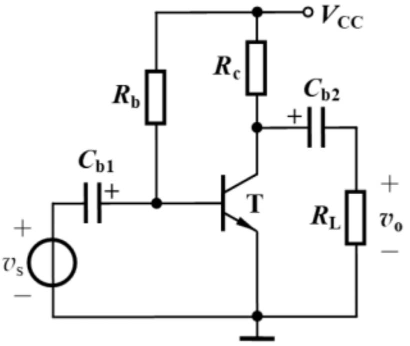
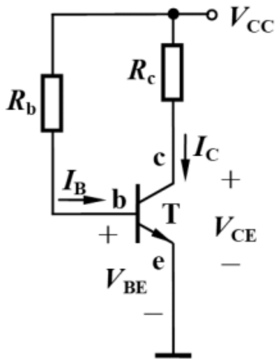
Using a diagram to analyze a BJT amplification circuit:



First step: draw the DC circuit



Input $i - v$ curve:

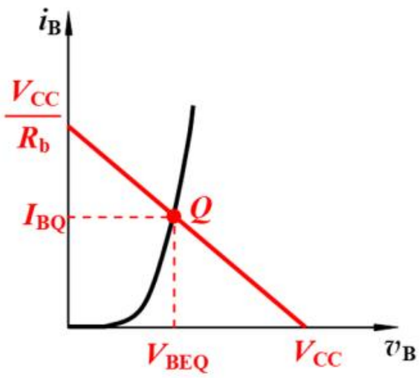
$$v_{BE} = V_{CC} - i_B R_b$$

Output $i - v$ curve:

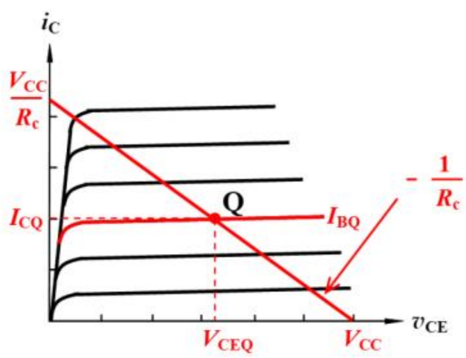
$$v_{CE} = V_{CC} - i_C R_c$$

Diagram analysis of static operating point :

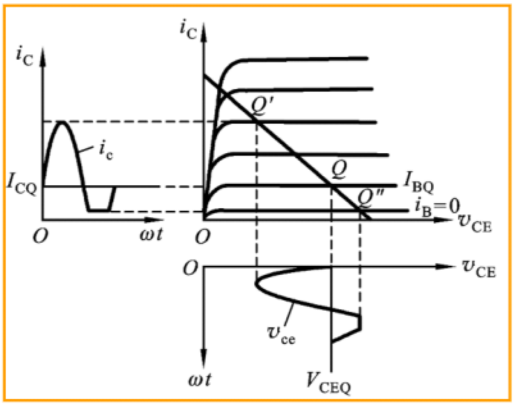
$$v_{BE} = V_{CC} - i_B R_b$$



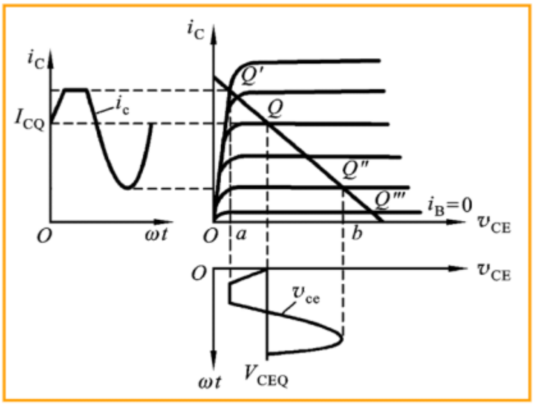
$$v_{CE} = V_{CC} - i_C R_c$$



The effects of Q point on waveform distortion:

