Experiment T1

Characteristics of Bipolar Junction Transistor (BJT) n-p-n in common-emitter circuit and characteristics of Field-Effect Transistor (FET) with n channel

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

1. Conduction in semiconductors. [1], [2], [3], [4].
2. The p-n junction. The semiconductor diode – how it works. [1], [2], [3].
3. The basis of working the bipolar junction transistor. [1], [2], [3].
4. The basis of working the filed-effect transistor. [1], [2], [3].

Purpose

1. To study the basic static properties of BJT transistor
2. To study the basic static properties of FET transistor.

Description of method of measurements of BJT.

The bipolar Junction Transistor (BJT) is investigated in common-emitter circuit. The Power Supply DF1731SB3A or MPS-3003L-3 together with Adjustable Voltage Regulator (ZN) enable put voltage across collector-emitter terminates of transistor. The Adjustable Current Source provides I_B current to Base Terminal of transistor. The kit of DMMs consists of ammeters and voltmeters enable to measure relevant currents and voltages. The obtained results allow to plot input, transfer, reversal and output characteristics of transistor and enable to calculate the h-parameters.

Experimental procedure

The output and reversal characteristic curves for bipolar junction transistor (BJT).

1. Check out connections according to the diagram given in the Fig.2.
2. Turn to the most left position the voltage knob on the Adjustable Voltage Regulator (ZN).
3. Set the rotary function switch on the Adjustable Current Source (ZP) to the „1” position (range from 0 to 0.5 mA).
4. Turn to the most left position the current knob on the Adjustable Current Source (ZP).
5. Set the rotary function switch on the DMM ammeter to the 200 mA range (measurement of I_C).
6. Set the rotary function switch on the DMM ammeter to the 200 μA range (measurement of I_B).
7. To measure DC voltage (U_{CE} and U_{BE}) set the rotary function switch on DMM voltmeter to the 20 V range.
8. After supervisor’s approval press the ON/OFF keys to power on the DMMs and DC Power Supply. (DF1731SB3A or MPS-3003L-3). Warning!!! Do not change the position of voltage knob on DC Power Supply.
9. Set the switch „Pł” on the measurement panel to the „0” position. It means the $R_L = 0\ \Omega$.
10. Increase the voltage U_{CE} from 0 to 8 V and determine the dependence U_{CE} on I_C for $I_B \approx 0$.
11. Repeat the procedure described in previous step setting the current I_B at the chosen values (ask supervisor) (range from 40 μA to 160 μA, step 40 μA).
12. Record the obtained results on the data sheet in the Data Table 1.
13. Turn to the most left position the current knob on the Adjustable Current Source (ZP).
14. Turn to the most left position the voltage knob on the Adjustable Voltage Regulator (ZN).
15. Plot the $I_C(U_{CE})$ dependences. As an example the family of I_C versus V_{CE} curves for several values of I_B is presented on Fig. 1.

Data Table 1.

U_{CE} [V]	ΔU_{CE} [V]	I_B [μA]	ΔI_B [μA]	U_{BE} [V]	ΔU_{BE} [V]	I_C [mA]	ΔI_C [mA]

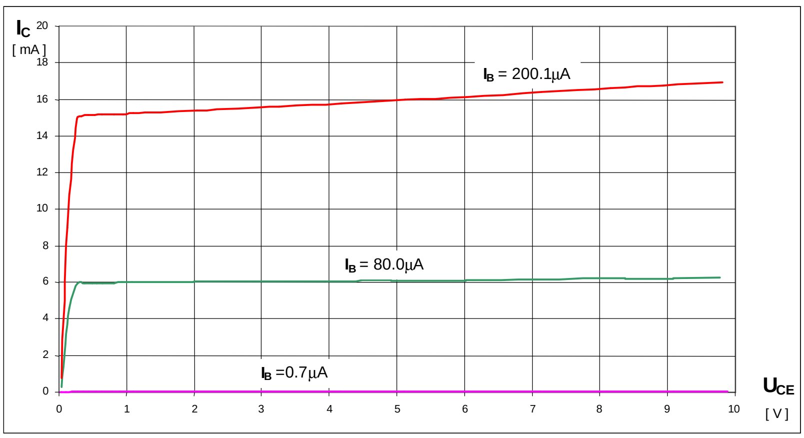

Fig. 1. Family of I_C versus U_{CE} for several values of I_B.

