FUNDAMENTALS OF ELECTRONICS

Department of Robotics and Mechatronics

Faculty of Mechanical Engineering and Robotics

AGH University of Science and Technology

Common Emitter Amplifier

LAB 9
LAB 10

TABLE OF CONTENTS

1. BIPOLAR TRANSISTOR 2
2. COMMON EMITTER AMPLIFIER 4
   2.1 Basic information 4
   2.2 Working of transistors amplifier 4
   2.3 The common emitter amplifier circuit 6
   2.4 Determining the optimal operating point 8
   2.5 The others transistor biasing method 11
3. REFERENCES 12

FUNDAMENTALS OF ELECTRONICS

1. BIPOLAR TRANSISTOR

Fig. 1 shows a typical circuit with a bipolar transistor. The load modeled as R_L is connected between the supply voltage (e.g. $12V_{DC}$) and the collector of the transistor.

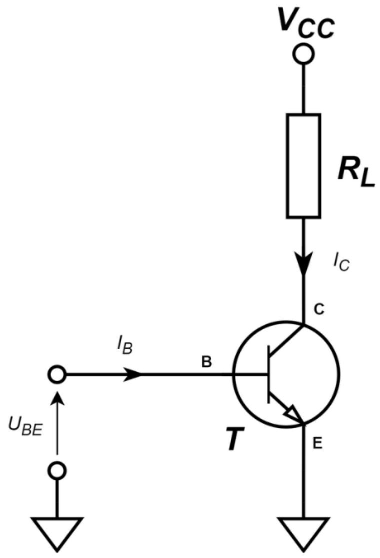


Fig. 1: A typical circuit with a NPN bipolar transistor

Assuming the circuit as shown in Fig. 1, the bipolar transistor can operate in three region depending on the value of the voltage U_{BE} and the load impedance (we assume that the voltage V_{CC} is positive and much greater than 0.7 V):

cut-off region (U_{BE} < 0.5 V) – there is no current from the collector to the emitter, thus the transistors act like a opened (non-conductive) switch; the equivalent circuit for this situation is shown in Fig. 2a;

active region (**U_{BE} > 0.5 V, $I_C = \beta \cdot I_B$)** – small working range, in this case the collector current is linearly related to the base current; the transistor "controls its resistance" to maintain a proportional current between the base and collector currents; the transistor, which operates in this region is used for signals amplification; the equivalent circuit for this situation is shown in Fig. 2b; the current gain factor is denoted as:

$$\beta = \frac{I_C}{I_B}$$

saturation region (**U_{BE} > 0.5 V; $\beta \cdot I_B > I_{C(SAT)}$)** – in this condition, the transistor is in saturation and the collector current becomes independent of the base current; the transistor is unable to reduce its channel resistance to flow to maintain collector current proportional to the base current; there is only a small UCE voltage drop about 0.6 V (like a diode in the forward-bias); the transistors act like a closed (conductive) switch; collector current depends only on external factors (load resistance/impedance); the equivalent circuit for this situation is shown in Fig. 2c.

