PROTOCOL

to laboratory exercise

Negative Feedback

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Negative Feedback

BC546 & BC556

Used Devices

Nr.	Device	Manufactor	Type	Place Nr.
1.	Function Generator	HAMEG	HM8030-6	-
2.	Power Supply	Conrad	PS2403D	-
3.	Oscilloscope	Tektronix	TDS 1001B	-

Used Programs

Nr.	Name	Version
1.	Altium Designer	13
2.	Micro-Cap	11

1 Table of Contents

2 Tasks

Task of this laboratory exercise was to build a Two Stage Complementary Amplifier. This circuit is used to amplify the voltage based on the given gain.

1. Calculation, construction
2. Measurement of the BIAS voltage
3. Measurement of the gain and voltage capability.
4. Measurement and visualizing of the Bode Plot (Amplitude- and Phaseresponse)
5. Measuring of input and output resistance (r_{IN} and r_{OUT})
6. Measurement of the Open Loop Gain

2.1 Measurement Circuit

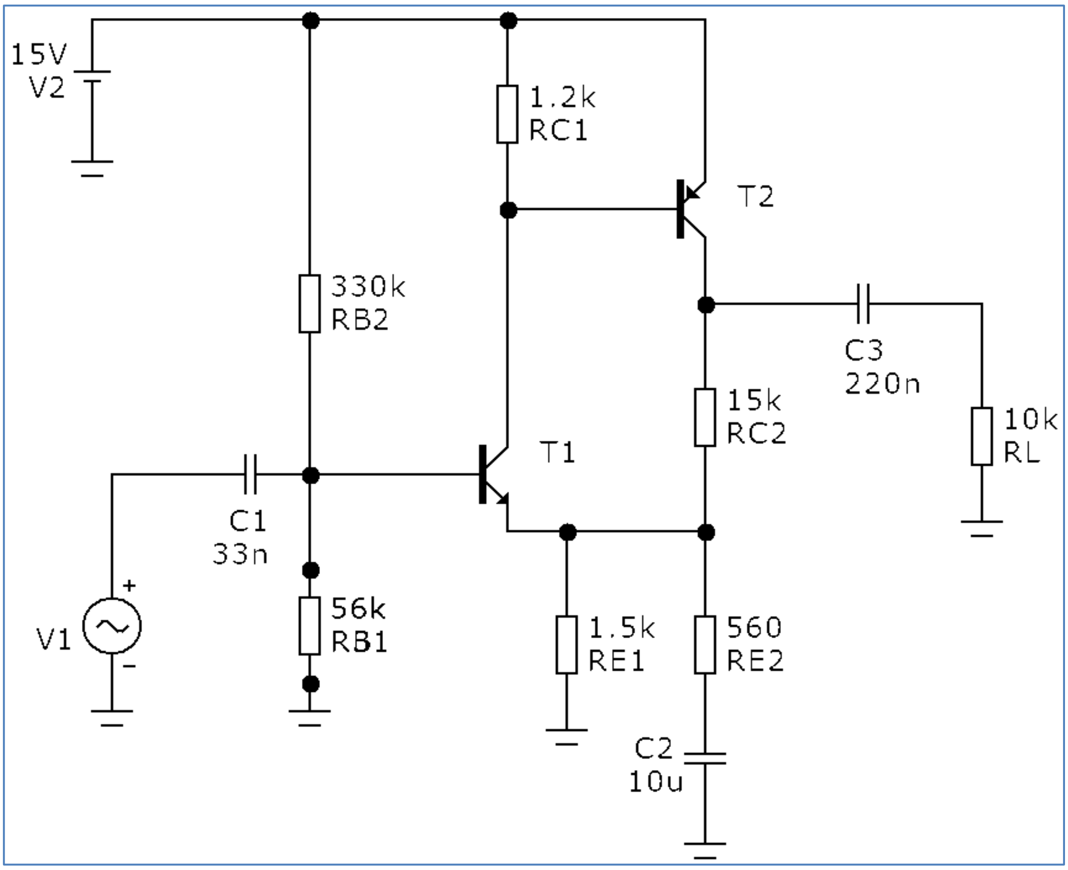

Figure 1 - Circuit of a two stage complementary amplifier

2.2 Given values

The taken assumptions at point *2.2.1 Assumptions* were taken based on the following dependencies.

$$1\,V \leq U_E \leq 2\,V$$

$$U_{CE2} \approx U_{RC2}$$

$$100\,\mu A \leq I_{C1}, I_{C2} \leq 1\,mA$$

$$10 * I_{B1} \leq I_Q \leq 20 * I_{B2}$$

2.2.1 Assumptions

$I_{C1} = I_{C2} = 500\,\mu A$	$V_{cc} = 15\,V$	$f_g = 100\,Hz$	$B = \beta = 300$
$U_{E1} = 1.5\,V$	$U_{B1} = U_{B2} = 2.1\,V$	$R_A = 10\,k\Omega$	$V_u = 30 = 29{,}54\,dB$

Table 1 - Value Assumptions

3 Calculation and Dimensioning

$$I_{B1} = \frac{I_{C1}}{250} = \frac{500\ \mu A}{250} = 2\ \mu A$$

$$I_Q = 20 * I_{B1} = 20 * 2\ \mu A = 40\ \mu A$$

3.1 Needed Voltages

$$U_{CE2} = U_{RC2} = \frac{V_{CC-}\ U_{E1}}{2} = \frac{15\ V - 1.5\ V}{2} = 6.75\ V$$

$$U_{RB2} = V_{CC} - U_{B1} = 15 - 2.1\ V = 12.9\ V$$

3.2 Resistors

Therefore that all needed voltages were assumed or calculated all resistors could be calculated now.

$$R_{C1} = \frac{U_{RC1}}{I_{C1}} = \frac{600\ mV}{500\ \mu A} = 1.2\ k\Omega$$

$$R_{C2} = \frac{U_{RC2}}{I_{C2}} = \frac{6.75\ V}{500\ \mu A} = 15\ k\Omega$$

$$R_{B1} = \frac{U_{RB1}}{I_Q} = \frac{2.24\ V}{40\ \mu A} = 56\ k\Omega$$

$$R_{B2} = \frac{U_{RB2}}{I_Q} = \frac{12.9\ V}{40\ \mu A} = 330\ k\Omega$$

$$R_{E1} = \frac{U_{E1}}{I_{C1} + I_{C2}} = \frac{1.5\ V}{1\ mA} = 1.5\ k\Omega$$

The formula for calculating the gain was converted to calculate R_{E2}, the last needed resistor.

$$R_{E2} = -\frac{R_{C2} * R_{E1}}{R_{C2} - V_u * R_{E1}} = 750\ \Omega \rightarrow R_{E2} = 560\ \Omega$$

To get a more accurate gain the resistor R_{E2} were chosen to be a smaller one, this would make a definite amplification of 30.

