Lodz University of Technology
Institute of Physics

Laboratory of electronics

Exercise E12IFE

Optoelectronics components

Version 1.1 (11 April 2019)

Table of contents:

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

1. Types of optoelectronic devices and their respective symbols in electronic circuit diagrams. [1-4]
2. Description of the properties of optoelectronic components. [1-3]
3. Structure of optical fibers. [1,4,5]

1. Purpose of the exercise

The purpose of this experiment is to comprehension of selected representative optoelectronic components: light emitters (photoemitters), light receivers (photodetectors) and photocouplers (opto-isolators), and to acquaint with the concept of fiber-optic transmission.

2. Hazards

Type	Absence	Low	Medium	High
electrical radiation 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)	+			

Before turning on the laser diode DL, always be sure that the laser diode is connected with photodetector by an optical fiber. Do not look at laser beam directly nor through a fiber. The cables with banana plugs are designed exclusively for use in low-voltage circuits - do not connect them to the mains supply 230V.

3. Introduction

Optoelectronic components are semiconductor devices which emit, detect or transform light (or, more precisely, electromagnetic radiation in ultraviolet, visual and infrared range). Their functioning is based on physical phenomena occurring in semiconductors as a result of mutual interaction of photons and electrons – mainly the internal photoelectric effect and electroluminescence. The internal photoelectric effect in junctionless devices demonstrates itself in growth of electric conductivity (photoconductance), whereas in p-n junctions it results in appearance of electromotive force (photovoltaic effect). Electroluminescence is a luminescence induced by electric current, which causes, for instance, injection of minority carriers through the p-n junction into some part of the semiconductor.

From the functional point of view, the optoelectronic devices can be divided into:

- Semiconductor sources of light (radiation), photoemitters – this group includes light-emitting diodes (LED, in Polish: DEL – diody elektroluminescencyjne) and semiconductor lasers.
- Semiconductor detectors of light (radiation), photodetectors – including photoresistors (junctionless components), photodiodes and phototransistors (junction components), and photovoltaic cells.
- Semiconductor devices based on optical coupling (a pair composed of a photoemitter and a photodetector) –photocouplers or opto-isolators.
- Radiation converters – semiconductor matrices for image analysis.

4. Available equipment

4.1. Experimental module

The front panel of experimental module is shown in Fig. 1. The module is composed of three parts:

1. On the left side there is a set of LEDs comprised of a laser diode DL and four light-emitting diodes DEL_1… DEL_4, a current source Z_1 adjustable in the range 0...19mA and a reference photodetector whose output voltage is proportional to the intensity of incident light. Moreover, in the lower left corner there is a light intensity switch which is designed only for use with the laser diode DL - the light intensity is proportional to the percent of the maximum emission 100%.
2. At the top right there is a set of photodetectors to investigate comprised of photoresistor FR, photodiode FD and phototransistor FT. The measurement circuit also includes a voltage source Z_2 adjustable in the range 0...12V.
3. At the bottom right an optocoupler is available (optocoupler consist of light-emitting diode and a phototransistor in the same opaque package), analog comparator and a potentiometer P used as an adjustable source of reference voltage for the comparator.

The optical connections between the selected light-emitting diode and photodetector are made with optical fiber, while the electrical connections are made using cables with banana plugs.

