

3/4 (2. Halbttag) | Transistor und Transistorverstärker

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1 Introduction

In this experiment, the bipolar transistor is used, but here as an emitter sequence for voltage amplification and as an impedance converter (buffer). Also, the negative feedback of alternating current and the behavior of different frequencies will be observed via a cascode circuit.

2 Theory

The whole theory of different kinds of transistors is still needed.

An emitter follower is an electronic component, with which a current can be amplified (factor γ), without any change in voltage (factor ν).

$$\nu = \frac{dU_E}{dU_B} \approx 1 \quad \gamma = \frac{dI_E}{dI_B} \approx 100. \quad (2.1)$$

This is why sometimes an emitter follower is called an impedance changer.

The negative feedback factor k denotes, which fraction of the output voltage is used for the negative feedback

$$\frac{1}{\nu} = \frac{1}{\nu_0} + k. \quad (2.2)$$

Though the amplification with negative feedback ν is lower than the open-loop gain ν_0 , ν is only dependent on the circuit and not on the transistor itself. This amplification can be described as follows

$$\frac{d\nu}{\nu} = \frac{d\nu_0}{\nu_0} \frac{\nu}{\nu_0}. \quad (2.3)$$

The bandwidth of the amplifier circuit is the frequency band, in which the amplification is constant. To increase the bandwidth, one can use a cascode circuit. To achieve such an amplification, the alternating voltage feedback of the collector on the basis is reduced by utilizing a second transistor to prevent a voltage swing. Given an input signal, the resulting change in voltage will be significantly lower than the change in the output signal. This results in a higher bandwidth.

Stabilization of the operating point can be achieved by using negative feedback, in particular negative feedback of voltage.

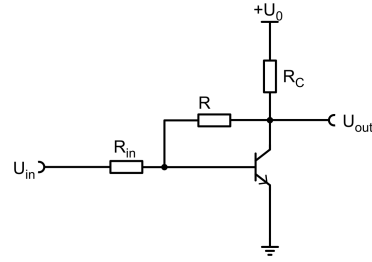


Figure 1: Transistor amplifier as common collector with negative feedback (voltage); figure 3/4.16 [1]

In this figure the resistor R sets the base potential as well as the operating point and couples the voltage from the collector back to the base. Due to this negative feedback the base current is reduced although the input current remains constant.

3 Preliminary Tasks

3.1 G

$\mathbb{Z} \nu = \frac{\gamma R_E}{r_{BE} + \gamma R_E}$ with $\gamma = \frac{dI_E}{dI_B}$ and $r_{BE} = \frac{dU_{BE}}{dI_B}$.

$$\begin{aligned}
 \nu &= \frac{dU_E}{dU_B} \\
 \Leftrightarrow &= \frac{dI_E R_E}{dU_{BE} + dU_E} \\
 \Leftrightarrow &= \frac{\frac{dI_E R_E}{dI_B}}{\frac{dU_{BE}}{dI_B} + \frac{dU_E}{dI_B}} \\
 \Leftrightarrow &= \frac{\gamma R_E}{r_{BE} + \gamma R_E}.
 \end{aligned} \tag{3.1}$$

3.2 H

The equation applies

$$\begin{aligned}
 \frac{r_{out}}{r_{in}} &= \frac{\frac{dU_E}{dI_E}}{\frac{dU_B}{dI_B}} \\
 \Leftrightarrow &= \frac{dU_E}{dI_E} \frac{dI_B}{dU_B} \\
 \Leftrightarrow &= \frac{dU_E}{dU_B} \frac{dI_B}{dI_E} \\
 \Leftrightarrow &\approx 1 \cdot \frac{1}{\gamma}.
 \end{aligned} \tag{3.3}$$

3.3 I

The equation applies

$$\begin{aligned}
 \nu &= \frac{dU_C}{dU_B} \\
 \Leftrightarrow &= \frac{dI_C R_C}{dU_{BE} + dU_E} \\
 \Leftrightarrow &= \frac{\frac{dI_C R_C}{dI_B}}{\frac{dU_{BE}}{dI_B} + \frac{dU_E}{dI_B}} \\
 \Leftrightarrow &= \frac{\beta R_C}{r_{BE} + \gamma R_E}.
 \end{aligned} \tag{3.5}$$

