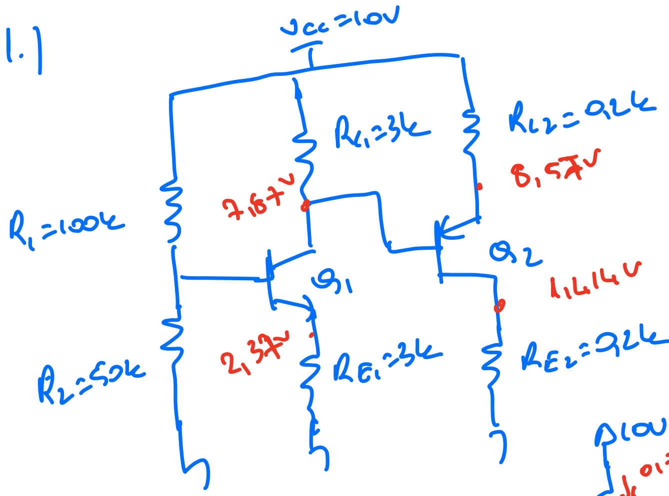
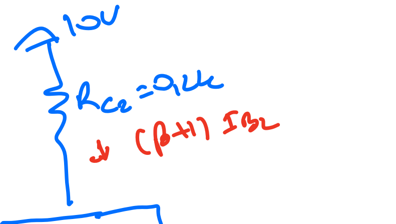
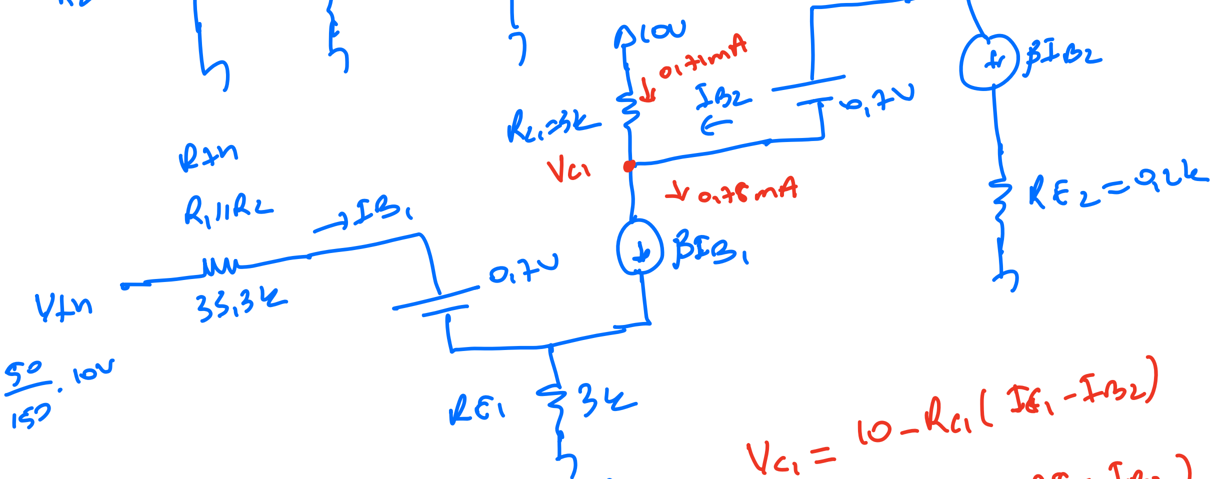
1.)



Rc2 and RE2 labeling should be swapped for Q2, values are the same. Doesn't affect the result.





$\frac{50}{150} \cdot 10V$

$V_{th} = R_{th} \cdot I_{B2} + 0.7V + (\beta+1) I_{B1} \cdot R_{E1}$

$3.33 = 33.3 I_{B1} + 0.7V + 303 I_{B1}$

$2.63 = 336.3 I_{B1}$

$I_{B1} = 7.82\ \mu A$

$I_{C1} = 0.78\ mA$

$I_{E_1} = 0.79\ mA$

$V_{c1} = 10 - R_{c1}(I_{E_1} - I_{B2})$

$V_{c1} = 10 - 3 \cdot (0.78 - I_{B2})$ (1)

$V_{c1} = 10 - R_{c2}(\beta+1) I_{B2} - 0.7V$

$V_{c1} = 10 - 0.2 \cdot 101 \cdot I_{B2} - 0.7$

$V_{c1} = 9.3 - 20.2 I_{B2}$ (2)

(1) = (2)

$7.66 + 3I_{B2} = 9.3 - 20.2 I_{B2}$

$23.2 I_{B2} = 1.64$

$I_{B2} = 70.7\ \mu A$

$I_{C2} = 7.07\ mA$

$I_{E2} = 7.14\ mA$

Q1 (V_{CE}, I_{C1}) (5.5V, 0.78mA)

$V_{c1} = 10 - 3 \cdot 0.71$

$V_{c1} = 7.87V$

$V_{E_1} = 3 \cdot 0.79$

$V_{E1} = 2.37V$

$V_{CE1} = 5.5V > 0.2V$

F.A. ✓

Q2 (V_{EC}, I_{C2}) (7.15V, 7.07mA)