3.3 Capacitors

For the following calculations the corner frequency was 100 Hz. Depending on real and available component values the next higher capacitor was choosen.

$$C_1 = \frac{1}{2\pi * f_g * (R_{B1}//R_{B2})} = \frac{1}{2\pi * 100\ Hz * (56\ k\Omega//330\ k\Omega)} = 33.24\ nF \rightarrow C_1 = 33\ nF$$

$$C_2 = \frac{1}{2\pi * f_g * R_{E2}} = \frac{1}{2\pi * 100\ Hz * 560\ \Omega} = 2{,}84\ \mu F \rightarrow C_2 = 10\ \mu F$$

$$C_3 = \frac{1}{2\pi * f_g * R_A} = \frac{1}{2\pi * 100\ Hz * 10\ k\Omega} = 160\ nF \rightarrow C_3 = 220\ nF$$

4 Basic Measurements

4.1 Bias Voltages

After final construction of the amplifier the bias voltages were measured. In this case the amplifier was operated with no input signal, so the operating point could be set and the bias voltages measured probably.

	Calculated	Measured
U_{B1}	2.1 V	**2 V**
U_{E1}	1.5 V	**1.5 V**
U_{BE}	0.6 V	**0.6 V**
U_{C1}	0.6 V	**0.6 V**
U_{BE2}	0.6 V	**0.6 V**
U_{CE1}	6.75 V	**6.46 V**
U_{RC2}	6.75V	**7.19 V**
U_{RB1}	2.24 V	**2.13 V**
U_{RB2}	12.9 V	**12.99 V**

Table 2 - Calculated and measured Values of the bias voltages

As seen in above table the measured and calculated values are very similar. Some differences were noticed but these are based on parasitic errors and irregular and non-ideal components.

4.2 Gain voltage

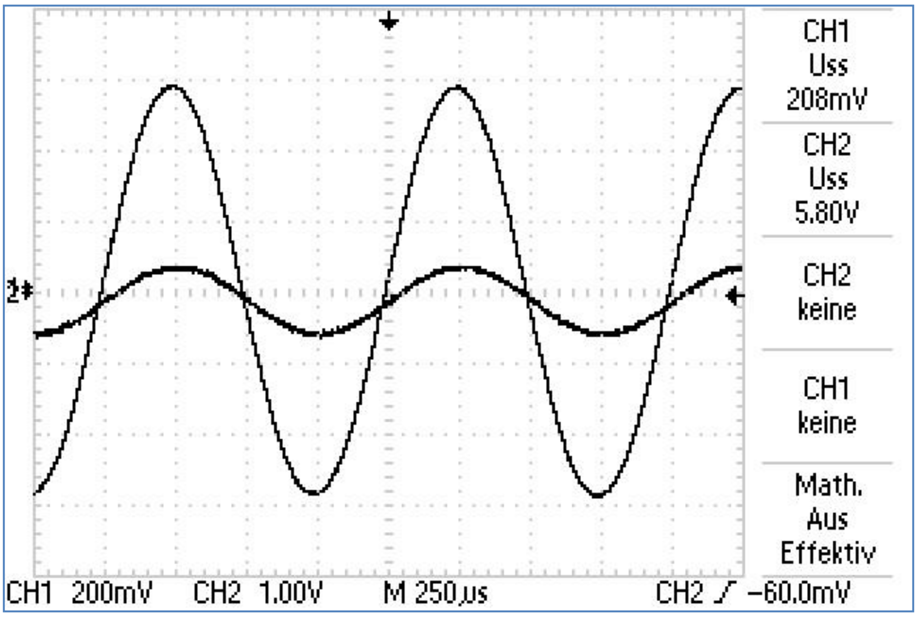

Figure 2 - Gain voltage

The amplifier was operated with an amplitude of 208 $mVpp$, the measured output voltage was 5.80 V. That implies that the gain is as assumed about 30.

$$V_u = \frac{U_A}{U_E} = \frac{5{,}8\ V}{208\ mV} = 27{,}88 = 28{,}90\ dB$$

In the gain voltage scope an amplification of 27.8 can be seen instead of 30. A more accurate measurement result would be achieved with a lower R_{E2}. This would cause a bigger amplification.

4.3 Voltage Capability

The voltage capability $U_{e_{max}}$ is about $225mV$. Is the input voltage higher than this voltage the amplifier starts going in saturation.