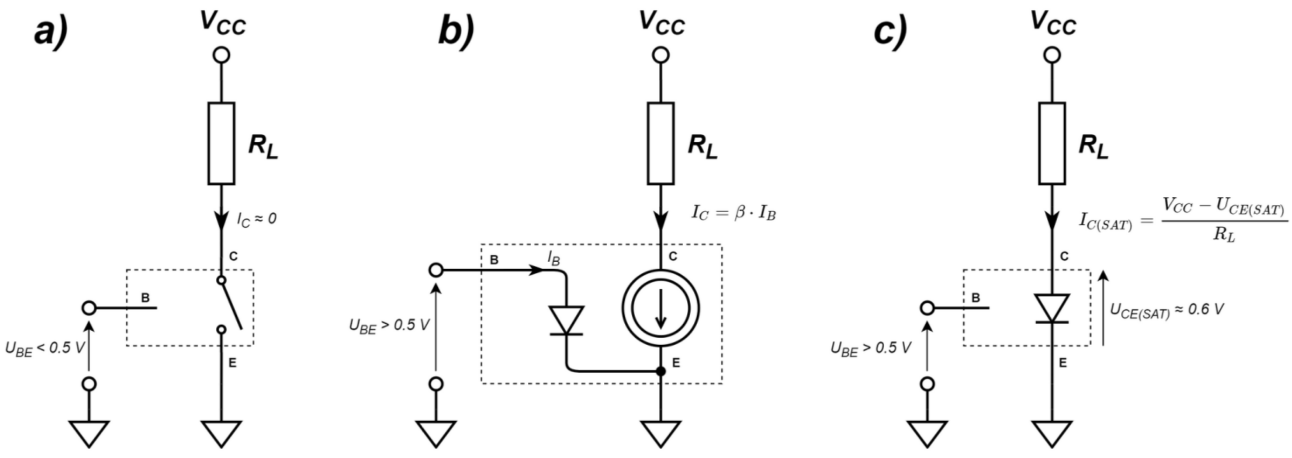


Fig. 2: Equivalent circuit of a transistor working in:
a) cut-off region; b) active region; c) saturation region

Consequently, the transistor is used in two operating modes:

- as a switch (relay) - is toggled between cut-off and saturation region - in this case transistor allows to turn on and off (e.g.: diode, light bulb, DC motor);
- as an amplifier - in this case transistor is in the active region and is able to amplify the input signal (voltage and/or current);

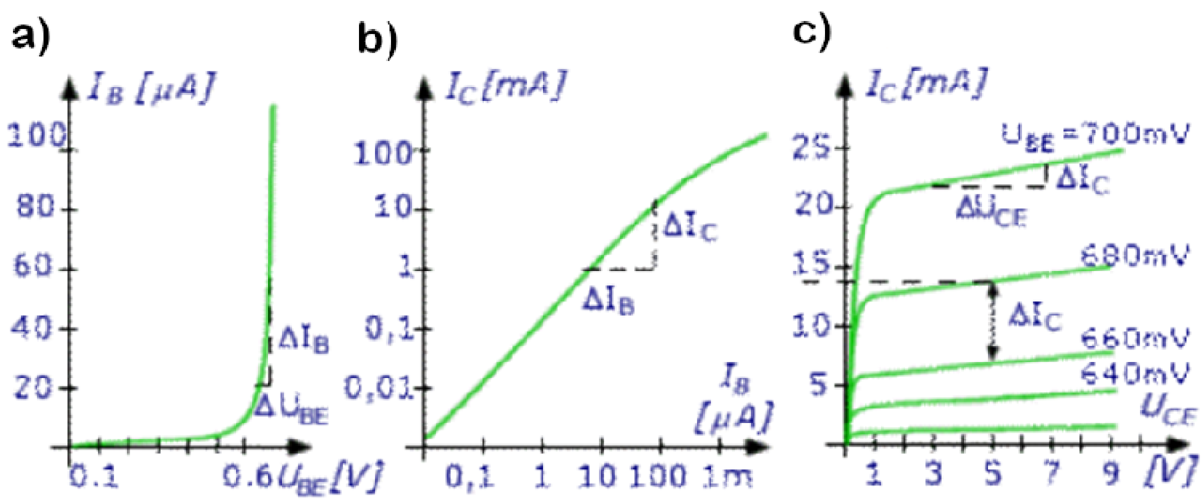


Fig. 3: Characteristics of an NPN bipolar transistor:
a) input characteristic; b) transfer characteristic; c) output characteristic.

2. COMMON EMITTER AMPLIFIER

2.1 Basic information

The amplifier in common emitter mode allows for voltage signal amplification (the amplitude of the output voltage is greater than the amplitude of the input voltage - factor k = gain). The CE amplifier has a lower and upper cut-off frequency. Therefore it does not amplify (efficiently) the signal below the lower cut-off frequency and above the upper cut-off frequency. Between this two frequencies, the gain of the amplifier is (approximately) constant. The amplifier in the CE configuration is most often used as one of the stages in acoustic amplifiers and radio-communication circuits.

