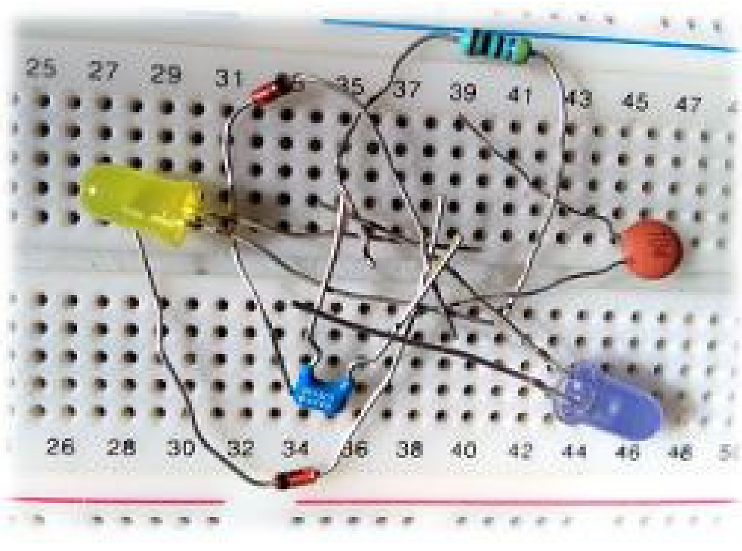
LAURA IVANCIU

EMILIA ȘIPOȘ

ELECTRONIC DEVICES

Laboratory manual



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Foreword

This laboratory manual is mainly addressed to first year students of the Faculty of Electronics, Telecommunications and Information Technology (English section), as well as to first year students of the Faculty of Automation and Computer Science. Other students that are discovering the Electronic Devices and Circuits universe can also find it useful.

The first laboratory work presents the lab instrumentation and provides the basic knowledge on the use and operation of each instrument. The remaining 10 laboratory works are designed to closely support the theoretical aspects taught during the lectures, by engaging the students in practical experiments and investigations.

The proposed experiments aim to achieve three main goals, namely:

a) to strengthen the students' confidence in their theoretical knowledge acquired during the lectures, by experimentally verifying these concepts;
b) to identify the differences between theoretic results (using device models) and experimental results (using physical devices);
c) to learn new methods and techniques for experimental circuits analysis and verification.

Each laboratory work (except for the first one) is organized in four sections, namely: *I. Objectives; II. Components and instrumentation; III. Preparation; IV. Explorations and results.*

The first section, *Objectives*, clearly states the concepts that the students will master, by the end of the lab session.

The second section, *Components and instrumentation*, enumerates the necessary electronic devices and instruments used in the experimental part.

The *Preparation* section is a set of questions and exercises which address the very same circuits that are to be built in the experimental part. This section represents homework for the students, and constitutes the theoretical reference to which the experimental results will be compared.

The last section, *Explorations and results*, is the core of each laboratory work, all previous sections converging towards it. Structured in a multi-level fashion, this section consists of one or more general topics, organized in sub-sections. Each sub-section has its own *Exploration* part and *Results* part. In the *Exploration* part, the reader is provided with a detailed description of the steps and actions to be followed in order to implement and analyze particular circuits. The *Results* part follows closely, and includes indications regarding the numerical values, signal waveforms and transfer characteristics that are to be followed and analyzed, throughout the experiments.

To fully exploit the measurements and optimize the learning experience, a strong emphasis is put on comparisons between theoretical and practical results.

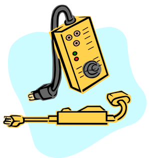
Cluj – Napoca, May 2022

The authors

LAB INSTRUMENTATION. VOLTAGE DIVIDER.

I. OBJECTIVE

a) Becoming accustomed to using the lab instrumentation (voltage supply, digital multimeter, signal generator, oscilloscope) necessary to the experimental study of some electronic devices and circuits.



II. COMPONENTS AND INSTRUMENTATION

The instruments we will use are the ones available in the *Electronic Devices and Circuits* lab: regulated power supply, digital multimeter, signal generator and dual channel oscilloscope. For electrical connections we will use conductors equipped with jacks at both ends and screened probes.

III. THEORETICAL ASPECTS

1. THE POWER SUPPLY

A regulated power supply has the purpose of maintaining the output voltage constant at the variation in certain limits of some quantities (input voltage, load, temperature, etc.).

The d.c. power supplies are used for feeding most of the electric circuits, supplying them d.c. electric power.

In the lab we use triple power supply (HM8040) that contains three floating supplies: two independent supplies (0-20V/0.5A) and one dependent supply (5V/1A). On the front panel the double power supply has (Fig.1):

- OUTPUT - push button for activating/deactivating all the outputs ;
- the optic working LED: is on when the supply is powered with the network voltage;
- each independent supply has two output terminals: red for plus and black for minus ;
- potentiometers for adjusting the output voltage (VOLTAGE) and the limiting current (CURRENT):
- 3-digit switchable display for current and voltage. Display resolution is 0.1V / 1Ma

Fig. 1. The front panel of the power supply HM8040

ATTENTION

If during an experiment the milliammeter of the source shows a high value (over 100mA) turn off the supply because there can be a fault on the experimental board.

2. THE DIGITAL MULTIMETER

The digital multimeter is an electronic instrument use to measure resistances, voltages and currents (dc and ac). For ac sinusoidal signals the effective value is measured. The signal processing and results display is digital.

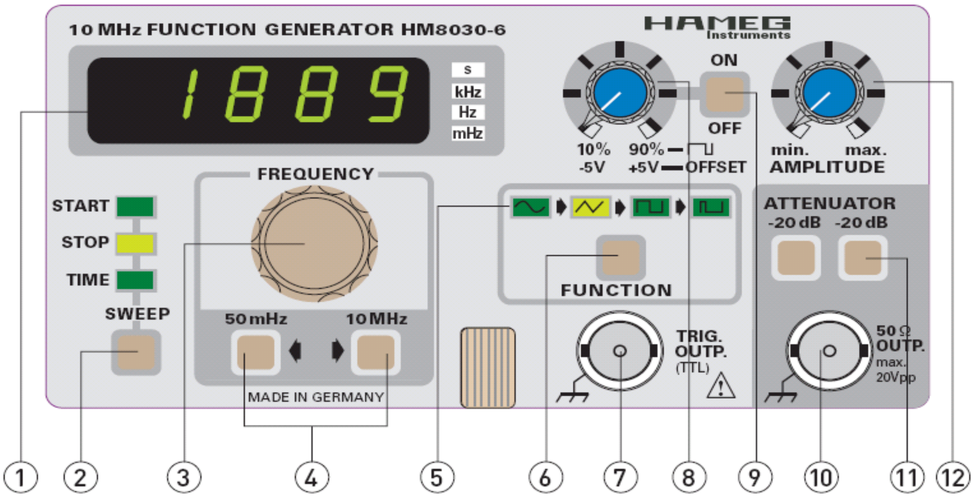
For each quantity the apparatus is equipped with several measuring domains. The best reading precision is obtained using the domain that has the smallest end of scale, without outrunning the scale.

Usually the multimeters have three measuring terminals:

– the measuring terminal (V, Ω, mA, hot wire, “+”); usually the wire applied to this terminal has the red color for all measured quantities except the direct current with an intensity greater than 2A. Sometimes the mA and V,Ω terminals are separated;
– the measuring terminal (10A: hot wire, “+”) only for measuring high values of direct current intensity (max 10A);
– the reference terminal (COM, cold wire, ground, “-“) with respect to which all the measurements are made; usually the wire applied to this terminal is black.

3. THE SIGNAL GENERATOR

The signal generator is an electronic instrument that provides variable signals of different shapes (sine, square, triangle, pulse, etc) allowing the modification of several parameters: amplitude, frequency, duty cycle, etc. The generator is used to apply variable signals to the electronic circuit that are experimentally studied.



Control elements of HM8030-6

① **DISPLAY (7 segment LED)**
5-digit frequency meter. LED indicators for mHz, Hz, kHz and s

② **SWEEP (push button) and Indication (LEDs)**
Button activates internal sweep generator. The LEDs indicate the function chosen with the SWEEP-Button. Settings are changed with ③ or ④.

③ **FREQUENCY (adjustment knob)**
Continuous and linear frequency fine adjustment, with the setting range from 0.09 to 1.1 (approx 0.045 to 1.1 in 10 MHz-range) overlapping the ranges selected with ④

④ **FREQUENCY (2 pushbuttons)**
Frequency range selection from 50 mHz to 10 MHz in 8 decade steps.

⑤ ∿ – ⋀ – ⎍ – ⊓⊔ **(LED s)**
Indication of selected function.

⑥ ∿ – ⋀ – ⎍ – ⊓⊔ **(pushbutton)**
Mode selection: Triangle, Sine, Square, Pulse and Off.

⑦ **TRIGGER OUTPUT (BNC connector)**
This short-circuit-proof output supplies a square signal in synchronism with the output signal. It is TTL compatible and has a duty-factor of approx. 50%.

⑧ **OFFSET (adjustment knob)**
Adjustment of the positive or negative offset voltage. This DC voltage can be super-imposed on the output signal. The max. offset voltage is ±5V (o.c.) or ±2.5V respectively when terminated into 50Ω. The offset voltage is available to all functions except for pulse and activated by ⑨. In operation mode OFF (no function activated) it can be used separatey. In pulse mode the pulse width is set with this control from 10% to 90%.

⑨ **ON (pushbutton)**
Activates the offset function except in pulse mode. If the ON-button is pushed in pulse mode, pulse width is set with the control ⑧ from 10% to 90%. In OFF-position the fixed pulse width amounts to 50%.

⑩ **50Ω OUTPUT (BNC connector)**
Short-circuit proof signal output of the generator. The output impedance is 50Ω and the max. output amplitude is $20V_{pp}$ (o.c.) or $10V_{pp}$ respectively when terminated into 50Ω.

⑪ **–20dB, –20bB (pushbutton)**
Two fixed attenuators, 20dB each. They can be used separately. When both pushbuttons are activated, a total attenuation of 40dB results. Including the amplitude control ⑫, the max. attenuation amounts to 60dB (factor 1000).

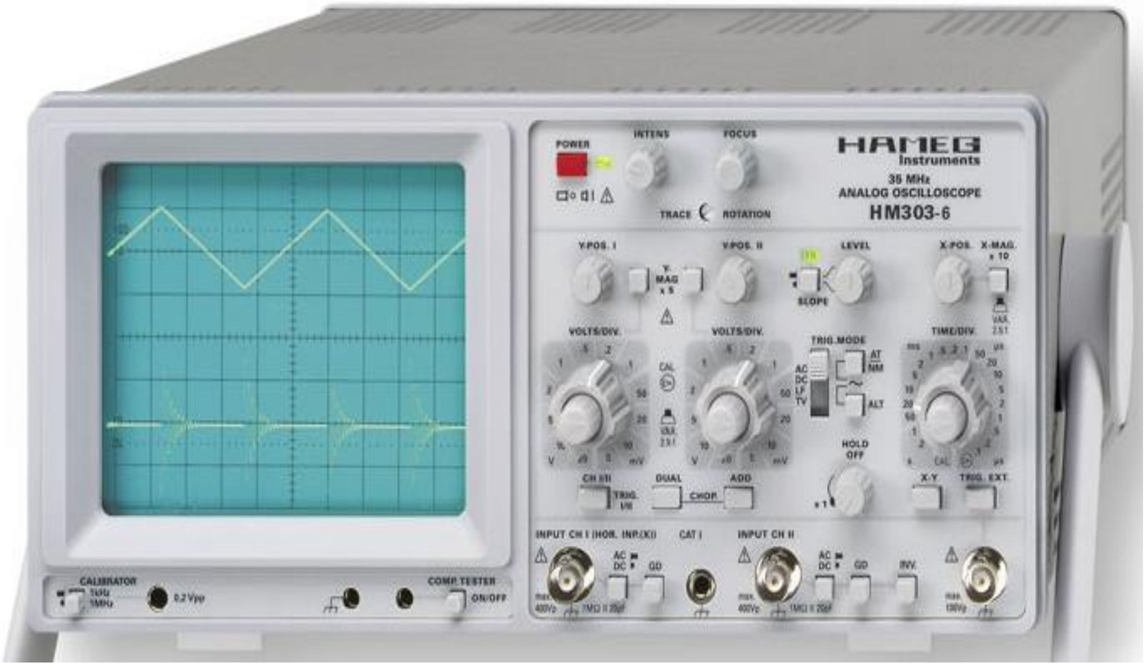
⑫ **AMPLITUDE (adjustment knob)**
Continuous adjustment of the output amplitude from 0 to –20dB terminated into 50Ω.