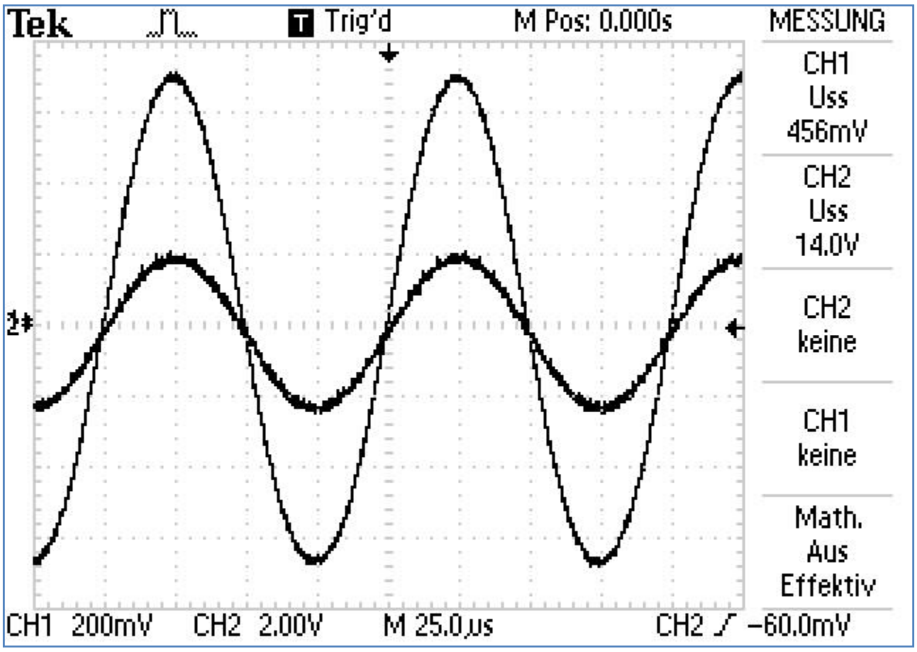

Figure 3 - Maximal voltage capability

With a higher input voltage ($\geq 480\ mV$) the output signal is already distorted. As seen in the following picture an amplitude of 229 $mVpp$ leads already to a saturation.

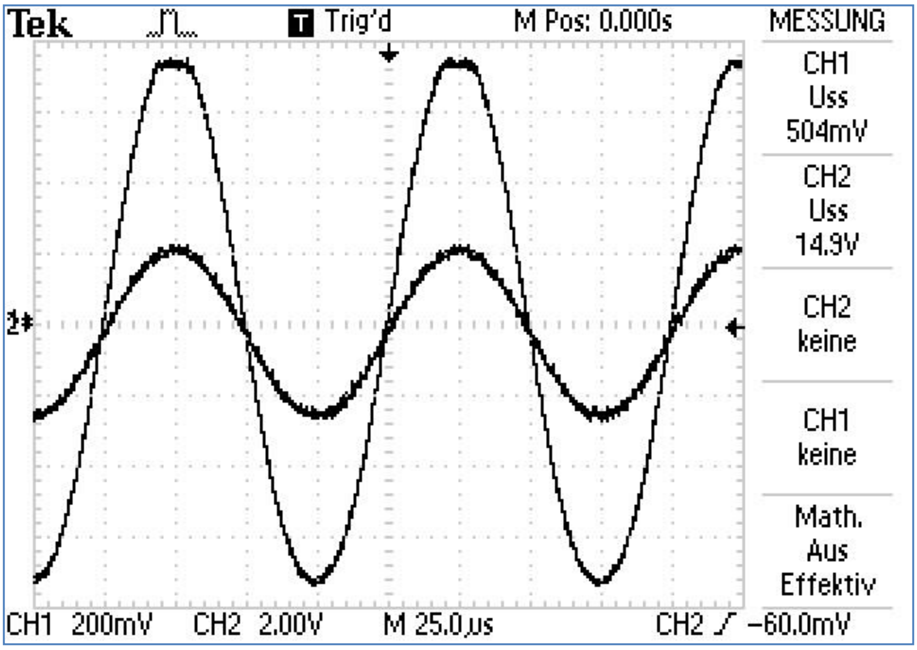

Figure 4 - Slightly distorted amplifier

With an amplitude of about 1 Vpp, which is way too high for a normal and functional operation, the amplifier is heavy overmodulated and already on saturation.
With 1 Vpp there is already a very steep rising rectangle signal at the output.

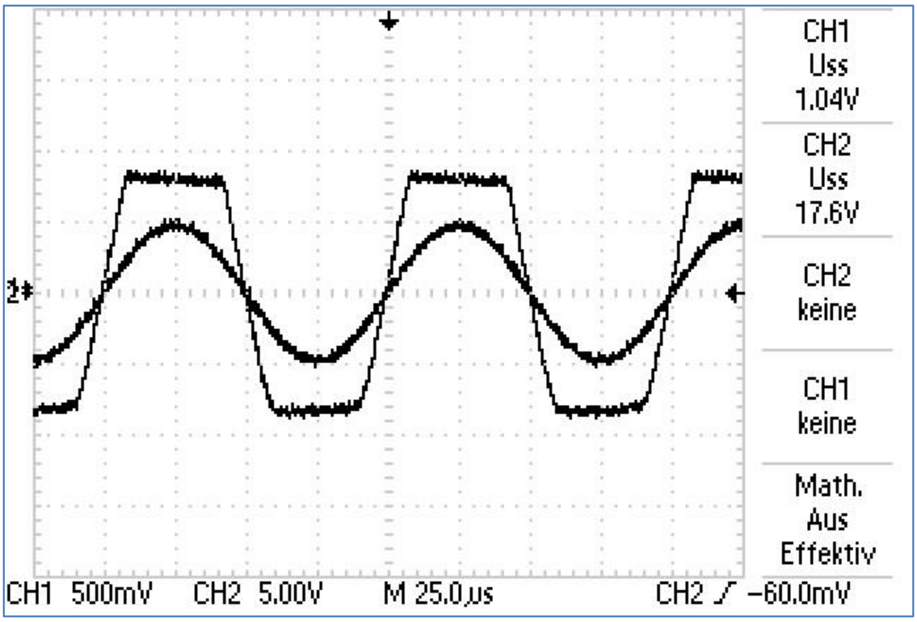

Figure 5 - Heavy distorted amplifier

5 Bode Plot

The following three values (U_e, U_a and dt) were measured with an oscilloscope by several multiple frequencies (20, 50, 100, 500, 1 000, 5 000, 10 000, 50 000, 1 000 000, 2 500 000 and 5 000 000) Hz

