LABORATORY
OF
ELECTRONIC ELEMENTS

Switching of Diodes and Transistors

REV. 1.0a

1. THE GOAL OF THE EXERCISE

- observation of diodes and transistors operation during switching,
- measurements of characteristic switching times,
- determination of basic dynamic parameters.

2. THE UTILIZED MODELS AND ELEMENTS

During the exercise, the following components will be used:
- NI ELVIS Prototyping Board (ELVIS) connected with PC,
- external power supply,
- oscilloscope,
- function generator,
- set of components shown in Table 1.

Table 1. Electronic elements required to perform the exercise

Diodes	e.g.: 1N4001, or others
Bipolar transistors	e.g.: BC 107, BC 337, BF 519, or others
MOS transistors	e.g.: BS 170, BS 107, or others
Resistors	10 Ω, 50 Ω, 100 Ω, 150 Ω, 1 kΩ, 100 kΩ

3. PREPARING THE DRAFT

3.1. Draw waveforms of voltage and current during switching of diodes,

3.2. Draw waveforms of voltage and current at the base and collector of the bipolar junction transistor working in common emitter mode, when switched.

4. THE COURSE OF THE EXERCISE

4.1. Measurements of diode switching times

Arrange the circuit according to Fig. 1. Attach the oscilloscope probes to the measuring points (P_1, P_2, P_3), and the input of the circuit connect with the external function generator RIGOL. Set a square symmetrical waveform in such a way to make possible observations of dynamic switching effects on the oscilloscope screen, as well as to measure switching times (e.g. for diode 1N4001: frequency around 100kHz, amplitude 10 V_{PP}, offset 0 V).
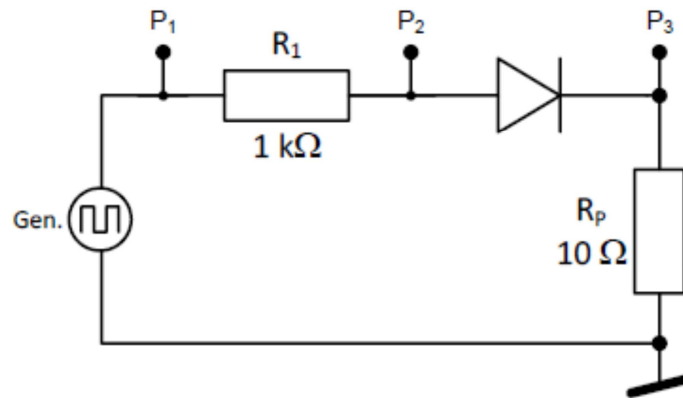
Fig. 1. Measuring circuit for investigation of switching parameters of diodes

Sketch (or save on USB memory stick) the voltage and current waveforms during switching of diodes.

Measure switching times (storage t_S and falling t_f) of the diode for different combinations of diode currents.

Measure a voltage drop on the diode at the turn-off moment, to estimate a serial resistance.

Repeat the experiments for other diodes.

> **REMARK:** Changing the amplitude and the offset of the generator waveform one can change the diode currents and get asymmetrical values. Use the oscilloscope cursors to measure times and voltages.

> Diode current can be estimated based on voltage drop (measured by means of oscilloscope) over the resistor R_P.

4.2. Investigation of bipolar junction transistor during switching

4.2.1. Determination of current gains for normal and inverse mode of operation – β_N i β_I.

Arrange the circuit according to Fig. 2. Measure and note the values of currents.

Swap the collector and emitter terminals, then measure once again the values of currents.

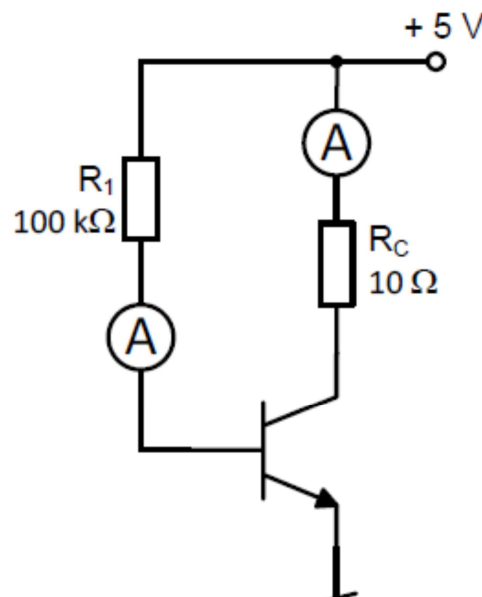> **REMARK:** Make sure that the transistor does not enter saturation state.