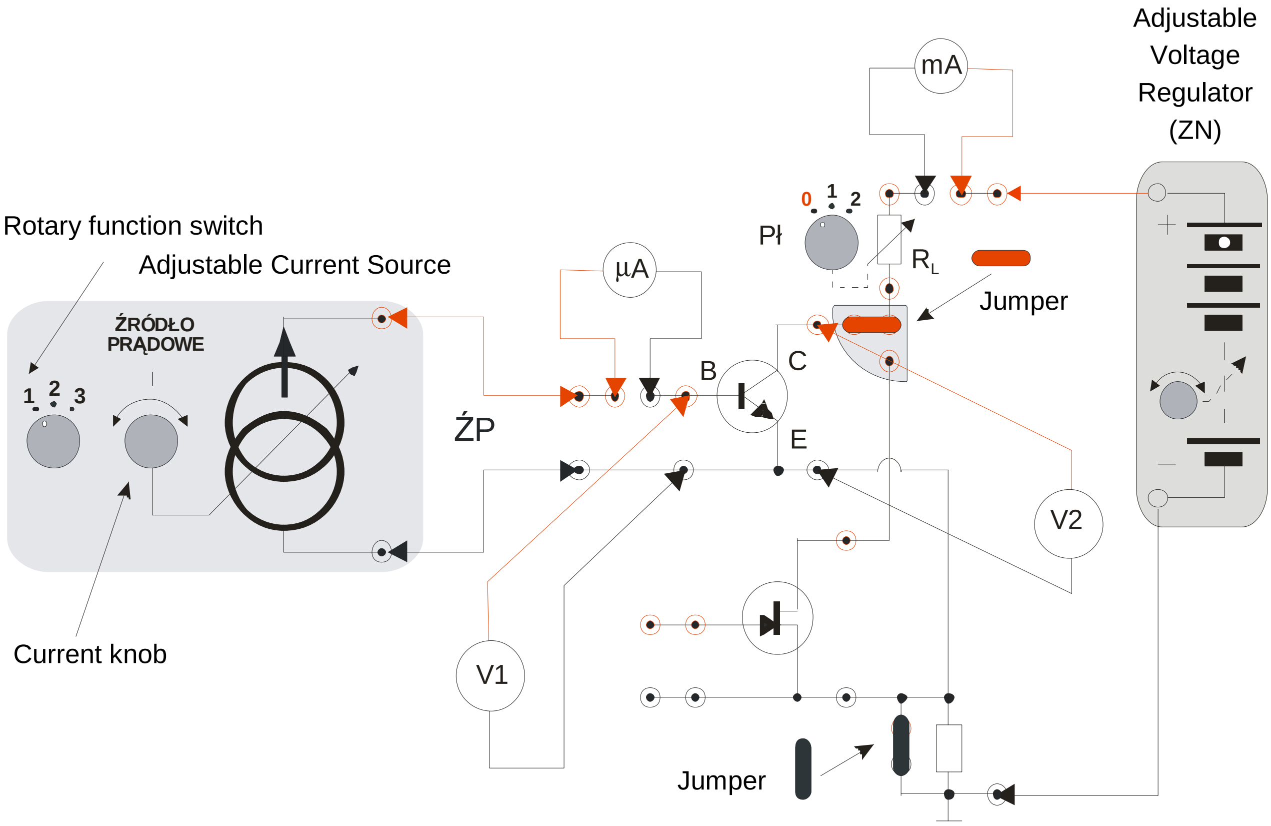

Fig 2. Diagram of connections for bipolar junction transistor's (BJT) characteristics.

The input and transfer characteristic curves for bipolar junction (BJT) transistor.

1. Turn to the most left position the current knob on the on the Adjustable Current Source (ZP).
2. Set the switch „Pł" on the measurement panel to the „0" position. It means the $R_L = 0\ \Omega$.
3. Set the voltage U_{CE} at chosen value (ask supervisor) (range from 3 V to 6 V)
4. Increase the current I_B from 0 μA to 160 μA with step of 10 μA determine the dependence of I_B on I_C and dependence of I_B on U_{BE}. Record the obtained result on the data sheet in the Data Table 1.
5. Repeat the procedure described in previous step setting the different value of U_{CE} (ask supervisor).
6. Switch off the DC Power Supply (DF1731SB3A or MPS-3003L-3).
7. Disconnect the Adjustable Current Source (ZP), Adjustable Voltage Power Supply (ZN), DMMs and Jumpers from measurement panel (testing set is presented at diagram in the Fig.2.)
8. Plot the $U_{BE}(I_B)$ dependences. As an example the family of U_{BE} versus of I_B curves for two values of U_{CE} is presented in Fig. 3

