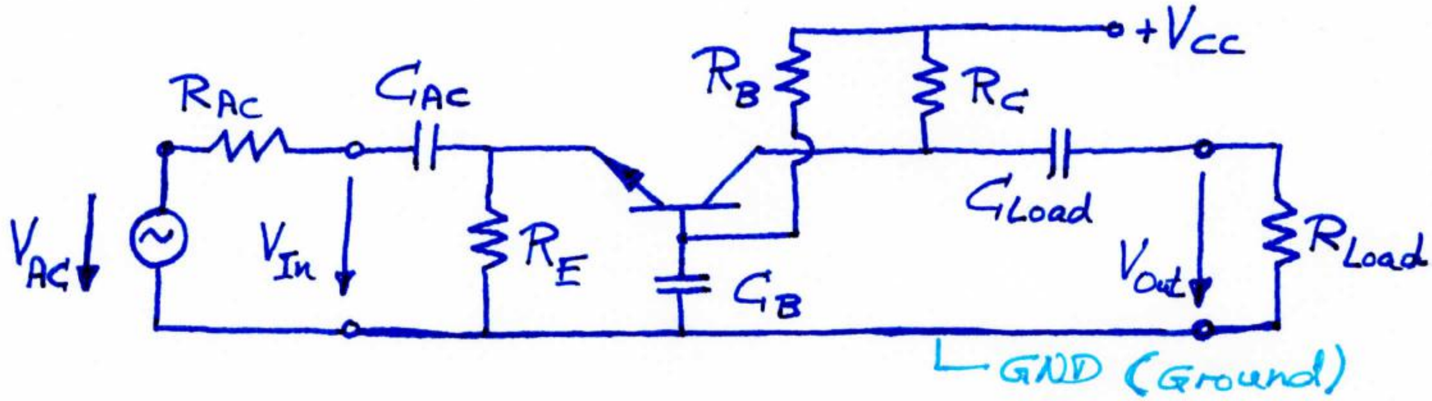
ITE - Homework 7 - Solution

Problem 1 Amplifier

(a) β = Current amplification in common-emitter configuration

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.99}{1-0.99} = \frac{0.99}{0.01} = 99 \approx \underline{\underline{100}}$$

(b) Redraw circuit diagram



(c) Base is shared (common) for AC signals.

⇒ Circuit is common-base configuration.

(d) $R_C = R_E = 500\,\Omega$ $\quad V_{RC} = 3.0\,V \quad$ Q-point ?

$$\Rightarrow I_C = \frac{V_{RC}}{R_C} = \frac{3.0\,V}{500\,\Omega} = \underline{\underline{6\text{ mA}}}$$

$$\Rightarrow I_B = \frac{I_C}{\beta} = \frac{6\,mA}{100} = 0.06\,mA = \underline{\underline{60\,\mu A}}$$

$$\Rightarrow I_E = I_C + I_B = 6\,mA + 60\,\mu A = \underline{\underline{6.06\,mA}}$$

$$\Rightarrow V_{RE} = 500\,\Omega \times 6.06\,mA = 3.03\,V$$

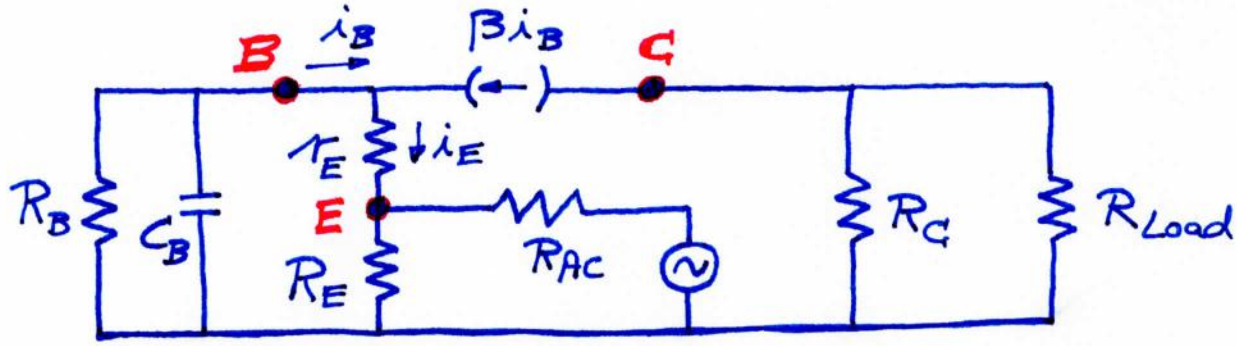
$$\Rightarrow V_{Base} = V_{RE} + V_{BE} = 3.03V + 0.7V = 3.73V$$

