the input voltage on the value for which the output voltage is near below 12V.
2. Remove the jumper from Input 1 position. Put the R_{S1} resistor instead of the jumper.
3. Measure the output voltage of amplifier without changing the input voltage.
4. Record the obtained result on the data sheet in the Data Table A1$^{\#}$.
5. Remove the R_{S1} resistor from input of amplifier.

III. Measurement of the output impedance of the amplifier

1. Insert the jumper to the Input 1 position.
2. Set the input voltage on the value for which the output voltage is near below 12V.
3. Measure the output voltage of amplifier for different positions of switch R_L.
4. Record the obtained result on the data sheet in the Data Table A1$^{\#}$.

IV. Measurement of the bandwidth of amplifier

1. Remove the Adjustable Power Supply and DMMs.
2. Connect the circuit according to the diagram given in Fig. M1b.
3. Select the sine waveform (without the DC OFFSET) by using the Function Select Switch on the Function Generator (FG) front panel and connect the output of FG to the both CH2 input of oscilloscope and input of amplifier (use T junction to divide the signal from the output of FG).
4. Connect the output of amplifier to CH1 input of oscilloscope.
5. Set the switches: Z_1 to the "1" position, Z_2 to the "3" position, and R_L to the "∞" position.
6. Set the output frequency of Function Generator to approx. 300Hz.
7. Set the input voltage amplitude to such a value for which the output amplitude should be about 8V and fulfill the oscilloscope screen.
8. Increasing the frequency of the input signal find the critical frequencies for which the output amplitude decreases sequentially 2, 3, 4, 5, 6, 8 and 10 times.
9. Repeat the procedure described above for setting the switch Z_2 sequentially to the "5" and "7" positions.
10. Draw the oscillograms with strongly marked oscilloscope settings and the following values: amplitude level, type of amplifier, period, Z_1 and Z_2, voltage gain.

V. Measurement of AC voltage gain

1. Set again the output frequency of Function Generator to approx. 300Hz.
2. Measure the input and output amplitudes of signals for various positions of Z_1 and Z_2 switches paying the special attention to non-deforming the signals.
3. Record the obtained results on the data sheet in the Data Table A1 with description “variable signal”.

