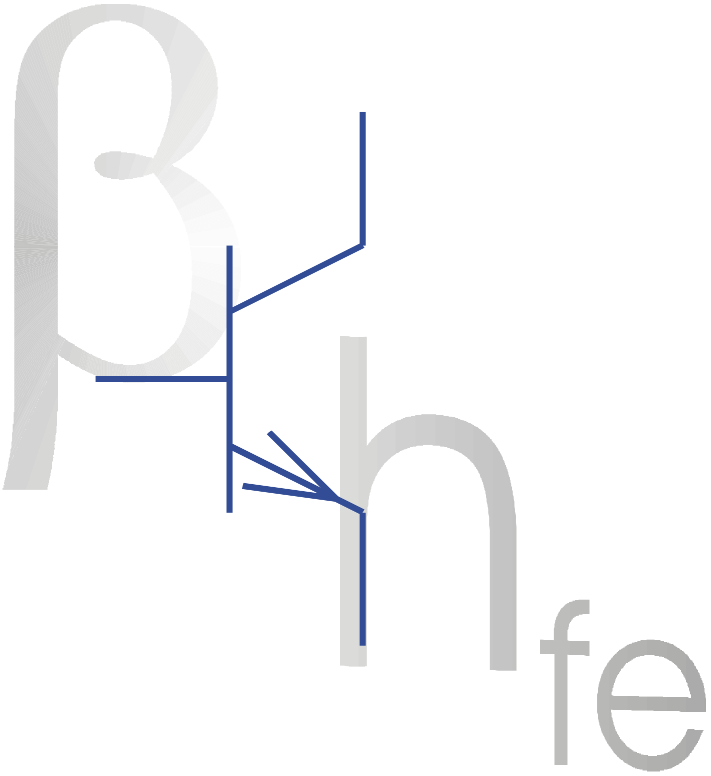
Lab-Report
Analogue Electronics

The Common-Emitter Amplifier



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1. Contents

2. Introduction

The common-emitter amplifier is one of the most common discrete amplifier used in conventional electronics. Its special characteristics were to be discovered in this lab session.

3. DC bias of common-emitter amplifier

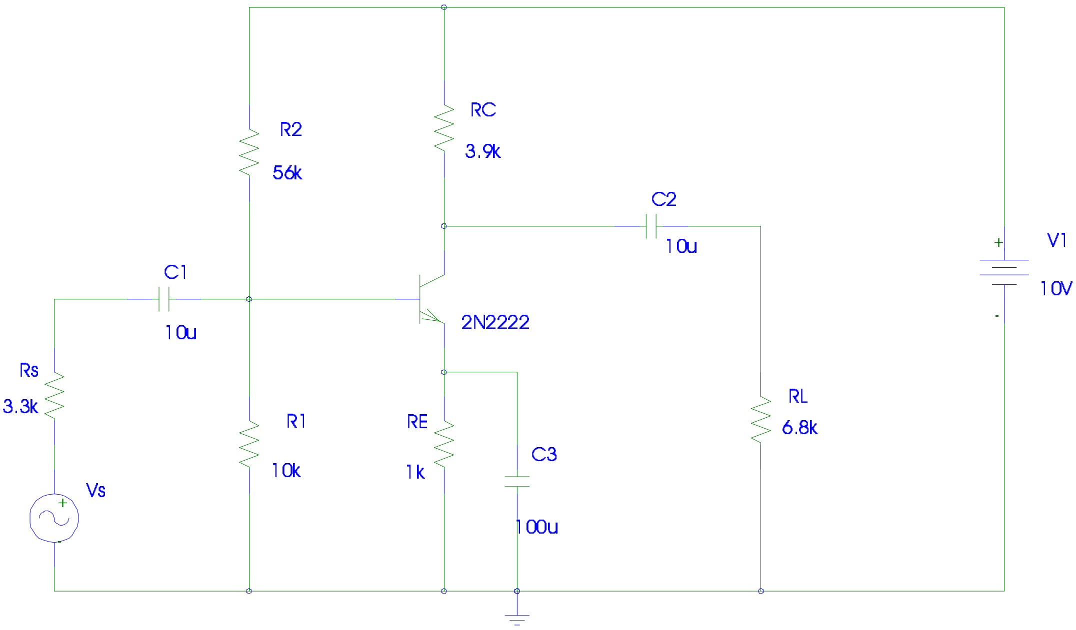


figure 1

a) Measurment of the "true" resistor values

For calculating the correct bias values at first the real values of the used resistors and capacitors have to be measured, because they all have got deviations from the printed values.

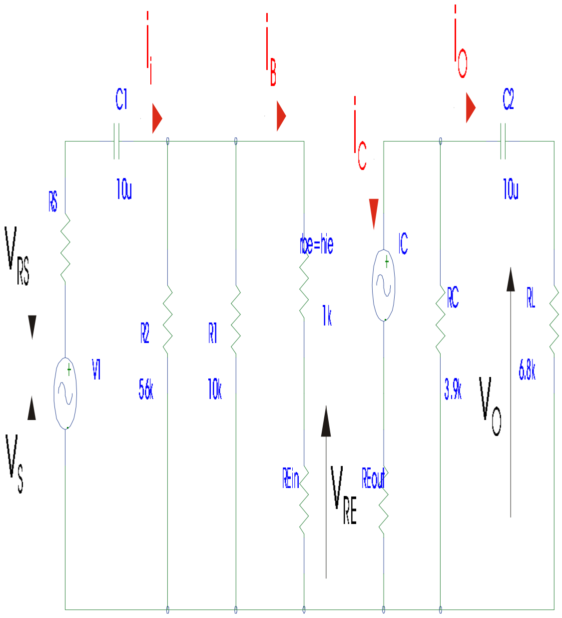
Also a measurement of the very small currents is not possible. So the voltage drop across the different devices has to be determined and then the flowing current can be calculated via KCL and Ohm's law.

The following values were measured:

R_S=3.26kΩ	C_1=80.54µF
R_1=9.99kΩ	C_2=8.949µF
R2=55.7kΩ	C_3=9.177µF
R_E=986Ω	
R_C=3.82kΩ	
RL=6.72kΩ	

b) DC-bias precalculation with given resistors

→ β=200, V_{BE}=0.7V



$$R_I = \frac{R_1 R_2}{R_1 + R_2} = \frac{10k\Omega \cdot 56k\Omega}{10k\Omega + 56k\Omega} = 8.485k\Omega$$

$$V_o = \frac{R_1}{R_1 + R_2} V_{CC} = \frac{10k\Omega}{10k\Omega + 56k\Omega} 10V = 1.515V$$

with $V_{BE} = 0.7V$

KCL :

$$0V = I_E R_E - V_O + R_I I_B$$
$$0V = (I_C + I_B) - V_O + R_I I_B$$
$$0V = I_B(\beta R_E + R_E + R_1) - V_O$$

$$\underline{\underline{I_B}} = \frac{V_O}{\beta R_E + R_E + R_I} = \frac{\frac{R_1}{R_1 + R_2} V_{CC}}{\beta R_E + R_E + \frac{R_1 R_2}{R_1 + R_2}} = \frac{\frac{10k\Omega}{10k\Omega + 56k\Omega} 10V}{200 \cdot 1000\Omega + 1000\Omega + 8.485k\Omega} = \underline{\underline{7.232\mu A}}$$

$$\underline{\underline{I_C}} = \beta I_B = 200 \cdot 7.232\mu A = \underline{\underline{1.446mA}}$$

$$V_{RC} = R_C I_C$$
$$V_{RC} = 3.9k\Omega \cdot 1.446mA$$
$$\underline{\underline{V_{RC} = 5.639V}}$$

$$V_{RE} = R_E I_E = R_C [I_B (\beta + 1)$$
$$V_{RE} = 1000\Omega (7.232\mu A \cdot 201)$$
$$\underline{\underline{V_{RE} = 1.454V}}$$

$$V_{CE} = V_{CC} - V_{RE} - V_{RE}$$
$$V_{CE} = 10V - 5.639V - 1.454V$$
$$\underline{\underline{V_{CE} = 2.907V}}$$

$$I_E = (\beta + 1) I_B$$
$$\underline{\underline{I_E}} = 201 \cdot 7.232\mu A = \underline{\underline{1.4536mA}}$$

$$V_{R2} = V_{CC} - V_{BE} - V_{RE}$$
$$V_{R2} = 10V - 0.7V - 1.454V$$
$$\underline{\underline{V_{R2} = 7.846V}}$$

$$I_{R2} = \frac{V_{R2}}{R_2} = \frac{7.846V}{56k\Omega}$$
$$\underline{\underline{I_{R2} = 0.140mA}}$$

$$V_C = V_{RE} + V_{CE} = 1.454V + 2.907V$$
$$\underline{\underline{V_C = 4.361V}}$$

$$\underline{\underline{I_{R1}}} = \frac{V_{R1}}{R_1} = \frac{2.54V}{10k\Omega} = \underline{\underline{0.215mA}}$$

$$V_{R1} = V_{CC} - V_{R2}$$
$$\underline{\underline{V_{R1}}} = 10V - 7.846V = \underline{\underline{2.154V}}$$

c) Measurement of DC-Voltages (DC-bias)

Next step was to measure the voltages in order to check the real bias and to calculate based on this values the DC current amplification and the other occurring currents and voltages.