$$\Rightarrow R_B = \frac{V_{CC} - V_{Base}}{I_{Base}} = \frac{12V - 3.73V}{60\mu A} = \underline{\underline{138\,k\Omega}}$$

(e) Differential emitter resistance

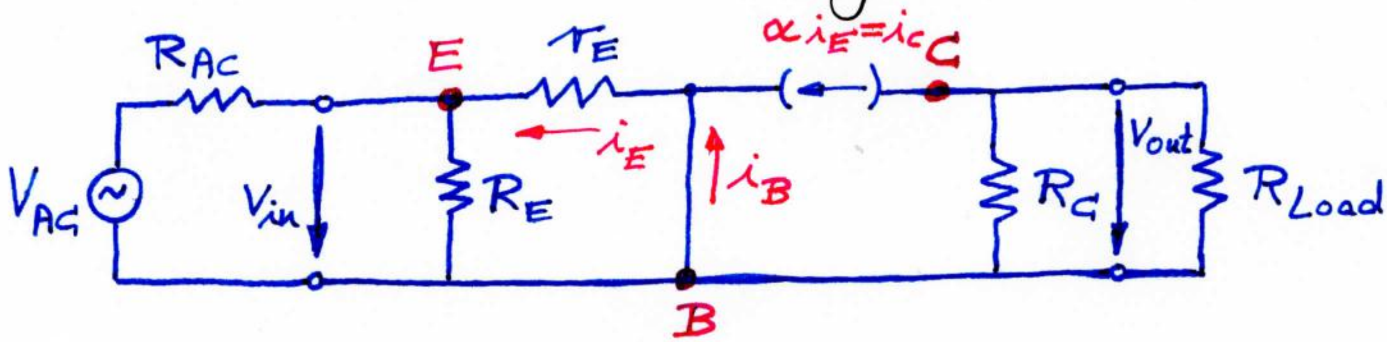
$$r_E = \frac{V_t}{I_E} = \frac{26mV}{6.06mA} = \underline{\underline{4.29\,\Omega}}$$

(f) AC small-signal equivalent circuit



Note: R_B is shorted by C_B ⇒ Base is connected to GND.

(g) Redraw circuit diagram



⇒ Linear circuit. ⇒ We can analyze effect of one source without considering other sources.

(h) $Z_{in} = \dfrac{V_{in}}{i_{in}} = \dfrac{V_{in}}{i_{RE} + i_{rE}} = \dfrac{V_{in}}{\dfrac{V_{in}}{R_E} + i_E}$

$= \left(\dfrac{V_{in}/R_E + i_E}{V_{in}} \right)^{-1} = \left(\dfrac{1}{R_E} + \dfrac{1}{r_E} \right)^{-1} = \underline{\underline{R_E \parallel r_E}}$

$\Rightarrow$ Note $r_E \ll R_E \Rightarrow Z_{in} \lessapprox r_E$

$\Rightarrow \underline{\underline{Z_{in} \approx r_E}}$ $\quad r_E = 4.29\,\Omega$

$Z_{in} \approx r_E = 4.29\,\Omega$ is relatively <u>low value</u>

(i) $Z_{out} = \dfrac{V_{out}}{i_{out}} = \dfrac{i_{out} R_C}{i_{out}} = \underline{\underline{R_C}}$

(j) $A_{VOC} = \dfrac{V_{out}}{V_{in}}$ when $R_{Load} = \infty$ (OC)

$A_{VOC} = \dfrac{V_{out}}{V_{in}} = \dfrac{i_C R_C}{i_E r_E} = \dfrac{\alpha\, i_E R_C}{i_E r_E} = \alpha \dfrac{R_C}{r_E} \approx \underline{\underline{\dfrac{R_C}{r_E}}}$