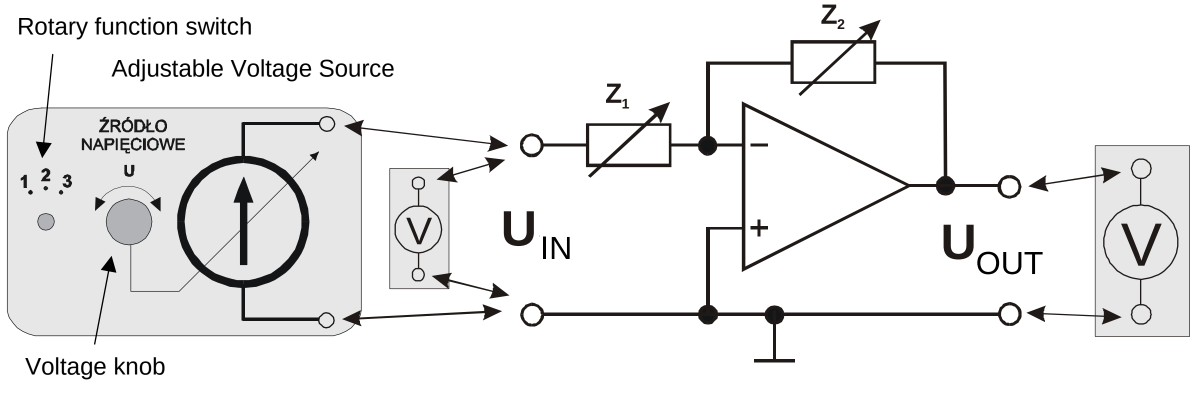

Fig. M1a

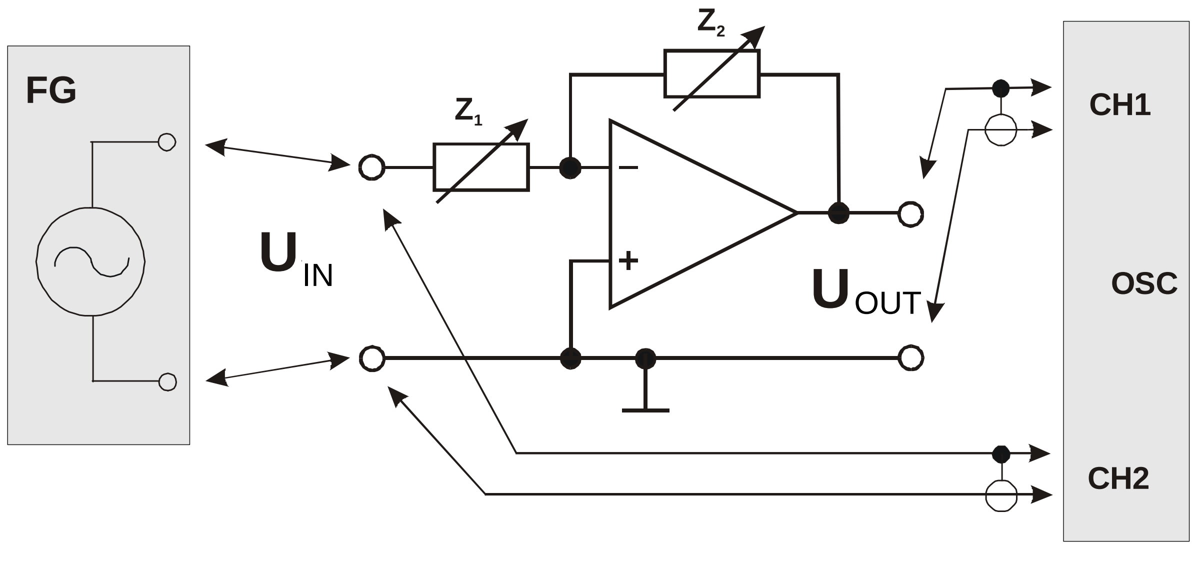

Fig. M1b

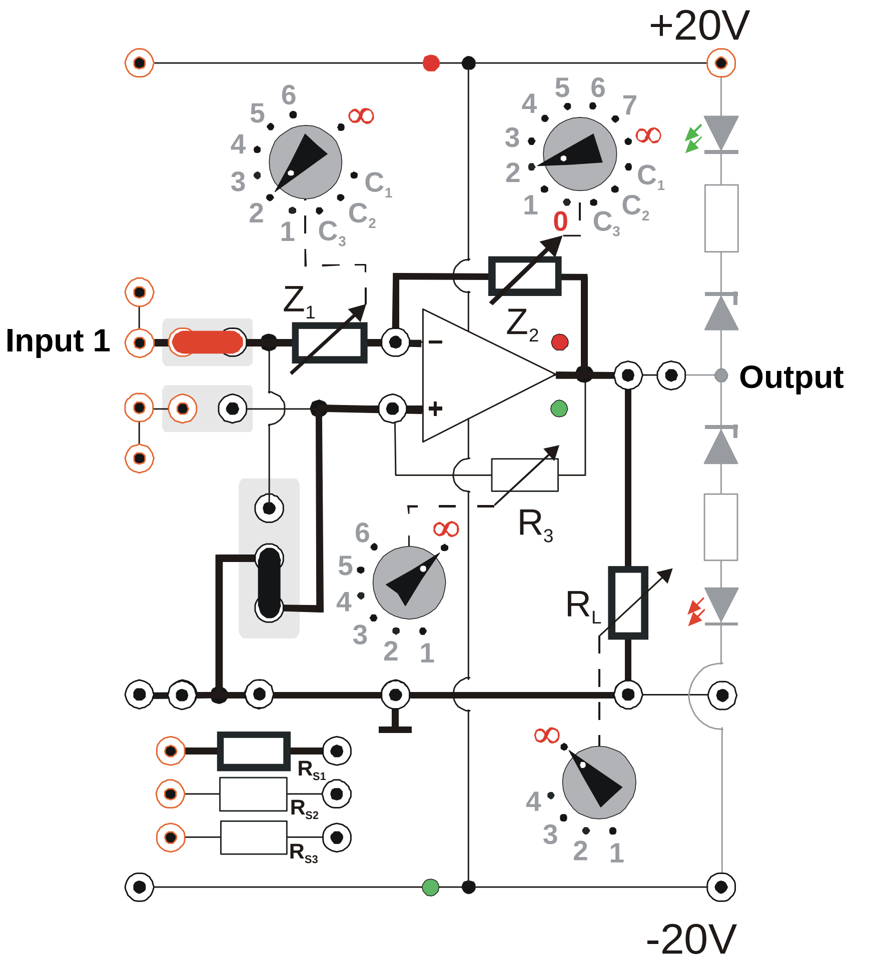

Fig. M1c

B. The noninverting amplifier.

(Connection diagrams are presented on Figures M2a, M2b, and M2c).

I. The transfer characteristic of amplifier

1. Connect the circuit according to the diagrams presented in Figs. M2a and M2c. Set the switches R_3 and R_L to the "∞" position. Set the rotary function switch on DMM's voltmeters to the 20 DC V.
2. Set the switches Z_1 and Z_2 to the "2" position (Fig. M2c).
3. Set the rotary function switch on the Adjustable Power Supply to the "2" position (Fig. M2a).
4. Increasing the input voltage from −12V to +12V determine the dependence of input voltage on output voltage.
5. Record the obtained result on the data sheet in the Data Table A2.
6. Set the switches Z_1 and Z_2 according to the supervisor's order and repeat the procedure described in previous steps.

Table A2 / (A2$^{\#}$) – Noninverting amplifier.

Z_1 / ($R_{S2}^{\#}$/$R_{S3}^{\#}$)	Z_2 / ($R_L^{\#}$)	Input voltage		Output voltage	
[Ω]	[Ω]	U_{IN} [V]	ΔU_{IN} [V]	U_{OUT} [V]	ΔU_{OUT} [V]

II. Measurement of the input impedance of the amplifier

1. Set the input voltage on the value for which the output voltage is near below 12V.
2. Remove the jumper from Input 2 position. Put the R_{S2} resistor instead of the jumper.
3. Measure the output voltage of amplifier without changing the input voltage.
4. Repeat procedures described above for R_{S3} instead of R_{S2}.
5. Record the obtained result on the data sheet in the Data Table A2$^{\#}$.
