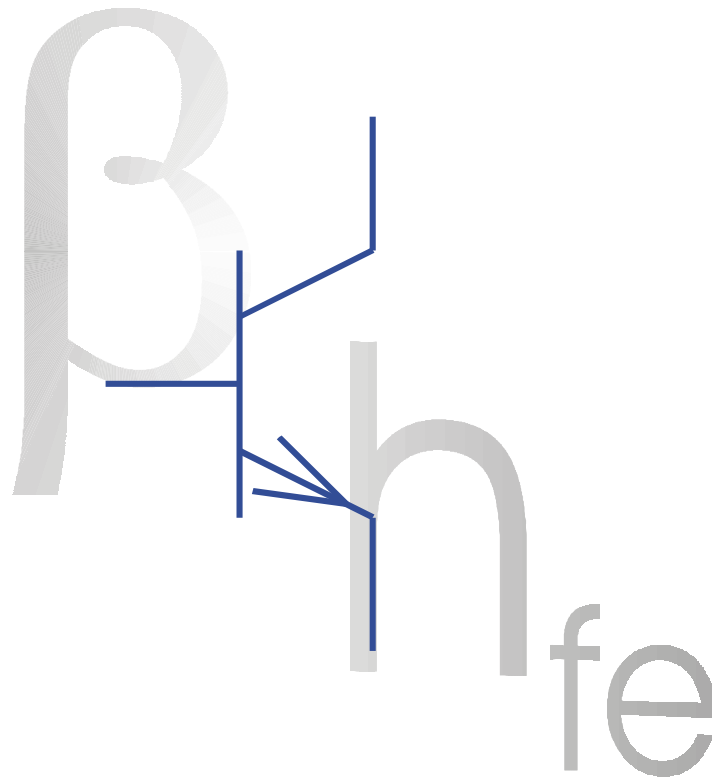


# Lab-Report

## Analogue Electronics

### *The Common-Emitter Amplifier*



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## 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

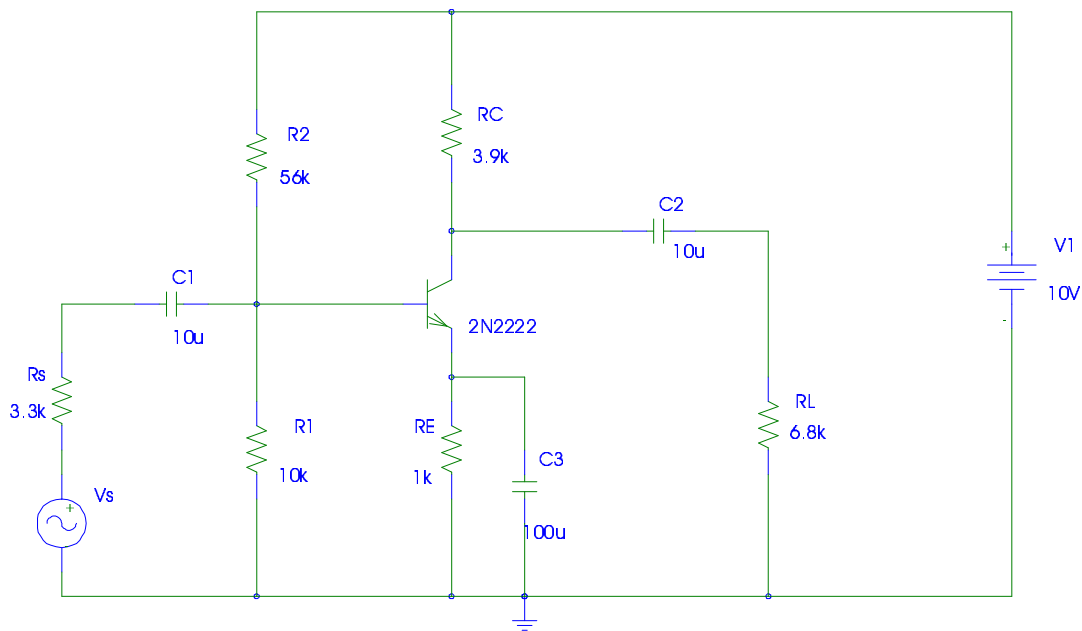


figure 1

### a) Measurement 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.

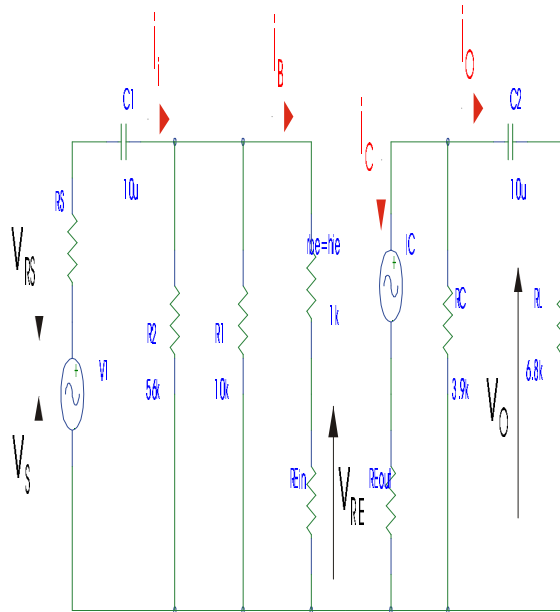
Also a measurement of the very small currents is not possible. So the voltage drop across the different devices has to be determined and then the flowing current can be calculated via KCL and Ohm's law.

