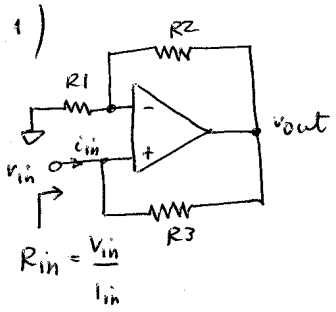
ELECTRÓNICA I - EXAME 23.01.2001 CORRECÇÃO

1)



OP AMP ideal $v_+ = v_-$ $\quad i_- = i_+ = 0$

$$i_{in} = \frac{v_{in} - v_{out}}{R3} \qquad (1)$$

$$v_- = v_{in} = \frac{R1}{R1+R2}\, v_{out}$$

logo $\quad v_{out} = \left(1 + \frac{R2}{R1}\right) v_{in}$

Substituindo em (1)

$$i_{in} = \frac{v_{in} - \left(1 + \frac{R2}{R1}\right) v_{in}}{R3}$$

$$i_{in} = -\frac{1}{R3}\,\frac{R2}{R1}\, v_{in}$$

logo $\quad R_{in} = \frac{v_{in}}{i_{in}} = -\frac{R1}{R2}\, R3$

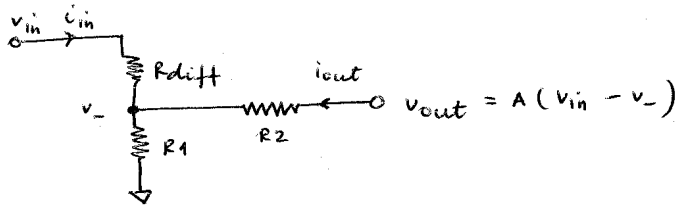
$R1 = 10\,K$

$R2 = 5k$

$R3 = 1K$

logo $R_{in} = -2k\,\Omega$

2)



$$v_- = R1\,(i_{in} + i_{out})$$

$$v_- = R_1 \left(\frac{v_{in} - v_-}{R_{diff}} + \frac{v_{out} - v_-}{R2}\right)$$

$$v_- \left(1 + \frac{R1}{R_{diff}} + \frac{R1}{R2}\right) = \frac{R1}{R_{diff}} v_{in} + \frac{R1}{R2} v_{out}$$

mas $\quad v_- = -\frac{v_{out}}{A} + v_{in}$

substituindo

$$\left(1 + \frac{R1}{R2}\right) v_{in} = \left[\frac{1}{A}\left(1 + \frac{R1}{R_{diff}} + \frac{R1}{R2}\right) + \frac{R1}{R2}\right] v_{out}$$

logo $\quad A_V = \frac{v_{out}}{v_{in}} = \frac{1 + \frac{R1}{R2}}{\frac{1}{A}\left(1 + \frac{R1}{R_{diff}} + \frac{R1}{R2}\right) + \frac{R1}{R2}} = \frac{1 + \frac{1}{9}}{10^{-4}\left(1 + 0.1 + \frac{1}{9}\right) + \frac{1}{9}}$

Fazendo $A \to \infty$

$$A_V = \frac{R2}{R1} + 1 = 10$$

$R_{in} = \frac{v_{in}}{i_{in}}$

$$v_{in} = R_{diff}\, i_{in} + R_1 (i_{in} + i_{out}) \qquad (1)$$

$$\text{mas} \quad i_{out} = \frac{A(v_{in} - v_-) - v_-}{R2}$$

$$\text{mas} \quad v_- = R_1 (i_{in} + i_{out})$$

substituindo

$$i_{out} = \frac{A}{R2} v_{in} - \frac{1}{R2}(1+A)\, v_-$$

$$i_{out} = \frac{A}{R2} v_{in} - \frac{R1}{R2}(1+A)(i_{in} + i_{out})$$

$$i_{out}\left(1 + \frac{R1}{R2}(1+A)\right) = \frac{A}{R2} v_{in} - \frac{R1}{R2}(1+A)\, i_{in}$$

logo $\quad i_{out} = \left[\frac{A}{R2} v_{in} - \frac{R1}{R2} i_{in}(1+A)\right] / \left[1 + \frac{R1}{R2}(1+A)\right]$

substituindo em (1)

$$v_{in} = \left[R_{diff} + R_1 - \frac{R_1 \frac{R_1}{R_2}(1+A)}{1 + \frac{R_1}{R_2}(1+A)} \right] i_{in} + \frac{\frac{A R_1}{R_2} v_{in}}{1 + \frac{R_1}{R_2}(1+A)}$$

$$\left[1 - \frac{\frac{A R_1}{R_2}}{1 + \frac{R_1}{R_2}(1+A)} \right] v_{in} = \left[R_{diff} + R_1 - \frac{R_1 \frac{R_1}{R_2}(1+A)}{1 + \frac{R_1}{R_2}(1+A)} \right] i_{in}$$