6. Remove the R_{S3} resistor.

III. Measurement of the output impedance of the amplifier

1. Insert the jumper to the Input 2 position.
2. Set the input voltage on the value for which the output voltage is near below 12V.
3. Measure the output voltage of amplifier for different positions of switch R_L.
4. Record the obtained result on the data sheet in the Data Table A2$^{\#}$.

IV. Measurement of the bandwidth of amplifier.

1. Remove the Adjustable Power Supply and DMMs.
2. Connect the circuit according to the diagram given in Fig. M2b.
3. Select the sine waveform (without the DC OFFSET) by using the Function Select Switch on the Function Generator (FG) front panel and connect the output of FG to the both CH2 input of oscilloscope and input of amplifier (use T junction to divide the signal from the output of FG).
4. Connect the output of amplifier to CH1 input of oscilloscope.
5. Set the switches: Z_1 to the "1" position, Z_2 to the "3" position, and R_L to the "∞" position.
6. Set the output frequency of Function Generator to approx. 300Hz.
7. Set the input voltage amplitude to such a value for which the output amplitude should be about 8V and fulfill the oscilloscope screen.
8. Increasing the frequency of the input signal find the critical frequencies for which the output amplitude decreases sequentially 2, 3, 4, 5, 6, 8 and 10 times.
9. Repeat the procedure described above for setting the switch Z_2 sequentially to the "5" and "7" positions.
10. Draw the oscillograms with strongly marked oscilloscope settings and the following values: amplitude level, type of amplifier, period, Z_1 and Z_2, voltage gain.