4. THE CATHODIC OSCILLOSCOPE

The oscilloscope is the most useful and versatile electronic test instrument. As usually used, it lets us “see” voltages in a circuit as a function of time, triggering on a particular point on the waveform so that a stationary display results.

The images obtained on the screen are called oscillograms. The oscilloscope can be used for:

- visualizing the time variation of electric voltages, as for measuring their parameters: peak to peak value, amplitude, the value of the dc component, period (frequency);
- visualizing the relationship between two time varying voltages, being able to determine the ratio of the frequencies and their phase difference;
- tracing the characteristic curves of some devices or materials (static characteristics of some devices or electric circuits, the hysteresis cycle of ferromagnetic materials, etc.)



The oscilloscope can work in two modes:

- **Y-t** mode: the y(t) curve appears on the screen
- **Y-X** mode: the y(x) curve appears on the screen, by eliminating the time between the y(t) and x(t) relation

The oscilloscopes used in the lab are: HAMEH HM303, HM304, HM507, HM1507 or Metrix OX6152. All the oscilloscopes share the same functions.

CONTROL ELEMENTS, SIGNALING AND ACCESS ON THE FRONT PANEL OF THE OSCILLOSCOPE

- POWER switch: by acting on the switch the oscilloscope will be supplied with the network voltage 230V a.c.;
- Adjusting elements for the control of the spot’s (trace’s) intensity and clarity on the oscilloscope screen: Brightness (controls the intensity of the trace), Focus (controls the focus of the trace) Astigmatism (is used in correlation with the focus to obtain a well defined spot);

ATTENTION

An **too big** intensity can cause the destruction of the luminescent substance on the screen of the oscilloscope;

- Adjusting elements for the spot (trace) movement on the vertical and horizontal: one for both channels on the x axis and one for each on the y axis;
- The magnifying glass on the X and Y axis: allows the visualization of the magnified signal on the vertical and horizontal with a certain factor usually 5 or 10 for the accurate reading of the signal to be measured;
- Calibrating knobs for the oscilloscope;
- Selecting device of the channel we want to visualize on the screen: we can display the signal taken from one channel, both signals simultaneous or the sum of the signals on the two channels;

- Knob, switch or potentiometer for:
    - Adjusting the scale factor:
    - time (one for both channels)
    - voltage (one for each channel)
- Switch for the coupling manner of the input signal (AC, DC, GND);

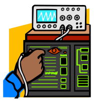
  *The oscilloscope is dc-coupled (**DC**): what we see on the screen is the signal voltage, dc value and all. If we want to see a small signal riding on o large dc voltage we can switch the input to ac coupling (**AC**) which capacitively couples the input with a time constant of about 0.1 second. The oscilloscope also has a grounded input position (**GND**), which lets us see where zero volts is on the screen.*

- Switch for the selection of the working mode Y-t or Y-X;
- Switch for synchronizing: internal or external;
- Switch for selecting the channels (one channel, the other one or both);
- Input BNC jacks: one for each channel;
- BNC jacks for applying an external synchronization signal (when the time base works in external synchronization regime).

IV. EXPLORATIONS AND RESULTS

1. OBTAINING DC VOLTAGES

1.1. ONE SIGN VOLTAGE (UNIPOLAR)



Exploration

- Adjust the voltage of one supply at desired voltage;
- Activate the output of the voltage source (OUTPUT pushbutton)
- Measure the voltage with the digital multimeter on the 0-20V DC domain, the “COM” terminal connected to the ‘-‘ terminal of the supply;

Results

- Are the voltages read on the buit-in voltmeter and with the multimeter identical or different? Why?
- Having to power a circuit with +12V with respect to the ground, which terminal of the supply will we connect to the ground wire and which to the power wire of the circuit? What if the circuit has to be powered with –12V with respect to the ground?
- Is it possible to obtain a dc voltage of 40V with the double supply? If yes, how?

Remarks

- For supplying an electronic circuit, we first adjust the voltage of the power supply at the desired value, connect the supply wires of the circuit and finally activate the output of the source.
- Any time we make some modifications in the experimental board (changing the connections, introducing a measuring instrument, etc.) we will do it with the board not supplied.

2. VOLTAGE VISUALIZATION WITH THE OSCILLOSCOPE

2.1. SETING THE OSCILLOSCOPE

Exploration

- Power on the oscilloscope using the POWER switch.
- Place the spot in the center of the screen using the vertical and horizontal displacement potentiometers.
- Select the one channel visualization in Y-t mode.

ATTENTION

Working with an extremely bright spot leads to the destruction of the luminescent substance on the cathode tube screen.

- You may adjust the focus and astigmatism potentiometer to obtain a more clearly delimited spot.
- If the spot doesn't appear you can act on the horizontal and vertical deflection knobs or/and the brightness potentiometer.

2.2 VISUALIZING IN Y-T MODE

Exploration

a) One signal visualization: do following

After starting the oscilloscope make the operations:

- Select the DC position if we want to visualize the signal with its dc component, or the AC position if we want to visualize just the alternating component of the signal.
- Generate a sinusoidal signal from the signal generator.
- Using a coaxial probe connect the output terminal of the signal generator with an input terminal of the oscilloscope (channel 1 or channel 2)
- From the time base change the time measure to be able to visualize the signal.

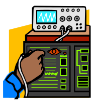
b) Visualizing two signals simultaneously
- Apply to one channel a variable signal from the signal generator and to the other channel a dc voltage from the power supply.
- Adjust the oscilloscope settings to be able to visualize both signals simultaneously.
- To obtain the optimum image on the oscilloscope screen you adjust the X and Y position knobs.

Results

a) One signal visualization
- Draw the waveform obtained on the oscilloscope screen.

b) Visualizing two signals simultaneously
- Draw the two waveforms obtained on the oscilloscope screen.

2.3. MEASUREMENTS IN Y-T MODE



Exploration

To help the measurements, the oscilloscope screen is squared. Each division contains 5 subdivisions. The measurement of voltages and time (period) is done by direct reading of the spot deviation on vertical (Volt/div) respectively on the horizontal (Time /div).

a) Voltages measurements
You can measure amplitude, peak-to-peak value and dc component of a signal. To do this, you multiply the vertical deviation read on the screen with the indication corresponding to the position of the knob. For example: if the total vertical deviation is 4.2 div and the knob is in the position 0.1V/div the total value of the voltage is:
4,2 div x 0,1 V/div = 0,42 V

b) Period measurement
The measurement is made using the time base knob indications. To do this you multiply the number of horizontal divisions, corresponding to a period, with the indications corresponding to the position of the knob. For example, if the horizontal deviation is 4.6 divisions and the indication is 5ms/div, the Ty period will be:
Ty = 4,6 div x 5ms/div = 23ms

Results

Draw the waveforms obtained on the oscilloscope screen. Read and write the amplitude of the signals. Compute and write the frequency of the signals.

2.4. MEASUREMENTS IN Y-X MODE

Exploration

- Apply two signals on both channels of the oscilloscope.
- Set the oscilloscope in Y-X working mode by pushing the XY button.

Results

Draw the graphic obtained on the oscilloscope screen.

3. Voltage divider

Exploration

- Build the circuits in Fig. 5. Apply a dc input voltage, $V_I = 10$ V.

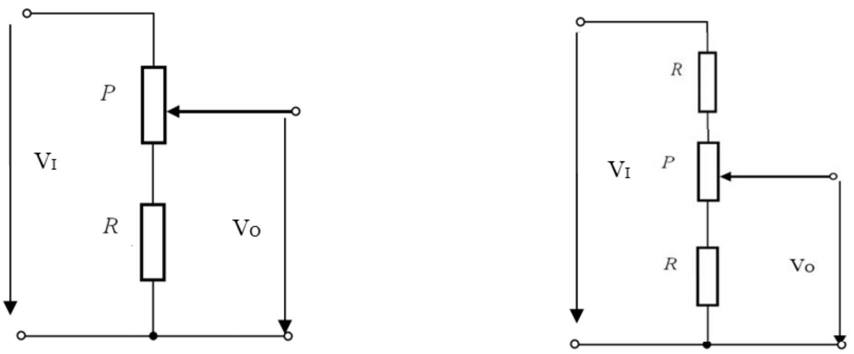


Fig. 5. Voltage divider circuits

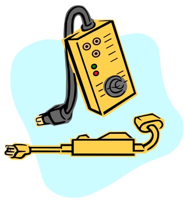
Results

- Measure the output voltage, V_O, for the tap of the potentiometer in various positions. What should be the positionj of the tap, so that the values for R and P can be computed?
- Compute the values for R and P, based on the measured values and on the relationship between V_I and V_O.

SEMICONDUCTOR DIODES

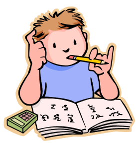
I. OBJECTIVES

a) The determination of the current-voltage characteristics for the rectifying diodes;
b) The determination of some static and differential parameters;



II. COMPONENTS AND INSTRUMENTATION

For the experiments you will use Si diodes: a 1N400x rectifying diode; resistances with different values. The dc voltage is obtained from a double regulated power supply and the sinusoidal voltage (with variable amplitude and frequency) is obtained from a signal generator. To visualize the variable voltages and the diodes' characteristics you will use a dual channel oscilloscope. You will also use a multimeter or even two if necessary.



III. PREPARATION

1. P. TESTING THE DIODES

The ohmmeter is quite useful for the quick analysis of diodes with junctions because the ohmmeter's equivalent circuit contains a voltage source (a battery) and a resistance.

- With the ohmmeter set on the diodes symbol, what should be on the display of ohmmeter, if the positive lead of the instrument is connected to the anode of the diode and the negative lead is connected to the cathode of the diode? What is the state of diode in this case?

2. P. RECTIFYING DIODES

2.1. P. CURRENT- VOLTAGE CHARACTERISTIC $i_D(v_D)$

- How does the $i_D(v_D)$ characteristic of a diode look like?

The IN400x diodes are characterised by the equation:

$$i_D = I_S (e^{\frac{v_D}{nV_T}} - 1)$$

$$I_s = 2.3 * 10^{-9} \text{ A}$$

$$n \cong 2$$

$$V_T = 25 \text{ mV, at } 27^0 \text{ C}$$

- In the points from the diode's characteristics in which I_{D1} = 30 mA and I_{D2} = 200 mA, compute the values of the static resistances, using the formulas:

$$r_{D1} = \frac{V_{D1}}{I_{D1}} \quad \text{and} \quad r_{D2} = \frac{V_{D2}}{I_{D2}}$$

- What are the values of the differential resistance (r_{d1} and r_{d2}) in the same points as before?

$$r_d = \frac{\Delta V_D}{\Delta I_D}$$

For each of two above operating points you will consider another one, close by. For example: for D_1 you can consider D_1' in which: I_{D1} = 33 mA, then: $\Delta I_{D1} = I_{D1} - I_{D1}'$

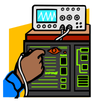
1.2. P. THE CHARACTERISTIC ON THE OSCILLOSCOPE USING AN EARTHED SOURCE

In order to see the characteristic on the oscilloscope you can use the assembly from Fig. 2. The resistance, R_T, has the role of a current - voltage traducer, necessary to visualize the current through the diode.

- Why can't the ground (GND) of the oscilloscope be connected between D and R, if v_I is a earthed (non floating) source (Fig. 2.)?
- What quantities will appear on the two axes of the oscilloscope (X and Y)?
- In which quadrant will the oscillograms be?

IV. EXPLORATIONS AND RESULTS

1. TESTING THE DIODES



Exploration

- With the digital ohmmeter you will check the status of the junctions of the rectifying diode. If the ohmmeter has the symbol of the diodes drawn on one of its domains, do the measurement within that domain, otherwise use any domain you want;
- Connect the rectifying diode with the anode to the (+) lead of the ohmmeter (forward bias of the diode) and then read the value;
- Reverse the direction of the diode's connection (reverse bias) and read this value too;

Results

- The values obtained after the 4 measurements (2 for each diode - in forward and reverse bias)
- If the diode is good, the results should be found in Table 1.