5.1 Measured Values

$f\ [Hz]$	$U_E\ [V]$	$U_A\ [V]$	$j\omega\ [dB]$	$dt\ [ms]$	$phi\ [°]$
20	0.181	0.7	11.7483893	12.08333333	87
50	0.181	1.8	19.9518786	2.2	39.6
100	0.181	3.38	25.4247625	0.27	9.72
500	0.181	5.2	29.1664954	0.022	3.96
1,000	0.181	5.3	29.3319459	0.0084	3.024
5,000	0.181	5.22	29.1998386	0.002	3.6
10,000	0.181	5.06	28.9294388	0.0008	2.88
5,000	0.181	5.02	28.8605028	0.0000534	0.9612
1,000,000	0.181	4.8	28.4712533	0	0
2,500,000	0.181	2.9	24.0943885	-0.000024	-21.6
5,000,000	0.181	1.7	19.4554069	-0.000046	-82.8

Table 3 - Bode plot measurement values

5.2 Amplitude response ($j\omega$)

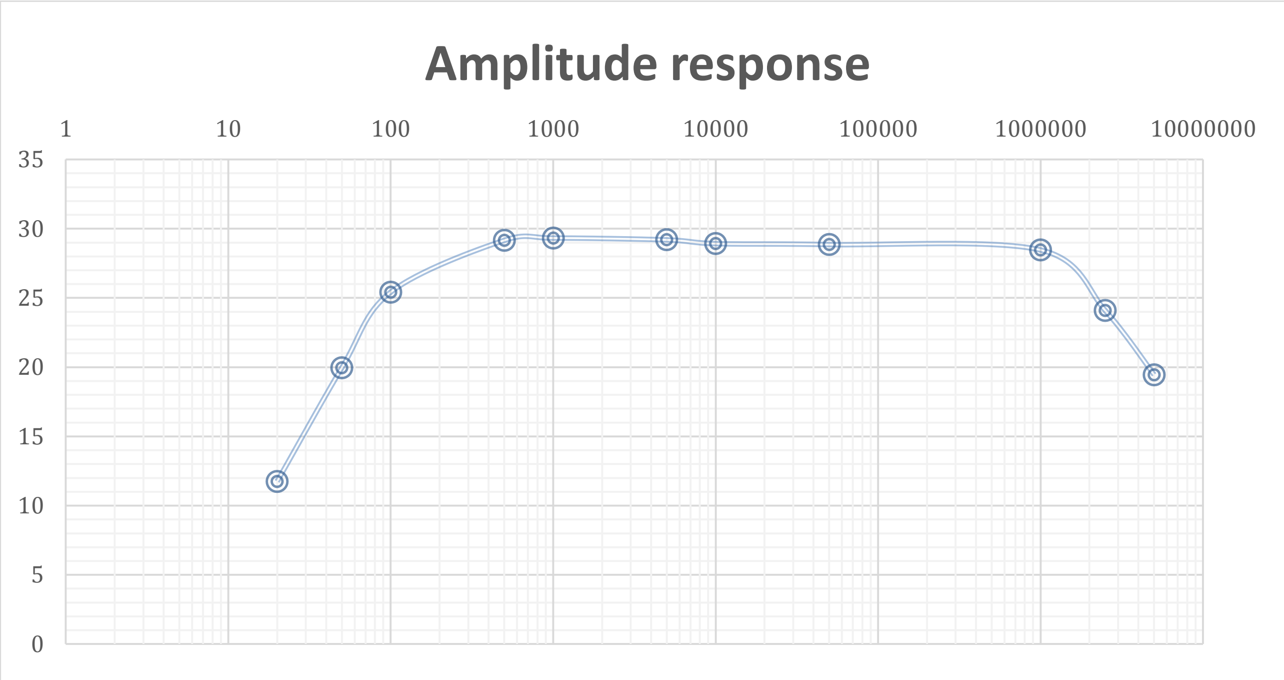

Figure 6 - Bode plot amplitude response

5.3 Phase response

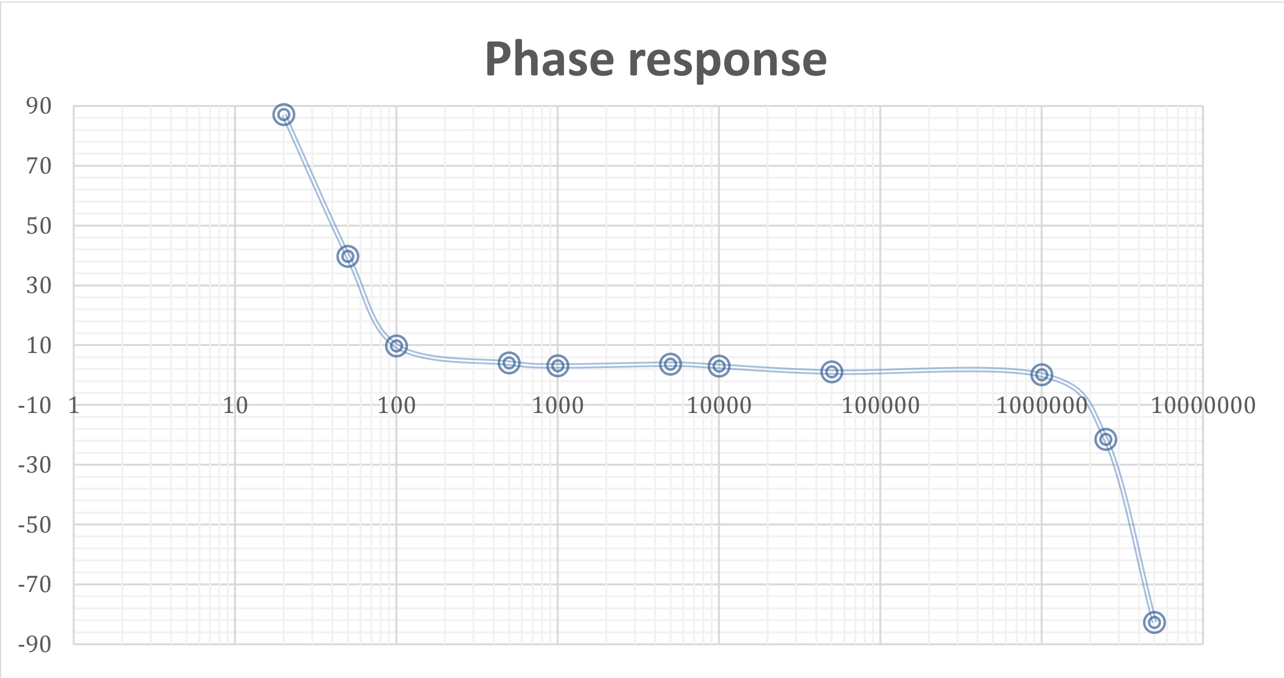

Figure 7 - Bode plot phase response

6 Input and output resistance r_{IN} and r_{OUT}

To measure the resistances of the amplifier, the input and output resistance, an additional extra circuit was built.