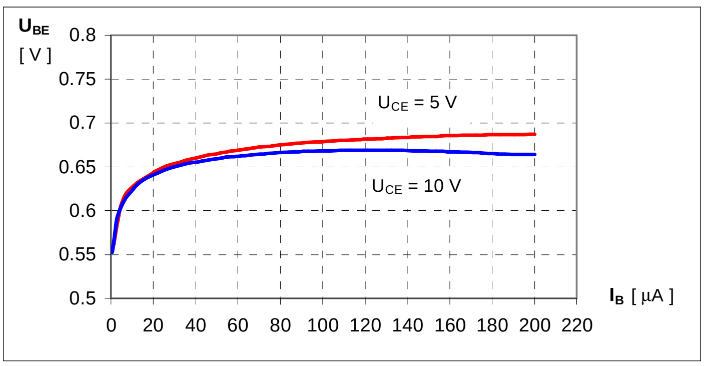

Fig. 3. Family of U_{BE} versus I_B for several values of U_{BE}.

Description of method of measurements of FET.

The Field-effect transistor (Junction Field-Effect Transistor JFET) is investigated in common-source circuit. The Power Supply DF1731SB3A or MPS-3003L-3 together with Adjustable Voltage Regulator (ZN) enable put voltage across source-drain terminates of transistor. The Adjustable Voltage Source provides U_{GS} voltage across gate-source terminates. The kit of DMMs consists of ammeters and voltmeters enable to measure relevant currents and voltages. The obtained results allow to graph the transfer and output characteristics of transistor.

Experimental procedure

The transfer (gate) characteristic curves for field-effect transistor (FET).

1. Check out connections according to the diagram given in the Fig.4.
2. Turn to the most left position the voltage knob on the Adjustable Voltage Power Supply (ZN).
3. Set the rotary function switch on the Adjustable Voltage Power Supply to the „1” position (range from −12 V to 0 V).
4. Turn to the most left position the voltage knob on the Adjustable Voltage Source.
5. Set the rotary function switch on the DMM ammeter to the 200 mA range (measurement of I_D).
6. Set the switch „Pł” on the measurement panel to the „0” position. It means the $R_L = 0\ \Omega$.
7. After supervisor’s approval switch on the DMMs and DC Power Supply. (DF1731SB3A or MPS-3003L-3). Warning!!! Do not change the position of voltage knob on DC Power Supply.
8. According to the supervisor’s order set the U_{DC} voltage. Increasing the U_{GS} voltage from −10 V to 0 V determine the dependence $I_D(U_{GS})$ for fixed U_{DS}.
9. Repeat the procedure described in previous step setting the voltage U_{DS} at chosen values (ask supervisor) (range from 1 V to 10 V).
10. Record the obtained results on the data sheet in the Data Table 2.
11. Plot the $I_D(U_{GS})$ dependences. As an example the family of I_D versus U_{GS} curves for two chosen values of U_{DS} is presented on Fig. 5.
12. Determine the cut-off voltage $U_{GS\ OFF}$ of FET transistor under the investigation.