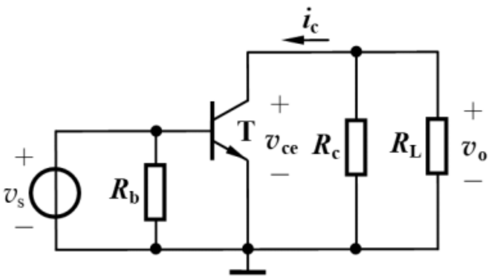


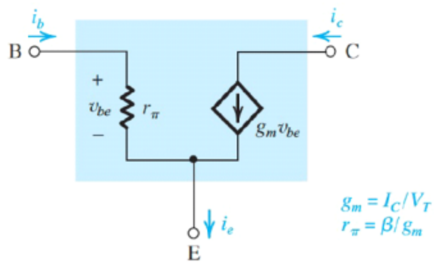
Cutoff distortion



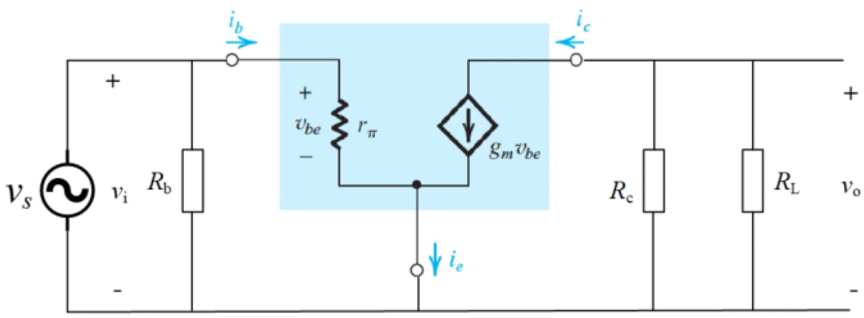
Saturation distortion

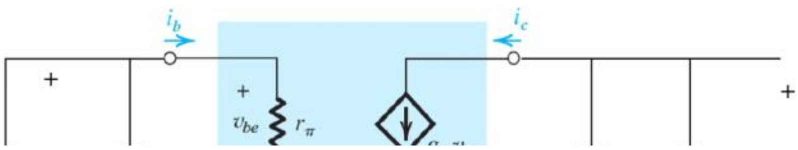
For the AC signal diagram:

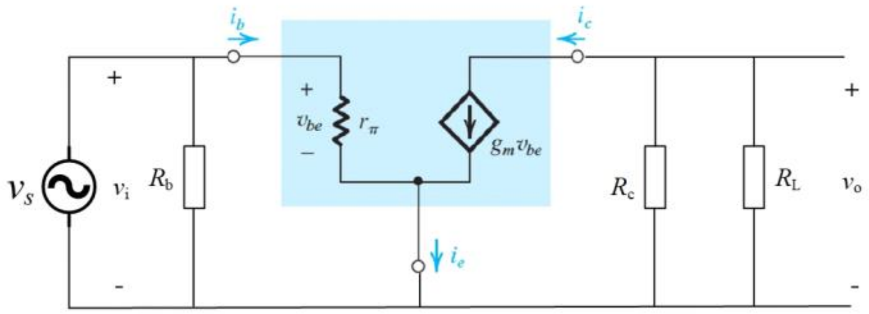


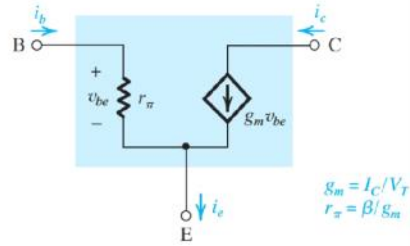


Small-signal model of a BJT









$$\boxed{v_i = v_{be} = i_b r_\pi}$$

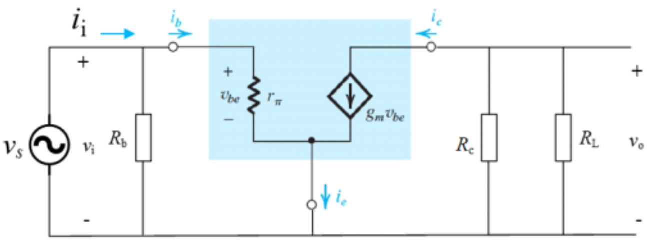
$$i_c = g_m v_{be} = g_m i_b r_\pi = g_m i_b\ \beta/g_m$$
$$= \beta i_b$$