6.1 Input resistance r_{IN}

6.1.1 Measurement setup

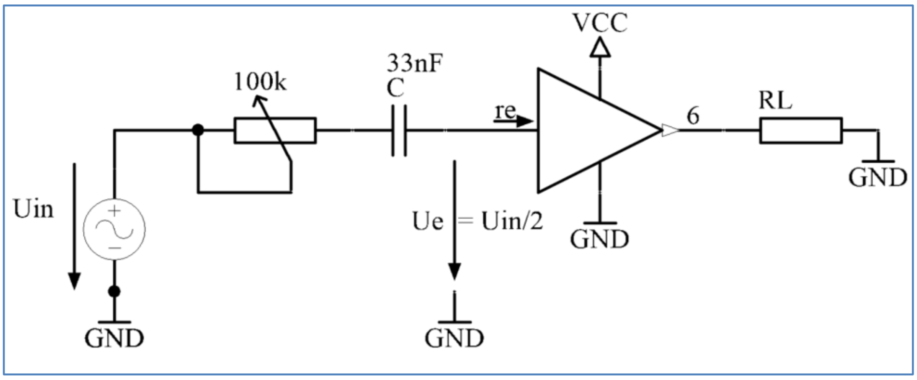

Figure 8 - Measurement circuit for the input resistance

6.1.2 Measurement results

The circuit was operated with a functiongenerator and the parameters of 200 mV and a frequency of 10 kHz at the input of the amplifier.

The 100 $k\Omega$ Potentiometer was changed until the measured voltage behind the capacitor U_E was half of the voltage from the input signal. U_E was measured behind the capacitor because otherwise a phase shift would exist.

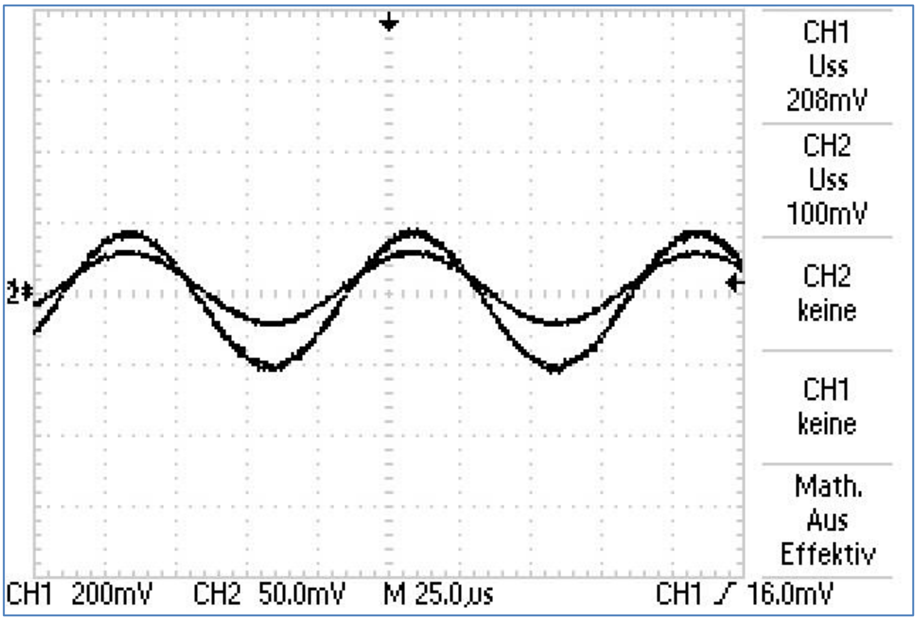

Figure 9 - Point where both voltages are the same

At the point where this happened ($U_e \cong 108\ mV$) the finely adjusted resistance of the potentiometer had exactly the same value as the input resistance of the amplifier. The potentiometer had a measured resistance of 55 $k\Omega$. Therefore the following assertion for r_{IN} was made.

$$\boldsymbol{r_{IN} = 55\ k\Omega}$$

The so measrured value could be calculated approximately with $r_{IN} \approx 56\ k\Omega\ //\ 330\ k\Omega \approx 47.87\ k\Omega$.

The same measurement with an input frequency of $100\ kHz$ resulted only in higher divergences. At $100\ kHz$ the result for r_{IN} was $62.4\ k\Omega$ which was much more inaccurate.

6.2 Output resistance r_{OUT}

6.2.1 Measurement setup

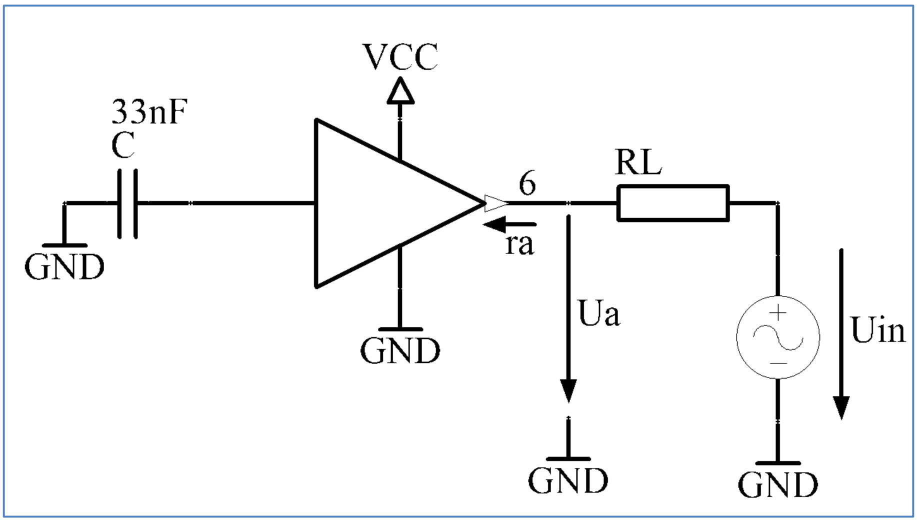

Figure 10 - Measurement circuit for the output resistance

6.2.1 Measurement results

The circuit was operated with a functiongenerator and the parameters of 10 V and a frequency of 10 kHz at the output of the amplifier. The capacitor located at the input was shunt to ground.