3.4 J

The equation applies

$$\begin{aligned}
 \frac{1}{\nu} &= \frac{1+k\nu_0}{\nu_0} \\
 \Leftrightarrow \nu &= \frac{\nu_0}{1+k\nu_0} \\
 \Leftrightarrow \frac{d\nu}{d\nu_0} &= \frac{1}{(1+k\nu_0)^2} \\
 \Leftrightarrow &= \frac{\nu}{\nu_0} \frac{1}{1+k\nu_0} \\
 \Leftrightarrow \frac{d\nu}{\nu} &= \frac{d\nu_0}{\nu_0} \frac{1}{1+k\nu_0} \\
 \Leftrightarrow &= \frac{d\nu_0}{\nu_0} \frac{\nu}{\nu_0}.
 \end{aligned} \tag{3.7}$$

3.5 K

The parallel capacitor with capacitance C_{CB} and transistor form a high-pass filter. This means that high frequency signals will run through the capacitor and not the transistor, resulting in them not being amplified.

3.6 L

There is no voltage change at point P, because the input signal to the transistor T2 is constant. The change in current $dI_E(T_2)$ is in return also zero.

3.7 M

For any transit frequency the equation holds $f_{\text{grenz gk}} \nu(f=0) = f_{\text{grenz}} \nu_0$. Thus $f_{\text{grenz gk}} = f_{\text{grenz}} \frac{\nu_0}{\nu(f=0)}$.

3.8 N

For increasing base current I_B , the collector voltage U_C and the voltage across the resistor U_{R_C} also increases. Because U_0 should be constant, the voltage drops across the resistor R , which in turn stabilizes the operating point.

4 Analysis

4.1 Voltage amplifier of the common collector

On circuit board I (Fig. 2) we construct a common collector with $dU_B = 2.1 V_{PP}$ and $U_B \approx 2 V$. To test the voltage amplification we chose a variety of different resistor combinations. The measurements are displayed in Tab. 1. We expect no change for different R_E .

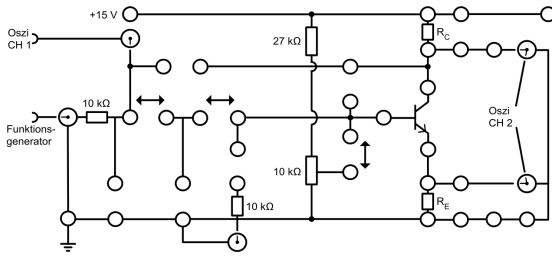


Figure 2: Circuit board 1[1]

R_C	R_E	amplification ν
360 Ω	1 k Ω	1.000(25)
360 Ω	22 k Ω	1.025(25)
360 Ω	47 k Ω	1.015(25)
1 k Ω	360 Ω	0.945(25)
22 k Ω	360 Ω	0.114(25)
47 k Ω	360 Ω	0.120(25)

Table 1: Voltage amplification for different resistor combinations

As we see, there is no significant variation of the amplification for different R_E . Though we can clearly see a lowering of the amplification for higher R_C , which is plausible since we have less current that can be amplified.

4.2 Common collector as buffer amplifier

Here we are tasked to match the impedance of a speaker, so we are able to hear an output. For this we firstly construct an Inverted Amplifier and test the speaker solely without a common collector. We observe, that the speaker does not produce any sound, because we haven't matched the impedance. Now we add a common collector as a buffer amplifier, which in theory should be able to match the impedance of the speaker. Unfortunately we could not get the circuit running and test the hypothesis.

4.3 Inverted amplifier

4.3.1 Phase relationship between input and output

Now we build a common emitter on circuit board I with $R_C = R_E = 390 \Omega$, $dU_B = 0.5 V_{PP}$, $U_B = 1.5 V$ and we choose a capacity prior to the input signal of $0.1 \mu F$. As we can see in the xy (CH1, CH2) configuration in fig. 3, the phase is not linear, but elliptic. Thus we have not the same phase. We found out through experimenting, that the multiple ellipses come from noise. The phase relationship and especially the noise is also visible in fig. 4, as the lines are rather thick. We can see that the phase difference is between $\frac{1}{2}\pi$ and 1π , because we now have coupled the capacitor.

