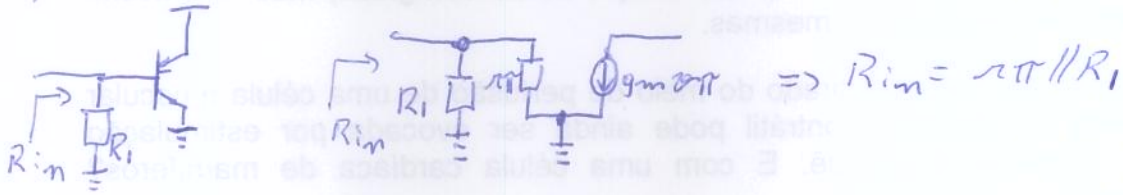


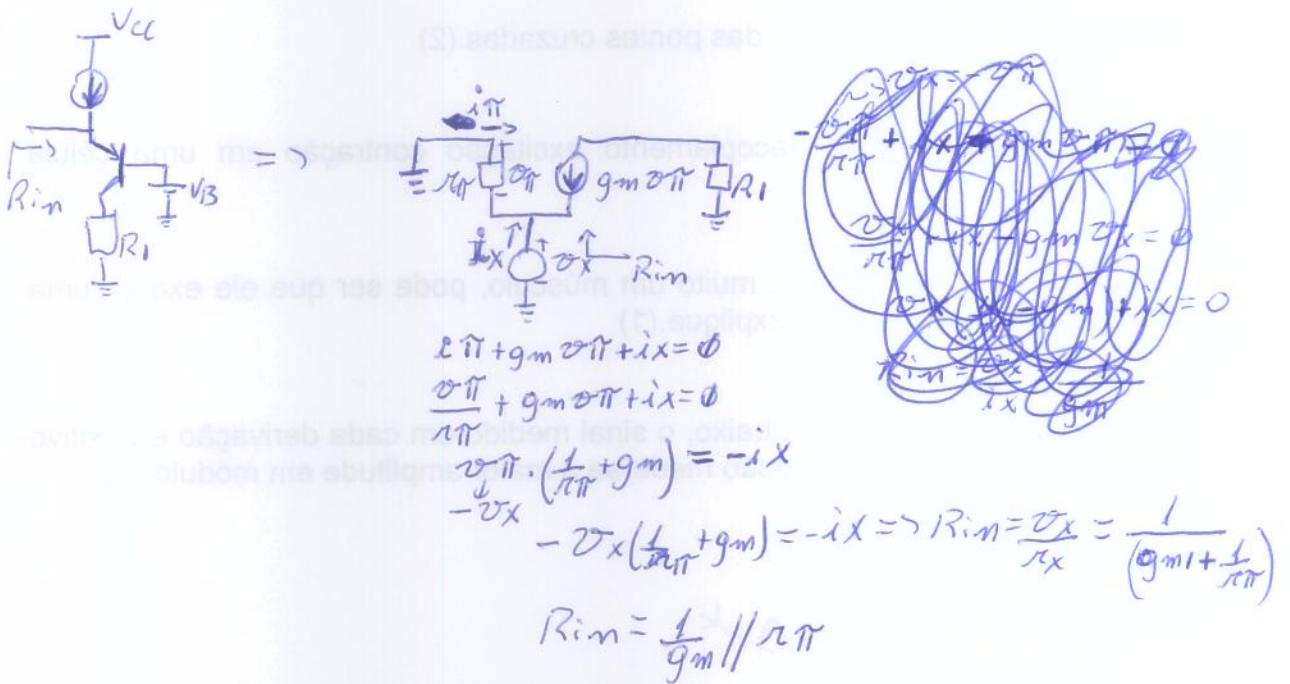
RAZAVI (5.5, 5.6, 5.9b, 5.13, 5.17, 5.38d, 5.47b, 5.52, 5.55, 5.58, 5.63, 5.68, 5.71, 5.72, 5.73)
CAP5

5.5 $V_A = \infty$, Z_{in} ?

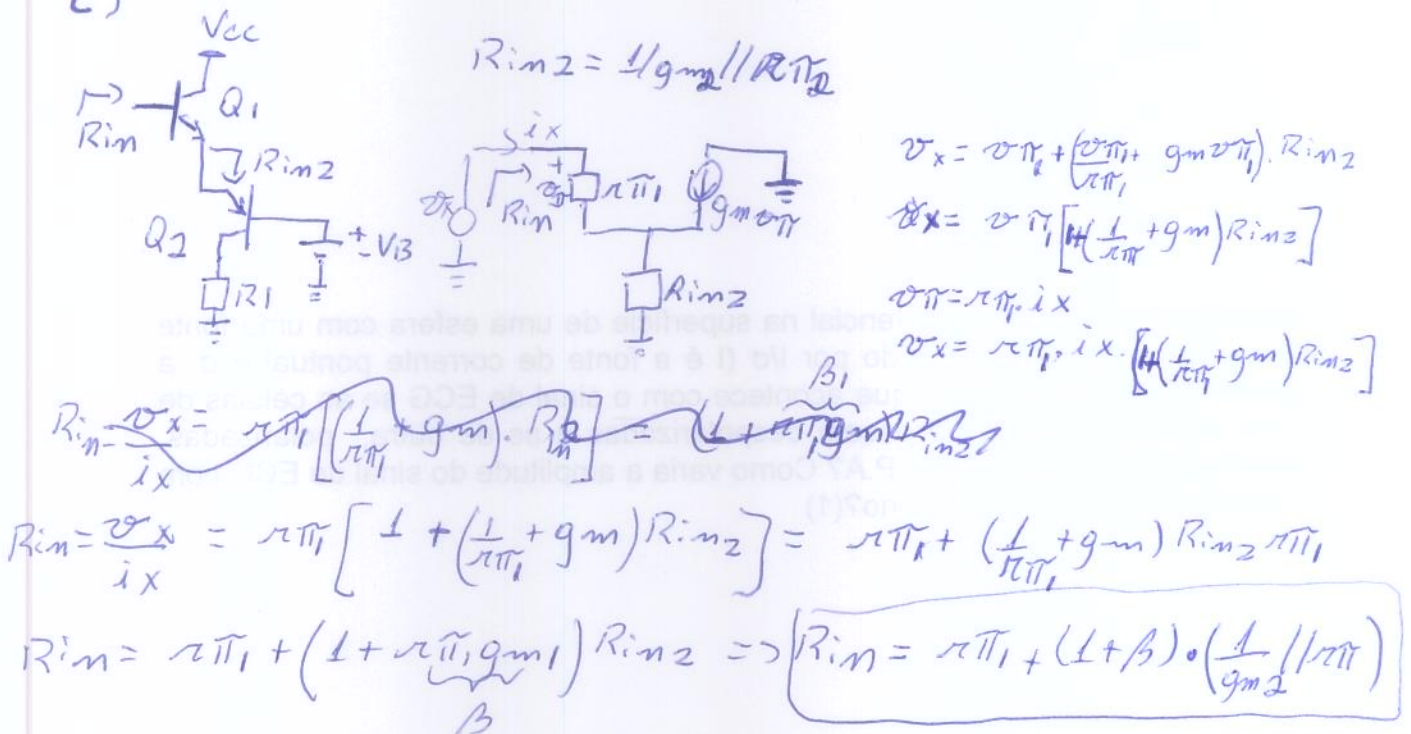
a)

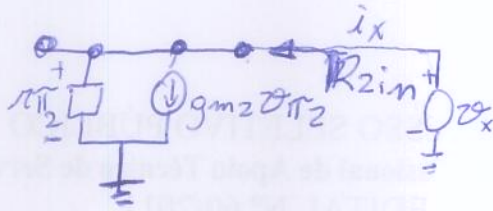
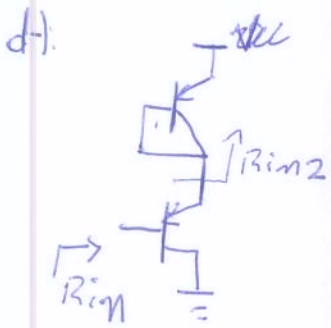


b)



c)

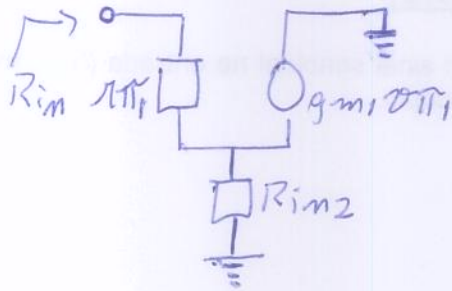




$$i_x = g_{m2} v_{\pi 2} + \frac{v_x}{r_{\pi 2}}$$

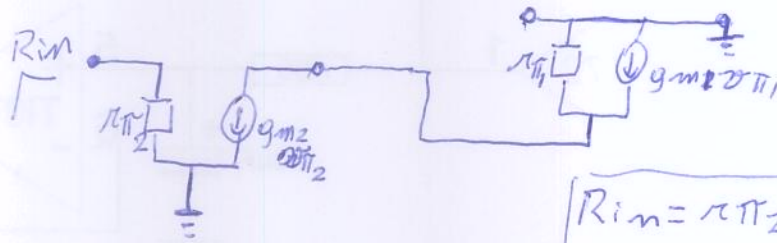
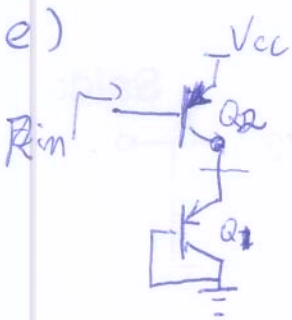
$$i_x = g_{m2} v_x + \frac{v_x}{r_{\pi 2}}$$

$$R_{in2} \frac{i_x}{v_x} = \frac{1}{g_{m2} + \frac{1}{r_{\pi 2}}} = \frac{1 \parallel r_{\pi 2}}{g_{m2}} = R_{in2}$$



mesmo caso anterior

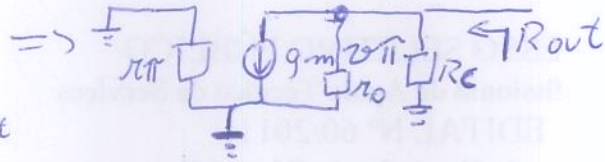
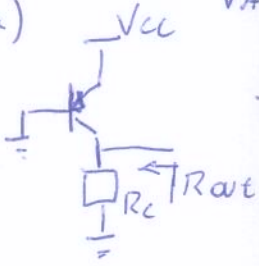
$$R_{in} = r_{\pi 1} + (1 + \beta) \cdot \left(\frac{1 \parallel r_{\pi 2}}{g_{m2}} \right)$$



$$R_{in} = r_{\pi 2}$$

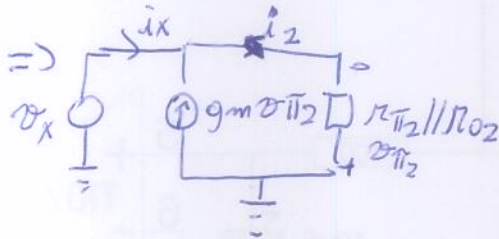
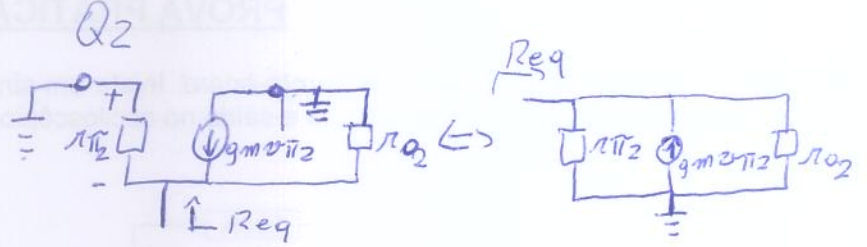
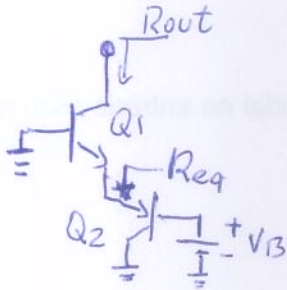
5.6

a) $V_A \neq \infty$



$$R_{out} = R_c \parallel r_o$$

b)