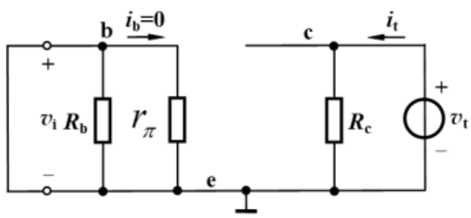
$$\boxed{v_o = -i_c \cdot \left(\frac{R_c R_L}{R_c + R_L}\right)}$$

AC small-signal amplification coefficient:

$$\boxed{A_V = \frac{v_o}{v_i} = \frac{-i_c \cdot \left(\frac{R_c R_L}{R_c + R_L}\right)}{i_b r_\pi} = -\frac{\beta \cdot R_c R_L}{r_\pi (R_c + R_L)}}$$

Input and output impedances:





Input impedance:

$$R_i = \frac{v_i}{i_i} = \frac{R_b r_\pi}{R_b + r_\pi}$$

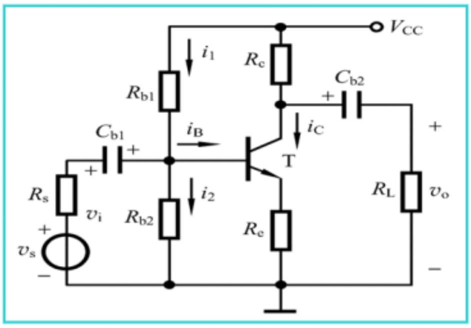
Output impedance:

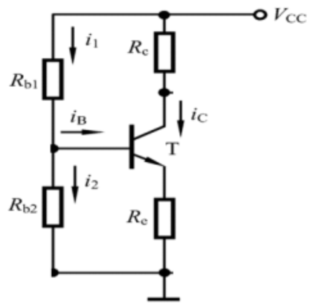
$$R_o = \left.\frac{v_t}{i_t}\right|_{v_s=0, R_L=\infty} = R_c$$

R_L is replaced with a voltage source (v_t):

Input source is short:

For a more complicated BJT circuit:





DC circuit

Q point:

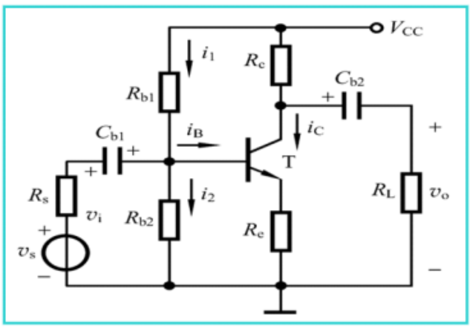
$$V_{BQ} \approx \frac{R_{b2}}{R_{b1} + R_{b2}} \cdot V_{CC}$$

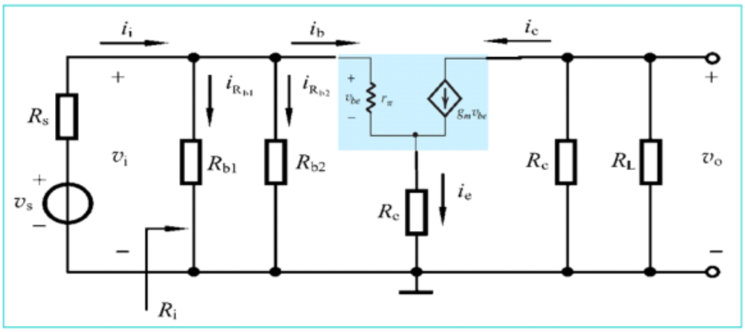
$$I_{CQ} \approx I_{EQ} = \frac{V_B - V_{BEQ}}{R_e}$$

$$I_{BQ} = \frac{I_{CQ}}{\beta}$$

$$V_{CEQ} \approx V_{CC} - I_{CQ}(R_c + R_e)$$

For a more complicated BJT circuit:





