Lodz University of Technology
Institute of Physics

Laboratory of electronics

Exercise E09IFE

Comparators

Version 1.1 (11 April 2018)

Table of contents:

Before starting the experiment one should learn 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 comparator. [1÷5].

1. Purpose of the exercise

The purpose of experiment is to gain knowledge on the properties of comparators and on applications of them.

2. Hazards

Type	Absence	Low	Medium	High
electrical shock hazards		+		
optical radiation hazards	+			
mechanical hazards (including acoustic hazards, noise)	+			
electromagnetic radiation hazards (invisible)	+			
biological hazards	+			
ionizing radiation hazards	+			
chemical hazards	+			
thermal hazards (including explosion and fire)	+			

The cables with banana plugs are designed exclusively for use in low-voltage circuits – do not connect them to the mains supply 230 V.

3. Introduction

Operational amplifier without the feedback resistors is often used as comparator for comparing the amplitude of one voltage with another. It is running in the open-loop mode. The typical comparator is presented in Fig 1.

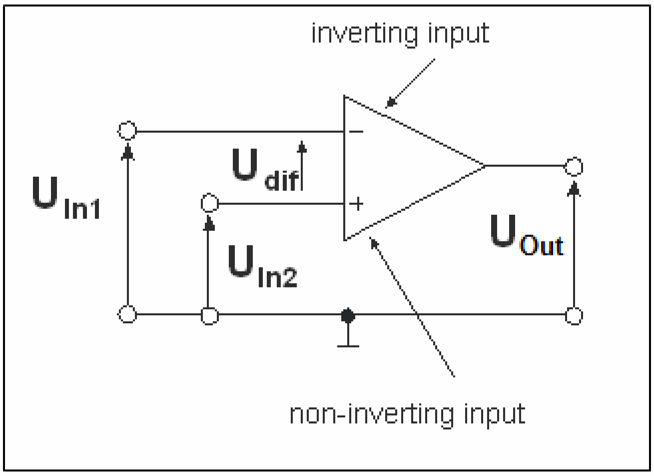

Fig.1. Comparator.

If U_{In2} is larger than U_{In1} then U_{out} is positive. If U_{In2} is smaller than U_{In1} then U_{out} is negative. This means that after application of a reference voltage to one of the inputs one can obtain a comparator circuit indicating whether the voltage measured on the other input is larger or smaller than the reference voltage.

The comparator is a particular kind of operational amplifier with asymmetrical input and high amplification which compares value of voltage applied to one input with the reference voltage applied to another input and produces logical signal 0 or 1 depending on the sign of difference between these voltages. Therefore comparator is one-bit analog-to-digital converter.

In practice each operational amplifier can work as comparator. Nevertheless usual operational amplifiers applied as comparators reveal some disadvantages. Therefore in practice special integrated comparators are used. The differences between comparators and usual operational amplifier are as follows:

a) Comparators are dedicated to work with open feedback loop whereas operational amplifiers are designed for work with various feedback coefficients,
b) Comparators are much faster than operational amplifiers,
c) Typical voltage levels at the output of a comparator are fitted to the level of digital signal, e.g. TTL, whereas application of operational amplifier requires additional circuit which fits the output voltage from the amplifier to the level of digital signal. In consequence, the circuits using the amplifier are more expensive,
d) Comparators have wider range of input voltages than amplifiers,
e) Comparators have smaller input resistances and larger polarizing currents than amplifiers,
f) Comparators with open collector outputs cannot be realized with use of operational amplifiers.

4. Available equipment

4.1. Experimental module

Schematic diagrams of experimental modules shown in Figures 2, 3 and 4.