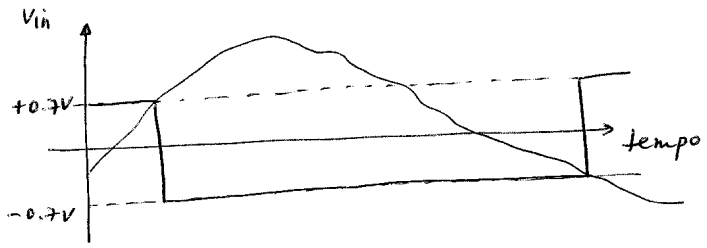
Fazendo $A \to \infty$ vem

$$v_{in} =$$

3) A saída do OP tem apenas dois valores: +15 V e -15V

(i) Se V_{out} (OP AMP) = +15V D2 conduz e $V_+ = 0.7$ V

(ii) Se V_{out} (OP AMP) = -15 V D1 conduz e $V_+ = -0.7$V



4) $$I_D = \frac{1}{2} \mu C_{ox} \frac{W}{L} (V_{GS} - V_T)^2$$

mas $V_{GS} = V_G - V_S = 0 - (R_S I_D + V_{SS})$

logo $$I_D = \frac{1}{2} \mu C_{ox} \frac{W}{L} (- R_S I_D - V_{SS} - V_T)^2$$

Substituindo

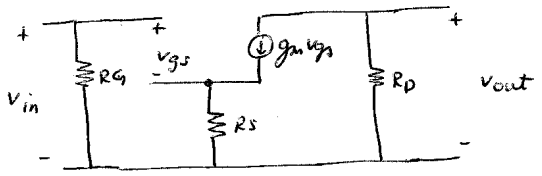
$$I_D = \frac{0.5}{2} \times 10^{-3} \left(-6 \times 10^3 I_D + 15 - 2 \right)^2$$

$$4 \times 10^3 I_D = \left(13 - 6 \times 10^3 I_D \right)^2$$

$$I_D = \begin{cases} 0.017\ A \longrightarrow V_S = 0.017 \times 6 \times 10^3 - 15 = -4.7\ V \quad OK \\ 0.027\ A \longrightarrow V_S = 0.027 \times 6 \times 10^3 - 15 = +1.2\ V \quad \text{IMPOSSÍVEL} \end{cases}$$

logo $I_D = 1.7\ mA$, $V_{GS} = 4.7\ V$, $V_{DS} = 7.7\ V$

4b)



$$v_{out} = -g_m v_{gs} R_D$$

mas $v_{in} = v_{gs} + R_S g_m v_{gs}$

$$v_{in} = (1 + R_S g_m) v_{gs}$$

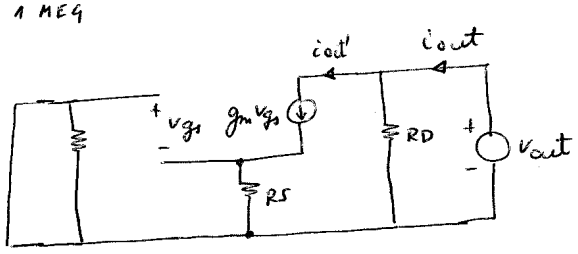
logo $$v_{out} = -\frac{g_m R_D}{1 + R_S g_m} v_{in}$$

$$A_V = -\frac{g_m R_D}{1 + R_S g_m} \quad \text{com} \quad g_m = \frac{\partial I_D}{\partial V_{GS}} = \frac{2 I_D}{(V_{GS} - V_T)}$$

$$A_V = -\frac{1.26 \times 10^{-3} \times 10^4}{1 + 1.26 \times 10^{-3} \times 6 \times 10^3} = -1.47 \qquad g_m = \frac{2 \times 1.7 \times 10^{-3}}{2.7} = 1.26 \times 10^{-3}\ A/V$$

4c) $R_{in} = R_G = 1\,M\Omega$

4d)



$R_{out} = R_D \parallel R'_{out}$

com $R'_{out} = \dfrac{v_{out}}{i'_{out}}$

mas $i'_{out} = g_m v_{gs}$

mas $v_{gs} = -R_S\, i'_{out}$

substituindo acima vem

$i'_{out} = -g_m R_S\, i'_{out}$

logo $i'_{out} = 0$

logo $R'_{out} =$ infinito

5a)

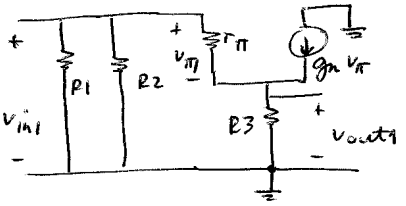
$V_{B1} = \dfrac{R2}{R1+R2} V_{CC} = 12\,V$

$V_{E1} = V_{B2} = 11.3\,V \longrightarrow I_{E1} = \dfrac{V_{E1}}{R3} = 2\,mA$

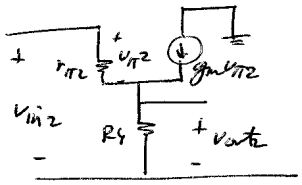
$V_{E2} = 10.6\,V \longrightarrow I_{E2} = \dfrac{V_{E2}}{R4} = 7\,mA$