If you obtain other situations, the diode is damaged (short circuit or open circuit).

Table 1

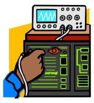
	The ohmmeter's domain	
	With D's symbol	Without D's symbol
D – forward bias	0.7 – 0.9 (v_D)	Low resistance
D – reverse bias	1 or over the scale	High resistance

2. RECTIFYING DIODES

For the experiments you will use a 1N400x semiconductor diode, where x can take any value between 1 and 7.

2.1. CURRENT-VOLTAGE CHARACTERISTIC $i_D(v_D)$

The point by point method

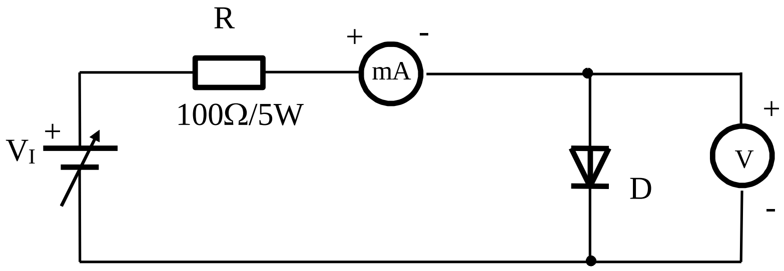


Exploration

Build the assembly from Fig. 1.

D – forward bias (direct)

- V_I – use a dc adjustable voltage source
- The miliammeter shows the current i_D and the voltmeter shows the voltage v_D



- Modify the voltage V_I in the domain [0, 12] [V] and measure some pairs of (i_D, v_D).

Fig. 1. Arrangement for plotting the diode terminal characteristic

D – reverse bias

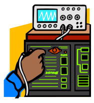
- Replace the positive voltage source V_I from the schematic in Fig. 1 with a negative voltage source (-40, 0) [V]. To obtain a voltage bigger than 20 V (absolute value), connect the two voltage sources from the double dc regulated power supply in series.
- Modify the voltage V_I in the domain [0, -40] [V] and measure some pairs of (i_D, v_D).

Results

- Table with the values of i_D, v_D for all the points measured in experiment 2.1 (both forward and reverse bias);
- Graphic i_D (v_D);
- Which is the diode's threshold value?
- Choose two operating points (I_{D1}, V_{D1}) and (I_{D2}, V_{D2}) for D, at $I_{D1} \cong 30$ mA and $I_{D2} \cong 100$ mA.

- Compute the static resistances r_{D1} and r_{D2} and differential resistances r_{d1} and r_{d2} in these points. For the computation of differential resistances, use the values from the operating point and a point close by (according to the table with i_D, v_D)

2.2. THE CHARACTERISTIC ON THE OSCILLOSCOPE USING AN EARTHED SOURCE



Exploration

Build the assembly from Fig. 2 using an earthed source (signal generator).

- v_I – sinusoidal voltage with 10 V amplitude and 100 Hz frequency, obtained from the signal generator;
- Visualise the diode's characteristic on the oscilloscope (XY mode), by connecting the signal from point A to one channel, and the signal from point B to the other one.
- Visualise the diode's characteristic for a 2 kHz frequency of the input signal.

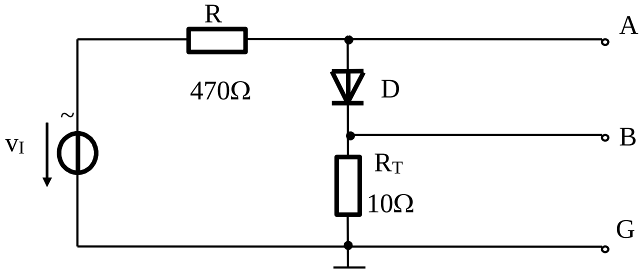


Fig. 2. Arrangement for displaying the $i_D(v_D)$ characteristic using an earthed source

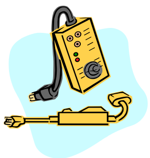
Results

- Draw the characteristics that you have obtained on the oscilloscope for the frequencies of 100 Hz and 2 kHz of the input sinusoidal signal.
- In which quadrant are the obtained characteristics?

DR SWITCHING CIRCUITS, TWO-PORT AND MULTI-PORT NETWORKS

I. OBJECTIVES

a) Finding out the VTC of a two-port DR network.
b) The deduction of the applications of a two-port DR network for different shapes of time-variation of the input voltage.
c) Finding out the electric function of a three-port network DR of space extreme.



II. COMPONENTS AND INSTRUMENTATION

You will use the experimental assembly equipped with 2 semiconducting diodes and resistors. Because you will apply and measure both dc and ac voltages you will need a dc regulated voltage supply, a signal generator, a digital multimeter and a dual channel oscilloscope.

III. PREPARATION

For all the circuits, consider for the diode the constant voltage drop model, with v_D=0.7 V.

1.P. CLAMP TWO-PORT DR NETWORK

1.1.P. VTC

- For the circuit in Fig. 1. deduce VTC, considering that the v_I (t) $\in$ [-10 V,10 V]. How does the VTC look like, if $v_I(t)\in[1,1.5][V]$?
- What is the circuit's function?
- What is the expression of the output voltage for both branches of the VTC?
- Draw $v_O(t)$ for $v_I(t)$ – sinusoidal voltage with 10 V amplitude and 100 Hz frequency.

1.2.P. VTC TRANSLATION

- How does VTC look like for the circuit in Fig. 2, considering v_{BIAS} = 5 V and $v_i(t)\in$[-10 V,+10 V] ?
- What is the expression of the output voltage for each branch of the VTC?

2.P. SPACE EXTREME THREE-PORT DR NETWORK

2.1.P. THE ELECTRIC FUNCTION

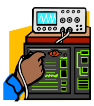
- What is the electric function of the three-port DR network represented in Fig. 3.? What is the mathematical expression of this function?
- For the circuit shown in Fig. 3., what is the time variation of the output voltage $v_O(t)$, for $v_A(t) = 5$ V and $v_B(t) = 10\sin\omega t$[V]?
- But for $v_B(t) = 10\sin\omega t$[V] and $v_A(t) = -1$ V?

IV. EXPLORATIONS AND RESULTS

1. CLAMP TWO-PORT DR NETWORK

From the four types of possible circuit configurations with 1R, 1D and a voltage source we have chosen, for the experiment, the one shown in Fig. 1 which is less familiar than the one with the output on R, but having the same importance.

1.1. VTC



Exploration

Build the assembly from Fig. 1.

a) VTC using the point-by-point method.

- The $v_I = 10$ V is obtained from the dc regulated voltage supply.
- You will measure v_I and v_O with a digital multimeter.
- You will also measure v_o for the following values of v_I : 5 V, 1.5 V, 0.8 V, 0.4 V, 0 V, -1 V, -5 V, -10 V.

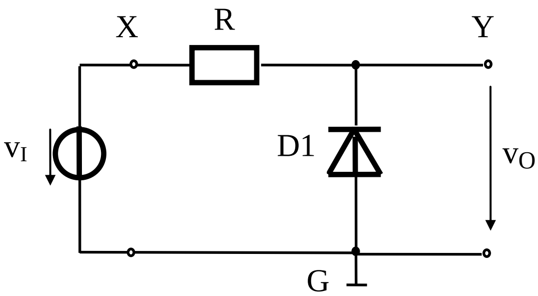
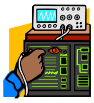


Fig. 1. Clamp two-port DR network

Results

a) VTC using the point-by-point method.

- Table with v_I and v_O for v_I=-10 V, -5 V, 0 V, +5 V, +10 V.
- Table with v_I and v_O for v_I=-1 V, 0 V, +0.4 V, +0.8 V, +1.5 V.
- Draw two graphs representing $v_O(v_I)$ for the data from the two tables.
- Specify on the graphs the on and the off states of the diode.
- In what situation the threshold voltage different from zero should be taken into account? Why?



Exploration

b) VTC on the oscilloscope.

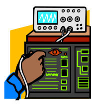
- You will obtain v_I from the signal generator, which is set to generate a sinusoidal voltage having an amplitude of 10 V and a frequency of 100 Hz.
- With the oscilloscope set on the Y-X mode you will set the origin of the system axis in the centre of the screen and then you will connect the input of the circuit to the X terminal and the output to the Y terminal.
- With the oscilloscope set on the Y-t mode you will set the reference for both channels in the middle of the screen and then you will connect the input of the circuit to the X terminal and the output to the Y terminal. Visualize simultaneously $v_I(t)$ and $v_O(t)$.

Results

b) VTC on the oscilloscope.

- Draw and compare the VTC obtained on the screen of the oscilloscope with the one obtained using the point-by-point method. For what value of the input voltage the diode goes from the on state to the off one?
- Draw the $v_I(t)$ and $v_O(t)$ waveforms.

1.2. VTC-TRANSLATION



Exploration

You will use the assembly from Fig. 2.

- V_{Bias} – is obtained from a dc voltage supply set at the value of 5 V.
- You will visualise on the oscilloscope the VTC. The experiment is the same as the one in paragraph 1.1.b. Exploration

Results

- Draw and analyse the VTC obtained. Compare this characteristic with one obtained at 1.1. Comment on the results.
- For what value of the input voltage does the diode change its state from the off to on one?
- On which direction did the VTC move in comparison to the one obtained at section 1.1.? How do you explain?

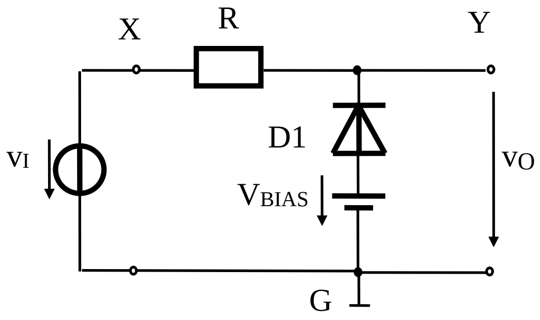


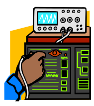
Fig. 2. Clamp two-port DR network with V_{Bias}

2. SPACE EXTREME THREE-PORT DR NETWORK

For the experiment you will use the three-port network from Fig. 3 with A, B as inputs and Y as output.

2.1. THE ELECTRIC FUNCTION

Build the assembly from Fig. 3.



Exploration

- v_A is a sinusoidal voltage with 100 Hz frequency and 10 V amplitude from the signal generator.
- v_B =5 V is a dc voltage.
- With the oscilloscope having 0 V in the centre of the screen you will visualize v_O and v_A.
- You will repeat the visualisation of v_A and v_O for v_B=-1 V.

Results

- Plot the waveforms for v_A, v_B, v_O, for v_B(t)=5 V and then for v_B(t)=-1 V.
- Show the time domains, on the waveforms, which represent the on and off states of the diode.
- Compare these results with the ones obtained at 2.1.P. Analyse them.
- Is it possible for both diodes to be simultaneous turned on? What about turned off?

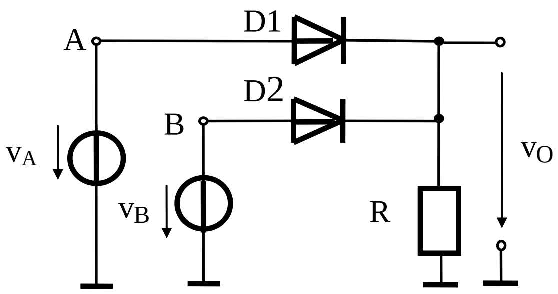
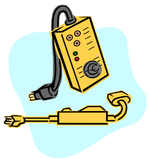


Fig. 3. DR three-port

DC SWITCHING TWO-PORT NETWORKS

I. OBJECTIVES

a) To understand the link between the structure and the functions of two-port DC networks.



II. COMPONENTS AND INSTRUMENTATION

You will use a breadboard, two semiconducting diodes of 1N4184 type (the stripe indicates the cathode) and two 330 nF capacitors. Because you will apply and measure both dc and ac voltages you will need a dc regulated voltage supply, a signal generator, a digital multimeter and a dual channel oscilloscope.

