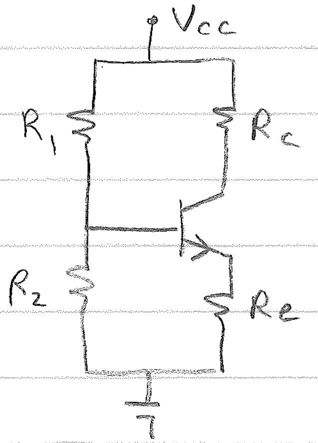
Homework #9 Solutions

4.2) Universal transistor DC bias circuit



$V_{cc} = 15\,V$
$R_1 = 10\,k\Omega$
$R_2 = 2.2\,k\Omega$
$R_c = 680\,\Omega$
$R_e = 100\,\Omega$
$\beta = 200$
$V_{be} = 0.72\,V$

Operating point: want I_c, I_b, V_{ce}

$$V_{eq} = \left(\frac{R_2}{R_1+R_2}\right)V_{cc}$$

$$V_{eq} = \left(\frac{2.2}{12.2}\right)(15\,V) = \underline{\underline{2.7\,V}}$$

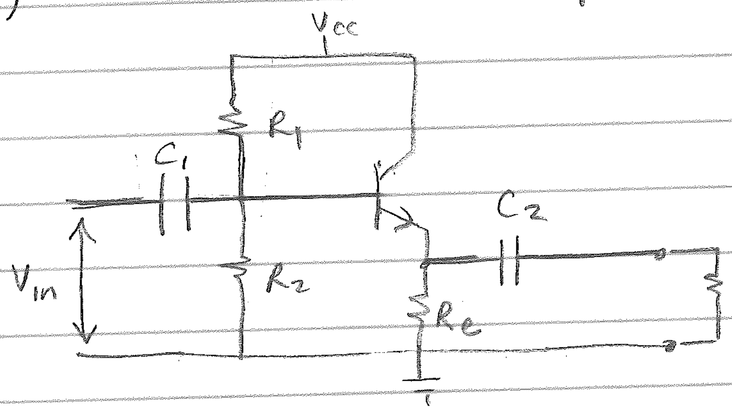
$$I_b = \frac{V_{eq} - V_{be}}{R_{eq} + (\beta+1)R_e}, \quad R_{eq} = \frac{R_1 R_2}{R_1+R_2} = \frac{10\cdot(2.2)}{12.2} = 1.8\,k\Omega$$

$$I_b = \frac{2.7 - 0.72}{(1.8\times10^3) + (201)(100)} = \underline{\underline{9.04\times10^{-5}\,A}}$$

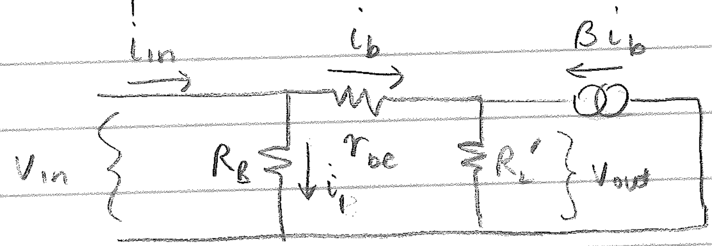
$$I_c = 200\,I_b = \underline{\underline{18.1\,mA}}$$

$$V_{ce} = V_{cc} - I_c\left(R_c + \frac{\beta+1}{\beta}R_e\right)$$
$$= 15 - (18.1\times10^{-3})\left[(680) + \frac{201}{200}(100)\right]$$
$$V_{ce} = \underline{\underline{0.873\,V}}$$

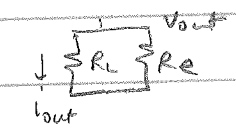
4.5) Common-collector amp : want g, Z_{in}



