Measurement of basic circuits of transistor amplifiers

1. Introduction

The aim of this measurement is to summarize the properties of basic circuitries of transistor-based amplifiers, and the investigation of common-emitter and common-base amplifiers and the Miller-effect.

1.1. Types of basic circuitries

The basic circuits of transistor amplifiers:

- common emitter
- common base
- common collector

They got their names after the electrode common for both the input and output. In the followings we will investigate amplifiers based on NPN transistors. The properties are the same for PNP-s also.

1.2. Practical applications

We use common emitter amplifier at sound frequencies for amplification aims since it provides high voltage and current amplification, while its input resistance is not too low and its output resistance is not too high.

Common collector amplifierswith high input and low output resistance can be used for fitting purposes, say if we'd like to drive a low input resistance device from a generator having high internal resistance. ($A_u \leq 1$)

Common base amplifiers are only used at high frequencies due to their low power amplification and disadvantageous input and output resistances, since the other two circuits aren't available in this frequency range.

The electric current amplification coefficient of a transistor (β or h21) decreases with increasing frequency, and becoming 1 at an f_T transit frequency, whose value depends on the exact type of the transistor. For a common emitter amplifier both voltage and current amplification depends on h21, the same is true for common collector amplifiers, consequently the power amplification of these circuitries decays precipitously with the square of the increasing frequency. The amplification of the common base amplifier does not depend on h21, this causes the fact, that such an amplifier reaches its upper cut-off frequency (where the power amplification reaches the half of its value measured at medium frequencies) at an h21-times higher value. Common base amplifiers are (were) used in high-frequency input pre-amplifiers of televisions and FM radios.

2. Biasing (setting the operating point)

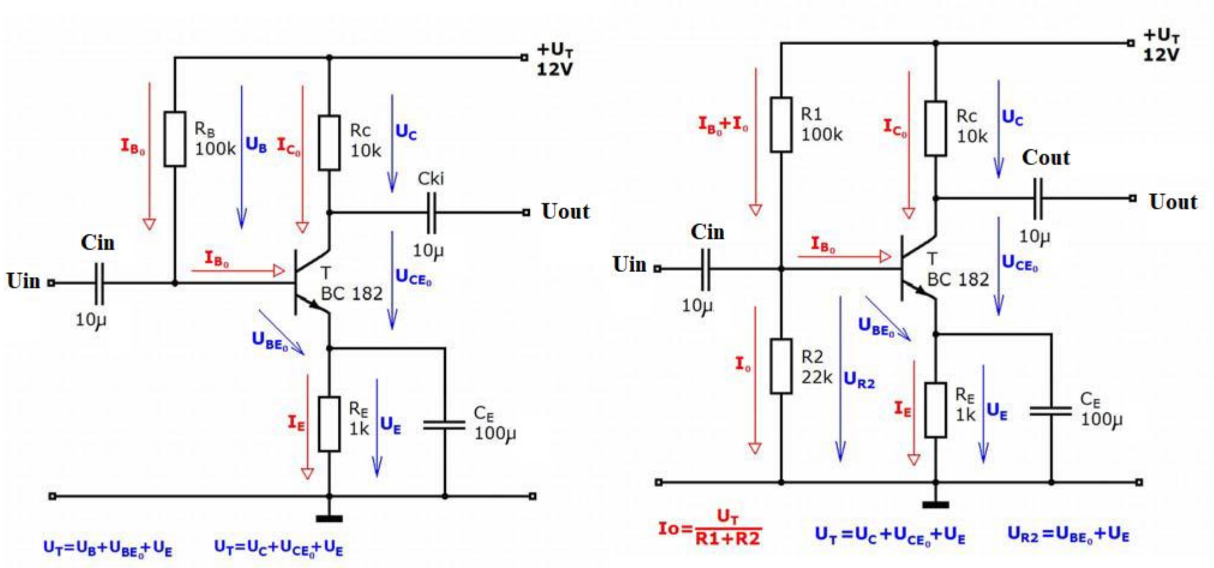

Figure 1. – Common emitter amplifier with current loaded and base divided bias

The wiring diagram of a base current loaded common emitter amplifier is shown on Figure 1. The base current is set by resistor R_B, since the lower operating point setting and the divisor resistor are missing. The disadvantage of such a circuitry is that it cannot provide enough stability, since it doesn't keep the voltage of the base constant, so this type assemble is used infrequently. The advantage of thebase-divided bias (right side on Figure 1.) is that the voltage divider can be considered unloaded, say it provides constant divided base voltage independently on a change in the base current. In the calibration of the input voltage divider, we need to consider that the dividing current (I_0) shall be an order of magnitude larger than the base current at the operating point. We can set the base-emitter voltage of the transistor by the input voltage divider (R_1 and R_2), whose typical value for a silicon transistor is 0.6-0.7 V. The operational resistance of the circuity is R_C. Voltage U_{CE}shall be set to the half of the supply voltage in order to keep the amplifier undistorted, say the operating point shall be able to move similarly in both directions. At common emitter amplifier the phase shift between input and output AC voltages is exactly 180° at maximum amplification.