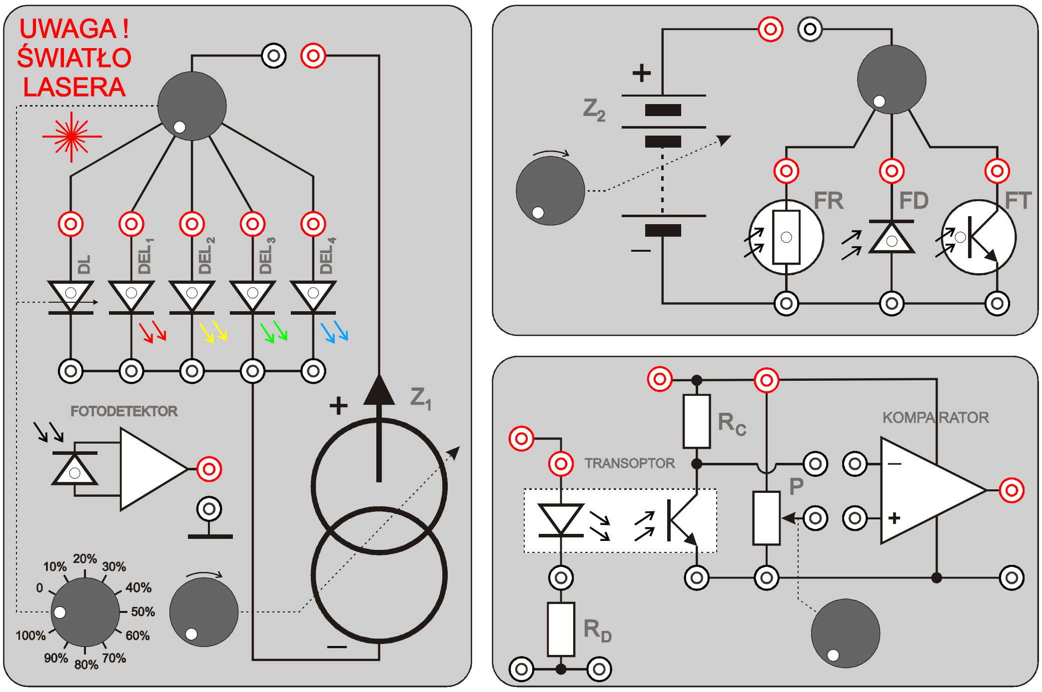

Fig. 1. The front panel of experimental module.

4.2. Multimeters

The voltages and currents in the experimental module will be measured using three digital multimeters. The following models may be used: KT890, M-3800, M-4650, UT-804 or Protek 506 [6].

4.3. Power supply

The experimental module is powered by the laboratory power supply SIGLENT SPD3303D [6]. In this experiment, only the channel that provides constant output voltage +5V is used.

4.4. Function generator

The light-emitting diode in the optocoupler is driven with a function generator DF1641B [6].

4.5. Oscilloscope

The waveforms on input and output of the optocoupler are observed on a dual channel oscilloscope GOS-620 or GOS-630 [6].

5. Experimental procedure

5.1. Current-voltage-illumination characteristics of a light-emitting diode

1. Unless the supervisor makes another suggestion, choose by yourself three of available light-emitting diodes (DEL) or laser diode (DL) for measurements. Connect the milliammeter (mA) and two voltmeters (V1) and (V2) to the experimental module as shown in Fig. 2. Turn the switch over the light-emitting diodes to select one of the chosen diodes and connect the diode with the photodetector using an optical fiber. Turn the other two regulators in the bottom part of the module to their extreme left position. Connect the power wires from the experimental module to the +5V output of the power supply (PS - SPD3303D).
   WARNING: the experimental module must be supplied from the power supply channel that provides a constant output voltage +5V (sockets on the right side of the power supply). Do not use the outputs which allow for voltage adjustment. Ignoring this recommendation threatens to damage the device.
2. Select the best measurement range of the milliammeter (mA) for currents up to 20mA DC (depending on the used multimeter the 20mA DC range for KT890 and M-3800, the 40mA DC range for UT804, the 200mA DC range for M-4650 or the range 400mA DC for Protek 506). Set the measurement range of both voltmeters (V1) and (V2) initially to no less than 20V DC (the range 20V DC or 40V DC).
3. After obtaining permission from the supervisor switch on the DMMs (Digital MultiMeters) and the power supply.
4. Using the regulator at the bottom of the measurement module set the maximum value of current generated by the current source Z_1 and select the optimal measurement ranges on the DMM voltmeters (V1) and (V2) for each of the diodes separately.
5. Determine the dependence of the voltage drop in the diode U_D and the photodetector's output voltage U_F on the current I_D generated by the power source Z_1 by changing I_D with the potentiometer between 0 and the maximum available value. The voltage U_F can be considered as directly proportional to the intensity of light illuminating the photodetector. Write down the measurement results in Table 1.
   WARNING: due to the large number of studied characteristics it is very important to begin with planning the optimal course of actions before starting the actual measurements. It can be assumed that 10-15 data points for one characteristic is sufficient, however it should be paid attention to ensure more or less uniform distances between data points along the entire curve in the plot.
6. Repeat the measurements for the other chosen light-emitting diodes.
7. Switch off the power supply and disconnect the circuit.

