

Versuch 4: Transistor

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1 Introduction

In this experiment we examine the properties of a bipolar transistor as a class A amplifier. To observe the properties we measured the characteristic curve of the transistor and tested different configurations of the emitter circuit.

2 Theorie

2.1 Small Signal Model

For small deviations around the operating point one can use the small signal model leading to the following equation.

$$\begin{pmatrix} dI_B \\ dI_C \end{pmatrix} = \begin{pmatrix} \frac{1}{r_{BE}} & S_r \\ S & \frac{1}{r_{CE}} \end{pmatrix} \begin{pmatrix} dU_{BE} \\ dU_{CE} \end{pmatrix} \quad (1)$$

whereby r_{BE} , r_{CE} and the steepness S can be calculated with

$$\frac{1}{r_{BE}} = \left. \frac{\partial I_B}{\partial U_{BE}} \right|_{U_{CE}} \quad (2)$$

$$\frac{1}{r_{CE}} = \left. \frac{\partial I_C}{\partial U_{CE}} \right|_{U_{BE}} \quad (3)$$

$$S = \left. \frac{\partial I_C}{\partial U_{BE}} \right|_{U_{CE}} = \frac{qI_C}{k_B T} \quad (4)$$

In addition to that I_B can be calculated the following proportionality

$$I_B \propto \exp\left(\frac{qU_{BE}}{k_B T}\right) \quad (5)$$

2.2 Emitter Circuit

An emitter circuit converts an input signal to an amplified output signal. The amplification of the output signal compared to the input signal can be given by

$$A = \frac{dU_a}{dU_e} = -S \cdot (R_C \parallel r_{CE} \parallel R_L) \quad (6)$$

and

$$A \approx -\frac{R_C \parallel R_L}{R_E} \quad (7)$$

if the amplification is in the range of basevoltage drift.

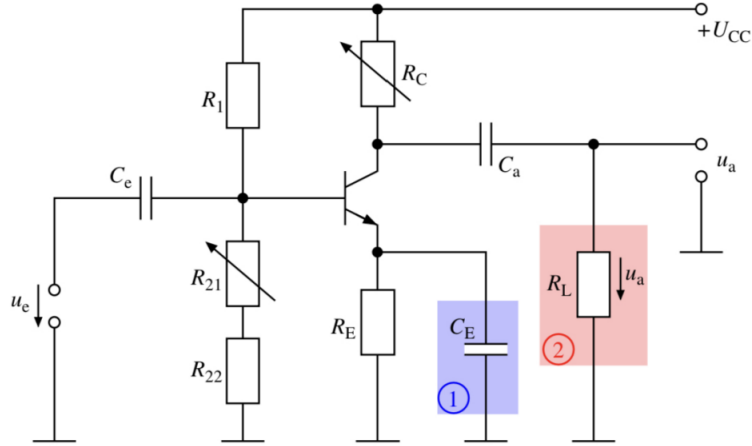


Figure 1: emittercircuit:

$R_1 = 47 \text{ k}\Omega$, $R_{22} = 100 \text{ }\Omega$, $R_E = 10 \text{ k}\Omega$, $C_e = 47 \text{ }\mu\text{F}$, $C_a = 470 \text{ }\mu\text{F}$, $U_{CC} = 9 \text{ V}$ R_{12} : potentiometer for the operating point, R_C : potentiometer 0 - 10 k Ω , u_e : inputvoltage, u_a : outputvoltage

3 Execution

3.1 Operating Point

A bipolar transistor has a specific basevoltage range (the so called operating point) in which it behaves approximately linear. This operating point is tuned by setting the resistance at the potentiometer R_{12} (see circuit diagram 1) to a point whereby the output amplitude u_a is maximal and the signal is not distorted. To tune the operating point, the load resistor R_L was removed and a sinusoidal frequency of 5.5 kHz was applied. U_{BE} , U_{CE} , I_C where measured with varying R_C for further evaluation.

3.2 Amplification of the Emittercircuit

To further examine the emitter circuit(see circuit diagram 1) the amplitude ratio u_a/u_e was measured for varying R_C in different circuit configurations: 1. with capacitor C_E but without resistor R_L 2. without capacitor C_E and without resistor R_L 3. with capacitor C_E and resistor R_L

3.3 Frequency Response

In this experiment the input frequency was varied from 6 Hz - 250 kHz to measure the phase shift and the amplitdude ratio u_a/u_e . Here circuit 1 with an collector resistor of R_C was used. In addition to that the oszilloscope was changed to x-y mode to observe lissajous curves.