3. Operation of base divided common emitter amplifier

Setting a sinusoidal signal increasing in the positive direction on the input increases the voltage of the base through the coupling capacitor. This growth opens the transistor, and the base current will increase. Emitter current also increases, so will the collector current. The voltage on R_C increases with the collector current, and since the supply voltage is constant, the collector voltage decreases. This decrease cuts out to the output through the coupling capacitor, say the output voltage changes in the opposite direction, the circuity turns the phase. A minor change in the base current causes a significant one in the collector current (current amplification!), this appears in the change of the output voltage.

4. Description of the measurement

4.1. Measure operating point settings

The typical DC supply voltage of transistor amplifiers is around 10-20 V. The data corresponding to the operating point can be easily determined via measuring voltage with a multimeter. During the measurement it is necessary to check that the essential DC voltages are present on the outputs of the transistor. If we need to use a transistor for amplification purposes its base-emitter diode shall be forward-biased (0.2-0.3 V for Ge and 0.5-0.7 V for Si) and its base collector diode shall be backward biased (with $U_T/2$).

While conducting the measurement, it is beneficial to probe and record the voltages of all three electrodes against the common ground. From this the voltage between the electrode pairs (the operating point voltages) can be calculated ($U_{BE}=U_B-U_E$, $U_{CE}=U_C-U_E$, etc.).

Along the measurement of operational point voltages, the input is left alone, no AC voltage is applied!

4.2. Measurement of saturation and the investigation of signal shape

Saturation can be determined with an oscilloscope since it is clearly visible when the signal starts to distort. The saturation voltage is the peak-to-peak value of the input voltage corresponding to the highest undistorted amplified output signal.

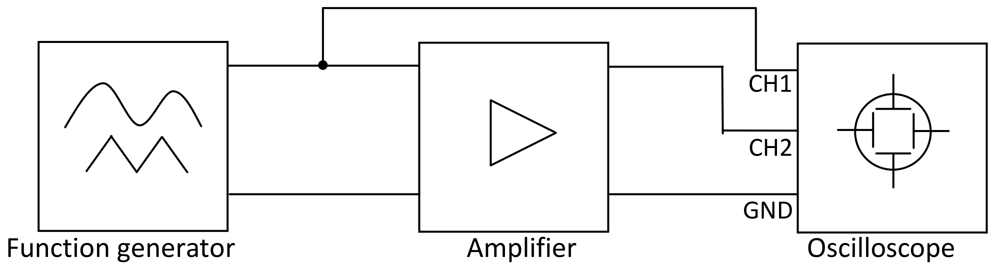

Figure 2. – Measurement of saturation

In telecommunications engineering the reference values are the ones measured at f=1000 Hz. Note, that if any other value isn't given, the measurement shall be performed with and f=1000 Hz sine signal! Increase the voltage of the generator to the point where we start to observe a distortion in the output. Record this input voltage, since it is the saturation of the amplifier! Always be cautious when any of the amplifier parameters exceeds this value while measuring, since data from an overdriven amplifier is always false.

4.3. Measure voltage amplification

Voltage amplification coefficient is given by the ratio of the output and input voltages. We need to measure these with a given load. The output cannot be distorted! Voltage amplification can be calculated using the previously given setup. Voltage amplification (A_u) is usually given in decibels a_u [dB]:

$$a_u = 20 \lg \left| \frac{U_{out}}{U_{in}} \right| \text{ [dB]}$$

4.4. Determine the cut-off

After we determined the frequency range, where the amplifier provides maximal amplification, the cut-offs can be determined by changing the frequency of the input (increase and decrease) while keeping a constant amplitude.There will be two frequencieswherethe amplification decreases with 3 dB. These two frequencies are the two cut-offs of the amplifier, here the voltage amplification decreases by a factor of $1/\sqrt{2}$. Measuring the amplification at different frequency values we get the transition characteristics (Figure 3.)