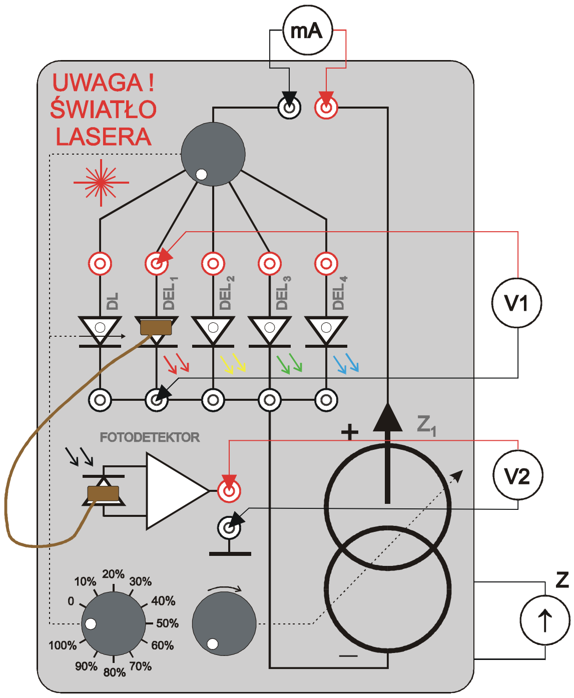

Fig. 2. Setup for determination of current voltage illumination characteristics of light emitting diodes.

#	Diode symbol	I_D [mA] mA	U_D [V] V1	U_F [V] V2

Table 1. Data table for measurements of current voltage illumination characteristics of light emitting diodes.

5.2. Current-voltage characteristics of photodetectors for various illumination intensity levels

1. Unless the supervisor orders otherwise, choose by yourself two of three available photodetectors for measurements. Connect the circuit shown in Fig. 3. Select the best measurement range for currents up to 20mA DC on the DMM milliammeter (mA) and the range no less than 20V DC on the voltmeter (V).
2. Turn the switch over the light-emitting diodes (top-left side) to select the dashed line leading to the regulator of relative light intensity of the laser diode (DL) and use the switch over the photodetectors (top-right side) to select one of the chosen photodetectors. Connect the laser diode DL with the photodetector using an optical fiber.
3. Before connecting the power supply, turn the regulator of relative light intensity of the laser diode (bottom-left side) to position "0" and turn the potentiometer next to the voltage source Z_2 to its extreme left position. After obtaining permission from the supervisor switch on the DMMs and the power supply.
   WARNING: Do not disconnect the optical fiber during the operation of the laser diode as doing so may cause eyesight damage.

4. Set relative light intensity Φ [%] of the laser diode to a freely chosen value and select the measurement range of the milliammeter which is optimal for the maximum voltage of the source Z_2. Plan the optimal course of measurements and determine the current-voltage characteristics of the chosen photodetector by changing the voltage of the source Z_2. Write down in Table 2 the relative value of the light intensity Φ and the measured values of the current I_F (mA) and voltage drop in the photodetector U_F (V). Repeat the measurements for at least two other levels of light intensity Φ.
5. In the same way, measure the current-voltage characteristics of the other chosen photodetector. Remember to switch off the laser diode before disconnecting the optical fiber by turning the regulator of relative light intensity to position "0". Moreover, the source Z_2 must be set to minimum voltage before changing photodetectors.

