Transistor amplifier

1. Objectives

The purpose of this exercise is to learn the characteristics of a single-stage transistor voltage amplifier. Measurement results of the transistor as well as the entire amplifier circuit will be compared with the calculated parameters. Based on the comparison of actual and theoretical parameters, it will be possible to assess the accuracy of the applied design methodology of the amplifier.

2. Components and instrumentation.

The scheme and PCB of the test system are shown in Appendix (Figures 1 and 2). The circuit is an amplifier in a common emitter configuration, and in case of the absence of a C3 capacitor, in an emitter-coupled configuration. Rg resistor models the output resistance of the signal source.

Additional resistors R11 and R22 form a divider (10 times) of input voltage, allowing for measurements with higher amplitudes of the generator signals. This divider is not part of the amplifier, which should be taken into account in the measurements by assuming that the input voltage of the amplifier is approximately 10 times smaller than that of the measuring generator.

3. Preparation.

Estimated time for preparation is 2 to 6 hours.

3.1. Readings

[1] Lab materials and lectures of the course.

[2] U. Tietze, Ch. Schenk, Electronic circuits. Handbook for Designers and Applications, Springer, 2008, p. 438-572, .

[3] P. Horowitz, W. Hill, The Art of Electronics, Cambridge Univ. Press, London, 2015, p.223-291

3.2. Problems

1. How to estimate the transistor quiescent point (ICQ, UCEQ) at the given values of polarized resistors and known parameters of the transistor (β, UBEQ) and the given voltage?
2. How to estimate the small signal parameters of a transistor amplifier in a common emitter configuration (voltage gain, effective voltage gain, input and output resistance, upper and lower limit frequencies) at the specified quiescent point and known components ?
3. How will the transistor's quiescent point change in the given circuit when changing one selected polarization resistor / when temperature change / when changing the current gain factor of the transistor ?
4. How will the amplifier parameters (gain, input and output resistances) change in the desired system when changing one selected polarity resistor /when temperature change / when changing the current gain factor of the transistor?
5. What is the difference between the voltage gain and the effective voltage gain?
6. How to measure the upper and lower limit of the amplifier?
7. What is decibel?
8. What is the voltage drop or increase of 3, 6, 10, 20 dB?
9. What are the different polarity of the bipolar transistor?
10. Bipolar transistor input and output, transistor quiescent point, static and dynamic load lines
11. Bipolar transistor models for DC and AC analysis for different frequency ranges
12. How negative feedback applied in amplifier with common emitter changes amplifier parameters (when there is no CE in diagram in Fig.1)?
13. Miller theorem .

3.3. Detailed preparation

1. For given transistor parameter (U_{BEQ}, U_{CEsat}, β, $r_{bb'}$, f_T) and R_L, R_g, Vcc design the transistor amplifier (one of the following cases):
   a) Given amplitude output voltage U_{outmax}, (Vcc can be given),
   b) Given small signal amplification and bandwidth (k_u, k_{usk}, f_d, f_g),
   c) Given quiescent point (I_{CQ}, U_{CEQ}),
2. Establish other parameters of the amp (this that were not given) and fulfill the Tab.1 (shaded cells) and applied calculated values on the schematic (Fig.1)
3. Annalise the designed amp using spice type program. Print results – transfer function print in dB and log frequency axis.
4. Failure to perform the above three points may result in a refusal to classes.

Note:

Parameters of the amp should be calculated for two cases: when resistor R_E is shunt with capacitor C_E and not shunt. In the second case amp is working with current-series feedback loop.
The system has been designed to reduce the bandwidth of the amplifier by connecting between the base and the collector of the transistor an additional capacitor Cd. This treatment is commonly called frequency compensation of the amplifier with dominant pole. Therefore, if the amplifier's upper frequency is given, the value of Cd must be additionally calculated.
If there is no preset low limit frequency in the design task, the following values for the calculation are assumed: C1 = 100nF, C2 = 100nF, CE = 100µF.
If not given for calculation take β=400 U_{BEQ}=0.65V, φ_T=25mV and transistor 2N2222 for simulations.