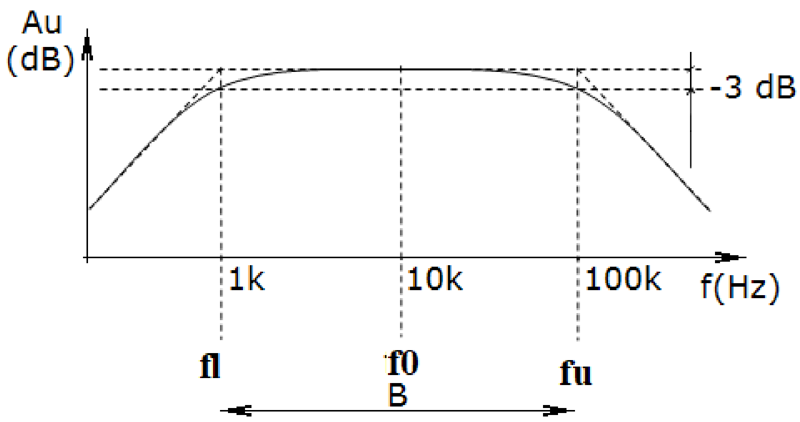

Figure 3. – Bode-diagram of an amplifier

The bandwidth of an amplifier is the interval between the lower (f_l) and upper (f_u) cut-off frequencies. It is essential to investigate where the signal steps out from the 3 dB band compared to the value measured at the middle value of the frequency-independent amplification interval (f_0). Bandwidth is calculated as $B=f_u-f_l$

4.5. Determine the phase shift (with analog oscilloscope)

From the basic circuits the common emitter amplifier provides a 180° phase shift at maximum amplification between the input and the output. We introduce two different methods to measure the phase shift. For a digital oscilloscope, the measurement of the phase shift can be set.

4.5.1. Lissajous-method

The setup is shown on Figure 4. We turn off the horizontal gauge and we switch on the input of the amplifier. The vertical couch is driven by the output. If a phase shift is present, the oscilloscope will display pattern similar to what is presented in Figure 4.b.

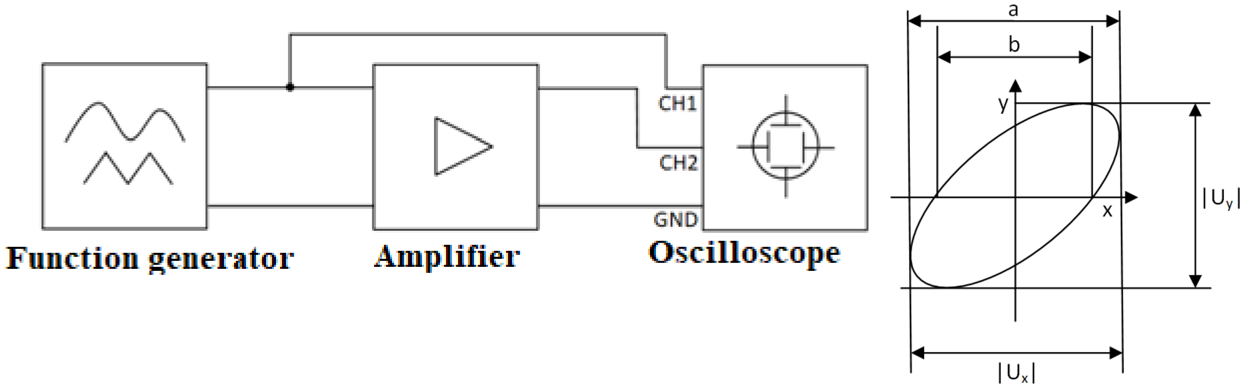

Figure 4. – Measure phase shift with Lissajous-method

Here the phase shift can be described as:

$$\sin\varphi = \frac{b}{a}\text{, if } |U_x| = |U_y|$$

4.5.2. Comparison method

With a two-channel oscilloscope,the comparison method is easily carried out. Display both signals on the same oscilloscope. The outcome of this method is shown in Figure 5. It is recommended to set the total period (T) to 8 divisions.

$$\varphi = \frac{t}{T} \cdot 360°$$

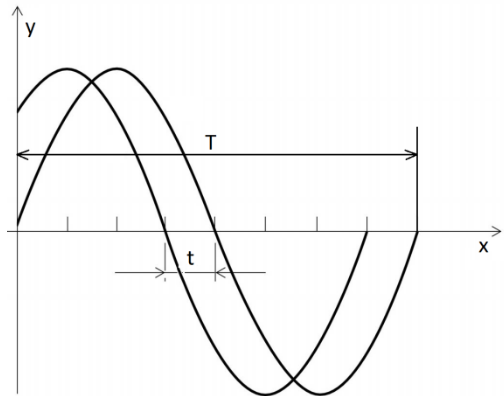

Figure 5. – Measure phase shift with comparison method

4.6. Measure input and output resistance

The input of the amplifier at a middle-band frequency can be replaced with a single resistance. The input resistance is the one that loads the signal source, say the driving stage.

