Circuitos Eletrônicos Analógicos
2a Avaliação - 04/07/16

Sem Consulta - Duração: 2h 40min

Nome: ______________________________

Justifique sucintamente as passagens
A interpretação é parte integrante da questão

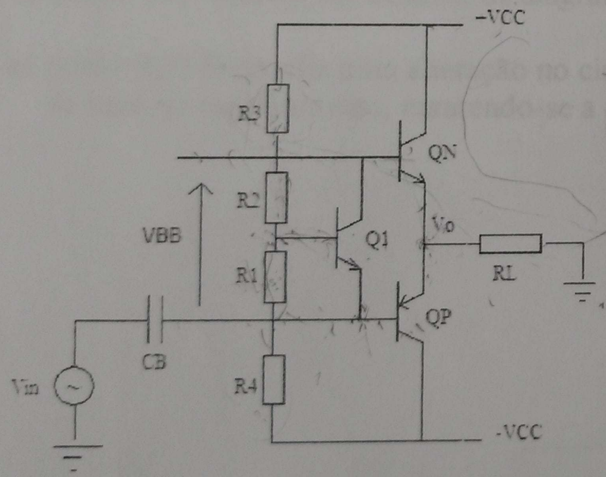
Questão 1 ***(Valor 3.5)*** **:** Considere os parâmetros listados. Impõe-se $V_o \leq 3.0V$ à saída.

a) *(valor 1.25)* Justificando, projetar o estágio classe-AB linear da Figura 1, tendo como condição quiescente $I_{QN} = I_{QP} = 2.5mA$ e $I_{Q1} = 1mA$.

b) *(valor 1.0)* Qual a eficiência do estágio, na condição $V_o = 1.75V$?

c) *(valor 0.5)* qual o impacto no valor calculado em b) ao considerar-se a dissipação nos componentes do circuito multiplicador de VBE?

d) *(valor 0.75)* Estimar a resistência à entrada do estágio, no ponto máximo do semiciclo positivo de Vin.



$Is_{\_QN} = 0.45pA$
$Is_{\_QP} = 0.12pA$
$Is_{\_Q1} = 0.07pA$

RL = 4 Ohms
$\beta_{\_QN} = 200$
$\beta_{\_QP} = 150$
$\beta_{\_Q1} = 200$

VCC/-VCC = +5/-5 V
V_T = 25mV

Figura 1

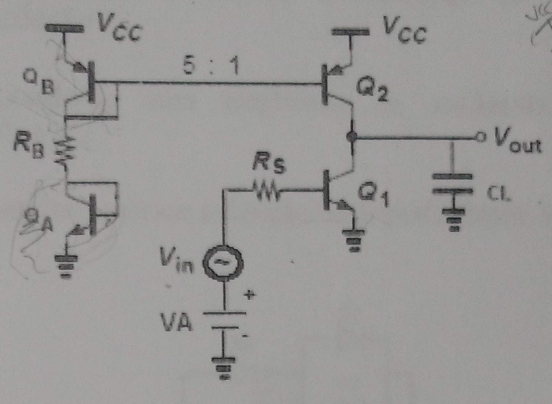
$V_{BB} = V_{BE1}\left(1 + \frac{R_2}{R_1}\right)$

$P = \frac{1}{2}\frac{(V_o)^2}{R}$

$0,75 = \frac{4}{\cancel{16}}$

$\eta = \frac{P_U}{P_T}$

Questão 2: (*Valor 3.25*) Considere $|V_A|_{NPN} = |V_A|_{PNP} = 20V$, $V_{CC} = 3.3V$, $|V_{BE}| = 0.6V$, $\beta_{NPN} = \beta_{PNP} = 150$, $R_B = 2K\Omega$, $C\pi = 8pF$, $C\mu = 12pF$, $CL = 1.5pF$, $V_T = 25mV$