AC equivalent is



R_L' is



$R_L \parallel R_e$

i_{out} is current through R_L

Current gain $g = \dfrac{i_{out}}{i_{in}}$ $\qquad i_{out} = V_{out}/R_L$

$$\therefore\ g = \frac{V_{out}/R_L}{i_{in}} \qquad V_{out} = \underbrace{(i_b + \beta i_b)}_{\text{total current through } R_L' \text{ equiv}} R_L'$$

$$\Rightarrow\ g = \frac{(i_b + \beta i_b) R_L'/R_L}{(i_{in})}$$

$$i_{in} = \underbrace{\frac{V_{in}}{R_B}}_{i_1} + i_b \qquad V_{in} = \underbrace{i_b r_{be}}_{\text{drop across } r_{be}} + (i_b + \beta i_b) R_L'$$

$$\Rightarrow i_{in} = \frac{1}{R_B}\left(i_b r_{be} + (\beta+1) i_b R_L'\right) + i_b$$

$$\Rightarrow\ g = \frac{R_B(1+\beta)\cancel{i_b}(R_L'/R_L)}{[\cancel{i_b} r_{be} + (\beta+1)\cancel{i_b} R_L' + \cancel{i_b} R_B]} \qquad R_L' = \frac{R_e R_L}{R_L + R_e}$$

$$R_L'/R_L = R_e/(R_e + R_L)$$

$$\boxed{g = (\beta+1) R_B \left(\frac{R_e}{R_e + R_L}\right) \frac{1}{[r_{be} + R_B + (\beta+1) R_L']}}$$

matching eqn 4.35

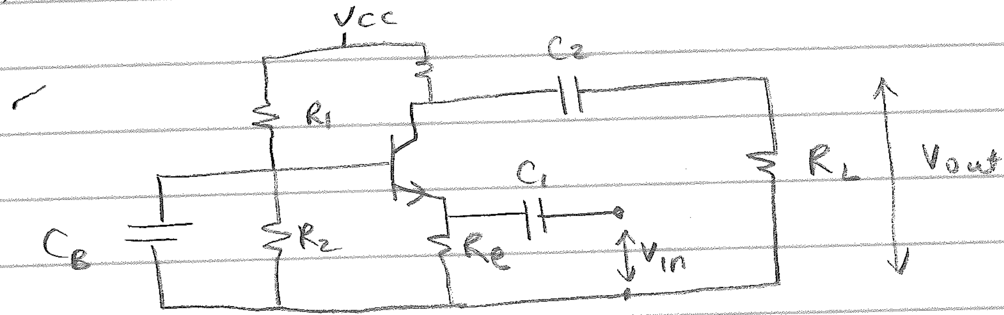
Input impedance $\quad Z_{in} = \dfrac{V_{in}}{i_{in}}$

$$Z_{in} = \frac{\cancel{i_b} r_{be} + (\beta+1)\cancel{i_b} R_L'}{\frac{1}{R_B}\left(\cancel{i_b} r_{be} + (\beta+1)\cancel{i_b} R_L'\right) + \cancel{i_b}}$$

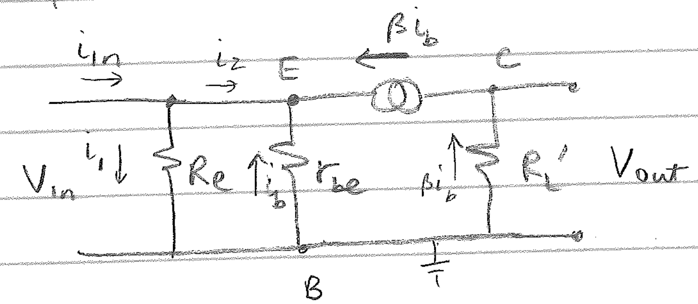
$$\boxed{Z_{in} = \frac{\left(r_{be} + (\beta+1)R_L'\right) R_B}{\left(r_{be} + (\beta+1)R_L' + R_B\right)}}$$