$= \dfrac{500\,\Omega}{4.29\,\Omega} = \underline{\underline{117}}$

(k) $A_{ISC} = \dfrac{i_{out}}{i_{in}}$ when $R_{Load} = 0$ (SC)

$A_{ISC} = \dfrac{i_{out}}{i_{in}} = \dfrac{i_C}{i_E + i_{RE}} \approx \dfrac{i_C}{i_E} = \underline{\underline{\alpha}} = \underline{\underline{0.99}}$

(l) $A_V = ?$ $\quad R_{Load} = 500\,\Omega \quad R_C = 500\,\Omega$

$A_V = \dfrac{V_{out}}{V_{in}} = \dfrac{i_C (R_C \parallel R_{Load})}{i_E\, r_E} \approx \dfrac{R_C \parallel R_{Load}}{r_E}$

$= \dfrac{500\,\Omega \parallel 500\,\Omega}{4.29\,\Omega} = \dfrac{250\,\Omega}{4.29\,\Omega} = \underline{\underline{58.5}}$

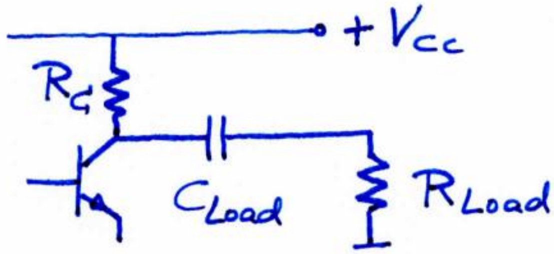
(m) The resistances R_C and R_{Load} act as current divider. Which part of i_c will flow through R_{Load}?

$$\Rightarrow i_{Load} = i_c \frac{1/R_{Load}}{1/R_{Load} + 1/R_C} = i_c \frac{(500\Omega)^{-1}}{(500\Omega)^{-1} + (500\Omega)^{-1}}$$

$$= \frac{1}{2} i_c$$

$$A_I = \frac{i_{out}}{i_{in}} = \frac{\frac{1}{2} i_c}{i_E} \approx \frac{1}{2}\alpha \approx \underline{\underline{0.5}}$$

(n)



$\left.\begin{array}{l} C_{Load} \text{ blocks DC} \\ C_{Load} \text{ lets pass AC} \end{array}\right\}$ This is a <u>high-frequency pass filter</u>

Relevant R is the R that C_{Load} will discharge through.

Inspection of circuit diagram reveals that $\underline{\text{relevant } R} = R_C + R_{Load} = \underline{\underline{1\ k\Omega}}$

Recall $\quad \omega_{3dB} = \omega_{cutoff} = \frac{1}{RC}$

$$\Rightarrow f_{3dB} = f_{cutoff} = \frac{1}{2\pi}\frac{1}{RC}$$

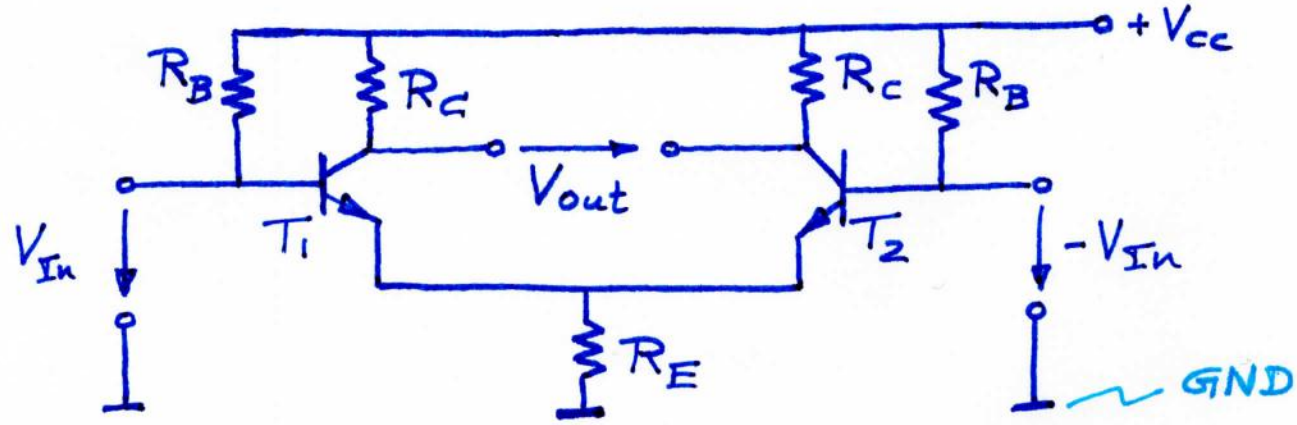
(o) $f_{cutoff} = \dfrac{1}{2\pi RC} \Rightarrow C = \dfrac{1}{2\pi R f_{3dB}}$