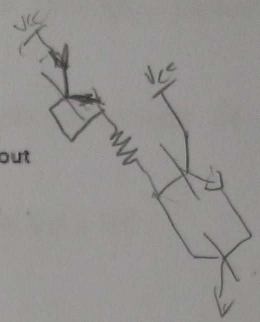


Figura 2

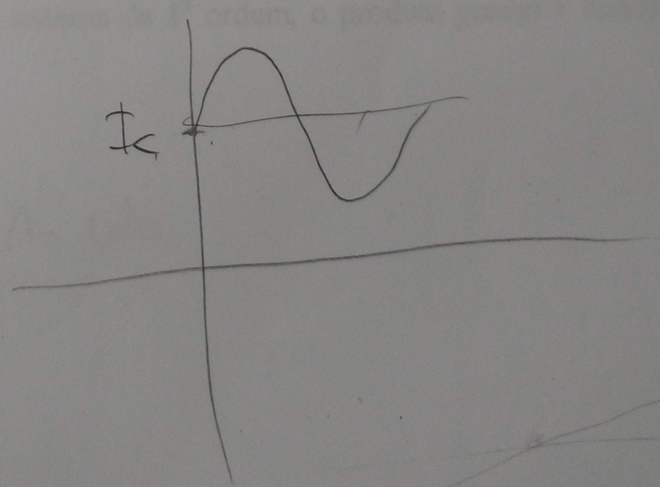
a) (*valor 0.75*) Que valor de Rs impõe $|Vout/Vin| = 110$ em médias frequências? Qual o valor necessário de V_A?

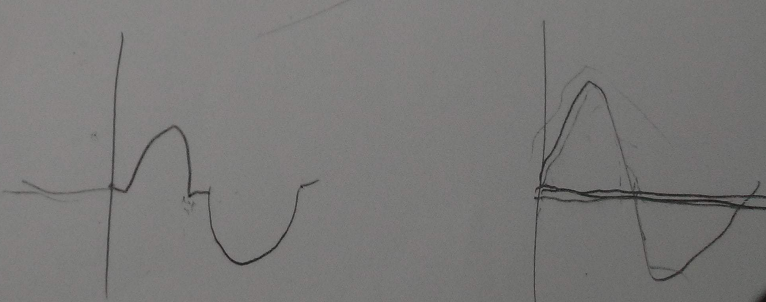
b) (*valor 0.75*) Determine, numericamente, o polo à entrada do amplificador

c) (*valor 0.75*) Determine, numericamente, o polo à saída do amplificador

d) (*valor 0.5*) Esboce, em detalhe, os diagramas de Bode (ganho e fase) do circuito.

e) (*valor 0.5*) Proponha uma alteração no circuito que minimize a influência da corrente de base no espelhamento, mantendo-se a corrente original em Q_2.



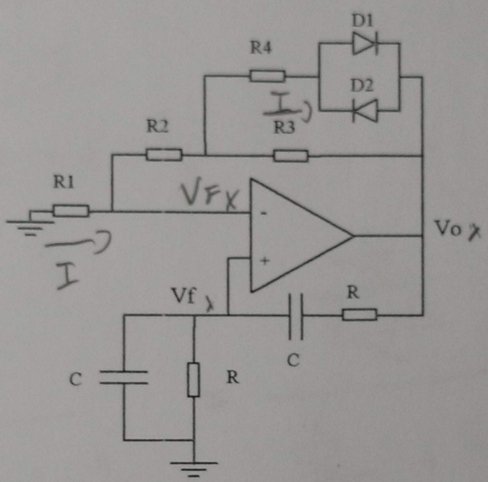


Questão 3: ***(Valor 2.25)*** Considere o oscilador linear da Figura 3. Admitindo amplificador operacional ideal, diodos com $V\gamma = 0.6V$ e $R1 = 3K\Omega$.

a) (*valor 0.75*) Justificando, determine a condição de oscilação estável e a frequência de oscilação.

b) (*valor 1.0*) Impondo-se uma amplitude de oscilação controlada de 1.0V, dimensione R_2, R_3 e R_4.

c) (*valor 0.5*) Em detalhe, esboce a função de transferência Vo x Vf.