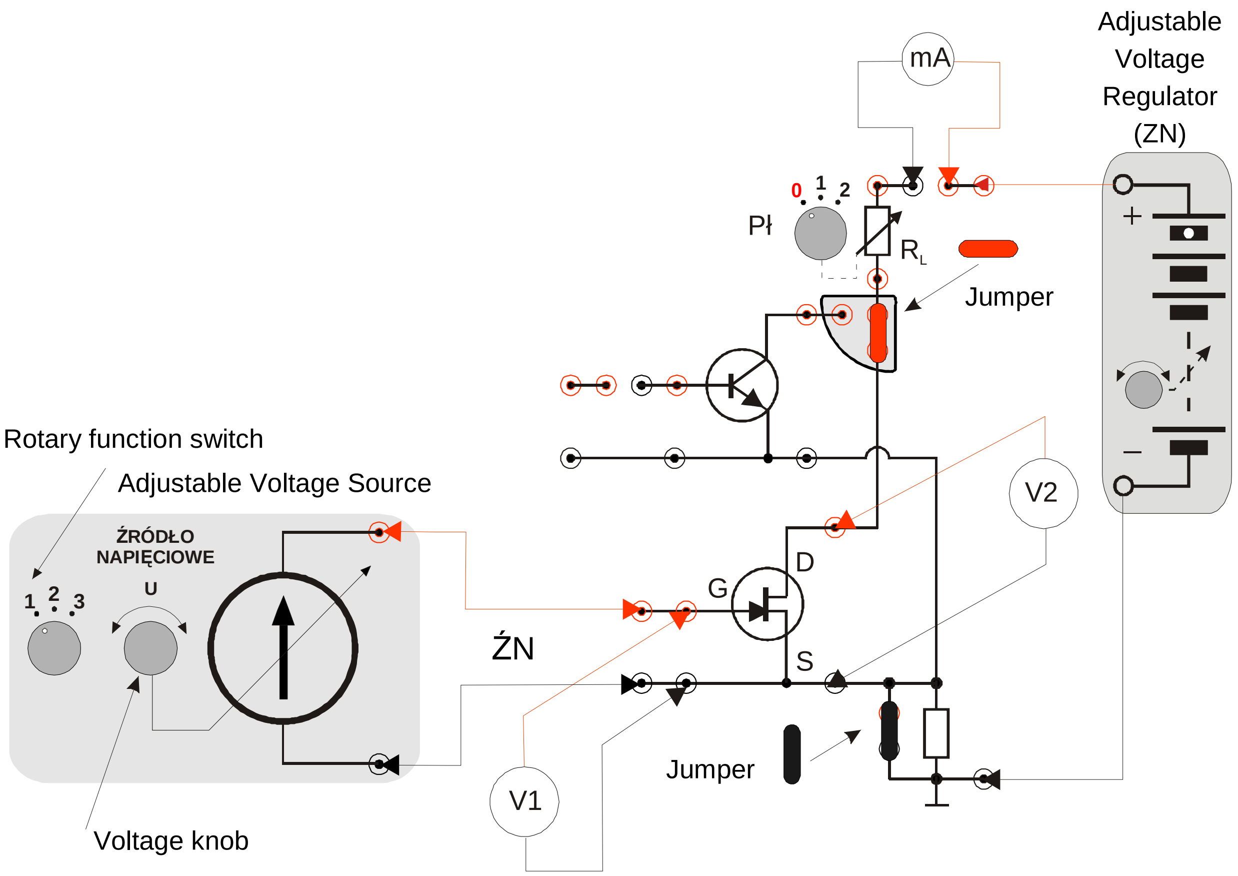

Fig. 4. Diagram of connections for FET transistor's characteristics.

Data Table 2.

U_{GS} [V]	ΔU_{GS} [V]	I_D [mA]	ΔI_D [mA]	U_{DS} [V]	ΔU_{DS} [V]

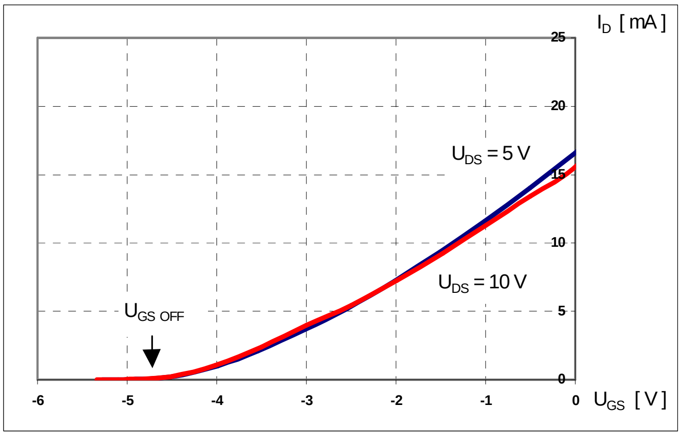

Fig. 5. Family of I_D versus U_{GS} for several values of U_{DS}.

The output (drain) characteristic curves for field-effect transistor (FET).