matching eqn 4.36

4.6) Common-base amplifier : a, g, Z_{in}, Z_{out}



AC equivalent



$R_L' = R_C \| R_L$

$$R_L' = \frac{R_C R_L}{R_C + R_L}$$

Voltage gain

$$a = \frac{V_{out}}{V_{in}} = \frac{-(\beta i_b) R_L'}{-r_{be} i_b}$$

$V_{out} = -\beta i_b R_L'$

$V_{in} = -r_{be} i_b$

$$\Rightarrow \boxed{a = \frac{\beta R_L'}{r_{be}}}$$ matches 4.38

i_{out} = current through R_L

Current gain $$g = \frac{i_{out}}{i_{in}} = \frac{V_{out}/R_L}{i_1 + i_2}$$

$i_{in} = i_1 + i_2$

$i_2 = -(\beta+1) i_b$

$$i_1 = \frac{V_{in}}{R_e} = -\frac{r_{be} i_b}{R_e}$$

$$i_{in} = -i_b\left(\frac{r_{be}}{R_e} + (\beta+1)\right)$$

$$g = \frac{-\beta \cancel{i_b} \frac{R_C \cancel{R_L}}{\cancel{R_L}(R_C+R_L)}}{-\cancel{i_b}\left(\frac{r_{be}}{R_e} + (\beta+1)\right)} \Rightarrow \boxed{g = \beta\left(\frac{R_C R_e}{R_C + R_L}\right)\left(\frac{1}{r_{be} + (\beta+1) R_e}\right)}$$

matches 4.39

Input impedance

$$Z_{in} = \frac{U_{in}}{i_{in}} = \frac{-r_{be}\cancel{i_b}}{-\cancel{i_b}\left(\frac{r_{be}}{R_e} + (\beta+1)\right)}$$

$$\boxed{Z_{in} = \frac{r_{be} R_e}{r_{be} + (\beta+1) R_e}}$$ matches 4.40

Output impedance

$R_L = \infty \Rightarrow R_L' = R_C$

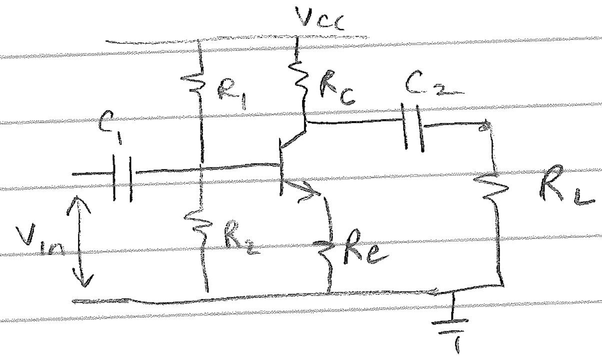
$$Z_{out} = \frac{U_{out}\,(\text{open})}{i_{out}\,(\text{short})} = \frac{-\beta i_b R_c}{-\beta i_b} = R_c$$

$(R_L = 0)$

$\to -\beta i_b$

$$\Rightarrow \boxed{Z_{out} = R_C}$$ matches 4.41

4.7) Circuit of Problem 2 configured as CE amp.