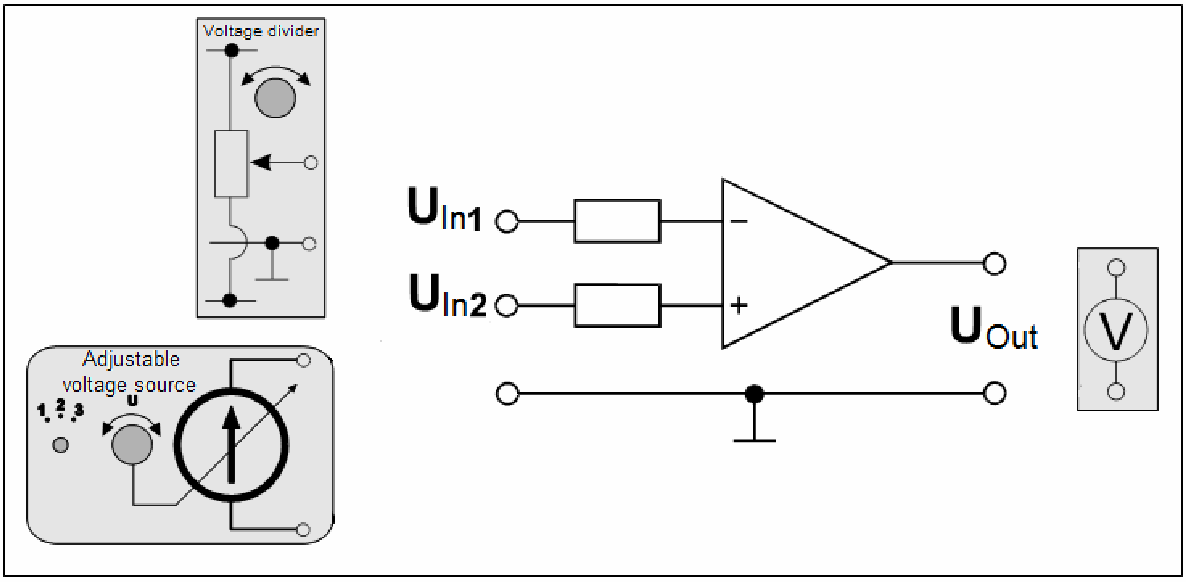

Fig. 2. Schematic diagram of the experimental module for a comparator without hysteresis.

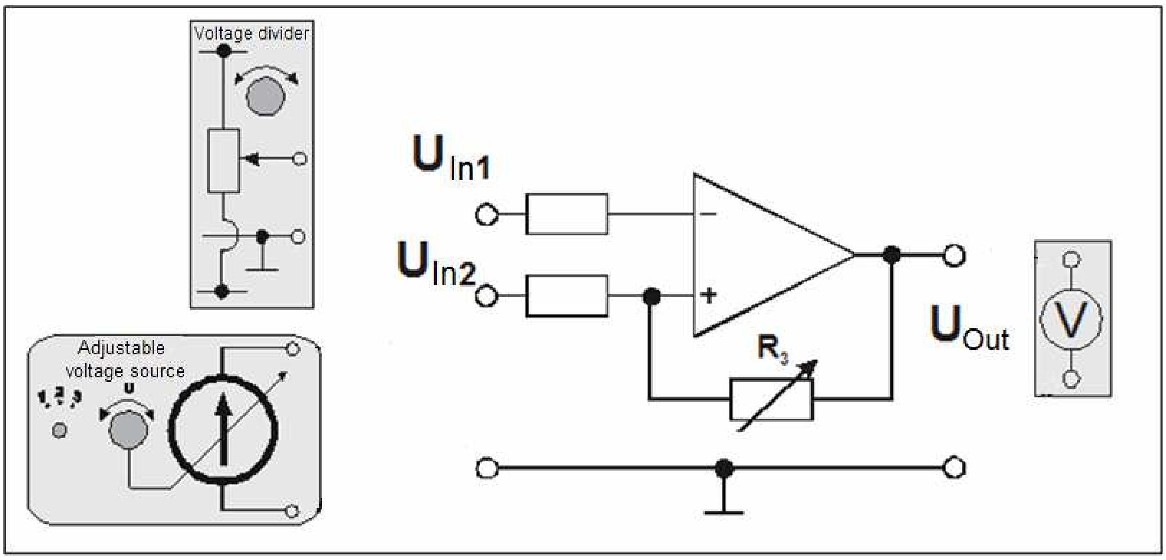

Fig. 3. Schematic diagram of the experimental module for a comparator with hysteresis.