3.4 Characteristic Curve

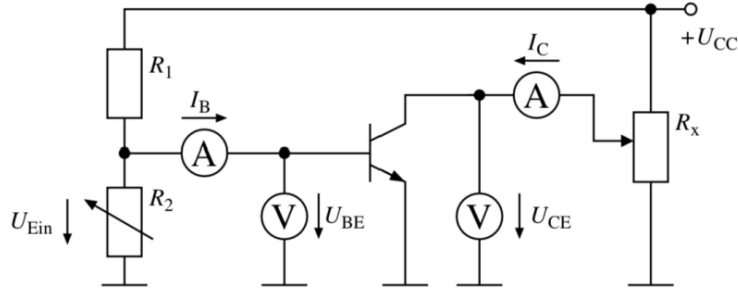


Figure 2: characteristic curve $R_1 = 1 \text{ k}\Omega$, $R_2 = 220 \text{ }\Omega$

To measure the characteristic curve of the transistor the circuit was change as shown in the circuit diagram 2. First the entry curve $I_B = f(U_{BE})|_{U_{CE}}$ was taken by changing U_{BE} from 0 to 670 mV and measuring I_B , U_{BE} and U_{CE} with multimeters according to the schematic 2. Therby U_{CE} was dialed in to match the results from experiment 1 4.2 with $R_C = 5 \text{ k}\Omega$. Afterwards the output characteristic curve $I_C = f(U_{CE})|_{U_{BE}}$ was recorded with a varying U_{CE} from 1 - 10 V by measuring I_C , U_{BE} and U_{CE} . This curve was measured in both directions to observe the effect of heat on the transistor.

4 Evaluation and Results

4.1 Preliminary Considerations

4.1.1 Measuring of the characteristic Values

The characteristic values of a transistor are different for each operating point. Therefore the measurements have to be done with the Voltages already applied. While measuring, there is already a Voltage aplied. This could messs with the Multimeter leadiging to wrong measurements, if it assumes free floating ends. This also meant that the resistance of the power supply and the resistor has to be taken into account, as is essentialy a second path for energy to flow parallel. Lastly the test voltage, which the multimeter uses to probe the resistance could be greater than the maximum of the small signal model, so that the multimeter measures outside the linear section.

4.1.2 Transformation of y to h parameters

The dependency of i_1 , i_2 , u_1 and u_2 in the small signal model can also be written in h parameter form as

$$\begin{pmatrix} u_{BE} \\ i_c \end{pmatrix} = \begin{pmatrix} r_{BE} & 0 \\ S \cdot r_{BE} & \frac{1}{r_{CE}} \end{pmatrix} \begin{pmatrix} i_b \\ u_{CE} \end{pmatrix}. \quad (8)$$

4.2 Characteristic Curve (Assignment 7)

As shown in table 4.2 some basevalues were recorded which were needed in following experiments. They seem to be in a reasonable range.

R_C in $k\Omega$	U_{BE} in V	U_{CE} in V	I_C in mA	S in $1/\Omega$
1	0,57	7,86	0,58	0.025
5	0,57	5,53	0,58	0.025
10	0,57	3,22	0,58	0.025

Table 1: Base values

The characteristic input curve is plotted in figure 3. With the slope of the tangent one can calculate the base resistance $r_{BE} = 3.92 \text{ k}\Omega$ with equation 2. The operating temperature $T = 272,2 \text{ K}$ can be obtained by using the fitparameters from the exponential fit and equation 5. Although the operating temperature has the correct magnitude it should be at least 30 K higher. With this operating temperature and equation 4 the steepness S can be calculated as shown in figure 4.2.

The characteristic output curve is plotted in figure 4. By utilizing equation 3 one can calculate the collector - emitter resistance $r_{CE} = 532 \text{ k}\Omega$ with the slope of the tangent. The high resistance was anticipated because no current should flow from collector to emitter in the closed transistor state.

4.3 Amplification (Assignment 8)

The voltage amplification with and without load resistor is shown in figure 5 and 6. To calculate the amplification, equation 6 was used due to the non conductive properties of C_E in low frequency ranges. While figure 5 and 7 display a linear behavior, figure 6 shows saturating properties.

By removing the emitter capacitor C_E the emittercircuit cannot work properly and one can only observe basevoltage drift. Therefore we used equation 7 to fit the measured values as shown in figure 7. While figure 5 and 7 display a linear behavior, figure 6 shows saturating properties. The measured values match the calculated curves pretty closely without any outliers.