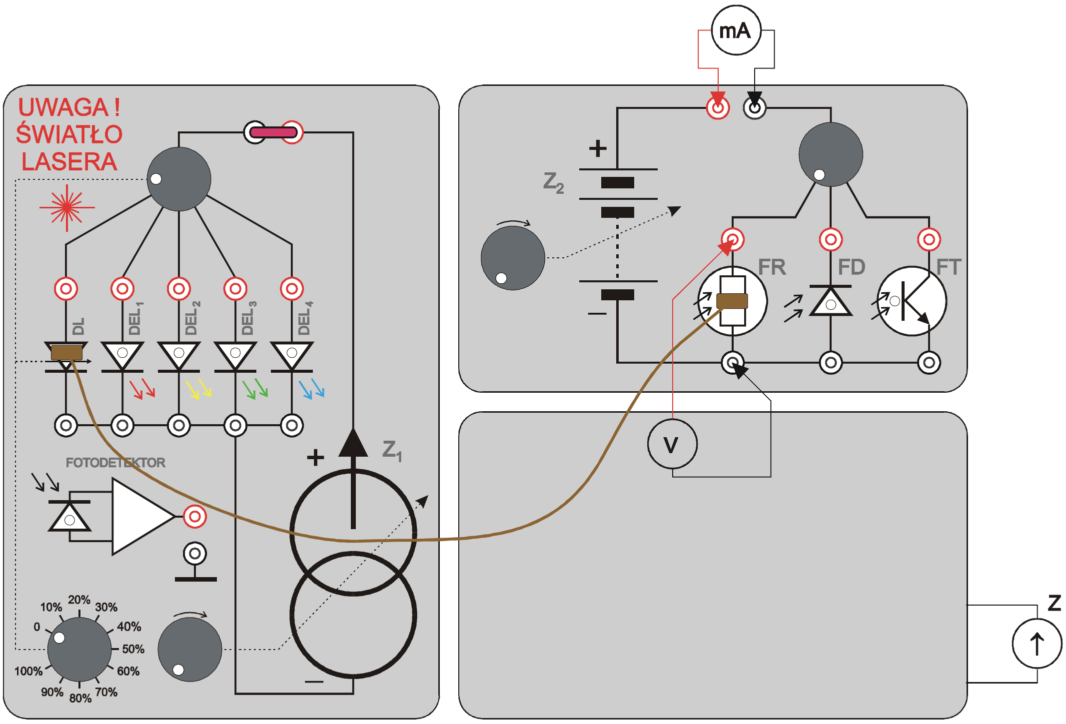

Fig. 3. Setup for determination of current-voltage characteristics of photodetectors in relation to illumination intensity level.

#	type of photodetector	Φ [%]	U_F [V] V	I_F [mA] mA

Table 2. Data table for measurements of current-voltage characteristics of photodetectors.

5.3. Transfer characteristic of a photocoupler

1. Connect the circuit shown in Fig. 4. Select the best measurement range for currents up to 20mA DC on the DMM milliammeters (mA1) and (mA2) and the range no less than 20V DC on the voltmeter (V).
   WARNING: Do not use external wires to connect power to the output circuit of the photocoupler because it has been already supplied within the experimental module. Turn the switch over the light-emitting diodes to one of the positions $DEL_1 \dots DEL_4$ – do not select the position DL, as values of current obtained from the source Z_1 at that setting may be too high. The control knob of the power source Z_1 should be turned to its extreme left position.
2. After obtaining permission from the supervisor, switch on the DMMs and the power supply.
3. Measure the voltage U_{CE} between the collector and the emitter of the photocoupler's phototransistor, neglecting the voltage drop in the milliammeter (mA2) in the collector's circuit.
4. Determine the dependence of phototransistor current I_O on photocoupler's diode (LED) current I_i by changing the current I_i from 0 to maximum available value with the potentiometer next to voltage source Z_1. Write down the measurement results in Table 3.