AC circuit

$$\boxed{v_i = v_{be} + i_e R_e = i_b r_\pi + i_e R_e = i_b r_\pi + (1+\beta) i_b R_e}$$

$$i_c = g_m v_{be} = g_m i_b r_\pi = g_m i_b \, \beta / g_m$$
$$= \beta i_b$$

$$\boxed{v_o = -i_c \cdot \left(\frac{R_c R_L}{R_c + R_L}\right)}$$

$$\boxed{A_V = \frac{v_o}{v_i}} = \frac{-i_c \cdot \left(\frac{R_c R_L}{R_c + R_L}\right)}{i_b r_\pi + (1+\beta) i_b R_e} = -\frac{\beta \cdot R_c R_L}{(r_\pi + (1+\beta) R_e)(R_c + R_L)}$$

Blackboard Notes for lecture_4

slide 4:

the slope of the straight line will contribute to different Q point.

slide 7:

the Q point should be properly selected, otherwise, it will result in waveform distortion.

slide 8:

$A_v = -\frac{\beta \cdot R_c R_L}{r_\pi (R_c + R_L)}$, be aware of the minus sign here,

it means the ~~phase~~ output signal and input signal are out of phase (180° phase differnce).

the amplification coefficient can be tuned by adjusting the value s of R_c and R_L.

slide 9:

please be aware of i_i which is generally not equal to i_B. Calculate input impedance and output impedance according to definitions.

slide 17:

for any complicated BJT circuit:

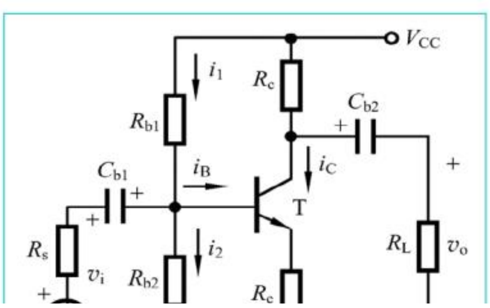
You need to formulate v_i and v_o, then calculate $A_v = \frac{v_o}{v_i}$

Also, DC circuit should be first drawed to determine Q point.

then AC circuit should be built to formulate v_i and v_o.

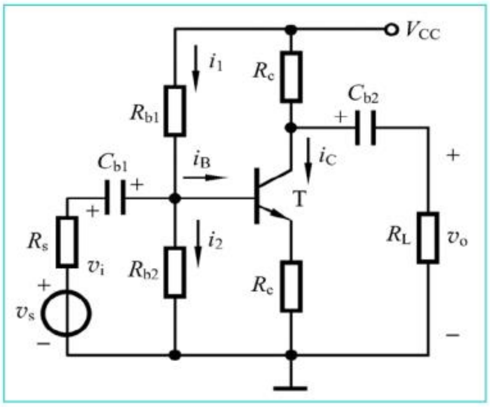
Practice Exercise _Lecture 4

1. For the following circuit, V_{CC} = 16 V, R_{b1} = 56 kΩ, R_{b2} = 20 kΩ, R_e = 2 kΩ, R_c = 3.3 kΩ, R_L = 6.2 kΩ, R_s = 500 Ω, β = 80, V_{BEQ} = 0.7 V.



Practice Exercise _Lecture 4

1. For the following circuit, $Vcc = 16$ V, $R_{b1} = 56$ kΩ, $R_{b2} = 20$ kΩ, $R_e = 2$ kΩ, $R_c = 3.3$ kΩ, $R_L = 6.2$ kΩ, $R_s = 500$ Ω, $\beta = 80$, $V_{BEQ} = 0.7$ V.



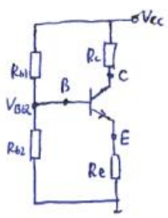
a. Draw its corresponding DC circuit, and calculate the Q operating point.

b. Draw its corresponding small-signal model, and calculate R_i, R_o, and A_v.

c. If a capacitor with a value of 50μF is parallel with R_e, please calculate (a) and (b) again.