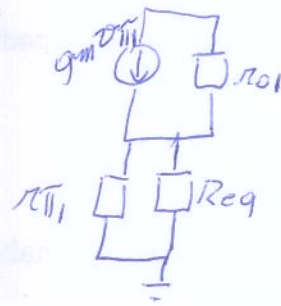
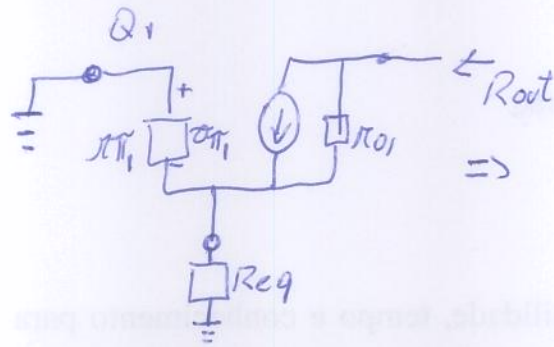
$$i_x + g_m v_{\pi 2} + i_2 = 0$$

$$i_x + g_m v_{\pi 2} + \frac{v_{\pi 2}}{r_{o2}} = 0$$

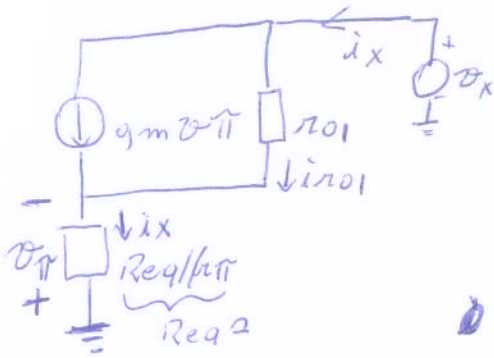
$$i_x = -\frac{v_{\pi 2}}{r_{o2}} \left(g_m + \frac{1}{r_{\pi 2} \parallel r_{o2}} \right)$$

$$i_x = v_x \left(g_m + \frac{1}{r_{o2} \parallel r_{\pi 2}} \right)$$

$$\Rightarrow \frac{v_x}{i_x} = R_{eq} = \frac{1}{g_m \parallel \frac{1}{r_{\pi 2} \parallel r_{o2}}}$$



3



$$i_x = g_{m1} v_{\pi} + i_{\pi o1}$$

$$\begin{cases} i_x = g_{m1} v_{\pi} + \frac{v_x + v_{\pi}}{r_{o1}} \\ i_x = -\frac{v_{\pi}}{R_{eq2}} \Rightarrow v_{\pi} = -i_x r_{\pi 1} \end{cases}$$

~~$$i_x = \frac{v_x + v_{\pi}}{r_{o1}} + g_{m1} v_{\pi} - \frac{v_{\pi}}{R_{eq2}}$$~~

~~$$i_x = -\frac{v_{\pi}}{R_{eq2}} + g_{m1} v_{\pi} + \frac{v_x + v_{\pi}}{r_{o1}} = i_x \left(\frac{1}{r_{o1}} + g_{m1} r_{\pi 1} \right) + \frac{v_x}{r_{o1}}$$~~

$$i_x = -g_{m1} i_x R_{eq2} + \frac{v_x - i_x R_{eq2}}{r_{o1}}$$

$$i_x = -g_{m1} i_x R_{eq2} + \frac{v_x}{r_{o1}} - \frac{i_x R_{eq2}}{r_{o1}}$$

$$i_x \cdot \left(g_{m1} R_{eq2} + \frac{R_{eq2}}{r_{o1}} + 1 \right) = \frac{v_x}{r_{o1}}$$

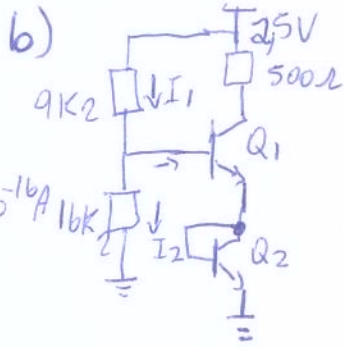
$$R_{out} = \frac{v_x}{i_x} = r_{o1} \cdot \left(1 + R_{eq2} \cdot \left(g_{m1} + \frac{1}{r_{o1}} \right) \right)$$

$$R_{out} = r_{o1} + r_{o1} R_{eq2} \left(g_{m1} + \frac{1}{r_{o1}} \right)$$

$$R_{out} = r_{o1} + R_{eq2} \cdot \left(g_{m1} r_{o1} + 1 \right)$$

$$R_{out} = r_{o1} + \left(1 + g_{m1} r_{o1} \right) r_{\pi 1} \parallel \frac{1}{g_{m2}} \parallel r_{\pi 2} \parallel r_{o2}$$

5.9



$$\beta = 100$$

$$I_s = 5 \cdot 10^{-16} \text{ A}$$

$$I_{E1} = I_{E2}$$

$$\Rightarrow I_{C1} = I_{C2} \Rightarrow \begin{cases} V_{BE1} = V_{BE2} \\ I_{B1} = I_{B2} \end{cases}$$

$$I_{B1} = I_1 - I_2 = \frac{V_{CC} - 2V_{BE}}{9 \cdot 10^3} - \frac{2V_{BE}}{16 \cdot 10^3}$$

$$I_{C1} = \beta I_{B1} = \beta \cdot \left(\frac{V_{CC} - 2V_{BE}}{9 \cdot 10^3} - \frac{2V_{BE}}{16 \cdot 10^3} \right)$$

$$I_{C1} = \beta \cdot \left(\frac{V_{CC} - 2V_T \ln \frac{I_{C1}}{I_s}}{9 \cdot 10^3} - \frac{2V_T \ln \frac{I_{C1}}{I_s}}{16 \cdot 10^3} \right)$$

$$I_{C1} - \beta \left(\frac{V_{CC} - 2V_T \ln \frac{I_{C1}}{I_s}}{9 \cdot 10^3} - \frac{2V_T \ln \frac{I_{C1}}{I_s}}{16 \cdot 10^3} \right) = 0$$

$$I_{C1} - \frac{\beta V_{CC}}{9 \cdot 10^3} + \frac{2\beta V_T \ln(I_{C1}/I_s)}{9 \cdot 10^3} + \frac{2\beta V_T \ln I_{C1}/I_s}{16 \cdot 10^3} = 0$$

$$I_C - \frac{\beta V_{CC}}{9 \cdot 10^3} + \frac{32\beta V_T \ln I_{C1}/I_s + 18\beta V_T \ln I_{C1}/I_s}{9 \cdot 16 \cdot 10^6} = 0$$

$$I_C - \frac{\beta V_{CC}}{9 \cdot 10^3} + \frac{50\beta V_T \ln I_{C1}/I_s}{9 \cdot 16 \cdot 10^6} = 0$$

⇓ Cálculo numérico

$$\boxed{I_C \approx 1,72 \text{ mA}}$$

$$V_{BE} = V_{BE1} = V_{BE2} = V_T \ln I_C / I_s = 5V_{BE} = 751 \text{ mV}$$

$$V_{CE2} = V_{BE} = 751 \text{ mV}$$

$$V_{CE1} = 2,5 - 500 I_C - V_{CE2} \Rightarrow V_{CE1} = 840 \text{ mV}$$

$$V_{B1} = 2 \cdot V_{BE} = 1,502 \text{ V}$$

$$V_{C1} = 2,5 - 500 I_C = 1,64 \text{ V} \Rightarrow V_{C1} > V_{B1} \Rightarrow Q_1 \text{ modo ACtivo}$$

Q2 próximo a saturação

5

5.9 b) Resolução iterativa

(1) $V_{BE} = 0,7$

$$I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right) \Rightarrow I_C = 1,0482 \cdot 10^{-4} A$$

$$I_B = \frac{V_{CC} - 2V_{BE}}{9 \cdot 10^3} - \frac{2V_{BE}}{16 \cdot 10^3} \Rightarrow I_B = 3,4722 \cdot 10^{-5} A$$

(2) $I_C = \beta I_B = 3,4722 \cdot 10^{-3} A$

$$V_{BE} = V_T \ln \frac{I_C}{I_S} = 0,7688 V$$

$$I_B = 1,0836 \cdot 10^{-5} A$$

(3) $I_C = 1,0836 \cdot 10^{-3} A$

$$V_{BE} = 0,7385 V$$

$$I_B = 2,1349 \cdot 10^{-5} A$$

(4) $I_C = 2,1349 \cdot 10^{-3} A$

$$V_{BE} = 0,7561 V$$

$$I_B = 1,5227 \cdot 10^{-5} A$$

(5) $I_C = 1,5227 \cdot 10^{-3} A$

$$V_{BE} = 0,7474 V$$

$$I_B = 1,8278 \cdot 10^{-5} A$$

(6) $I_C = 1,8278 \cdot 10^{-3} A$

$$V_{BE} = 0,7521 V$$

$$I_B = 1,6629 \cdot 10^{-5} A$$

(7) $I_C = 1,66 \cdot 10^{-3} A$

$$V_{BE} = 0,7497 V$$

$$I_B = 1,7482 \cdot 10^{-5} A$$

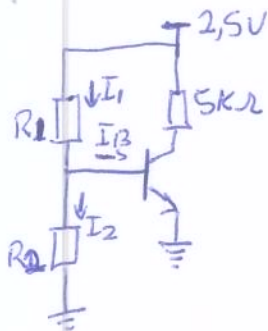
(8) $I_C = 1,7482 \cdot 10^{-3} A$

$$V_{BE} = 0,7497 V$$

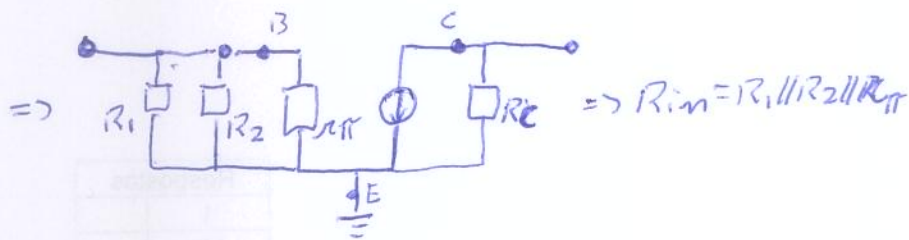
$$I_B = 1,7482 \cdot 10^{-5} A$$

mw

5.13



$R_{in} > 10k\Omega$
 $g_m = \frac{1}{260} S$
 $\beta = 100$
 $I_S = 2 \cdot 10^{-17} A$
 $V_A = \infty$
 $R_1 \text{ e } R_2 \text{ min?}$



$g_m = \frac{I_C}{V_T} \Rightarrow \frac{1}{260} = \frac{2 \cdot 10^{-3} I_C}{26 \cdot 10^{-3}} \Rightarrow I_C = 1 \cdot 10^{-4} A$

$V_{BE} = V_T \ln \frac{I_C}{I_S} \Rightarrow V_{BE} = 0,7603V$

$I_B = \frac{I_C}{\beta} \Rightarrow I_B = 1 \cdot 10^{-6} A$

$r_{\pi} = \frac{\beta}{g_m} \Rightarrow r_{\pi} = 26 \cdot 10^3 K\Omega \sim \text{impedância máxima}$

$2,5 - R_1 I_1 - V_{BE} = 0 \Rightarrow R_1 = \frac{2,5 - V_{BE}}{I_1} \Rightarrow R_1 = \frac{2,5 - V_{BE}}{I_2 + I_3} \Rightarrow R_1 = \frac{2,5 - V_{BE}}{\frac{V_{BE} + I_B}{R_2}} \quad (1)$

$r_{\pi} || R_1 || R_2 > 10k\Omega \Rightarrow r_{\pi} || R_{eq} > 10k\Omega \Rightarrow \left(\frac{1}{r_{\pi}} + \frac{1}{R_{eq}} \right)^{-1} > 10k\Omega \Rightarrow \frac{r_{\pi} R_{eq}}{r_{\pi} + R_{eq}} > 10 \cdot 10^3$
 $\Rightarrow r_{\pi} R_{eq} > 10^4 r_{\pi} + 10^4 R_{eq} \Rightarrow R_{eq} (r_{\pi} - 10^4) > 10^4 r_{\pi} \Rightarrow R_{eq} > 16,250\Omega$

$R_{eq} = R_1 || R_2 \Rightarrow R_{eq} = \frac{R_1 R_2}{R_1 + R_2} \Rightarrow R_{eq} R_1 + R_{eq} R_2 = R_1 R_2 \Rightarrow R_1 (R_2 - R_{eq}) = R_{eq} R_2$

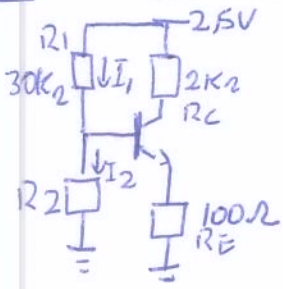
$R_1 = \frac{R_{eq} R_2}{R_2 - R_{eq}} \Rightarrow \frac{2,5 - V_{BE}}{\frac{V_{BE} + I_B}{R_2}} = \frac{R_{eq} R_2}{R_2 - R_{eq}} \Rightarrow \frac{2,5 - V_{BE}}{\frac{V_{BE} + R_2 I_B}{R_2}} = \frac{R_{eq} R_2}{R_2 - R_{eq}}$