III. PREPARATION

The exercises in this paragraph will be solved using the constant voltage drop diode model.

1.P. TEMPORAL EXTREME (MAXIMUM/MINIMUM) DC TWO-PORT NETWORKS

WAVEFORMS AND OPERATION OF THE CIRCUIT

• How do the waveforms for $v_O(t)$ and $v_D(t)$ look like, in steady state, for the circuits shown in Fig. 1 and Fig. 2 if $v_I(t)$=5 V d.c. (Fig. 1) and $v_I(t)$= -5 V d.c. (Fig. 2)?

• How do the waveforms for $v_O(t)$ and $v_D(t)$ look like, in steady state, for the circuits shown in Fig. 1 and Fig. 2 if $v_I(t)$ is a sinusoidal voltage with 0.3 V amplitudes?

• How do the waveforms for $v_O(t)$ and $v_D(t)$ look like, in steady state, for the circuits shown in Fig. 1 and Fig. 2 if $v_I(t)$ is a sinusoidal voltage with 10 V amplitudes?

2.P. TRANSLATION TWO-PORT DC NETWORK (UPWARD/DOWNWARD)

WAVEFORMS AND OPERATION OF THE CIRCUIT

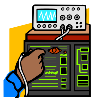
• How do the waveforms for $v_O(t)$ and $v_C(t)$ look like, in steady state, for the circuits shown in Fig. 3 and Fig. 4 if $v_I(t)$ is a sinusoidal voltage with 0.3 V amplitudes?

• How do the waveforms for $v_O(t)$ and $v_C(t)$ look like, in steady state, for the circuits shown in Fig. 3 and Fig. 3 if $v_I(t)$ is a sinusoidal voltage with 10 V amplitudes?

IV. EXPLORATIONS AND RESULTS

1. TEMPORAL EXTREME (MAXIMUM/MINIMUM) DC TWO-PORT NETWORKS

1.1 TEMPORAL MAXIMUM TWO-PORT NETWORK - WAVEFORMS AND THE OPERATION OF THE CIRCUIT



Exploration

Build the circuit shown in Fig. 1.

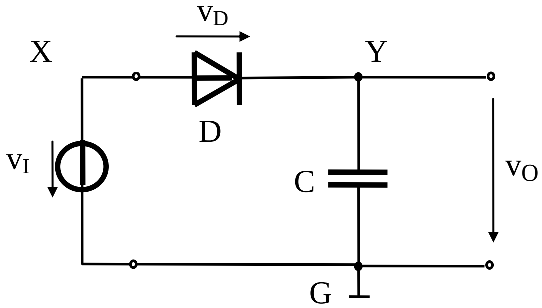


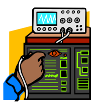
Fig. 1. Temporal maximum two-port

- You will apply at the input a 5 V d.c. voltage from dc regulated voltage supply.
- V_D and V_O are measured using a digital multimeter.
- At the input of the circuit apply a sinusoidal voltage with 500 Hz frequency of and 0.3 V amplitude obtained from the signal generator.
- The signals v_I and v_O are displayed on the oscilloscope set in Y-t mode, both of the channels being directly coupled and having 0 V in the centre of the screen. The two leads are connected in the points X, Y and the ground in the point G.
- The measurements are done again for 10 V amplitude of v_I.

Results

- The values of v_O and v_D for v_I =5 V d.c.
- The waveforms for $v_I(t)$, $v_O(t)$ and $v_D(t)$ considering 0.3 V and 10 V amplitude for the sinusoidal input voltage; $v_D(t)$ is obtained from the difference between $v_I(t)$ and $v_O(t)$.

1.2 TEMPORAL MINIMUM TWO-PORT NETWORK - WAVEFORMS AND THE OPERATION OF THE CIRCUIT



Exploration

Build the circuit shown in Fig. 2.

- You will apply at the input a – 5 V d.c. voltage from dc regulated voltage supply.

• V_D and V_O are measured using a digital multimeter.
• At the input of the circuit apply a sinusoidal voltage with 500 Hz frequency of and 0.3 V amplitude obtained from the signal generator.
• The signals v_I and v_O are displayed on the oscilloscope set in Y-t mode, both of the channels being directly coupled and having 0 V in the centre of the screen. The two leads are connected in the points X, Y and the ground in the point G.
• The measurements are done again for 10 V amplitude of v_I.

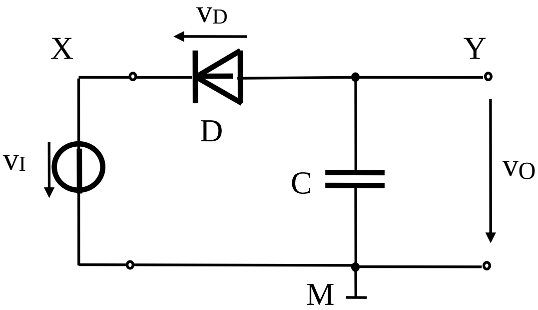


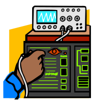
Fig. 2. Temporal minimum two-port

Results

• The values of v_O and v_D for v_I = -5 V d.c.
• The waveforms for $v_I(t)$, $v_O(t)$ and $v_D(t)$ considering 0.3 V and 10 V amplitude for the sinusoidal input voltage; $v_D(t)$ is obtained from the difference between $v_I(t)$ and $v_O(t)$.

2. TRANSLATION TWO-PORT DC NETWORK (UPWARD/DOWNWARD)

2.1 UPWARD TRANSLATION DC TWO-PORT NETWORK – WAVEFORMS AND THE OPERATION OF THE CIRCUIT



Exploration

Build the circuit shown in Fig. 3.

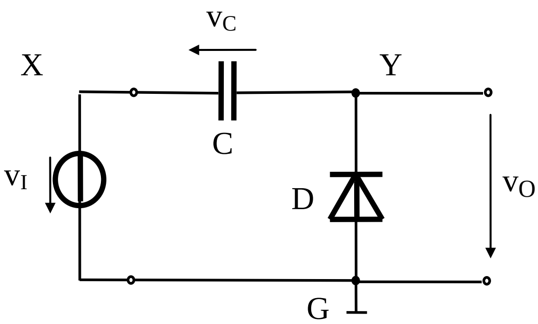


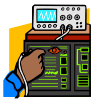
Fig. 3. Upward translation two-por

• At the input of the circuit it is applied a sinusoidal voltage with frequency of 500 Hz and amplitude of 0.3 V obtained from the signal generator.
• The signals v_I and v_O are visualized on the calibrated oscilloscope set in Y-t mode, both of the channels being directly coupled and having 0 V in the centre of the screen. The two leads are connected in the points X, Y and the ground in the point G.
• The measurements are done again for 10 V amplitude of v_I.

Results

• The waveforms for $v_I(t)$, $v_O(t)$ and $v_D(t)$ considering the following values for the amplitude of the sinusoidal input voltage: 0.3 V and 10 V. $v_C(t)$ is computed as the difference between $v_I(t)$ and $v_O(t)$.

2.2 DOWNWARD TRANSLATION DC TWO-PORT NETWORK – WAVEFORMS AND THE OPERATION OF THE CIRCUIT



Exploration

Build the circuit shown in Fig. 4.

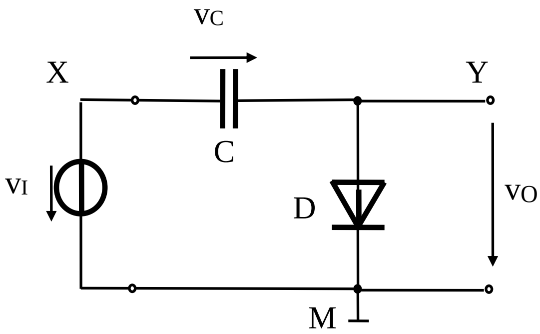


Fig. 4. Downward translation two-port

• At the input of the circuit it is applied a sinusoidal voltage with frequency of 500 Hz and amplitude of 0.3 V obtained from the signal generator.
• The signals v_I and v_O are visualized on the calibrated oscilloscope set in Y-t mode, both of the channels being directly coupled and having 0 V in the centre of the screen. The two leads are connected in the points X, Y and the ground in the point G.
• The measurements are done again for 10 V amplitude of v_I.

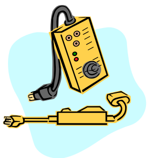
Results

• The waveforms for $v_I(t)$, $v_O(t)$ and $v_D(t)$ considering the following values for the amplitude of the sinusoidal input voltage: 0.3 V and 10 V. $v_C(t)$ is computed as the difference between $v_I(t)$ and $v_O(t)$.

VOLTAGE DOUBLER AND RECTIFIERS WITH CAPACITIVE FILTER

I. OBJECTIVES

a) To understand how voltage multipliers (doubler) can be built using simple DC circuits.
b) To determine how the frequency of the input voltage influences the rectified output voltage.



II. COMPONENTS AND INSTRUMENTATION

You will use a breadboard, semiconductor diodes of 1N4184 type (the stripe indicates the cathode), 330 nF capacitors and a 10 kΩ resistor. Because you will apply and measure ac voltages, you will need a signal generator and a dual channel oscilloscope.

III. PREPARATION

1.P. Voltage doubler

The questions address the circuit in Fig. 1.

- What is the function of the circuit consisting of D_1 and C_1, with the output $v_{O1}(t)$?
- Plot $v_I(t)$, $v_{O1}(t)$ and $v_{C1}(t)$ in steady state, if $v_I(t)$ is a sinusoidal voltage with 10 V amplitude.
- What is the function of the circuit consisting of D_2 and C_2, with the output $v_O(t)$?
- Plot $v_I(t)$, $v_O(t)$ and $v_{D2}(t)$ in steady state, if $v_I(t)$ is a sinusoidal voltage with 10 V amplitude.

2.P. Half-wave rectifier with capacitive filter

The questions address the circuit in Fig. 2.

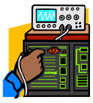
- Plot $v_I(t)$ and $v_O(t)$, if $v_I(t)$ is a sinusoidal voltage with 10 V amplitude.
- Compute the output voltage ripple Δv_O for f = 100 Hz and f = 1 kHz.
- What is the effect of the frequency on $v_O(t)$ and Δv_O?

3.P. Spatial maximum circuit with capacitive filter

The questions address the circuit in Fig. 3.

- Plot $v_A(t)$, $v_B(t)$ and $v_O(t)$, if $v_A(t)$ is a sinusoidal voltage with 10 V amplitude, and $v_B(t)$ is a dc voltage, 5 V amplitude.
- Can the output voltage ripple Δv_O be computed using the same equation as for the previous circuit? Justify your answer.

IV. EXPLORATIONS AND RESULTS



1. Voltage doubler
Exploration

Build the circuit shown in Fig. 1.

- At the input of the circuit apply a sinusoidal voltage with 500 Hz frequency and 10 V amplitude obtained from the signal generator.
- $v_I(t)$, $v_{O1}(t)$ and $v_O(t)$ are visualized on the oscilloscope. Because you can visualize only two signals simultaneously you will visualize first $v_I(t)$ and $v_{O1}(t)$ and then $v_I(t)$ and $v_O(t)$, using the DC setting for both channels.

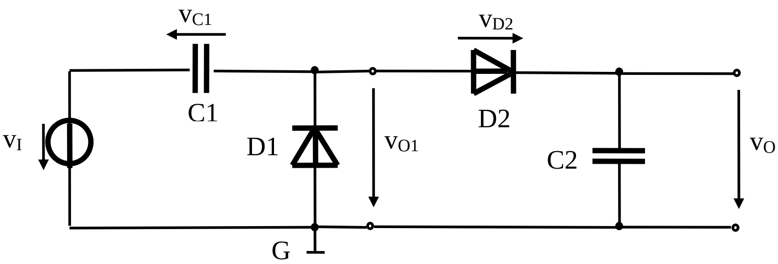
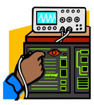


Fig. 1. Voltage doubler

Results

- Draw the waveforms for $v_I(t)$, $v_{O1}(t)$, $v_O(t)$, $v_{C1}(t)$ and $v_{D2}(t)$ for 10 V amplitude of the input voltage.

2. Half-wave rectifier with capacitive filter



Exploration

Build the circuit shown in Fig. 2.