$V_{E2} = 10 - 0.2 \cdot 7.14$

$V_{E2} = 8.57V$

or $V_{c1} + 0.7V$

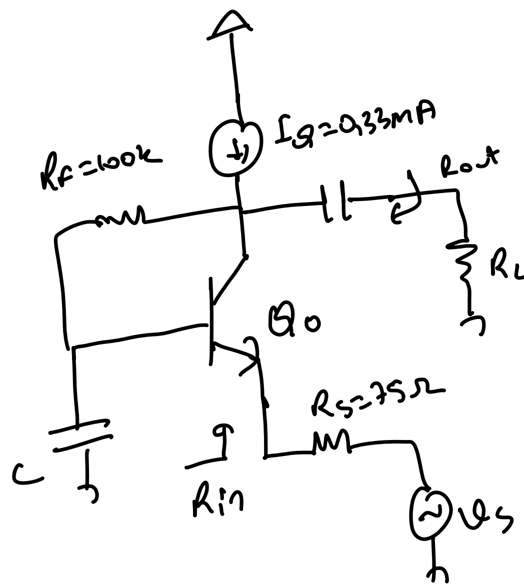
$V_{c2} = 0.2 \cdot 7.07$

$V_{c2} = 1.414V$

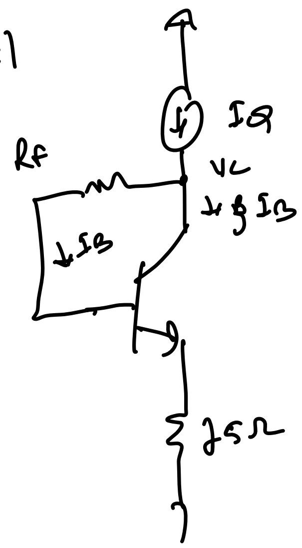
$V_{EC2} = 7.15V > 0.2V$

F.A. ✓

2.)



a)



$I_Q = I_E = (\beta+1) I_B = 0.33mA$

$I_C = \frac{\beta}{\beta+1} \cdot I_Q = 0.327mA$

note that

$V_{CE} = R_F I_B + 0.7$

$V_{CE} = 100k \cdot \frac{0.33}{101} + 0.7 = 1.027V$

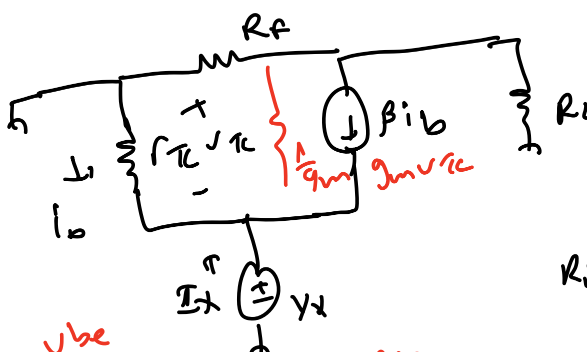
$V_{CE} > 0.2V$ F.A. ✓

$V_E = 0.075 \cdot 0.33$

$V_E = 0.025V$

$r_\pi = \frac{\beta \cdot V_T}{I_C} = \frac{100 \cdot 0.026}{0.327} = 7.95k$, $g_m = \frac{\beta}{r_\pi} = 12.6 \frac{mA}{V}$

b)



$v_\pi = v_{be}$ in class

or $(\frac{1}{g_m} \| r_\pi) = R_{in}$

$v_{be} = -v_e$

$g_m v_{be} = -g_m v_e$

R_{in}

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

$V_x = -V_\pi = -r_\pi i_b$

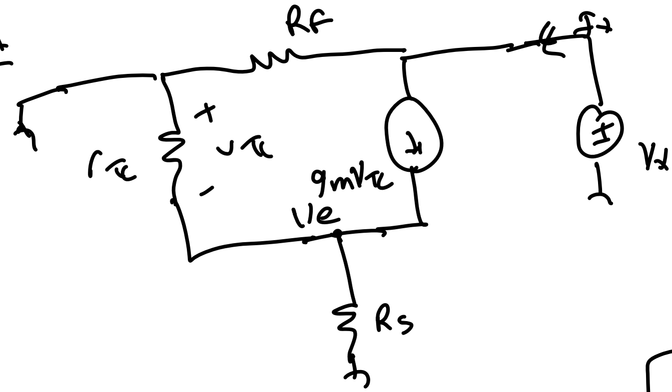
$R_{in} = \frac{V_x}{I_x} = \frac{r_\pi}{\beta+1} = \frac{7.95k}{101}$

$R_{in} = r_e = 78.7\Omega$

R_F has no effect

I used v_π instead of v_{be} in the small signal solutions.

Rout



$v_e = g_m v_\pi (R_s \| r_\pi)$

$v_e = -v_\pi$

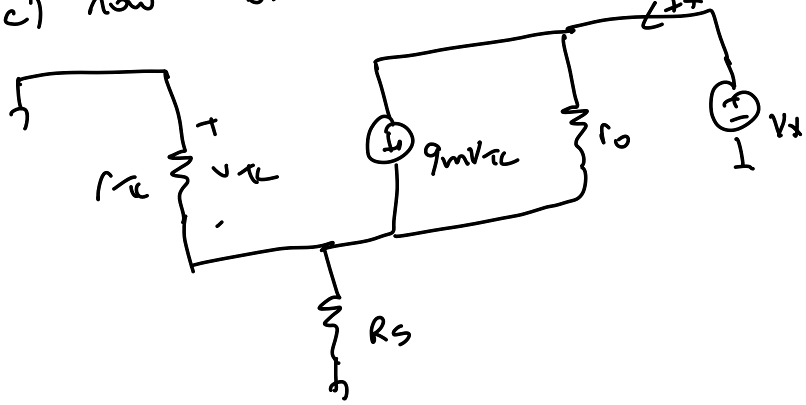
$-v_\pi = g_m v_\pi (R_s \| r_\pi)$

$v_\pi = 0$ or $g_m (-)$ ~~X~~

$v_\pi = 0$

$$\boxed{\frac{V_x}{I_x} = R_f = 100k = R_{out}}$$

c) now $r_o = 100k$.



note that Rf is from Vout to gnd

so $R_{out} = R_f \| R_{out1}$

will add Rf @ the end.