The following values were measured:

$R_S=3.26k\Omega$	$C_1=80.54\mu F$
$R_1=9.99k\Omega$	$C_2=8.949\mu F$
$R_2=55.7k\Omega$	$C_3=9.177\mu F$
$R_E=986\Omega$	
$R_C=3.82k\Omega$	
$R_L=6.72k\Omega$	

## b) DC-bias precalculation with given resistors

→  $\beta=200$ ,  $V_{BE}=0.7V$



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

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

with  $V_{BE} = 0.7V$

KCL :

$$0V = I_E R_E - V_O + R_1 I_B$$

$$0V = (I_C + I_B) R_E - V_O + R_1 I_B$$

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

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

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

$$I_E = (\beta + 1) I_B$$

$$I_E = 201 \cdot 7.232\mu A = \underline{\underline{1.4536mA}}$$

$$V_{RC} = R_C I_C$$

$$V_{RC} = 3.9k\Omega \cdot 1.446mA$$

$$\underline{\underline{V_{RC} = 5.639V}}$$

$$V_{R2} = V_{CC} - V_{BE} - V_{RE}$$

$$V_{R2} = 10V - 0.7V - 1.454V$$

$$\underline{\underline{V_{R2} = 7.846V}}$$

$$V_{RE} = R_E I_E = R_C [I_B (\beta + 1)]$$

$$V_{RE} = 1000\Omega (7.232\mu A \cdot 201)$$

$$\underline{\underline{V_{RE} = 1.454V}}$$

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

$$\underline{\underline{I_{R2} = 0.140mA}}$$

$$V_{CE} = V_{CC} - V_{RC} - V_{RE}$$

$$V_{CE} = 10V - 5.639V - 1.454V$$

$$\underline{\underline{V_{CE} = 2.907V}}$$

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

$$\underline{\underline{V_C = 4.361V}}$$

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

$$V_{R1} = V_{CC} - V_{R2}$$

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

### 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.

$$\begin{aligned}V_{R1} &= 1.477\text{V} \\V_{R2} &= 8.51\text{V} \\V_{RE} &= 0.863\text{V} \\V_{RC} &= 3.33\text{V} \\V_C &= 6.66 \\V_{BE} &= 0.618 \\V_{CE} &= 5.80\end{aligned}$$

### d) Calculation of $I_B$ , $I_C$ and $\beta$ with measured values

#### **i. $I_B$ with $I_E$ and $I_C$ ( $R_E$ and $R_C$ )**

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

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

$$I_B = I_E - I_C$$

$$I_B = 0.875\text{mA} - 0.8713\text{mA}$$

$$I_B = 3.7\mu\text{A}$$

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

#### **ii. $I_B$ with $I_1$ and $I_2$ ( $R_1$ and $R_2$ )**

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

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

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

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

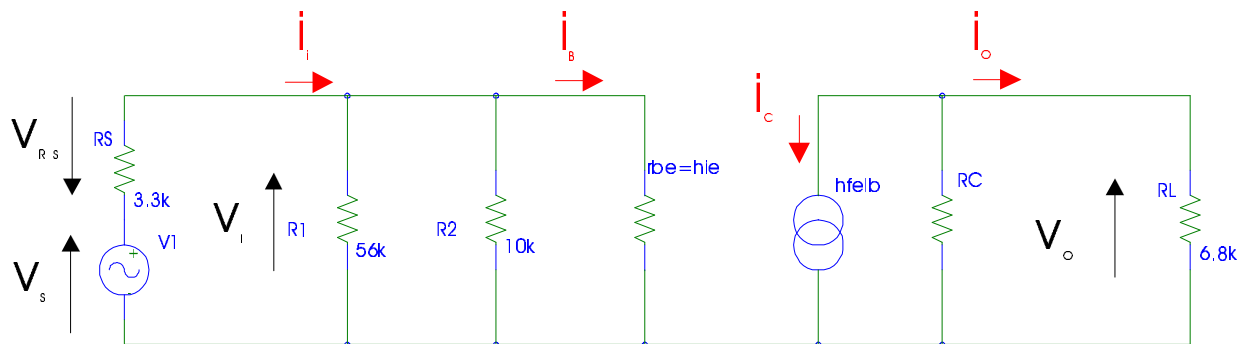
## 4. AC and small signal characteristics

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 negligible 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
- $v_i$ : amplifier 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  $f=1\text{kHz}$  works as voltage source V1)

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

**d) Calculation and derivation of the small signal parameters**

ALL THEORETICAL VALUES WITH INDEX ' (i.e. R')

**i. Amplifier input resistance  $R_i$**

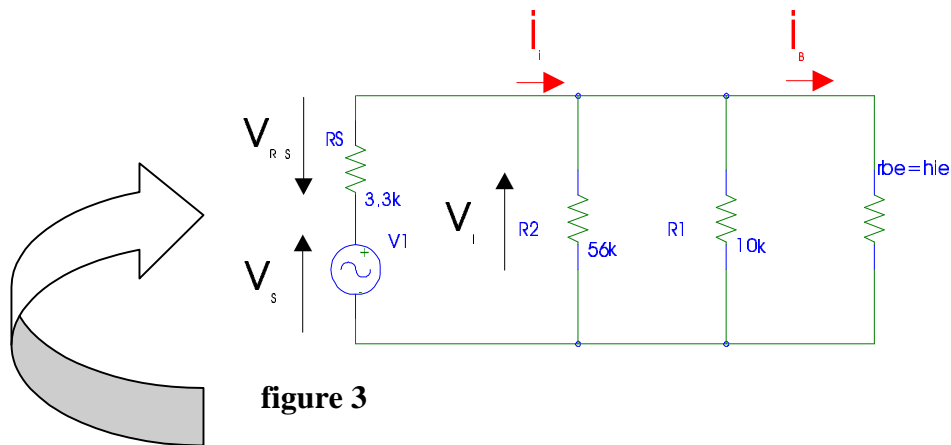


figure 3

Theoretical Values for  $R_i$  :