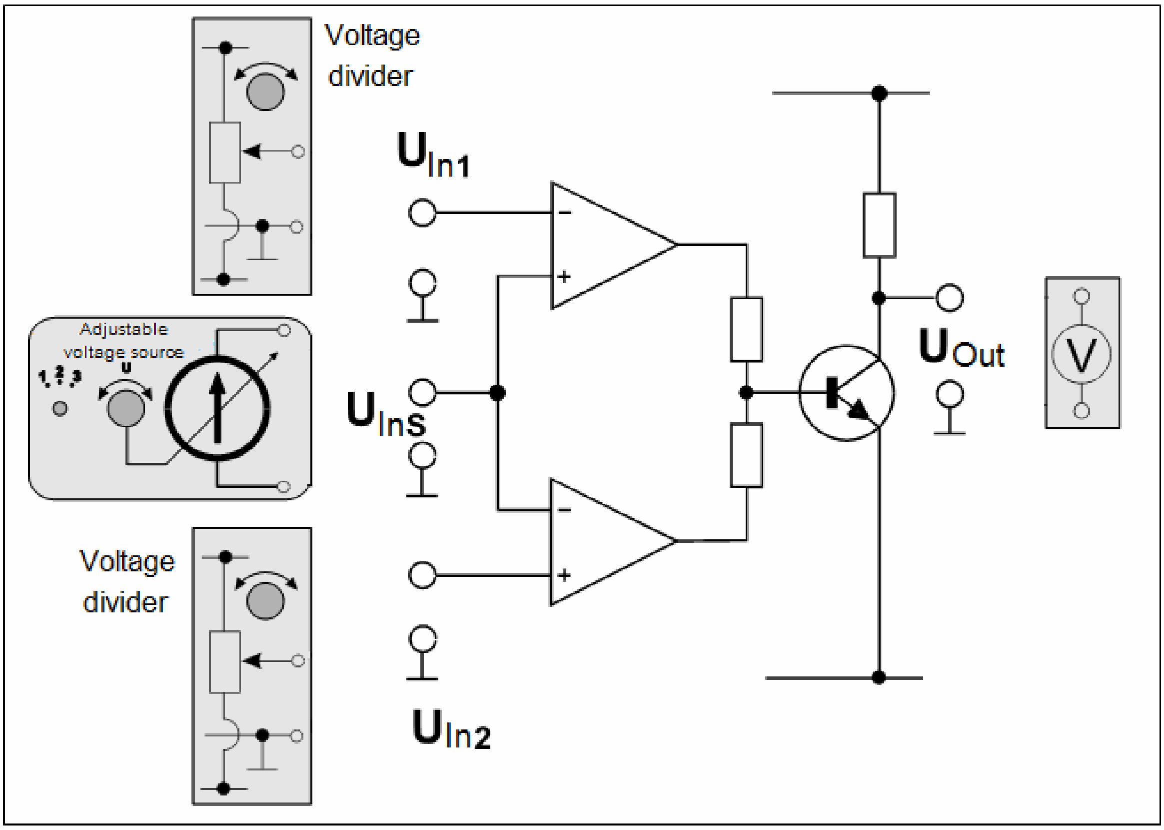

Fig. 4. Schematic diagram of the experimental module for a window comparator.

4.2. Multimeters

Measurements of voltages and currents in the experimental module are performed using digital multimeters KT890, M-3800, M-4650, UT-804 or Protek 506 [6]. Before measurements, check whether the voltage measuring mode is selected with the switches of each digital multimeter and whether the test probes are connected to the appropriate input terminals. One should also remember to choose the proper ranges of the multimeters.

4.3. Power supply

The experimental modules are powered using the laboratory power supply SIGLENT model SPD3303D [6]. Before starting the measurements the +5V output of the stabilized power supply SPD3303D should be connected with the module ZŹS (the module includes an adjustable voltage source). The other modules containing voltage dividers and comparators require the voltages –20V and +20V, symmetrical with respect to ground, that can be obtained from the CH1 and CH2 channels of the power supply working in the SERIAL mode.

5. Experimental procedure

Comparator basing on operational amplifier is investigating in three typical circuits:

- comparator without hysteresis (amplifier with open feedback loop),
- comparator with hysteresis (amplifier with positive feedback loop),
- window comparator.