4. Measurements - Contest of the report

1. All passive components of the amplifier should be measured and the values applied to the circuit diagram (Fig.1). Also measure (if possible) the current gain β_0 (h_{21}, h_{FE}) of the transistor with the millimeter available on the stand.
2. Assemble the amplifier circuit according to Figs. 1 and 2. After assembling the system, connect the power supply wires to the PCB, taking into account the polarity of the supply voltage. Connect one coaxial cable terminated with a BNC connector on one side, to the amplifier input. Using a probe connect the output of the amp to one of the inputs of the oscilloscope. To control the input voltage, the second input of the oscilloscope should be connected to the input of the amplifier.
3. Measure the quiescent point of the amp:
   - voltage U_{CEQ},
   - voltage U_{BEQ},
   - collector current I_{CQ} (by means of voltage drop across Rc and applying Ohm low). Results put on (Fig.1) and in the Tab.1

Check if there is a capacitor CE applied – all measurements should be done for amplifier without negative feedback. All results put to the Tab. 1.

4. Connect input of the amp with generator and the output to oscilloscope (use probe 1:10). Adjust the frequency to 10kHz and amplitude small enough to achieve undisturbed output signal (pure sin).
5. Changing amplitude of input signal establish maximum undisturbed output voltage.

All of nest measurements should be done when output signal is undisturbed.

6. Observing input and output voltages on the oscilloscope (measure rather CycRMS than Peak-Peak voltages) establish voltage gain of the amp taking divider R11-R22 into account.

$$K_{Veff} = \frac{u_{OUT}}{u_{IN}}$$

7. Shorting resistor Rg using a jumper establish voltage gain (simple gain and not the effective one).
8. Establish input resistivity of the amp (problem 7):

$$r_{in} = \frac{R_g}{\frac{K_V}{K_{Veff}} - 1} - r_{out(\mathrm{divider}\text{-Fig.1})}$$

9. Measuring output voltage with and without resistor RL, establish output resistivity (problem 7).
10. Changing generator frequency establish upper fu and lower fl limit frequencies (-3dB).
11. Changing generator frequency measure the transfer function (module and phase) of the amp. Make a chart.
12. **Measurements 4-11 repeat for the amp with negative feedback (without capacitor C_E).**

13. The report should contain:

a) Title page
b) Design calculations
c) Computer analysis (SPICE program) – quiescent point, transfer function (module and phase) in dB vs logaritmic frequency axis. B vs f w skali logarytmicznej) i fazową],
d) Fullfilled Tab.1,
e) Schematic diagram with all parameters filled (Fig.1)
f) Transfer function (module and phase) measured during classes (in dB and log frequency axis) *NOTE :read in appendix A how to measure phase using scope without this function implemented*.
g) Conclusions containing explanation of difference between calculated and measured amp parameters.

5. Additional materials

Tab 1. Table of calculated and measured amp parameters.
Fig.1. Schematic diagram of the amp.
Fig.2 PCB of the amp.
Fig.3 Axis for transfer function (module and phase).

Tab. 1. Parameters of the amp: calculated and measured.

	Amp without negative feedback (with CE)				Amp with negative feedback (without CE)			
Parametr	Given or calculated		Measured		Given or calculated		Measured	
U_{CEQ} [V]								
U_{BEQ} [V]								
I_{CQ} [mA]								
$U_{OUTmaxP\text{-}P}$[V]								
K_{Veff}[V/V]; [dB]								
K_V [V/V]; [dB]								
f_l[Hz]								
f_u[kHz]								
r_{OUT}[kΩ]								
r_{IN}[kΩ]								