$\Rightarrow R_{eq} R_2 \frac{V_{BE} + R_2 I_B}{R_2} = (R_2 - R_{eq}) (2,5 - V_{BE}) \Rightarrow R_{eq} V_{BE} + R_2 R_{eq} I_B = R_2 (2,5 - V_{BE}) - R_{eq} (2,5 - V_{BE})$

$\Rightarrow R_2 (2,5 - V_{BE} - R_{eq} I_B) = R_{eq} (V_{BE} + 2,5 - V_{BE}) \Rightarrow R_2 = 2,3571 \cdot 10^4 \Omega$

$R_1 = 5,2318 \cdot 10^4 \Omega$

5.17



$$\begin{aligned} \beta &= 100 \\ I_S &= 10^{-17} \\ V_A &= \infty \\ V_T &= 26 \text{ mV} \end{aligned}$$

$$V_{CE} \gg V_{BE} \Rightarrow V_{CC} - I_C R_C \gg V_T \ln \frac{V_{CE} I_C}{I_S}$$

$$\Rightarrow V_T \ln \frac{I_C}{I_S} + I_C R_C - V_{CC} = 0$$

↓ Cálculo numérico (solve)
MATLAB

$$\Rightarrow I_C = 8,3330 \cdot 10^{-4} \text{ A}$$

↳ máximo

$$I_B = \frac{I_C}{\beta} \Rightarrow I_B = 8,3330 \cdot 10^{-6} \text{ A}$$

$$I_E = \frac{\beta}{\beta + 1} \cdot I_C \Rightarrow I_E = 8,2505 \cdot 10^{-4} \text{ A}$$

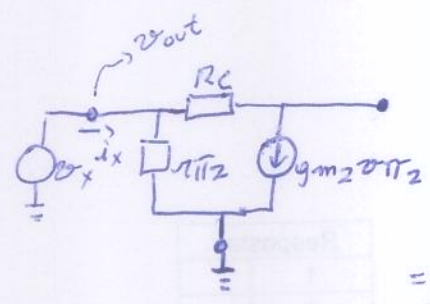
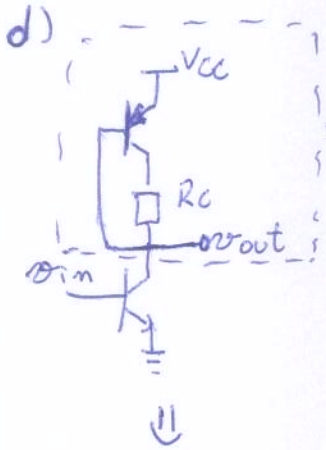
$$V_{BE} = V_T \ln \frac{I_C}{I_S} \Rightarrow V_{BE} = 0,8334 \text{ V}$$

$$V_B = V_{BE} + R_E \cdot I_E \Rightarrow V_B = 0,9159$$

$$I_2 = I_1 - I_B \Rightarrow \frac{V_B}{R_2} = \frac{V_{CC} - V_B}{R_1} - I_B \Rightarrow R_2 = 2,059 \cdot 10^4 \Omega$$

↳ máximo

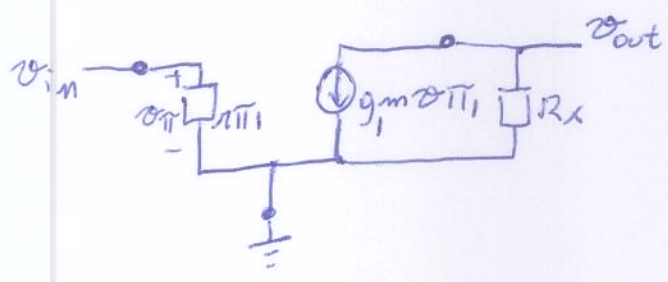
5.38



$$i_x = \frac{v_x}{r_{\pi 2}} + g_{m2} v_{\pi 2}$$

$$i_x = \frac{v_x}{r_{\pi 2}} + g_{m2} v_x$$

$$\Rightarrow \frac{v_x}{i_x} = \frac{1}{\frac{1}{r_{\pi 2}} + g_{m2}} \Rightarrow R_x = r_{\pi 2} \parallel \frac{1}{g_{m2}}$$



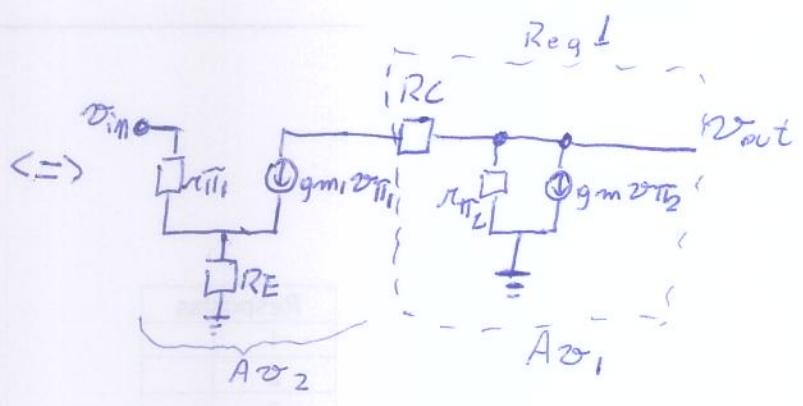
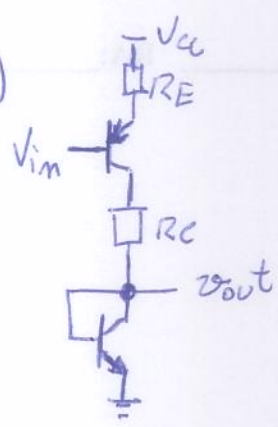
$$R_{in} = r_{\pi 1}$$

$$v_{out} = -v_{in} \cdot g_{m1} \cdot R_x \Rightarrow A_{v2} = -g_{m1} \left(R_L \parallel \frac{1}{g_{m2}} \right)$$

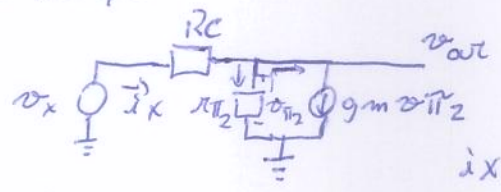
$$R_{out} = R_x \Rightarrow R_{out} = r_{\pi 2} \parallel \frac{1}{g_{m2}}$$

5.47

b)



• Req1



$$i_x = i_{\pi 2} + g_{m2} v_{\pi 2}$$

$$i_x = \frac{v_{\pi 2}}{r_{\pi 2}} + g_{m2} v_{\pi 2} \Rightarrow \textcircled{1}$$

$$i_x = \frac{v_x - v_{\pi 2}}{R_C} \Rightarrow v_{\pi 2} = v_x - i_x R_C \textcircled{2}$$

$$\textcircled{1} \Rightarrow i_x = \frac{v_x - i_x R_C}{r_{\pi 2}} + g_{m2} (v_x - i_x R_C) \Rightarrow i_x = \frac{v_x}{r_{\pi 2}} - \frac{i_x R_C}{r_{\pi 2}} + g_{m2} v_x - g_{m2} i_x R_C$$

$$i_x \left(1 + \frac{R_C}{r_{\pi 2}} + g_{m2} R_C \right) = v_x \cdot \left(\frac{1}{r_{\pi 2}} + g_{m2} \right) \Rightarrow R_{eq1} = \frac{v_x}{i_x} = \frac{1 + R_C \left(\frac{1}{r_{\pi 2}} + g_{m2} \right)}{\left(\frac{1}{r_{\pi 2}} + g_{m2} \right)}$$

$$R_{eq1} = \left(1 + R_C \left(\frac{1}{r_{\pi 2}} + g_{m2} \right) \right) \cdot \left(\frac{1}{r_{\pi 2}} + g_{m2} \right)^{-1} \Rightarrow R_{eq1} = \left(\frac{1}{r_{\pi 2}} + g_{m2} \right)^{-1} + R_C$$

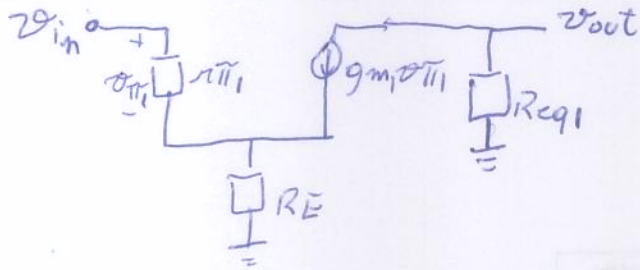
$$R_{eq1} = R_C + r_{\pi 2} \parallel \frac{1}{g_{m2}}$$

• Av1 =

$$v_{out} = v_{\pi 2} \textcircled{2} \Rightarrow v_{out}' = v_x - i_x R_C \Rightarrow v_{out}' = v_x - \frac{v_x R_C}{R_{eq1}} \Rightarrow \frac{v_{out}'}{v_x} = 1 - \frac{R_C}{R_C + r_{\pi 2} \parallel \frac{1}{g_{m2}}}$$

$$A_{v1} = \frac{R_C + r_{\pi 2} \parallel \frac{1}{g_{m2}} - R_C}{R_C + r_{\pi 2} \parallel \frac{1}{g_{m2}}} \Rightarrow A_{v1} = \frac{r_{\pi 2} \parallel \frac{1}{g_{m2}}}{R_C + r_{\pi 2} \parallel \frac{1}{g_{m2}}}$$

• A_{v2} -



~~$v_{\pi_1} = v_{in} - v_{RE}$~~

$v_{\pi_1} = v_{in} - v_{RE}$

$v_{\pi_1} = v_{in} - RE \left(\frac{v_{\pi_1}}{r_{\pi_1}} + g_{m1} v_{\pi_1} \right)$

$v_{\pi_1} = v_{in} - RE v_{\pi_1} \left(\frac{1}{r_{\pi_1}} + g_{m1} \right) \Rightarrow v_{\pi_1} \left(1 + RE \cdot \left(\frac{r_{\pi_1} + 1}{g_{m1}} \right)^{-1} \right) = v_{in}$

$$v_{\pi_1} = \frac{v_{in}}{1 + RE \left(\frac{r_{\pi_1} + 1}{g_{m1}} \right)^{-1}} \quad (A)$$

$v_{out} = -g_{m1} v_{\pi_1} R_{eq1} = -g_{m1} \frac{v_{in}}{1 + RE \left(\frac{r_{\pi_1} + 1}{g_{m1}} \right)^{-1}} R_{eq1}$

$$\frac{v_{out}}{v_{in}} = \frac{-R_{eq1}}{\frac{1}{g_{m1}} \left[1 + RE \cdot \left(\frac{1}{r_{\pi_1}} + g_{m1} \right) \right]} = \frac{-R_{eq1}}{\frac{1}{g_{m1}} + \frac{RE}{g_{m1}} \cdot \left(\frac{1}{r_{\pi_1}} + g_{m1} \right)}$$

$$\frac{v_{out}}{v_{in}} = \frac{-R_{eq1}}{\frac{1}{g_{m1}} + \frac{RE}{\beta}} \Rightarrow A_{v2} = \frac{-R_{eq1}}{\frac{1}{g_{m1}} + \frac{RE}{\beta}}$$

$$A_{v2} = \frac{R_c + r_{\pi_2} \parallel g_{m2}}{\frac{1}{g_{m1}} + RE \left(1 + \frac{1}{\beta} \right)}$$

• $Z_{in} = \frac{v_{in}}{i_{in}}$

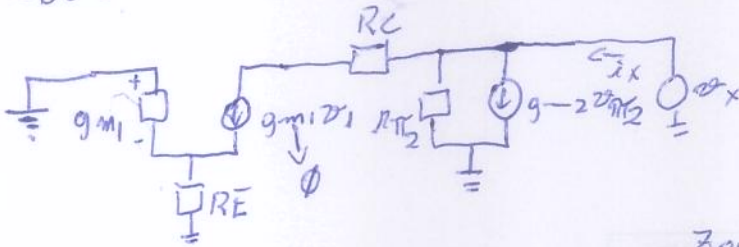
(A) $v_{in} = v_{\pi_1} \left(1 + RE \cdot \left(\frac{r_{\pi_1} + 1}{g_{m1}} \right)^{-1} \right)$