Answers to practice exercise of lecture - 4

a. DC circuit:
C becomes open!



$$V_{BQ} \approx \frac{R_{b2}}{R_{b1}+R_{b2}} \cdot V_{cc} = 4.21\text{ V}$$

V_{BEQ}

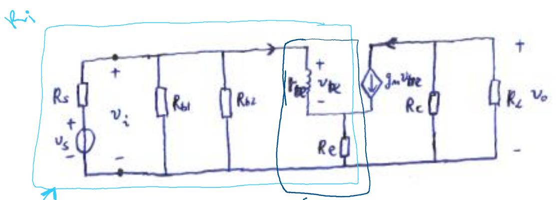
$$I_{CQ} \approx I_{EQ} = \frac{V_{BQ} - V_{BEQ}}{Re} = 1.755\text{ mA}$$

$$V_{CEQ} = V_{cc} - I_{CQ} \cdot R_c - I_{EQ} \cdot Re \approx V_{cc} - I_{CQ}(R_c + Re) = 6.69\text{V}$$

$$I_{BQ} = \frac{I_{CQ}}{\beta} = \frac{1.755\text{mA}}{80} = 21.9\ \mu\text{A}$$

Q (21.9 μA, 1.755mA, 6.69V)

b. C becomes short's here!



$$R_i = R_{b1} // R_{b2} // [r_{be} + (1+\beta) Re] \approx 13.5\text{k}\Omega$$

$$r_{be} = \frac{\beta}{g_m}, \quad g_m = \frac{I_{CQ}}{V_T} = \frac{1.755\text{mA}}{26\text{mV}} = 0.0675\text{ S}$$

$$r_{be} = 80/0.0675 \approx 1185\,\Omega = 1.185\text{ k}\Omega$$

$$R_o \approx R_c = 3.3\text{ k}\Omega$$

$$R_o = \frac{V_a}{I_c}$$

V_a = early voltage effect

$15 < V_a < 200$

R_L

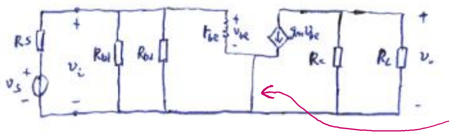
$$A_v = \frac{v_o}{v_i} = -\frac{\beta \cdot (R_c // R_L)}{r_{be} + (1+\beta) Re} \approx -1.05$$

Rember this!

c. if a capacitor is parallel with Re, ~~recalculate a~~.

the Q point is the same as the capacitor is regarded as open in DC circuit. AKA Re disappears

recalculate (b). Since capacitor is regarded as short for AC circuit.



$Re \parallel C = 0$

as C are short for this model

$R_i = R_{b1} // R_{b2} // r_{be} \approx 1.1\ k\Omega$

$R_o = R_c = 3.3\ k\Omega$

This is a mistake! should be $R_L \parallel R_c$

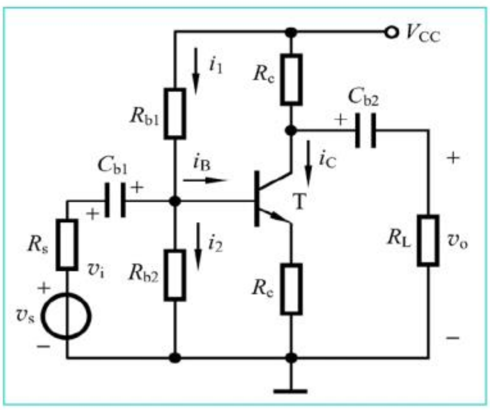
$A_v = \frac{v_o}{v_i} = -\frac{\beta \cdot (R_{b1} // R_{b2})}{r_{be}} \approx -995$

check this again, yes

... Calculations done by us ...

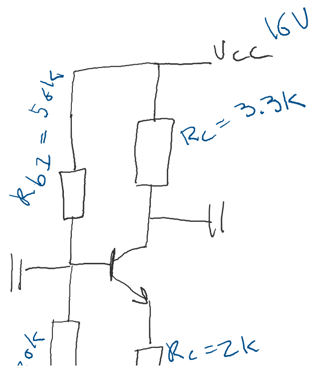
Practice Exercise _Lecture 4

1. For the following circuit, $Vcc = 16$ V, $R_{b1} = 56$ kΩ, $R_{b2} = 20$ kΩ, $R_e = 2$ kΩ, $R_c = 3.3$ kΩ, $R_L = 6.2$ kΩ, $R_s = 500$ Ω, $\beta = 80$, $V_{BEQ} = 0.7$ V.



   a. Draw its corresponding DC circuit, and calculate the Q operating point.
   b. Draw its corresponding small-signal model, and calculate R_i, R_o, and A_v.
   c. If a capacitor with a value of 50μF is parallel with R_e, please calculate (a) and (b) again.