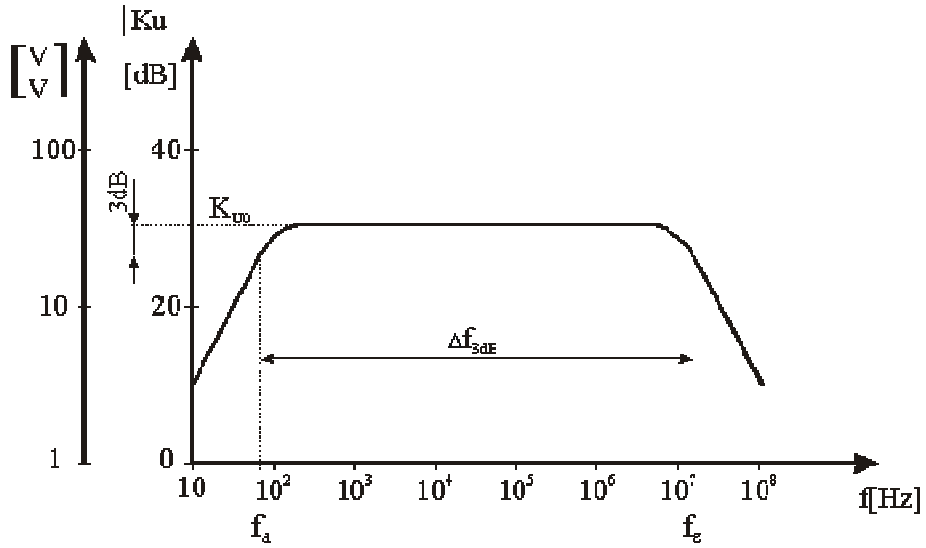


Fig. 4: Amplitude-frequency characteristics of the amplifier in CE configuration

2.2 Working of transistors amplifier

After turn on the supply voltage, the transistor becomes polarized assuming the static operating point marked in Fig. 5 as Q. The AC signal applied to the input of the amplifier is added to the static voltage (DC offset) determined by the initial bias of the transistor base. Thus, the voltage U_{BE} alternates around the point Q, which is the static operating point of the transistor amplifier. Changing this voltage causes the base current to change according to the input characteristics $I_B = f(U_{BE})$. The alternating signal should be small enough to assume that the amplifier works on the linear section of the characteristic. The base current fluctuates around the I_{BQ} value. Next, base current changes cause collector current changes witch gain β (transfer characteristic $I_C = f(I_B)$). Collector current changes cause proportional voltage changes on the R_C resistor (resistor between supply and transistor's collector). Voltage changes U_{CE} have a greater amplitude (k - gain) than the input voltage U_{BE}, which means that the signal voltage amplification has occurred ($k = U_{OUT}/U_{IN}$).