$i_{in} = \frac{v_{\pi_1}}{r_{\pi_1}}$

$Z_{in} = r_{\pi_1} \cdot \left[1 + RE \cdot \left(\frac{1}{r_{\pi_1}} + g_{m1} \right) \right] = r_{\pi_1} + RE r_{\pi_1} \left(\frac{1}{r_{\pi_1}} + \frac{\beta}{r_{\pi_1}} \right)$

$$Z_{in} = r_{\pi_1} + RE \cdot (1 + \beta)$$

• Z_{out}



$$i_x = g_{m2} v_{\pi_2} + \frac{v_{\pi_2}}{r_{\pi_2}}$$

$$v_{\pi_2} = v_x$$

$$i_x = v_x \cdot (g_{m2} + \frac{1}{r_{\pi_2}})$$

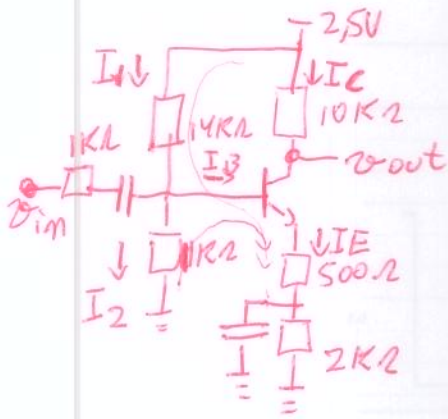
$$Z_{out} = \frac{v_x}{i_x} = \frac{1}{g_{m2} + \frac{1}{r_{\pi_2}}} \Rightarrow Z_{out} = \frac{1}{g_{m2}} \parallel r_{\pi_2}$$

$$A_v = A_{v1} \cdot A_{v2} \Rightarrow A_v = \frac{r_{\pi_2} \parallel \frac{1}{g_{m2}}}{(R_C + r_{\pi_2} \parallel \frac{1}{g_{m2}})} \cdot \frac{(R_C + r_{\pi_2} \parallel \frac{1}{g_{m2}})}{\frac{1}{g_{m1}} + R_E (1 + \frac{1}{\beta})}$$

$$A_v = \frac{r_{\pi_2} \parallel \frac{1}{g_{m2}}}{\frac{1}{g_{m1}} + R_E \cdot \underbrace{\left(1 + \frac{1}{\beta}\right)}_{\approx 1}}$$

AM

(5.52) c) A? $I_S = 8 \cdot 10^{-16} \text{ A}$; $\beta = 100$; $V_A = \infty$



$$\bullet I_3 = I_1 - I_2$$

$$\bullet I_1 = \frac{V_{CC} - (500 + 2000) \cdot I_E - V_{BE}}{14000}$$

$$\bullet I_2 = \frac{V_{BE} + (500 + 2000) \cdot I_E}{11000}$$

$$\bullet I_3 = \frac{V_{CC} - 2500 I_E - V_{BE}}{14000} - \frac{V_{BE} + 2500 I_E}{11000}$$

$$\Rightarrow I_B = \frac{I_C}{\beta} \approx \frac{I_C}{100} \text{ e } I_E = \frac{\beta + 1}{\beta} \cdot I_C \Rightarrow \boxed{I_B = I_C \cdot 10^{-2} \text{ e } I_E = 0,9901 I_C}$$

$$I_C \cdot 10^{-2} = \frac{2,5 - 2500 \cdot 0,9901 I_C - V_{BE}}{14000} - \frac{V_{BE} + 2500 \cdot 0,9901 I_C}{11000}$$

$$I_C = \frac{110(2,5 - 2,4752 \cdot 10^3 I_C - V_{BE}) - 140(V_{BE} + 2,4752 \cdot 10^3 I_C)}{140 \cdot 110}$$

$$I_C = \frac{275 - 2,7278 \cdot 10^5 I_C - 110 V_{BE} - 140 V_{BE} - 3,4653 \cdot 10^5 I_C}{15.400}$$

$$15.400 I_C = -6.1881 \cdot 10^5 I_C - 250 V_{BE} + 275$$

$$\Rightarrow 6.3421 \cdot 10^5 I_C + 250 V_{BE} - 275 = 0$$

$$V_{BE} = V_T \ln \frac{I_C}{I_S}$$

$V_T = 0,026$

$$\Rightarrow 6,3421 \cdot 10^5 I_C + 250 \cdot 0,026 \ln \frac{I_C}{8 \cdot 10^{-16}} - 275 = 0$$

$$6,3421 \cdot 10^5 I_C + 6,5 \cdot \ln \frac{I_C}{8 \cdot 10^{-16}} - 275 = 0$$

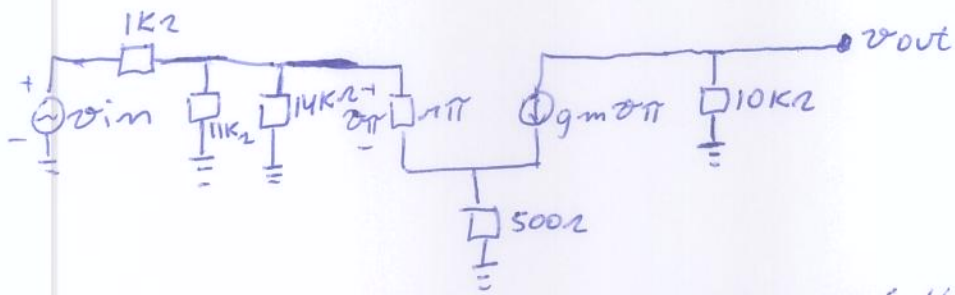
$$\Rightarrow \boxed{I_C = 1,6651 \cdot 10^{-4} \text{ A}}$$

$$\bullet g_m = \frac{I_C}{V_T} \approx \frac{I_C}{0,026} \Rightarrow \boxed{g_m = 6,4041 \cdot 10^{-3} \text{ S}}$$

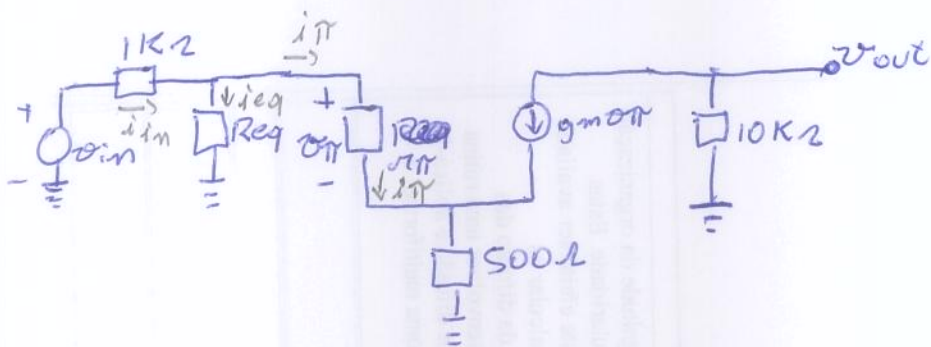
$$\bullet r_{\pi} = \frac{\beta}{g_m} \Rightarrow \boxed{r_{\pi} = 1,5615 \cdot 10^4 \Omega}$$

$$\boxed{r_o = \infty}$$

o Modelo de Pequenos Sinais



$$\Downarrow R_{eq} = 11k\Omega // 14k\Omega = 6.160\Omega$$



$$v_{in} = 1000 i_{in} + v_{\pi} + 500 \cdot (i_{\pi} + g_m v_{\pi})$$

$$v_{in} = 1000 i_{in} + v_{\pi} + 500 \left(\frac{v_{\pi}}{r_{\pi}} + g_m v_{\pi} \right)$$

$$v_{in} = 1000 \cdot i_{in} + v_{\pi} \cdot \left[1 + 500 \left(\frac{1}{r_{\pi}} + g_m \right) \right]$$

$$v_{in} = 1000 \cdot (i_{eq} + i_{\pi}) + v_{\pi} \left[1 + 500 \left(\frac{1}{r_{\pi}} + g_m \right) \right]$$

$$\frac{v_{\pi} + 500 \left(\frac{v_{\pi}}{r_{\pi}} + g_m v_{\pi} \right)}{R_{eq}}$$

$$v_{in} = 1000 \cdot \left(\frac{v_{\pi} + 500(v_{\pi} + g_m v_{\pi})}{R_{eq}} + \frac{v_{\pi}}{1k\Omega} \right) + v_{\pi} \left[1 + 500 \left(\frac{1}{1k\Omega} + g_m \right) \right]$$

$$v_{in} = \frac{1000}{R_{eq}} \cdot \left(v_{\pi} + 500 \left(\frac{v_{\pi}}{1k\Omega} + g_m v_{\pi} \right) + \frac{v_{\pi}}{1k\Omega} \right) + v_{\pi} \left[1 + 500 \left(\frac{1}{1k\Omega} + g_m \right) \right]$$

$$v_{in} = \frac{1000 v_{\pi}}{R_{eq}} \left(1 + 500 \left(\frac{1}{1k\Omega} + g_m \right) + \frac{1}{1k\Omega} \right) + v_{\pi} \left[1 + 500 \left(\frac{1}{1k\Omega} + g_m \right) \right]$$

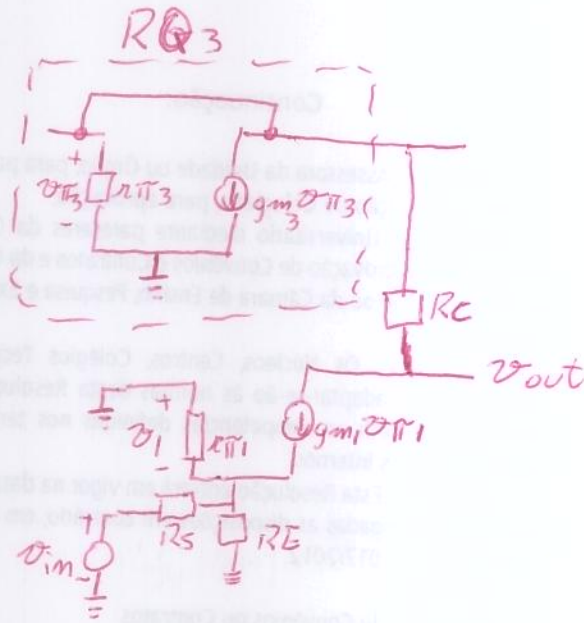
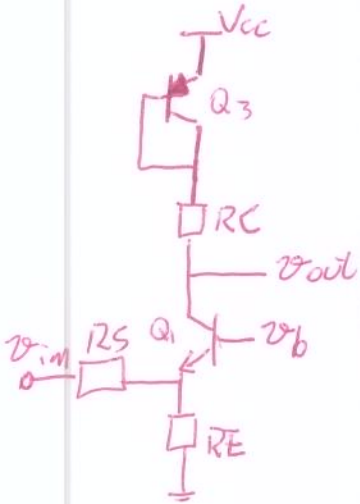
$$v_{in} = v_{\pi} \cdot \left\{ \frac{1000}{R_{eq}} \cdot \left[1 + 500 \left(\frac{1}{1k\Omega} + g_m \right) + \frac{1}{1k\Omega} \right] + 1 + 500 \left(\frac{1}{1k\Omega} + g_m \right) \right\}$$

$$v_{out} = -10000 \cdot g_m v_{\pi}$$

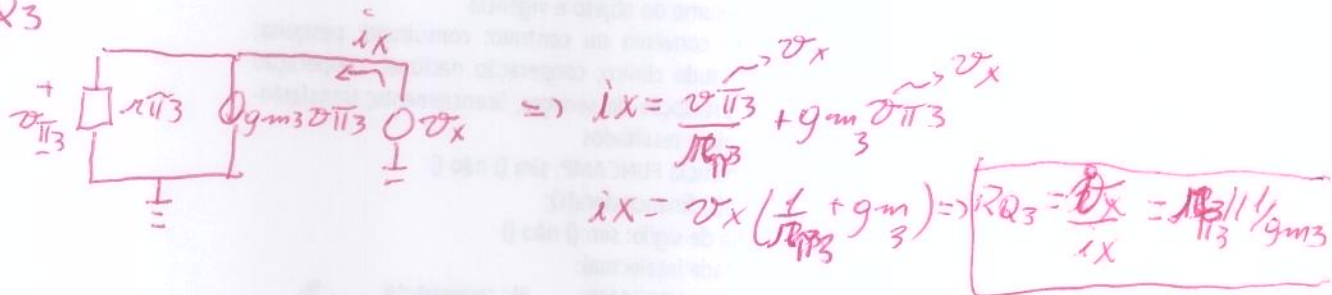
$$A_v = \frac{v_{out}}{v_{in}} = - \left(\frac{\left\{ \frac{1000}{R_{eq}} \cdot \left[1 + 500 \left(\frac{1}{1k\Omega} + g_m \right) + \frac{1}{1k\Omega} \right] + 1 + 500 \left(\frac{1}{1k\Omega} + g_m \right) \right\}^{-1}}{10000 g_m} \right)$$

$$A_v = 13,0127 \text{ } \mu\text{V}$$

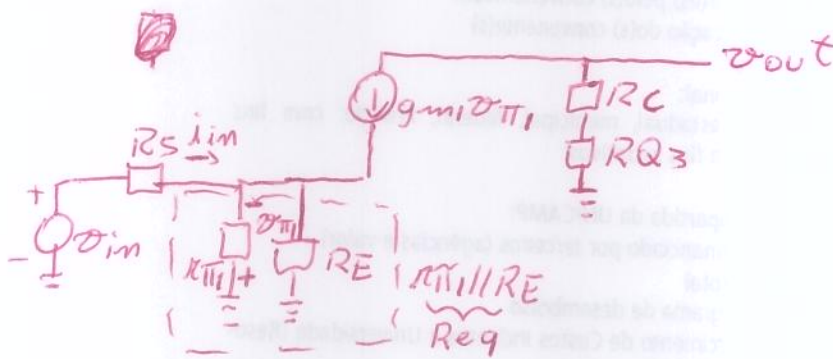
5.55 d)