$R = 10K\Omega$
$C = 4.7nF$

$$\left(\frac{e_1}{R_1}\right)^2 = \left(\frac{E_1}{R_2}\right)^2$$

$E_1^2 =$

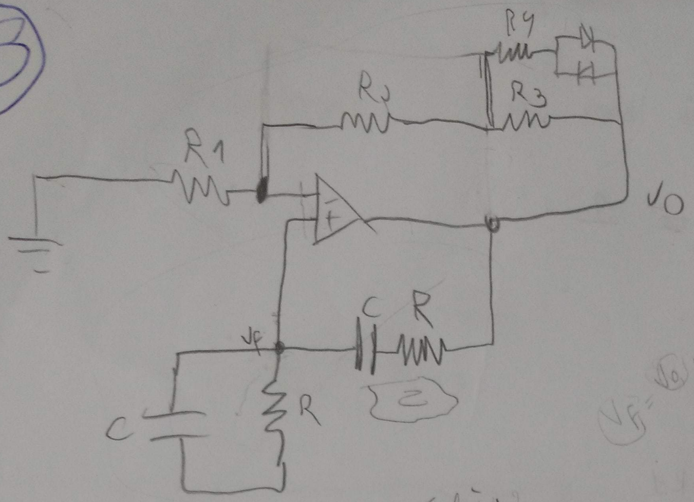
Figura 3

Questão 4: ***(Valor 1.0)*** Demonstre que, em um sistema com realimentação negativa, em que o circuito ativo corresponde a um sistema de 1ª ordem, o produto *ganho* x *banda passante* = constante.

$$\frac{x}{y} = \frac{A_0}{1 + \frac{s}{\omega_0}} \qquad GBW = A_0 \omega_0$$

$$\frac{x}{y} = \frac{A}{1 + \beta A} = \frac{\frac{A_0}{1 + \frac{s}{\omega_0}}}{1 + \frac{A_0}{1 + \frac{s}{\omega_0}}} =$$

③



$$\frac{Y(s)}{X(s)} = \frac{H(s)}{1-L(s)}$$

$V_f = V_o \cdot \frac{X}{X+Y}$

Seleção

$$L(s) = \left(1 + \frac{R_2 + R_3}{R_1}\right) \cdot \frac{C//R}{C//R + C+R}$$

Atin.

$$C//R = \frac{C \cdot R}{C+R} = \frac{\frac{1}{sC} \cdot R}{\frac{1}{sC} + \frac{R}{1}}$$

$$\frac{R}{sC} \cdot \frac{sC}{sCR+1}$$

$$\frac{C//R}{C//R \quad C+R} = \frac{\frac{\frac{R}{sC}}{\frac{1}{sC}+R}}{\frac{\frac{R}{sC}}{\frac{1}{sC}+R} + R + \frac{1}{sC}} = \frac{\frac{\frac{R}{\cancel{sC}}}{\frac{1+sRC}{\cancel{sC}}}}{\frac{\frac{R}{\cancel{sC}}}{\frac{1+sRC}{\cancel{sC}}} + R + 1/sC} = \frac{\frac{R}{1+sRC}}{\frac{R}{1+sRC} + R + 1/sC}$$

$$= \frac{R}{\cancel{1+sRC}} \cdot \frac{\cancel{1+sRC}}{R + \left(R + \frac{1}{sC}\right)\left(1+sRC\right)} = \frac{R}{R + R + \frac{1}{sCR} + sR^2C + R}$$

$\div \frac{1/R}{}$

$$L(s) = \left(1 + \frac{R_2 + R_3}{R_1}\right) \frac{1}{3 + sRC + \frac{1}{sCR}}$$

Na frequencia de oscilação

$$sRC = -\frac{1}{sC}$$

$$f = \frac{1}{2\pi RC} = \frac{1}{2\pi (10k)(4{,}7 \cdot 10^{-9})} = 3{,}38\,kHz$$

