

Laboratory Exercise 2

DC characteristics of Bipolar Junction Transistors (BJT)

The aim of the exercise

The main aim of this laboratory exercise is to understand principles of operation of Bipolar Junction Transistors (BJT). It covers the measurements of static and small signal parameters.

Backgrounds

Physical structure of the BJT

BJT is a semiconductor device having a three-layer structure with three external electrodes, the emitter (E), the base (B), and the collector (C). As shown in Fig. 1, the structure may be p-n-p or n-p-n type. Despite of the transistor type the emitter layer has always more acceptor or donor impurities added than the base or the collector layer. This asymmetry results from different roles the emitter and the collector layers play in the BJT. In normal operation of the BJT (as an amplifier), the base-emitter junction is forward biased and the base-collector junction is reverse biased. Transistor amplification is controlled by changing the current flow through the base-emitter junction.

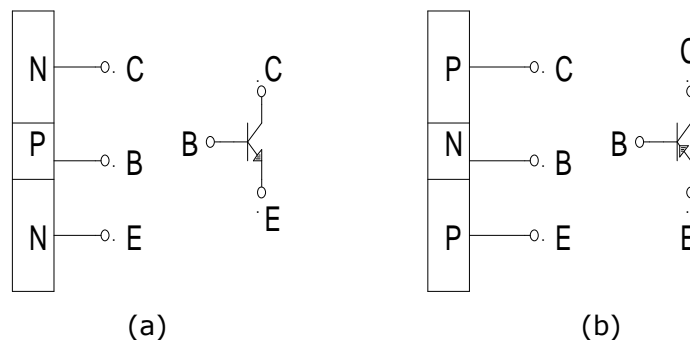


Fig. 1. The n-p-n BJT (a) and the p-n-p BJT (b) along with their symbols

There are three operating configurations of the BJT. These are the common-emitter (OE) configuration, the common-base configuration (OB), and the common-collector (OC) configuration. These configurations are shown in Fig. 2.

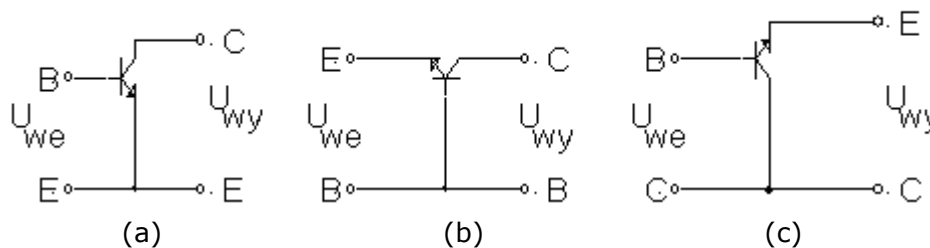


Fig. 2 The n-p-n transistor operating configurations:
(a) common-emitter, (b) common-base, (c) common-collector

DC characteristics

Four types of characteristics can be defined for each of the transistor operating configurations. These characteristics define relationships among DC currents and DC voltages at the transistor input and output:

- input characteristics $U_{IN}(I_{IN})$ for $U_{OUT} = \text{const.}$
- forward current gain characteristics $I_{OUT}(I_{IN})$ for $U_{OUT} = \text{const.}$
- reverse voltage gain characteristics $U_{IN}(U_{OUT})$ for $I_{IN} = \text{const.}$
- output characteristics $I_{OUT}(U_{OUT})$ for $I_{IN} = \text{const.}$

Typical BJT characteristics for the common-emitter configuration are illustrated in Fig. 3.