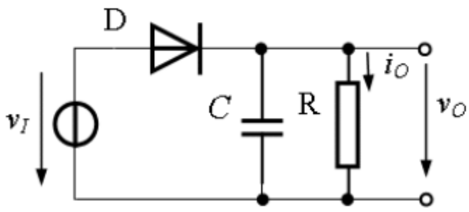


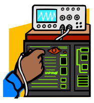
Fig. 2. Half-wave rectifier with capacitive filter

- At the input of the circuit apply a sinusoidal voltage with 100 Hz frequency and 10 V amplitude obtained from the signal generator.
- Visualize v_I and v_O on the oscilloscope, using the DC setting for both channels.
- Compute the output voltage ripple, by reading the values from the oscilloscope.
- Change the frequency of the input voltage to f = 1 kHz. Recompute the output voltage ripple, by reading the values from the oscilloscope.

Results

- Plot of $v_I(t)$, $v_O(t)$.
- Computed output voltage ripple for f = 100 Hz and f = 1 kHz.
- How does the frequency influence $v_O(t)$ and Δv_O ?

3. Spatial maximum circuit with capacitive filter



Exploration

Build the circuit shown in Fig. 3

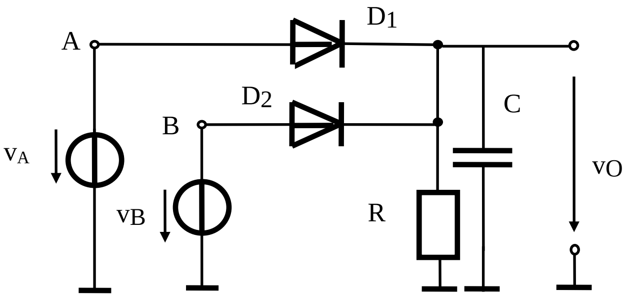


Fig. 3. Spatial maximum circuit with capacitive filter

- At the input of the circuit apply v_A - sinusoidal voltage with 100 Hz frequency and 10 V amplitude obtained from the signal generator, and $V_B = 5$ V from the power supply.
- Visualize v_A and v_O on the oscilloscope, using the DC setting for both channels.
- Compute the output voltage ripple, by reading the values from the oscilloscope.
- Change the frequency of the input voltage to f = 1 kHz. Recompute the output voltage ripple, by reading the values from the oscilloscope.

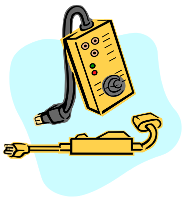
Results

- Plot of $v_A(t)$, $v_O(t)$.
- Computed output voltage ripple for f = 100 Hz and f = 1 kHz.
- How does the frequency influence $v_O(t)$ and Δv_O ?
- How does Δv_O change, compared to the previous circuit?

CIRCUITS WITH ZENER DIODES AND LEDS

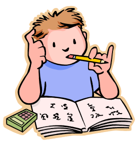
I. OBJECTIVES

a) The determination of the current-voltage characteristics for the rectifying diodes;
b) The determination of the function of Zener diodes in double voltage clamp circuits
c) The determination of the functioning of LEDs in logic level indicator circuits



II. COMPONENTS AND INSTRUMENTATION

For the experiments you will use Si diodes: rectifying diodes; two Zener diodes (DZ3V3 and DZ6V8), resistors with different values. The dc voltage is obtained from a double regulated power supply and the sinusoidal voltage (with variable amplitude and frequency) is obtained from a signal generator. To visualize the variable voltages and the diodes' characteristics you will use a dual channel oscilloscope. You will also use a multimeter to measure the dc voltages.



III. PREPARATION

1. P. ZENER DIODE

1.1. P. The $i_Z(v_Z)$ characteristic on the oscilloscope

- How does $i_Z(v_Z)$ characteristic look like?

1.2. P. Asymmetrical double voltage clamp (limiter) with Zener diodes

- What is the value of the regulation voltage, V_Z, for DZ3V3 and DZ6V8?
- For the circuit in Fig. 2, deduce VTC $v_O(v_I)$ for v_I in [-10; 10] V. Specify the states (on/off) for the two diodes on the plot.

2. P. Circuits with LEDs

- For the circuit in Fig. 3, what is the role of the diodes D1, D2? What is the role of the 3 LEDs, LED1, LED2, LED3?
- Fill in the electrical functioning table:

v_A [V]	v_B [V]	v_O [V]	D1	D2	LED1	LED2	LED3
0	0						
0	10						
10	0						
10	10						

- Assume the positive logical convention – high voltage level (10 V): "1" logic, low voltage level (0 V): “0”. Fill in the truth table.

A	B	OUT
0	0	
0	1	
1	0	
1	1	

IV. EXPLORATIONS AND RESULTS

1. ZENER DIODE

1.1. The $i_Z(v_Z)$ characteristic on the oscilloscope

Exploration

Build the circuit in Fig. 1.

- v_S – sinusoidal voltage with 10 V amplitude and 100 Hz frequency, obtained from the signal generator;
- Visualise the diode’s characteristic on the oscilloscope (XY mode), by connecting the signal from point A to one channel, and the signal from point B to the other one.

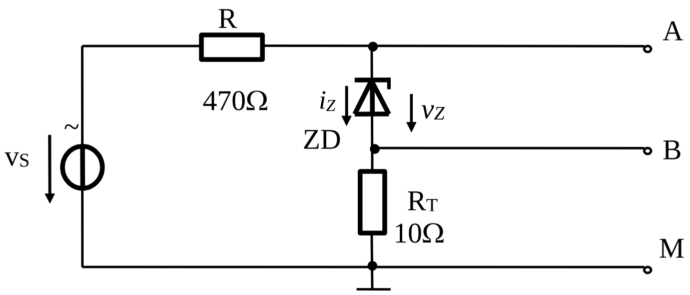


Fig. 1. Arrangement for displaying the $i_Z(v_Z)$ characteristic using an earthed source

Results

- Draw the obtained characteristic from the oscilloscope.
- In which quadrant is the regulation region of *ZD*?

1.2. P. Asymmetrical double voltage clamp (limiter) with Zener diodes

Exploration

Build the circuit in Fig. 2.

- v_I - sinusoidal voltage with 10 V amplitude and 100 Hz frequency, obtained from the signal generator;
- Visualize the input voltage and the output voltage on the oscilloscope, using the XY mode.

Results

- Draw VTC $v_O(v_I)$ from the oscilloscope.

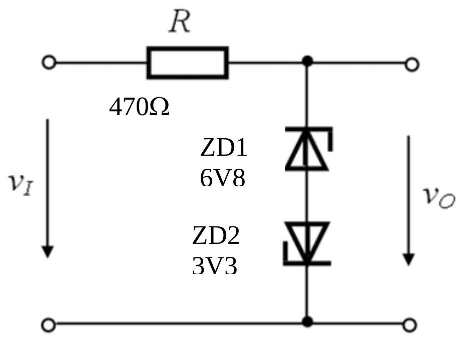


Fig. 2 Asymmetrical double voltage clamp (limiter) with Zener diodes

2. Circuits with LEDs

Exploration

Build the circuit in Fig. 3.

- v_A, v_B are dc voltages
- v_O is measured with the voltmeter.
- v_A, v_B will successively have all 4 combinations of values, according with the following table. Fill in the table with the measured values for v_O, v_{LED3} and the states of the 3 LEDs.

v_A [V]	v_B [V]	v_O [V]	v_{LED3} [V]	LED1	LED2	LED3
0	0					
0	10					
10	0					
10	10					

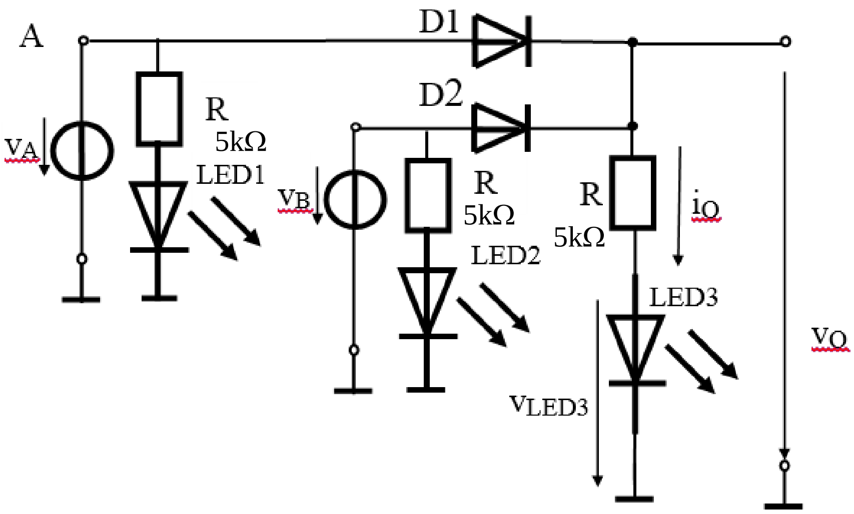


Fig. 3. Logic level indicator with diodes and LEDs

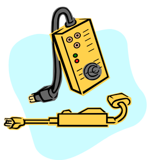
Results

- Measured values for v_O, v_{LED3} and the states of the 3 LEDs.
- For what values of v_O is LED3 on?
- What is the logic function of the circuit?
- What is the value of the maximum output current, $i_{O,\,max}$?

VOLTAGE COMPARATORS WITH OPERATIONAL AMPLIFIERS - SIMPLE COMPARATORS

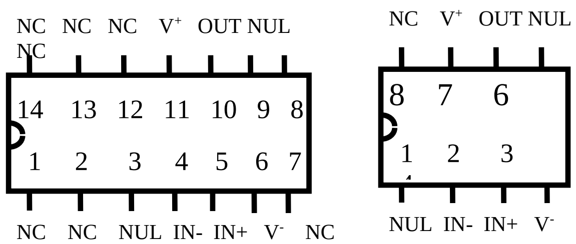
I. OBJECTIVES

a) Determining the voltage transfer characteristics (VTC) for simple voltage comparators (without feedback).
b) Determining the output voltage in accordance with the configuration of the circuits and the input voltage.
c) Determining the effects of modifying the supply and reference voltages on the VTC of comparators.



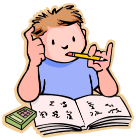
II. COMPONENTS AND INSTRUMENTATION

You will use the breadboard, two 741 operational amplifiers (see Fig. 1), a 10 KΩ potentiometer, resistors of different values and a 10 nF capacitor. In order to supply the assembly you will use a dual dc regulated power supply, and as a sinusoidal signal source you will use a signal generator. In order to visualize the voltages you need a dual channel cathodic oscilloscope and for some dc voltages you need a dc voltmeter.



NC – not connected
NUL – offset compensator
IN^- - inverting input
IN^+ - non-inverting input
V^- - negative voltage supply
V^+ - positive voltage supply
OUT – output

Fig. 1. LM 741 OP-AMP. Connection diagram



III. PREPARATION

1. P. INVERTING COMPARATOR

Use the circuit from Fig. 2 supplied with $+V_{PS}$=12V, $-V_{PS}$=-12V.

A. Waveforms

- What does $v_O(t)$ look like, if $v_I(t)$ is a sinusoidal voltage with 5 V amplitude and 200 Hz frequency, for V_{REF} =0 V? But for V_{REF} =4 V?
- Which is the value of the threshold voltage V_{Th} (the value of v_I for which the comparator switches)?
- What does $v_O(t)$ look like for a 1 V amplitude of v_I?

B. VTC

- What does VTC $v_O(v_I)$ look like for V_{REF} = 0 V?
- What does VTC $v_O(v_I)$ look like for V_{REF} = 4 V? But for V_{REF} = -4 V?

C. The effects of modifying the supply voltage

What does the $v_O(t)$ look like for a sinusoidal v_I with a 8 V amplitude and 200 Hz frequency, V_{REF} =0 V, if $+V_{PS}$=9 V, $-V_{PS}$=-9 V? What if $+V_{PS}$=15 V, $-V_{PS}$=-9 V?

2. P. NON- INVERTING COMPARATOR

- Draw the schematic of a non- inverting voltage comparator with the possibility of adjusting V_{Th} between $+V_{PS}$ and $-V_{PS}$.
- What does VTC for the non- inverting comparator look like, for V_{Th}=0 V?