(b) $\boxed{D_1 \text{ OFF } D_2 \text{ OFF}}$

$$|Av| = \left(1 + \left(\frac{R_3 + R_2}{R_1}\right)\right)\left(\frac{1}{3}\right) = 1 \ (+10\%)$$

$$1 + \frac{R_3 + R_2}{R_1} = 3.3$$

$$R_2 + R_3 = 2.3 R_1$$

$\boxed{D_1 \text{ ON } \quad D_2 \text{ ON}}$

$$|Av| = \left(1 + \frac{R_3 // R_4 + R_2}{R_1}\right)\left(\frac{1}{3}\right) = 1 \ (-10\%)$$

$$1 + \frac{R_3 // R_4 + R_2}{R_1} = 2,7$$

$$R_3 // R_4 + R_2 = R_1 (1,7)$$

$V_y = 0,6V \qquad R_1 = 3K\Omega \qquad V_{0x} = 1V$

$$\boxed{V_{Fx} = \frac{V_{0x}}{3,3}}$$

$$\boxed{I = \frac{V_{Fx}}{R_1} = \frac{V_y}{R_3}}$$

$$\frac{R_3}{R_1} = \frac{V_y}{\frac{V_{0x}}{3.33}} - R_3 = R_1 \frac{V_y}{V_{0x}} 3.3 = 3K\left(\frac{0,6}{1}\right) 3.3 = 5,94K\Omega$$

$$1 + \frac{R_3 + R_2}{R_1} = 3,3$$

$$R_2 = 2,3 R_1 - R_3$$

$$R_2 = 960\ \Omega$$

$$1 + \frac{R_3 // R_4 + R_2}{R_1} = 2,7$$

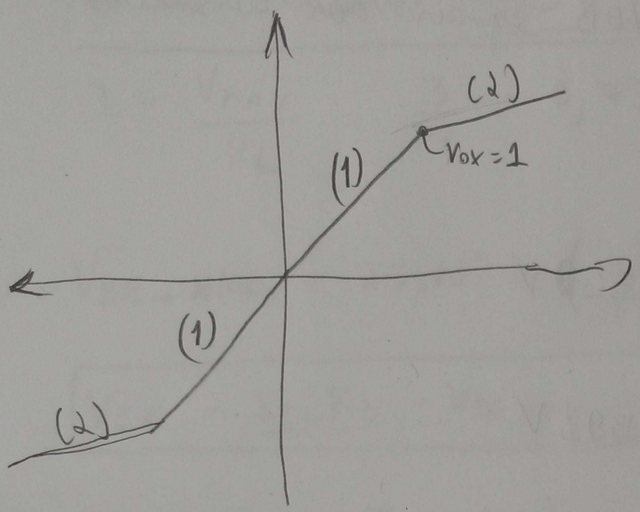
$$\frac{R_3 \cdot R_4}{R_3 + R_4} = 1,7 R_1 - R_2$$

$$5,94k R_4 = 4,14K (R_3 + R_4)$$

$$1,8K R_4 =$$

$$\boxed{R_4 = 13,662K\Omega}$$

3) Configuração Ampop não inversor

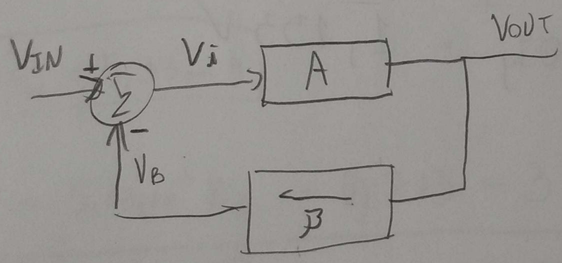


(1) $|A_V| = 1 + \frac{R_2 + R_3}{R_4}$

(2) $|A_V| = \frac{1 + R_2 + R_3 // R_4}{R_4}$

Precisa de mais algo ?