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

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

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

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

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

Measured value of  $R_i$  :

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

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  $R_o$

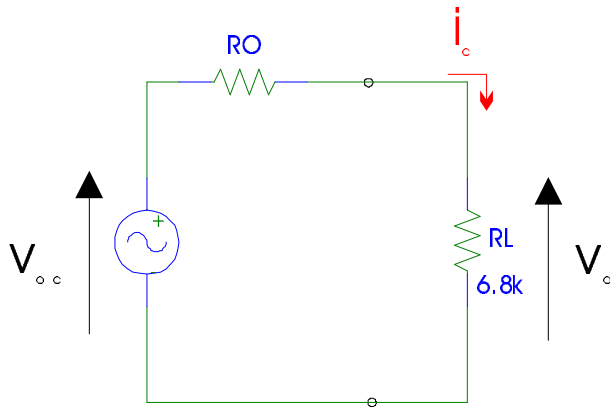


figure 4

Theoretical value of  $R_o$  :

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

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

Measured value of  $R_o$  :

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

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

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

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

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

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

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

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  $A_{vo}$  :

$$A'_{vo} = \frac{V_{oc}}{V_i} \Big|_{R_L \rightarrow \infty}$$

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

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

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

Measured value of  $A_{vo}$  :

$$A_{vo} = \frac{V_{oc}}{V_i}$$

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

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

### iv. Voltage amplification with load $A_v$

Theoretical value of  $A_v$  :

$$A'_v = \frac{V_o}{V_i}$$

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

$$A'_v = -\frac{h_{fe} (R_C \parallel R_L)}{h_{ie}} = \frac{h_{fe} (R_C \parallel R_L)}{h_{fe} \frac{26mV}{I_E}}$$

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

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

Measured value of  $A_v$  :

$$A_v = \frac{V_o}{V_i}$$

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

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

### v. Current amplification $A_i$

Theoretical value of  $A_i$  :

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

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

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

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

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

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 $A_p$

Theoretic values of  $A_p$  :

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

$$A'_p = \left| h_{fe} \frac{R_1}{h_{ie} + R_1} \frac{h_{fe} (R_C \parallel R_L)}{h_{ie}} \right|$$

$$A'_p = \left| h_{fe} \frac{R_1}{h_{ie} + R_1} \frac{R_C \parallel R_L}{26\text{mV} / I_E} \right|$$

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

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

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 k $\Omega$	3.72k $\Omega$	115	74	117	8685
calculated	2.52 k $\Omega$	3.9k $\Omega$	218	138	140	19494

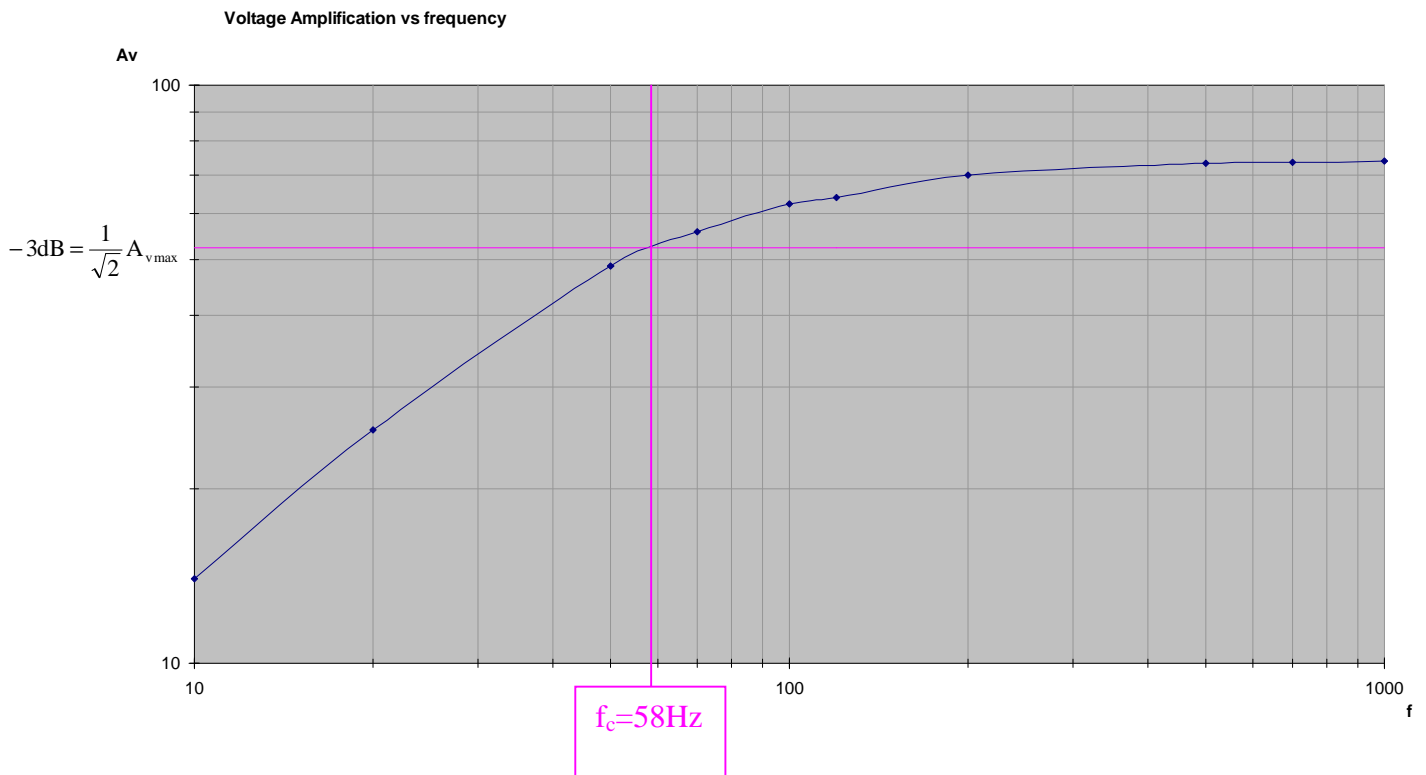
The measured and the calculated values are partly very different. Major problem of the determination of the Bias and the small signal parameters were the uncertain measurements. Especially the small values like  $I_B$  and the input current of the small signal equivalent circuit were very difficult to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