$V_x = (I_x - g_m v_\pi) r_o + I_x (R_s \| r_\pi)$

$v_e = -v_\pi = I_x \cdot (R_s \| r_\pi)$

$V_x = \left[I_x + g_m I_x (R_s \| r_\pi) \right] r_o + I_x (R_s \| r_\pi)$

$\frac{V_x}{I_x} = R_{out1} = \left[1 + g_m (R_s \| r_\pi) \right] r_o + R_s \| r_\pi$

$R_{out1} = \left[1 + 12.6 \cdot \underbrace{(0.075 \| 7.95)}_{\sim 0.075} \right] r_o + 0.075 \| 7.95$

$R_{out1} = 1.945 r_o + \underbrace{0.075}_{\sim \text{small}}$

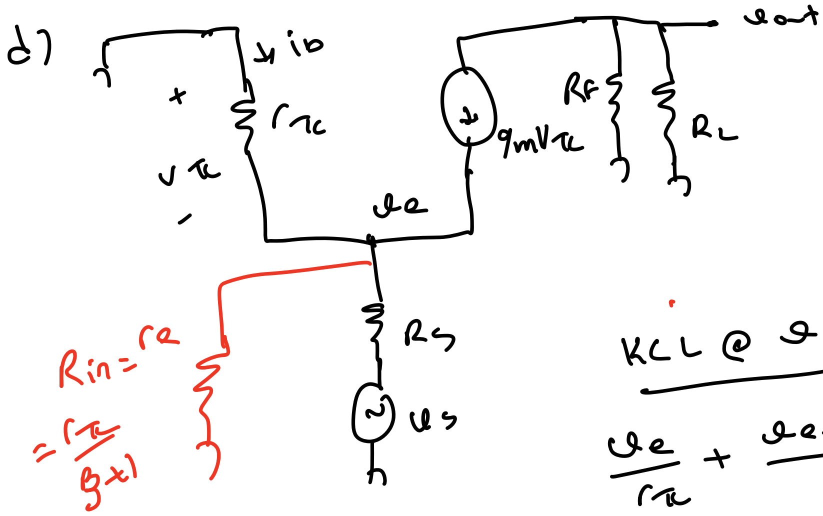
$R_{out1} = 194.5k$

$R_{out} = 194.5 \| R_f$

$R_{out} = 194.5 \| 100$

$$\boxed{R_{out} = 66 k\Omega}$$

d)



R_F between v_{out} and gnd

so $(R_F \| R_L)$

$\sim R_L$ since $R_F \gg R_L$

KCL @ v_e $\qquad v_e = -v_\pi$

$$\frac{v_e}{r_\pi} + \frac{v_e - v_s}{R_S} - g_m v_\pi = 0$$

$$\frac{v_s}{R_S} = -v_\pi\left(\frac{1}{r_\pi} + \frac{1}{R_S} + g_m\right)$$

$$v_\pi = -\frac{v_s}{R_S} \cdot \left(r_\pi \| R_S \| \frac{1}{g_m}\right)$$

$$r_\pi \| \frac{1}{g_m} = \frac{\frac{r_\pi}{g_m}}{r_\pi + \frac{1}{g_m}} = \frac{r_\pi}{\beta+1}$$

$$v_{out} = -g_m v_\pi (R_L \| R_F)$$

$$\frac{v_{out}}{v_s} = \frac{g_m (R_L \| R_F)}{R_S} \cdot \left(r_\pi \| R_S \| \frac{1}{g_m}\right)$$

$$\frac{v_{out}}{v_s} = \frac{g_m (R_L \| R_F)}{R_S} \cdot \left(\frac{r_\pi}{\beta+1} \| R_S\right) = \frac{12.6 \cdot (100 \| 1.5)}{0.075} \cdot \left(\frac{0.0784}{0.075}\right)$$

$$\frac{v_{out}}{v_s} = \underbrace{12.6 \cdot (100 \| 1.5)}_{g_m (R_F \| R_L)} \cdot \underbrace{\frac{78}{78+75}}_{\to \frac{R_{in}}{R_{in}+R_S}} = 9.5 \text{ V/V}$$