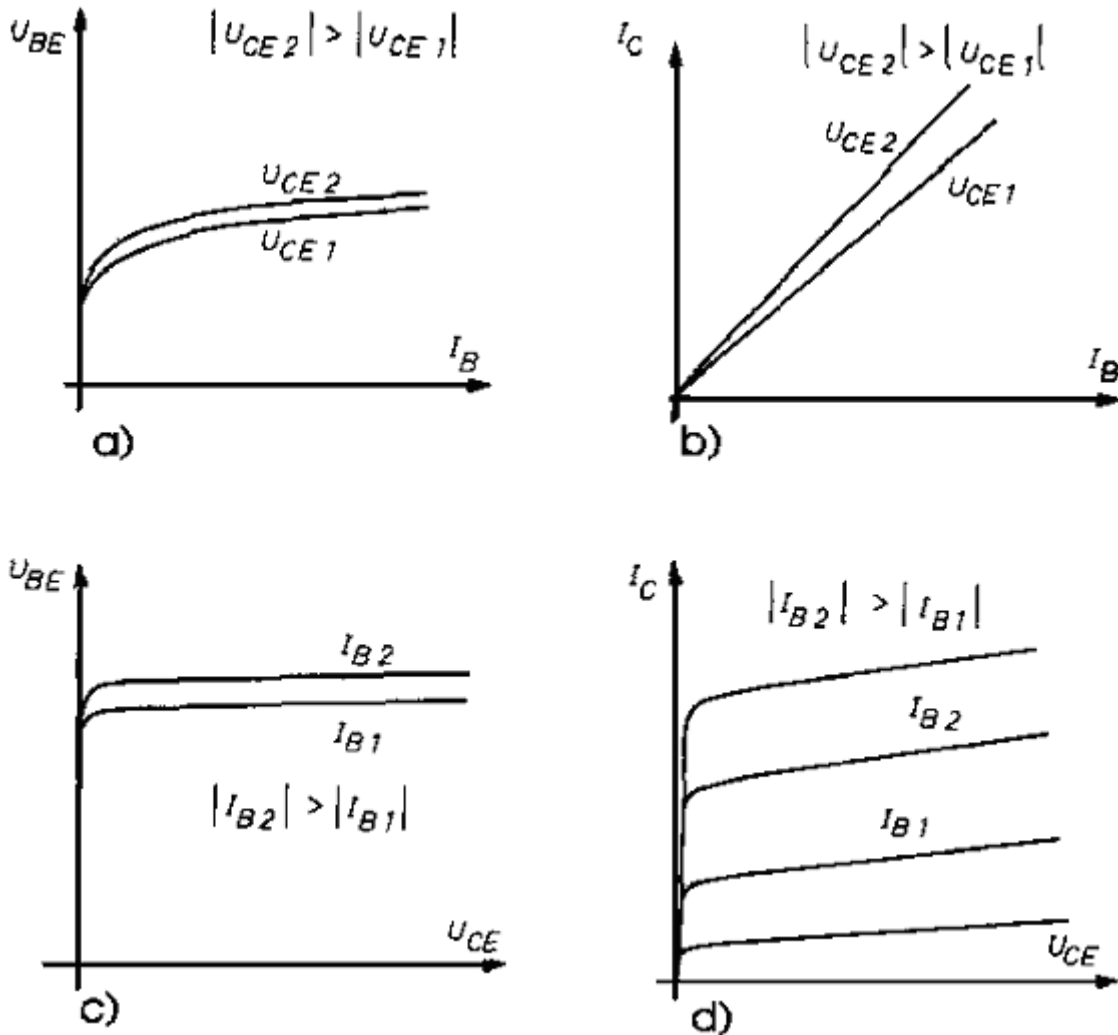


Fig. 3. BJT common-emitter configuration characteristics: (a) input characteristic, (b) forward current gain characteristic, (c) reverse voltage gain characteristic, (d) output characteristic

In practice the most important transistor characteristic is the output characteristic which is used to determine the transistor operating regions with respect to the defined operating point (see Fig. 4). These regions are as follows:

- **cut-off region** - the region lying below the $I_B = 0$ curve; in this region, both transistor junctions are reverse biased,
- **saturation region** - which corresponds to the high slope fragments of the transistor output characteristics; in this region both transistor junctions are forward biased,
- **active region** - lying between the saturation and the cut-off regions corresponding to the flat fragments of the output characteristics; in this region the base-emitter junction is forward biased and the base-collector junction is reverse biased,

Moreover:

- **safe operating region/area (SOA)** - this is the fragment of the three above regions bounded by the maximum collector current, the maximum collector-emitter voltage and the power dissipation curve (hyperbola).