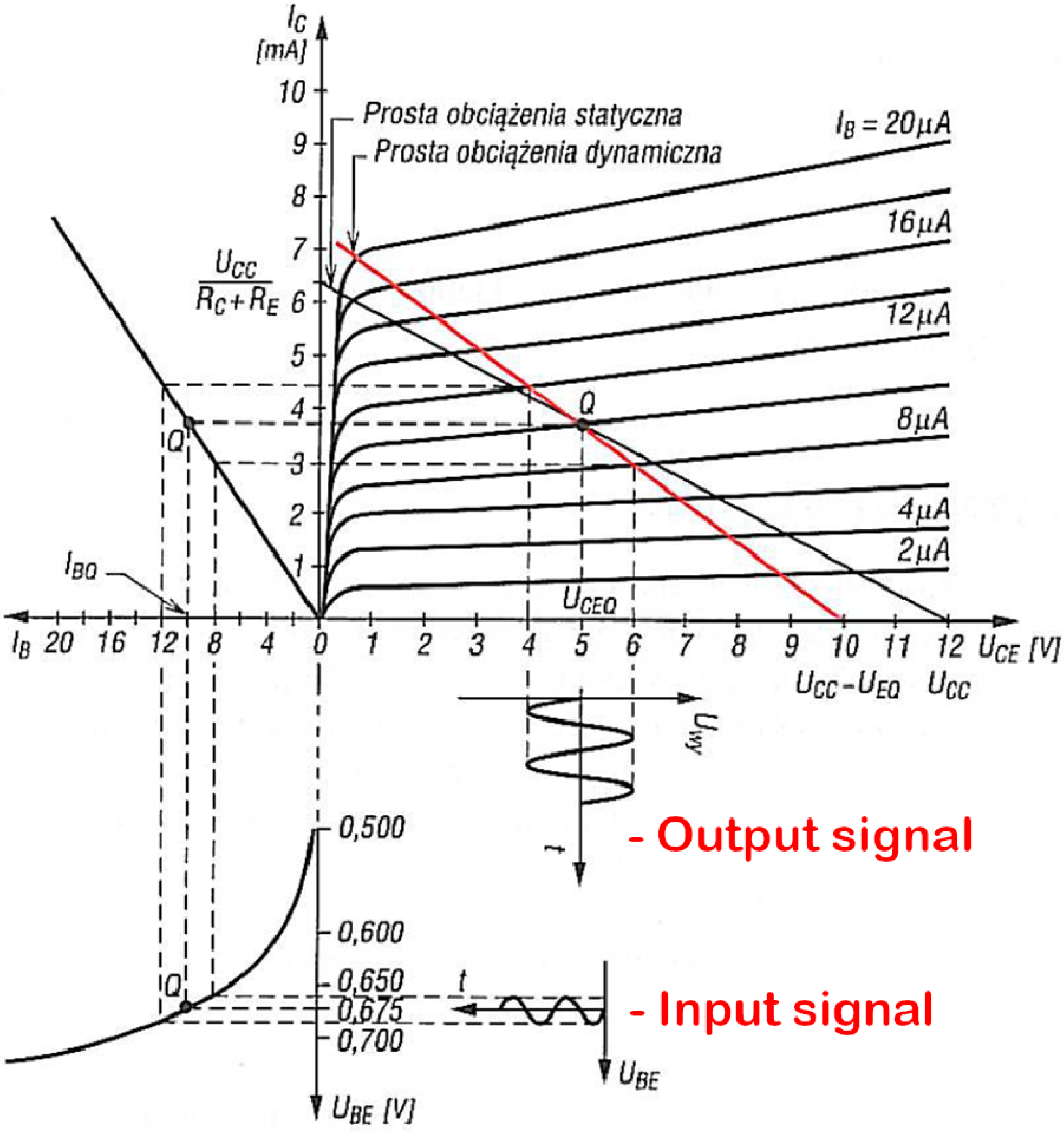


Fig. 5: Working of transistors amplifier [4]

2.3 The common emitter amplifier circuit

Fig. 6 shows the common emitter amplifier in the most common version of the transistor base bias – voltage divider bias. The transistor works as an amplifier (in the active region), when the U_{BE} voltage is about 0.6 V. It should be ensured that such a value of the constant voltage offset appears on the transistor's base.