V. Measurement of AC voltage gain

1. Set again the output frequency of Function Generator to approx. 300Hz.
2. Measure the input and output amplitudes of signals for various positions of Z_1 and Z_2 switches paying the special attention to non-deforming the signals.
3. Record the obtained results on the data sheet in the Data Table A2 with description "variable signal".

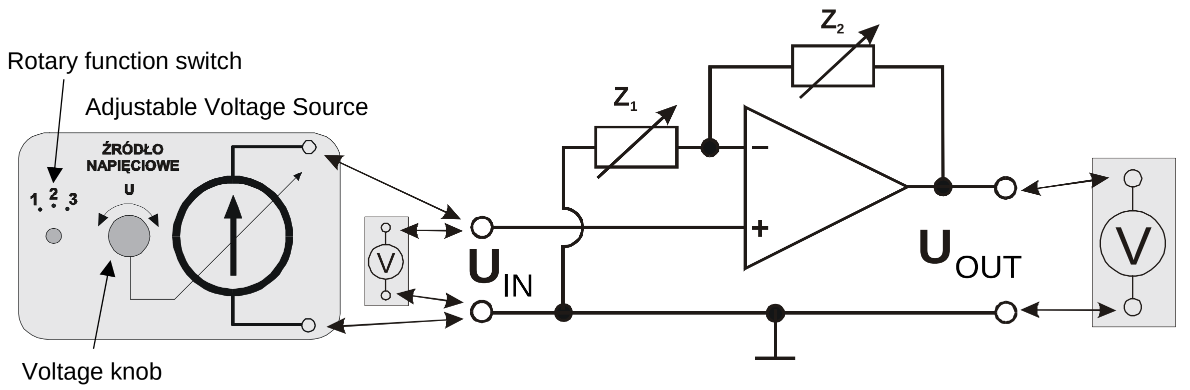

Fig. M2a

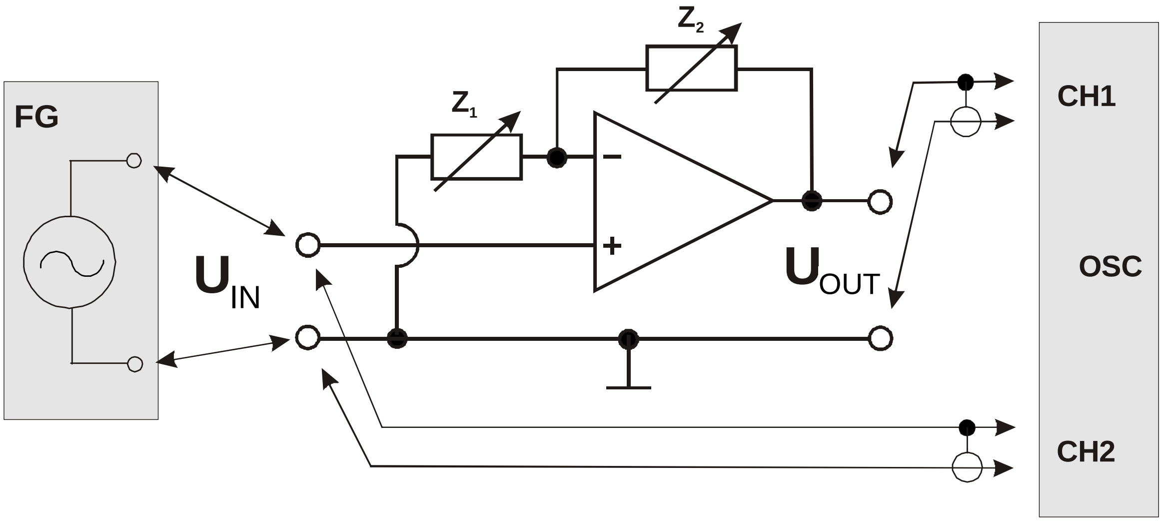

Fig. M2b

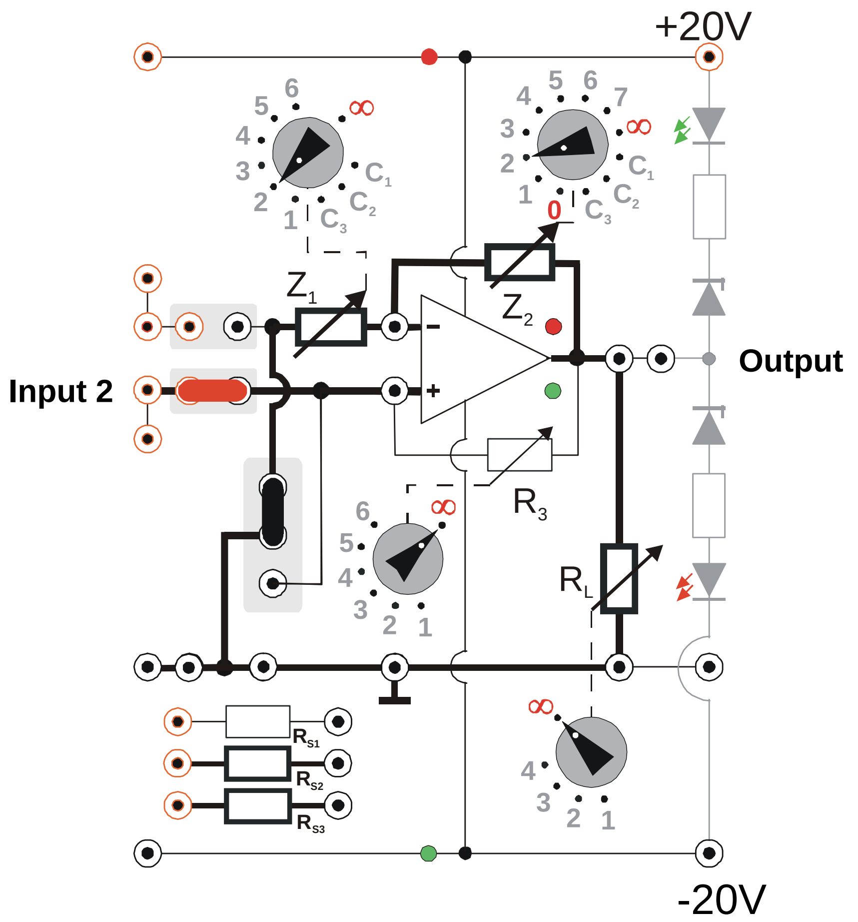

Fig. M2c

C. The voltage-follower

(Connection diagrams are presented on Figures M3a and M3b).

I. The transfer characteristic of amplifier

1. Connect the circuit according to the diagrams presented in Figs. M3a and M3b. Set the switches R_3 and R_L to the "∞" position. Set the rotary function switch on DMM's voltmeters to the 20 DC V.
2. Set the switch Z_1 to "∞" position and switch Z_2 to the "0" position (Fig. M3b).
3. Set the rotary function switch on the Adjustable Power Supply to the "2" position (Fig. M3a).
4. Increasing the input voltage from −12V to +12V determine the dependence of input voltage on output voltage.
5. Record the obtained result on the data sheet in the Data Table A3.

