DEPARTMENT OF ELECTRONICS AGH UST

LABORATORY
OF
ELECTRONICS ELEMENTS

SMALL-SIGNAL PARAMETERS OF BIPOLAR JUNCTION TRANSISTORS

REV. 1.0

1. THE GOAL OF THE EXERCISE

- to get acquainted with measurement methods and determination of small-signal parameters of electronic devices,
- determination of small-signal parameters constituting hybrid and hybrid π models of bipolar junction transistors.

2. THE UTILIZED MODELS AND ELEMENTS

During the exercise following components will be used:

- NI ELVIS Prototyping Board (ELVIS) connected with PC,
  - Virtual measurement devices:
  - Variable Power Supply (VPS).
- Agilent 34401A multimeter,
- signal generator,
- Tektronix oscilloscope,
- set of electronic elements listed in Table 1.

Table 1. Values of electronic elements required to perform the exercise

Resistors	2 x 20 Ω, 1 kΩ, 4,7 kΩ, 10 kΩ, 100 kΩ, 1 MΩ
Capacitors	10 μF, 47 μF (or 100 μF)
Transistors	BD 411 or BD 283, or BC337, or another

3. PREPARING THE DRAFT

3.1. Sketch a four-terminal hybrid and hybrid π models of bipolar junction transistor. Give definition formulas for these parameters.

3.2. Having the output characteristics of the bipolar transistor subjected to experiments during exercise 5, for example (U_{CE} = 4 V, I_C = 5 mA), estimate (according to definitions) the small-signal hybrid parameters of the bipolar transistor.

4. THE COURSE OF THE EXERCISE

REMARK: Measurements of all the small-signal parameters are performed in a specific operating point of the transistor. Since the measuring system is powered from a DC voltage source, it is sufficient to control the collector current while maintaining its constant value. Most of the small-signal parameters can be measured in the measurement system shown in Fig. 1. The values of the elements were chosen to meet (at least partially) the necessary conditions to determine the individual parameters. There may be a need to change the value of the resistor R_1 for different types of transistors (for low gain transistors it should have a value, e.g. 4,7 kΩ, and for those with high gain it can be 100 kΩ). Capacitor C_1 introduces a short circuit for AC signal, in order to eliminate the influence of the internal resistance of the ammeter on measurement results.