A simple measurement method to determine the AC input resistance of the amplifier is shown on Figure 6.

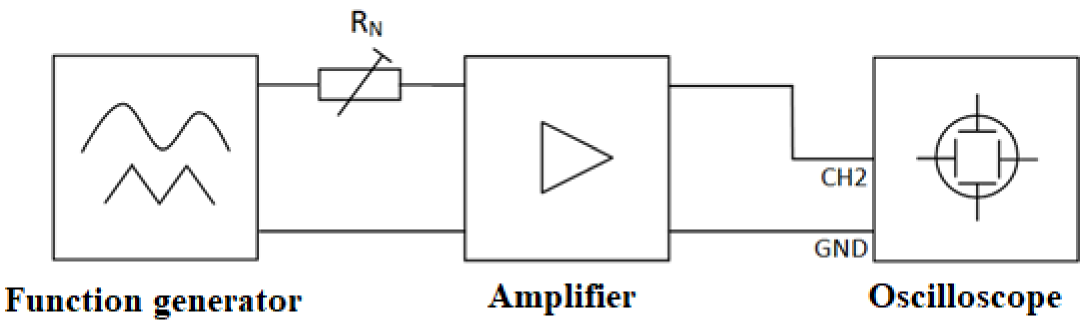

Figure 6. – Measure input resistance

Measure at maximal amplification with a frequency smaller than the cut-off. Record the output voltage with $R_N = 0\ \Omega$! Then change the tuneable R_N while the output decreases to the half of its previous value. Here R_N is exactly the input resistance.

Another method is to install a serial measurement resistor with a known resistance between the driving and the input and drive the amplifier through this resistor. Record voltages U_g and U_{in}. The input resistance then can be calculated.

The input can be replaced with a generator driven by the input signal and a resistor. The output resistance is the one on which the load is connected to.

Output resistance can be determined with the voltage comparison method. Measure the output voltage and install the R_N potentiometer resistor. Change its value to the point, where the half of the original output is measure. Here R_N is equal to the output impedance of the amplifier.Another method is to measure it in two steps. Without changing the input voltage, we measure the output voltage without any load (open-circle output voltage, $U_{out,\ OC}$) and with load ($U_{out,\ load}$). Then the output resistance can be calculated.

4.7. Signal-to-noise ratio (SNR)

SNR is a widely spread nomination. It gives the ratio of the effective and the faulty or irrelevant information. It is defined as the ratio of the power of the signal and the power of the background and noise. At an amplifier the power of the noise and the signal do not need to be maximal along the measurement of the SNR, consequently we need to designate a reference signal, which will be the basis of the measurements. We need to install a 1 kHz sine signal on the input and increase its amplitude to the cut-off. The value of the output shall be recorded. Then the input shall be decreased to zero, and the output needs to be measured, which is the noise itself. The ratio of the two is the SNR.

4.8. Distortion

The nonlinear behaviour of an amplifier is manifested when there are frequency components in the spectrum of the output which do not play a role in the input. Distortion is the change in the shape of a signal going through the circuit. There are diverse types of distortions. The two main types are linear and non-linear distortion. In a distortion measurement, we drive the circuit with a sinusoidal signal having frequency f, and investigate the appearance of harmonics 2f, 3f etc. in the output.

5. The Miller-effect

Some capacitances between the three electrodes of a transistor can be always measured. When a transistor is built, the manufacturer will attempt to minimize the capacitance between the electrodes, however this value will always be non-zero. Their effect can be significant at higher frequencies. Capacitances of a transistor is shown on Figure 7. Miller-effect appears at the collector-base transition. In this circuity the increase of the base voltage causes a decrease in the collector voltage, say there is a capacitance between the input and the output, which effects significantly the frequency characteristics of the transistor.