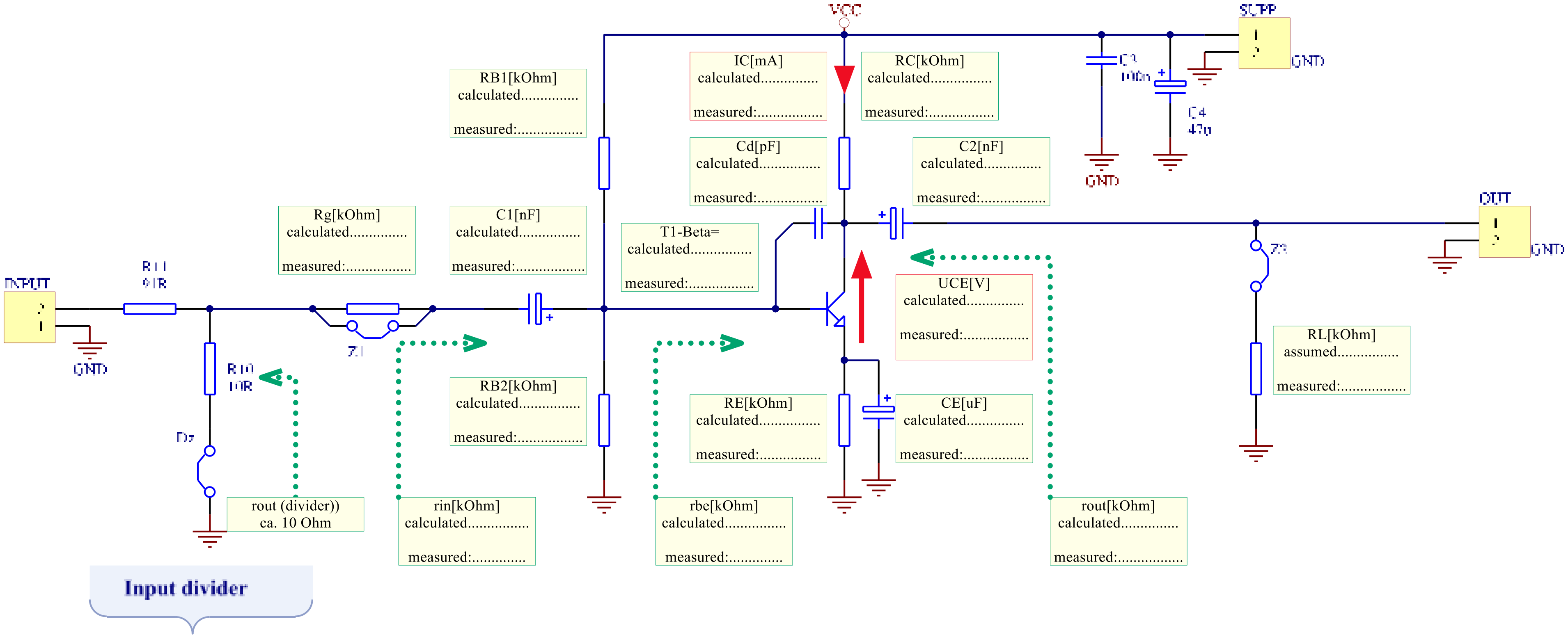


Fig.1 Schematic diagram of the amp.