• RQ3



• Modelo de pequenos sinais equivalente



• $v_{Req} = -v_{\pi 1}$

• $v_{Req} = (g_{m1} v_{\pi 1} + i_{in}) \cdot Req = \left[g_{m1} v_{\pi 1} + \frac{v_{Req}}{Req} - g_{m1} v_{\pi 1} \right] Req$

• $-v_{\pi 1} = v_{\pi 1} \left[g_{m1} - \frac{1}{Req} + \dots \right]$

• $v_{Req} = Req \cdot i$

• $v_{in} = v_{RS} + v_{Req} = RS \cdot i_{in} - v_{\pi 1} = RS \cdot (i_{Req} - g_{m1} v_{\pi 1}) - v_{\pi 1}$

• $v_{in} = RS \cdot \left[\frac{v_{Req}}{Req} - g_{m1} v_{\pi 1} \right] - v_{\pi 1}$

$$v_{in} = R_S v_{\pi 1} \left[\frac{1}{R_{eq}} - g_{m1} \right] - v_1$$

$$v_{in} = -v_{\pi 1} \left[R_S \left(\frac{1}{R_{eq}} + g_{m1} \right) + 1 \right]$$

$$v_{out} = -g_{m1} v_{\pi 1} (R_C + R_{Q3})$$

$$A_v = \frac{v_{out}}{v_{in}} = \frac{+g_{m1} (R_C + R_{Q3})}{R_S \left(\frac{1}{R_{eq}} + g_{m1} \right) + 1} \div \left(\frac{1}{R_{eq}} + g_{m1} \right)$$

$$A_v = \frac{-g_{m1} (R_C + R_{Q3}) \cdot \left(\frac{1}{R_{eq}} + g_{m1} \right)^{-1}}{R_S + \frac{1}{R_{eq}} \cdot \left(\frac{1}{R_{eq}} + g_{m1} \right)^{-1}}$$

$$A_v = \frac{+g_{m1} (R_C + R_{Q3} \parallel \frac{1}{g_{m3}}) \cdot (r_{\pi 1} \parallel R_E \parallel \frac{1}{g_{m1}})}{R_S + r_{\pi 1} \parallel R_E \parallel \frac{1}{g_{m1}}}$$

obs: $r_{\pi 1} = \frac{\beta}{g_{m1}} \Rightarrow r_{\pi 1} \parallel \frac{1}{g_{m1}} \approx \frac{1}{g_{m1}}$

$$\Rightarrow A_v \approx \frac{g_{m1} (R_C + R_{Q3} \parallel \frac{1}{g_{m3}}) \cdot R_E \parallel \frac{1}{g_{m1}}}{R_S + R_E \parallel \frac{1}{g_{m1}}}$$

$$\beta = 100; I_S = 8 \cdot 10^{-16} \text{ A}; V_A = \infty$$

$$a) 2,5 = 13000 \bar{I}_1 + V_{BE} + 400 \bar{I}_E$$

$$2,5 = 13000(\bar{I}_B + \bar{I}_2) + V_{BE} + 400 \bar{I}_E$$

esqueci do cap.
da base

$$2,5 = 13000 \cdot \left[\frac{\bar{I}_C}{\beta} + \frac{V_{BE} + 400 \bar{I}_E}{12000} \right] + V_{BE} + (400/\alpha) \bar{I}_C$$

$$2,5 = 13000 \left[\frac{\bar{I}_C}{\beta} + \frac{V_{BE} + (400/\alpha) \bar{I}_C}{12000} \right] + V_{BE} + (400/\alpha) \bar{I}_C$$

$$2,5 = \frac{13000 \bar{I}_C}{\beta} + \frac{13000}{12000} \cdot \left(V_{BE} + \frac{400 \bar{I}_C}{\alpha} \right) + V_{BE} + \frac{400 \bar{I}_C}{\alpha}$$

$$2,5 = \frac{13000 \bar{I}_C}{\beta} + \frac{13000}{12000} \cdot V_{BE} + \frac{13000}{12000} \frac{400 \bar{I}_C}{\alpha} + \frac{400 \bar{I}_C}{\alpha} + V_{BE}$$

$$\bar{I}_C \cdot \left(\frac{13000}{\beta} + \frac{13000}{12000} \frac{400}{\alpha} + \frac{400}{\alpha} \right) + V_{BE} \left(\frac{13000}{12000} + 1 \right) - 2,5 = 0$$

$$\Rightarrow 971,6667 \bar{I}_C + 2,0833 V_{BE} - 2,5 = 0$$

obs

$$\alpha = \frac{\beta + 1}{\beta} = 0,9901$$

$$\Rightarrow V_{BE} = V_T \ln \frac{\bar{I}_C}{I_S}$$

\downarrow
0,026 $I_S \approx 8 \cdot 10^{-16}$

$$\Rightarrow 971,6667 \bar{I}_C + 2,0833 \cdot 0,026 \ln \frac{\bar{I}_C}{8 \cdot 10^{-16}} - 2,5 = 0$$

$$971,6667 \bar{I}_C + 0,0542 \ln \frac{\bar{I}_C}{8 \cdot 10^{-16}} - 2,5 = 0$$

$$\boxed{\bar{I}_C = 1,0191 \cdot 10^{-3} \text{ A}}$$

$$V_{BE} = V_T \ln \frac{\bar{I}_C}{I_S} \Rightarrow \boxed{V_{BE} = 0,7247 \text{ V}}$$

\downarrow
0,026 $I_S \approx 8 \cdot 10^{-16}$

$$V_E = 400 \cdot \bar{I}_E = 400 \cdot \alpha \bar{I}_C \Rightarrow \boxed{V_E = 0,4036 \text{ V}}$$

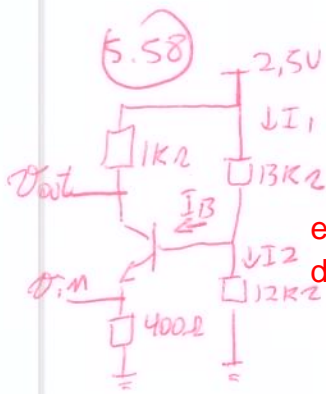
$$V_B = V_E + V_{BE} \Rightarrow \boxed{V_B = 1,112 \text{ V}}$$

~~$$V_C = 1000 \cdot \bar{I}_C \Rightarrow \boxed{V_C = 1,0191 \text{ V}}$$~~

$$V_C = 2,5 - 1000 \bar{I}_C \Rightarrow \boxed{V_C = 1,4809 \text{ V}}$$

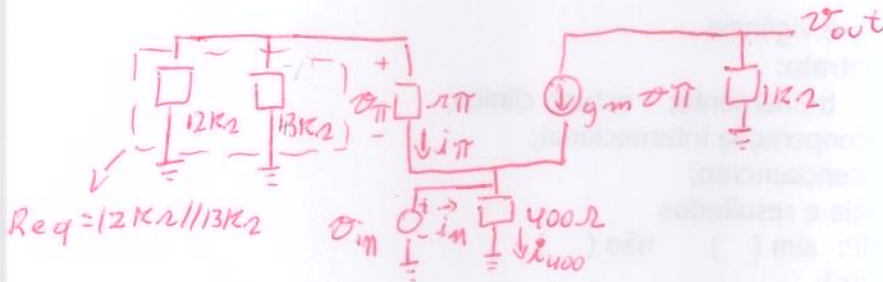
$$V_B > V_E$$
~~$$V_B > V_C$$~~

$V_B > V_E \Rightarrow$ Região Ativa
 $V_C > V_B$
 OK



$$b) g_m = \frac{I_c}{V_T} = \frac{1,0 \text{ mA} \cdot 10^{-3}}{0,26} \Rightarrow g_m = 0,0392 \text{ S}$$

$$r_{\pi} = \frac{\beta}{g_m} = \frac{100}{0,0392} \Rightarrow r_{\pi} = 2,5513 \cdot 10^3 \Omega$$



$$\bullet v_{in} + v_{\pi} + v_{Req} = 0$$

$$v_{in} = -v_{\pi} - R_{eq} \cdot i_{\pi} = -v_{\pi} - R_{eq} \cdot \frac{v_{\pi}}{r_{\pi}}$$

$$v_{in} = -v_{\pi} \cdot \left(1 + \frac{R_{eq}}{r_{\pi}}\right)$$

$$\bullet v_{out} = -g_m v_{\pi} \cdot 1000$$

$$\bullet A_v = \frac{v_{out}}{v_{in}} = \frac{1000 g_m}{1 + \frac{12000 || 13000}{2,5513 \cdot 10^3}} \approx 0,0392 \Rightarrow A_v = 11,3749$$

$$\bullet R_{in} \sim \frac{v_{\pi}}{i_{in}} \sim \frac{v_{in}}{400}$$

$$i_{in} + i_{\pi} + g_m v_{\pi} - i_{400} = 0$$

$$i_{in} = -\frac{v_{\pi}}{r_{\pi}} - g_m v_{\pi} + \frac{v_{in}}{400} \sim -\frac{v_{\pi}}{r_{\pi}} \left(1 + \frac{R_{eq}}{r_{\pi}}\right)$$

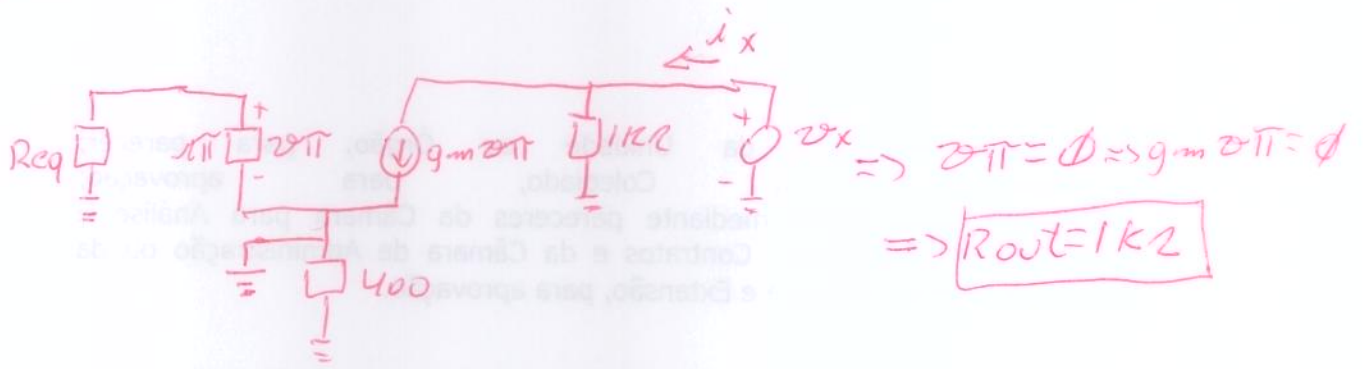
$$i_{in} = -\frac{v_{\pi}}{r_{\pi}} \left(\frac{1}{r_{\pi}} + g_m + \frac{1}{400} \cdot \left(1 + \frac{R_{eq}}{r_{\pi}}\right) \right)$$

$$v_{in} = -\frac{v_{\pi}}{r_{\pi}} \left(1 + \frac{R_{eq}}{r_{\pi}}\right)$$

$$R_{in} = \frac{v_{in}}{i_{in}} = \frac{1 + \frac{R_{eq}}{r_{\pi}}}{\frac{1}{r_{\pi}} + g_m + \frac{1}{400} \cdot \left(1 + \frac{R_{eq}}{r_{\pi}}\right)} \Rightarrow R_{in} = 71,4867 \Omega$$