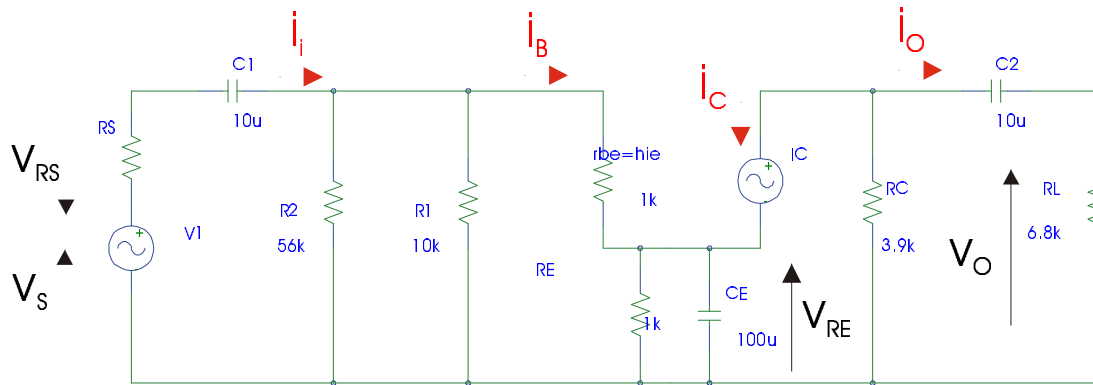


**figure 5**

The cut-off frequency is defined as the frequency, when the amplification is dropped down to 70.7% (-3dB or  $\frac{1}{\sqrt{2}}$ ).

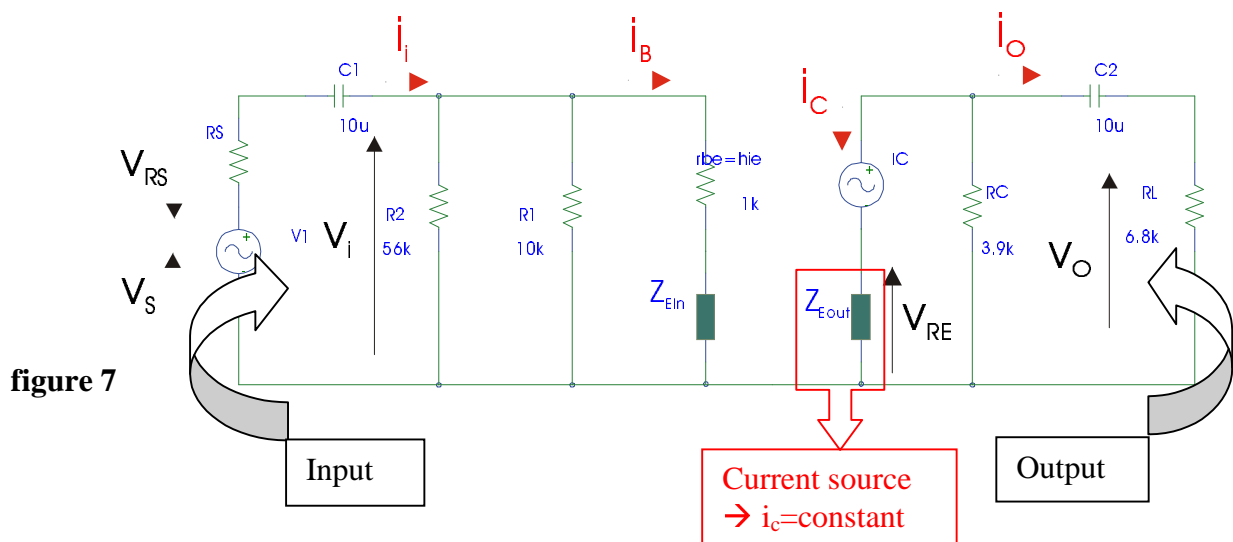
Below this frequency there is still amplification, but the frequency range of amplifiers is commonly defined by the 3dB cut-off frequency.

**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  $1500\Omega$  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  $(\beta+1)R_E$  can be neglected because of its large resistance