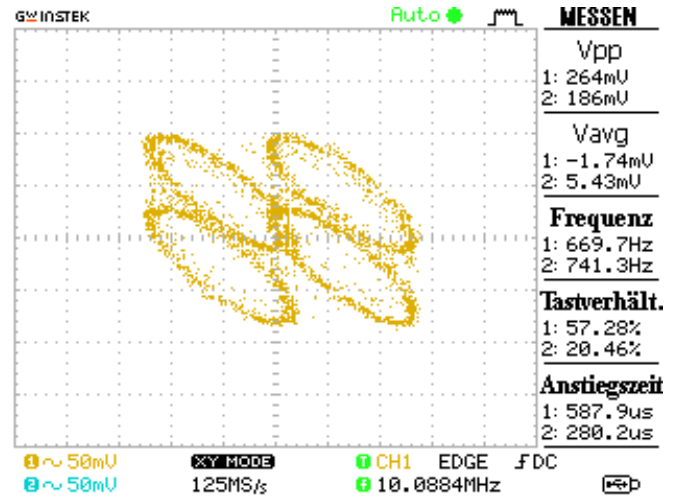


Figure 3: Phase relationship in phase space

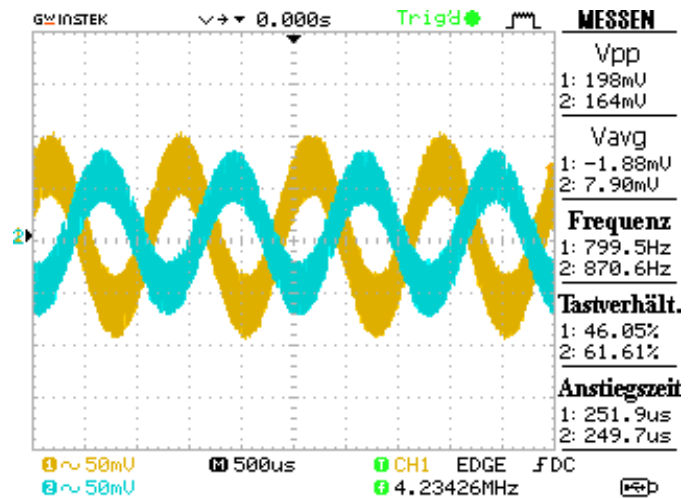


Figure 4: Phase relationship in voltage/time space

4.3.2 Voltage amplification of the inverted amplifier

We measure the voltage amplification with different values for the resistors R_E and R_C . The results are displayed in tab. 2.

R_C	R_E	amplification ν	$\nu = -\frac{R_C}{R_E}$
360 Ω	470 Ω	-0.686(24)	-0.830
360 Ω	1 k Ω	-0.437(24)	-0.390
360 Ω	4.7 k Ω	-0.250(25)	-0.083
360 Ω	33 k Ω	-0.196(25)	-0.012
360 Ω	47 k Ω	-0.180(25)	-0.008
470 Ω	360 Ω	-0.857(24)	-1.205
1 k Ω	360 Ω	-1.491(25)	-2.564
4.7 k Ω	360 Ω	-2.284(22)	-12.05
33 k Ω	360 Ω	-0.234(27)	-84.62
47 k Ω	360 Ω	-0.234(27)	-120.5

Table 2: Voltage amplification for different resistor combinations

We notice that the part, where R_C stays constant, the experimental values follow the theoretical ones in their general trend, but are not exactly the same. For the part where R_E stays constant we observe that first the data follows the calculations, but to the end, with the highest resistance, just drop. It seems that there is a sweet spot for an optimal amplification. Then it should have to do something with resonance, so the amplification is frequency dependent.

4.3.3 Resistance of a Transistor

Now with the special case, that $R_E = 0 \Omega$ and $E_C = 390 \Omega$, we can read the peak-to-peak voltage from oscillogramm and calculate the amplification and $\beta = \frac{I_C}{I_E}$ with $I = \frac{U}{R}$.