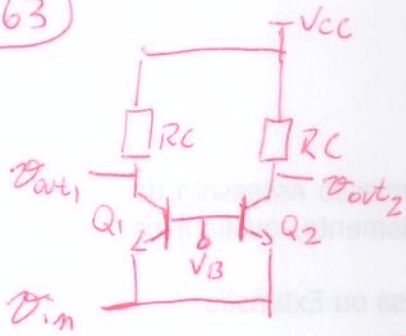
$$R_{in} = 71,4867 \Omega$$

• R_{out}



ROSE TADEU JORGE
Reitor

5.63

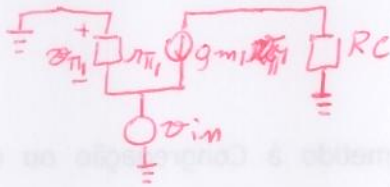


$$\left. \begin{aligned} I_{S1} &= 2 I_{S2} \\ V_{BE1} &= V_{BE2} \end{aligned} \right\} \bar{I}_{C1} = 2 \cdot \bar{I}_{C2}$$

$$\bar{I}_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right)$$

$$g_m = \frac{\bar{I}_C}{V_T}$$

$$\Rightarrow g_{m1} = 2g_{m2}$$



$$v_{in} = -v_{\pi 1}$$

$$v_{out} = -g_{m1} v_{\pi 1} R_C$$

$$A_v = g_{m1} R_C$$

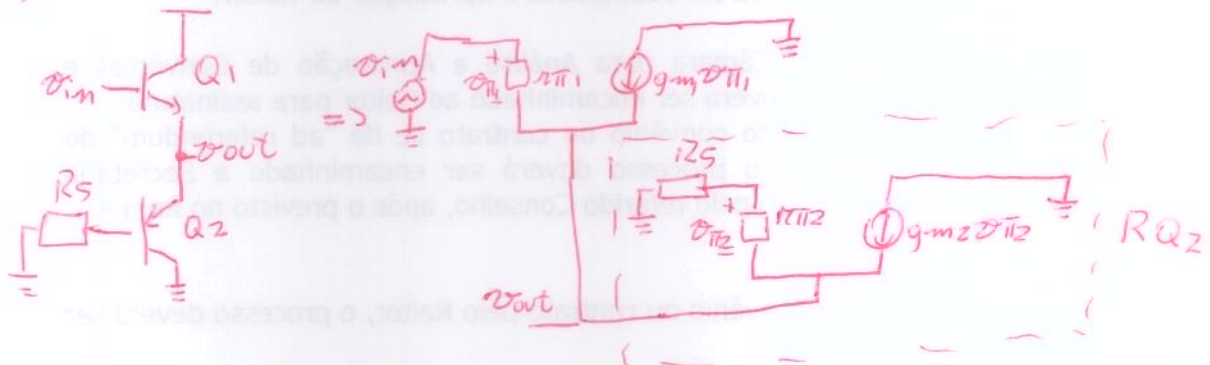
$$\frac{v_{out1}}{v_{in}} = g_{m1} R_C = 2 \cdot g_{m2} R_C$$

$$\frac{v_{out2}}{v_{in}} = g_{m2} R_C$$

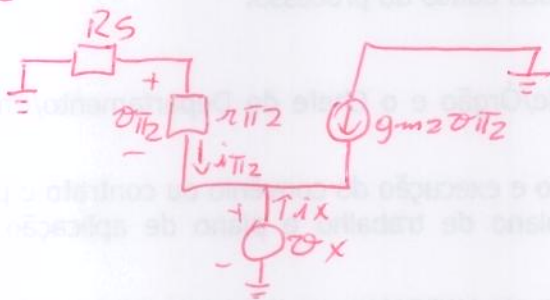
$$A_{v1} = 2 A_{v2} \quad \text{ou} \quad v_{out1} = 2 v_{out2}$$

5.63

c)



• R_{Q2}



$$v_x = -v_{\pi 2} - v_{RS}$$

$$v_x = -v_{\pi 2} - \frac{v_{\pi 2}}{r_{\pi 2}} R_S$$

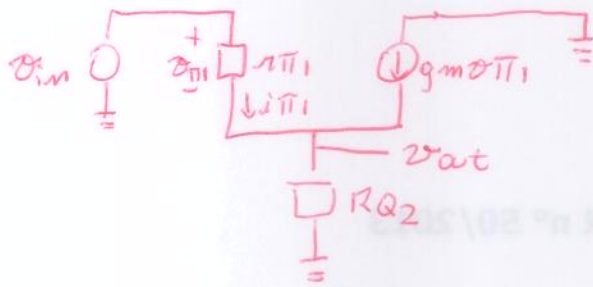
$$v_x = -v_{\pi 2} \cdot \left(1 + \frac{R_S}{r_{\pi 2}}\right)$$

$$i_x = -g_m v_{\pi 2} - i_{\pi 2}$$

$$i_x = -g_m v_{\pi 2} - \frac{v_{\pi 2}}{r_{\pi 2}}$$

$$i_x = -v_{\pi 2} \cdot \left(g_m + \frac{1}{r_{\pi 2}}\right)$$

$$\Rightarrow R_{Q2} = \frac{v_x}{i_x} = \frac{1 + \frac{R_S}{r_{\pi 2}}}{g_m + \frac{1}{r_{\pi 2}}} \Rightarrow R_{Q2} = \left(1 + \frac{R_S}{r_{\pi 2}}\right) \cdot \left(\frac{1}{g_m} \parallel r_{\pi 2}\right)$$



$$v_{in} = v_{\pi_1} + v_{R_{Q2}} = v_{\pi_1} + i_{R_{Q2}} \cdot R_{Q2} = v_{\pi_1} + R_{Q2} \cdot (i_{\pi_1} + g_m v_{\pi_1}) = v_{\pi_1} + R_{Q2} \left(\frac{v_{\pi_1}}{r_{\pi_1}} + g_m v_{\pi_1} \right)$$

$$v_{in} = v_{\pi_1} \cdot \left(1 + R_{Q2} \cdot \left(\frac{1}{r_{\pi_1}} + g_m \right) \right)$$

$$v_{out} = v_{R_{Q2}} = R_{Q2} \left(\frac{v_{\pi_1}}{r_{\pi_1}} + g_m v_{\pi_1} \right)$$

$$v_{out} = v_{\pi_1} R_{Q2} \left(\frac{1}{r_{\pi_1}} + g_m \right)$$

$$A_v = \frac{v_{out}}{v_{in}} = \frac{R_{Q2} \left(\frac{1}{r_{\pi_1}} + g_m \right) \cdot v_{\pi_1}}{v_{\pi_1} \cdot \left(1 + R_{Q2} \left(\frac{1}{r_{\pi_1}} + g_m \right) \right)} = \frac{R_{Q2} \left(\frac{1}{r_{\pi_1}} + g_m \right)}{1 + R_{Q2} \left(\frac{1}{r_{\pi_1}} + g_m \right)}$$

$$A_v = \frac{R_{Q2}}{\left(\frac{1}{r_{\pi_1}} + g_m \right)^{-1} + R_{Q2}} \Rightarrow A_v = \frac{R_{Q2}}{r_{\pi_1} \parallel \frac{1}{g_m} + R_{Q2}}$$

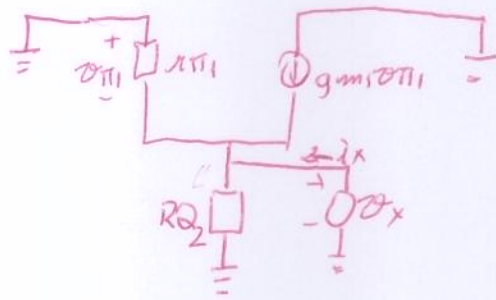
• R_{in}

$$v_{in} = v_{\pi_1} \left(1 + R_{Q2} \left(\frac{1}{r_{\pi_1}} + g_m \right) \right) \left\{ \begin{array}{l} R_{in} = r_{\pi_1} \left(1 + R_{Q2} \left(\frac{1}{r_{\pi_1}} + g_m \right) \right) \\ R_{in} = r_{\pi_1} + R_{Q2} (1 + g_m r_{\pi_1}) \end{array} \right.$$

$$i_{in} = \frac{v_{\pi_1}}{r_{\pi_1}}$$

$$R_{in} = r_{\pi_1} + R_{Q2} (1 + \beta)$$

• Rout



$$v_x = -v_{\pi 1}$$

$$i_x + g_{m1}v_{\pi 1} + \frac{v_x}{R_{eq}} = 0$$

$\hookrightarrow r_{\pi 1} \parallel R_{Q2}$

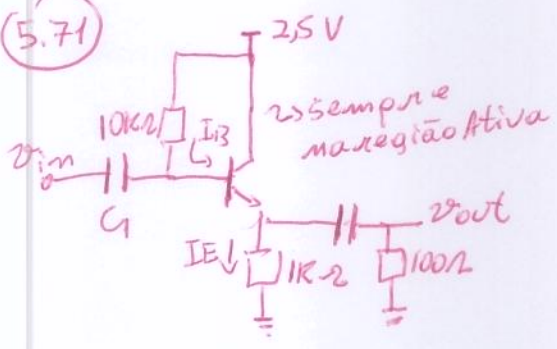
$$i_x = g_{m1}v_x - \frac{v_x}{R_{eq}} = 0$$

$$\frac{v_x}{i_x} = \left(g_{m1} + \frac{1}{R_{eq}} \right)^{-1}$$

$$R_{out} = \frac{1}{g_{m1}} \parallel R_{eq} \Rightarrow R_{out} = \frac{1}{g_{m1}} \parallel r_{\pi 1} \parallel R_{Q2}$$

5.71

Ar? ; $I_S = 7 \cdot 10^{-16} A$; $\beta = 100$; $V_A = 5V$



sempre na região Ativa

$$2,5 - 10 \cdot 1000 I_B - V_{BE} - 1000 I_E = 0$$

$$2,5 = 10 \cdot 1000 \frac{I_C}{\beta} + V_{BE} + 1000 I_E = 0$$

$$I_C \cdot \left(\frac{10 \cdot 1000}{\beta} + \frac{1000}{\alpha} \right) + V_{BE} = 2,5$$

$\beta \approx 100$ $\alpha \approx 0,9901$

$$\Rightarrow I_C \cdot 1110 + V_{BE} = 2,5 \Rightarrow V_{BE} = 2,5 - 1110 I_C$$

$$\Rightarrow I_C = I_S \exp \frac{V_{BE}}{V_T} \cdot \left(1 + \frac{V_{CE}}{V_A} \right)$$

$7 \cdot 10^{-16}$ $V_T \approx 0,026$ $V_A \approx 5V$

$$\bullet V_{CE} = 2,5 - 1000 I_E \Rightarrow V_{CE} = 2,5 - 1010 I_C \Rightarrow V_{CE} = 2,5 - 1010 I_C$$

$$\left[7 \cdot 10^{-16} \cdot \exp \frac{V_{BE}}{0,026} \cdot \left(1 + \frac{2,5 - 1010 I_C}{5} \right) \right] \cdot 1110$$

$$I_C = I_S \exp \left(\frac{2,5 - 1110 I_C}{0,026} \right) \cdot \left(1 + \frac{2,5 - 1010 I_C}{5} \right)$$

$$I_C - 7 \cdot 10^{-16} \exp \left(\frac{2,5 - 1110 I_C}{0,026} \right) \cdot \left(1 + \frac{2,5 - 1010 I_C}{5} \right) = 0$$

