Aim of the Experiment

Introduction to the basic principles of transistors and elementary circuit techniques.

Literature

/1/ U.Tietz - Ch. Schenk; Halbleiterschaltungstechnik; Springer-Verlag

/2/ K.-H. Rohe; Elektronik für Physiker; Teubner Studienbücher

/3/ J.Pütz; Einführung in die Elektronik; Fischer-Taschenbuch-Verlag

HALBLEITER in annex V of the GPII script

Exercises

1. Recording and construction of the (static) characteristic curves of a npn-transistors (2N3904) for an operating voltage (supply voltage) of 12 V. Determining current amplification for the static case.

   Design an amplifier stage with negative feedback for stabilization.

2. Dimensioning the circuit: Estimating the working resistance of the base series resistance.
3. Experimental check of the collector resistance curves by varying the base series resistance and determining the current amplification.
4. Amplifying an input ac voltage as a signal. Measuring the voltage amplification and comparing the result with the theoretical expectation.

Physical Principles

Principles of Operation of a Transistor

Refer to the literature and *HALBLEITER* in annex V of the GPII script

Transistor Circuits

A transistor can be operated under different circuit configurations. Depending on whether the emitter (E), base (B) or collector (C) lies on the common reference potential of the circuit (ground), one differentiates between an *emitter-*, *base-* or *collector circuit*. In the scope of this experiment, only the emitter circuit will be handled.

Characteristic Parameters and Characteristic Curves

A transistor is specified by three currents and three voltages: I_B, I_C, I_E and U_{EC}, U_{BC} and U_{EB}. The sum of the three currents is zero, whereby the current flowing into the transistor is taken as positive and the out flowing current as negative:

$$I_B + I_C + I_E = 0 \tag{1}$$

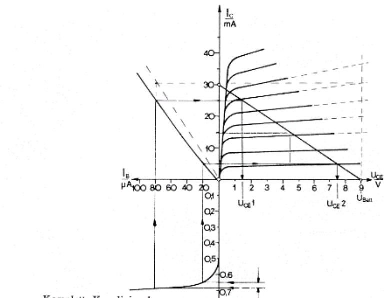
Correspondingly, for the voltage one has:

$$U_{EC} = U_{BC} + U_{EB} \tag{2}$$

From the six variables, two are always dependent on the other four as seen in (1) and (2) and can be expressed in terms of these.

In the emitter circuit, the transmitter can be considered as a current amplifier in which a small change in base current ΔI_B causes in a large change in collector current ΔI_C . The current amplification factor and other parameters of the transistor or circuit can be taken from the *four-quadrant characteristic curves,* which show the interdependence of the four independent variables among one another. From the characteristic curves one can read:

- in the first quadrant the output resistance (U_{EC}/I_C),
- in the second quadrant the current amplification (I_C/I_B),
- in the third quadrant the input resistance (U_{EB}/I_B) und
- in the fourth quadrant the reverse voltage transfer ratio (U_{EB}/U_{EC}).



Komplette Kennlinien des Transistors und die des Kollektorwiderstandes

From the characteristic curves of the first quadrant it is clear that the value of the collector current only depends in a small way on the emitter-collector voltage. This is a useful property since such a voltage drop at the load only leads to a small reverse bias of amplification.

The second quadrant reproduces the current amplification ß which is practically constant over a wide range:

$$\beta = \frac{I_C}{I_B} \quad \text{or} \quad = \frac{\Delta I_C}{\Delta I_B} \tag{3}$$

The third quadrant essentially corresponds to a "normal" diode characteristic in the direction of current flow; here the emitter-basis diode.

The fourth quadrant describes how a change in the emitter-collector voltage affects the base voltage (reverse voltage transfer, *Punch-through*).

Power Hyperbola

The current through the transistor, together with the non-vanishing internal resistance, leads to power loss and self heating which, at large values, can damage the transistor. The maximum permissible power loss $U_{EC} \cdot I_C$ (neglecting base power) can be plotted as a *power hyperbola* in the field for the output characteristics (1. quadrant).