The idea behind this measurement setup was to send a signal at the output into the amplifier. The voltage between output and load resistor was measured and for these voltage the following formula was effected and applicable. The measured value for U_A was 92 mV.

$$r_{OUT} = R_L * \frac{U_A}{U_{in}} = 10\ k\Omega * \frac{92\ mV}{1\ V} \rightarrow \boldsymbol{r_{OUT} = 920\ \Omega}$$

7 Open loop gain

To measure the open loop gain the circuit was a little bit adopted. First a voltage divider at the input was built, to make a very low input voltage (about 1 mV) possible. The voltage divider has a factor of 1:100 and therefore a 100 mV signal from the functiongenerator would affect an input signal of 1 mV at the amplifier input pin.
In addition to this the resistor R_{E2} was removed and the capacitor C_2 replaced with a 100 μF Capacity. With this modification the open loop gate could be measured with the voltage values of U_E and U_A.

7.1 Measurement circuit

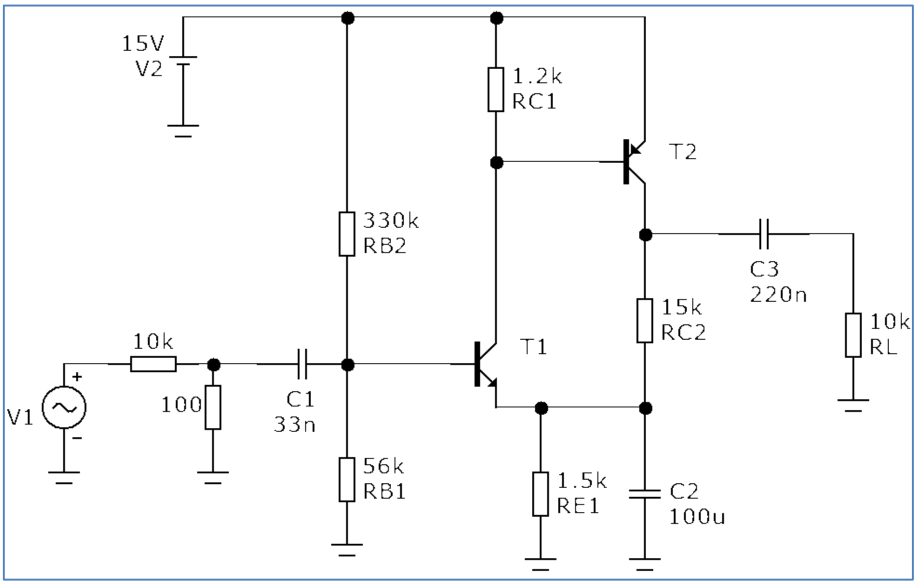

Figure 11 - Measurement circuit for the open loop gain

7.2 Measurement results

Channel 1 was the voltage directly from the functiongenerator and the probe on channel 2 was connected to the amplifier output pin.

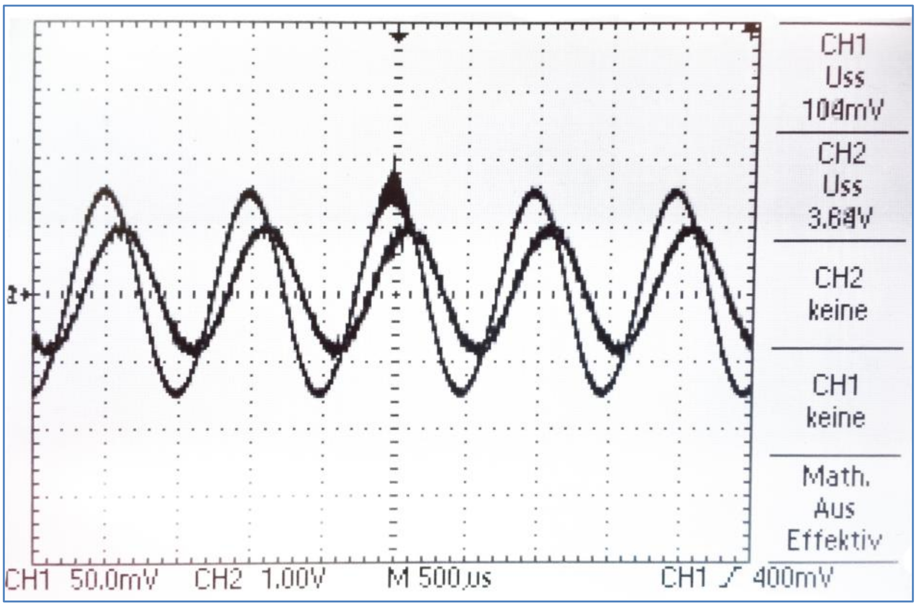

Figure 12 - Gain masurement for open loop

For correct calculations for the open loop gain the direct input voltage (behind the voltage divider) needs to be taken.

$$V_{OL} = \frac{U_A}{U_E} = \frac{3.64\ V}{1.04\ mV} \rightarrow V_{OL} = 3500 \cong 70\ dB$$

8 Simulation

To simulate aboves already built circuit the same circuit was simulated in Micro-Cap to compare the simulations results with the measurement results.