preferred method

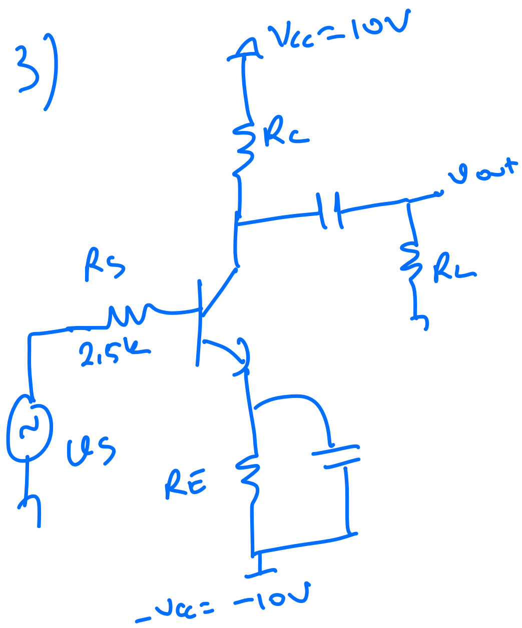
or $v_e = \frac{R_{in}}{R_{in}+R_S} \cdot v_s = -v_\pi \qquad R_{in}: R_e = \frac{r_\pi}{\beta+1}$

$$v_{out} = -g_m v_\pi (R_F \| R_L)$$

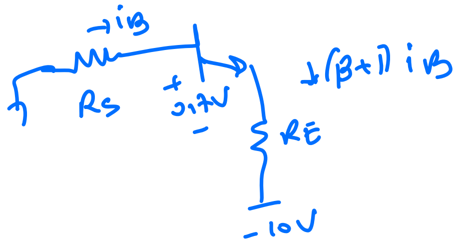
$$\frac{v_{out}}{v_s} = \frac{R_{in}}{R_{in}+R_S} \cdot g_m (R_F \| R_L) \leftarrow \text{same result as the KCL}$$

we can write v_π by looking @ the input resistance (R_{in})

3)



a) $v_s = 0$ $\qquad$ $i_e = 0{,}5mA$



$$R_s i_B + 0{,}7V + (\beta+1) i_B \cdot R_E - 10 = 0$$

$$i_e = (\beta+1) i_B = 0{,}5mA$$

$$i_B = \frac{0{,}5}{101} = 4{,}95\,\mu A$$

$$2{,}5 \cdot 4{,}95 \cdot 10^{-3} + 0{,}7 + 0{,}5 R_E = 10$$

$$\boxed{R_E = 18{,}58\,k}$$

b) $V_C = V_{CC} - i_C R_C$

$$5 = 10 - 0{,}5 \cdot \frac{100}{101} \cdot R_C$$

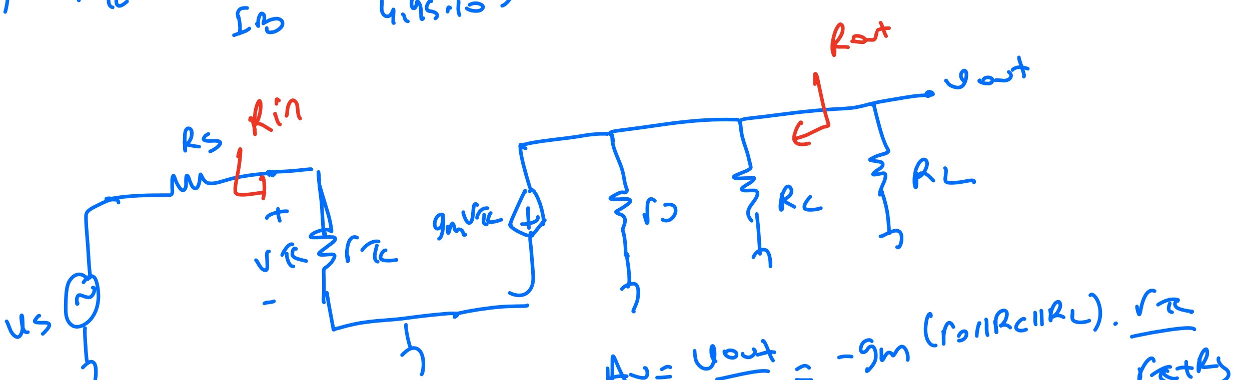
$$\boxed{R_C = 10{,}1\,k\Omega}$$

$V_C = 5V$

$V_E = 18{,}58 \cdot 0{,}5 - 10$

$\left.\right\}$ $V_{CE} > 0{,}2V$ f.A. ✓

c) $r_\pi = \frac{V_T}{I_B} = \frac{0{,}026}{4{,}95 \cdot 10^{-3}} = 5{,}3k$ $\qquad$ $g_m = \frac{\beta}{r_\pi} = 19\frac{mA}{V}$ ✓



$$v_{out} = -g_m v_\pi (r_o \| R_C \| R_L) \Rightarrow A_v = \frac{v_{out}}{v_s} = -g_m (r_o \| R_C \| R_L) \cdot \frac{r_\pi}{r_\pi + R_s}$$