V_{R1}=1.477V
V_{R2}=8.51V
V_{RE}=0.863V
V_{RC}=3.33V
V_C=6.66
V_{BE}=0.618
V_{CE}=5.80

d) Calculation of I_B, I_C and β with measured values

i. I_B with I_E and I_C (R_E and R_C)

$$I_E = \frac{V_{RE}}{R_E} = \frac{0.863V}{986\Omega} = 0.875mA$$

$$I_C = \frac{V_{RC}}{R_C} = \frac{3.33V}{3.82k\Omega} = 0.8713mA$$

$$I_B = I_E - I_C$$

$$I_B = 0.875mA - 0.8713mA$$

$$I_B = 3.7\mu A$$

$$\underline{\underline{\beta = h_{fe}}} = \frac{I_C}{I_B} = \frac{0.8713mA}{3.7\mu A} \underline{\underline{= 235}}$$

ii. I_B with I_1 and I_2 (R_1 and R_2)

$$I_{R1} = \frac{V_{R1}}{R_1} = \frac{1.477V}{9.99k\Omega} = 0.14785mA$$

$$I_{R2} = \frac{V_{R2}}{R_2} = \frac{8.51V}{55.7k\Omega} = 0.15278mA$$

$$I_B = I_{R2} - I_{R1} = 0.15278mA - 0.14785mA = 4.93\mu A$$

$$\underline{\underline{\beta}} = \frac{I_C}{I_B} = \frac{0.8713mA}{4.93\mu A} = \underline{\underline{177}}$$

4. AC and small signal characteristics

Next part of the lab was to determine the small signal characteristics of the common-emitter amplifier. Small signal characteristics are the essential values for the amplification function of the circuit.

For calculation of these characteristics a special model is used, the small signal model of the BJT. These models are derived from the characteristic curves of the real devices and, when properly devised, can be used to predict accurately the behaviour of semiconductor devices in practical applications such as voltage and current amplification.

By computer simulation more complex models can be used.

a) BJT small signal behavioural model

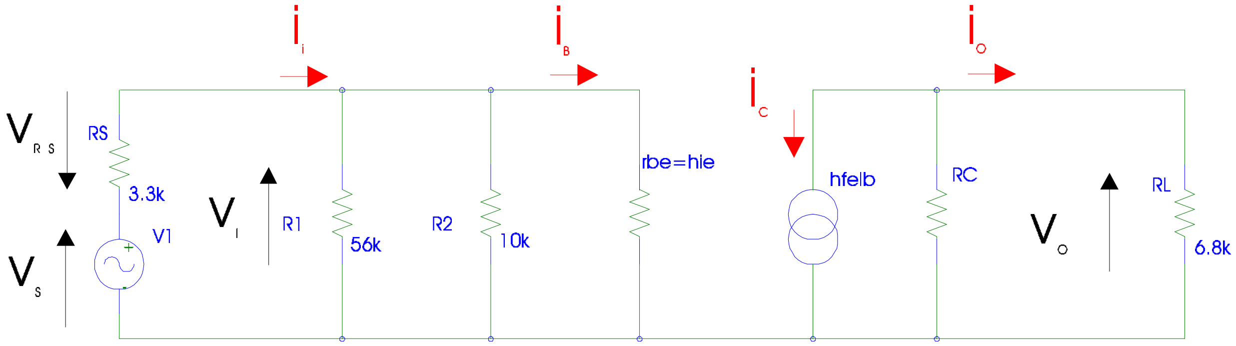


figure 2

In the small signal model for mid frequencies the capacitors are short circuited because their impedance is negligble to the rest of the circuit.

b) Definitions of the small signal parameters

v_{oc}: open circuit output voltage
v_o: output voltage with load
v_s: signal voltage
v_i: ampifier input voltage
v_{rs}: voltage drop across sensor resistor
R_i: amplifier input resistance
R_o: amplifier output resistance
A_{vo}: amplifier voltage gain without load
A_v: amplifier voltage gain with load
A_i: amplifier current gain
A_p: amplifier power gain

c) Measured small signal values

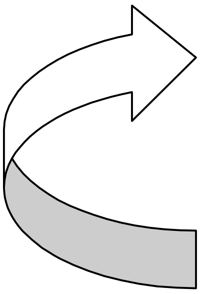
(A generator with f=1kHz works as voltage source V1)

v_s=20mV
v_{oc}=1.242V
v_o=0.799V
v_i=10.8mV
v_{rs}=9.1mV

d) Calculation and derivation of the small signal parameters

ALL THEORETICAL VALUES WITH INDEX ‘ (i.e. R’)

i. Amplifier input resistance R_i



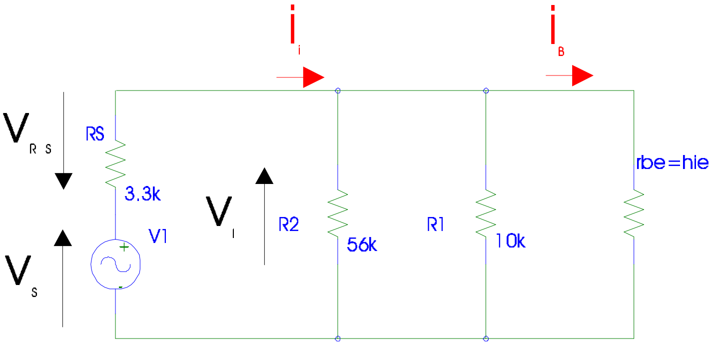


figure 3

Theoretical Values for R_i :

$$R'_i = \frac{v_i}{i_i} = R_1 \parallel R_2 \parallel h_{ie}$$

$$R'_i = R_1 \parallel R_2 \parallel h_{fe} r_e \qquad \text{with } r_e = \frac{26\text{mV}}{I_E}$$

$$R'_i = R_1 \parallel R_2 \parallel h_{fe} \frac{26\text{mV}}{I_E}$$

$$R'_i = 10\text{k}\Omega \parallel 56\text{k}\Omega \parallel 200 \frac{26\text{mV}}{1.453\text{mA}}$$

$$\underline{\underline{R'_i}} = \frac{1}{\frac{1}{10\text{k}\Omega} + \frac{1}{56\text{k}\Omega} + \frac{1}{3.578\text{k}\Omega}} \underline{\underline{= 2.52\text{k}\Omega}}$$

Measured value of R_i :

$$\underline{\underline{R_i}} = \frac{v_i}{i_i} = \frac{v_i}{v_{rs}/r_s} = \frac{10.8\text{mV}}{9.1\text{mV}/3.26\text{k}\Omega} \underline{\underline{= 3.87\text{k}\Omega}}$$

The theoretical value of R_i fits good with the determination due the measured values. The measurement of v_i and i_i was relative uncertain because of the small values and not using the whole range of the measuring instrument (~20mV to 200mV Range).

ii. Amplifier output resistance R_o

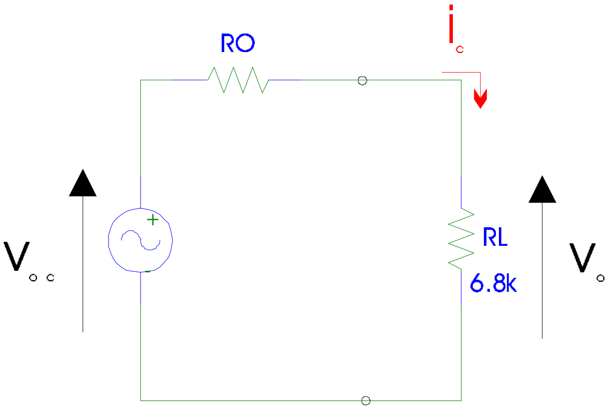


figure 4

Theoretical value of R_o :