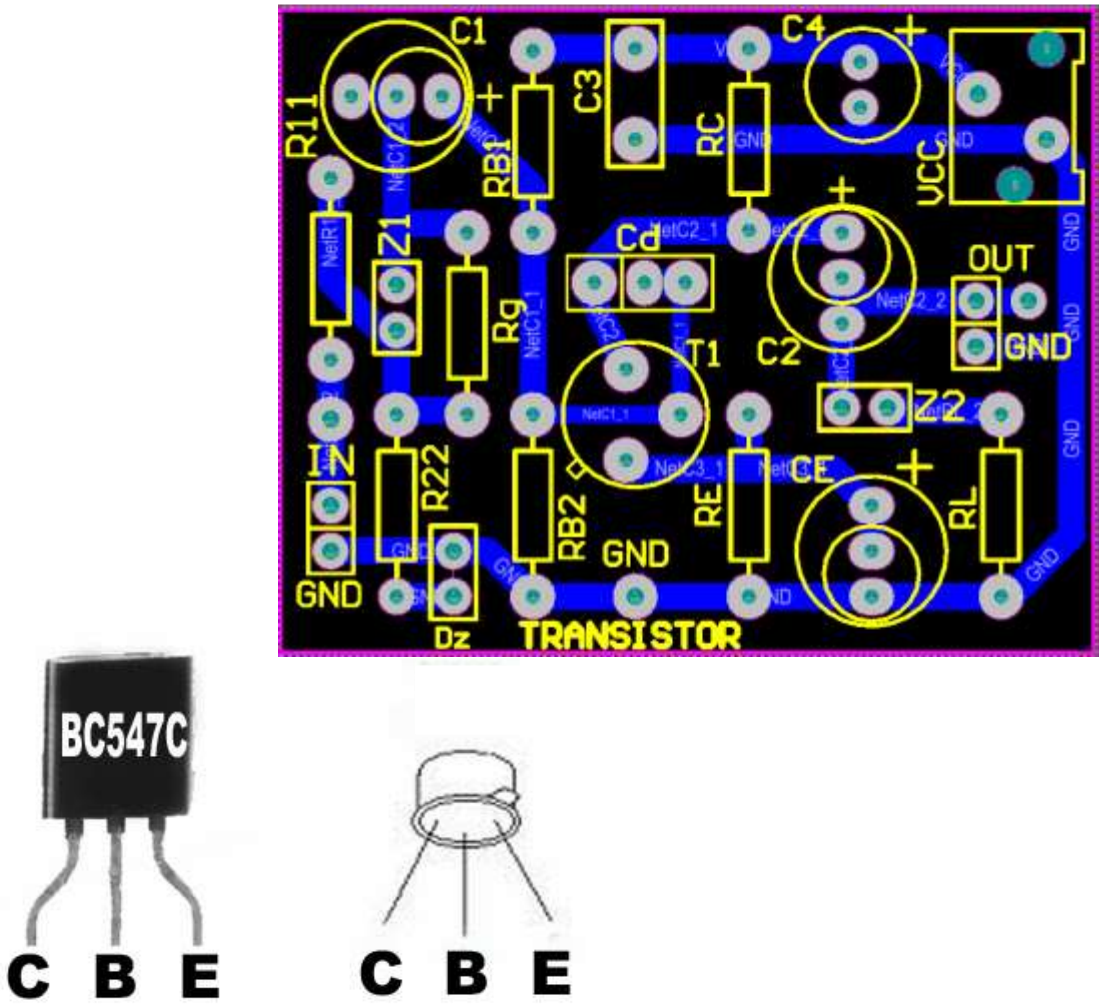
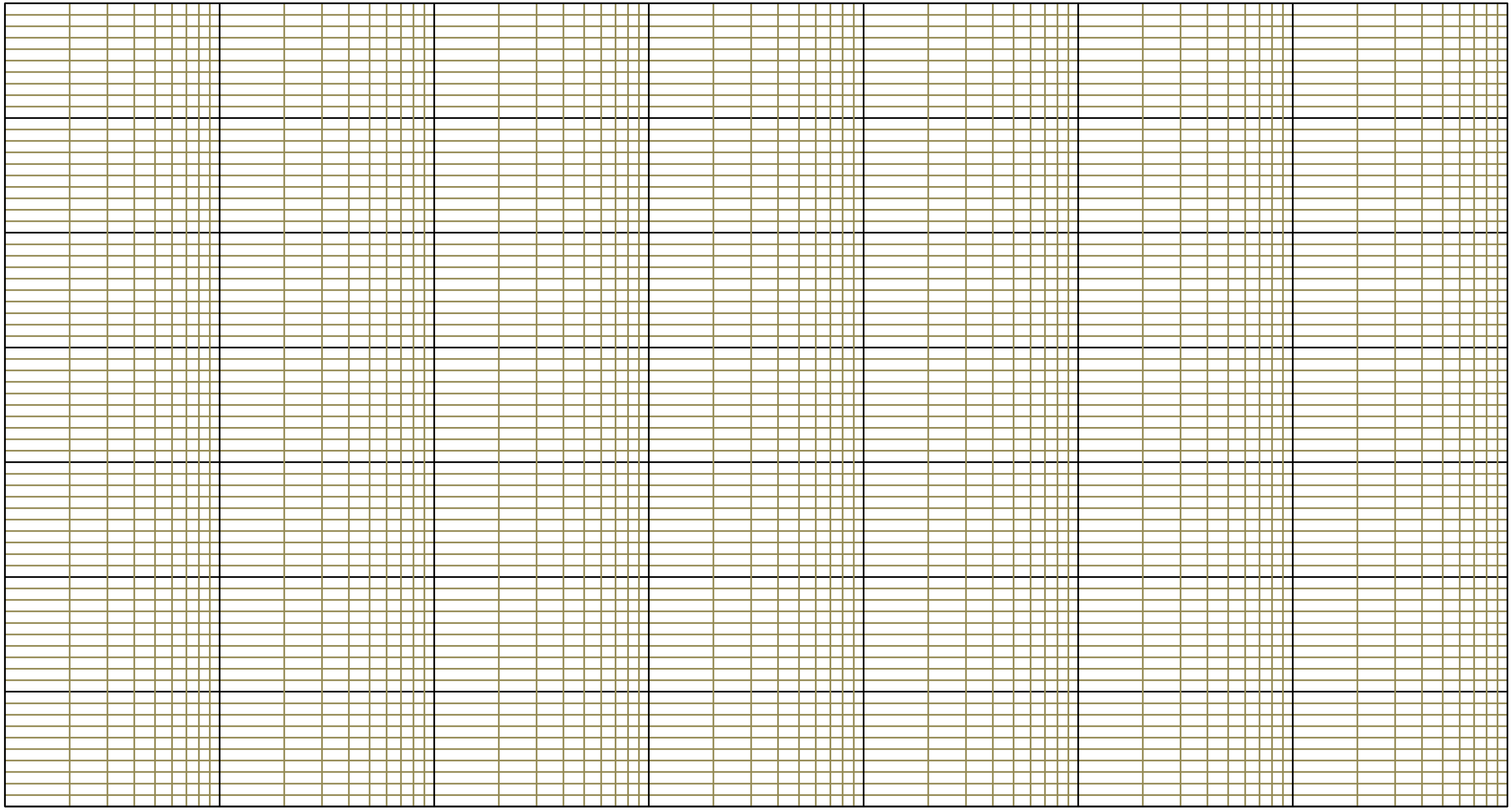