$$v_\pi = \frac{r_\pi}{r_\pi + R_s} \cdot v_s$$

$$A_v = -19 \cdot (200 \| 10 \| 10{,}1) \cdot \frac{5{,}3}{5{,}3 + 2{,}5}$$

$$A_v = -19 \cdot 4{,}9 \cdot 0{,}68$$

$$\boxed{A_v = -63{,}3\,\frac{V}{V}}$$

d) $R_{in} = r_\pi$

$\boxed{R_{in} = 9.3\,k\Omega}$

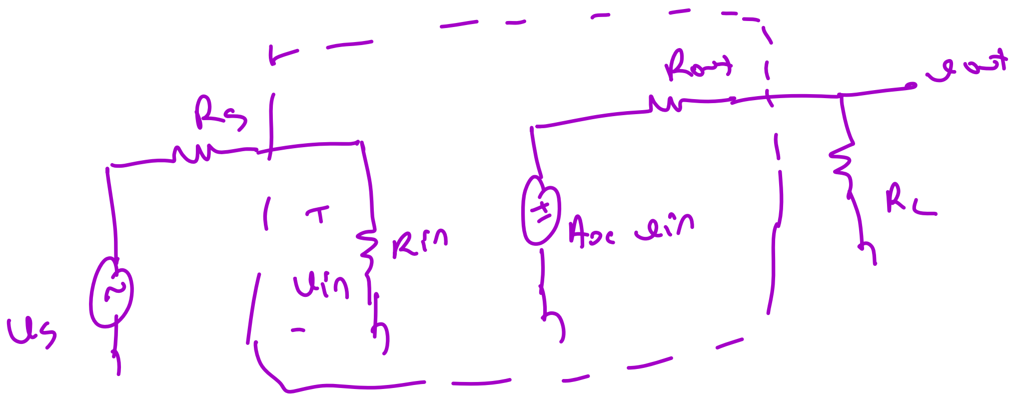
for R_{out} and v_{in}

$v_\pi = 0$

$R_{out} = r_o \| R_C = 200 \| 10.1$

$\boxed{R_{out} = 9.6\,k\Omega}$

e)



R_s and R_L are handled separately

for A_{oc} $\quad R_L \to \infty$

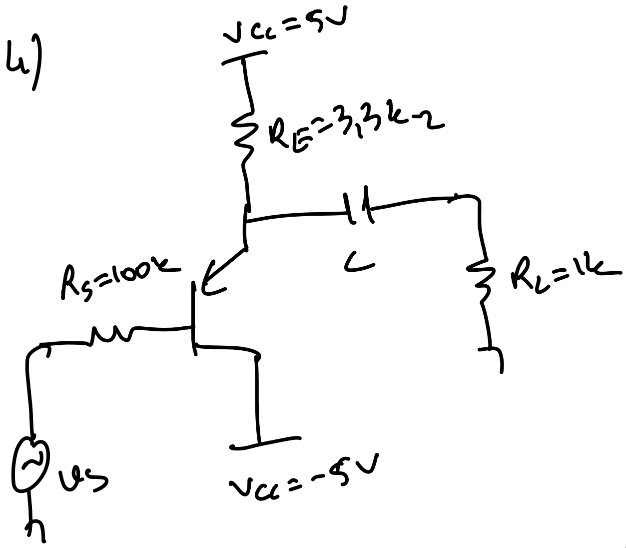
$R_s = 0 \quad R_{out} = 9.6k$

$$A_{oc} = -g_m (r_o \| R_C) = -19 \cdot (\overbrace{200 \| 10.1}) = -19.9.6$$

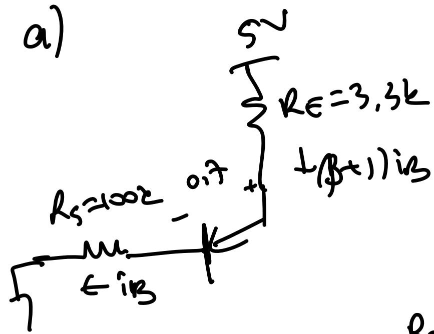
$$\boxed{A_{oc} = -182.4\ \frac{V}{V}}$$

$$\frac{v_{out}}{v_s} = \frac{R_{in}}{R_{in}+R_s} \cdot A_{oc} \cdot \frac{R_L}{R_L+R_{out}}$$ gives the same answer as in (c)

4)



a)



$5 = (\beta+1) i_B \cdot R_E + 0{,}7 + R_S i_B$

$5 = 101\, i_B\, 3{,}3 + 0{,}7 + 100 i_B$

$4{,}3V = 433{,}3\, i_B$

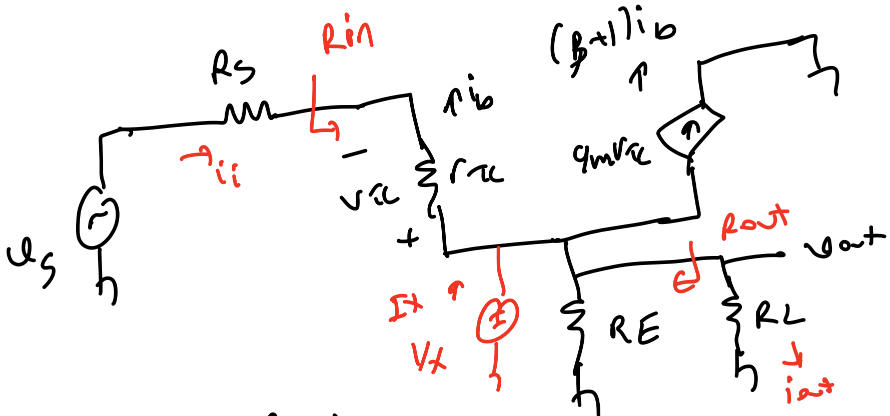
$\boxed{i_B = 9{,}92\ \mu A}$

$\boxed{i_E = (\beta+1) \cdot i_B = 1mA}$

b) $r_\pi = \frac{V_T}{I_B} = \frac{0{,}026}{9{,}92 \cdot 10^{-3}} = 2{,}6k\Omega$

$g_m = \frac{\beta}{r_\pi} = 38{,}2\ \frac{mA}{V}$

note that this is a common collector amplifier.