8.1 Voltages and currents (Bias)

8.1.1 Voltages

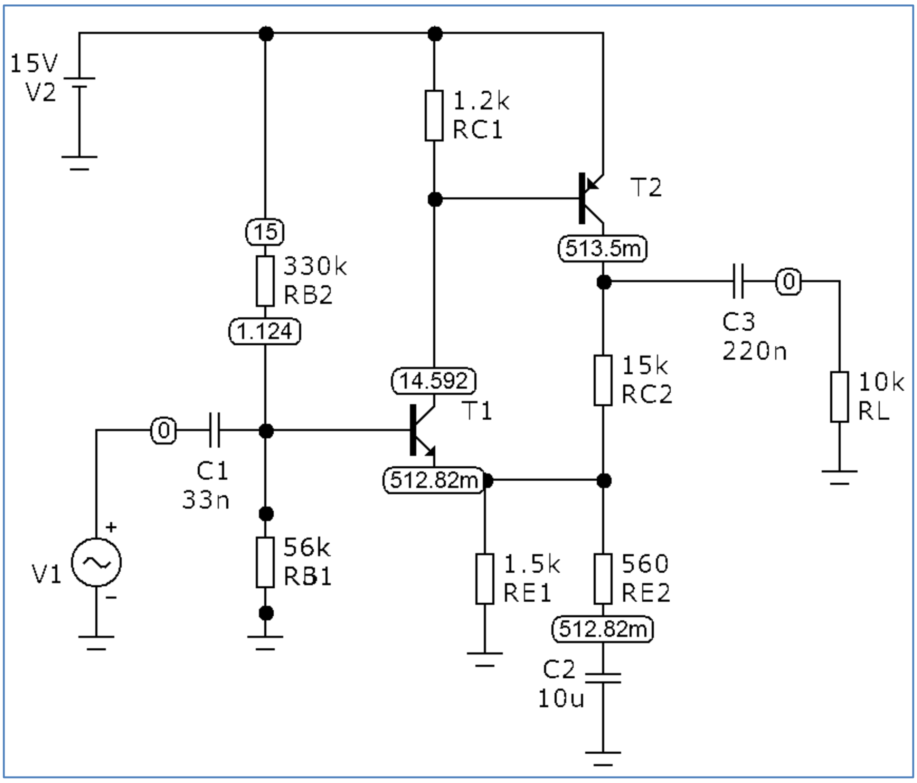

Figure 13 - Simulation of the bias voltages

8.1.2 Currents

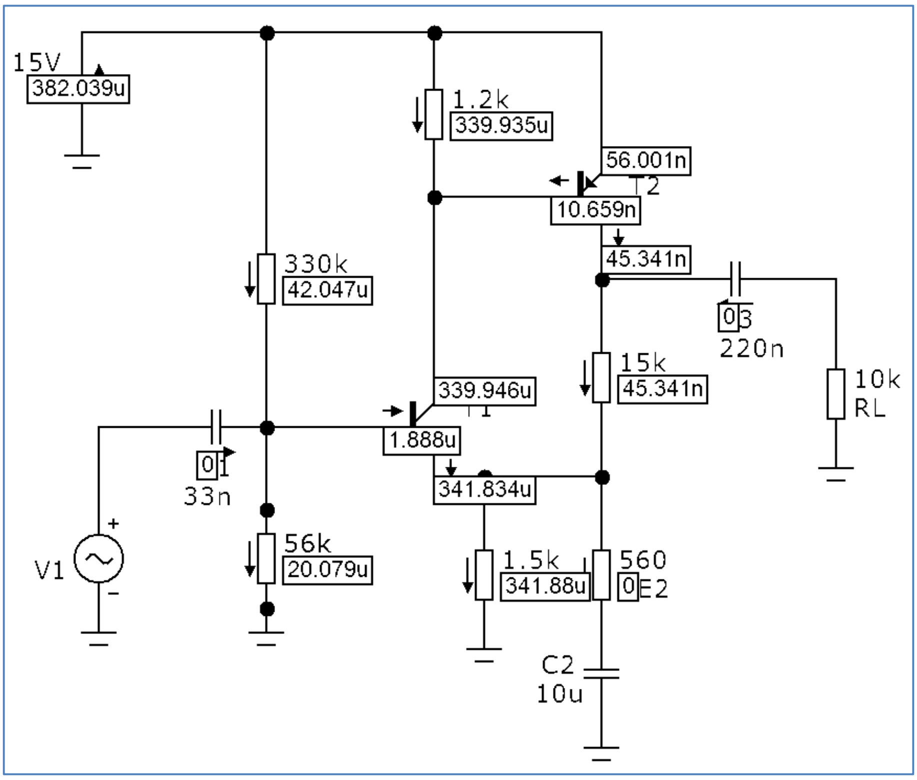

Figure 14 - Simulation of the bias currents

8.2 Bode plot

8.2.1 Simulation Circuit

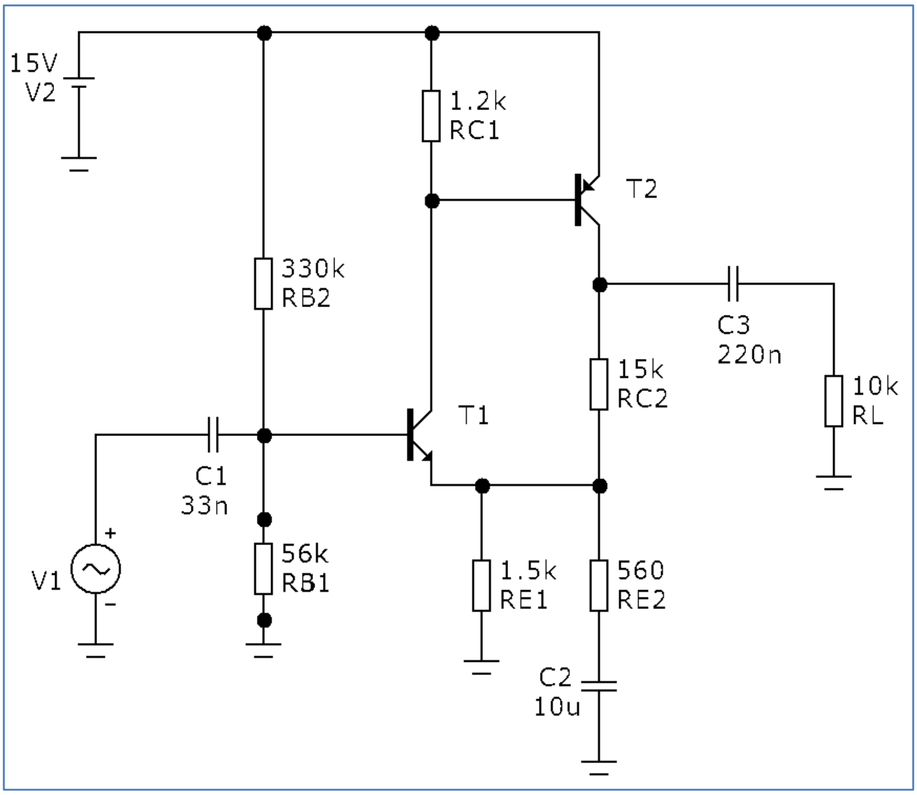

Figure 15 - Simulation circuit of the bode plot