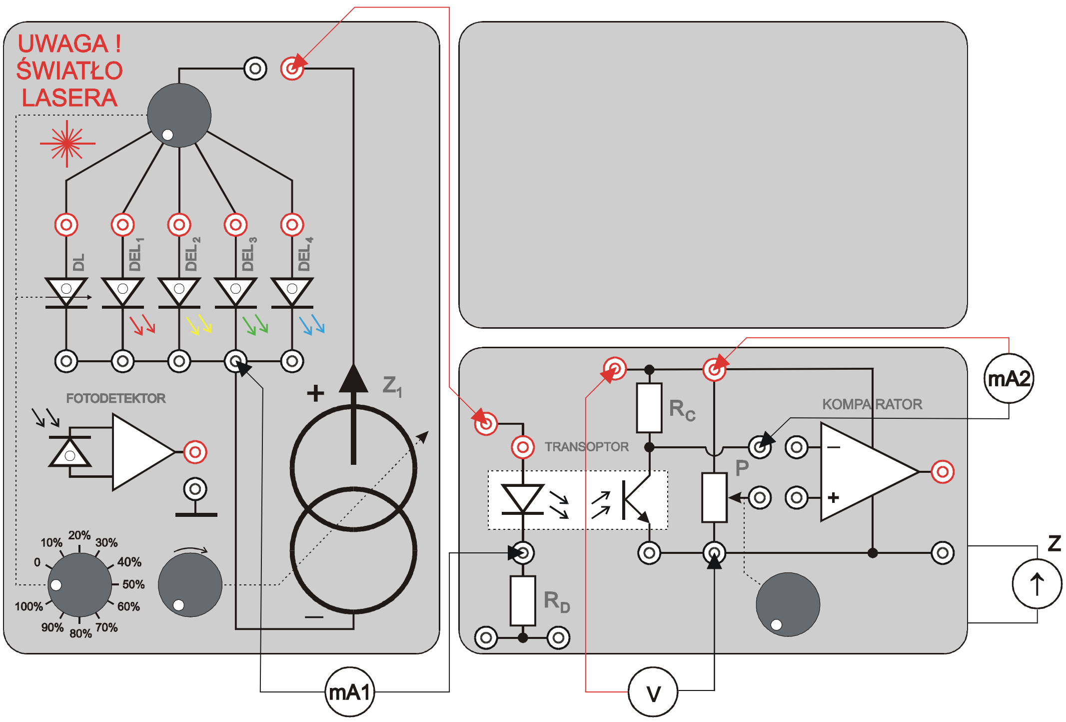

Fig. 4. Setup for determination of transfer characteristic of a photocoupler.

#	U_{CE} [V] V	I_i [mA] mA1	I_O [mA] mA2

Table 3. Data table for measurements of transfer characteristic of a photocoupler.

5.4. Investigation of dynamic properties of a photocoupler

1. Connect the circuit shown in Fig. 5.
2. Switch on the oscilloscope (GOS-620 or GOS-630) and the function generator (DF1641B). Select the rectangular signal in the generator, set maximum amplitude of the output signal with attenuators switched off and set the initial frequency of 50 Hz.
3. Gradually increase the frequency, continuously observing the oscillograms on the oscilloscope working in dual-channel mode, until significant distortions appear in the signal from the photocoupler's output circuit. Sketch the shapes of the oscillograms and write down the frequency.
4. Without changing the frequency found during the last observation, connect the input Y2 of the oscilloscope with the output of the comparator and connect the inputs of the comparator using jumpers as shown in Fig. 6. Sketch the oscillograms.
5. Turn the knob of the potentiometer P until the signal on the comparator's output has shape and fill ratio close to the input signal. Sketch the the oscillograms.
6. Try to estimate the maximum frequency at which it is possible to recreate the shape of the original signal on the comparator's output. Sketch the oscillograms. Pay your attention to the time shift between the signals in both oscilloscope's channels.
7. Switch off the power and disconnect all connections.