IV. EXPLORATIONS AND RESULTS

1. INVERTING COMPARATOR

Consider the experimental circuit of Fig. 2.

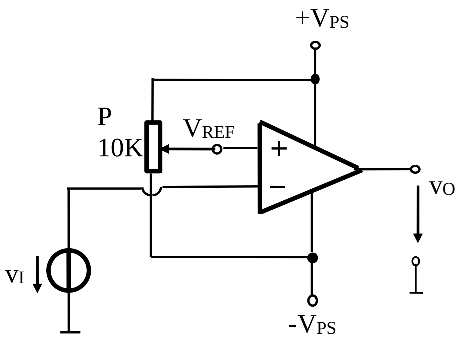
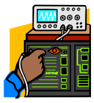


Fig. 2. Basic inverting comparator

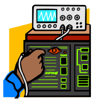


Exploration

The assembly is supplied with a symmetrical differential voltage, $+V_{PS}$=12 V, $-V_{PS}$=-12 V from the dual dc regulated power supply.

- $v_I = 8\sin 2\pi \cdot 200t$[V][Hz] from the signal generator.
- Using P, adjust the value of V_{REF}; measure this value with a dc voltmeter.

A. Waveforms



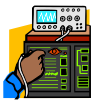
Exploration

- Using the calibrated oscilloscope you will visualize $v_I(t)$ and $v_O(t)$ for V_{REF}=0 V and for V_{REF} = 4 V.
- Modify the amplitude of v_I to 2 V.
- You will visualize $v_O(t)$ and $v_I(t)$ for V_{REF} = - 4 V.
- For a v_I amplitude of 8
- V and for V_{REF} = - 4 V you will see $v_O(t)$ and $v_I(t)$ on the oscilloscope.

Results

- $v_I(t)$ and $v_O(t)$ for a v_I amplitude of 8 V, for V_{REF} = 0 V and for V_{REF} = 4 V.
- What are the values of the threshold voltage V_{Th} of the comparator in the two situations above? To find V_{Th} from the waveforms of v_I and $v_{O,}$ remember that V_{Th} is the instantaneous value of $v_{I,}$ when the comparator switches.
- What is the relation between V_{Th} and V_{REF}?
- $v_O(t)$ for a v_I amplitude of 2 V and V_{REF} = 4 V.
- Why isn't $v_O(t)$ a rectangular voltage anymore?
- V_{Th} =?

B. VTC



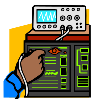
Exploration

- Adjust $v_I = 8\sin 2\,\pi \cdot 200t$ [V][Hz] and V_{REF} = 0 V.
- Using the calibrated oscilloscope, Y-X mode, visualize VTC $v_O(v_I)$, applying to the two inputs X and Y of the oscilloscope the two voltages $v_I(t)$ and respectively $v_O(t)$.
- Visualize VTC for V_{REF} = 4 V.
- Visualize VTC for V_{REF} = - 4 V.

Results

- VTC for V_{REF}=0 V, 4 V, -4 V.
- How does VTC change, on the coordinate system v_I-v_O, when modifying V_{REF}? Why?

C. The effects of modifying the supply voltage



Exploration

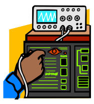
The assembly is supplied with a symmetrical differential voltage, $+V_{PS}$=9 V, $-V_{PS}$=-9 V from the dual dc regulated power supply.

- $v_I = 8\sin 2\pi \cdot 200t$[V][Hz] from the signal generator.
- V_{REF} = 0 V by adjusting P.
- Using the oscilloscope, Y- t mode, visualize $v_I(t)$ and $v_O(t)$.
- Modify the supply voltages: $+V_{PS}$=15 V, $-V_{PS}$=-9 V.
- Visualize $v_I(t)$ and $v_O(t)$ on the oscilloscope.

Results

- $v_I(t)$ and $v_O(t)$ for $+V_{PS}$=9 V, $-V_{PS}$=-9 V and for $+V_{PS}$=15 V, $-V_{PS}$=-9 V.
- What is the effect of modifying the supply voltage on the V_{Th}?
- Which are the maximum and minimum values of the output voltage of the comparator, V_{OH} and V_{OL}, if the values of the supply voltage change? Compare the values of V_{OH} and V_{OL} with the ones you obtained at sections **A** and **B**.

2. NON- INVERTING COMPARATOR



Exploration

Build the experimental circuit drawn at **2. P.**

- $v_I = 8\sin 2\pi\cdot 200t$[V][Hz] from the signal generator.
- Using P, adjust V_{REF}, which is measured with a dc voltmeter.
- Visualize $v_I(t)$ and $v_O(t)$ for V_{REF}=0 V, 4 V, -4 V
- Visualize VTC $v_O(v_I)$ for V_{REF}=0 V, 4 V, -4 V

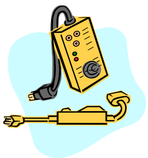
Results

- $v_I(t)$ and $v_O(t)$ for V_{REF}=, 4 V, -4 V
- VTC for V_{REF}=0 V, 4 V, -4 V
- What is the difference between the current VTC and the one obtained at **1.B**?

OPTICAL INDICATOR FOR VOLTAGE LEVEL WITH OPAMP

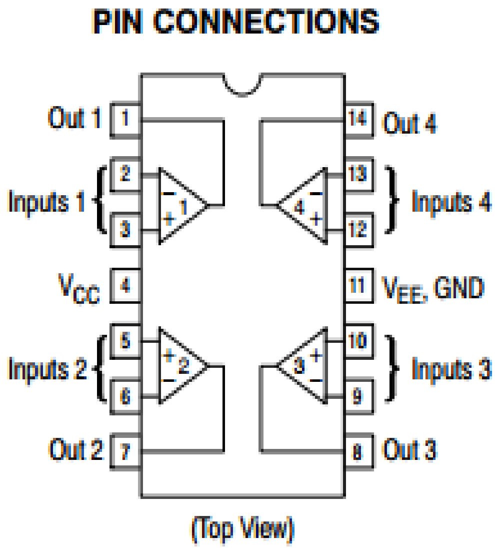
I. OBJECTIVE

a) To assemble an electronic circuit with multiple simple comparators with OpAmp, that visually indicates the level of the input voltage.



II. COMPONENTS AND INSTRUMENTATION

We use a breadboard, an LM324 integrated circuit (single supply quad operational amplifier) which contains 4 OpAmps, several resistors and 4 LEDs, with different colors. The dc voltage for the power supplies and for the dc input is obtained from the triple power supply. The sinusoidal input voltage is obtained from the signal generator and visualized on the oscilloscope. The pinout diagram for the LM324 is presented in Fig. 1.



Inputs 1, 2, 3, 4 – inputs for OpAmps 1, 2, 3, 4
Out 1, 2, 3, 4 – outputs for OpAmps 1, 2, 3, 4
V_{CC} - positive power supply
V_{EE}, GND – negative power supply or ground.

Fig. 1. Pinout diagram for LM324

III. EXPLORATION AND RESULTS

Exploration

Build the schematic in Fig. 2.

- From the 4 OpAmps available in the LM324, you will use only 3.
- The circuit is supplied with $+V_{PS}$=12 V, $-V_{PS}$=0 V from the tripple power supply.

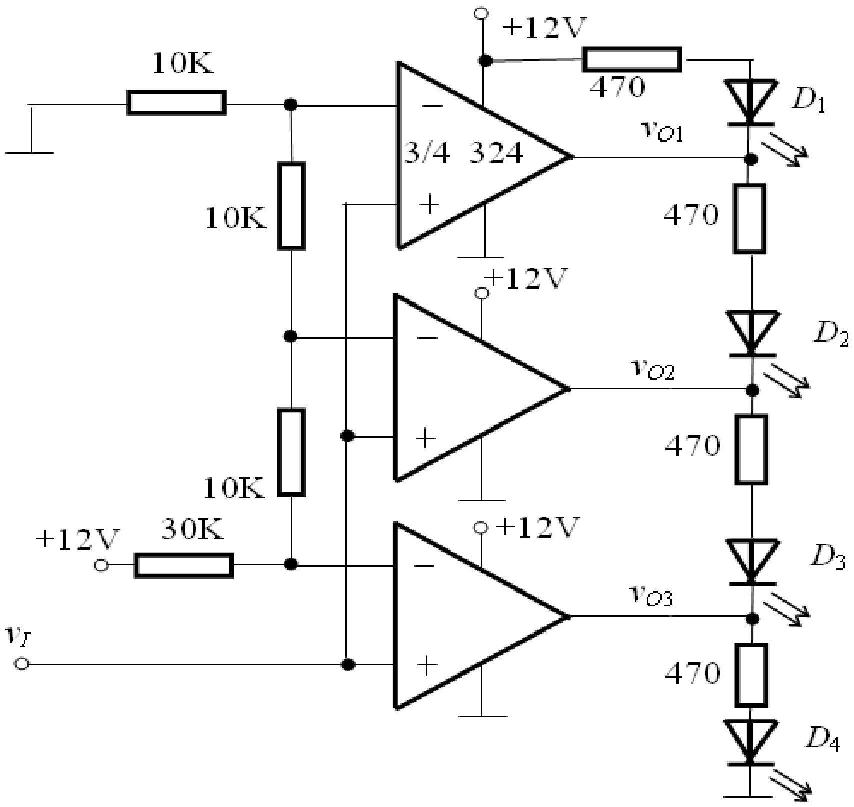


Fig. 2. Optical indicator for voltage level with OpAmp

a) Optical indicator for the level of a DC voltage

- v_I is an adjustable dcvoltage, obtained from the triple power supply, and it can take values between 0 and 12 V.

Results

- For what range of values of $v_I(t)$ does each LED light up?

b) Optical indicator for the level of an AC voltage

Note: because the integrated circuit LM324 is supplied with $+V_{PS}$=12 V, $-V_{PS}$=0 V, the input voltage v_I will have to include a dc component of +5 V. So, $v_I = 5V d.c. + 4\sin 2\pi \cdot 10t$ [V], [Hz] from the signal generator.

- Visualise $v_I(t)$ on the oscilloscope, set onY-t mode..

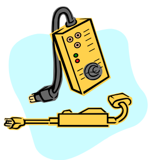
Results

- For what frequency range of $v_I(t)$ do the LEDs light up gradually?
- For what frequency range of $v_I(t)$ do the LEDs light up continuously?

VOLTAGE COMPARATORS WITH OPERATIONAL AMPLIFIERS - HYSTERESIS COMPARATORS

I. OBJECTIVES

a) Determining the voltage transfer characteristics (VTC) for hysteresis comparators.
b) Determining the output voltage in accordance with the configuration of the circuits and the input voltage.
c) Determining the effects of modifying the supply and reference voltages on the VTC of hysteresis comparators.
d) Deduction of the noise effect, overlapped on the input voltage on the comparator’s switchings.



II. COMPONENTS AND INSTRUMENTATION

Use the breadboard, two operational amplifiers 741, a 10 KΩ potentiometer, resistors of different values and a 10 nF capacitor. In order to supply the assembly, you will use a double dc regulated source, and as a sinusoidal signal source you will use a signal generator. In order to visualise the voltages, you need a dual channel oscilloscope and for some dc voltages you need a dc voltmeter.

III. PREPARATION

1.P. NONINVERTING COMPARATOR

For the schematic of Fig. 1 the following data is given: $+V_{PS}$=12 V, $-V_{PS}$=-12 V.

- Which is VTC for the non-inverting comparator with positive feedback?
- What does $v_O(t)$ look like for $v_I(t)$ sinusoidal voltage with 3 V amplitude and 200 Hz frequency? What happens if the amplitude of v_I is 8 V?

2.P. INVERTING COMPARATOR

Use the schematic of Fig. 2.

- Which are the expression of the threshold voltages $V_{Th,L}$ and $V_{Th,H}$?
- What are the values of $V_{Th,L}$ and $V_{Th,H}$ for V_{REF} = 0 V, $+V_{PS}$=12 V, $-V_{PS}$=-12 V?
- Which is the VTC $v_O(v_I)$? What is the sense of movement on the hysteresis curve?
- What is the width of the hysteresys curve $\Delta V_{Th}=V_{Th,H}-V_{Th,L}$?
- What are the effects of modifying the supply voltage over VTC?
- What are the effects of modifying V_{REF} over VTC?
- What does $v_O(t)$ look like when $v_I = 8\sin 2\pi \cdot 200t$ [V][HZ], for the above data? What happens if the amplitude of v_I is 1 V?