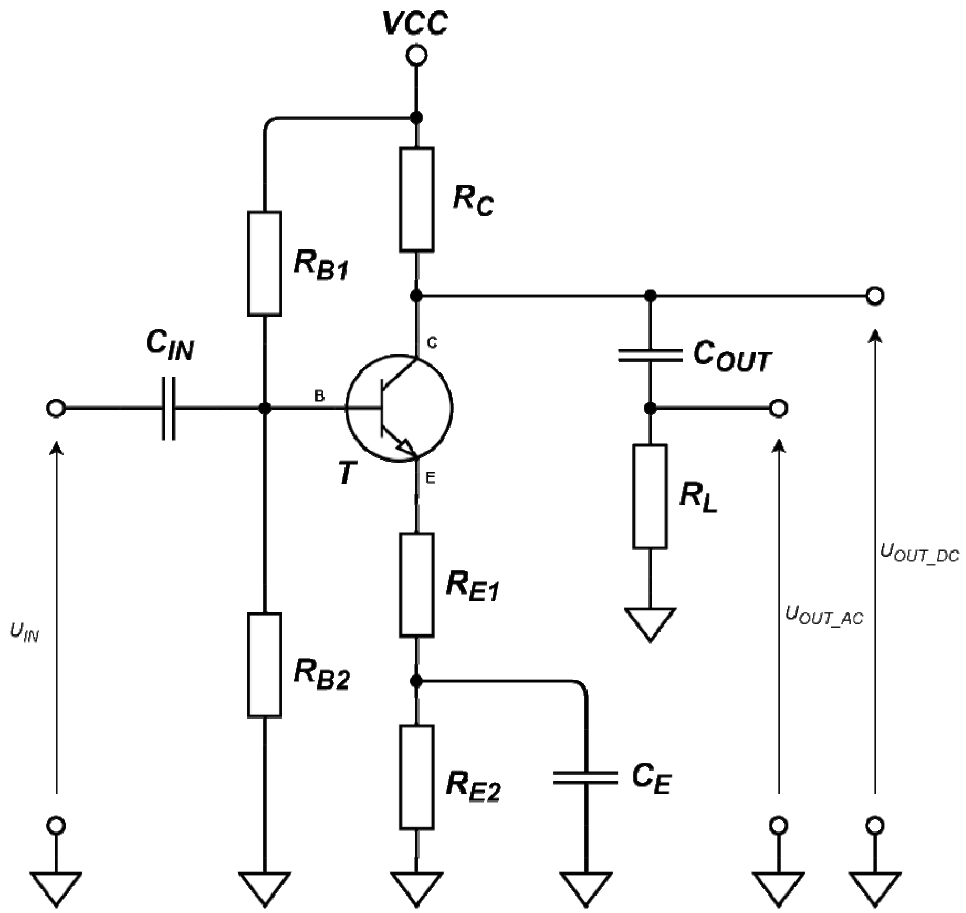


Fig. 6: The common emitter amplifier circuit

In Common Emitter Amplifier circuits, capacitors C_{IN}, C_E and C_{OUT} are used as coupling capacitors to separate the AC signals from the DC biasing voltage. This ensures that the bias condition set up for the circuit to operate correctly is not affected by any additional amplifier stages, as the capacitors will only pass AC signals and block any DC component. The output AC signal is then superimposed on the biasing of the following stages. Their capacitance should be chosen so that for the frequency of the signals amplified by the system, their impedances are close to zero.

The components of the amplifier and their functions are described below.

T – bipolar NPN transistor. It is an active element that has the feature of a linear relationship between the collector and the base current. For small changes the u_{BE} voltage around the operating point, it can be assumed that the relationship $i_C = f(u_{BE})$ is linear. This approximation is the basis of use a transistor for linear amplification of electrical signals. The transistor must have a properly set operating point. The operating point of the bipolar transistor is understood as the values of base current and collector-emitter voltage in a static state.

R_{B1}, R_{B2} - resistor voltage divider setting the base potential of the transistor. It is assumed that the value of the current of the resistive divider is much greater than the value of the base current of the transistor, at the set operating point. Additionally, parallel connection of the resistors with the C_{IN} capacitor create a high-pass filter for the input signal. $(R_{B1} \,||\, R_{B2})\cdot C_{IN}$.

R_{E1} + R_{E2} - emitter resistors setting the value of the emitter current of the transistor. For the assumed values: collector current I_C, base potential V_B and base-emitter voltage U_{BE}, the value of its resistance is determined from the formula:

$$R_E \approx \frac{V_B - U_{BE}}{I_C}.$$

This resistor causes negative feedback for direct current. Each small change of the base potential of the transistor, causes almost the same change of its emitter potential (because the U_{BE} voltage value changes slightly even with large changes of the base potential).

Additionally, the R_{E1} resistor allow adjustment of the gain by changing the emitter impedance for the AC component of the signal.

C_E - capacitor (usually electrolytic with high capacity value) is a "short-circuit" for the AC component of the emitter current. The high capacity causes low reactance for the AC component of the signal.

R_C - collector resistor. This resistor value have impact on the value of the voltage U_{CE} (transistor operating point), the gain of the amplifier, and the value of the upper cut-off frequency of the amplifier. Usually it is assumed that the collector resistor should be about 10 times larger than the emitter resistor.