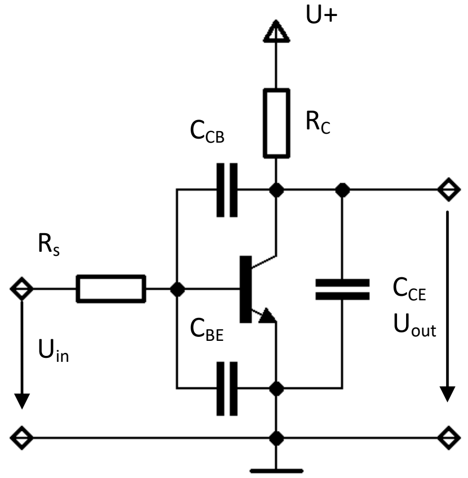

Figure 7. – Capacitances in a transistor

Suppose that our transistor is having a voltage amplification A, then C_{CB}- can be replaced by a capacitance having value $(1+A)C_{CB}$between the base and the ground. The frequency limiting effect of C_{CB}can be significant at large amplifications. It can be seen that the value of the Miller capacitance is determined by the amplification, say if we would like to amplify, the time-constant can only be decreased by reducing the input resistance. A method for the alleviation of the Miller-effect is shown on Figure 8.

U+
R_C

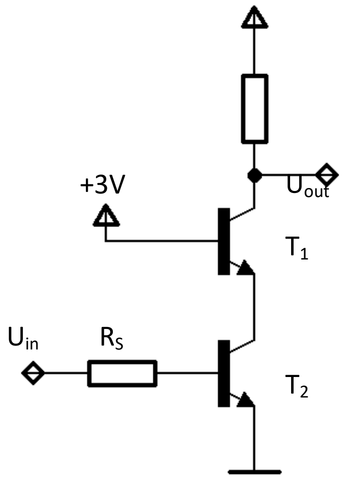

Figure 8. – Cascadecircuit

In this circuit there is no direct feedback from the output to the input, say the amplification does not multiply the capacitances of transistors C_{CB}.
In a cascade circuit installing the second transistor causes the fact, that the output voltage will not be drained from the collector ofT_2. On$T_1$the Miller-effect is fend off by the fact, that its base is connected to a DC voltage, in other words the capacitance will not play a role in this setup.

There are methods lowering the Miller-effect, but stray capacitances cannot be totally eliminated. This has serious consequences, which clearly appears at microprocessors used in computers. The increase in the complexity of the integrated circuits and the decrease of its size, devices and wires are more and more near to each other (width of wires in a microchip today is a fraction of a micron), and the width of the insulation between them is in the same order of magnitude. This decrease in size automatically leads to the increase in stray capacitances, which decreases the operational speed of the system. This can only be avoided by lowering the input resistances of the driving steps. Currents are producing Joule-heat, which is proportional toI^2. Higher currents mean increased heat production. Fast, high frequency processorsheat up fast, this is why they require enhanced cooling.

6. Measurement exercises

M1. Investigation of common emitter amplifier

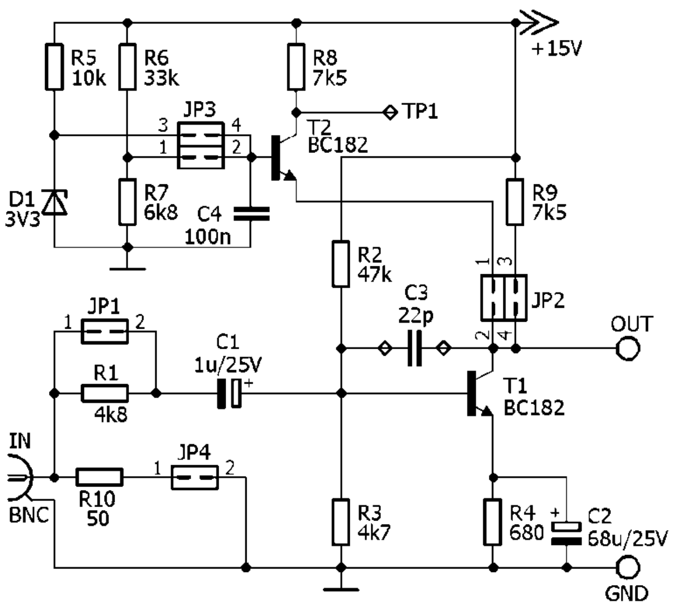

Figure 9.–Common emitter amplifier onthe 3rd or "D" block of panel no. V.