$R_{in} = r_\pi + \underline{(\beta+1) \cdot (R_E \| R_L)}$

RE and RL reflected to the base

$R_{in} = 2{,}6 + 101 \cdot (3{,}3 \| 1)$

$\boxed{R_{in} = 80{,}1k}$

large Rin

common collector.

Rout RE‖ Rout1

gnd vs.

$I_x = (\beta+1)\, i_b$

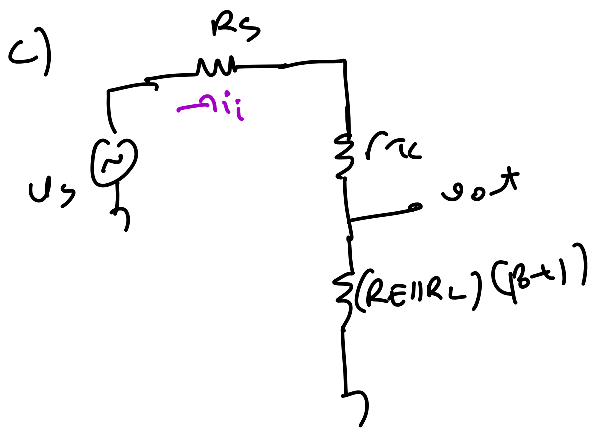
$V_x = i_b (r_\pi + R_S)$

$\frac{V_x}{I_x} = R_{out1} = \frac{r_\pi + R_S}{\beta+1}$

$R_{out} = 3{,}3 \| \frac{2{,}6+100}{101}$

$R_{out} = 0{,}776k$

$\boxed{R_{out} = 776\Omega}$ small Rout c)



the current through RE||RL is $(\beta+1)\, i_b$ when reflected to the base $(\beta+1)\, R_E \| R_L$ since the current in the base is i_b.

$$A_v = \frac{v_{out}}{v_s} = \frac{(\beta+1)\cdot(R_E \| R_L)}{(\beta+1)\cdot(R_E \| R_L) + r_\pi + R_s}$$

$$A_v = \frac{101\cdot(3{,}3 \,\|\, 1)}{101\cdot(3{,}3 \,\|\, 1) + 2{,}6 + 100} = \frac{101\cdot 0{,}767}{101\cdot 0{,}767 + 2{,}6 + 100}$$

$$\boxed{A_v = 0{,}43 \ \frac{v}{v}}$$

d) $i_{out} = \frac{v_{out}}{R_L}$ $\quad i_i = \frac{v_s}{R_s + r_\pi + (\beta+1)\, R_E \| R_L}$

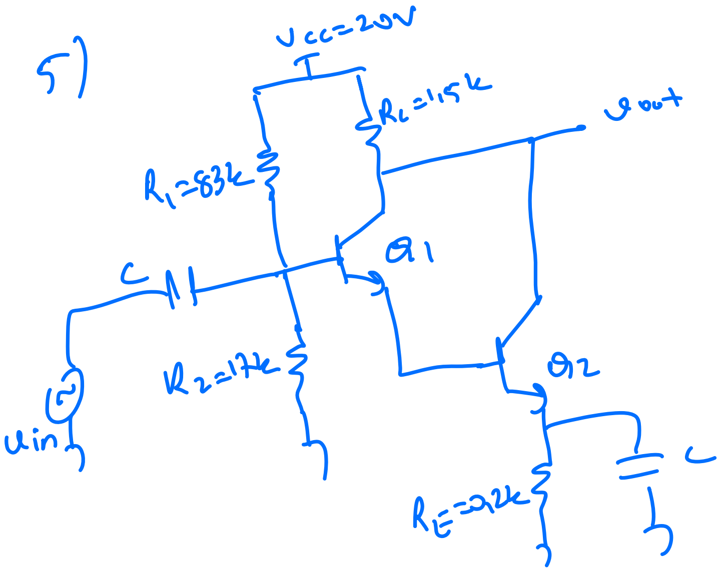
$$\frac{i_{out}}{i_i} = \frac{v_{out}}{v_s} \cdot \frac{R_s + r_\pi + (\beta+1)\cdot R_E \| R_L}{R_L} = \frac{v_{out}}{v_s} \cdot \frac{R_s + R_{in}}{R_L}$$

$$\boxed{\frac{i_{out}}{i_i} = 0{,}43 \cdot \frac{100 + 80{,}1}{1} = 77{,}44 \ \frac{A}{A}}$$