C_{IN} – is used as coupling capacitors to separate the AC component of the input signals from the DC biasing voltage. Additionally, parallel connected resistors $(R_{B1} \,||\, R_{B2})$ with the C_{IN} capacitor create a high-pass filter for the input signal $(R_{B1} \,||\, R_{B2})\cdot C_{IN}$.

C_{OUT} – the purpose of use the capacitor is remove the constant component (the voltage offset) from the output signal. Additionally, parallel connected resistors $(R_C \,||\, R_L)$ with the C_{OUT} capacitor create a high-pass filter for the output signal $(R_C \,||\, R_L)\cdot C_{OUT}$.

R_L – load resistance value.

2.4 Determining the optimal operating point

Fig. 7 shows the AC and DC diagrams of the Common Emitter Amplifier. Principles of building a DC scheme:

- capacitors turn into gaps (the capacitor impedance at low frequencies is very high);
- coils turn into short-circuits (the coil impedance is very low for low frequencies).

Principles of building a AC scheme (circuit for AC components of the signals):

- capacitors turn into short-circuits (the capacitor impedance at high frequencies is very low);
- coils turn into gaps (the coil impedance is very high for high frequencies);
- each DC potential (e.g. supply voltage) is replaced by a common zero potential (GND).

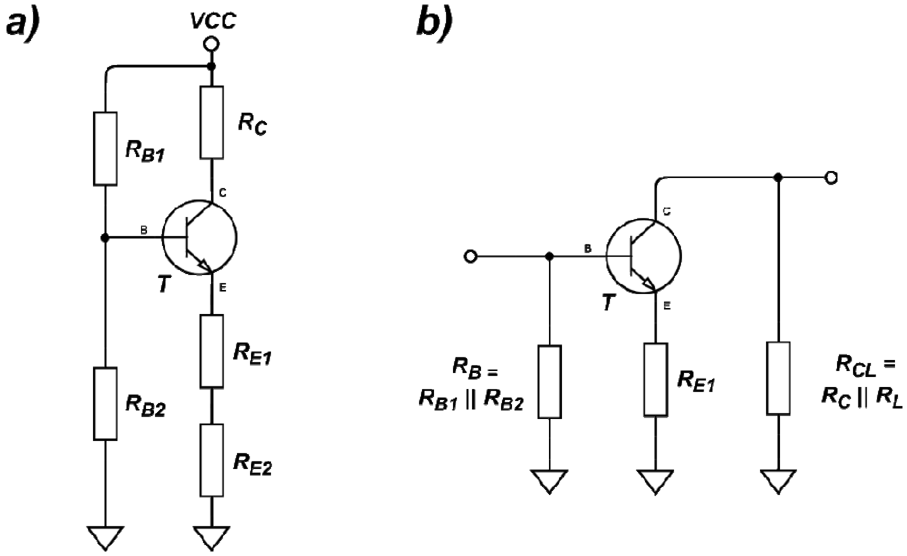


Fig. 7: Equivalent diagram:
a) DC; b) AC component of the signal.

There are instantaneous values of voltages and currents in the circuit:

$$i_C = I_{CQ} + i_c \,,$$

$$u_{CE} = U_{CEQ} + u_{ce} \,.$$

They are a superposition of constant I_{CQ}, U_{CEQ} and alternating components i_c, u_{ce}. The constant components of current and voltage are related by the relationship:

$$V_{CC} = U_{CEQ} + I_{CQ}(R_C + R_{E1} + R_{E2})$$

It is the equation of static load line in the field of the output characteristics of the transistor ($i_C = f(u_{CE})$) fig. 8 - a.