The measurements are performed for DC voltages applied by adjustable voltage source and voltage divider. The operation of comparator are studied by means of voltmeters connected with inputs and output of the operational amplifier.

The amplifier is supplied from stabilized power supply SPD3303D working in the SERIAL mode with chosen voltages –20V and +20V, symmetrical with respect to ground.

The control LEDs placed near the output of comparator show the saturation of comparator. The red light means maximum positive voltage and green light means minimum negative voltage.

5.1. Comparator without hysteresis. The transfer characteristic of comparator

1. Connect the circuit according to the diagrams presented in Figs. 5a and 5b. Remove the vertical jumper and plug the horizontal (red) jumper in vicinity of In1. Set the switches R_3 and R_L to the "∞" position. Set the rotary function switch on DMM's into voltmeters mode with the measuring range 20V or 40V DC (depending on type of multimeter). Next connect one of voltmeters between ground (⊥) and the output Out, and another two voltmeters between ground and the inputs In1 and In2. Connect the lines +20V, –20V and ground in the experimental module with appropriate outputs of the power supply working in the SERIAL mode.
2. Set the switch Z_1 to the "**2**" position and the switch Z_2 to the "∞" position.
3. Set the rotary function switch on the adjustable power supply to the "**2**" position.
4. Put the R_{S1} resistor near the In2 input position (below the horizontal red jumper).
5. Connect the adjustable voltage source to the non-inverting input In2.
6. Connect the voltage divider to the inverting input In1.
7. After checking the circuit by the supervisor, switch on the power supply.
8. Set sequentially three voltages U_{In1} (on the inverting input In1) from the range (–8V ÷ +8V), differing by 2V at least. Prepare the transfer characteristic of the comparator for each of them, changing the voltage U_{In2} (on input In2) from extreme negative to extreme positive value. Record the results in table 1.
9. Interchange the connections of the voltage divider and voltage source, i.e. voltage divider to the input In2 (non-inverting) and a voltage source to the input In1 (inverting).
10. Repeat the measurements from the point 8 by setting this time another three different voltages U_{In2} (on the non-inverting input In2) and changing the voltage U_{In1} (on the input In1).
11. Switch off the power supply.

Input voltage U_{In1} [V]	Input voltage U_{In2} [V]	Output voltage U_{Out} [V]

Tab.1. Results obtained for comparator without hysteresis.