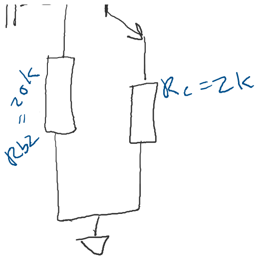
A



Q point $(I_{BQ}, I_{CQ}, V_{CEQ})$

- $I_{BQ} = \frac{U_{BQ} - V_{BEQ}}{RB}$

$V_{BQ} = \frac{Rb2}{Rb2 + Rb1} \cdot V_{cc} = 4.2$



$V_{BQ} = \frac{\ldots}{R_{b2} + R_{b1}} \cdot V_{cc} = 4.2$

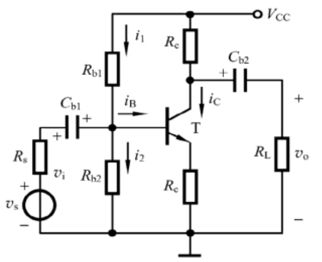
$R_B = R_{b1} \parallel R_{b2} \parallel ?$ so we can't!

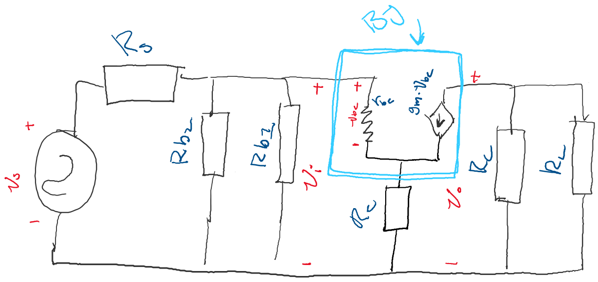
$I_{EQ} \approx I_{CQ} = \frac{V_{BQ} - V_{BEQ}}{R_e} = \frac{4.2 - 0.6}{2k} = 1.8\ m[A]$

$I_{BQ} = \frac{I_{CQ}}{\beta} = \frac{1.8m[A]}{80\,[\cdot]} = 22.5\mu\ [A]$

$V_{CEQ} = V_{CC} - I_{CQ} \cdot R_c - I_{EQ} \cdot R_e = 16 - 1.8m \cdot (3.3k - 2k) = 6.46\ [V]$

$Q(22.5\mu[A],\ 1.8m[A],\ 6.46[V])$





SÅ SKAL VI LIGE HAVE FUNDET NOGEN VARIABLER

$gm := \frac{I_{CQ}}{V_T} = 67.51 \times 10^{-3}$

$r_{be} := \frac{\beta}{gm} = 1.19 \times 10^{3} \xrightarrow{\text{affix unit ohm}} 1.19 \times 10^{3}\ \Omega$

Vi bruger faktisk ikke lige R_i, men nu udregner vi den så sku alligevel.

$R_i := \frac{1}{\frac{1}{R_{b1}} + \frac{1}{R_{b2}} + \frac{1}{(r_{be} + (1+\beta) \cdot R_E)}} = 13516.22465 \xrightarrow{\text{affix unit ohm}} 13.52 \times 10^{3}\ \Omega$

Det vigtigest er faktisk hvor sidste "resistor led" da vi genbruger den igen, sener til vores A_V

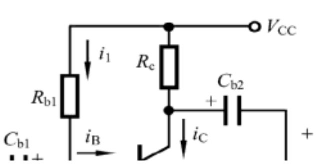
R_o, skal vi dog bruge og derfor regner vi den nu her.

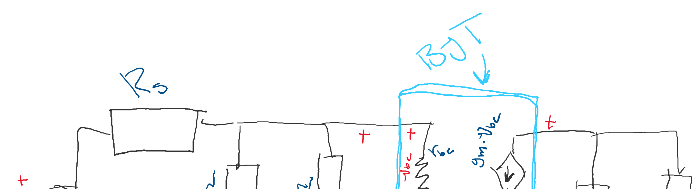
$R_o := \frac{1}{\frac{1}{R_C} + \frac{1}{R_L}} = 2153.684211 \xrightarrow{\text{affix unit ohm}} 2.15 \times 10^{3}\ \Omega$