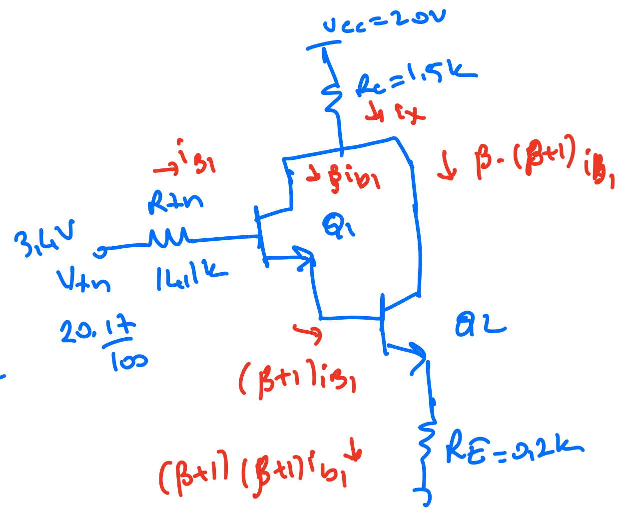
or simply. $i_e = (\beta+1)\, i_b$, there will be a current division @ the output $\frac{R_E}{R_E + R_L}$ so $\frac{i_{out}}{i_{in}} = (\beta+1)\cdot \frac{R_E}{R_E + R_L} = 101 \cdot \frac{3{,}3}{3{,}3+1}$

$$\boxed{A_i = 77{,}5}$$

5)



a.) Dc analysis



$i_{B_2} = (\beta+1) i_{B_1}$

$i_{e_2} = (\beta+1) i_{B_2} = (\beta+1)^2 i_{B_1}$

$V_{th} = R_{th} i_{B_1} + \underbrace{0{,}7}_{V_{BE_1}} + \underbrace{0{,}7}_{V_{BE_2}} + (\beta+1)^2 i_{B_1} \cdot R_E$

$3{,}4 = 1{,}41\, i_{B_1} + 1{,}4 + (101)^2\, i_{B_1} \cdot 0{,}2$

$2 = 2054{,}3\, i_{B_1}$

$i_{B_1} = 0{,}97\,\mu A$

$i_{e_1} = i_{B_2} = (\beta+1)\, i_{B_1} = 0{,}1\, mA$

$i_{e_2} = 9{,}93\, mA$

$i_x = \beta i_{B_1} + \beta\cdot(\beta+1) i_{B_1}$

$i_x = 0{,}097 + 9{,}83$

$i_x = 9{,}93\, mA$

V_c for both $V_c = 20 - 1{,}5 \cdot 9{,}93$

$V_c = 5{,}1\, V$

$V_{E_2} = 1{,}99\, V$

$V_{E_1} = V_{E_2} + 0{,}7$

$V_{E_1} = 2{,}69\, V$

$V_{CE_2} = 3{,}11\, V$

$I_{C_2} = 9{,}83\, mA$

$V_{CE_1} = 2{,}41\, V$

$I_{C_1} = 0{,}097\, mA$

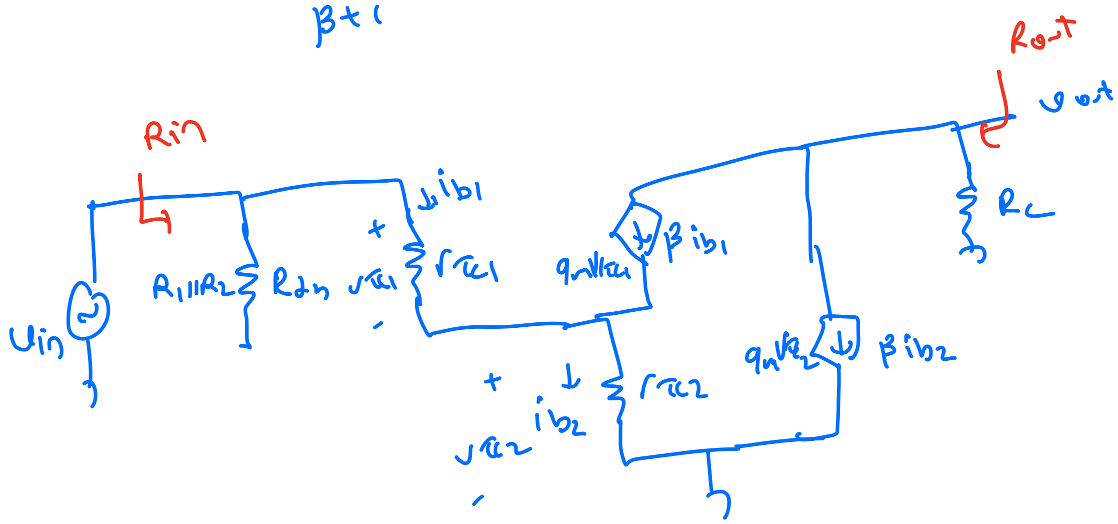
$V_{CE_1}, V_{CE_2} > 0{,}2\, V$

both F.A. ✓

This configuration is known as Darlington pair. Q2 currents are β times Q1 currents.

b) $r_{\pi 1} = \frac{V_T}{I_{B1}} = \frac{0{,}026}{0{,}97 \cdot 10^{-3}} = 26{,}8\,k$ $g_{m1} = \frac{\beta}{r_{\pi 1}} = 3{,}73\, mA$ ✓

$r_{\pi 2} = \frac{r_{\pi 1}}{\beta + 1} = 0{,}27\,k$ $g_{m2} = 376{,}9\, mA$ ✓



$i_{b2} = (\beta + 1)\, i_{b1}$

$v_{out} = -\left[\beta i_{b1} + (\beta+1)\beta i_{b1}\right] \cdot R_C$ $\frac{v_{out}}{v_{in}} = -\frac{\beta(\beta+2) R_C}{2 r_{\pi 1}}$

$v_{in} = i_{b1} r_{\pi 1} + i_{b2} r_{\pi 2}$ $\frac{v_{out}}{v_{in}} = -\frac{100 \cdot 102 \cdot 1{,}5}{2 \cdot 26{,}8}$