Before connecting the circuit (Figure 9.) to the voltage supply, the jumpers should be set up as described: the jumpers (JP, blue square cap including a short circuit) by the following: $JP_1$is opened, JP_2 3-4is closed, JP_3 3-4 is closed, $JP_4$is opened, C_3 not plugged in. Numbers and their direction next to the jumpers on the figure are similar the ones on the panel. Then connect +15 V supply voltage!

a) Measure the DC operational point voltages of the amplifier by the (U_B, U_E, U_C) and calculate the base-emitter (U_{BE}) and collector-emitter (U_{CE}) voltages!Here consider that there is a serial Si protecting diode on the panel plugged serial to the supply voltage.

b) Measure the saturation! Perform it with the oscilloscope! Construct the layout shown on Figure 2. Increase the amplitude of the 1 kHz sinusoidal signal set up on the function generator from zero to the point where the output starts to distort on the scope. Read the peak-to-peak value of the input here, this is the saturation.

c) Measure the frequency response (measurement of A_u=f(f) and φ=f(f) functions)! Frequency dependence of amplifiers is given by amplitude and phase characteristics. Calculate amplification in dB at all given frequencies and produce the frequency response of the amplifier! Use logarithmic frequency axis on the plot! Record the measured and calculated data similarly as in the table below (U_{in}be approximately 50mV peak-to-peak).

f [Hz]	50	100	200	500	1000	2000	5000	10000	20000	50000	100000
U_{in} [mV]											
U_{out} [mV]											
A_u											
a_u [dB]											
φ [°]											

Table 1. – Investigate frequency response

d) Measure the upper and lower cut-offs, and calculate the bandwidth (B)!
e) Plug in a 22pF capacitor(C_3) between the collector and base ofT_1. How does C_3modify the upper cut-off frequency?
f) Modify the circuit by plugging in T_2!JP_2 1-2 should be closed, 3-4 opened. This will form a cascade circuit. Measure upper cut-off frequency! What is the explanation of such a great change in the cut-off frequency?

Note: On panels where this signal is not output, it must be measured on TP1! To fix the tip of the probe while measuring.

M2. Investigation of common collector amplifier

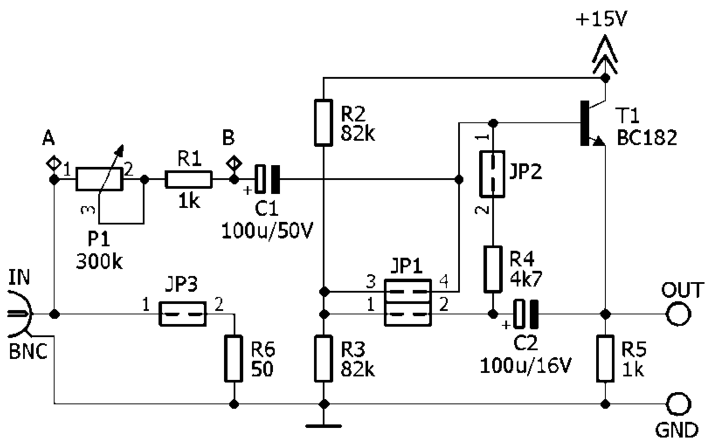

Figure 10. - Common collector amplifier on the 2nd or "E"block of panel no. V.

Before starting the measurement, apply the following settings in the circuit shown on Figure 10.: turn $P_1$with a screwdriver counterclockwise to its end point, JP_1 1-2 opened and 3-4 closed, JP_2 opened, JP_3 opened.

a) Give a 1 V peak-to-peak 1 kHz sinusoidal signal to the input! Investigate the output signal and determine the amplification and the phase shift!
b) Investigate these parameters with input frequencies 100 Hz, 10 kHz, 100 kHz and 1 MHz using a similar amplitude.
c) Turn back the input to 1 kHz! Using a screwdriver, turn the P1 potentiometer until you see half of the maximum signal (Vpp) at the output. Plug off the supply and the input and measure the resistance between points A and B with a multimeter! Since the serial resistance halved the previous output, this is the input resistance (R_{in}).
d) Turn $P_1$with the screwdriver counterclockwise to its end.Let JP_1 1-2 closed and 3-4 opened, JP_2 closed, JP_3 opened. This is the so-called high input resistance FK amplifier. Change the value of potmeter P_1such as the output shall be the half of the original. Then plug off the supply and the input signals, and measure the resistance between A and B. What do you observe?

The applied measurement devices, generators, wires and parts shall be marked in the report with their type, serial number, number of pieces and values if they can read on the device! Please consider adjusting the quality and size of the photos so the overall report remains under 10 MB.
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