$R'_o = R_C$ with $h_{OE} = 0S$

$$R'_o = 3.9k\Omega$$

Measured value of R_o :

$$R_o = \frac{V_{oc} - V_o}{V_o / R_L}$$

$$R_o = \frac{1.242V - 0.799V}{0.799V / 6.72k\Omega} = 3.72k\Omega$$

From these in the lab measured values h_{OE} can be easily determined:

$$\frac{1}{R_O} = \frac{1}{h_{OE}} + \frac{1}{R_C}$$

$$\frac{1}{h_{OE}} = \frac{1}{R_O} - \frac{1}{R_C}$$

$$h_{OE} = \frac{1}{\frac{1}{R_O} - \frac{1}{R_C}} = \frac{1}{\frac{1}{3.72k\Omega} - \frac{1}{3.82k\Omega}}$$

$$h_{OE} = 142.1k\Omega$$

It can be seen, that h_{OE} can be let out at calculation of BJTs, because of its large value to the rest of the circuit.

iii. Voltage amplification without load A_{vo}

Theoretical values of A_{vo} :

$$A'_{vo} = \left.\frac{v_{oc}}{v_i}\right|_{R_L \to \infty}$$

$$A'_{vo} = \frac{-i_c R_C}{h_{ie} i_B} = -\frac{h_{fe} i_B R_C}{h_{ie} i_B}$$

$$A'_{vo} = -\frac{h_{fe} R_C}{h_{ie}} = -\frac{h_{fe} R_C}{h_{fe} \frac{26\text{mV}}{I_E}}$$

$$\underline{\underline{A'_{vo}}} = \frac{3.9\text{k}\Omega}{26\text{mV} / 1.4536\text{mA}} \underline{\underline{= 218}}$$

Measured value of A_{vo} :

$$A_{vo} = \frac{v_{oc}}{v_i}$$

$$A_{vo} = \frac{1.242\text{V}}{10.8\text{mV}}$$

$$\underline{\underline{A_{vo} = 115}}$$

iv. Voltage amplification with load A_v

Theoretical value of A_v :

$$A'_v = \frac{v_o}{v_i}$$

$$A'_v = \frac{-i_c \left(R_C \| R_L\right)}{h_{ie} i_B}$$

$$A'_v = -\frac{h_{fe}\left(R_c \| R_L\right)}{h_{ie}} = \frac{h_{fe}\left(R_c \| R_L\right)}{h_{fe} \frac{26\text{mV}}{I_E}}$$

$$A'_v = \frac{R_C \| R_L}{26\text{mV} / I_E} = \frac{\frac{R_C \cdot R_L}{R_C + R_L}}{26\text{mV} / I_E}$$

$$\underline{\underline{A'_v}} = \frac{2.479\text{k}\Omega}{26\text{mV} / 1.4536\text{mA}} \underline{\underline{= 138}}$$

Measured value of A_v :

$$A_v = \frac{v_o}{v_i}$$

$$A_v = \frac{0.799\text{V}}{10.8\text{mV}}$$

$$\underline{\underline{A_v = 74}}$$

v. Current amplification A_i

Theoretical value of A_i :

$$A'_i = \frac{i_C}{i_I}$$

$$A'_i = \frac{h_{fe} i_B}{i_I} \qquad \text{with } i_B = \frac{R_1 \| R_2}{h_{ie} + R_1 \| R_2} i_I$$

$$A'_i = h_{fe} \frac{R_1 \| R_2}{h_{ie} + R_1 \| R_2} = h_{fe} \frac{R_1 \| R_2}{h_{fe}\, {}^{26\text{mV}}\!/\!_{I_E} + R_1 \| R_2}$$

$$A'_i = 200 \frac{8.485\text{k}\Omega}{3.58\text{k}\Omega + 8.485\text{k}\Omega}$$

$$\underline{\underline{A'_i = 140}}$$

Measured value of A_i :

$$A_i = \frac{i_C}{i_I} = \frac{{}^{v_{oc}}\!/\!_{R_c}}{{}^{v_{rs}}\!/\!_{R_s}}$$

$$A_i = \frac{{}^{1.242\text{V}}\!/\!_{3.82\text{k}\Omega}}{{}^{9.1\text{mV}}\!/\!_{3.26\text{k}\Omega}}$$

$$\underline{\underline{A_i = 117}}$$

vi. Amplifier power gain A_p

Theeoretic values of A_p :

$$A'_p = |A_i \cdot A_v|$$

$$A'_p = \left| h_{fe} \frac{R_I}{h_{ie} + R_I} \frac{h_{fe}(R_C \| R_L)}{h_{ie}} \right|$$

$$A'_p = \left| h_{fe} \frac{R_I}{h_{ie} + R_I} \frac{R_C \| R_L}{{}^{26\text{mV}}\!/\!_{I_E}} \right|$$

$$A'_p = \left| 200 \frac{8.458\text{k}\Omega}{3.58\text{k}\Omega + 8.458\text{k}\Omega} \cdot \frac{2.479\text{k}\Omega}{{}^{26\text{mV}}\!/\!_{1.1436\text{mA}}} \right|$$

$$\underline{\underline{A'_p = 19494}}$$

Measured value of A_p :

$$A'_p = |A_i \cdot A_v|$$

$$A'_p = 74 \cdot 117$$

$$\underline{\underline{A'_p = 8658}}$$

e) Comparison between measured and calculated values

i. DC-Bias

Measurand	V_{RC}	V_{RE}	V_{CE}	V_C	V_{R1}	V_{R2}	h_{fe}
measured	3.33V	0.863V	5.80V	6.66V	2.154V	7.846V	237/ 177
calculated	5.639V	1.454V	2.907V	4.361V	2.154V	7.846V	200

ii. Small signal parameters

Measurand	R_{in}	R_{out}	A_{vo}	A_v	A_i	A_p
measured	3.87 kΩ	3.72kΩ	115	74	117	8685
calculated	2.52 kΩ	3.9kΩ	218	138	140	19494

The measured and the calculated values are partly very different. Major problem of the determination of the Bias and the small signal parameters were the uncertain measurements. Especially the small values like I_B and the input current of the small signal equivalent circuit were very difficult to determine exactly.

5. Frequency response of the CE-amplifier

a) Measured frequency response of A_v

The voltage amplification over a range from 10Hz to 1kHz was to measure to determine the cut-off frequency of the CE-Amplifier.

f/Hz	10	20	50	70	100	120	200	500	700	1000
v_i/mV	13.1	12.8	11.4	11.1	10.7	11.4	10.2	10	10	10
v_o/mV	183.4	0.324	555	618	667	730	714	734	736	738
v_o/v_i	14	25.31	48.7	55.7	62.3	64	70	73.4	73.6	73.8

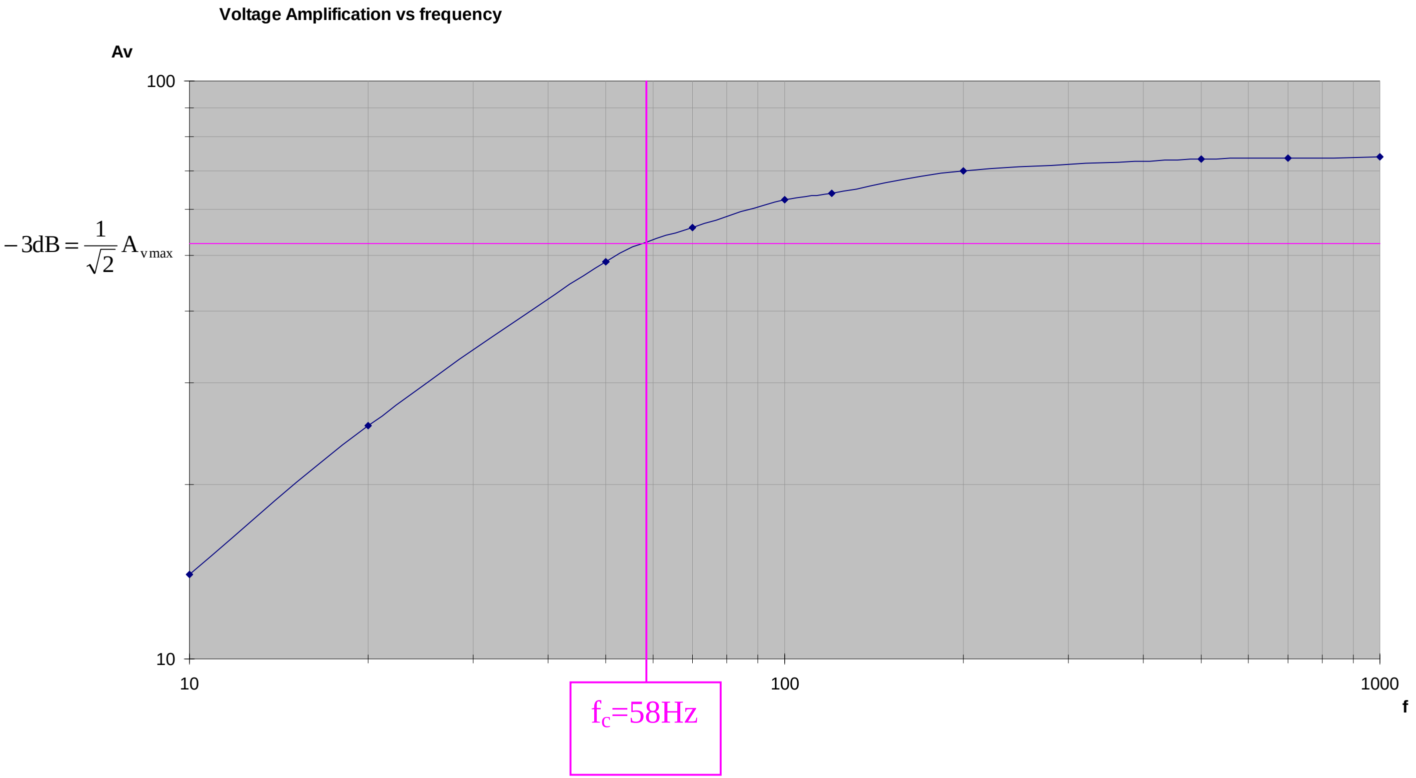


figure 5

The cut-off frequency is defined as the frequency, when the amplification is dropped down to 70.7% (-3dB or ½√2).
Below this frequency there is still amplification, but the frequency range of amplifiers is commonly defined by the 3dB cut-off freuency.