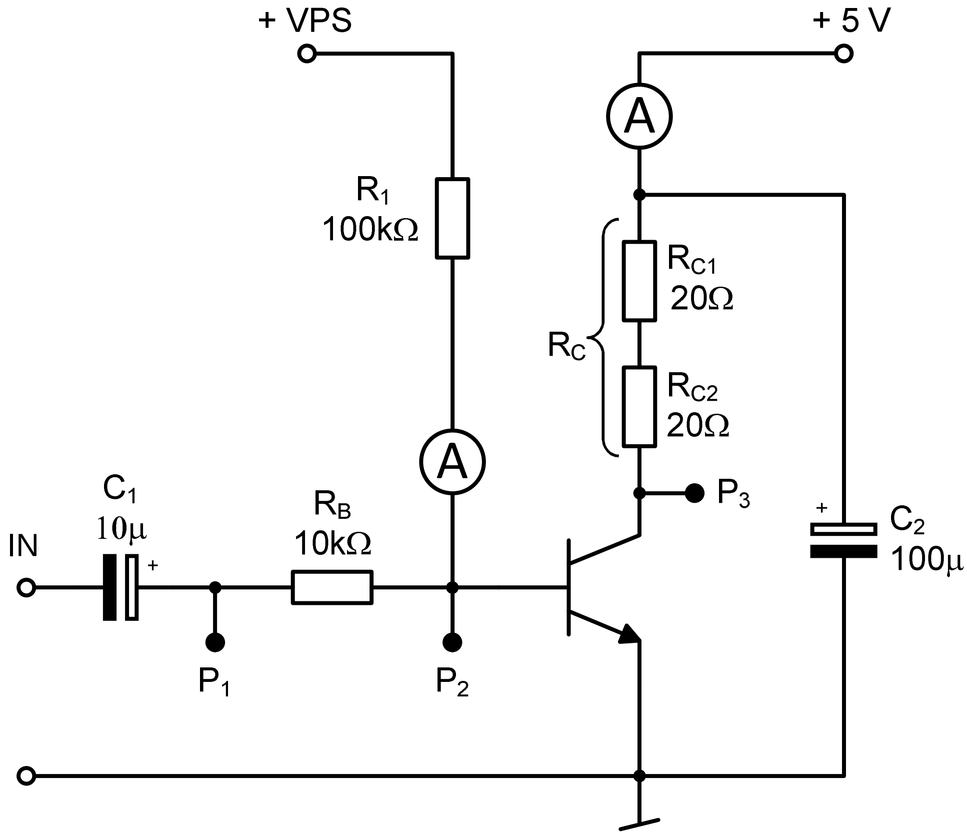

Fig. 1. A circuit used for measurements and determination of small-signal parameters

4.1. Measurements of DC current gain (β) and small-signal current gain (h_{21e} – hybrid model) against frequency

- Arrange the circuit to determine the small-signal parameters of bipolar transistor according to Fig. 1. DO NOT introduce the ammeter into the base circuit.
- By means of +VPS, set a voltage to get collector current I_C= **25 mA** (operating point), or other value indicated by the teacher.
- Reconnect the ammeter to the base circuit; put a jumper in its place in the collector circuit. Measure the base current. Note the base and collector currents (these results will allow to calculate the DC current gain β).
- Reconnect the ammeter into collector circuit again (a jumper in the base circuit) and check the value of collector current I_C.
- Connect the oscilloscope probes to the measurement points **P_1, P_2** i **P_3**. Set the partition coefficient of the probe to **X10**. You must use an external oscilloscope, it is not recommended to use the virtual instrument Scope.
- Connect the external generator to the input. Set a sinusoidal signal with a frequency **1kHz** and amplitude **100mV** (the wave observed at **P_1**).
- By changing the frequency of the input, measure the voltage amplitudes at points **P_1, P_2** i **P_3** (carry out, e.g. 3 measurements for a frequency decade, up to a frequency for which the amplitude at P_3 is still measureable).

  REMARK: The oscilloscope can be used to measure the voltage amplitude in each channel (MEASURE function). However, TEKTRONIX model measures the value of the voltage peak to peak (V_{Pk-Pk}), which also can be used in the calculations.

4.2. Measurement of the output conductance h_{22e}

Figure 2 shows a circuit of the measurement system for determination of the output small-signal conductance (h_{22e}) of the bipolar transistor. Measuring the voltage u_{ce} (small-signal) and collector current i_c forced by the generator, one can calculate the output conductance according to the definition. The transistor has to be biased and it should work at the same operating point, the same as in previous measurements; moreover it should be ensured that the input is "open" for small-signal component. This condition is met by the use of high-value resistor in the base (R_1).