$f_{cutoff} \to f_{3dB}$

$$C = \frac{1}{2\pi \, 1k\Omega \, 1kHz} = \underline{\underline{159\,nF}}$$

Problem 2 Differential amplifier

(a) Circuit diagram



(b) Q-point

$V_{RE} = 1V \quad V_{CE} = 5V \quad V_{cc} = 12V$

Current through $R_E = I_{RE} = 20\,mA$

$$\Rightarrow R_E = \frac{V_{RE}}{I_{RE}} = \frac{1V}{20\,mA} = \underline{\underline{50\Omega}}$$

$$I_{C1} \approx I_{E1} = \frac{1}{2} I_{RE} = \underline{\underline{10\,mA}}$$

KVL $\quad V_{cc} = V_{RE} + V_{CE} + V_{RC}$

$$\Rightarrow V_{RC} = V_{cc} - V_{CE} - V_{RE} = 12V - 5V - 1V = 6V$$

$$\Rightarrow R_C = \frac{V_{RC}}{I_{RC}} = \frac{6V}{10\,mA} = \underline{\underline{600\Omega}}$$

$$I_B = I_c/\beta = \frac{10\,mA}{100} = \underline{\underline{0.1\,mA}}$$

$$V_{RB} = V_{cc} - V_{RE} - V_{BE} = 12V - 1V - 0.7V = 10.3V$$

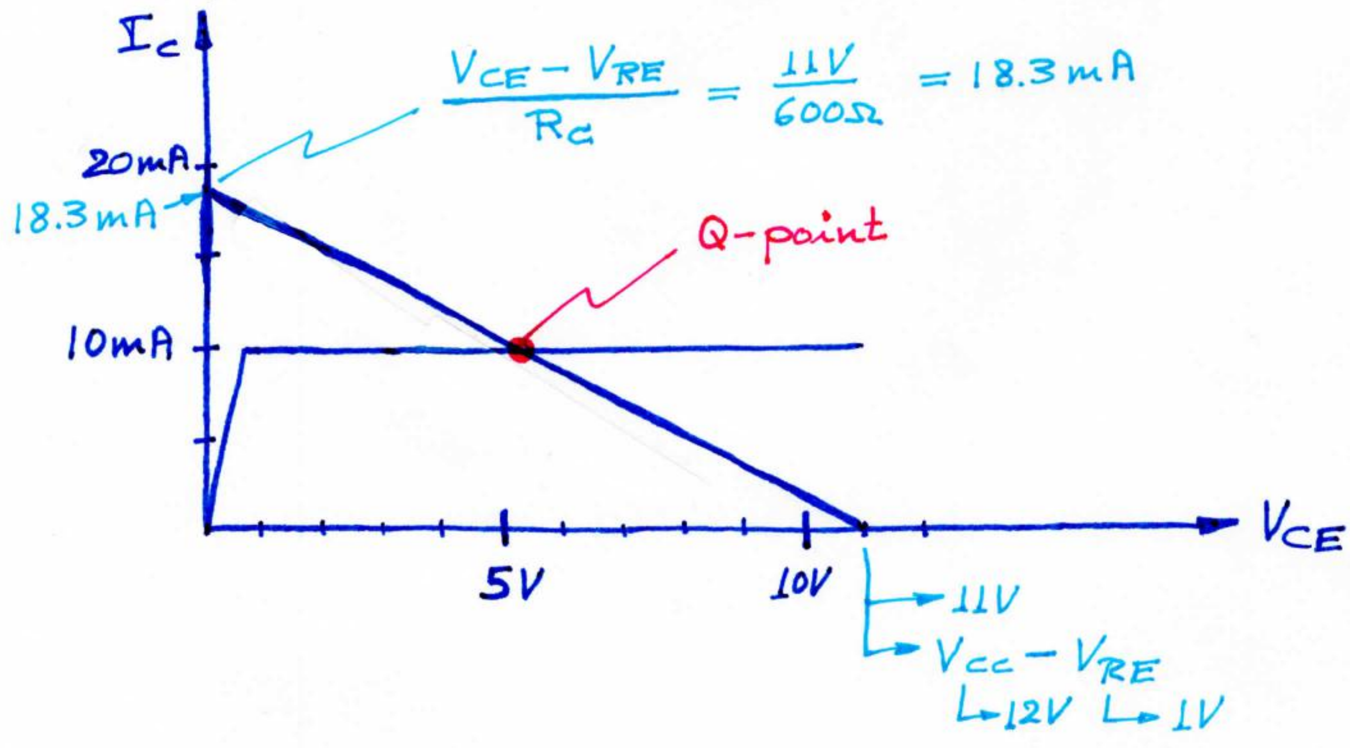
$$\Rightarrow R_B = V_{RB}/I_{RB} = 10.3V/0.1mA = \underline{\underline{103\,k\Omega}}$$