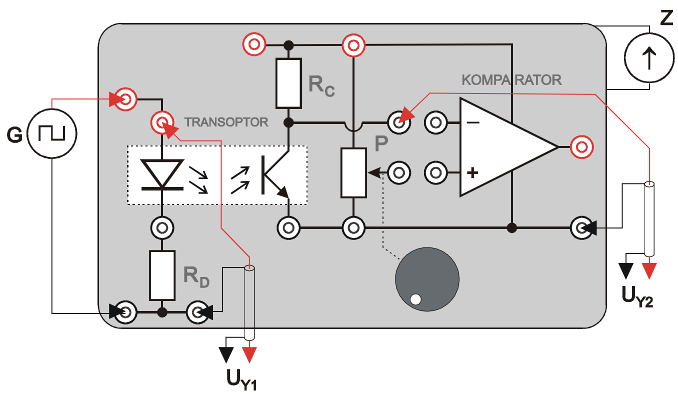

Fig. 5. Setup for observation of digital signal distortions introduced by a photocoupler.

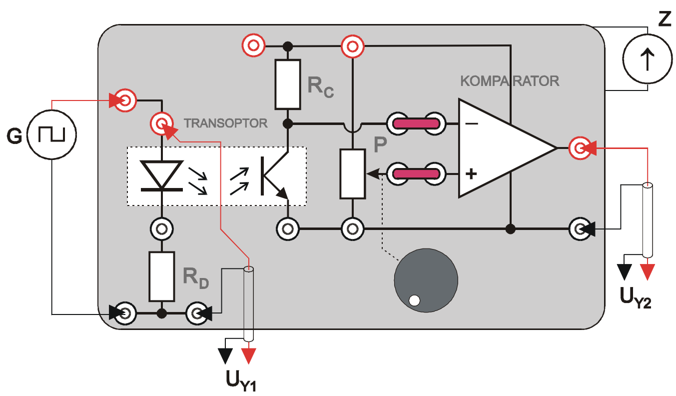

Fig. 6. Setup for observation of digital signal restoration in the comparator.

6. Report elaboration

Report has to be composed of:

1. Front page (by using a pattern).
2. Description of experiment purposes.
3. Schematic diagrams of tested circuits.
4. List of used instruments and devices (id number, type, setting and range values).
5. Measuring results.
6. Plots of current-voltage characteristics of light-emitting diodes $I_D = f_1(U_D)$ and plots of the voltage on the photodetector's output (approximately proportional to the intensity of emitted light) as a function of the diode current $U_F = f_2(I_D)$. Determine the dependency type (e.g. linear, logarithmic, exponential). Example characteristics are shown in appendix A1.
7. Plots of current-voltage characteristics of photodetectors $I_F = f_3(U_F)$ at various illumination intensities Φ. All plots obtained for a single photodetector at different illuminations Φ should be shown in the same coordinate system. Example characteristics are shown in appendix A2.
8. Analysis of the plots made in previous step. Check out if changes in illumination intensity Φ have linear influence on the current I_F at fixed voltage U_F. In order to do that, draw vertical lines corresponding to a particular voltage U_F on the plots made in the previous step and read the coordinates I_F of the intersections of these lines with the plots. Show these results as plots of the dependence $I_F = f_4(\Phi)$. Since dark currents in the examined photodetectors are very small, an additional point (0, 0) can be included in the plots.
9. Plot of the photocoupler's transition characteristic $I_O = f_5(I_i)$ and plot of the photocoupler's current ratio $N = I_O / I_i$ as a function of I_i. Evaluate usability of the investigated photocoupler for transmission of analog signals.
10. Oscillograms observed during investigation of photocoupler's dynamic properties with descriptions and oscilloscope settings included. By comparing the oscillograms from both channels, estimate the time of signal propagation through the photocoupler-comparator circuit.
11. Remarks and final conclusions.

The report will be evaluated for the language, completeness, correctness, clarity of presentation of the results (in the form of tables, graphs, oscillograms, the values read from the oscillograms together with descriptions) and quality of discussion and conclusions. All of the components listed above will be evaluated in the report. Theoretical introduction is not required and is not included in the assessment.