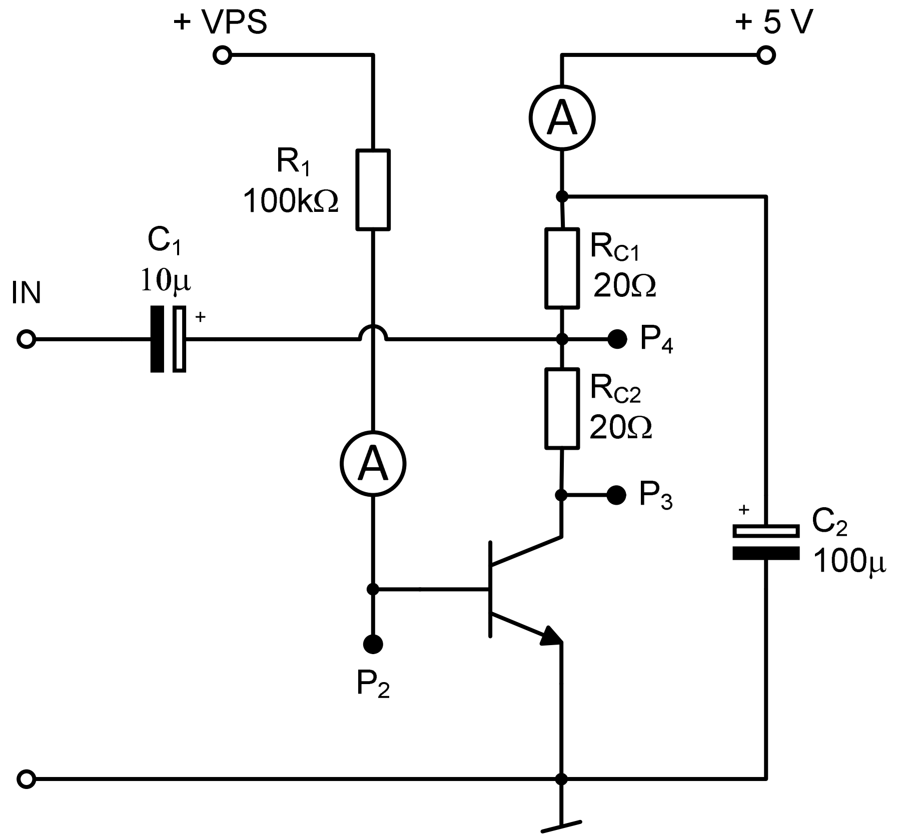

Fig. 2. A circuit used for determination of the output conductance of BJT (h_{22e}).

- Assemble the system to determine the output conductance of the bipolar transistor according to Fig. 3. <u>Do not connect the generator to the input of the circuit.</u>
- By means of +VPS, set the voltage in such a way that the collector current is equal to **25mA** (the same operating point of the transistor as previously).
- Connect the oscilloscope probes to the points **P_3** and **P_4**. Set the partition coefficient of the probe to **X10**.
- Connect the external generator to the input. Set sinusoidal signal with a frequency **1kHz** and amplitude **100mV** (the wave observed at **P_4**).
- Carefully measure the voltage values: u_{in} and u_{ce} (at points **P_3** and **P_4**).

  REMARK: in case of a very small voltage difference, one can make use of oscilloscope and measure the voltage difference at two channels by means of MATH function.

4.3. Measurement of the base-collector junction capacitance $c_{b'c}$

In the circuit from Fig. 3, one can measure the junction capacitance of a reverse biased base-collector junction ($C_{b'c}$) of the bipolar transistor. Transistor works in the cut-off area. The measured capacitance together with capacitor C_3 create a voltage divider. By measuring the two voltages, one can determine the value of $C_{b'c}$.

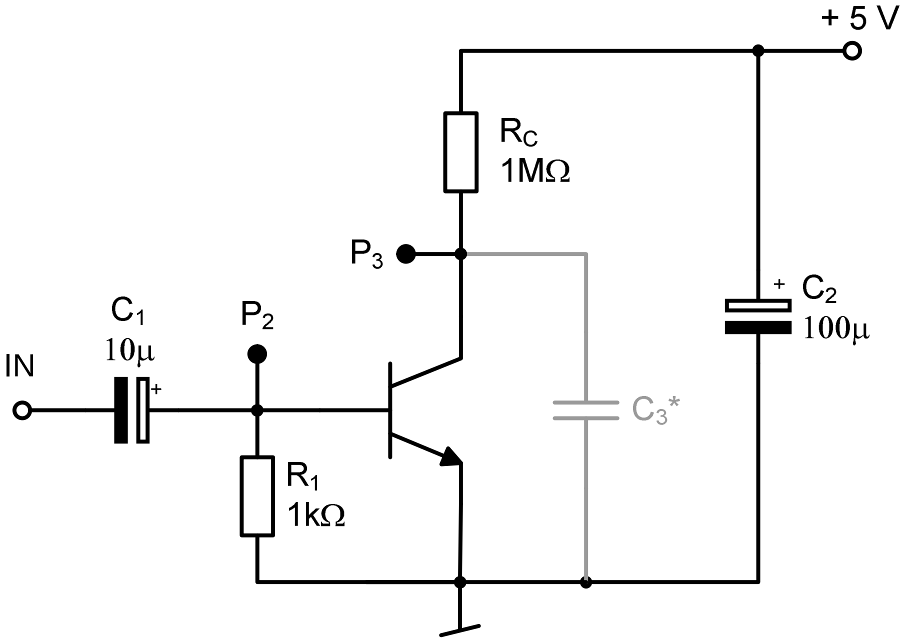

Fig. 3. A circuit used for determination of the base-collector junction capacitance ($C_{b'c}$).