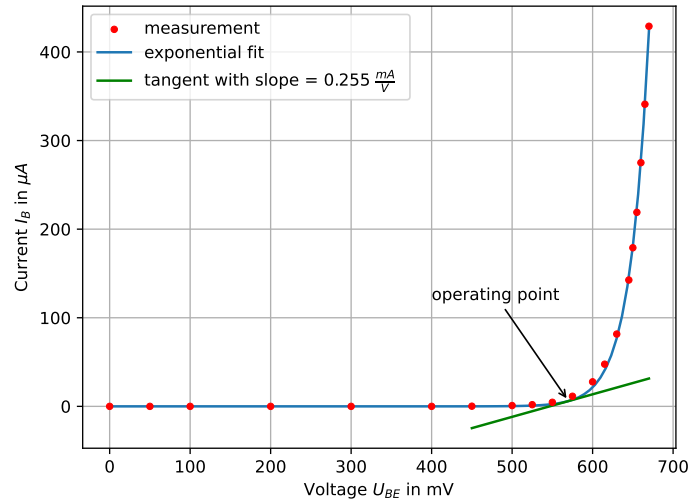


Figure 3: Characteristic curve from the input

4.4 Frequency Response (Assignment 10)

Another important characteristic of a transistor is the frequency response. Therefore the amplitude and phase response is plotted in figure 8 and 9. Therby the amplidude response behaves like a high pass filter from 0 - 10^3 Hz and like a low pass filter from 10^3 - 10^6 Hz.

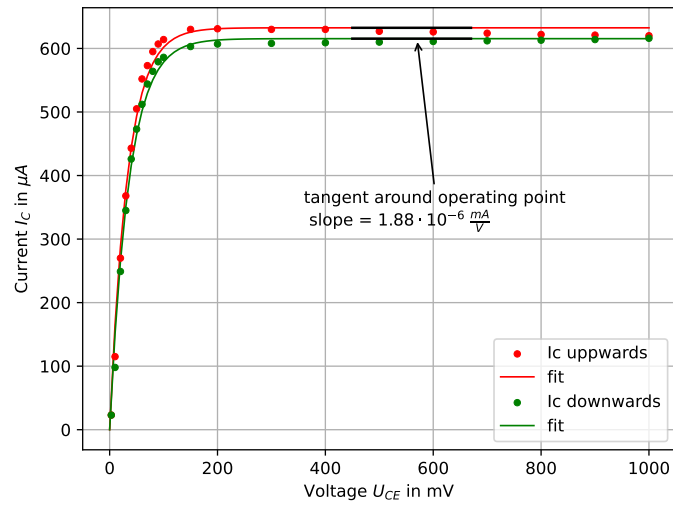


Figure 4: Characteristic curve from the output

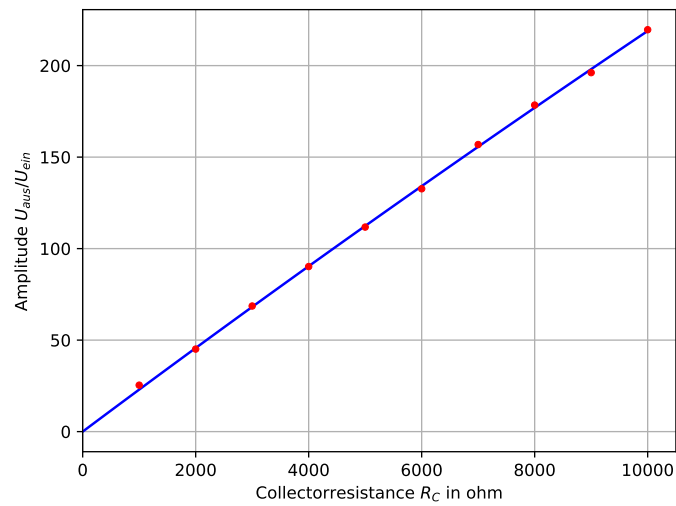


Figure 5: Amplification curve of the emittercircuit with capacitor C_E and without load resistor R_L