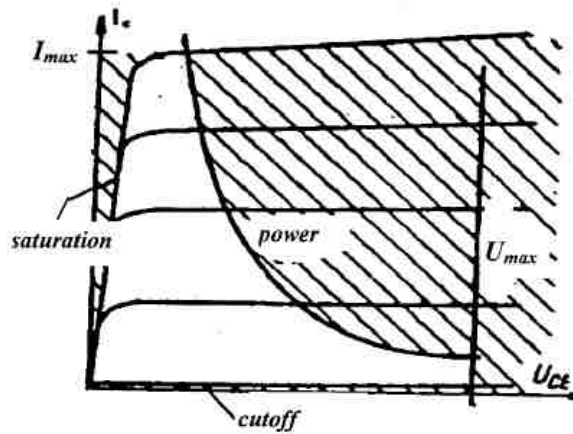


Fig.4. Transistor output characteristics with different operating regions

Small signal parameters – BJT hybrid model

If the transistor input signal is a low frequency small amplitude signal the BJT can be modelled as a linear two-port device. Equations describing such a device can be written in the form:

$$u_1 = h_{11}i_1 + h_{12}u_2$$

$$i_2 = h_{21}i_1 + h_{22}u_2$$

where subscripts 1 and 2 denote earlier used subscripts "in" and "out" respectively. Parameters of the above equations are real numbers and represent slope angles of the tangents to the relevant transistor characteristics for the given operating point. The parameters can be computed in the following way:

$$h_{11} = \left. \frac{\partial U_1}{\partial I_1} \right|_{U_2 = \text{const.}}$$

h_{11} corresponds to the slope of the input characteristic,

$$h_{12} = \left. \frac{\partial U_1}{\partial U_2} \right|_{I_1 = \text{const.}}$$

h_{12} corresponds to the slope of the reverse voltage gain characteristic,

$$h_{21} = \left. \frac{\partial I_2}{\partial I_1} \right|_{U_2 = \text{const.}}$$

h_{21} corresponds to the slope of the forward current gain characteristic,

$$h_{22} = \left. \frac{\partial I_2}{\partial U_2} \right|_{I_1 = \text{const.}}$$

h_{22} corresponds to the slope of the output characteristic.

In engineering practice the h-parameters are calculated not from the differential expressions but are approximated by relevant difference expressions. On the basis of the hybrid parameters an equivalent transistor circuit can be constructed and the transistor small-signal model can be created. The BJT equivalent circuit is shown in Fig. 5. It allows to interpret each of the model parameters in a physical manner:

- h_{11} - input impedance if the output is short-circuited,
- h_{12} - reverse voltage gain if the input is open-circuited,
- h_{21} - short-circuit forward current gain,
- h_{22} - output impedance if the input is open-circuited.

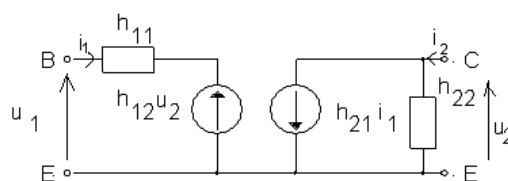


Fig. 5. Equivalent circuit for the transistor corresponding to the hybrid model

Switching

Each junction has two capacities: C_j (the junction capacitance) and C_d (the diffusive capacitance). Fig. 6 shows the equivalent circuit of BJT for the dynamic states.