7. References

7.1. Basic reference materials

[1] A. Pawlaczyk, „Elementy i układy optoelektroniczne”, WKiŁ, Warszawa 1984.
[2] M. Rusek, J. Pasierbiński, „Elementy i układy elektroniczne w pytaniach i odpowiedziach”, WNT, Warszawa 2003.
[3] J. Cieślak, „Półprzewodnikowe elementy optoelektoniczne”, Wydawnictwo Ministerstwa Obrony Narodowej, Waraszawa 1981.
[4] T. Masewicz, „Radioelektronika dla praktyków”, WKiŁ, Warszawa 1986.
[5] „Encyklopedia techniki. Elektronika”, WNT, Warszawa 1983.

7.2. Other reference materials

[6] User guides for multimeters, power supply, function generator, and oscilloscope available on the website:
https://fizyka.p.lodz.pl/pl/dla-studentow/fundamentals-of-electronics/

8. Appendixes

A1. Example characteristics of light-emitting diodes

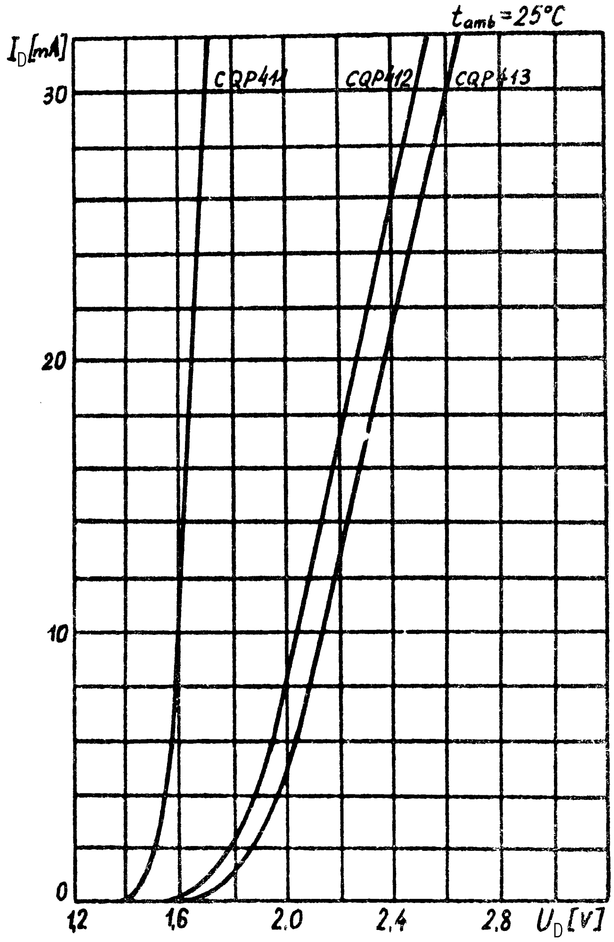

Fig. A1.1. Static current-voltage characteristics $I_D(U_D)$ of light-emitting diodes: CQP411 (red light, made of GaAsP by epiplanar technique), CQP412 (green light, made of GaP by epitaxial technique), CQP413 (yellow light, made of GaP by epiplanar technique). All dependencies are approximately exponential.