DC bias

$R_1 = 10\,k\Omega$

$R_2 = 2.2\,k\Omega$

$R_c = 680\,\Omega$

$R_e = 100\,\Omega$

$\beta = 200$

$V_{be} = 0.72\,V$

$R_L = 1\,k\Omega$

Voltage gain $\quad a = \dfrac{-\beta R_L'}{r_{be} + (\beta+1)R_e}$

$$R_L' = R_L \| R_c = \frac{(10^3)(680)}{680+10^3} = 404.8\ \Omega$$

What is r_{be}? Use eqn 2.6

$$r_{be} = \frac{0.025}{I_b} = \frac{0.025}{9.04\times10^{-5}} = 277\ \Omega$$

OK → to neglect since $r_{be} < (\beta+1)R_e$

$$a = \frac{-200(404.8)}{277+(201)(100)} = \underline{\underline{-3.97}}$$

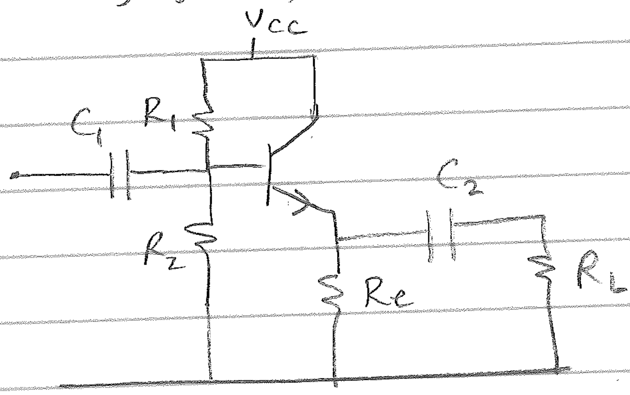
Current gain $\quad g = -\beta\left(\dfrac{R_B}{R_B + r_{be} + (\beta+1)R_e}\right)\left(\dfrac{R_c}{R_c+R_L}\right)$

$$R_B = R_1 \| R_2 = \frac{(10)(2.2)}{12.2} = 1.8\ k\Omega$$

$$g = -200\left(\frac{1.8\times10^3}{1.8\times10^3+277+(201)(100)}\right)\left(\frac{680}{680+1000}\right) = \underline{\underline{-6.57}}$$

4.8) Transistor amp w/ $a \sim 1$, $g \sim 100$

For unity gain, use <u>emitter follower</u> (CC amp)



We need to find the operating point for the transistor with specs in Fig 4.3.1 which has $\beta \sim 100$ in plateau regime

We will get $$g = (\beta+1)\left(\frac{R_B}{R_B + r_{be} + (\beta+1)R_L'}\right)\left(\frac{R_e}{R_e+R_L}\right)$$

For small load and largish R_B

we will get

$$g \sim (\beta+1)\ \frac{R_B}{R_B}\ \frac{R_e}{R_e} \sim \beta$$

So just need to choose R_1, R_2, R_e for $I_b \sim$ few 10's of μA to be in the linear operating regime

Take $\left[\begin{array}{l} I_b = 20\ \mu A \\ I_c = 3.6\ mA \\ V_{ce} = 4\ V \end{array}\right]$ → from Fig 4.3.1 (other points OK)

→ This is the <u>goal</u>, select components for this

Assume $V_{be} = 0.6\ V$ (V_{pn})

Pick $V_{cc} = 15\ V$

Pick $R_1 = 10\ k\Omega$, $R_2 = 100\ k\Omega$

$R_{eq} = \frac{(10)(100)}{110} = 9\ k\Omega$, $V_{eq} = \frac{100}{110} V_{cc} = 13.6\ V$

$$V. \quad I_b = \frac{V_{eq} - V_{be}}{R_{eq} + (\beta+1) R_e}$$

Solve for R_e to get desired $I_b = 20\ \mu A$

$$R_{eq} + (\beta+1) R_e = \frac{V_{eq} - V_{be}}{I_b}$$

$$R_e = \left(\frac{V_{eq} - V_{be}}{I_b} - R_{eq} \right) \frac{1}{(\beta+1)}$$

$$R_e = \left(\frac{13.6V - 0.6V}{20 \times 10^{-6}} - 9.1 \times 10^{3} \right) = \underline{\underline{3.3\ k\Omega}}$$

Check: $V_{ce} = V_{cc} - I_c \left(\frac{\beta+1}{\beta} R_e \right) = 3V$, still OK for being in the operating regime

So we have chosen $\left[\begin{array}{l} R_1 = 10\ k\Omega \\ R_2 = 100\ k\Omega \\ R_e = 3.3\ k\Omega \end{array} \right.$

Assume R_L small

(Other choices OK)