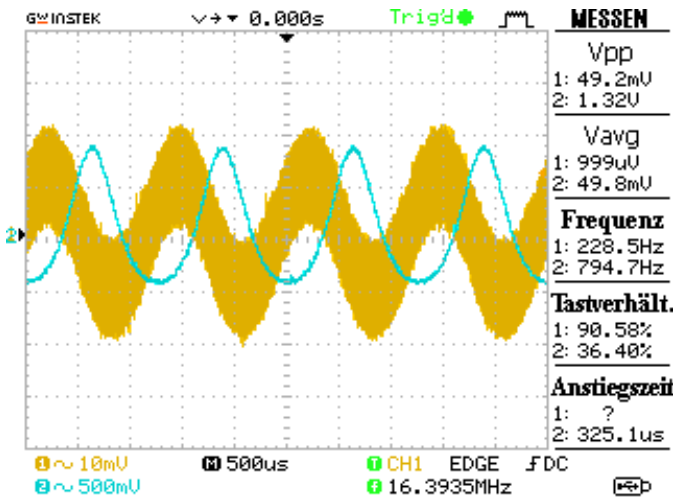


Figure 5: Phase relationship in phase space

4.4 Common Collector as Buffer Amplifier

Here we are tasked to match the impedance of a speaker, so we are able to hear an output. For this we firstly construct an Inverted Amplifier and test the speaker solely without a Common Collector. We observe, that the speaker does not produce any sound, because we haven't matched the impedance. Now we add a Common Collector as a Buffer Amplifier, which in theory should be able to match the impedance of the speaker. Unfortunately we could not get the circuit running and test the hypothesis.

4.5 Inverted Amplifier

4.5.1 Phase Relationship between input and output

Now we build a Common Emitter on Circuit Board I

4.6 Alternating current cancellation of negative feedback

In this task, the noise visible on the oscilloscope is reduced by increasing the voltage of the input signal.

Changing R_E to be zero, the amplification $|\nu|$ is maximised. The range in which the transistor has enough voltage to output a sinusoidal signal, meaning the signal lies within the dynamic range, is between $R_P \in [1.359 \text{ k}\Omega, 3.161 \text{ k}\Omega]$. R_P is the potentiometer changing the offset voltage. For $R_E = 390 \Omega$ (which is $|\nu| = 1$), the potentiometer has a range of $R_P \in [1.178 \text{ k}\Omega, 10 \text{ k}\Omega = \max(R_P)]$.

Now a capacitor with capacitance $C = 0.1 \mu\text{F}$ is connected in parallel with R_E . The previous amplification of around 10 is achieved for a signal with frequency 44 kHz. This makes sense, because the capacitor in parallel acts as a low pass, letting frequencies below 44 kHz pass through it, such that no amplification of 10 is achieved. The resistance above 44 kHz is high enough so that the signal passes through the transistor and gets amplified.

4.7 Frequency response of a cascode circuit

A [transistor amplifier circuit](#) is constructed on [circuit board 2](#). Output 2 is used here.

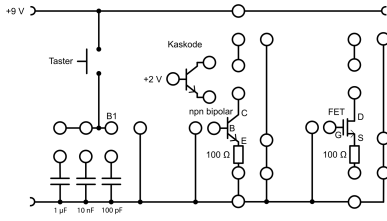


Figure 6: Circuit board 2; Abb. 3.5[1]

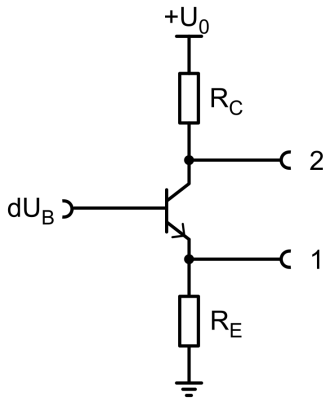


Figure 7: Transistor amplifier circuit using output 2; Abb. 3/4.15[1]

To achieve an amplification of 10, the emitter and collector resistors are chosen to be $R_E = 100\ \Omega$ and $R_C = 1\ \text{k}\Omega = 10 \cdot R_E$. The input signal is a sinusoidal wave of 100 Hz with $U_{PP} = 200\ \text{mV}$. The DC-offset is set via a voltage divider.