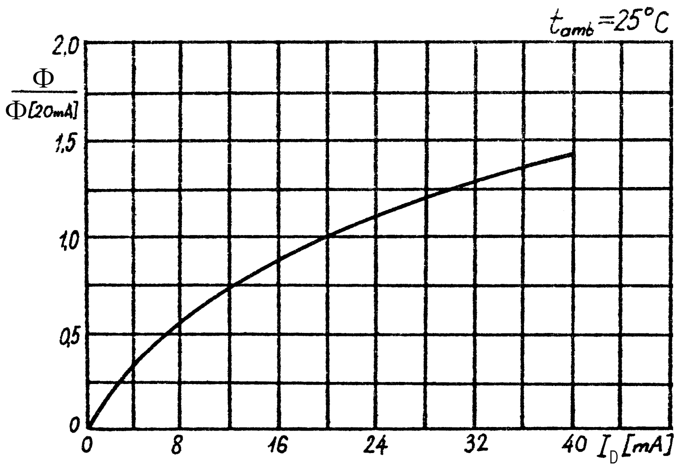

Fig. A1.2. The dependence of relative luminosity $\Phi/\Phi_{(20\ mA)}$ on the conduction current I_D for light-emitting diodes CQP411…413. The shape of the curve is logarithmic.

A2. Example characteristics of photodetectors

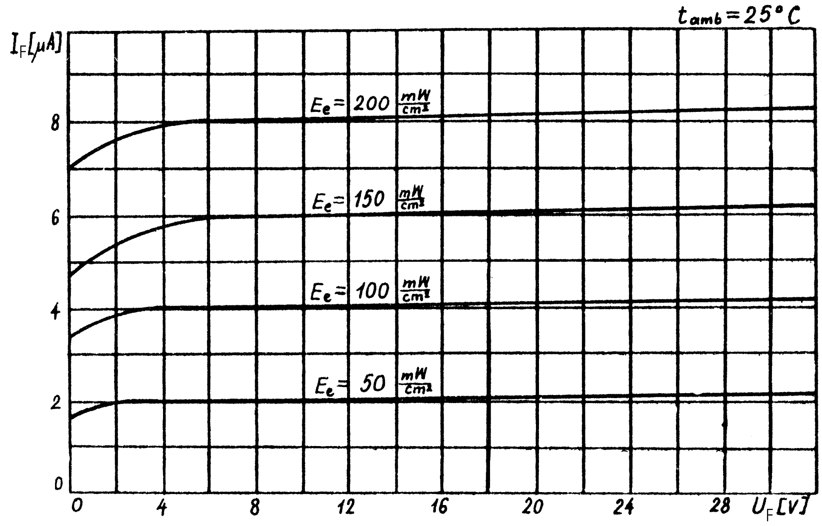

Fig. A2.1. Current-voltage characteristics $I_F(U_F)$ of a reverse-biased photodiode BPSP 34, for various values of illumination power density E_e. With increasing voltage U_F the curves tend to constant functions.

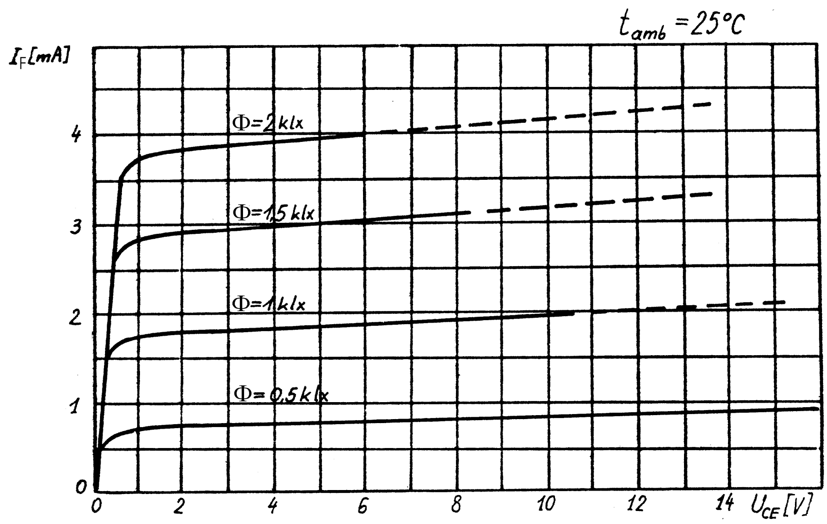

Fig. A2.2. Current-voltage output characteristics $I_F(U_{CE})$ of a phototransistor BPRP 24 for various values of illumination intensity Φ. The dependencies become linear for $U_{CE} \geq 2V$.