$v_{in} = i_{b1} r_{\pi 1} + (\beta+1) \cdot i_{b1} r_{\pi 2}$ $r_{\pi 1}$

$v_{in} = 2\, i_{b1} r_{\pi 1}$ $\boxed{A_v = -285{,}4\ V/V}$

c) Rin

$R_{in} = R_{th} \| r_{\pi 1} + (\beta+1) r_{\pi 2}$

$R_{in} = R_{th} \| 2 r_{\pi 1}$

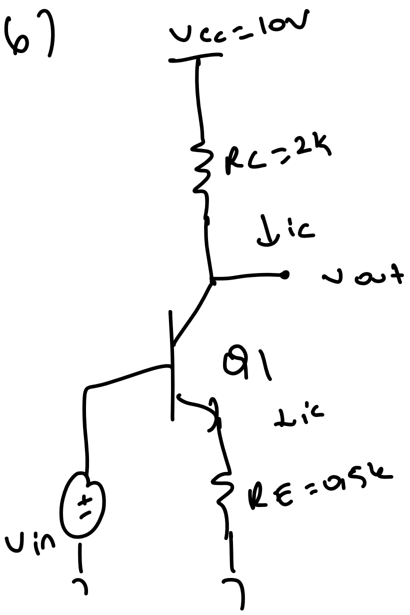
$R_{in} = 14{,}1 \| 2 \cdot 26{,}8$

$\boxed{R_{in} = 11{,}2\,k}$

$\boxed{R_{out} = R_C = 1{,}5\,k\Omega}$

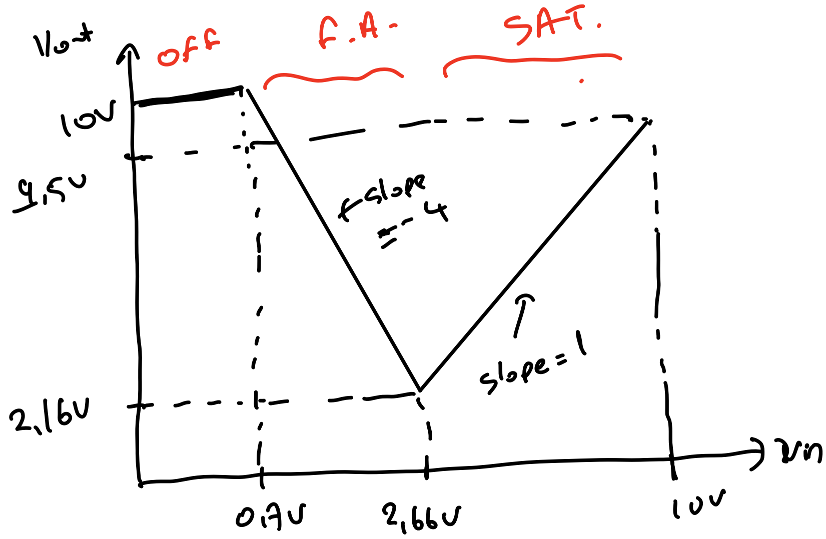
for Rout and vin $v_{\pi 1} = v_{\pi 2} = 0$

6)



$\beta \to$ large implies $i_c = i_E$ (ignore base current)

$V_{BE}(on) = 0.7V$, $V_{CE}(SAT) = 0.2V$



for $\underline{V_{in} < 0.7V}$ Q1 is off $\quad i_c = 0 \quad V_{out} = 10 - i_c R_c = 10V$

(BE and BC junctions are off)

$\underline{V_{in} > 0.7V}$ Assume forward active

$$i_c = \frac{V_{in} - 0.7}{R_E} \qquad V_{out} = V_{cc} - R_c \cdot \frac{V_{in} - 0.7}{R_E} = 10 - 4 \cdot (V_{in} - 0.7)$$

$V_{out} = 12.8 - 4V_{in}$, V_{out} drops linearly with V_{in}.

when $V_{CE} = 0.2V$ Q1 enters into SAT.

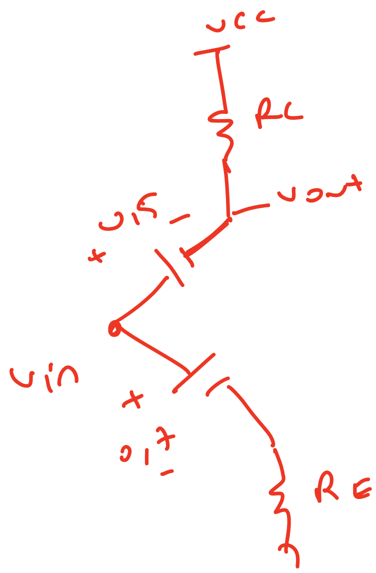
$V_{CE} = V_{out} - V_E = 12.8 - 4V_{in} - (V_{in} - 0.7) = 0.2$

$13.5 - 5V_{in} = 0.2$, $5V_{in} = 13.3$

$\leftarrow \left\{ \begin{array}{l} V_{in} = 2.66V \\ V_{out} = 2.16V \end{array} \right.$

note that $V_{BC} = 0.5V$
B-C junction is on
at this point.

once B-C junction is ON. or Q_1 is in SAT.



$V_{out} = V_{in} - 0.5V$ from this point ON. ($V_{in} \geq 2.66V$)

there will be a constant 0.5V difference between Vin and Vout