b) Determination of the theoretical cut-off frequency

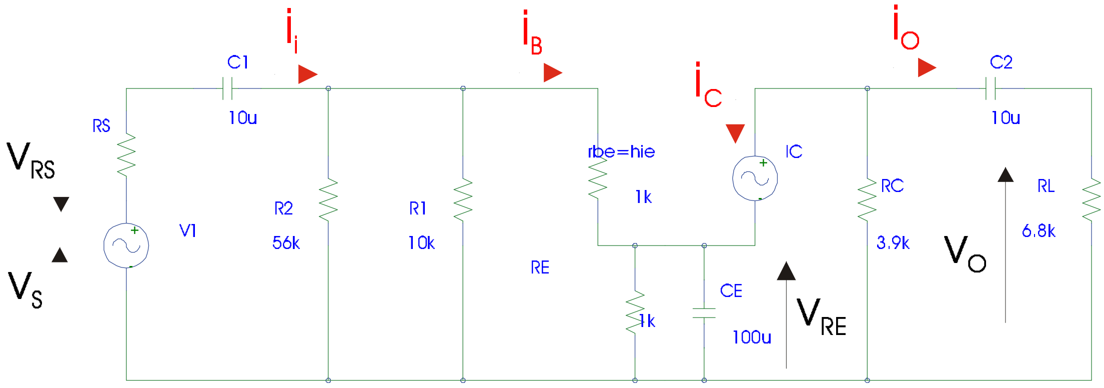
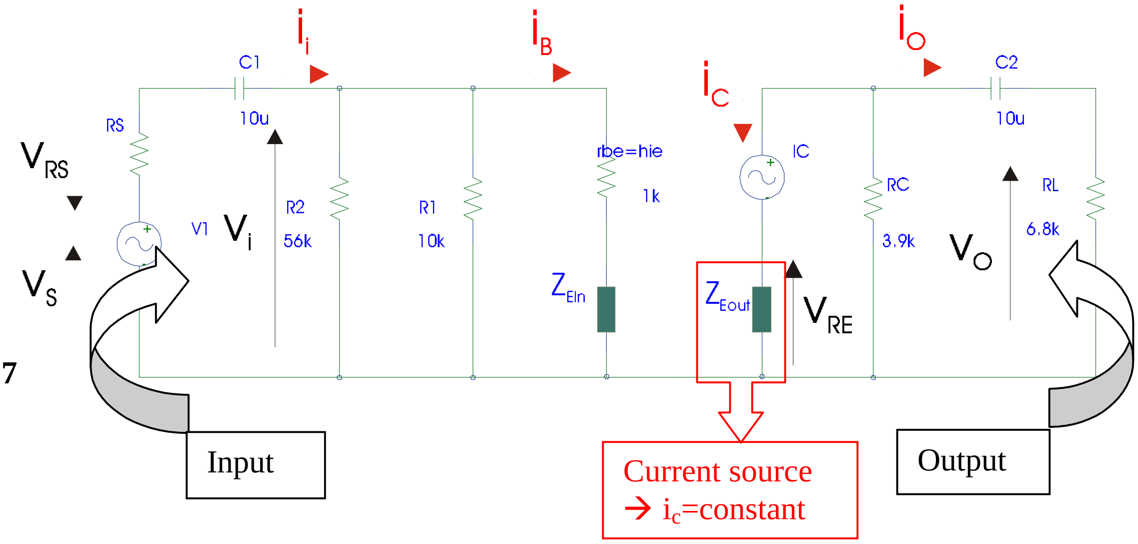


figure 6

Figure 6 shows the equivalent circuit for low and mid frequencies.
To determine the cut-off frequency the input and output circuit has to be separated.

figure 7



The cut-off frequency of the CE-Amplifier is above all depending on the emitter bypass capacitor $C_E=C_3$. The impedance of the two coupling capacitors is about 1500Ω at 10Hz each and can be neglected because of these small values in comparison to the rest of the circuit.

For the input circuit:

$$I_B = \frac{v_i}{h_{ie} + R_{In} + Z_{EIn}}$$

$$\text{where } Z_{EIn} = (\beta+1)Z_E = \frac{\beta+1}{\frac{1}{R_E} + j\omega C_E} = \frac{1}{\frac{1}{(\beta+1)R_E} + j\omega\frac{C_E}{\beta+1}}$$

The current through (β+1)R_E can be neglected because of it's large resistance

$$i_B = \frac{v_{in}}{h_{ie} + R_{In} - j\dfrac{\beta+1}{\omega C_E}}$$

The current I_B will drop to 70.7% of it's maximum value when the voltage drop at (h_{ie}+R_{In}) and Z_E are of the same magnitude.

$$\frac{\dfrac{1}{\omega C_E}}{\beta+1} = R_{In} + h_{ie}$$

$$\omega_{cutoff} = \frac{\beta+1}{C_E(R_{in}+h_{ie})} \text{ where } R_{in} = R_1 \| R_2 \| R_S = 2.38\text{k}\Omega$$

$$\underline{\underline{\omega_c}} = \frac{201}{100\mu\text{F}(2.38\text{k}\Omega + 3.577\text{k}\Omega)} = \underline{\underline{337\frac{1}{\text{s}}}}$$

$$\underline{\underline{f_c}} = \frac{\omega_c}{2\pi f} = \underline{\underline{54\text{Hz}}}$$

The calculated cut-off frequency is with 54Hz very close at the measured value of 58 Hz.
The exact calculation of the cut-off frequency is very complex and is done in most cases with a computer and a simulation software like (P) or (H)spice.
On the following pages (P)spice printouts of the simulated CE-Amplifier can be found.

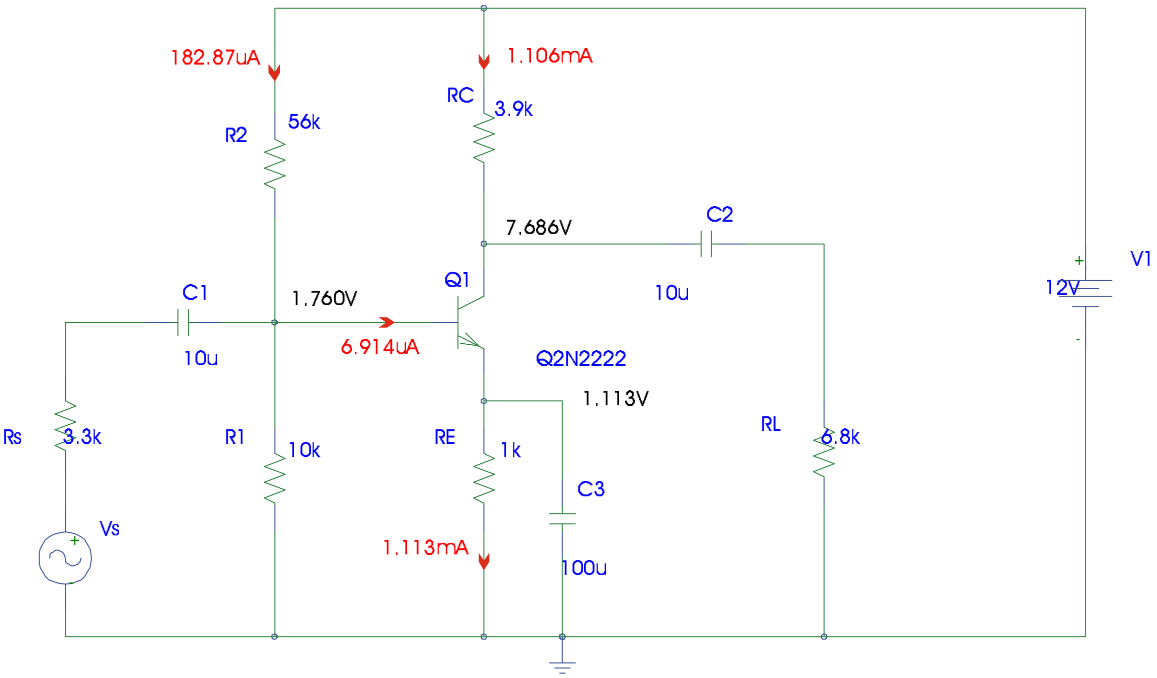


figure 8

figure 8 shows the BIAS calculated by a (P)spice simulation.