1. Turn to the most left position the voltage knob on the Adjustable Voltage Regulator (ZN).
2. Set the rotary function switch on the Adjustable Voltage Power Supply to the „1” position (range from –12 V to 0 V).
3. Adjust the Adjustable Voltage Source at $U_{GS} \cong U_{GSOFF}$.
4. Set the rotary function switch on the DMM ammeter to the 200 mA range (measurement of I_D).
5. Set the switch „Pł” on the measurement panel to the „0” position. It means the $R_L = 0\ \Omega$.
6. Increase the U_{DS} voltage from 0 V to 15 V and determine the dependence $I_D(U_{DS})$ for fixed $U_{GS} \cong U_{GSOFF}$.
7. Repeat the procedure described in previous step setting the voltage U_{GS} at chosen values (ask supervisor) (range from $U_{GS\,OFF}$ to 0 V).
8. Record the obtained results on the data sheet the Data Table 2.
9. Plot the $I_D(U_{DS})$ dependences. As an example the family of I_D versus U_{DS} curves for several values of U_{GS} is presented on Fig. 6.
10. Switch off the DC Power Supply.

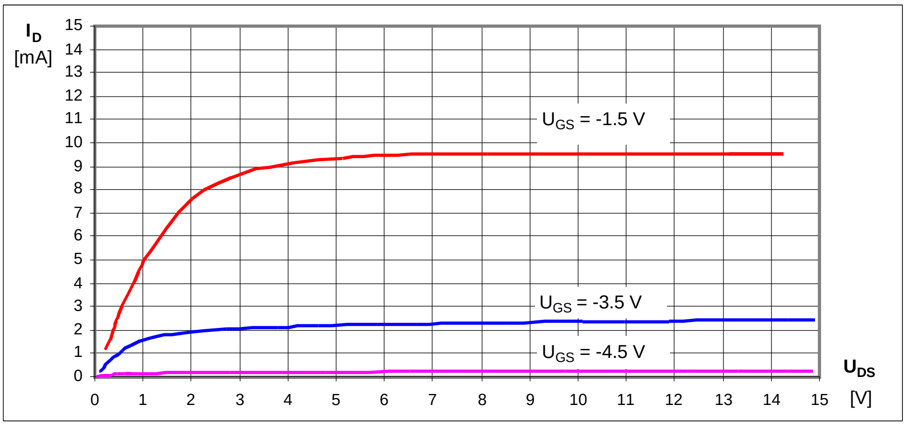

Fig. 6. Family of I_D versus U_{DS} for several values of U_{GS}.

Dynamic output characteristic for field-effect transistor (FET).

1. Remove all jumpers from measurement panel !!!
2. Check out connections according to the diagram given in the Fig.7.
3. Connect the Function Generator output with Oscilloscope CH1 input and D and S terminals of FET transistor using the T-type connector. Use BNC-BNC wire for connecting Generator with Oscilloscope and BNC-Banana Plug wire for connecting Generator with FET transistor. Pay attention on proper connections – black connector to the ground and the red wire terminal to the $+U_{CC}$ connector.
4. Connect the Oscilloscope CH2 input with R_Y resistor (U_Y on Fig. 7) using the BNC-Banana Plug wire. Pay attention on proper connections – black banana plug connector to the ground and the red one to the S terminal of the FET transistor.
5. After supervisor's approval switch on Adjustable Voltage Source, Oscilloscope and Function Generator.
6. Adjust the Adjustable Voltage Source at $U_{GS} \cong U_{GS\ OFF}$.
7. Select the triangle waveform by using the Function Select Switch on the Function Generator front panel. Select the DC coupling mode on Oscilloscope CH1 input. Set the output frequency on Function Generator to approx. 1 kHz and the output voltage signal to approx. 10 V (peak to peak). Pull out the knob PULL TO VAR DC OFFSET on Function Generator and adjust the DC voltage (the triangle signal on the oscilloscope's screen must be shifted on half of U_{PP} (peak to peak). The output generator signal should vary from 0 V to 10 V (must be greater than zero volts).
8. Put the jumper in the "drain" circuit. Leave the R_Y resistor to be un-short-circuited.
9. Set the rotary frequency switch to X-Y to operate Oscilloscope as X-Y oscilloscope. CH1 can be applied as a horizontal deflection (X-axis) while CH2 provides vertical deflection (Y-axis).
10. Change the U_{GS} voltage from $U_{GS\ OFF}$ to 0 V.
11. Copy the signals from the Oscilloscope's screen and compare them with those obtained in previous, static measurements.