8.2.2 Simulation Setup

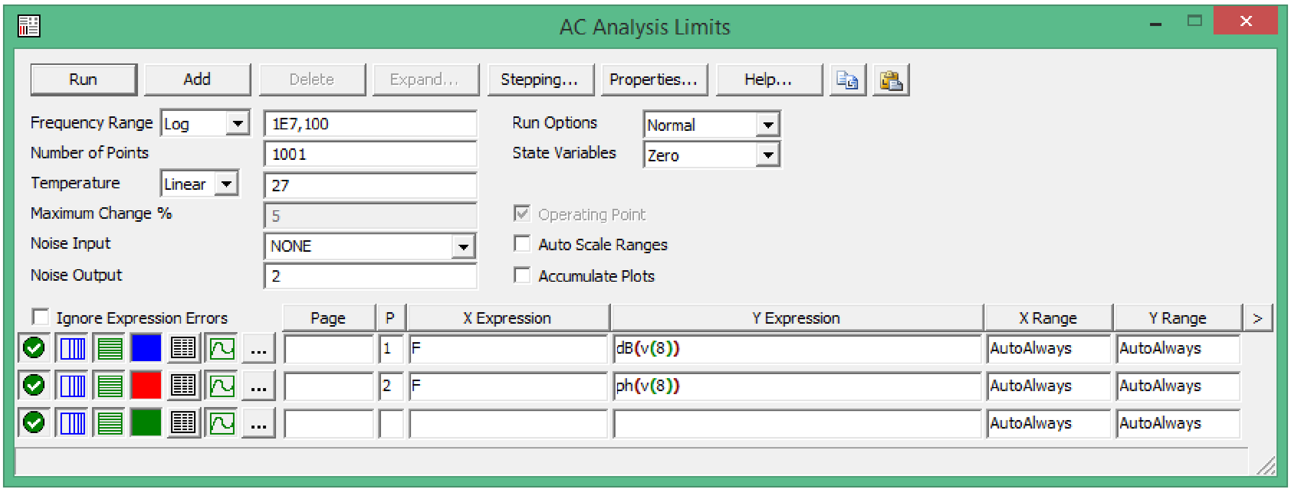

Figure 16 - Bode plot simulation settings

8.2.3 Simulation Results

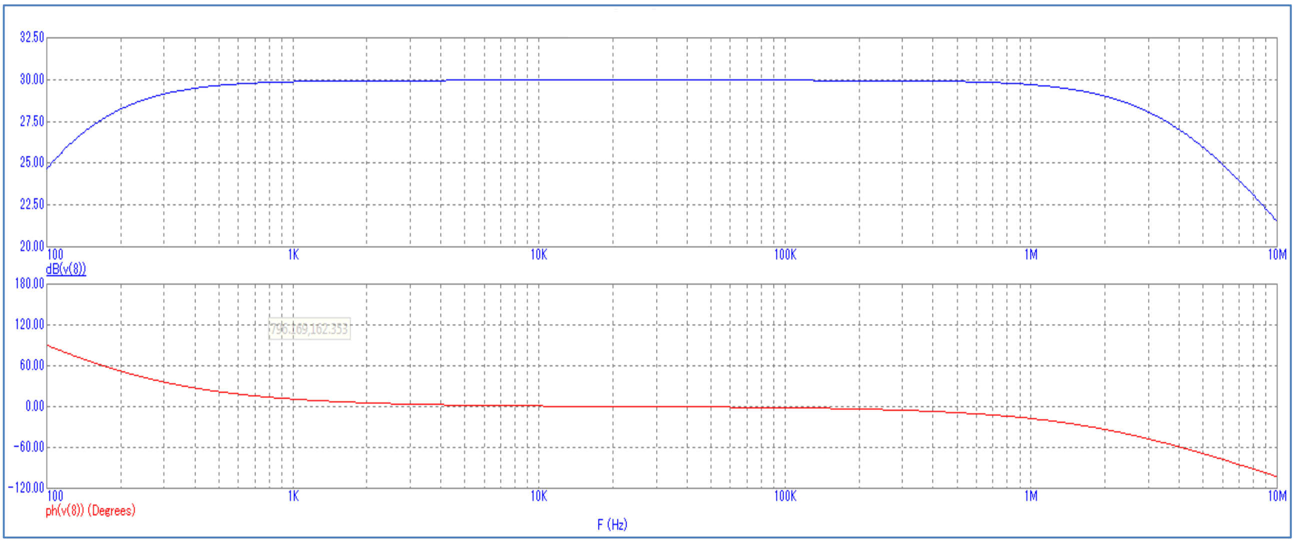

Figure 17 - Simulated bode plot in Micro-Cap

Finally can be seen that all realised simulations very similar if not even equal to the measured and calculated values were.

9 List of Figures