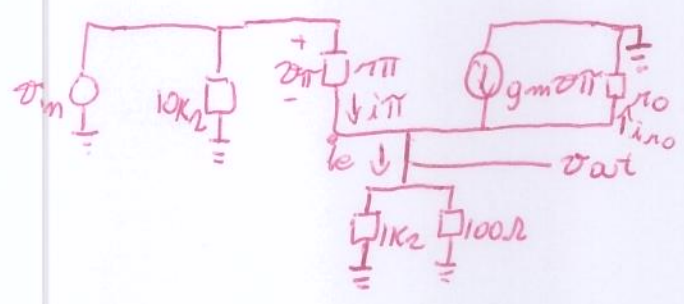
$$I_C = 1,5897 \cdot 10^{-3} A$$

$$V_{BE} = 2,5 - 1110 \cdot I_C \Rightarrow V_{BE} = 0,7355 V$$

$$\bullet g_m = \frac{I_C}{V_T} \Rightarrow g_m = 0,0611 S$$

$$\bullet r_o = \frac{V_A}{I_C} \Rightarrow r_o = 3,1453 \cdot 10^3 \Omega$$

$$\bullet r_{\pi} = \frac{\beta}{g_m} \Rightarrow r_{\pi} = 1,6355 \cdot 10^3 \Omega$$



$$\bullet v_{out} = (1000 || 100) \cdot \left(\frac{v_{\pi}}{r_{\pi}} + g_m v_{\pi} \right)$$

$$\bullet v_{out} = (1000 || 100) \cdot v_{\pi} \cdot \left(\frac{1}{r_{\pi}} + g_m \right)$$

$$\bullet v_{in} = v_{\pi} + v_{out}$$

$$\bullet v_{out} = 100/1000 \cdot i_e = 90,9091 \cdot (i_{\pi} + g_m v_{\pi} - i_{x0})$$

$$v_{out} = 90,9091 \left(\frac{v_{\pi}}{r_{\pi}} + g_m v_{\pi} - \frac{v_{out}}{r_0} \right)$$

$$v_{out} = 90,9091 \left[v_{\pi} \left(\frac{1}{r_{\pi}} + g_m \right) - \frac{v_{out}}{r_0} \right]$$

$\begin{matrix} \xrightarrow{0,0611} \\ \downarrow & \downarrow \\ \underbrace{1,6355 \cdot 10^3}_{0,0618} & \underbrace{3,1453 \cdot 10^3} \end{matrix}$

$$v_{out} = 5,6139 v_{\pi} - 0,0289 v_{out}$$

$$\boxed{v_{out} = 5,4562 v_{\pi}}$$

~~$v_{in} = v_{out}$~~

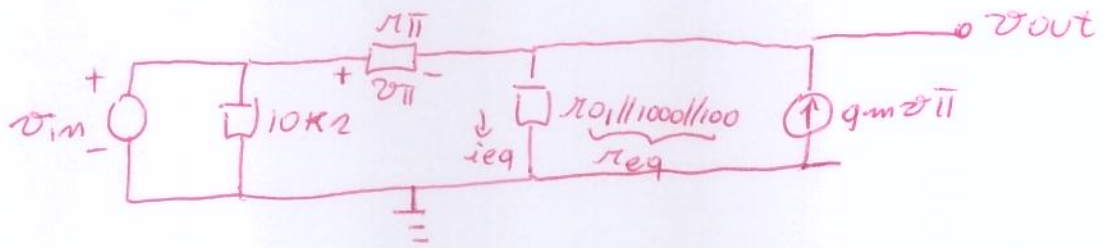
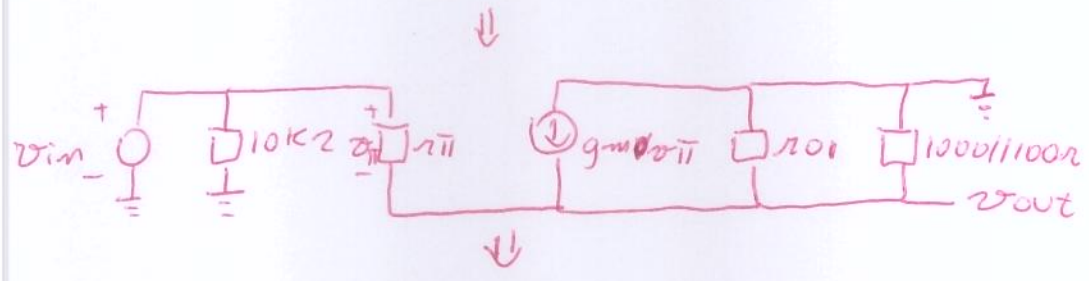
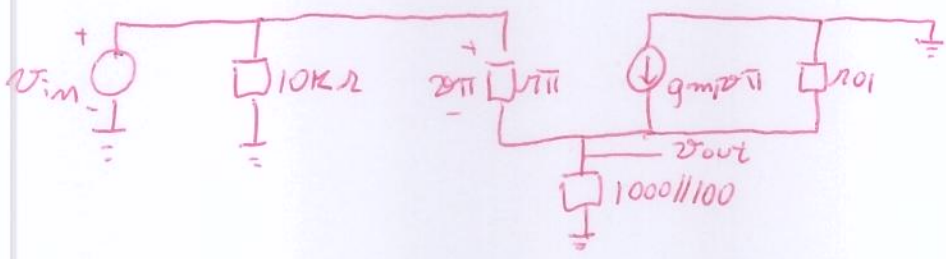
$$\bullet v_{in} = v_{\pi} + v_{out} \Rightarrow v_{out} = v_{in} - v_{\pi} \Rightarrow \boxed{v_{\pi} = v_{in} - v_{out}}$$

$$\Rightarrow v_{out} = 5,4562 (v_{in} - v_{out})$$

$$v_{out} \cdot 6,4562 = 5,4562 v_{in}$$

$$\boxed{A_v = \frac{v_{out}}{v_{in}} = 0,8451}$$

outro modo de resolver



• $v_{in} = v_{\pi} + r_{eq} \cdot i_{eq} = v_{\pi} + r_{eq} \cdot \left(\frac{v_{\pi}}{r_{\pi}} + g_m v_{\pi} \right) = v_{\pi} + r_{eq} v_{\pi} \left(\frac{1}{r_{\pi}} + g_m \right)$

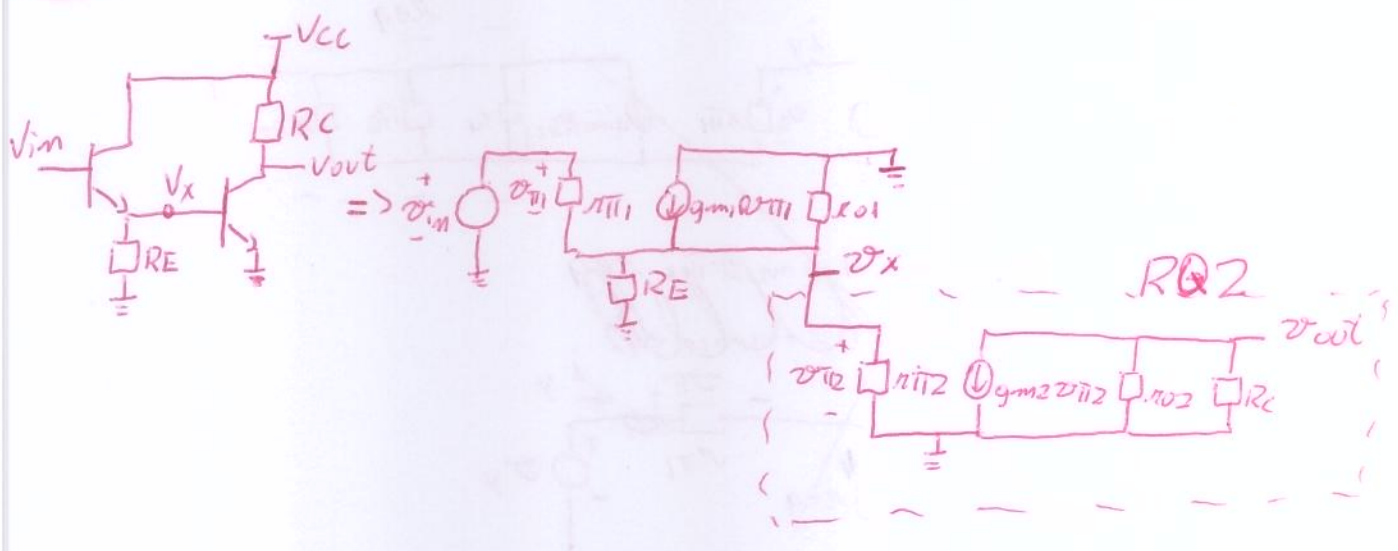
$v_{in} = v_{\pi} \left[1 + r_{eq} \left(\frac{1}{r_{\pi}} + g_m \right) \right]$

• $v_{out} = r_{eq} \cdot i_{eq} \Rightarrow v_{out} = v_{\pi} r_{eq} \left(\frac{1}{r_{\pi}} + g_m \right)$

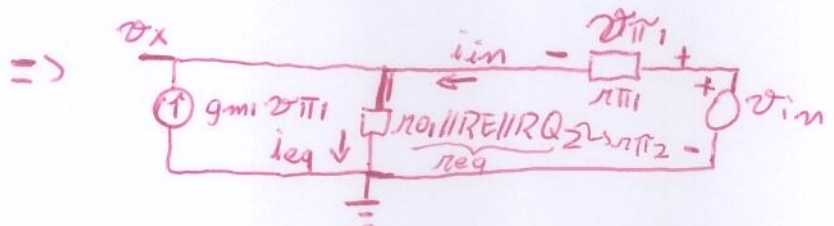
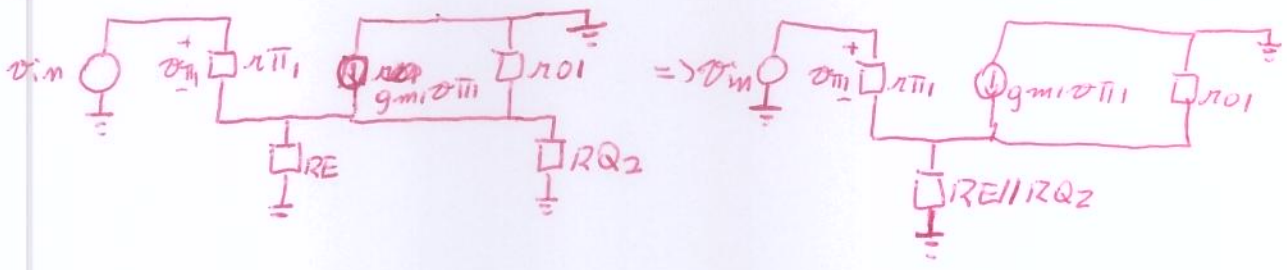
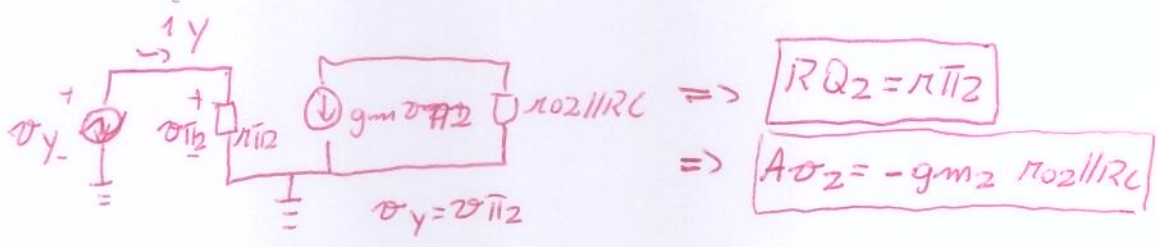
• $A_v = \frac{v_{out}}{v_{in}} = \frac{r_{eq} \cdot \left(\frac{1}{r_{\pi}} + g_m \right) \cdot v_{\pi}}{1 + r_{eq} \cdot \left(\frac{1}{r_{\pi}} + g_m \right) \cdot v_{\pi}} = \frac{r_{eq}}{\left(\frac{1}{r_{\pi}} + g_m \right)^{-1} + r_{eq}}$

$A_v = \frac{1000 || 1000 || 100}{\left(\frac{1}{100} + 0.04 \right)^{-1} + 1000 || 1000 || 100} \Rightarrow A_v = 0,8454$

5.72



• RQ2



- $v_{in} = v_{\pi} + r_{eq} \cdot i_{eq} = v_{\pi 1} + r_{eq} \cdot (i_{in} + g_{m1} v_{\pi 1}) = v_{\pi 1} + r_{eq} \left(\frac{v_{\pi 1}}{\pi\pi_1} + g_{m1} v_{\pi 1} \right)$
- $v_{in} = v_{\pi 1} \left[1 + r_{eq} \left(\frac{1}{\pi\pi_1} + g_{m1} \right) \right]$
- $i_{in} = \frac{v_{\pi 1}}{\pi\pi_1} \Rightarrow R_{in} = \pi\pi_1 \cdot \left[1 + r_{eq} \left(\frac{1}{\pi\pi_1} + g_{m1} \right) \right]$