Fig. 2. Measuring circuit for determination of current gain

4.2.2. Measurements of collector current rise time.

Arrange the circuit according to Fig. 3. Supply a square symmetrical waveform (from external generator) to the input. Attach oscilloscope probes to the measuring points P_1, P_2, P_3. For active operation mode of the transistor, measure the collector current rise time t_r for two different values of R_C (e.g. 10Ω and 50Ω). Time measurements should be taken for values of current ranging from 10% to 90% of its maximum value.

Swap the transistor into inverse mode and take the measurements as in the active mode (if the U_{CE} amplitude is to low, the R_C value should be increased).

REMARK: Make sure that the transistor does not enter saturation state.
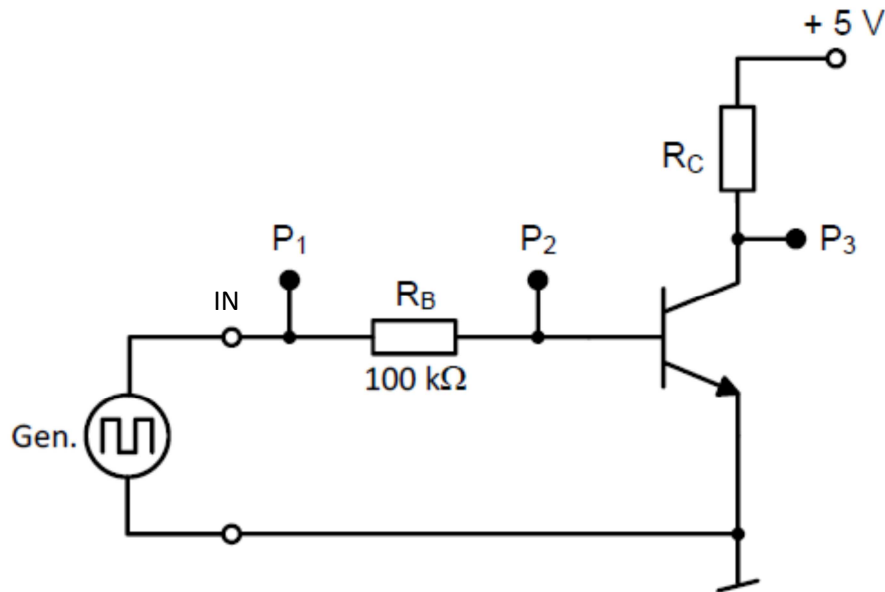

Fig. 3. Circuit for investigation of dynamic operation of bipolar transistor

4.2.3. Measurements of storage time.

In the same circuits as in Fig. 3, choose the value of R_C, and the input amplitude, to get "overdrive" of the transistor – entering into saturation state.

Observe the influence of current value on storage times – copy an exemplary waveform to the report.

Measure storage times t_S for different base currents.

REMARK: Changing the amplitude and the offset of the generator waveform, one can change the base currents and get asymmetrical values.

Base current can be estimated based on resistor R_B and the input voltage (input loop).