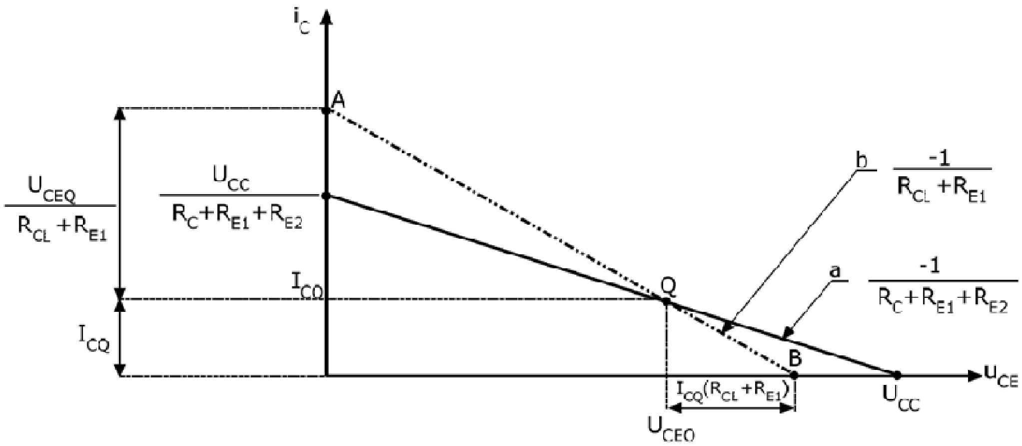


Fig. 8: Static (a) and dynamic (b) load line in the field of the output characteristic of the transistor.

The operating point Q lies at the intersection of the static load line with the output characteristic of the transistor determined by the base current I_{BQ}:

$$V_{CC}\frac{R_{B2}}{R_{B1}+R_{B2}} = I_{BQ}R_B + U_{BEQ} + I_{BQ}(\beta+1)(R_{E1}+R_{E2})\,.$$

The relationship between the variable component of the collector current and the collector-emitter voltage is described by the equation::

$$i_c = -\frac{u_{ce}}{R_{CL}+R_{E1}}\,.$$

Based on the above dependencies, we get:

$$i_C = -\frac{u_{ce}}{R_{CL}+R_{E1}} + I_{CQ} + \frac{U_{CEQ}}{R_{CL}+R_{E1}}\,.$$

It is an equation for dynamic load line in the field of the output characteristics of the transistor (fig. 8-b). The dynamic load line passes through the work point Q. Thus, the instantaneous value of the collector current i_C can maximally increase to the value (omitting the saturation area of the transistor for simplicity):

$$i_{C\,max} = i_C(u_{CE}=0) = I_{CQ} + \frac{U_{CEQ}}{R_{CL}+R_{E1}},$$

and achieve the minimum value:

$$i_{C\,min} = 0.$$

The instantaneous value of the collector potential u_C is a superposition of the constant component:

$$U_C = U_{CC} - I_{CQ}R_C\ ,$$

and the variable component:

$$u_c = -i_c R_{CL}\ .$$

Using the above dependencies, we obtain the instantaneous value of the collector potential u_C as a function of the instantaneous value of the collector current i_C:

$$u_C = U_C + u_c\ ,$$

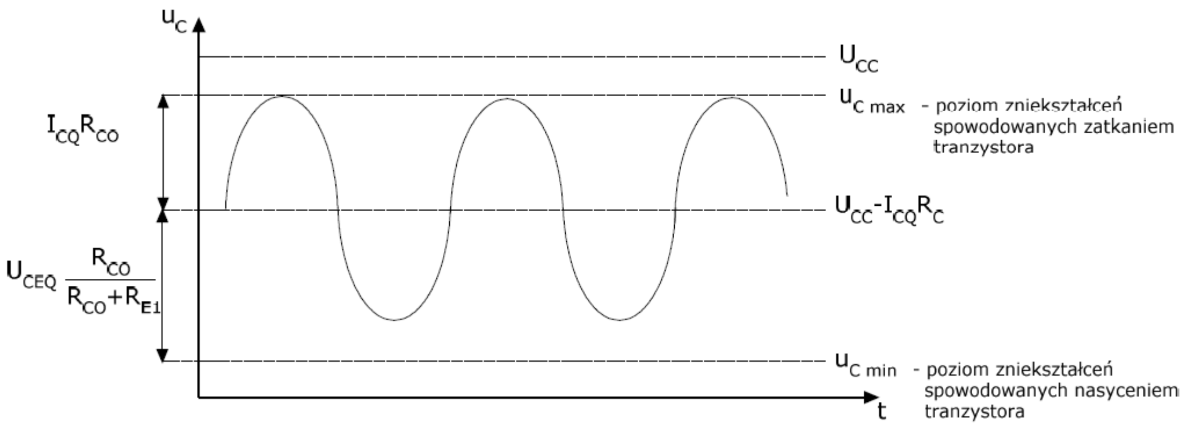
$$u_{C\,(i_C)} = V_{CC} - I_{CQ}R_C + I_{CQ}R_{CL} - i_C R_{CL}\ .$$