Spice printout of frequency response A_V

c) Frequency response of A_i

f/Hz	10	20	50	70	100	120	200	500	700	1000
v_{rs}/mV	4.5	6.2	8.0	8.3	8.7	8.9	9.1	9.2	9.2	9.3
v_o/mV	197	351	600	668	720	738	771	792	795	797
$\frac{v_{rs}}{R_s} \Big/ \mu A$	1.38	1.90	2.45	2.54	2.67	2.73	2.79	2.82	2.82	2.85
$\frac{v_o}{R_L} \Big/ \mu A$	29.31	52.23	89.29	99.4	107	110	115	118	118	119
A_i	21	27.5	36	39	40	40,5	41	42	42	42

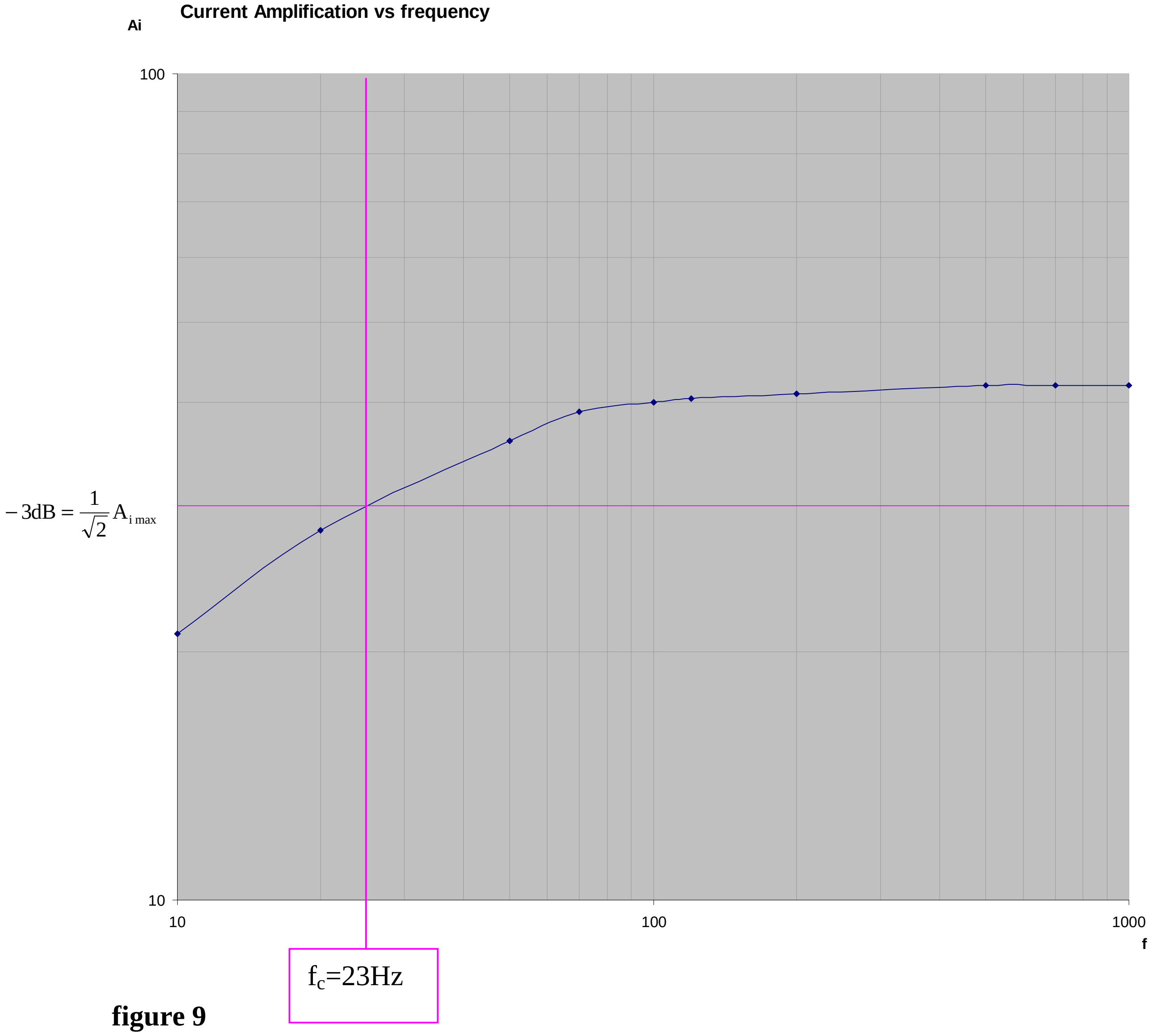


figure 9

The cut-off frequency of the current amplification is read out from the diagram 23Hz. This frequency is above all determined by the capacitor C_E.

Spice printout of the frequency response of the current amplification A_i vs frequency

6. Disconnection of bypass capacitor C_3

Next step of the Lab was to disconnect the Emitter bypass capacitor to proof the importance of the bypass capacitor especially on the voltage and current amplification, the main

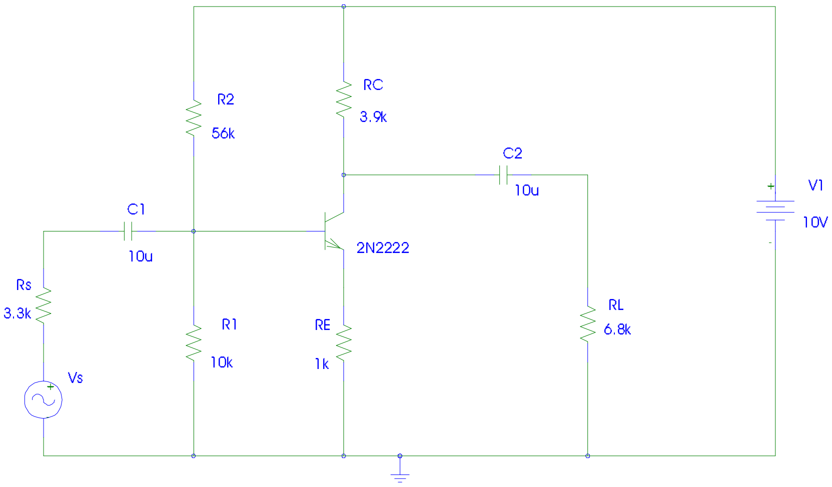


figure 10

Figure 10 shows the schematics of the CE-Amplifier with disconnected C_3.

7. DC-Bias with disconnected C_3

a) Calculation of DC-Bias

The calculated DC-Bias with disconnected capacitor C_3 can't change, because C_3 has no influence to any DC-values. C_3 is not used for calculation of the DC-Bias and so it's not able to change it.

→ see DC-Bias values at DC-bias precalculation with given resistors

b) Measurement of DC-Voltages (DC-bias)

The same DC-bias measurements were to make with disconnected C_3 like in the first part of the Lab.

V_{R1}=1.479V
V_{R2}=8.47V
V_{RE}=0.849V
V_{RC}=3.27V
V_C=6.65
V_{BE}=0.625
V_{CE}=5.81

c) Calculation of I_B, I_C and β with measured values(C_3 disconnected)

i. I_B with I_E and I_C (R_E and R_C)

$$I_E = \frac{V_{RE}}{R_E} = \frac{0.849V}{986\Omega} = 0.861mA$$

$$I_C = \frac{V_{RC}}{R_C} = \frac{3.27V}{3.82k\Omega} = 0.856mA$$

$$I_B = I_E - I_C$$

$$I_B = 0.861mA - 0.856mA$$

$$I_B = 5\mu A$$

$$\underline{\underline{\beta = h_{fe}}} = \frac{I_C}{I_B} = \frac{0.856mA}{5\mu A} \underline{\underline{= 171.2}}$$

ii. I_B with I_1 and I_2 (R_1 and R_2)

$$I_{R1} = \frac{V_{R1}}{R_1} = \frac{1.479V}{9.99k\Omega} = 0.14805mA$$

$$I_{R2} = \frac{V_{R2}}{R_2} = \frac{8.47V}{55.7k\Omega} = 0.15206mA$$

$$I_B = I_{R2} - I_{R1} = 0.15206mA - 0.14805mA = 4.01\mu A$$

$$\underline{\underline{\beta}} = \frac{I_C}{I_B} = \frac{0.856mA}{4.01\mu A} = \underline{\underline{213}}$$

The different values of $\beta = h_{fe}$ can be led back to the uncertainty of measurement, because the measured values were very small and at the lower range of the measuring instrument.