Working Point Resistance and Voltage Amplification

With a given supply voltage U_o in the collector circuit, the collector current can be limited by a resistor R_A (working resistor). Depending on the current, a part of the supply voltage drops across the resistor so that the collector voltage U_{CE} is also limited. Since the voltage drop is dependent on the collector current, this boundary forms a falling straight line (*collector-resistance line*) in the field for the output characteristics and is fixed by the points $I_C = U_o/R_A$ for $U_{EC} = 0$ (short circuit case) and $U_{EC} = U_o$ for $I_C = 0$ (blocking).

The working resistor must be selected so that the resistance line does not cut the power hyperbola.

The emitter circuit with a working resistor represents a simple voltage amplifier. Due to the working resistor, a change in voltage occurs at the collector which is proportional to the change in current. The ratio $\Delta U_{EB}/\Delta U_{EC}$ is termed the *voltage amplification* v:

(4) $$v = \frac{\Delta U_{EC}}{\Delta U_{EB}} = \frac{R_A \cdot \Delta I_C}{\Delta U_{EB}} \bigg| \cdot \frac{\Delta I_B}{\Delta I_B} = \frac{\beta \cdot R_A}{r_{EB}}$$

where r_{EB} is the *differential input resistance* $\Delta U_{EB}/\Delta I_B$.

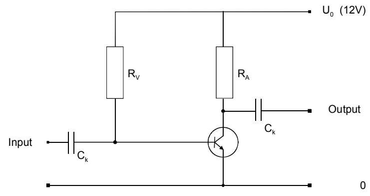
Such a simple amplifier works inverting, i.e., an increase in voltage or current at the input acts to lower the voltage at the output due to the increasing collector current and the larger voltage drop across the working resistor.

Working Point

A transistor only amplifies in the range of positive emitter-base currents. In order to transmit ac signals undistorted, a positive dc signal must be superimposed on the base. The associated point in the fields of the characteristic curves is called the *working point*. The working points are often selected as the half maximum permissible collector currents or half the supply voltages. The working point or the associated base quiescent current can be set by a so called base dropping resistor or a voltage divider ahead of the supply voltage.

In applications in amplifier circuits, setting up a working point has the disadvantage, that even in quiescent current operation without a signal at the input of the circuit, relatively high currents with power losses flow in the collector circuit (»Class-A-amplifier« in HiFi technology).

The following diagram represents a simple amplifier stage with base dropping resistor R_V, a working point resistor R_A and two coupling capacitors C_K:



Static and Dynamic Characteristic Curves

The characteristic curves described above under the assumption of freely specified variables, e.g., the collector-emitter voltage U_{EC}, are called *static characteristics*. However, the inclusion of a working point resistor results in considerable feedback of the dependent quantity (here the collector current due to the voltage drop across the working point resistor) on the independent variable. In this case one obtains so called *dynamic characteristics*, which can be substantially different from the static ones.

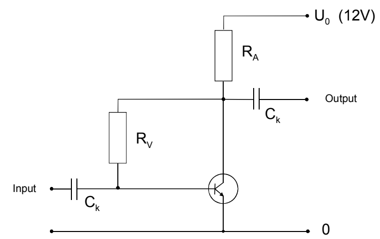
Stabilization

Since the conductivity of semiconductors is strongly dependent on the temperature, one must keep the influence of internal- and external heating on the properties of a circuit as low as possible by introducing special stabilization measures. The most important type of stabilization is *negative feedback*. Negative feedback means that a part of the amplified output signal is inverted and fed back to the input to counteract a change in the amplification factor. The price to pay is a reduction in total amplification.

There are many types of negative feedback. Which is suitable depends above all on the internal resistance of the stage driving the amplifier. In the present case so called *parallel negative feedback* will be investigated (see figure below).

If the amplification increases (with unchanged input signal) hence producing a rise in collector current, then this results in a drop in the collector potential due to the voltage drop across the working point resistor. Since the base dropping resistor R_V forms a voltage divider with the emitter-base resistance, the base potential and the base current also drop so that the collector current again decreases.

The measure of stabilization is described by the action via the base dropping resistance of the feedback ratio (feedback factor) $\alpha = \Delta U_{EB}/\Delta U_{EC}$ and the voltage amplification *v*. These determine the "*forward*" effect of a change in base potential on the collector potential. Both data are fixed by the dimensioning of the circuit elements.