4.3. Investigation of MOS transistor during switching

Arrange the circuit according to Fig. 4. Set a positive square waveform – choose appropriately OFFSET value (input amplitude 5 V_{pp}, OFFSET 2.5 V). Attach the oscilloscope probes to the measuring points P_1, P_2, P_3. Set supplying voltage $U_Z = 5V$. For different values of R_G (e.g. 10 Ω, 100 Ω, 1 kΩ, etc.) copy the output voltage waveform and measure the rise as well as falling times of output U_{DS} voltage. Note the shape of the waveform in the vicinity of half the amplitude. Then, increase twice the supplying voltage and the input amplitude ($U_Z = 10V$, input amplitude 10 V_{PP}, OFFSET = 5 V).
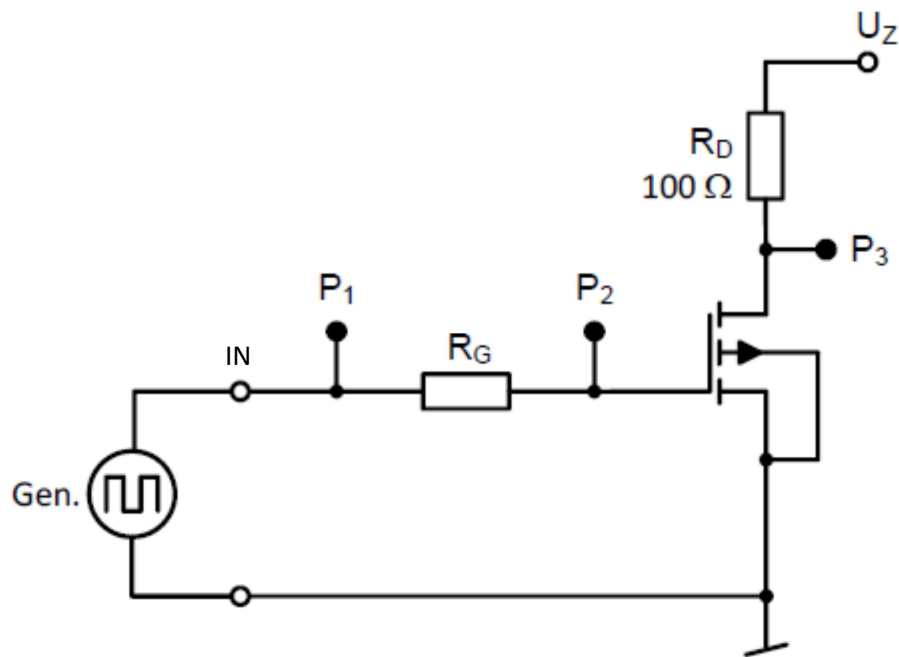
Fig. 4. Measuring circuit for investigation of **n-MOS** transistor

5. DATA ANALYSIS

5.1. Diode

- Paste to the report the current and voltage waveforms taken during switching of diodes. Mark the characteristic switching times observed in p. 4.1.
- Based on the measured times, calculate the carriers transfer time *TT* using the following formula:

$$t_S = TT \cdot \ln\left(\frac{|I_R| + I_F}{|I_R|}\right)$$

I_F – forward diode current,
I_R – reverse diode current.

- Calculate the series resistance of the examined diodes.
- Show in table the obtained results (times and resistances), for different combinations of currents.
- Compare the obtained results with data sheets, and then comment. Pay attention to the applications of these diodes.

5.2. Bipolar transistor

- Based on the measured base and collector currents, taken in p. 4.2.1, calculate the current gains for normal and inverse modes of operation – β_N i β_I.
- Based on the measured times, taken in p. 4.2.2, calculate the transistor time constants: τ_{BN}, τ_N, τ_{BI}, τ_I. Show the results in a table.
- Comment the obtained results and derive some conclusions.
- Based on the measured times, taken in p. 4.2.3, calculate the parameter τ_S for different cases. Show the results in a table.

- Compare the obtained results with data sheets, and then comment. Derive some conclusions.
- For each case, estimate the maximum frequency of the transistor working as current switch, assuming that the permissible change of impulse duty cycle should not exceed 10%, comparing with input pulses.

5.3. MOS transistor

- Place in a table the values of measured times for different resistors and supplying voltages. Comment the obtained results.
- Based on copied waveforms for different resistors, clarify the reason for such shapes of output signals.

6. LITERATURE

[1] Lecture (P. Dziurdzia)

[2] J. Koprowski „Podstawowe przyrządy półprzewodnikowe", AGH Kraków 2009 (pol)

[3] W. Marciniak "Przyrządy półprzewodnikowe" (pol)