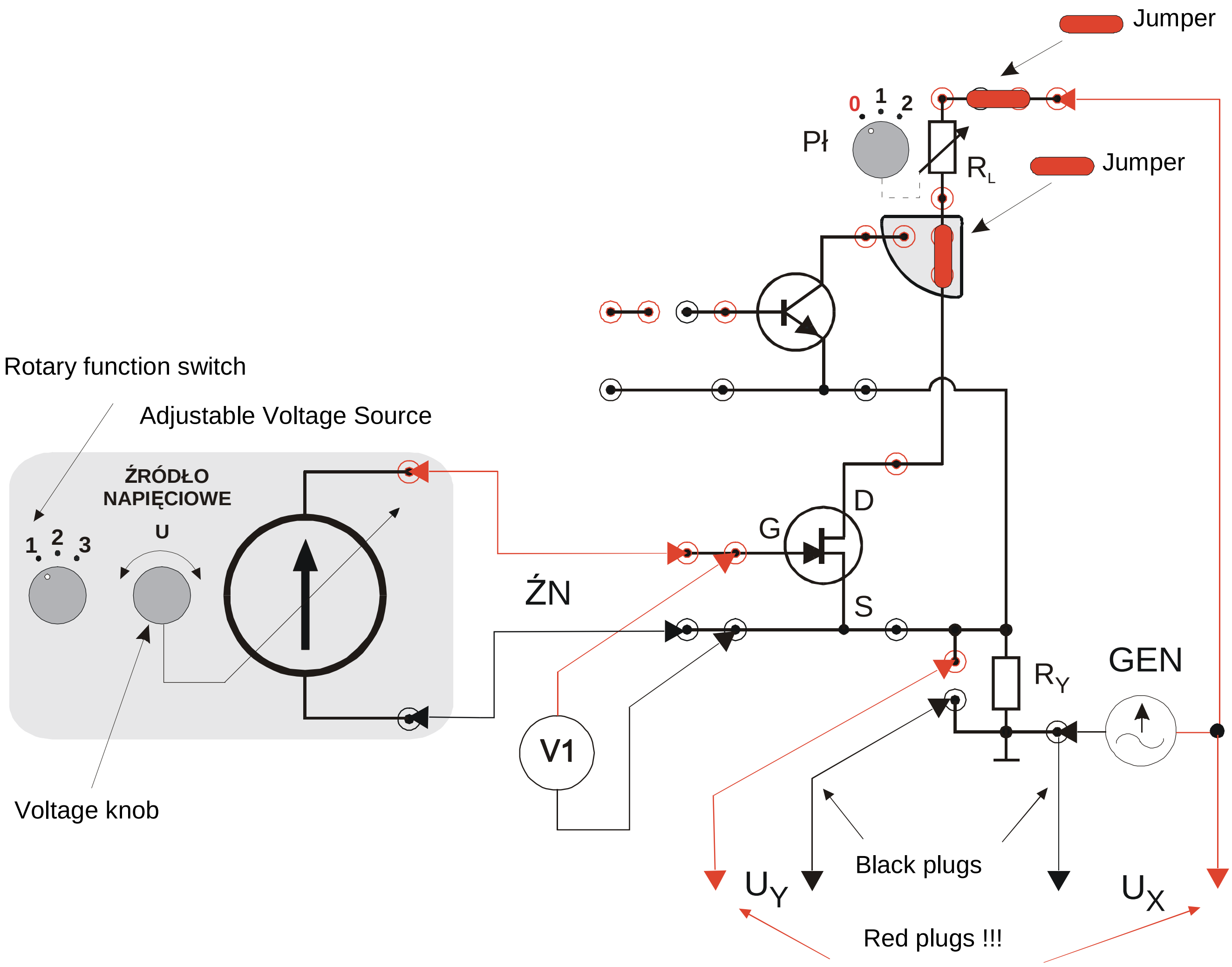

Fig. 7. Diagram of connections for FET dynamic output characteristics.

Calculations and presentation of results

1. For bipolar junction transistor (BJT):

   a) Plot the ($I_C(U_{CE})$ I_B=const) dependences,
   b) Plot the ($U_{BE}(U_{CE})$ I_B=const) dependences,
   c) Plot the ($U_{BE}(I_B)$ U_{CE}=const) dependences,
   d) Plot the ($I_C(I_B)$ U_{CE}=const) dependences.