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

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

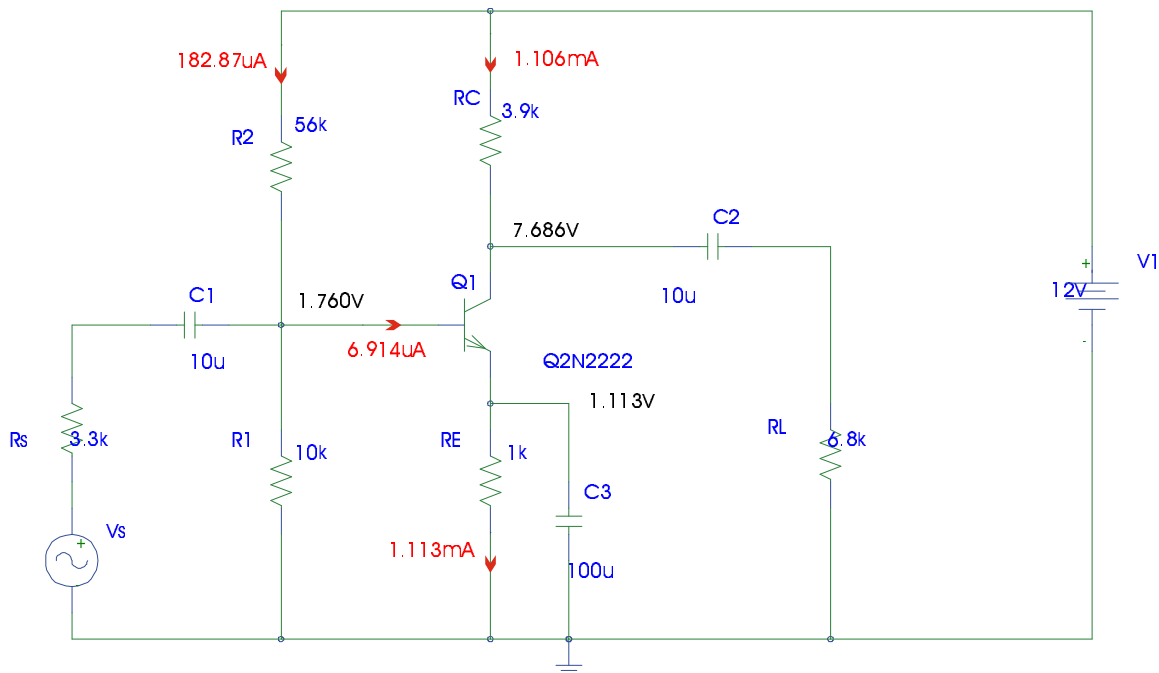
$$\frac{1}{\omega C_E} = R_{in} + h_{ie}$$

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

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

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

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.



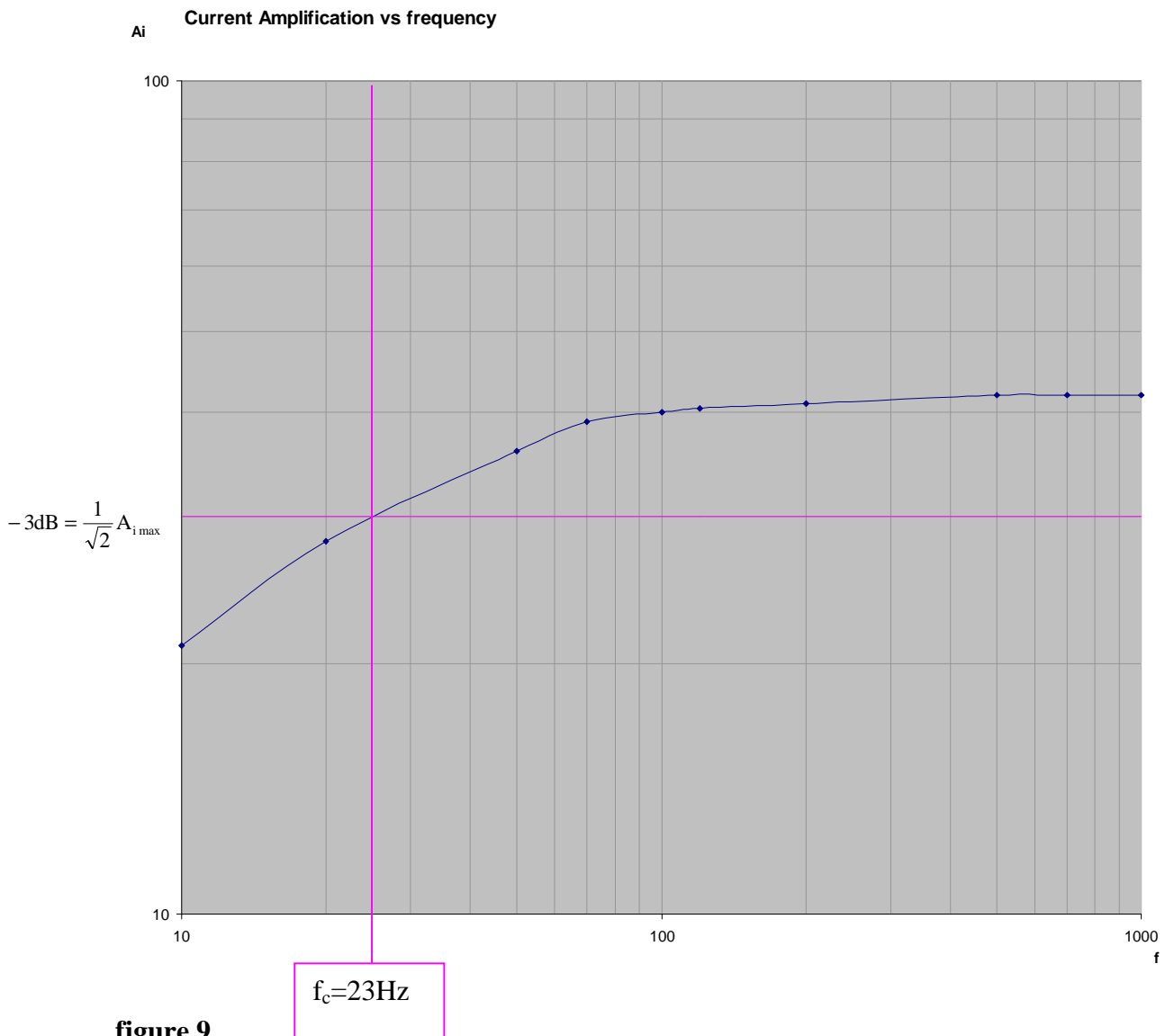
**figure 8**

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
$\frac{v_{rs}}{R_s}/\mu A$	1.38	1.90	2.45	2.54	2.67	2.73	2.79	2.82	2.82	2.85
$\frac{v_o}{R_L}/\mu A$	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