4



$\begin{cases} V_i = V_{IN} - V_B \\ V_{OUT} = V_i A \end{cases}$ $\quad \{ V_B = B V_{OUT}$

$A_f \quad \frac{V_{OUT}}{A} = V_{IN} - B V_{OU}$

$V_{OUT}\left(\frac{1}{A} + B\right) = V_{IN}$

Malha fechada $\frac{V_{OUT}}{V_{IN}} = \frac{1}{\frac{1 + BA}{A}} = \frac{A_0}{1 + B A_0}$

Aberta $\frac{V_{OUT}}{V_{IN}} = \frac{A_0}{1 + \left(\frac{s}{\omega_0}\right)}$

$\boxed{GBW = A_0 \omega_0}$

Malha fechada

$$\frac{Y}{X}(s) = \frac{\frac{A_0}{1 + \frac{s}{\omega_0}}}{1 + B\left(\frac{A_0}{1 + \frac{s}{\omega_0}}\right)} = \frac{\frac{A_0}{\frac{\omega_0 + s}{\omega_0}}}{1 + B \frac{A_0}{\frac{\omega_0 + s}{\omega_0}}} = \frac{\frac{A_0 \omega_0}{\omega_0 + s}}{1 + B \frac{A_0 \omega_0}{\omega_0 + s}} = \frac{A_0 \omega_0}{\omega_0 + s + B A_0 \omega_0}$$

$$= \frac{A_0 + \omega_0}{s + \omega_0(1 + B A_0)} = \frac{\frac{A_0}{(1 + B A_0)}}{1 + \frac{s}{\omega_0(1 + BA)}}$$

$GBW = \frac{A_0}{\cancel{(1 + B A_0)}} \omega_0 \cancel{(1 + B A_0)}$

$\boxed{GBW = A_0 W_0}$

Questão 1

Passo #1 Determina VBB a partir das curvas dos Transistores.

$$V_{BE} = V_T \ln\left(\frac{I_C}{I_S}\right)$$

$$V_{BE_{Q\_N}} = 25m \ln\left(\frac{2,5 \times 10^{-3}}{0,45 \times 10^{-12}}\right) = 0,560\,V$$

$$V_{BE_{Q\_P}} = 25 \ln\left(\frac{2,5 \times 10^{-3}}{0,12 \times 10^{-12}}\right) = 0,593\,V$$

$$V_{BE_{Q\_1}} = 25 \ln\left(\frac{1 \times 10^{-3}}{0,07 \times 10^{-12}}\right) = 0,584\,V$$

$$V_{BB} = V_{BE_{Q\_N}} @ I_q + V_{BE_{Q\_P}} @ I_q = 1,153\,V$$

$$\boxed{V_{BB} = V_{BEQ1}\left(1 + \frac{R_2}{R_1}\right)}$$

$$\frac{1,153}{0,584} - 1 = \frac{R_2}{R_1} \qquad \boxed{0,97 R_1 = R_2}$$

$$\boxed{R_1 = 1K}$$

logo

$$\boxed{R_2 = 970\,\Omega}$$

Parte 2 $\boxed{\text{Determinar } R3}$ $\boxed{\text{Maxima excursão Positiva}}$

Maxima excursão $\boxed{V_0 \leq 3V}$

$$I = \frac{V_{MAX}}{R_L} = \frac{3}{4} = 0,75\,A$$

$$V_{BE\_NMAX} = 25\times10^{-3} \ln\left(\frac{0,75}{0,45\times10^{-12}}\right) = 0,703\,V$$

$$\boxed{V_{CC} - I_{R_3} R_3 - V_{BE\_NMAX} - V_0 = 0}$$

$$I_{R3_M} = I_{R2} + I_{Q1} + I_{BQN_{MAX}}$$

$$I_{R3_M} = \frac{V_{R2}}{R_2} + I_{Q1} + \frac{I_{CQNMAX}}{\beta} = \frac{0,569}{970} + 1\times10^{-3} + \frac{0,75}{200} = 5,33\,mA$$