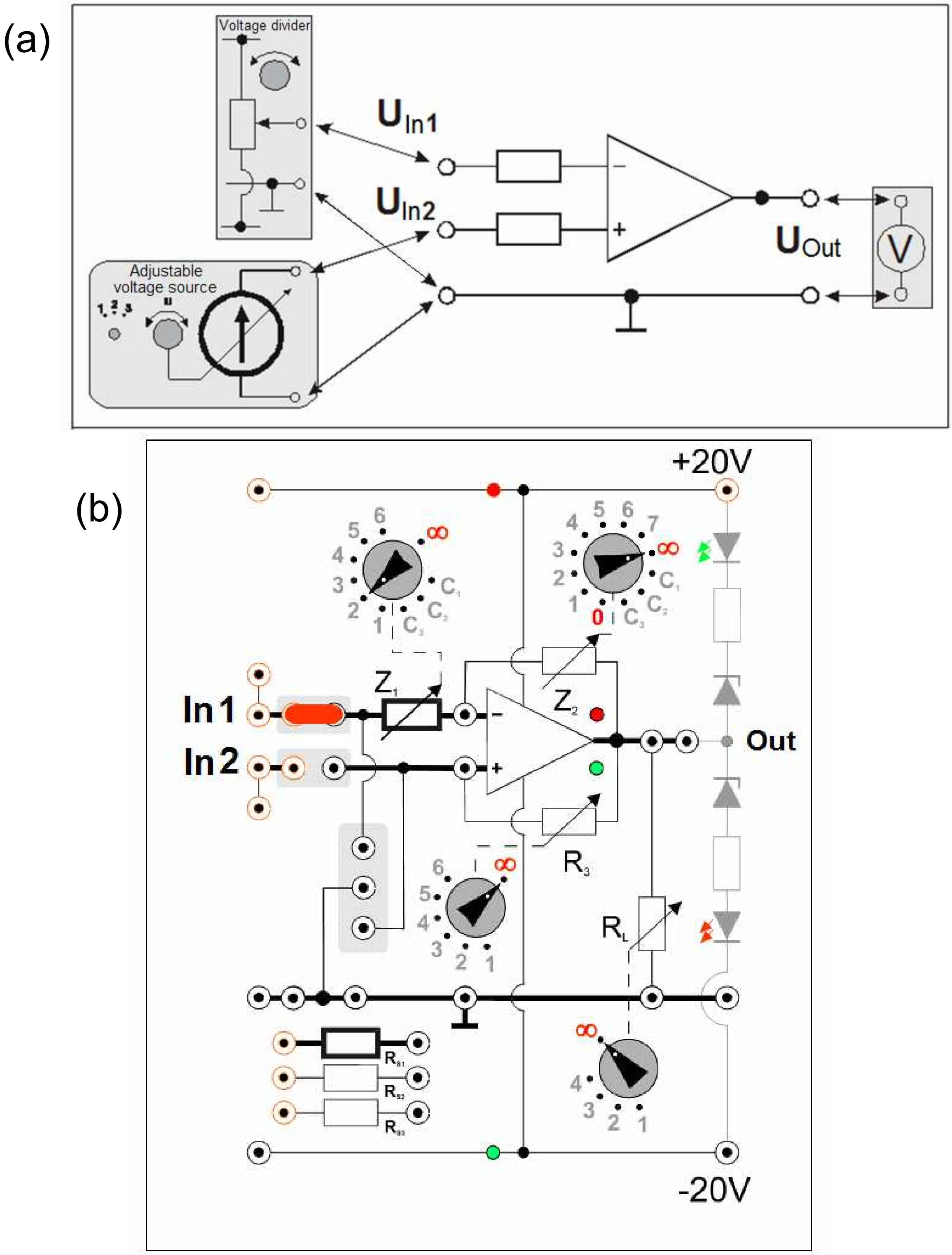

Fig. 5a and 5b. Scheme of connections for the transfer characteristic of comparator without hysteresis.

5.2. Comparator with hysteresis. The transfer characteristic of comparator

1. Connect the circuit according to the diagrams presented in Figs. 6a and 6b. Remove the vertical jumper and plug the horizontal (red) jumper in vicinity of In1. Set the switches R_L to the "∞" position. Set the rotary function switch on DMM's into voltmeters mode with the measuring range 20V or 40V DC. Next connect one of voltmeters between ground (⊥) and the output Out, and another two voltmeters between ground and the inputs In1 and In2. Connect the lines +20V, –20V and ground in the experimental module with appropriate outputs of the power supply working in the SERIAL mode.
2. Set the switch Z_1 to the "**2**" position and the switch Z_2 to the "∞" position.
3. Set the rotary function switch on the adjustable power supply to the "2" position.
4. Put the R_{S1} resistor near the In2 input position (below the horizontal red jumper).
5. Connect the adjustable voltage source to the non-inverting input In2.
6. Connect the voltage divider to the inverting input In1.
7. After checking the circuit by the supervisor, switch on the power supply.
8. Set the voltage U_{In1} on the inverting input In1 from the range (–2V ÷ +2V).
9. Changing the voltage U_{In2} on the input In2 prepare two transfer characteristic of comparator for R_3 resistance switch set at positions „**1**", „**5**" or „**2**", „**6**". Change the voltage U_{In2} first from the extreme negative values to extreme positive values and next from the extreme positive to extreme negative. In case of erroneous switching of the potentiometer knob, repeat all the measurements. Record the results in table 2.
10. Interchange the connections of the voltage divider and voltage source, i.e. voltage divider to the input In2 (non-inverting) and a voltage source to the input In1 (inverting).
11. Repeat the measurements from the point 8 and 9 by setting this time voltage U_{In2} (on the non-inverting input In2) and changing the voltage U_{In1} (on the input In1).
12. Switch off the power supply.