3.P. INVERTING COMPARATOR FOR NOISY SIGNAL

Use the schematic in Fig. 3. We want to study the effect of the noise overlapped on the input voltage, on the switches of the comparator without feedback.

In Fig. 3 the input signal of the comparator (v_I) is obtained by summing the sinusoidal input voltage (v_s), with 10 V amplitude and 200 Hz frequency with a triangular signal v_n (considered to be the noise) with 2.2 V amplitude and 2.7 KHz frequency.

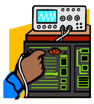
The summing is made using the R_1 and R_2 resistors. The noise voltage is generated by a multivibrator circuit (framed by the marked area).

- What do $v_s(t)$, $v_n(t)$, $v_I(t)$ look like?
- What does $v_O(t)$ look like?

IV. EXPLORATIONS AND RESULTS

1. NONINVERTING COMPARATOR

Use the circuit shown in Fig. 1.



Exploration

- Supply the assembly with $+V_{PS}$=12 V, $-V_{PS}$=-12 V.
- v_I is a sinusoidal voltage with 8 V amplitude and 200 Hz frequency from the signal generator.
- Using the calibrated oscilloscope, you will see $v_I(t)$, $v_O(t)$ and VTC $v_O(v_I)$.

Results

- $v_I(t)$, $v_O(t)$.
- VTC

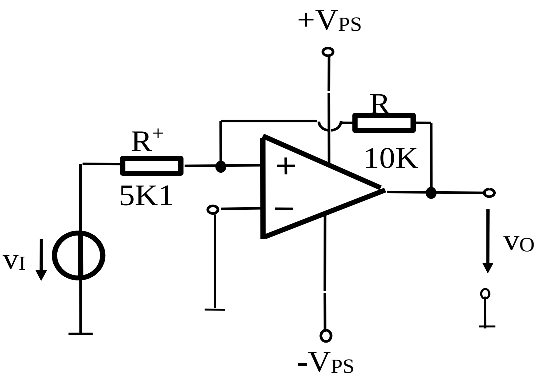


Fig. 1. Noninverting comparator with positive feedback

2. INVERTING COMPARATOR

Exploration

Use the experimental schematic from Fig. 2.

- $+V_{PS}$=12 V, $-V_{PS}$=-12 V from the dual dc regulated power supply.
- Adjust V_{REF} = 0 V, using P.
- $v_I = 8\sin 2\pi \cdot 200t$[V][Hz] from the signal generator.
- Using the oscilloscope, Y-t mode, visualize $v_I(t)$ and $v_O(t)$.
- Using the oscilloscope, Y-X mode visualize VTC $v_O(v_I)$, applying the voltages v_I and v_O on the X and Y inputs of the oscilloscope .
- Modify the amplitude of v_I to 1 V.
- Using the oscilloscope, Y-t mode, visualize $v_I(t)$ and $v_O(t)$.

Results

- $v_I(t)$ and $v_O(t)$ for a v_I amplitude of 8 V and 1 V.
- VTC $v_O(v_I)$ when the amplitude of v_I is 8 V.
- What are the values of the threshold voltages $V_{Th,H}$ and $V_{Th,L}$, and of the output voltage V_{OH} and V_{OL}?

A. The effects of modifying the voltage supply

Exploration

- Modify the supply voltages to $+V_{PS}$=9 V, $-V_{PS}$=-9 V.
- Using the oscilloscope visualize $v_I(t)$, $v_O(t)$, then VTC $v_O(v_I)$ for V_{REF}= 0 V and v_I amplitude of 8 V.
- Modify the supply voltages to $+V_{PS}$=15 V, $-V_{PS}$=-9 V.
- Visualize $v_I(t)$, $v_O(t)$ and VTC.

Results

- $v_I(t)$, $v_O(t)$, $v_O(v_I)$ for $+V_{PS}$=9 V, $-V_{PS}$=-9 V, and for $+V_{PS}$=15 V, $-V_{PS}$=-9 V.

B. The effects of modifying V_{REF}

Exploration

- Supply the assembly with $+V_{PS}$=12 V, $-V_{PS}$=-12 V.

- Adjust P until V_{REF} =3 V.
- Using the oscilloscope, visualize $v_I(t)$, $v_O(t)$ and $v_O(v_I)$.
- Set V_{REF} = -3 V. Using the oscilloscope visualize $v_I(t)$, $v_O(t)$ and $v_O(v_I)$.

Results

- $v_I(t)$, $v_O(t)$, $v_O(v_I)$ for V_{REF} = 3 V and for V_{REF} = -3 V

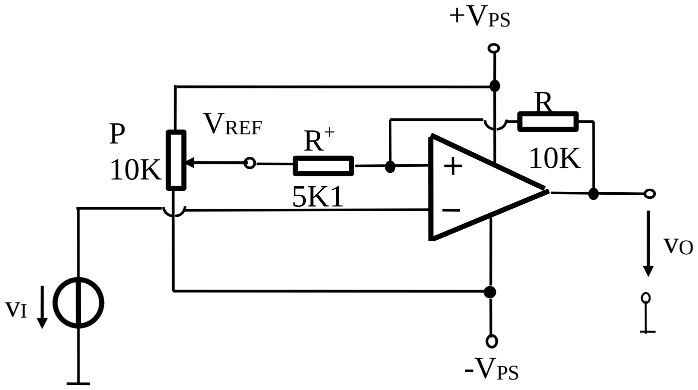


Fig. 2. Inverting comparator with positive feedback

3. INVERTING COMPARATOR FOR NOISY SIGNAL

Use the circuit shown in Fig. 3.

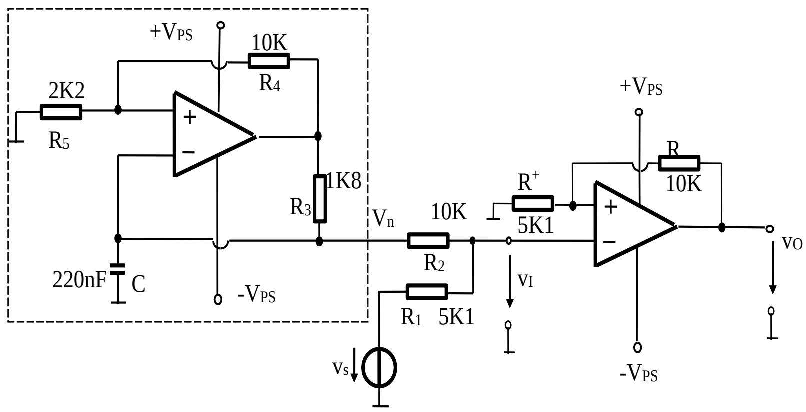


Fig. 3. Inverting comparator with positive feedback and noisy signal

Exploration

- Supply the assembly with +V_{PS}=12 V, -V_{PS}=-12 V.
- Using the oscilloscope, visualize v_I and v_O at the same time.
- Is the hysteresis comparator able to successfully compare the noisy signal?

- Remove R. What is the new function of the second OpAmp? How is the output signal different from the previous case?

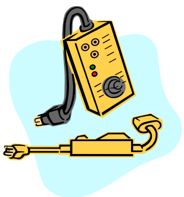
Results

- $v_I(t), v_O(t)$.

RAIL-TO-RAIL AMPLIFIERS WITH DIFFERENTIAL AND UNIPOLAR SUPPLY

I. OBJECTIVES

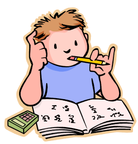
a) Determination of the gain for the non-inverting and inverting amplifiers with differential supply, and for the inverting amplifier with unipolar supply.
b) Determination of the causes that lead to the limitation of the amplifier's output voltage (saturation of the amplifier).
c) Understanding the principle behind unipolar amplifiers (dc biasing).
d) Understanding the difference between regular and rail-to-rail OpAmps.



II. COMPONENTS AND INSTRUMENTATION

Use the breadboard, an AD820 rail-to-rail OpAmp, various resistors and a capacitor. The differential supply of the board is achieved using a double dc regulated voltage supply. The input voltage is obtained from the signal generator. To visualize the voltage waveforms, a dual-channel oscilloscope is used.

The connection diagram of the AD820 terminals is the same as for LM741 and can be found in the lab about *Voltage comparators with operational amplifiers – simple comparators*.



III. PREPARATION

1.P. NON-INVERTING AMPLIFIER

1.1.P. WAVEFORMS. THE SATURATION OF THE AMPLIFIER

For this paragraph, use the circuit from Fig. 1.

a)

- What is the value of the voltage gain A_v?
- What does $v_O(t)$ look like for $v_I(t)$ a sinusoidal voltage with 1 KHz frequency and 1 V amplitude? What about for 2 V amplitude?

b)

- What is the value of A_v, if R^- is 44 KΩ ?
- What does $v_O(t)$ look like for R^-=44 KΩ and v_I=2sin2π1000t[V][Hz]?

c)

- The dc voltage supply is changed to ±10V.
- Find the input voltage value for which the op-amp enters the saturation region.
- What does $v_O(t)$ look like, in this case, for R^-=22 KΩ, v_I=sin2π1000t[V][Hz] ?

1.2.P. VTC

- What does the VTC look like for the circuit in Fig. 1?
- How does the VTC change if R^- = 44 KΩ ?
- What is the range of v_O values?

2.P. INVERTING AMPLIFIER

2.1.P. WAVEFORMS

- What is the value of the voltage gain for the circuit from Fig. 2?
- Determine the output voltage $v_O(t)$ waveform for $v_I(t)$ a sinusoidal voltage with 1 V amplitude and 1 KHz frequency. What about for an input voltage of 2 V amplitude?
- If R=0, what is the value of the voltage gain?

2.2.P. VOLTAGE TRANSFER CHARACTERISTIC (VTC)

- What does the VTC look like for the circuit in Fig. 2?
- How does the above VTC change if R^- = 44 KΩ?

3.P. INVERTING AMPLIFIER WITH UNIPOLAR SUPPLY

3.1.P. WAVEFORMS AND VTC

- What is the value of the voltage gain for the circuit from Fig. 2, if the negative supply becomes 0 (unipolar supply)?
- For the circuit in Fig. 3, what does the output voltage $v_O(t)$ look like, for $v_I(t)$ a sinusoidal voltage with 0.5 V amplitude and 1 KHz frequency? What about for an input voltage of 1 V amplitude?
- What is the purpose of capacitor C_2?
- What are the values of the ac and dc gains?

$$A_{v,ac} = \frac{v_o}{v_i} \quad A_{v,dc} = \frac{V_O}{V_I}$$

- What does the VTC look like for the circuit in Fig. 3?
- What is the active region of the amplifier?

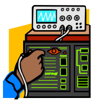
IV. EXPLORATIONS AND RESULTS

1.NON-INVERTING AMPLIFIER

1.1. WAVEFORMS. THE SATURATION OF THE AMPLIFIER

Build the circuit shown in Fig. 1.

a)



Exploration

- $v_I(t)$-sinusoidal signal with 1KHz frequency, obtained from the signal generator.
- With the oscilloscope on the Y-t mode, visualise $v_I(t)$ and $v_O(t)$ for the amplitude of v_I equal with 1 V and 2 V.

Results

- Draw the waveforms of $v_I(t)$ and $v_O(t)$ for v_I with amplitude of 1 V and 2 V.
- From the waveform obtained for v_I with 2V amplitude, find the range of values for v_I in order to avoid the saturation of the op-amp (the maximum undistorted output signal).

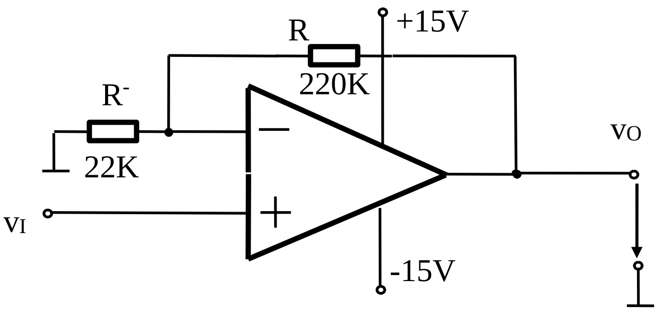


Fig. 1. Non-inverting amplifier

b)

Exploration

- R^- = 44 K (by connecting in series two 22 KΩ resistances).
- Visualise $v_I(t)$ and $v_O(t)$ for $v_I(t) = 2\sin 2\pi 1000t$ [V][Hz].