Table A3 / (A3#) – The voltage-follower.

Z_1 / (R_{S2}#)	Z_2 / (R_L#)	Input voltage		Output voltage	
[Ω]	[Ω]	U_{We} [V]	ΔU_{We} [V]	U_{Wy} [V]	ΔU_{Wy} [V]

II. Measurement of the input impedance of the amplifier

1. Set the input voltage on the value for which the output voltage is near below 12V.
2. Remove the jumper from Input 2 position. Put the R_{S2} resistor instead of the jumper.
3. Measure the output voltage of amplifier without changing the input voltage.
4. Repeat procedures described above for R_{S3} instead of R_{S2}.
5. Record the obtained result on the data sheet in the Data Table A3#.
6. Remove the R_{S3} resistor.

III. Measurement of the output impedance of the amplifier

1. Insert the jumper to the Input 2 position.
2. Set the input voltage on the value for which the output voltage is near below 12V.
3. Measure the output voltage of amplifier for different positions of switch R_L.
4. Record the obtained result on the data sheet in the Data Table A3#.

IV. Measurement of the bandwidth of amplifier

1. Remove the Adjustable Power Supply and DMMs.
2. Select the sine waveform (without the DC OFFSET) by using the Function Select Switch on the Function Generator (FG) front panel and connect the output of FG to the both CH2 input of oscilloscope and input of amplifier (use T junction to divide the signal from the output of FG).
3. Connect the output of amplifier to CH1 input of oscilloscope.
4. Set the output frequency of Function Generator to approx. 300Hz.
5. Set the input voltage amplitude to such a value for which the output amplitude should be about 8V and fulfill the oscilloscope screen.
6. Increasing the frequency of the input signal find the critical frequencies for which the output amplitude decreases sequentially 2, 3, 4, 5, 6, 8 and 10 times.
7. Draw the oscillograms with strongly marked oscilloscope settings and the following values: amplitude level, type of amplifier, period, Z_1 and Z_2, voltage gain.