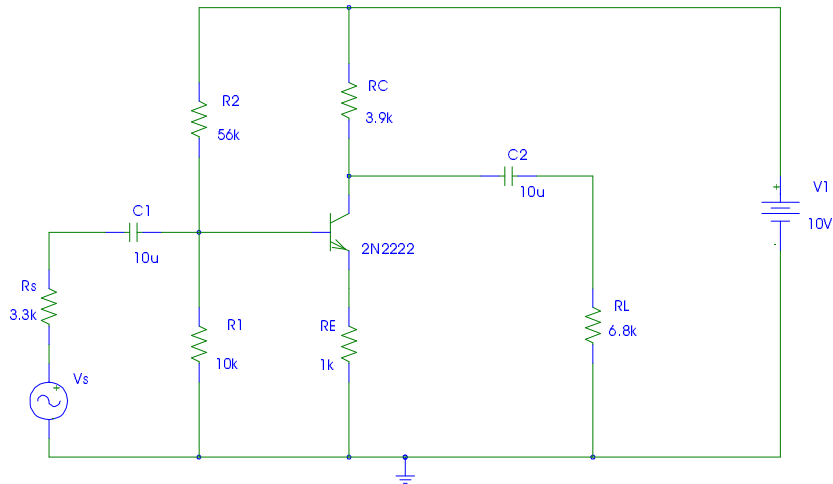
**figure 9**

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  $\beta$  with measured values(  $C_3$  disconnected)**

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

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

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

$$I_B = I_E - I_C$$

$$I_B = 0.861mA - 0.856mA$$

$$I_B = 5\mu A$$

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

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

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

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

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

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

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.

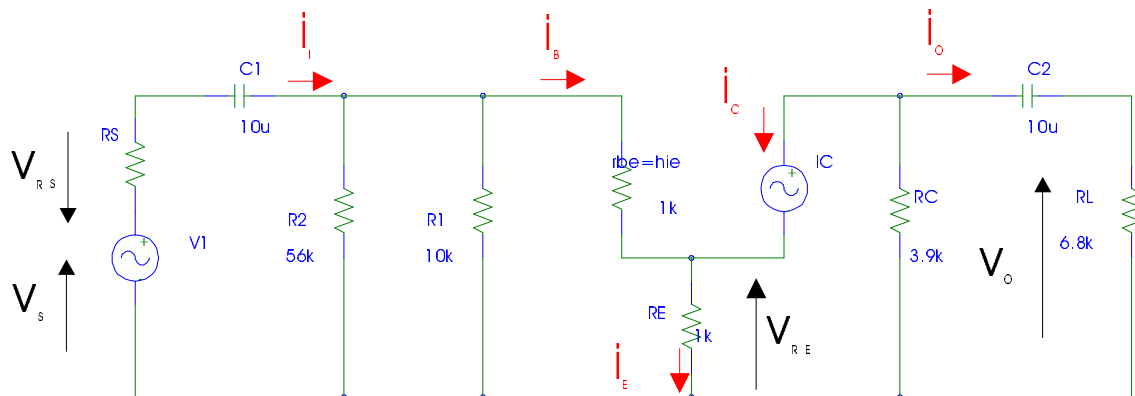
## 8. AC and small signal characteristics (without C<sub>3</sub>)

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<sub>3</sub> 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<sub>E</sub>, 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<sub>3</sub>

→ The input voltages are increased by a factor 10 to obtain better measurands at the low amplifications without bypass capacitor.

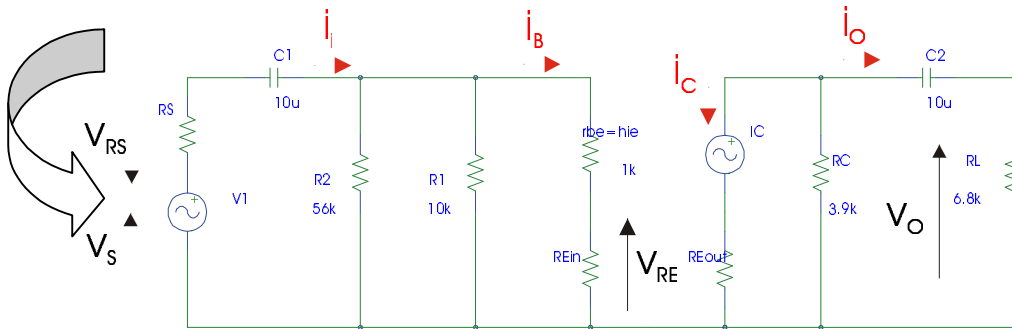
(A generator with  $f=1\text{kHz}$  works as voltage source V1)

$$\begin{aligned}v_s &= 200\text{mV} \\v_{oc} &= 533\text{mV} \\v_o &= 340\text{mV} \\v_i &= 143\text{mV} \\v_{rs} &= 57.3\text{mV}\end{aligned}$$

**c) Calculation and derivation of the small signal parameters (mid freq., without C<sub>3</sub>)**

ALL THEORETICAL VALUES WITH INDEX ' (i.e. R')

**i. Amplifier input resistance R<sub>i</sub>**



**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<sub>E</sub>.

Theoretical value of R<sub>in</sub> :

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

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

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

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

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

Measured Value of R<sub>in</sub> :

$$R_{in} = \frac{V_i}{i_i} = \frac{V_i}{V_{rs}/R_s}$$

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

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

The calculated value of R<sub>in</sub> is very close to the measured value. The approximation of R<sub>Ein</sub> can be done because there's a negligible difference between h<sub>fe</sub> and (h<sub>fe</sub>+1).