\downarrow
 $\frac{v_{in}}{i_{in}}$

$$R_{in} = r_{\pi 1} + r_{\pi 1} \text{Re}q \left(\frac{1}{r_{\pi 1}} + g_{m1} \right) = r_{\pi 1} + \text{Re}q \left(1 + \underbrace{r_{\pi 1} g_{m1}}_{\beta} \right)$$

$$R_{in} = r_{\pi 1} + r_{o1} \parallel R_E \parallel r_{\pi 2} \cdot (1 + \beta)$$

$$v_x = v_{req} = r_{eq} \cdot \left(\frac{v_{\pi 1}}{r_{\pi 1}} + g_{m1} v_{\pi 1} \right) = r_{eq} \cdot v_{\pi 1} \left(\frac{1}{r_{\pi 1}} + g_{m1} \right)$$

$$A_{v1} = \frac{v_x}{v_{in}} = \frac{r_{eq} \cdot \left(\frac{1}{r_{\pi 1}} + g_{m1} \right)}{1 + r_{eq} \cdot \left(\frac{1}{r_{\pi 1}} + g_{m1} \right)} \cdot \left(\frac{1}{r_{\pi 1}} + g_{m1} \right)^{-1}$$

$$A_{v1} = \frac{r_{eq}}{r_{eq} + \left(\frac{1}{r_{\pi 1}} + g_{m1} \right)^{-1}} \Rightarrow A_{v1} \approx \frac{r_{eq}}{r_{eq} + \frac{1}{g_{m1}}}$$

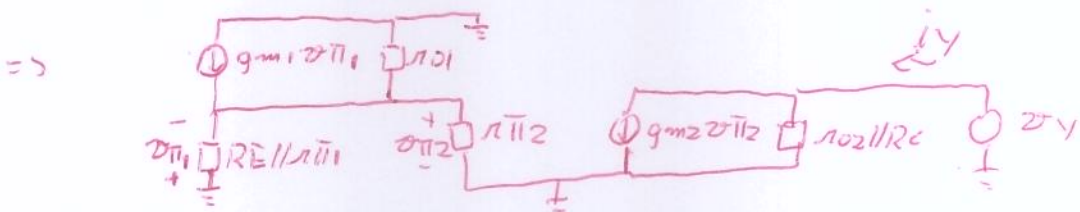
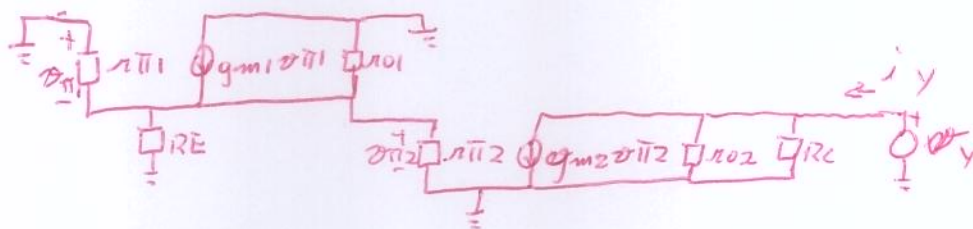
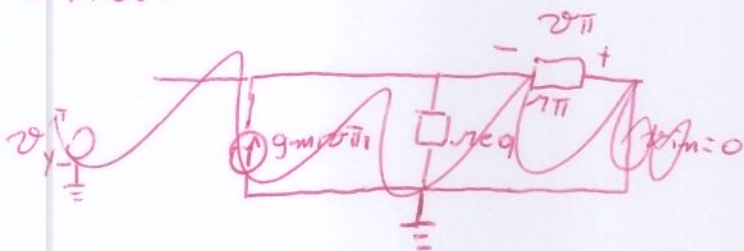
$\alpha \rightarrow \frac{g_{m1}}{\beta} + g_{m1} \approx g_m$

$$A_{v1} \approx \frac{r_{o1} \parallel R_E \parallel r_{\pi 2}}{\frac{1}{g_{m1}} + r_{o1} \parallel R_E \parallel r_{\pi 2}}$$

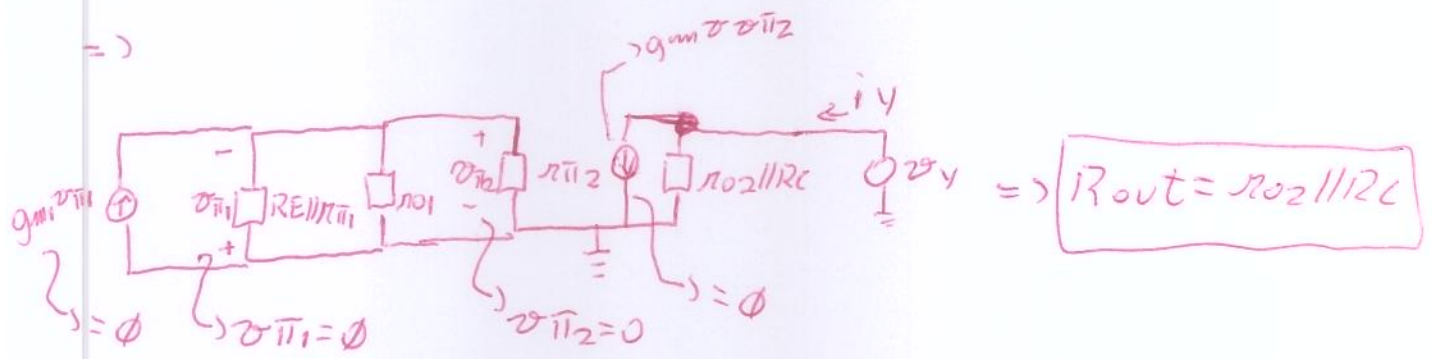
$$\Rightarrow A_v = A_{v1} \cdot A_{v2} \Rightarrow$$

$$A_v = -g_{m2} (r_{o2} \parallel R_C) \cdot \frac{r_{o1} \parallel R_E \parallel r_{\pi 2}}{\frac{1}{g_{m1}} + r_{o1} \parallel R_E \parallel r_{\pi 2}}$$

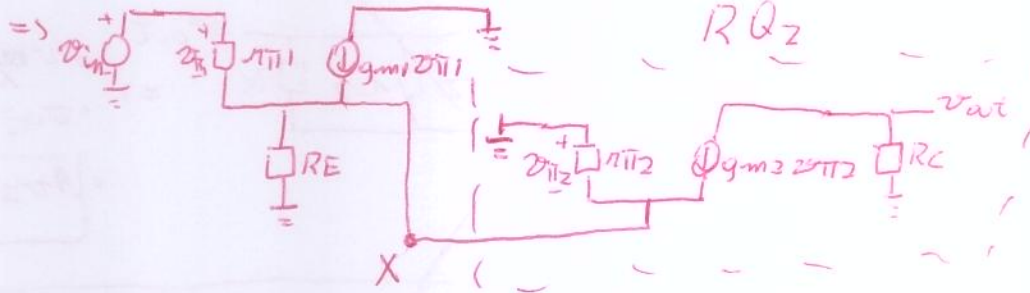
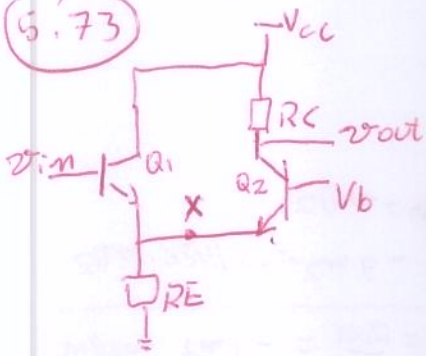
• Rout



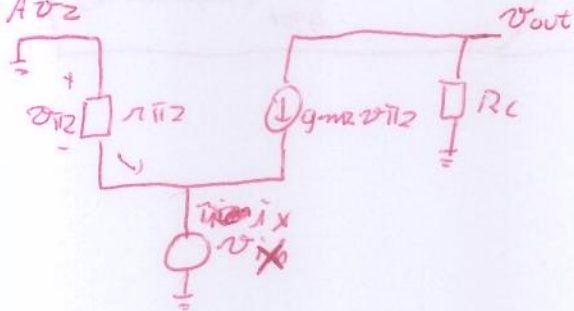
=>



5.73



• R_{Q2} e A_{v2}



$$v_x = -v_{\pi 2}$$

$$v_{out} = -g_{m2} v_{\pi 2} \cdot R_C$$

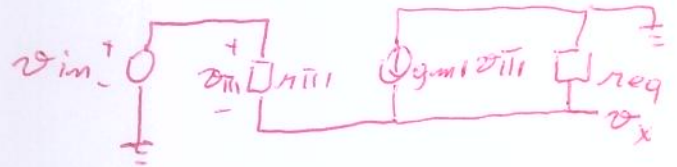
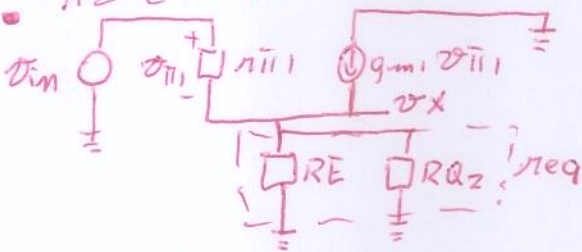
$$v_{out} = g_{m2} R_C v_x$$

$$\boxed{\frac{v_{out}}{v_x} = g_{m2} R_C}$$

$$i_x = -g_{m2} v_{\pi 2} - \frac{v_{\pi 2}}{R_{\pi 2}} \Rightarrow i_x = -v_{\pi 2} \left(g_{m2} + \frac{1}{R_{\pi 2}} \right) \Rightarrow i_x = v_x \left(g_{m2} + \frac{1}{R_{\pi 2}} \right)$$

$$R_{Q2} = \frac{v_x}{i_x} = \left(g_{m2} + \frac{1}{R_{\pi 2}} \right)^{-1} \Rightarrow \boxed{R_{Q2} = \frac{1}{g_{m2}} \parallel R_{\pi 2}}$$

• A_{v2} e R_{in}



$$\Rightarrow v_x = R_{eq} \cdot i_{eq} = R_{eq} \cdot \left(\frac{v_{\pi 1}}{R_{\pi 1}} + g_{m1} v_{\pi 1} \right)$$

$$v_x = v_{\pi 1} R_{eq} \left(\frac{1}{R_{\pi 1}} + g_{m1} \right)$$

$$v_{in} = v_{\pi 1} + R_{eq} \cdot i_{eq} = v_{\pi 1} + v_{\pi 1} R_{eq} \left(\frac{1}{R_{\pi 1}} + g_{m1} \right)$$

$$v_{in} = v_{\pi 1} \cdot \left[1 + R_{eq} \left(\frac{1}{R_{\pi 1}} + g_{m1} \right) \right]$$

$$\frac{v_x}{v_{in}} = \frac{R_{eq} \left(\frac{1}{R_{\pi 1}} + g_{m1} \right)}{1 + R_{eq} \left(\frac{1}{R_{\pi 1}} + g_{m1} \right)} \Rightarrow \frac{v_x}{v_{in}} = \frac{R_{eq}}{R_{\pi 1} + R_{eq}}$$

$$\frac{v_x}{v_{in}} = \frac{RE \parallel \frac{1}{g_{m2}} \parallel r_{\pi 2}}{(\underbrace{r_{\pi 1} \parallel g_{m1}}_{\sim \frac{1}{g_{m1}}}) + RE \parallel \frac{1}{g_{m2}} \parallel r_{\pi 2}}$$

$$A_v = \frac{v_{out}}{v_x} \cdot \frac{v_x}{v_{in}} \Rightarrow A_v \approx g_{m2} R_C \cdot \frac{RE \parallel \frac{1}{g_{m2}} \parallel r_{\pi 2}}{\frac{1}{g_{m1}} + RE \parallel \frac{1}{g_{m2}} \parallel r_{\pi 2}}$$

• $i_{in} = \frac{v_{in}}{r_{in}}$

• $i_{in} = \frac{v_{in}}{r_{in}} = r_{\pi 1} \left[1 + \text{Re}q \left(\frac{1}{r_{\pi 1}} + g_{m1} \right) \right] = r_{\pi 1} + \text{Re}q \left(1 + r_{\pi 1} g_{m1} \right)$

$$r_{in} = r_{\pi 1} + \text{Re}q(\beta + 1) \Rightarrow r_{in} = r_{\pi 1} + (\beta + 1) \cdot \left(RE \parallel \frac{1}{g_{m2}} \parallel r_{\pi 2} \right)$$

• Rout

$$v_{in} = 0 \Rightarrow v_{\pi 1} = 0 \Rightarrow g_{m1} v_{\pi 1} = 0 \Rightarrow v_{\pi 2} = 0 \Rightarrow g_{m2} v_{\pi 2} = 0 \Rightarrow R_{out} = R_C$$