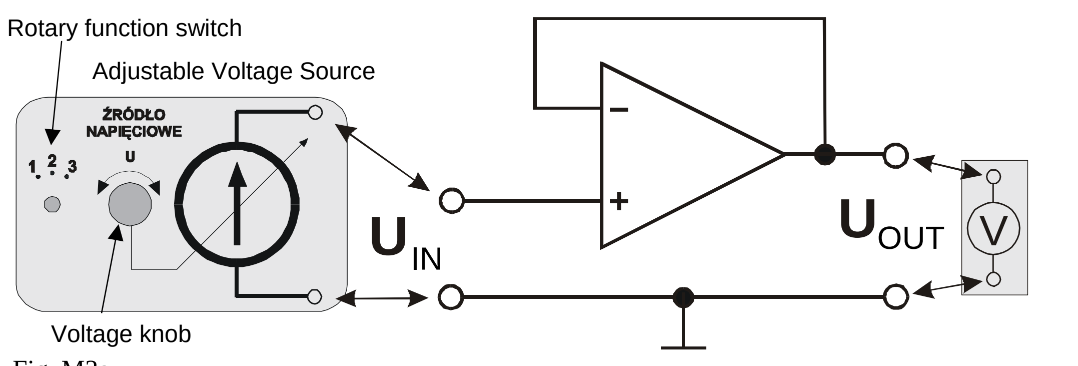

Fig. M3a

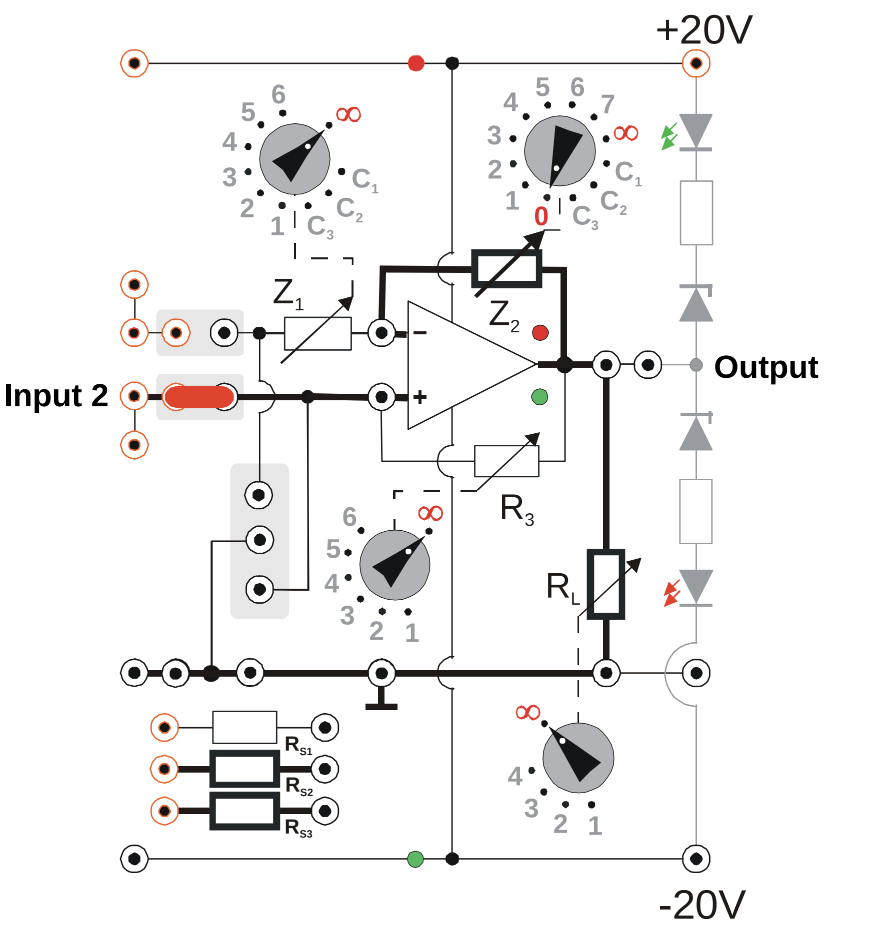

Fig. M3b

Report elaboration

1. Plot the transfer characteristic of inverting amplifier - $U_{OUT} = f(U_{IN})$.
2. Find the DC voltage gain of inverting amplifier for relevant combinations of Z_1 and Z_2 and compare them with those obtained from equations (1):

$$k_u = -\frac{Z_2}{Z_1} \qquad \text{and} \qquad k_u{}^A[\mathrm{dB}] = 20\log\left(\left|\frac{U_{OUT}}{U_{IN}}\right|\right). \tag{1}$$

3. Plot the voltage gain coefficient k_u of inverting amplifier versus frequency for different combinations of Z_1 and Z_2 . Apply logarithmic scale for frequency (the sample plot is presented in Fig. O1).
4. Find the input and output impedance of inverting amplifier applying the equations (2):

$$R_{IN} = \frac{R_{S1}}{\dfrac{U_{OUT1}}{U_{IN1}} - 1}; \qquad R_{OUT} = \frac{U_{OUT1} - U_{OUT2}}{\dfrac{U_{OUT2}}{R_{L2}} - \dfrac{U_{OUT1}}{R_{L1}}}. \tag{2}$$

   Derive the relevant formulas and calculate the measuring errors for R_{IN} and R_{OUT}.