## ii. Amplifier output resistance $R_o$

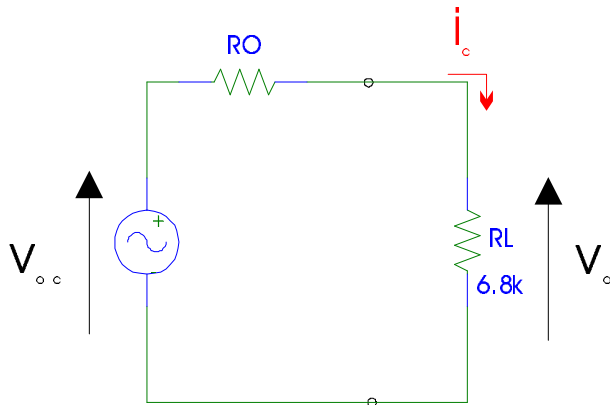


figure 13

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  $R_o$  :

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

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

Measured value of  $R_o$  :

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

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

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

## iii. Voltage amplification at mid frequencies without load

Theoretical value of  $A_{vo}$  :

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

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

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

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

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  $A_{vo}$  :

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

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

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

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

Measured value of  $A_{vo}$  :

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

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

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

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  $A_i$  :

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

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

$$A'_i = h_{fe} \frac{R_1 \parallel R_2}{h_{ie} + R_E (h_{fe} + 1) + R_1 \parallel R_2} = h_{fe} \frac{R_1 \parallel R_2}{h_{fe} \frac{26mV}{I_E} + R_E (h_{fe} + 1) + R_1 \parallel R_2}$$

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

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

Measured value of  $A_i$  :

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

$$A_i = \frac{533mV / 3.82k\Omega}{57.3mV / 3.26k\Omega}$$

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

**vi. Amplifier power gain  $A_p$**

Theoretic values of  $A_p$  :

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

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

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

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

Measured value of  $A_p$  :

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

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

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

**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	8.14k $\Omega$	3.81k $\Omega$	3.3	2.38	8	19
calculated	200	8.15k $\Omega$	3.9k $\Omega$	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

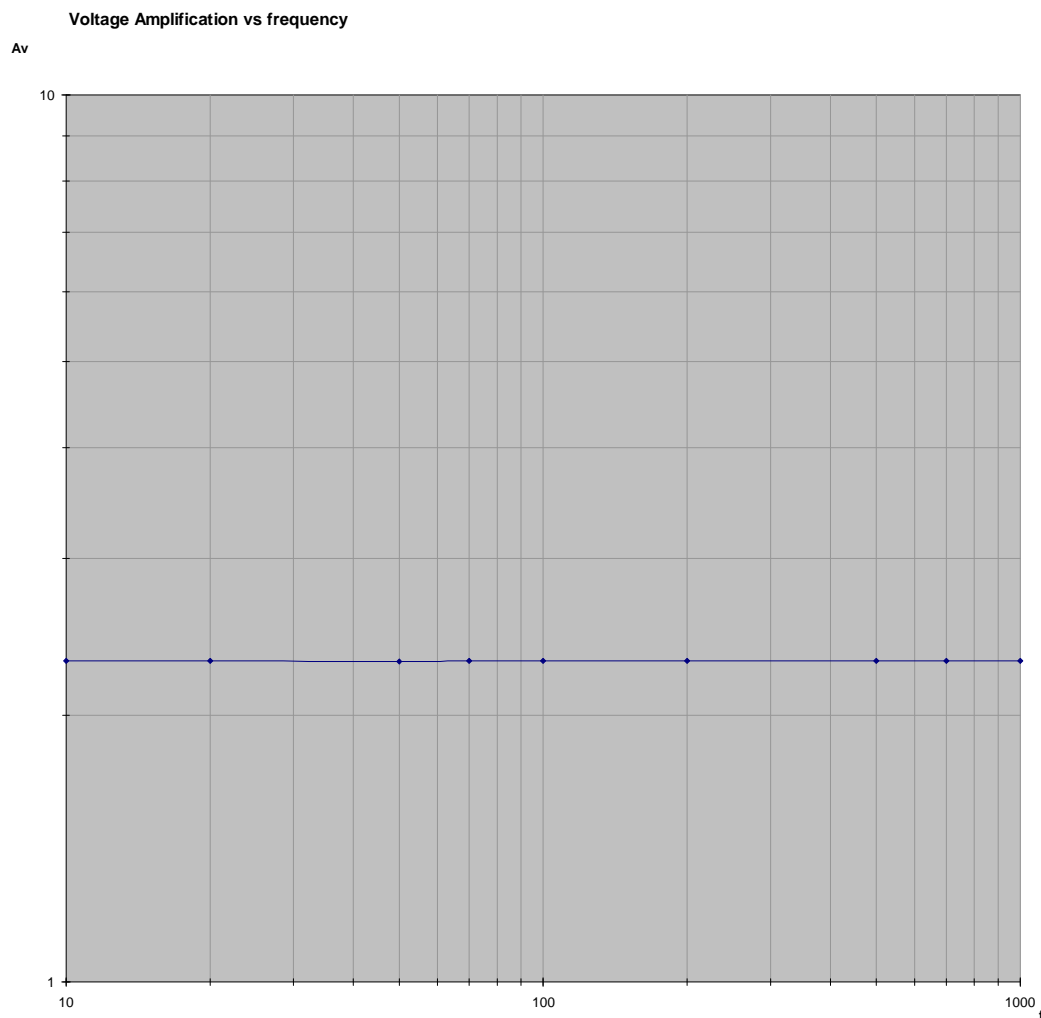


figure 14

$f_c$  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.