8. AC and small signal characteristics (without C_3)

Next part of the lab was to determine the small signal characteristics of the common-emitter amplifier.

By computer simulation more complex models can be used.

a) BJT small signal behavioural model

With the disconnected Capacitor C_3 another model of the circuit has to be used now, because the Emitter Resistor is now not short circuited at mid-frequencies and generates an important current feedback of the AC-signals through I_E, which reduces the amplification of the CE-Amplifier considerably.

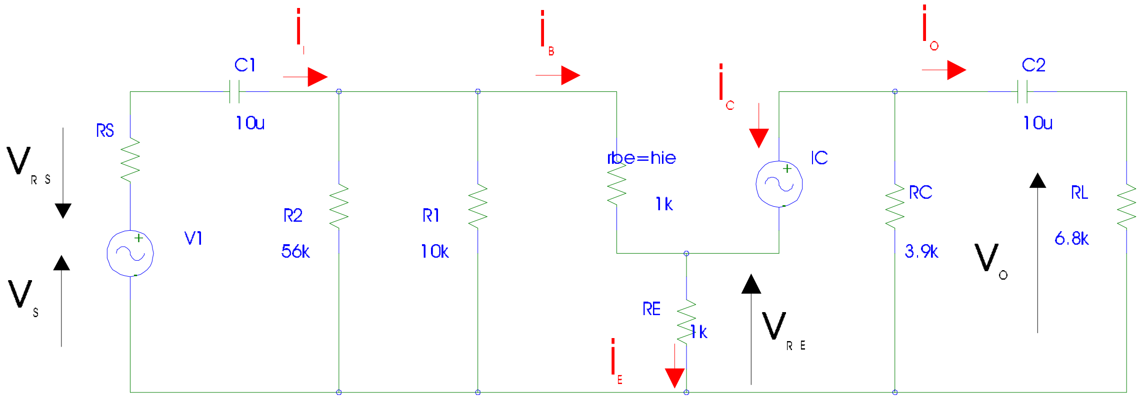


figure 11

All the definitions can be taken from Definitions of the small signal parameters

b) Measured small signal values without C_3

→ The input voltages are increased by a factor 10 to obtain better measurands at the low amplifications without bypass capacitor.
(A generator with f=1kHz works as voltage source V1)

v_s=200mV
v_{oc}=533mV
v_o=340mV
v_i=143mV
v_{rs}=57.3mV

c) Calculation and derivation of the small signal parameters (mid freq., without C_3)

ALL THEORETICAL VALUES WITH INDEX ‘ (i.e. R’)

i. Amplifier input resistance R_i

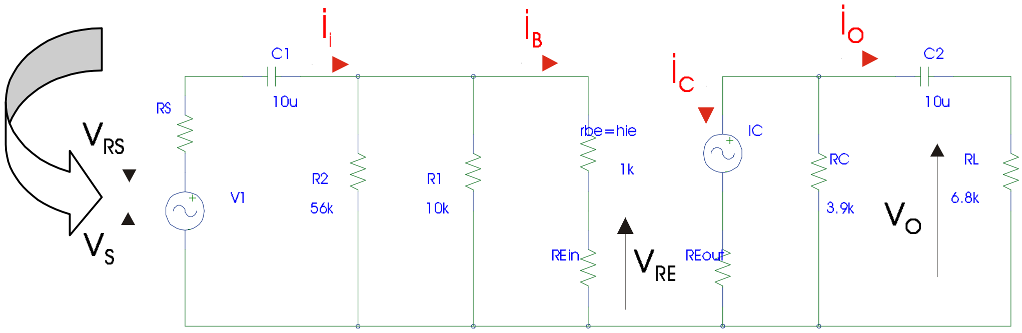


figure 12

The Figure 12 shows, that the Emitter resistor is divided into two parts for separating input and output circuit.
The connection between both is given through the voltage drop at the emitter resistor R_E.

Theoretical value of R_{in} :

$$R'_{in} = R_2 \| R_1 \| (h_{ie} + R_{EIn}) \quad \text{where } R_{EIn} = \frac{v_{RE}}{i_B} = \frac{(h_{fe}+1)R_E i_B}{i_B}$$

$$R'_{in} = R_2 \| R_1 \| \left[h_{ie} + (h_{fe}+1)R_E\right]$$

$$R'_{in} \approx R_2 \| R_1 \| (h_{ie} + h_{fe}R_E)$$

$$R'_{in} \approx \frac{1}{\frac{1}{56k\Omega} + \frac{1}{10k\Omega} + \frac{1}{3.577k\Omega + 200 \times 1k\Omega}}$$

$$R'_{in} \approx 8.15k\Omega$$

Measured Value of R_{in} :

$$R_{in} = \frac{v_i}{i_i} = \frac{v_i}{v_{rs}/R_s}$$

$$R_{in} = \frac{143mV}{57.3mV/3.26k\Omega}$$

$$R_{in} = 8.14k\Omega$$

The calculated value of R_{in} is very close to the measured value. The approximation of R_{Ein} can be done because there’s a negligible difference between h_{fe} and $(h_{fe}+1)$.

ii. Amplifier output resistance R_o

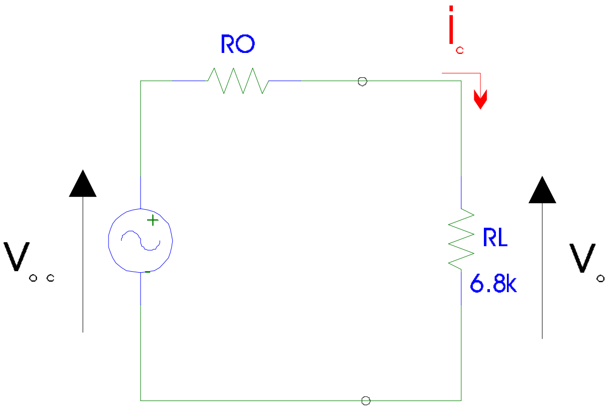


figure 13

It's the same small signal model than in the first part. The series connection of the current source and the emitter resistor can be reduced to the current source only.

Theoretical value of R_o:

$$R'_o = R_C \qquad \text{with } h_{OE} = 0S$$

$$\underline{\underline{R'_o = 3.9k\Omega}}$$

Measured value of R_o:

$$R_o = \frac{v_{oc} - v_o}{v_o / R_L}$$

$$\underline{\underline{R_o}} = \frac{533mV - 340mV}{340mV / 6.72k\Omega} = \underline{\underline{3.81k\Omega}}$$

The calculated and the measured value are again very close together.

iii. Voltage amplification at mid frequencies without load

Theoretical value of A_{vo}:

$$A'_{vo} = \frac{v_{oc}}{v_i} = \frac{-h_{fe} i_B R_C}{i_B (h_{ie} + R_{Ein})}$$

$$A_{vo} = \frac{-h_{fe} R_C}{(h_{ie} + R_{Ein})}$$

$$A_{vo} = -\frac{h_{fe} R_C}{h_{ie} + (h_{fe} + 1) R_E} \approx \frac{h_{fe} R_C}{h_{ie} + h_{fe} R_E}$$

$$\underline{\underline{A_{vo}}} = \frac{200 \cdot 3.9k\Omega}{3.577\ k\Omega + 200 \cdot 1k\Omega} = \underline{\underline{3.83}}$$

Measured value of A_{vo}:

$$A_{vo} = \frac{v_{oc}}{v_i}$$

$$A_{vo} = \frac{533mV}{143mV}$$

$$\underline{\underline{a_{vo} = 3.3}}$$

The Voltage amplification is very low, because the emitter resistor without bypass capacitor causes a current feedback which results in a low Amplification at all frequencies (see frequency response).

iv. Voltage amplification at mid frequencies with load

Theoretical value of A_{vo} :

$$A'_v = \frac{v_o}{v_i} = \frac{-h_{fe} i_B (R_C \| R_L)}{i_B (h_{ie} + R_{Ein})}$$

$$A'_v = \frac{-h_{fe} (R_C \| R_L)}{(h_{ie} + R_{Ein})}$$

$$A'_v = -\frac{h_{fe} (R_C \| R_L)}{h_{ie} + (h_{fe}+1) R_E} \approx \frac{h_{fe} (R_C \| R_L)}{h_{ie} + h_{fe} R_E}$$

$$\underline{\underline{A'_v}} = \frac{200 \cdot \dfrac{3.9\text{k}\Omega \cdot 6.8\text{k}\Omega}{3.9\text{k}\Omega + 6.8\text{k}\Omega}}{3.577\text{k}\Omega + 200 \cdot 1\text{k}\Omega} \underline{\underline{= 2.45}}$$