Resistor R_3 [Ω]	Input voltage U_{In1} [V]	Input voltage U_{In2} [V]	Output voltage U_{Out} [V]

Tab.2. Results obtained for comparator with hysteresis.

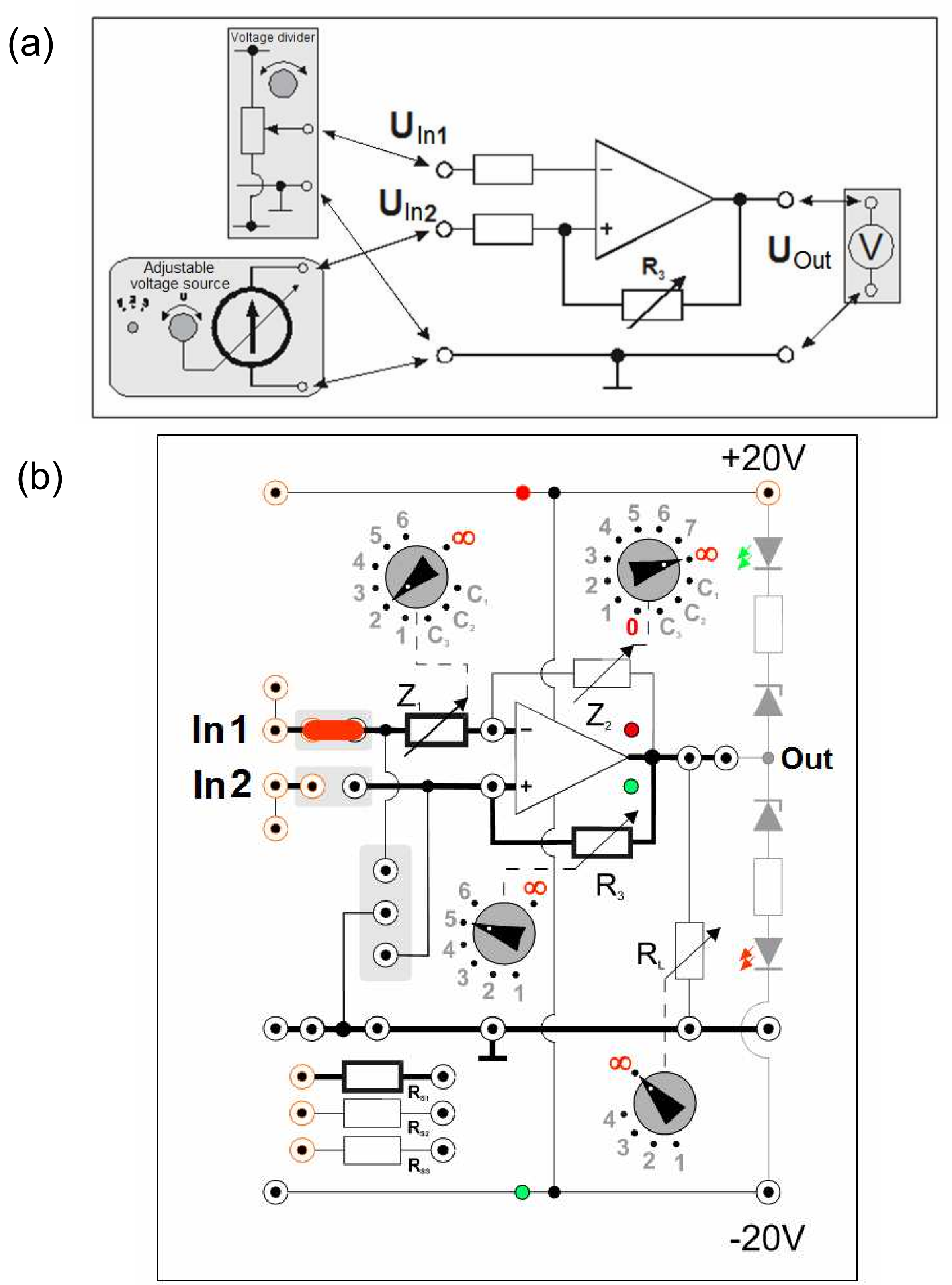

Fig. 6a and 6b. Scheme of connections for the transfer characteristic of comparator with hysteresis.