Results

- Draw the waveforms of v_I and v_O.
- What is the value of the voltage gain?

c)

Exploration

- The voltage supply is changed to ±10 V.
- Visualise $v_I(t)$ and $v_O(t)$ for $v_I(t)$-sinusoidal voltage with 1 KHz frequency and 1 V amplitude; R^-= 22KΩ.

Results

- Draw the waveforms of $v_I(t)$ and $v_O(t)$.
- How does the voltage supply influence the range of v_O values?

1.2. VOLTAGE TRANSFER CHARACTERISTIC (VTC)

Exploration

- v_I =5sin2π500t[V][Hz] obtained for the signal generator.
- With the oscilloscope on the Y-X mode, visualise $v_O(v_I)$.
- Modify R^- to 44 KΩ by connecting in series two resistors of 22 KΩ.
- Visualise $v_O(v_I)$.

Results

- Draw the VTC for R^- = 22 KΩ and R^- = 44 KΩ.
- What are the maximum and the minimum values of v_O?

2. INVERTING AMPLIFIER

2.1.WAVEFORMS

Build the circuit shown in Fig. 2.

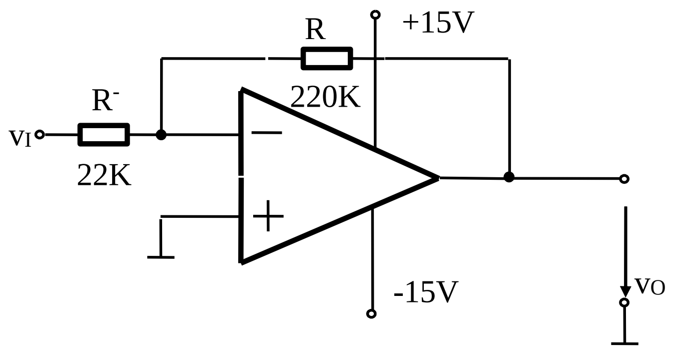


Fig. 2. Inverting amplifier

Exploration

- $v_I(t)$=sin2π1000t[V][Hz]-from the signal generator.
- With the oscilloscope on the Y-X mode, visualise $v_I(t)$ and $v_O(t)$.
- Repeat the visualisation for v_I with 2 V amplitude.
- Draw the circuit that results by short circuiting R (R = 0).
- With the same v_I as above, visualise $v_I(t)$ and $v_O(t)$.

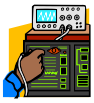
Results

- Draw the $v_I(t)$ and $v_O(t)$ waveforms for v_I with 1 V and 2 V amplitudes and R=220 KΩ,

R^-=22 KΩ.

- Draw the waveforms for v_I and v_O for R=0; $R^-= \infty$.
- What is the gain of the circuit and what is the name of the amplifier?

2.2.VOLTAGE TRANSFER CHARACTERISTIC (VTC)



Exploration

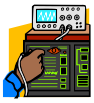
- Visualise $v_O(v_I)$ on the oscilloscope, for: R^-=22 KΩ and R^-=44 KΩ

Results

- Draw the VTC for R^-=22 KΩ and R^-=44 KΩ.
- What are the output voltage values for which the op-amp is saturated?

3.INVERTING AMPLIFIER WITH UNIPOLAR SUPPLY

3.1. WAVEFORMS AND VTC



Exploration

- For the circuit in Fig. 2, using GND instead of the negative supply, visualise $v_I(t)$ and $v_O(t)$, for $v_I(t)=0.5\sin 2\pi 1000t$[V][Hz]. Which half-wave of the input gets amplified?
- With the oscilloscope on X-Y mode, visualise the VTC $v_O(v_I)$.

Build the circuit shown in Fig. 3.

- $v_I(t)=0.5\sin 2\pi 1000t$[V][Hz]-from the signal generator.
- With the oscilloscope on Y-t mode, and both channels set to DC, visualise $v_I(t)$ and $v_O(t)$.

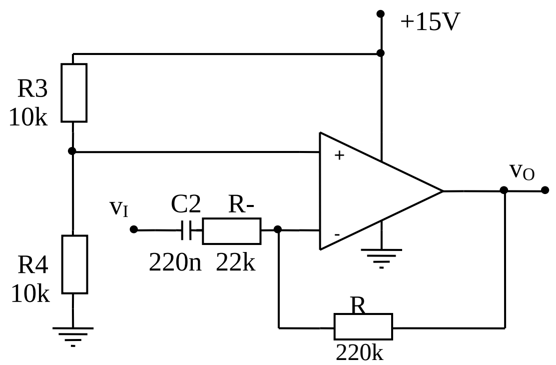


Fig. 3. Inverting amplifier with unipolar supply

- $v_I(t)=1\sin 2\pi 1000t$[V][Hz]-from the signal generator.
- With the oscilloscope on Y-t mode, and both channels set to DC, visualise $v_I(t)$ and $v_O(t)$.
- With the oscilloscope on X-Y mode, visualise the VTC $v_O(v_I)$.

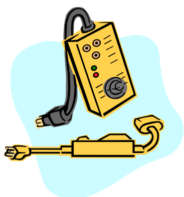
Results

- Draw the waveforms for v_I and v_O for both amplitudes specified above.
- Draw the VTC.

BJT OPERATING REGIONS

I. OBJECTIVES

a) Experimental determination of the boundaries between the operating regions of the BJT.
b) Understanding how a BJT can be used as a switch, for logic circuits, or as an amplifier.



II. COMPONENTS AND INSTRUMENTATION

Use the breadboard, an 2N2368 npn BJT, some resistors and two LEDs. The supply is obtained from the double dc regulated voltage supply. The input voltage is obtained from the signal generator. To visualize the voltage waveforms, a dual-channel oscilloscope is used.

The terminals of the 2N2368 npn BJT are shown in Fig. 1.

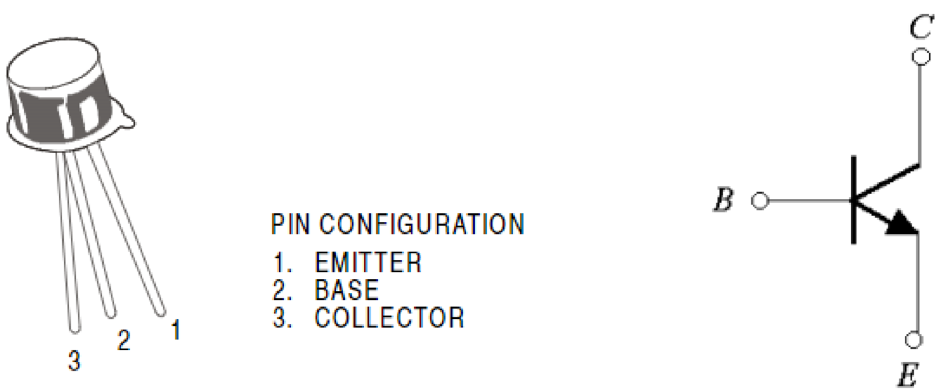


Fig. 1. Pinout diagram for 2N2368 npn BJT

III. PREPARATION

For T we consider: β=100, V_{BEon} = 0.6 V, V_{CEsat} = 0.2 V.

1.P. THE VTC DEPENDENCE ON R_C AND V_{CC}

For this paragraph, use the circuit from Fig. 2.

- $v_A(t)=10\sin(2\pi\ 1000t)$ [V] [Hz]

- What does the VTC $v_Y(v_A)$look like for the circuit from Fig. 2 with R_B =10 kΩ and R_C = 10kΩ? Specify the operating regions of T (off, a_F, exc) on the plot.
- What are the values of v_A for which T is off? What about the saturation state?
- What does the VTC look like if R_C = 2.2 kΩ? (R_B = 10 kΩ)
- What changes on the VTC when V_{CC} = 15 V?

2.P. BJT AS A SWITCH – THE LOGIC FUNCTION

For this paragraph, use the circuit from Fig. 2 and the logic convention 0 V - "0" logic, 10 V - "1" logic.

- Compute v_Y for v_A = 0 V. What is the operating region of T?
- Compute v_Y for v_A = 10 V. What is the operating region of T?
- Draw the electric operating table, using v_A as input and v_y as output.
- Draw the logic table, using A as input and Y as output. What is the logic function of the circuit?

3.P. BJT AS AN AMPLIFIER

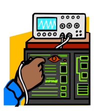
For this paragraph, use the circuit from Fig. 3 and assume v_A – variable dc voltage, between 0 and 5 V.

- What is the minimum value of v_A for which the LEDs become on? What does this mean, in terms of currents through T?

IV. EXPLORATIONS AND RESULTS

1. THE VTC DEPENDENCE ON R_C AND V_{CC}

Build the circuit in Fig. 2.



Exploration

- $v_A = 10 \sin(2\pi 1000t)$[V][Hz]
- Using the oscilloscope in X-Y mode, visualise $v_Y(v_A)$ for

a) R_B = 10 kΩ
R_C = 10 kΩ

b) R_B = 10 kΩ
R_C = 2.2 kΩ

- Determine the boundaries between off and a_F, and a_F and exc. How are these values modified when R_C changes?
- Change V_{CC} = 15 V. Repeat the previous visualizations. Determine the boundaries between off and a_F, and a_F and exc. How are these values modified, compared to the previous case?

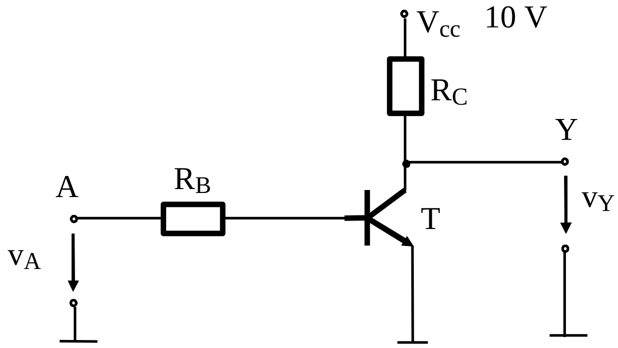


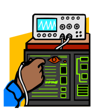
Fig. 2. Circuit with BJT

Results

- Draw the VTC $v_Y(v_A)$ for the above cases.
- What are the values of v_A for which the BJT is off and in exc?
- How do R_C and V_{CC} influence the VTC $v_Y(v_A)$?

2. BJT AS A SWITCH – THE LOGIC FUNCTION

Build the circuit in Fig. 2.



Exploration

- $v_A \in \{0\ V; 10\ V\}$
- Measure v_Y with the dc voltmeter
- Compute the current through T, for v_A = 0 V and for v_A = 10 V.

Results

- Fill in the following table, using the measured values of v_Y

Input voltage v_A	Output voltage v_Y	Current through T
0 V		
10 V		

- Draw the logic table, using A as input and Y as output. What is the logic function of the circuit?

3. BJT AS AN AMPLIFIER

Build the circuit in Fig. 3.

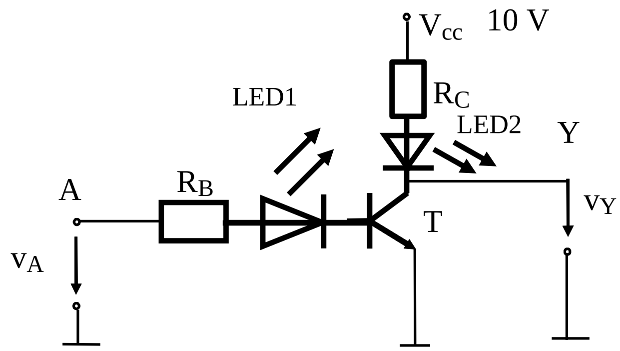
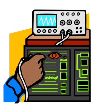


Fig. 3. Circuit with BJT and LEDs



Exploration

- $v_A \in [0\text{ V}; 5\text{ V}]$ – adjustable dc voltage
- Find the minimum value of v_A for which the LEDs become on. How can you tell that the output current (the current in the collector terminal of T) is greater than the input current (the current in the base terminal of T)?

Results

- Minimum value of v_A for which the LEDs become on.

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