Measured value of A_{vo} :

$$A_{vo} = \frac{v_{oc}}{v_i}$$

$$A_{vo} = \frac{340\text{mV}}{143\text{mV}}$$

$$\underline{\underline{A_{vo} = 2.38}}$$

The amplification without bypass capacitor is again very low, but the theoretical value and the measured value are very close together.

v. Current amplification A_i

Theoretical value of A_i :

$$A'_i = \frac{i_C}{i_I}$$

$$A'_i = \frac{h_{fe} i_B}{i_I} \qquad \text{with } i_B = \frac{R_1 \| R_2}{h_{ie} + (h_{fe}+1) R_E + R_1 \| R_2} i_I$$

$$A'_i = h_{fe} \frac{R_1 \| R_2}{h_{ie} + R_E (h_{fe}+1) + R_1 \| R_2} = h_{fe} \frac{R_1 \| R_2}{h_{fe}\, {}^{26\text{mV}}\!/_{I_E} + R_E (h_{fe}+1) + R_1 \| R_2}$$

$$A'_i = 200 \frac{8.485\text{k}\Omega}{3.58\text{k}\Omega + 1\text{k}\Omega(201) + 8.485\text{k}\Omega}$$

$$\underline{\underline{A'_i \approx 8}}$$

Measured value of A_i :

$$A_i = \frac{i_C}{i_I} = \frac{{}^{v_{oc}}\!/_{R_c}}{{}^{v_{rs}}\!/_{R_s}}$$

$$A_i = \frac{{}^{533\text{mV}}\!/_{3.82\text{k}\Omega}}{{}^{57.3\text{mV}}\!/_{3.26\text{k}\Omega}}$$

$$\underline{\underline{A_i = 7.93}}$$

vi. Amplifier power gain A_p

$\underline{\text{Theeoretic values of } A_p :}$

$$A'_p = \left| A_i \cdot A_v \right|$$

$$A'_p = \left| h_{fe} \frac{R_1 \| R_2}{h_{ie} + R_E(\beta + 1) + R_1 \| R_2} \times \frac{R_C \| R_L}{h_{ie} / h_{fe} + R_E} \right|$$

$$A'_p = \left| 200 \frac{8.48\text{k}\Omega}{3.577\text{k}\Omega + 1\text{k}\Omega \cdot 201 + 8.48\text{k}\Omega} \times \frac{2.479\text{k}\Omega}{3.577\text{k}\Omega / 200 + 1\text{k}\Omega} \right|$$

$$\underline{\underline{A'_p = 19}}$$

$\underline{\text{Measured value of } A_p :}$

$$A'_p = \left| A_i \cdot A_v \right|$$

$$A'_p = 7.93 \cdot 2.38$$

$$\underline{\underline{A'_p = 19}}$$

d) Comparison between measured and calculated values

Measurand	**h_{fe}**	**R_{in}**	**R_{out}**	**A_{vo}**	**A_v**	**A_i**	**A_p**
measured	171/213	8.14kΩ	3.81kΩ	3.3	2.38	8	19
calculated	200	8.15kΩ	3.9kΩ	3.83	2.45	8	19

9. Frequency response of the CE-amplifier without C_3

a) Frequency response of A_v

f/Hz	10	20	50	70	100	200	500	700	1000
v_i/mV	134	131.8	131.4	131.2	131.3	130.9	130.9	730.9	130.9
v_o/mV	305	309	311	310	311	310	310	310	310
v_o/v_i	2.3	2.3	2.4	2.3	2.3	2.3	2.3	2.3	2.3

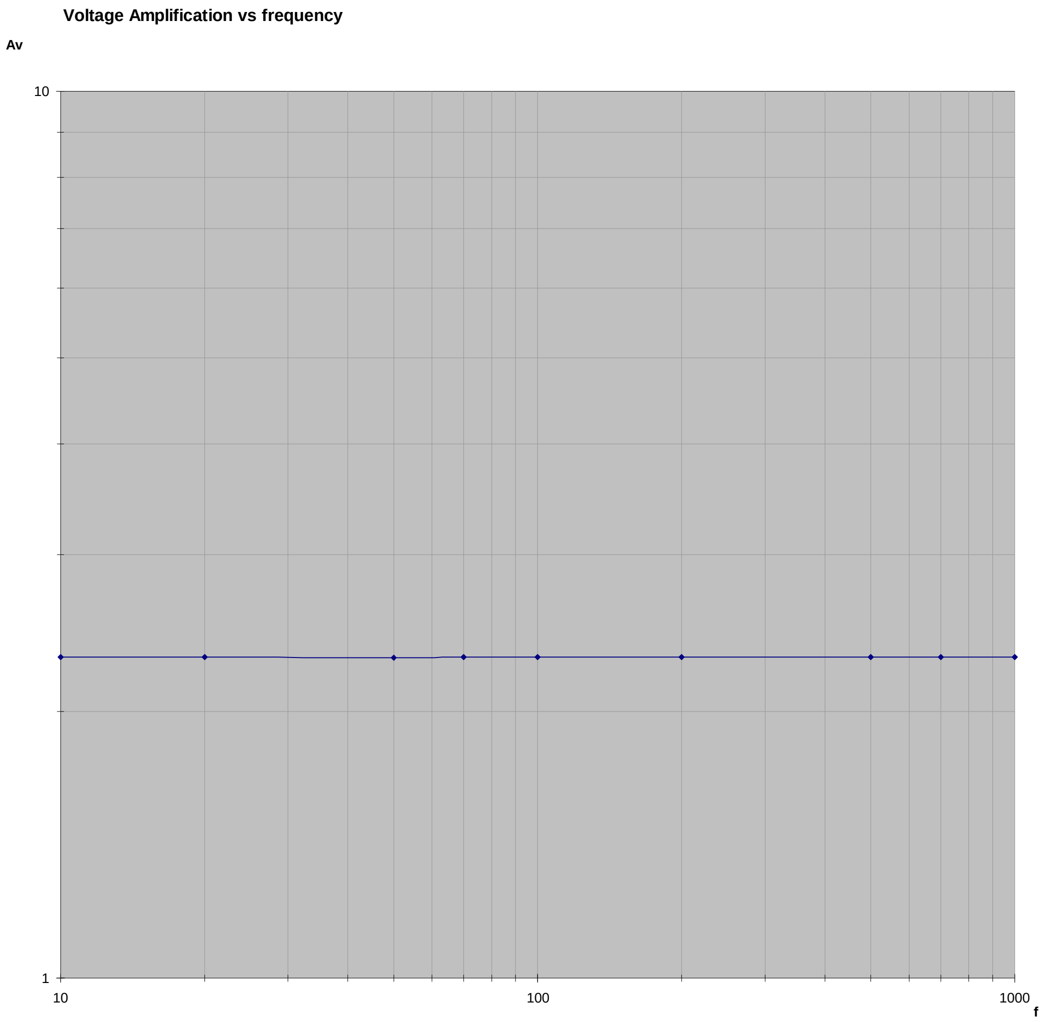


figure 14

f_c is not readable and so the cut-off frequency is much lower than 10Hz. The current amplification is linear over the low and mid frequency band.

(P)spice printout of the Voltage Amplification without bypass capacitor

b) Theoretical calculation of the lower cut-off frequency

At this circuit only the coupling capacitors have an influence to the lower cut -off frequency because the bypass capacitor is removed.

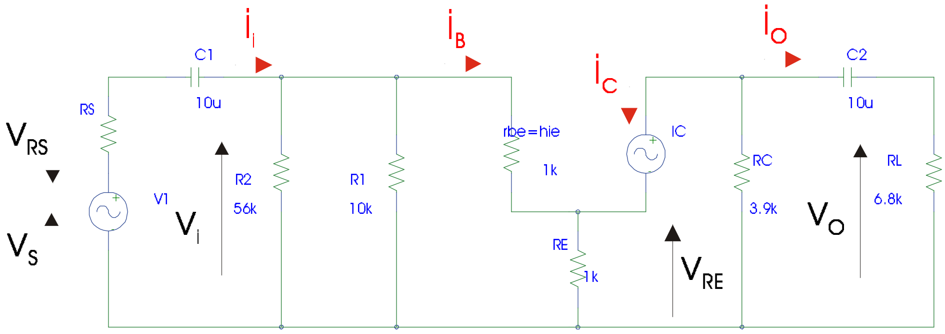


figure 15

figure 15 shows the small signal equivalent circuit for the CE-Ampflifier with disconnected bypass capacitor.