5a)

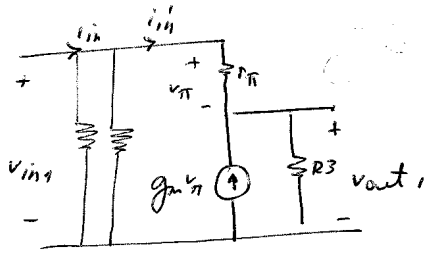
1° andar



2° andar



circuito equivalente



$v_{out} = R3\,(g_{m1} v_{\pi 1} + i'_{in})$

mas $i'_{in} = \dfrac{v_{\pi 1}}{r_\pi}$

logo

$v_{out} = R3\left(g_{m1} + \dfrac{1}{r_\pi}\right) v_{\pi 1}$

por outro lado

$v_{in\,1} = v_{\pi 1} + v_{out}$

logo $v_{\pi 1} = (v_{in\,1} - v_{out\,1})$

Fica $v_{out\,1}\left\{1 + \dfrac{R3}{r_{\pi 1}} + R3\,g_{m1}\right) = \left(R3\,g_m + \dfrac{R3}{r_\pi}\right) v_{in\,1}$

logo $A_{v1} = \dfrac{v_{out\,1}}{v_{in\,1}} = \dfrac{R3\,g_{m1} + \frac{R3}{r_\pi}}{1 + R3\,g_{m1} + \frac{R3}{r_\pi}}$

com $g_{m1} = \dfrac{\partial I_{c1}}{\partial v_{BE}} = \dfrac{I_{c1}}{V_T}$

e $r_{\pi 1} = \dfrac{V_T}{I_{B1}} = \beta / g_{m1}$

$$A_{v2} = \frac{v_{out2}}{i_{out2}} = \frac{R4\, g_{m2} + \frac{R4}{r_{\pi 2}}}{1 + R4\, g_{m2} + \frac{R4}{r_{\pi 2}}} \qquad \text{com } g_{m2} = \frac{I_{C2}}{V_T}$$

$$\text{e } r_{\pi 2} = \frac{V_T}{I_{B2}} = \frac{\beta}{g_{m2}}$$

5-b)

$$R_{in1} = R4 \,||\, R2 \,||\, R'_{in1}$$

$$R'_{in1} = \frac{v_{in1}}{i'_{in1}}$$

mas $v_{in1} = r_\pi\, i_{in1} + (i_{in1} + g_m v_\pi)\, R3$

$v_{in1} = r_\pi\, i_{in1} + (i_{in1} + g_m r_\pi\, i_{in1})\, R3$

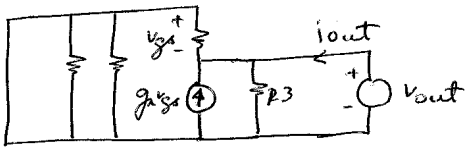
$v_{in1} = (r_\pi + R3 + g_m r_\pi R3)\, i_{in1}$

logo $R'_{in1} = r_\pi + (1 + g_m r_\pi) R3$

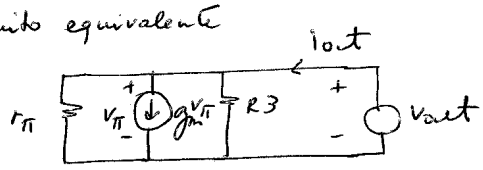
logo $R_{in1} = R1 \,||\, R2 \,||\, [r_{\pi 1} + (1 + g_{m1} r_{\pi 1})] R3$

logo $R_{in2} = r_{\pi 2} + (1 + g_{m2} r_{\pi 2}) R4$

5-c)



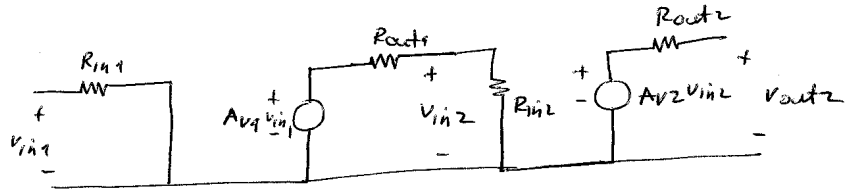
circuito equivalente



logo $R_{out1} = R3 \,||\, R_{\pi 1} \,||\, \frac{1}{g_{m1}}$

logo $R_{out2} = R4 \,||\, r_{\pi 2} \,||\, \frac{1}{g_{m2}}$

circuito equivalente total



ganho total

$$A_V = A_{V1} \times A_{V2} \times \frac{R_{in2}}{R_{out1} + R_{in2}}$$

Resistência de entrada

$$R_{in} = R_{in1}$$

Resistência de saída

$$R_{out} = R_{out2}$$