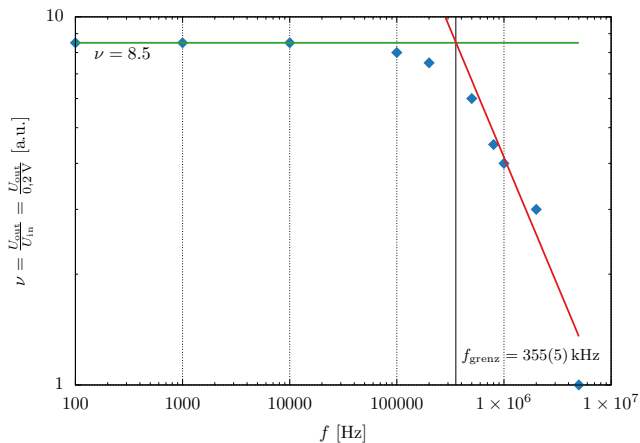


Figure 8: Bode-plot of a transistor amplifier circuit

frequency [Hz]	voltage [V]	ν [a.u.]
100	1.7	8.5
1000	1.7	8.5
10000	1.7	8.5
100000	1.6	8.0
200000	1.5	7.5
500000	1.2	6.0
800000	0.9	4.5
1000000	0.8	4.0
2000000	0.6	3.0
5000000	0.2	1.0

Table 3: Values to 8

The fit curve is given by $f(x) = x^m \cdot b$, with $m = -0.695\,813(246300)\ \text{Hz}^{-1}$ and $b = 62\,123.800(2149) \times 10^5$. As expected, the amplification stays the same until the cutoff frequency $f_{\text{grenz}} = 355(5)\ \text{kHz}$ is reached. After that, the amplification decreases exponentially. At an amplification of $\nu = 1$ the input voltage of 200 mV is reached. The transit frequency is calculated via

$$f_T = f_{\text{grenz}} \nu_0 = 355(5)\ \text{kHz} \cdot 8.5 = 3017.5(425)\ \text{kHz}. \quad (4.1)$$

To calculate the bandwidth one can solve for x in

$$1 = x^m \cdot b \Leftrightarrow x = B = 7.73(61)\ \text{MHz}. \quad (4.2)$$

Due to lack of time, it was not possible to construct the cocode circuit and measure the amplification–frequency relation again. Though it was expected to see a decline in amplification for an increase in bandwidth. The transit frequency would have still been the same.

4.8 Amplifier with negative feedback

Due to time contrains it was not possible to complete the final task.

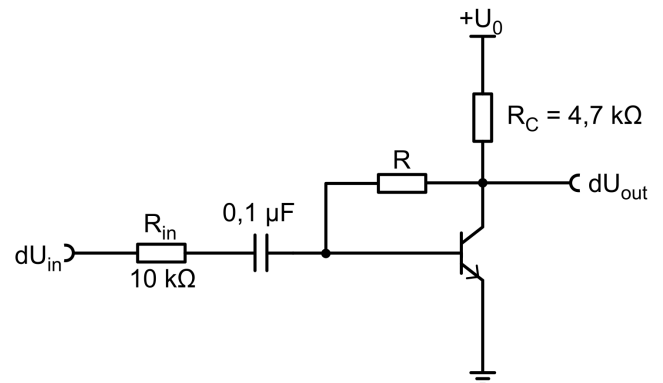


Figure 9: Amplifier with negative feedback; Abb. 4.1[1]

With $R = 100\ \text{k}\Omega$ as well as $R = 33\ \text{k}\Omega$ the voltage amplification $\frac{dU_{\text{out}}}{dU_{\text{in}}}$ should have been measured for an

input frequency of $f = 1$ kHz.

Because R_{in} reduces the amplification, measurements have to be taken after R_{in} as well. One would expect an increase in amplification because no voltage can drop across R_{in} .

5 Conclusion

Also one could demonstrate the effect of an high-pass used in an amplifier, by connecting a capacitor in parallel and

comparing the frequencies at which a similar amplification is achieved.

The cutoff frequency of an amplifier circuit is demonstrated in a bode-plot (8). It can be seen that the amplification stays constant and suddenly falls at the cutoff frequency of $f_{\text{grenz}} = 355(5)$ kHz. One can now calculate the transit frequency to be $f_T = 3017.5(425)$ kHz and the bandwidth $B = 7.73(61)$ MHz.

Due to lack of time the comparison with a cascode circuit as well as the last task couldn't be completed. The expected results have been discussed nevertheless.

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Source

[1] Fabian Hügging. *Elektronik-Praktikum Versuchsanleitung*. Universität Bonn, kurs b edition, 2024.