2. According to the h-parameter model of bipolar junction transistor for a common emitter circuit:

$$U_{BE} = \left(\frac{\partial U_{BE}}{\partial I_B}\right)_{U_{CE}=const} \bullet I_B + \left(\frac{\partial U_{BE}}{\partial U_{CE}}\right)_{I_B=const} \bullet U_{CE} \,,$$
$$I_C = \left(\frac{\partial I_C}{\partial I_B}\right)_{U_{CE}=const} \bullet I_B + \left(\frac{\partial I_C}{\partial U_{CE}}\right)_{I_B=const} \bullet U_{CE} \,,$$

where the first partial derivatives of relevant functions define:

a) input resistance: $$h_{11e} = \left(\frac{\partial U_{BE}}{\partial I_B}\right)_{U_{CE}=const}$$

(varies from 100 Ω to 5 kΩ)

b) DC transfer voltage gain: $$h_{12e} = \left(\frac{\partial U_{BE}}{\partial U_{CE}}\right)_{I_B=const}$$

(varies from 0.01 to 0.0001)

c) DC current gain: $$h_{21e} = \left(\frac{\partial I_C}{\partial I_B}\right)_{U_{CE}=const}$$

(varies from 30 to 300)

d) output conductance: $$h_{22e} = \left(\frac{\partial I_C}{\partial U_{CE}}\right)_{I_B=const}$$

(varies from 10^{-6} S to 10^{-4} S)(S – siemens).

Hence, the voltage U_{BE} and current I_C can be describe as:

$$U_{BE} = h_{11e} \cdot I_B + h_{12e} \cdot U_{CE} \,,$$
$$I_C = h_{21e} \cdot I_B + h_{22e} \cdot U_{CE} \,.$$

To obtain the h-parameters the relevant partial derivatives should be calculated and characteristics of BJT can be applied for this. The merged all static characteristics are shown in Fig. 8. The yellow areas show the data ranges for calculations.

For BJT under investigation:

A.) plot the merged static characteristic,

B.) calculate from the linear regression method coefficients:
   a. input resistance,
   b. DC voltage transfer gain,
   c. DC current gain,
   d. output conductance.

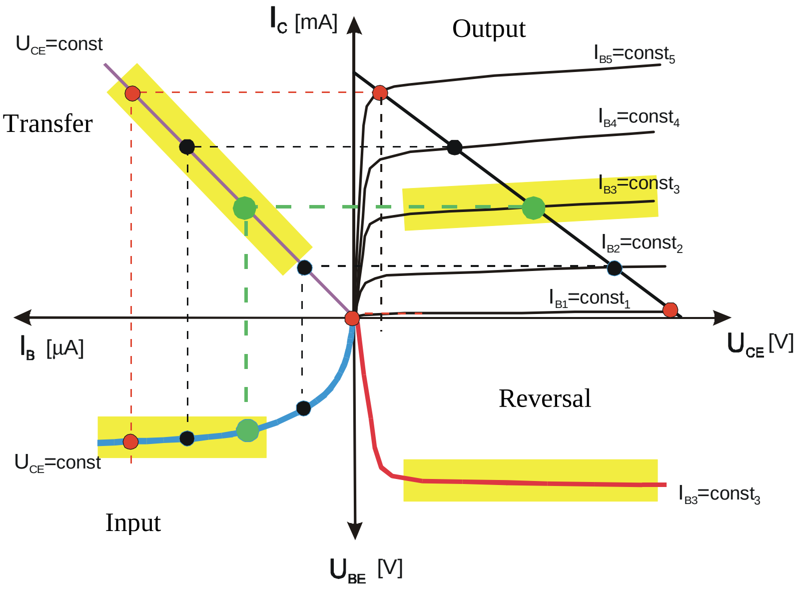

Fig. 8. Example of merged characteristic of BJT in common emitter circuit.

3. For Field-Effect Transistor (FET):

   a) Plot the ($I_D(U_{GS})$ U_{DS}=const) dependences,
   b) Show the value of $U_{GS\ OFF}$.
   c) Plot the ($I_D(U_{DS})$ U_{GS}=const) dependences,
   d) Plot the merged characteristic.

4. Discuss the obtained results for BJTs and FETs.

References

[1] R. Śledziewski, *Elektronika dla Fizyków*, PWN, Warszawa, 1984.
[2] K. Bracławski. Antoni Siennicki, *Elementy półprzewodnikowe*, WSiP, Warszawa, 1986.
[3] A. Rusek, *Podstawy Elektroniki* – tom I i II, WSiP, Warszawa, 1984.
[4] A. Sukiennicki, Alfred Zagórski, *Fizyka ciała stałego*, WNT, Warszawa, 1984.
[5] J. Rydzewski, *Pomiary oscyloskopowe*, WNT, Warszawa, 1994.