5.3. The window comparator. The transfer characteristic of comparator (extended version)

1. Connect the circuit according to the diagrams presented in Figs. 7a and 7b. Set the rotary function switch on DMM's into voltmeters mode with the measuring range 20V or 40V DC. Next connect one of voltmeters between ground (⊥) and the output Out, and another three voltmeters between ground and the inputs In1, InS and In2. Connect the lines +20V, –20V and ground in the experimental module with appropriate outputs of the power supply working in the SERIAL mode.
2. Connect the adjustable voltage source between ground (⊥) and the InS input.
3. Connect one of voltage dividers between ground (⊥) and input In1 (inverting).
4. Connect the other voltage divider between ground (⊥) and input In2 (non-inverting).
5. Set the rotary function switch on the adjustable power supply to the "**2**" position.
6. After checking the circuit by the supervisor, switch on the power supply.
7. Set the voltage U_{In1} on the inverting input In1 from the range (+1V ÷ +3V).
8. Set the voltage U_{In2} on the non-inverting input In2 from the range (–3V ÷ –1V).
9. Prepare the transfer characteristic of comparator changing the voltage on the input InS from the extreme negative values to extreme positive values. Record the results in table 3. Note states of LEDs (for each value of U_{InS}, respectively) on the output of the window comparator and the outputs of both components comparators indicated in Fig. 7b as 1 and 2.
10. Switch off the power supply.

U_{In1} [V]	U_{In2} [V]	U_{InS} [V]	U_{Out} [V]	control LEDs				
				1 - upper		2 - lower		output
				Green	Red	Green	Red	Blue

Tab.3. Results obtained for window comparator.