Maximum value:

$$u_{C\,max} = u_C(i_{C\,min}) = V_{CC} - I_{CQ}R_C + I_{CQ}R_{CL}\,,$$

and minima value:

$$u_{C\,min} = u_C(i_{C\,max}) = V_{CC} - I_{CQ}R_C - U_{CEQ}\frac{R_{CL}}{R_{CL} + R_{E1}}.$$



Thus, the operating point is optimally selected when:

$$I_{CQ}R_{CL} = U_{CEQ}\frac{R_{CL}}{R_{CL} + R_{E1}},$$

that is, when it lies in the middle of dynamic load line.

The best possible position for this Q-point is as close to the center position of the dynamic load line.

2.5 The others transistor biasing method

Fig. 9 shows other methods of biasing the transistor:

a) base bias;
b) collector feedback bias.

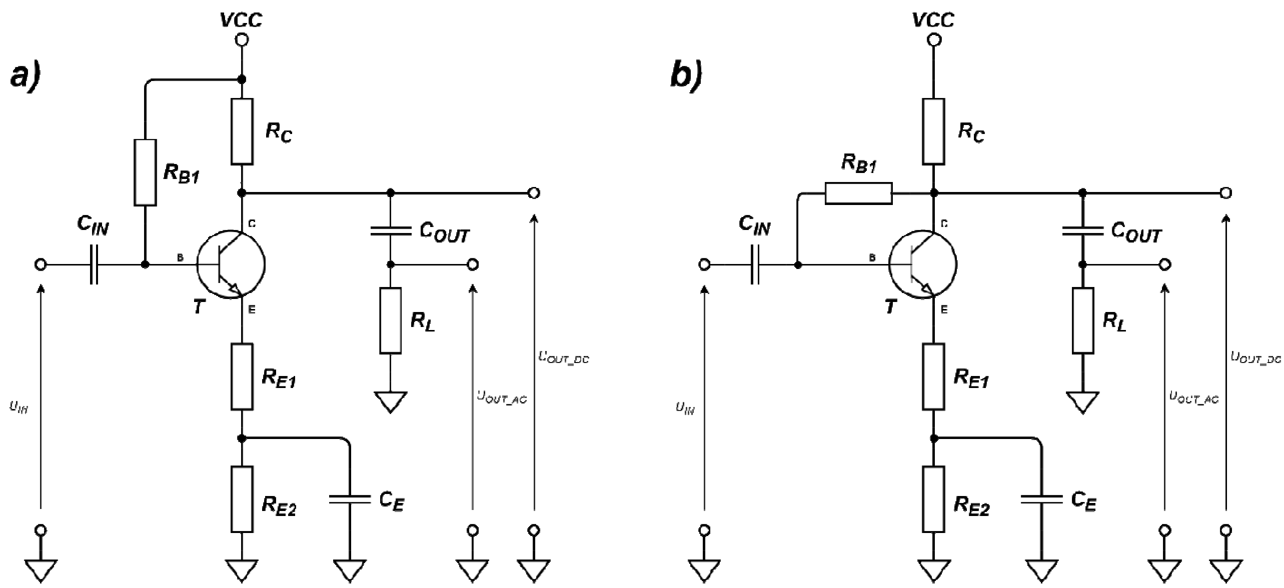


Fig. 9: Transistor biasing method:
a) base bias;
b) collector feedback bias

3. REFERENCES

[1] Laboratorium z podstawowych układów elektronicznych KL-210: Rozdział 6 – Wzmacniacze tranzystorowe

[2] https://home.agh.edu.pl/~maziarz

[3] http://www.zstio-elektronika.pl/pliki_t_elektronik/TE_Z1-01.pdf

[4] Podstawy elektroniki – część 2; Barbara Pióro, Marek Pióro.

[5] https://www.electronics-tutorials.ws/