(c) At Q-point: $V_E = 1V$ $V_C = 6V$ $V_{CE} = 5V$

$I_C = 10mA$ $I_E = 10mA$

V_E can be considered "virtual ground" because V_E does not change. Currents through transistors change but sum $I_{E1} + I_{E2} = I_{RE}$ does not $\Rightarrow V_E = \text{constant}$

Output characteristic

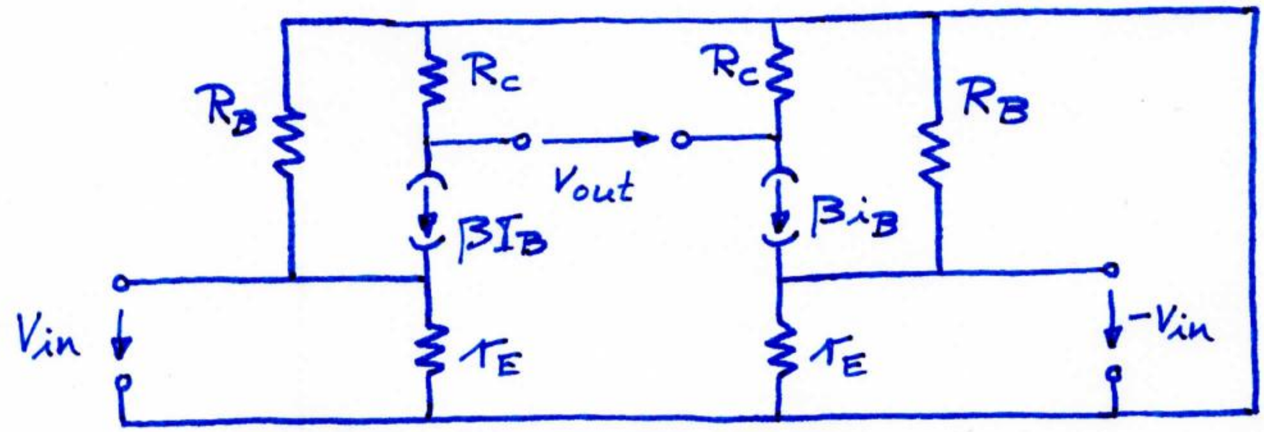


(d) Differential emitter resistance r_E

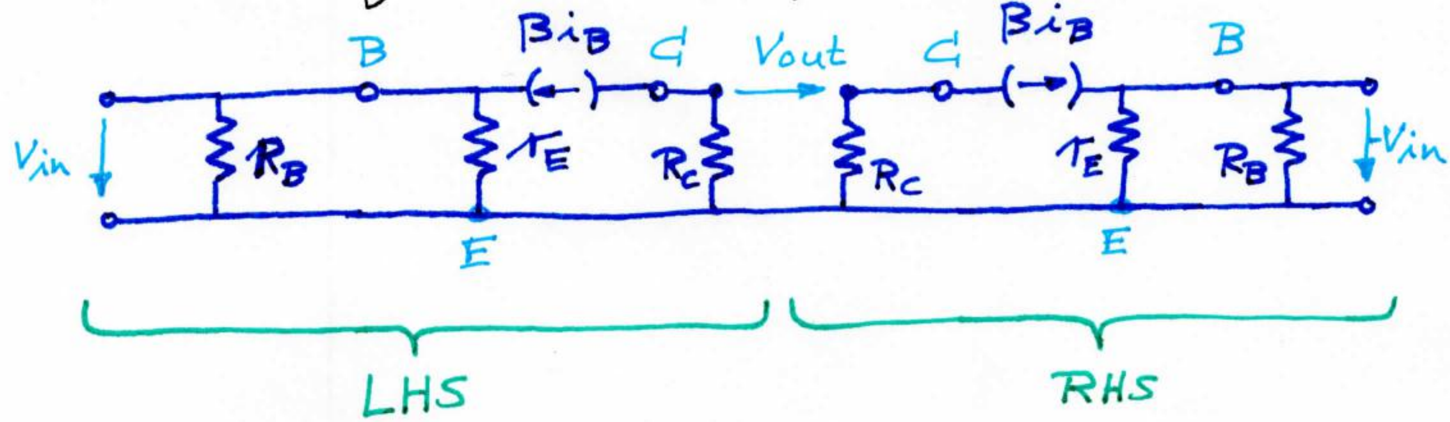
(may also be called dynamic emitter resistance)

$$r_E = \frac{V_t}{I_E} = \frac{26mV}{10mA} = \underline{\underline{2.6\Omega}}$$

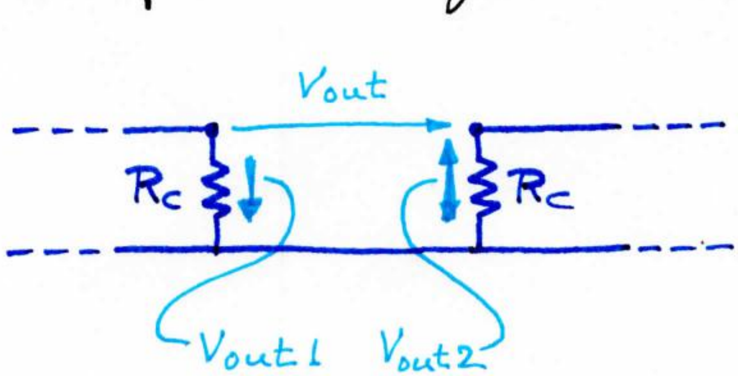
Small-signal equivalent circuit



Redrawing (simplifying) the circuit



LHS and RHS are identical. We therefore analyze only the LHS and double the output voltage



$$V_{out} = V_{out1} + V_{out2}$$
$$= 2\,V_{out1}$$

(e) LHS circuit:

$$A_{Voc} = \frac{V_{out}}{V_{in}} = \frac{\beta i_B R_C}{(\beta+1) i_B r_E} \approx \frac{R_C}{r_E}$$

Same A_{Voc} for RHS circuit due to symmetry

$\Rightarrow$ Total amplification $A_{Voc} = \frac{2 V_{out}}{V_{in}} = \frac{2R_E}{r_E}$

(f) Numerical value

$$A_{Voc} = 2\frac{R_E}{r_E} = 2\,\frac{600\Omega}{2.6\Omega} = 461$$

(g) Two amplifier stages in series

$$A_{Voc}\Big|_{2\text{ stages}} = A_{Voc}^{\,2} = 461^2 = 212\,000$$

Problem 3 True/false questions

(a) True $I_C = \alpha I_E$

$\alpha \lessapprox 1.0$

(b) True Will not work properly

(c) True α and β are reduced

(d) False Circuit will likely still work

(e) True α and β are reduced

(f) True $I_B = \frac{I_C}{\beta} = \frac{I_E}{\beta+1}$

$\Rightarrow I_B \ll I_C$ and $I_B \ll I_E$

(g) True BE $\Rightarrow$ Forward bias

CE $\Rightarrow$ Reverse bias.