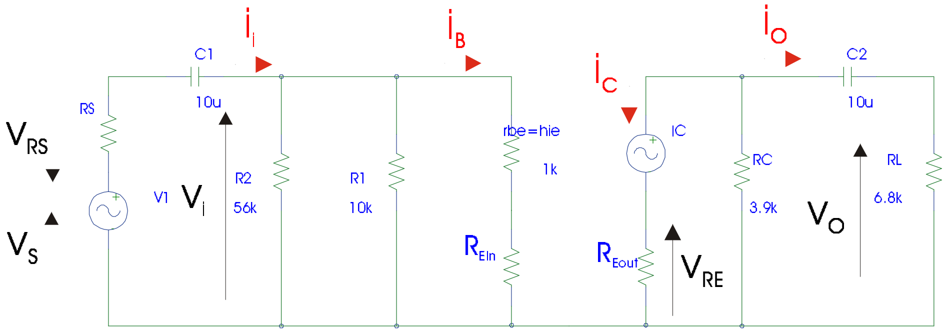


figure 16

In figure 16 the emitter resistor is separated into its input and output circuit part.

For the input circuit:

$$i_i = \frac{v_i}{R_{in} + \frac{1}{j\omega C}}$$

$$i_B = \frac{R_1 \| R_2}{R_1 \| R_2 + h_{ie} + R_{Ein}} i_i = \frac{R_B}{R_B + h_{ie} + R_{Ein}} \frac{v_i}{R_{in} + \frac{1}{j\omega C_1}}$$

$$i_B = \frac{1}{(h_{ie} + R_{Ein})\left(1 + \frac{1}{j\omega R_{in} C_1}\right)} v_i \text{ where } R_{in} = R_B \| (h_{ie} + R_{Ein})$$

For the output circuit:

$$i_o = \frac{R_C}{R_C + R_L + \frac{1}{j\omega C_2}} i_c = \frac{R_C}{R_C + R_L + \frac{1}{j\omega C_2}} h_{fe} i_B$$

$$v_o = -R_L i_o = -\frac{R_L R_C h_{fe}}{R_L + R_C + \frac{1}{j\omega C_2}} i_b \quad \text{where } R_C \Vert R_L = \frac{R_C R_L}{R_C + R_L}$$

$$v_o = \frac{(R_C \Vert R_L) h_{fe}}{1 + \frac{1}{j\omega (R_L + R_C) C_2}} i_B$$

Combining the I/P and O/P circuit

$$A_v = \frac{v_o}{v_i} = -\frac{(R_C \Vert R_L) h_{fe}}{1 + \frac{1}{j\omega (R_L + R_C) C_2}} \frac{1}{\left(1 + \frac{1}{j\omega R_{In} C_1}\right)(h_{ie} + R_{Ein})} \quad \text{where } A_{vmid} = -\frac{h_{fe}(R_C \Vert R_L)}{h_{ie} + (1 + h_{fe}) R_E}$$

$$\tau_1 = R_{In} C_1 = \left[R_B \Vert (h_{ie} + (1 + h_{fe}) R_E)\right] C_1$$

$$\tau_2 = (R_C + R_L) C_2$$

$$A_V(s) = \frac{v_o}{v_i} = A_{vmid} \frac{\tau_1 \tau_2 s^2}{(1 + \tau_1 s)(1 + \tau_2 s)}$$

Using the calculated values:

$$\tau_1 = (8.48\text{k}\Omega \Vert 8.14\text{k}\Omega) 10\mu\text{F}$$

$$\tau_1 = 0.081\text{s}$$

$$\omega_1 = \frac{1}{\tau_1} = 12.28 \quad \Rightarrow \quad \underline{f_{c1} = \frac{\omega_1}{2\pi} = 1.95\text{Hz}}$$

$$\tau_2 = (3{,}9\text{k}\Omega + 6.8\text{k}\Omega) 10\mu\text{F}$$

$$\tau_2 = 0.107\text{s}$$

$$\omega_2 = \frac{1}{\tau_2} = 9.34\text{Hz} \quad \Rightarrow \quad \underline{f_{c1} = \frac{\omega_2}{2\pi} = 1.48\text{Hz}}$$

$$\omega_1 \approx \omega_2 \quad \Rightarrow \quad \left|\frac{A(s)}{A_{mid}}\right| = \left|\frac{s^2}{(s + \omega_c)^2}\right| = \frac{\omega^2}{\omega^2 + \omega_c^2}$$

$$\omega_L = 1.55 \omega_C$$

$$\underline{\underline{\omega_c \approx 2\text{Hz}}}$$

This low frequency was not measurable in the lab, because the generator and the measuring instruments were not able to determine such a low frequency correctly.

The amplification of the CE-Amplifier without bypass capacitor reaches nearly into the DC-region.

c) Frequency response of A_i without C_3

f/Hz	10	20	50	70	100	200	500	700	1000
v_{rs}/mV	56	57	57	57	57	57	57	57	57
v_o/mV	333	337	339	339	340	339	339	339	339
$\frac{v_{rs}}{R_s}/\mu A$	17.17	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
$\frac{v_o}{R_L}/\mu A$	49.55	50	50.5	50.5	50.5	50.5	50.5	50.5	50.5
A_i	2.88	2.87	2.88	2.88	2.88	2.88	2.88	2.88	2.88

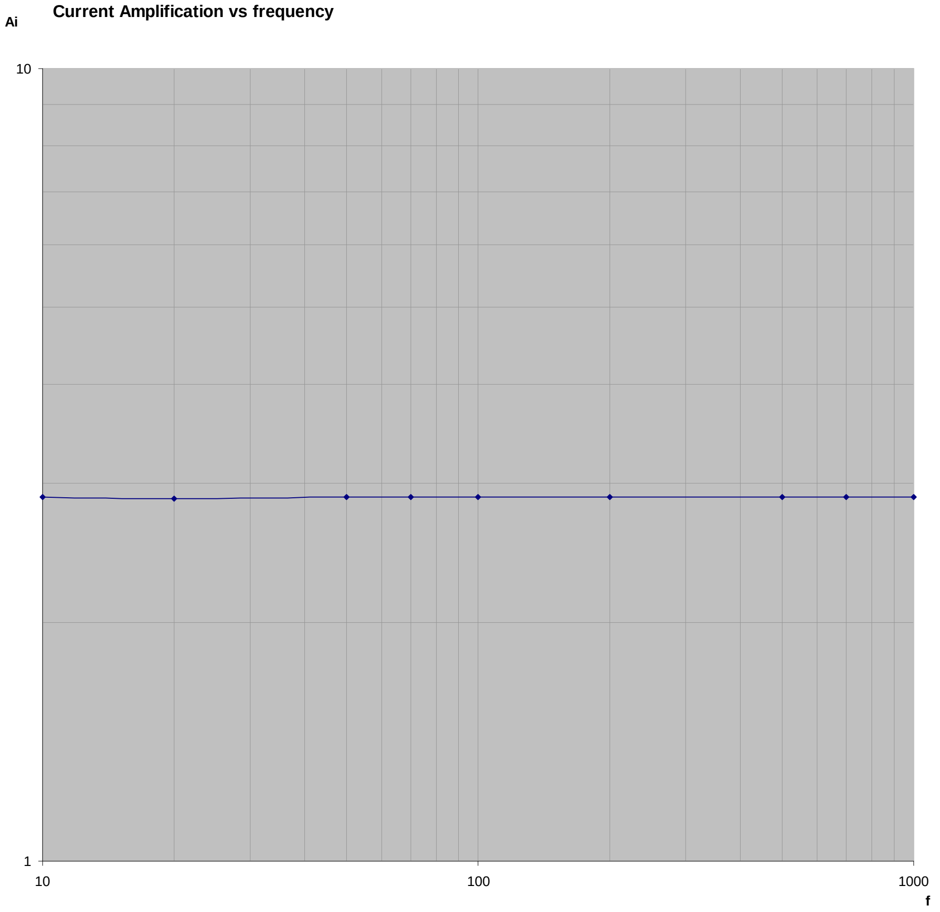


figure 17

f_c is not readable and so the cut-off frequency is much lower than 10Hz.

The current and voltage amplification of the CE-amplifier is very low, but constant during the lower frequencies, therefor the CE-Amplifier without bypass capacitor is not often used.
For low frequency amplification usually direct coupled amplifiers with bypass capacitors are used. If the circuit is well designed the lower cut-off frequency is mostly determined by the emitter capacitor and NOT by the coupling capacitors.

(P)spice printout of the current amplification vs frequency