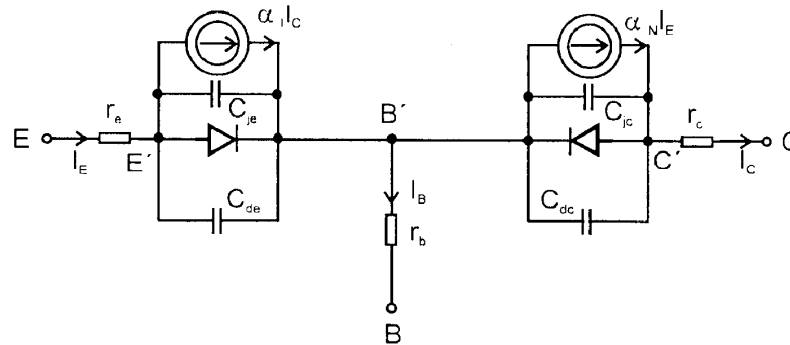


Fig. 6. The equivalent circuit for dynamic states

The transistors are applied in switching circuits as the controlled keys. Such a basic key is introduced in Fig. 7. In this circuit, the change of base current causes movement of the operating point along the load line plotted on the output characteristics (see Fig. 7). In point P1, the transistor is in the cut-off region and both its junctions are reversely biased. Between point P1 and P2, the transistor is in active region and base-emitter junction is forward biased and base-collector junction is reverse biased. In point P2, the transistor is in saturation region and both its junctions are forward biased.

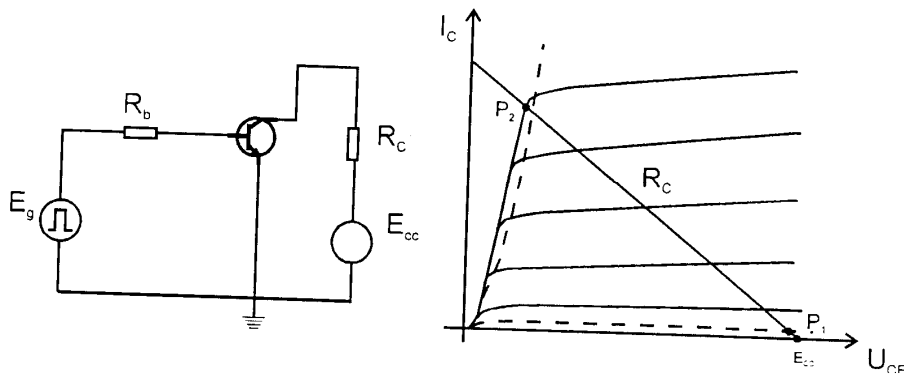


Fig. 7. Basic key circuit and the output characteristics with the load line

The transistor switching depends on transistor parameters and the circuit in which the transistor is being switched. The changes of voltages and currents during BJT switching are presented in Fig. 8. The switching on starts when the voltage E_g changes its value from $-E_R$ to E_F . It consists of two stages. The time when the junction capacity E-B reloads is called „delay time" t_d . This time covers also the time that is necessary for the injected through the emitter junction carriers to pass the base region and enter the collector junction. In this moment the „rise time" begins t_r . Switching on is completed when the voltage reaches the constant value. The switching on time: $t_{ON} = t_d + t_r$.

The switching off starts when the voltage E_g changes its value from E_F to $-E_R$. It consists of two stages. During the first stage that lasts for t_s - "store time", both diffusion capacitances are discharged. The second stage lasts for t_f - "fall time" and is required for base-collector junction capacitance to be reloaded. Then, this junction can take all the voltage. The switching off time is $t_{OFF} = t_s + t_f$.

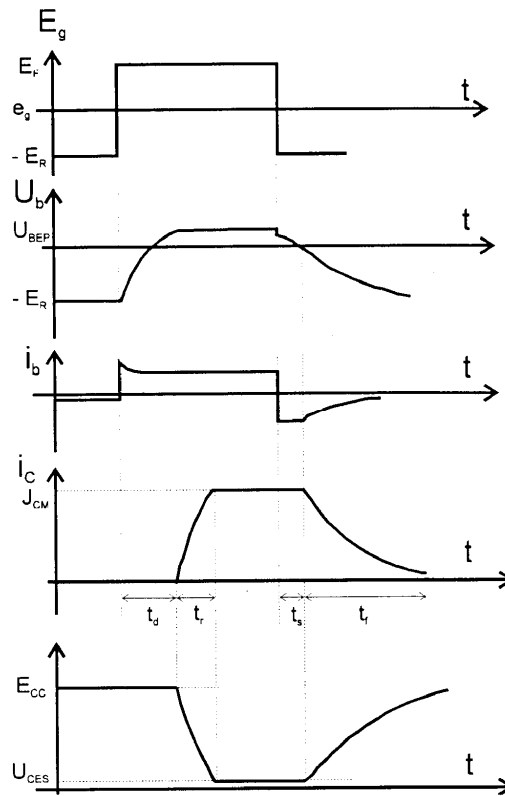


Fig. 8. Switching – changes of voltages and currents

The scope of the exercise

The exercise covers measurements of the small-power n-p-n type transistor - BC 107.