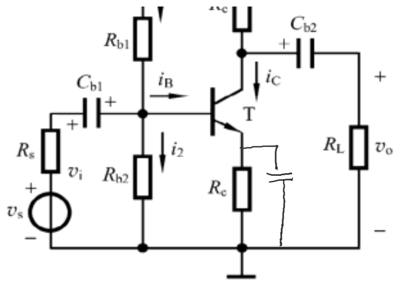
$A_V := -\frac{\beta \cdot R_o}{r_{be} + (1+\beta) \cdot R_E}$

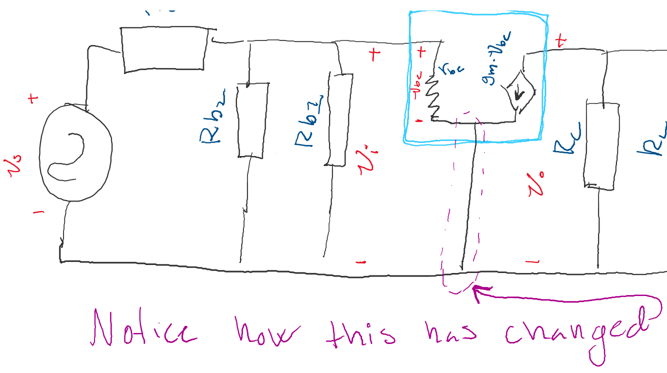
$$A_V := -1.055824549 \tag{1.2.1}$$

3. a C || Re









FIND THE Q-POINT

Q (I_cq, I_eq, V_ceq)

$V_{BQ} := \frac{R_{b2}}{R_{b1}+R_{b2}} \cdot VCC = 4.21 \xrightarrow{\text{affix unit volt}} 4.21\ \mathrm{V}$

$I_{EQ} := \frac{V_{BQ} - V_{BEQ}}{R_E} = 1.76 \times 10^{-3}$

Og så siger vi at der rooughly er det samme:
$I_{CQ} := I_{EQ}$

$$1.76 \times 10^{-3} \tag{1.3.1.1}$$

$I_{BQ} := \frac{I_{CQ}}{\beta}$

$$21.94 \times 10^{-6} \tag{1.3.1.2}$$

$V_{CEQ} := VCC - I_{CQ} \cdot R_C - I_{EQ} \cdot R_E$

$$6.70 \tag{1.3.1.3}$$

$\xrightarrow{\text{affix unit volt}}$

$$6.697105259\ \mathrm{V} \tag{1.3.1.4}$$

Så er dit Q point altså:

I_{BQ}

$$21.94 \times 10^{-6} \tag{1.3.1.5}$$

HVIS DU NU LIGE IKKE HAVDE REGNET DET (DUCKING) UD, SÅ ER DET OVENOVER I AMPERE
I_{CQ}

$$1.76 \times 10^{-3} \tag{1.3.1.6}$$

HVIS DU NU LIGE IKKE HAVDE REGNET DET (DUCKING) UD, SÅ ER DET OVENOVER I AMPERE
V_{CEQ}

$$6.697105259 \tag{1.3.1.7}$$

$Q(I_{BQ}, I_{CQ}, V_{CEQ})$

$$Q(21.94 \times 10^{-6}, 1.76 \times 10^{-3}, 6.70) \tag{1.3.1.8}$$

A new A_V is found

$gm := \frac{I_{CQ}}{V_T} = 67.51 \times 10^{-3}$

Yo, pssst, makker. Husk at $r_{be} = r_\pi$

$r_{be} := \frac{\beta}{gm} = 1.19 \times 10^3 \xrightarrow{\text{affix unit ohm}} 1.19 \times 10^3\ \Omega$

$R_{In} := \frac{1}{\frac{1}{R_{b1}} + \frac{1}{R_{b2}} + \frac{1}{r_{be}}} = 1096.811539$

$R_{out} := \frac{1}{\frac{1}{R_C} + \frac{1}{R_L}} = 2153.684211$

$A_V := -\frac{\beta \cdot R_{out}}{r_{be}}$

$$A_V := -145.3954827 \tag{1.3.2.1}$$

Fortegnet er negativt da den er inverterende, husk nu lige det.