- Arrange the circuit to determine the capacitance of the base-collector junction $C_{b'c}$ of the bipolar transistor, according to Fig. 4.

  REMARK: Value of the capacitor C_3 depends on the transistor subjected to the measurements. For DB411 or BDP285, it can be 75pF, and for BC 109 (or other low power transistor) capacitor C_3 can be omitted. Its role will be fulfilled by an oscilloscope probe capacitance (which should be always taken into account in calculations).
- Connect the oscilloscope probes to the points **P_2** and **P_3**. Set the partition coefficient of the probe to **X10**.
- Connect the external generator to the input. Set sinusoidal signal with a frequency **100kHz** and amplitude **500mV** (the wave observed at **P_2**).
- Measure the values of the voltages at the base and the collector of the transistor (at points **P_2** and **P_3**).

5. DATA ANALYSIS

5.1. Current gain: β and h_{21e}

- Based on the measured values of the base and the collector currents, calculate the DC current gain β.
- Based on the measured voltages at the measurement points **P_1, P_2** and **P_3**, calculate the small-signal current gain h_{21e} (the results gather in a table).
- Draw a characteristic of the current gain h_{21e} against frequency, on a logarithmic scale.
- From the graph, determine the frequencies f_β and f_T of the transistor.
- Compare the results with the data sheets of the tested transistor.

5.2. Small-signal impedance h_{11e}

- On the basis of measurements of voltages for frequency **1kHz** at the measuring points $\mathbf{P_1}$ and $\mathbf{P_2}$, made in section 4.1, calculate the small-signal value of input impedance h_{11e} of the bipolar transistor.

5.3. Small-signal parameters of hybrid-π model: g_m, $r_{b'e}$, $r_{bb'}$ as well as n

Transconductance g_m, dynamic resistance of the base-emitter junction $r_{b'e}$, and distributed base resistance $r_{bb'}$, they are the parameters of **hybryd π** model of a bipolar junction transistor. Based on the results obtained in section 4.1, calculate the above mentioned parameters of the transistor.

- Using the results of previous calculations and measurements for the signal with a frequency of **1kHz**, calculate the value of the transconductance, the emission factor, the dynamic resistance of the base-emitter junction, and the distributed base resistance.
- Calculate the diffusion capacitance of the base-emitter junction and the transition time of carriers.

5.4. Output conductance h_{22e} of the transistor

Based on the results of measurements made in section 4.2, calculate the output conductance h_{22e} of the bipolar junction transistor.

5.5. Base-collector junction capacitance $c_{b'c}$

Based on the results of measurements made in section 4.3, calculate the base-collector junction capacitance $C_{b'c}$.

REMARK: capacitance of the oscilloscope probes should be considered in the calculations (16 pF when the partition coefficient of the probe is set to X10, or 95 pF, when the partition coefficient of the probe is set to X1 in case of TEKTRONIX probe, as well as 100 pF and 20,5 pF in case of HanTek PP-80 probe respectively).

5.6. Based on the results of small-signal parameters, calculate the emitter-junction capacitance $c_{b'e}$.

5.7. Draw a small-signal hybryd-π model, and introduce the determined values of the parameters. Gather the small-signal parameters calculated in the draft and gained through the exercise in one table. Compare and comment the results.

6. LITERATURE

[1] Lecture (P. Dziurdzia)

[2] Behzad Razavi „Fundamentals of Microelectronics"

[3] W. Marciniak "Przyrządy półprzewodnikowe" (pol)

[4] Appendix to ex. 6 (pol)