$$\boxed{I_{R3_M} = 5,33\,mA}$$

$$5 - 5,33\times10^{-3} R_3 - 0,703 - 3 = 0$$

$$\boxed{R_3 = \frac{1,297}{5,33\times10^{-3}} = 243,3\,\Omega}$$

Parte 3 Determinar R4 $\boxed{\text{Maxima excursão Negativa}}$

mesmo raciocínio de antes

$$V_{BE\_PMAX} = 25\times10^{-3} \ln\left(\frac{0,75}{0,12\times10^{-12}}\right) = 0,736\,V$$

$$I_{R4} = \frac{V_{BEQ1}}{R_1} + I_{Q1} + \frac{I_C}{\beta} = \frac{0,584}{1K} + 1\times10^{-3} + \frac{0,75}{150} = 6,54\,mA$$

$$V_{CC} - I_{R4} R_4 - |V_{BE\_PMAX}| - |V_{OM}| = 0$$

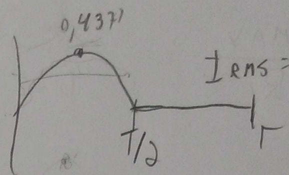
$$5 - 6,54\times10^{-3} R_4 - 0,736 - 3 = 0$$

$$\boxed{R_4 = 193,27\,\Omega}$$

(b)

$$P_L = \frac{1}{2}\frac{(\hat{V}_o)^2}{R_L} = \frac{1}{2}\frac{(1,75)^2}{4} = 0,382\ W$$

$$I_S = \frac{1}{T}\int_0^{T} \frac{\hat{V}_o}{R_L} \sin(2\pi t/T)\,dt = \frac{\hat{V}_o}{R_L}\frac{1}{\cancel{T}}\frac{\cancel{T}}{2\pi}\cdot 2 = \frac{1}{\pi}\frac{\hat{V}_o}{R_L}$$



$$I_{RMS} = \frac{0,437}{\sqrt{2}}$$

$$P_S = 2\,V_{CC}\,I_S = \frac{2\,V_{CC}\,\hat{V}_o}{\pi\,R_L}$$

$$\eta = \frac{P_L}{P_S} = \frac{1}{2}\frac{\hat{V}_o^2}{R_L}\frac{\pi R_L}{2 V_{CC}\hat{V}_o} = \frac{\pi}{4}\frac{\hat{V}_o}{V_{CC}} = \frac{\pi}{4}\frac{1,75}{5} = 0,27$$

27,4%

(c) Considerando

$$I_{bias} = \frac{2\,V_{CC}}{R_{bias}} = \frac{2\cdot 5}{1K+960+243+193} = 4,1\ mA$$

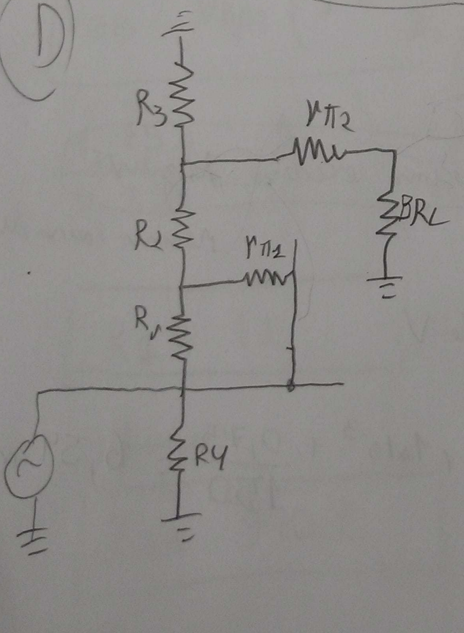
$$\boxed{P_L = 0,383\ W}$$

$$P_{S_N} = 2V_{CC}(I_S + I_{BIAS}) = 1,43$$

$$\eta = \frac{P_L}{P_{S_N}} = 26,6\ \%$$

Influencia de 1% no rendimiento

(D)



$$\boxed{r_{in} = R_4 // (R_1 // r_{\pi 1} + R_2 + (R_3 // (r_{\pi 2} + \beta R_L)))}$$