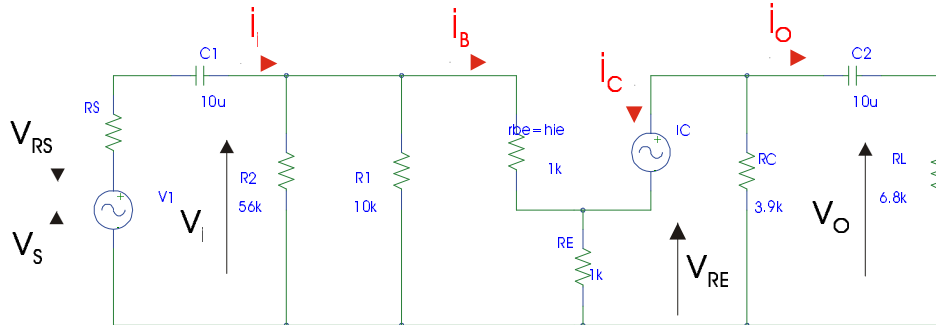


figure 15

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

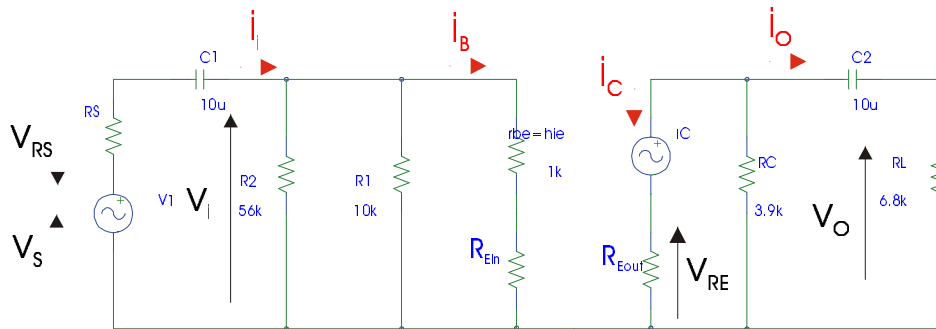


figure 16

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

**For the input circuit:**

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

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

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

**For the output circuit:**

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

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

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

**Combining the I/P and O/P circuit**

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

$$\tau_1 = R_{in} C_1 = [R_B \parallel (h_{ie} + (1 + h_{fe}) R_E)] C_1$$

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

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

**Using the calculated values:**

$$\tau_1 = (8.48k\Omega \parallel 8.14k\Omega) 10\mu F$$

$$\tau_1 = 0.081s$$

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

$$\tau_2 = (3.9k\Omega + 6.8k\Omega) 10\mu F$$

$$\tau_2 = 0.107s$$

$$\omega_2 = \frac{1}{\tau_2} = 9.34Hz \Rightarrow f_{c2} = \frac{\omega_2}{2\pi} = 1.48Hz$$

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

$$\omega_L = 1.55\omega_c$$

$$\omega_c \approx 2Hz$$

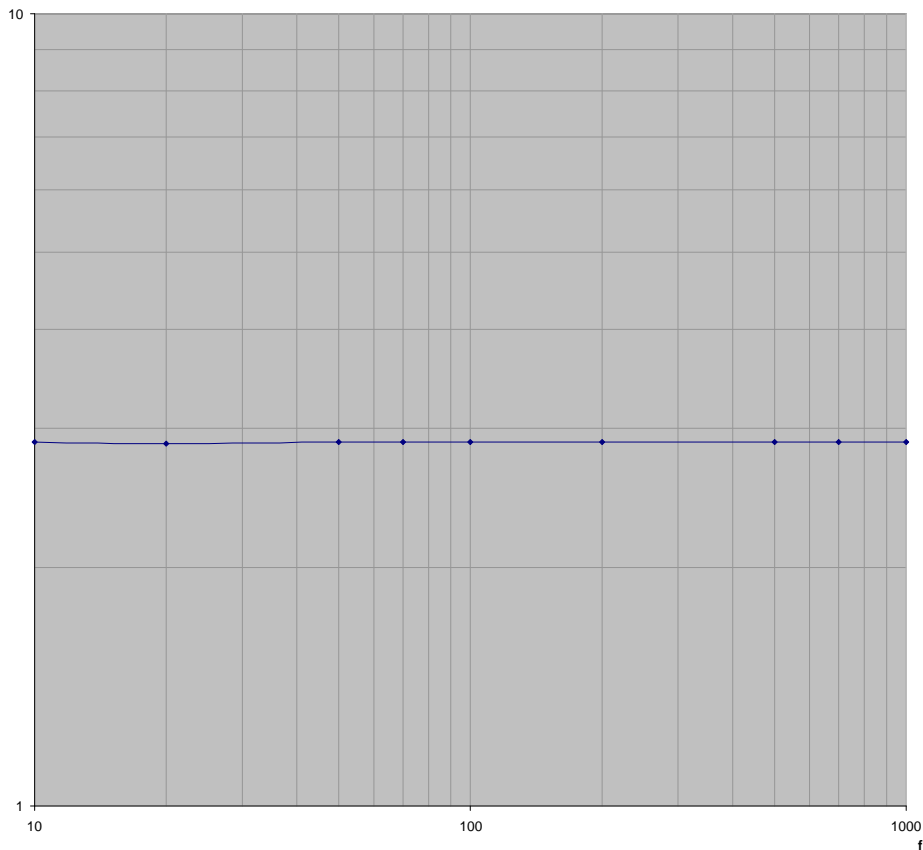
This low frequency was not measurable in the lab, because the generator and the measuring instruments were not able to determine such a low frequency correctly.

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

**c) Frequency response of  $A_i$  without  $C_3$**

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

$A_i$  Current Amplification vs frequency



**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, therefore 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