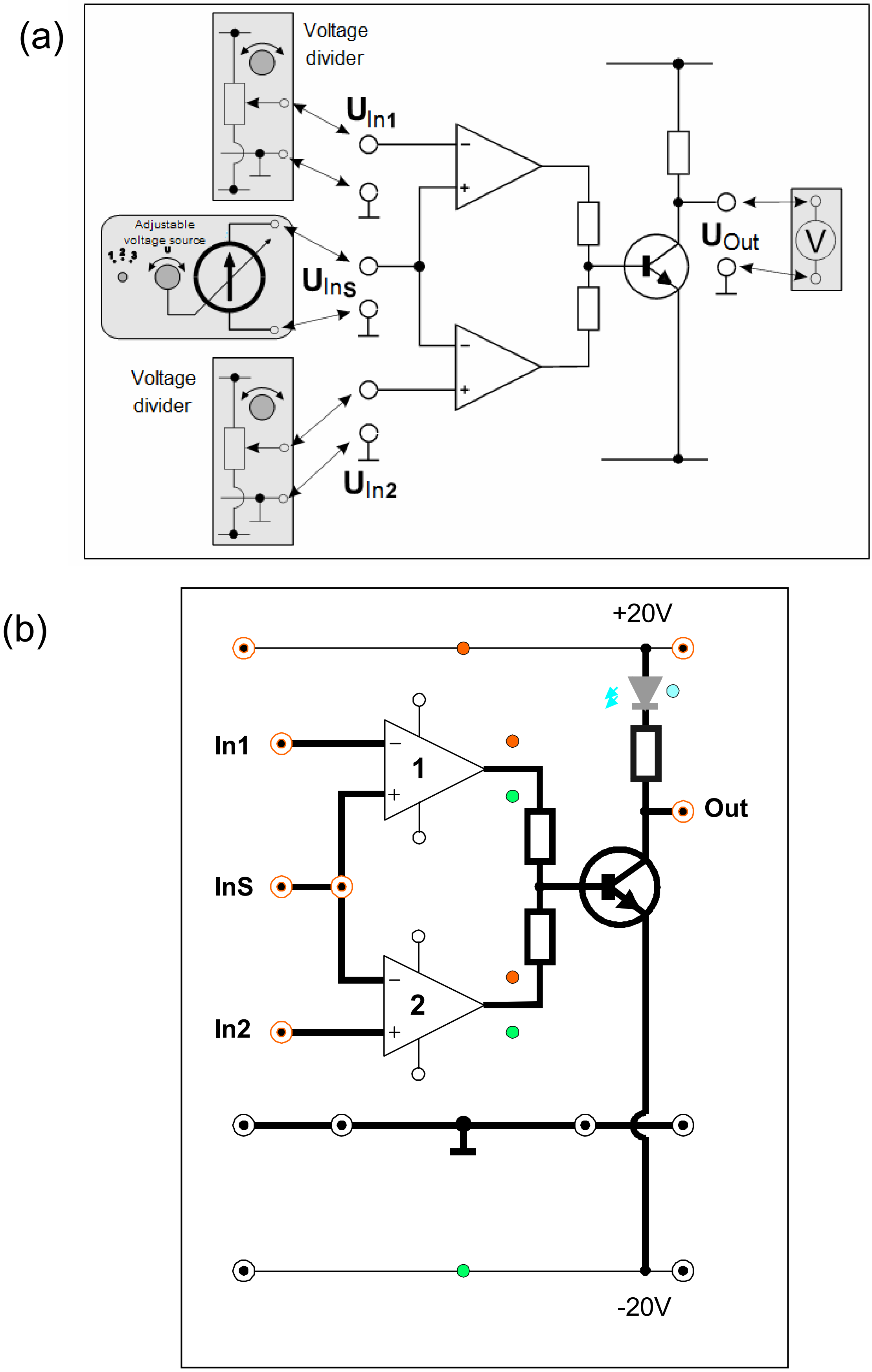

Fig. 7a and 7b. Scheme of connections for the transfer characteristic of window comparator.

6. Guidelines on writing reports

Report has to be composed of:

1. Front page.
2. Description of experiment purposes.
3. Schematic diagrams of tested circuits.
   The report should contain only diagrams of the systems, which were actually compiled during the measurements. Each scheme must be accompanied by a sequence number and entitled. All the components shown in the diagram must be clearly described and identified using commonly used symbols.
4. List of used instruments and devices (id/stock number, type, setting and range values).
5. Results of measurements and states of LEDs gathered in tables.
6. Plots, analysis, interpretation and sub-conclusions related to all required points of "Experimental procedure".
   - 6.1. Common plot of all transfer characteristics of comparator without hysteresis prepared in part 5.1.
   - 6.1. Common plot of all transfer characteristics of comparator with hysteresis prepared in part 5.2.
   - 6.2. Common plot of resulting transfer characteristic of window comparator and two characteristics of component comparators (indicated as 1 and 2 in Fig. 7b) prepared in part 5.3.
7. Remarks and final conclusions.
   The comments should contain estimation of the accuracy of measurements and own observations about the course of the exercise.

The report will be subject to the assessment of the presence and accuracy of all of the above components, clarity of presentation of the results (in the form of tables, graphs) and the quality of discussions and proposals formulated. Theoretical introduction is not required and in case of its inclusion in the report it will not affect the assessment.

7. References

7.1. Basic reference materials

[1] M. Rusek, J. Pasierbiński, *Elementy i układy elektroniczne w pytaniach i odpowiedziach*, WNT, Warszawa, 1999.
[2] M. Nadachowski, Z. Kulka, *Scalone układy analogowe*, WKiŁ, Warszawa, 1985.
[3] P. Horowitz, W. Hill, *Sztuka elektroniki. Cz. 1.*, (tłum. ang.), WKiŁ, Warszawa, 2003.
[4] Z. Nosal, J. Baranowski, *Układy elektroniczne. Cz. I. Układy analogowe liniowe*, Seria Podręczniki Akademickie, (Elektronika, Informatyka, Telekomunikacja), WNT, Warszawa, 2003.
[5] A. Filipowski, *Układy elektroniczne analogowe i cyfrowe*, Seria Podręczniki Akademickie, (Elektronika, Informatyka, Telekomunikacja), WNT, Warszawa, 2004.

7.2. Other reference materials

[6] User manuals of the power supply and DMMs.
https://fizyka.p.lodz.pl/pl/dla-studentow/fundamentals-of-electronics/

8. Appendix

A.1. 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