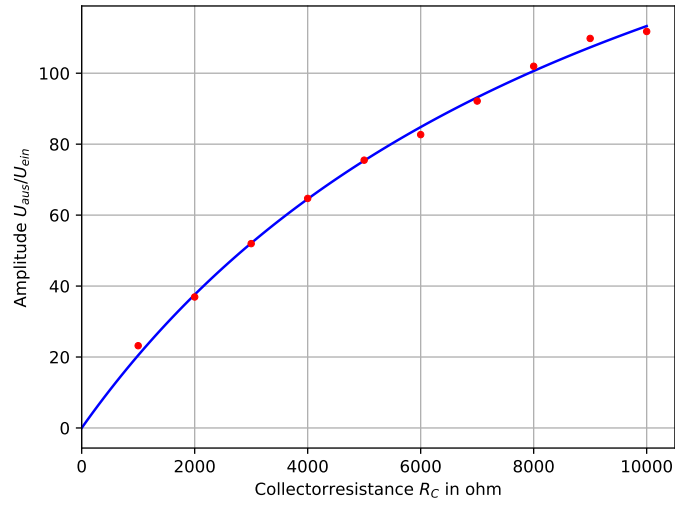


Figure 6: Amplification curve of the emittercircuit with capacitor C_E and load resistor R_L

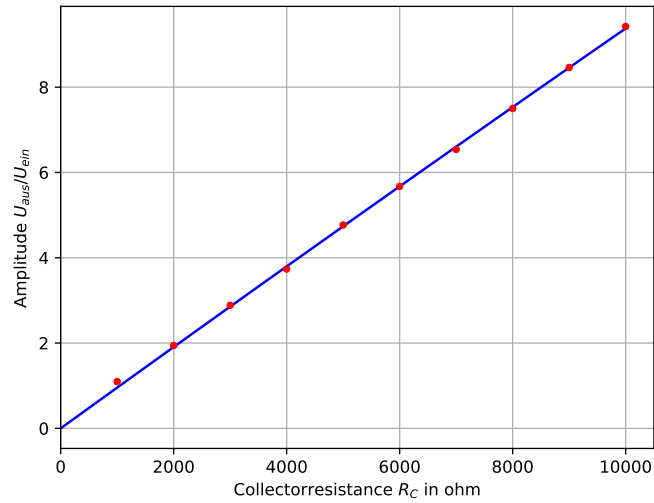


Figure 7: Amplification curve of the emittercircuit without capacitor C_E and load resistor R_L

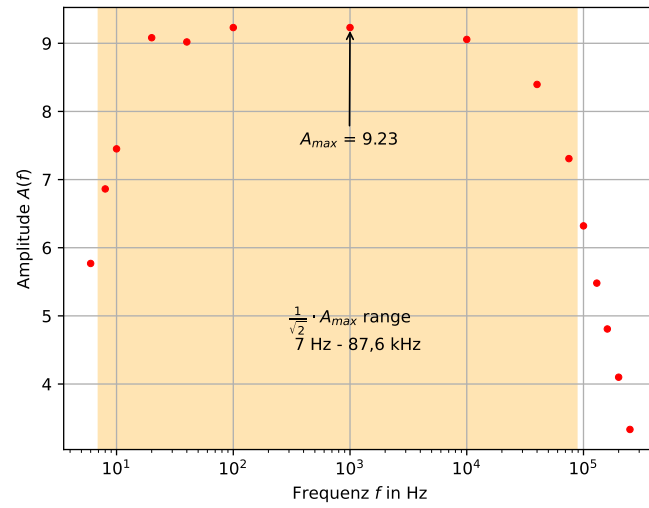


Figure 8: Amplitude response for different frequencies

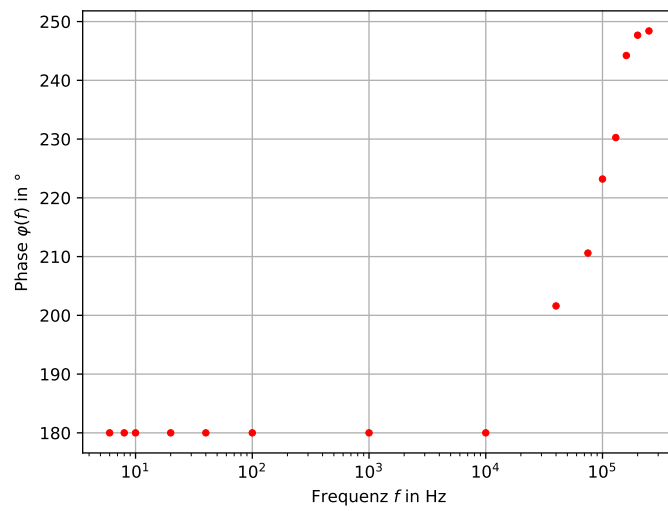


Figure 9: Phase response for different frequencies