- Take the static characteristics of BJT operating in common-emitter configuration.
- Perform the small signal parameter measurements of BJT operating in common-emitter configuration.
- Examine the pulse response of BJT

Exercise

Measurements of transistor DC characteristics

For the analysed transistor, measure four characteristics with the aid of measurement circuit shown in Fig. 9, each for listed values of the respective parameters. **Consult the values with the instructor.**

Output $I_C = f(U_{CE})$ for $I_B = 10, 20, 30, 40, 50$ and $60 \mu A$,

Input $U_{BE} = f(I_B)$ for $U_{CE} = 2$ and $10 V$,

Forward current gain $I_C = f(I_B)$ for $U_{CE} = 2$ and $10 V$,

Reverse voltage gain $U_{BE} = f(U_{CE})$ for $I_B = 10$ and $60 \mu A$,

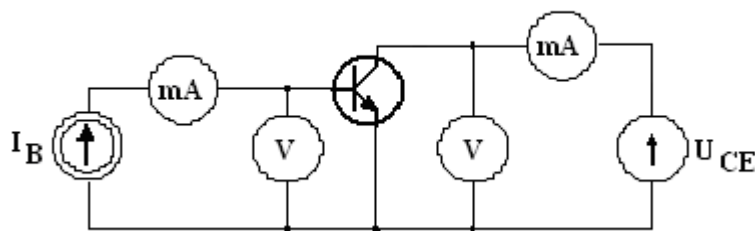


Fig.9. Scheme of measurement circuit for BJT DC characteristics

Small signal parameters – hybrid model

Make the measurements of small-signal characteristics $h_{11e}(I_C)$, $h_{21e}(I_C)$, $h_{12e}(I_C)$, $h_{22e}(I_C)$ for BJT in CE configuration. The collector current should vary in the range 0-50mA

for $U_{CE} = 2V$ (REMARK: for exact values and limitations ask the class instructor).The circuit diagrams are shown in Fig. 10 a, b.