If $\Delta U_{EC}'$ is an assumed change in collector potential without feedback, then with feedback the change is:

(5) $$\Delta U_{EC} = \Delta U_{EC}' - \alpha \ \Delta U_{EC} \ v$$

Solving for the actual change in output voltage gives:

(6) $$\Delta U_{EC} = \frac{\Delta U_{EC}'}{1 + \alpha \, v}$$

In other words, the higher the feedback factor and the higher the amplification the less is the actual output voltage fluctuation.

Presentation of the Physical Principles

(as preparation for part of the report): A summary of the functioning of a transistor. Describe and discuss the quadrants of the characteristic curves and the examples of the circuits to be investigated.

Apparatus and Equipment

Plug-in circuit board with transistor and other circuit elements (resistors, potentiometer).

Power supply unit 12 V; battery (1.5 V mono-cell) for base current. Various multimeters.

Experiment and Evaluation

General information

The open layout of the circuit and the comparatively high resolution of the digital multimeters gives rise to a certain instability of the measured values, resulting a number "jungle" which is a nuisance but unavoidable. In the scope of the accuracy to be achieved one should not be over fastidious in trying to set "smooth" values for the measuring variables.

The maximum ratings of the transistor are not to be exceeded (see lab bench script), to prevent overloading and damaging the transistor.

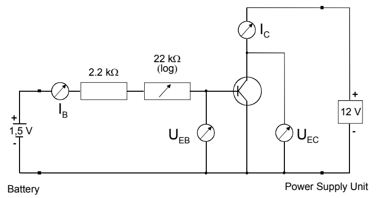
On the other hand, during the measurements, critically observe the measured data quantitatively (order of magnitude, qualitative behavior, relative stability), in order to recognize a damaged transistor in time.

To Exercise 1

The circuit is layed out according to the diagram below. Pay attention to an appropriate use of the measuring instruments (resolution) and in particular the correct voltage measurement in the base-collector circuit. Record the circuit construction and the use of the measuring instruments.

Make a check of the power loss ($U_{EC}\cdot I_C$) for each measurement setting to avoid overloading the circuit.

Record the measured data and as a control plot the values during the measurements.



Four data sets (I_C and U_{EB} as a function of U_{EC}) with I_B = 30, 60, 90 and 120 μA as parameters are to be recorded. The second and third quadrants of the field for the characteristic curves shall be constructed for an assumed voltage supply of 12 V. The static current amplification I_C/I_B is calculated from the second quadrant and the differential input resistance r_{EB} from the third. The determination of r_{EB} may be inaccurate because of the small voltage difference and the fluctuation of the data thus giving only a rough estimate of the value.

To Exercise 2.1

A small working resistance causes small voltage drops and is not suited for voltage amplification. A too higher working resistance could cause U_{EC} drop too low and thus act as a current limiter. A suitable *closed circuit voltage* U_{EC} lies at about half of the supply voltage for the circuit (here 6 V). The working resistance R_A is calculated from the required voltage drop across the working resistor and the quiescent current I_C at the working point and the base dropping resistance R_V is calculated from U_{EC} less the base threshold voltage and the base quiescent current I_B at the working point.

To Exercise 2.2

The amplifier circuit is built according to the circuit diagram on page 6 with the previously determined values for R_A und R_V, and with a supply voltage of 12 V the collector resistance curve (U_{EC}/I_C) is measured by varying the base dropping resistance. One requires fort he evaluation, the exact value of the working resistance.

Record the measured values (U_{EC}/I_C) together with the expected resistance curves in in the field for the characteristic curves. Construct the dynamic I_B/I_C characteristic curve and from this calculate the dynamic current amplification.

To Exercis 2.3

The circuit is complemented by two 0.1 μF coupling capacitors (see circuit diagram, page 6), and a sine signal (about 1000 Hz) applied to the input (function generator *Voltcraft* 7202). The signal can be suitably attenuated at the function generator by pressing the ATT 20-dB button.

The input circuit with the coupling capacitor and the emitter-base resistance represents an *R-C* circuit and thus a frequency dependent voltage divider (high-pass filter).

At first observe the input signal at the coupling capacitor and at the base of the transistor and the output signal on the oscilloscope (voltage ratio and phase as a function of frequency). Record the observations. AS a trial, select a larger base dropping resistor and increase the input signal.

Finally, determine the voltage amplification by measuring the input- and output voltage with the HC-5050-DB multimeter.