5. Based on measurements of input and output amplitudes for inverting amplifier find the AC voltage gains corresponding to relevant combinations of Z_1 and Z_2 and compare them with those obtained from equations (1).
6. Plot the transfer characteristic of noninverting amplifier - $U_{OUT} = f(U_{IN})$.
7. Find the DC voltage gain of noninverting amplifier for relevant combinations of Z_1 and Z_2 and compare them with those obtained from equations (3):

$$k_u = 1 + \frac{Z_2}{Z_1} \qquad \text{and} \qquad k_u{}^A[\mathrm{dB}] = 20\log\left(\left|\frac{U_{OUT}}{U_{IN}}\right|\right). \tag{3}$$

8. Plot the voltage gain coefficient k_u of noninverting amplifier versus frequency for different combinations of Z_1 and Z_2 . Apply logarithmic scale for frequency.
9. Find the input and output impedance of noninverting amplifier applying the equations (4).

$$R_{IN} = \frac{R_{S2}}{\dfrac{U_{OUT}}{U_{OUT2}} - 1} \quad \text{and/or} \quad R_{IN} = \frac{R_{S3}}{\dfrac{U_{OUT}}{U_{OUT3}} - 1}; \qquad R_{OUT} = \frac{U_{OUT1} - U_{OUT2}}{\dfrac{U_{OUT2}}{R_{L2}} - \dfrac{U_{OUT1}}{R_{L1}}}. \tag{4}$$

   Derive the relevant formulas and calculate the measuring errors for R_{IN} and R_{OUT}.

10. Based on measurements of input and output amplitudes for noninverting amplifier find the AC voltage gains corresponding to relevant combinations of Z_1 and Z_2 and compare them with those obtained from equations (3).
11. Plot the transfer characteristic of voltage-follower - $U_{OUT} = f(U_{IN})$.
12. Find the DC voltage gain of voltage-follower and compare it with this obtained from equations (3) (Z_2=0).
13. Find the input and output impedance of voltage-follower applying the equations (4). Derive the relevant formulas and calculate the measuring errors for R_{IN} and R_{OUT}.
14. Based on measurements of input and output amplitudes for voltage-follower find the AC voltage gain and compare it with this obtained from equations (3).

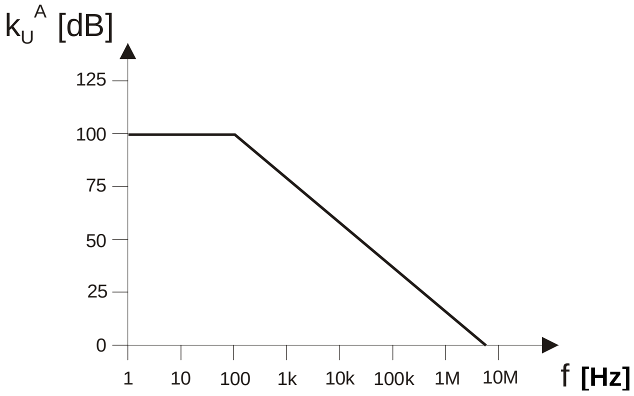

Fig. O1. The sample plot of k_u^A versus frequency.
Frequency is presented in logarithmic scale.

Tables of resistances and capacitances

Z_1	
Position	Value
1	5 kΩ
2	10 kΩ
3	15 kΩ
4	20 kΩ
5	25 kΩ
6	30 kΩ
∞	∞ Ω
C_1	0,1 μF
C_2	1,0 μF
C_3	10 μF

Z_2	
Position	Value
0	0 Ω
1	10 kΩ
2	20 kΩ
3	50 kΩ
4	100 kΩ
5	200 kΩ
6	500 kΩ
7	1 MΩ
∞	∞ Ω
C_1	0,1 μF
C_2	1,0 μF
C_3	10 μF

R_3	
Position	Value
1	20 kΩ
2	50 kΩ
3	100 kΩ
4	200 kΩ
5	500 kΩ
6	1 MΩ
∞	∞ Ω

R_L	
Position	Value
1	2 kΩ
2	5 kΩ
3	10 kΩ
4	20 kΩ
∞	∞ Ω

R_{S1}	10 kΩ
R_{S2}	300 kΩ
R_{S3}	10 MΩ

References

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