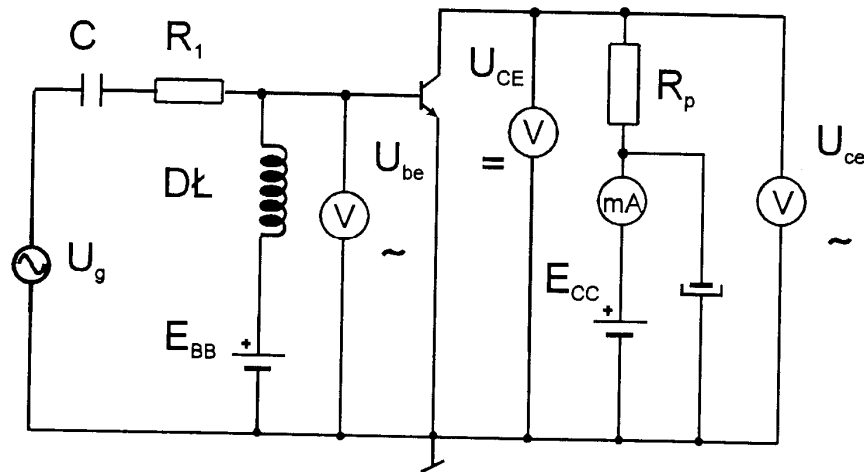


Fig. 10a. The circuit diagram for h_{11e} and h_{21e} characteristics

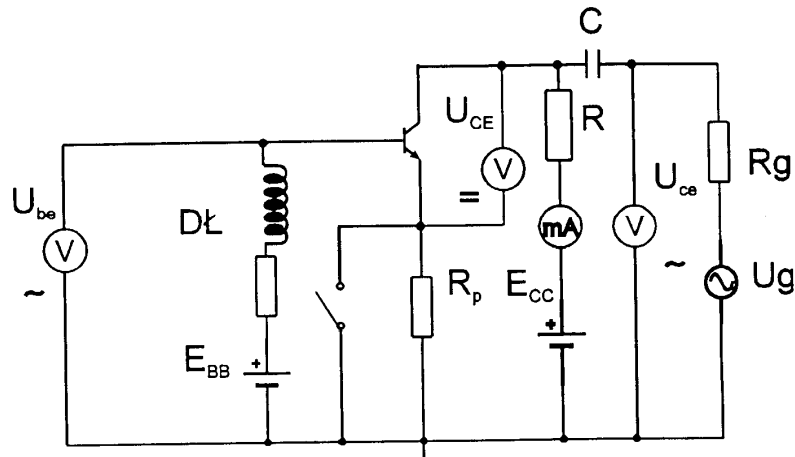


Fig. 10b. The circuit diagram for h_{12e} and h_{22e} characteristics

NOTE: The resistor R_p is used for measurement and evaluation of h_{22e} parameter

The parameters should be calculated with the aid of following formulas:

$$h_{11e} = R_1 \frac{U_{be}}{U_g} \qquad h_{21e} = \frac{R_1 U_{ce}}{R_p U_g}$$

$$h_{12e} = \frac{U_{be}}{U_{ce}} \qquad h_{22e} = \frac{1}{R_p} \frac{U_g}{|U_{ce} - U_g|}$$

BJT Switching

Find the pulse response of the BJT. Evaluate switching on and off times with respect to:

- resistance R_B for the settled amplitude of the generator signal and E_{CC} voltage
- resistance R_C for the settled amplitude of the generator signal and E_{CC} voltage
- capacitance C for the settled resistance R_C , amplitude of the generator signal and E_{CC} voltage

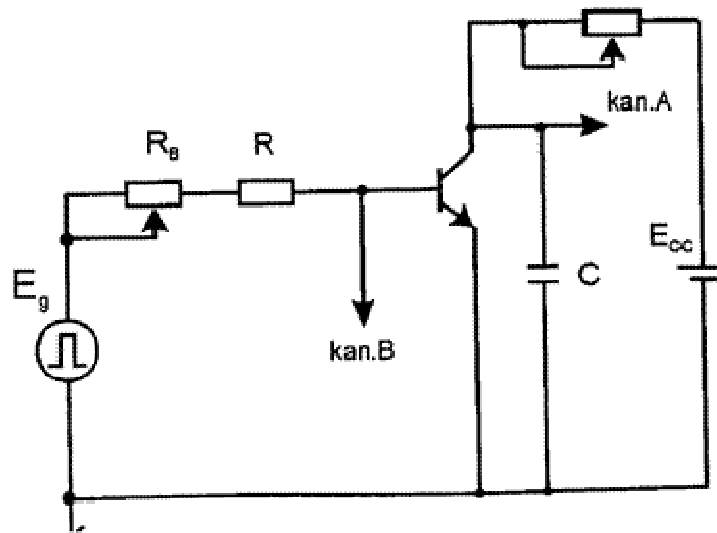


Fig.14. The circuit diagram for pulse response of BJT

Report

The report from the laboratory exercise should contain:

- DC Characteristics of the tested transistor (REMARK: gather the characteristic on one graph).
- Determine hybrid parameters for a chosen operating point.
- For the tested transistor, plot its characteristics and then plot straight lines corresponding to transistor hybrid parameters (calculated in the previous point),
- Characteristics of h parameters versus collector current.
- Switching characteristics of tested transistor (switching times t_d , t_r , t_s and t_f should be gathered in the table).
- Remarks, observations and conclusions.

References:

- [1] Z.Lisik, Podstawy fizyki półprzewodników, PŁ, 1994 (in polish)
- [2] J.Baranowski, Półprzewodnikowe układy impulsowe i cyfrowe, WNT 1976 (in polish)
- [3] B.V. Zeghbroeck, Principles of Semiconductor Devices, 2011,
<http://ecee.colorado.edu/~bart/book/book/contents.htm> [access 10.2014]