Fig 2. PCB of the amp.



Rys.3 Siatka do wykreślania charakterystyk amplitudowych i fazowych

6. Appendix - Phase shift measurement in case the oscilloscope is deprived of this function

Measurement of the phase shift between the two sine signals is most easily done on the screen of the oscilloscope. When measuring, keep in mind that the zero axes of both waveforms must overlap as shown in Fig. A.1. Then the offset between waveforms can be calculated as:

$$\varphi = 360^0 \frac{\Delta t}{T} = 360^0 * \Delta t * f \quad , \qquad (A.1)$$

Where *Δt, T* – times read directly from scope Fig.A.1

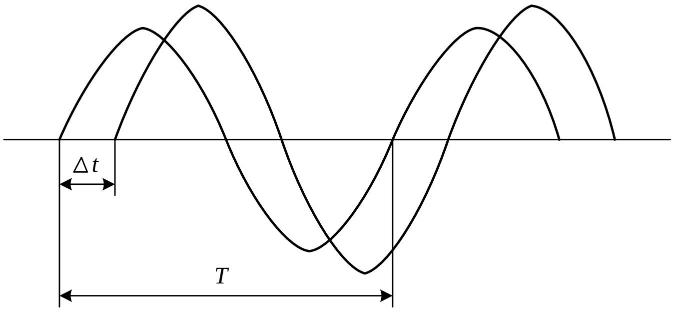


Fig.A.1. Idea phase shift measurement.

The pahse shift can also be measured using the Lissajous curve obtained on an XY oscilloscope regime (Fig. A.2). The phase offset between waveforms is calculated from the relation:

$$\varphi = \arcsin \frac{a}{b} \quad , \qquad (A.2)$$

where: a, b- reading from scope according to Fig.A.2

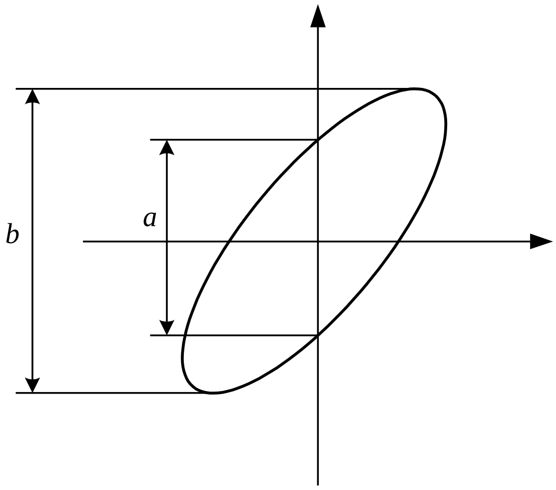


Fig.A.2. Idea phase shift measurement in XY regime of the scope