Questão 2

Determinando I_{QB}

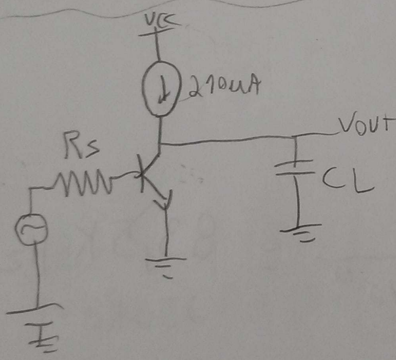
$$\boxed{V_{CC} - V_{BE_{QB}} - V_{RB} - V_{BE_{QA}} = 0}$$

$$I_{R3} \cdot R_3 = V_{CC} - 2V_{BE} \Rightarrow I_{R3} = \frac{(3{,}3 - 1{,}2)}{2k} = 1{,}05\,mA$$

$$V_{BE_{QB}} = V_{BE_{Q2}}$$

$$V_T \ln\left(\frac{I_{Q3}}{I_{SB}}\right) = V_T \ln\left(\frac{I_{Q2}}{I_{S2}}\right) \qquad \boxed{I_{SB} = 5 I_{S2}} \qquad \boxed{I_{Q3} \approx I_{R3}}$$

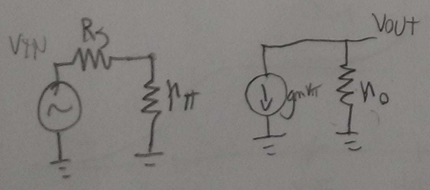
$$\frac{I_{R3}}{\cancel{I_{SB}}} = \frac{5 I_{Q2}}{\cancel{I_{SB}}} \qquad I_{Q2} = \frac{1{,}05\,mA}{5} = 210\,\mu A$$



$$\left\{ g_m = \frac{I_C}{V_T} \right. \quad \left\{ B r_e = r_\pi \right. \qquad \left\{ \begin{array}{l} g_m = \frac{210\times10^{-6}}{25\times10^{-6}} = 8{,}4\times10^{-3} \\ r_\pi = \frac{150}{8{,}4\times10^{-3}} = 17{,}85\,K\Omega \end{array} \right.$$

$$r_\pi = \frac{B}{g_m}$$

$$r_o \simeq \frac{|V_A|}{|I_C|} \simeq \frac{20}{210\times10^{-6}} = 95{,}23\,K\Omega$$



$$\left\{ \begin{array}{l} V_{IN} = I_\pi (R_S + r_\pi) \\ V_{OUT} = -g_m r_\pi I_\pi r_o \end{array} \right.$$

$$\frac{V_{OUT}}{V_I} = -\frac{g_m r_\pi r_o}{R_S + r_\pi} = -B \frac{r_o}{R_S + r_\pi}$$

$\rightarrow$ Para $|A_V| = 110$

$$110 = +B \frac{r_o}{R_S + r_\pi} = 150 \frac{95{,}23\times10^3}{R_S + 17{,}85\times10^3}$$

$$\boxed{R_S = 112\,K\Omega}$$

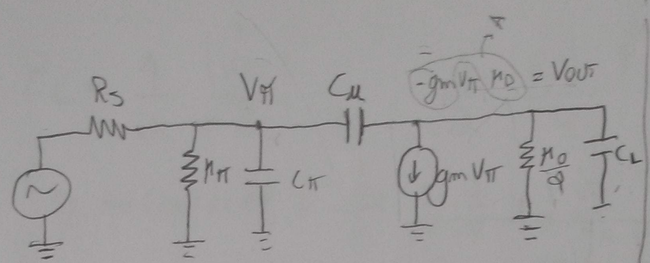
$$\boxed{V_A - V_{RS} - V_{BE} = 0}$$

$$V_A - \frac{I_C}{B} R_S - V_{BE} = 0$$

$$V_A = \frac{210\times10^{-6}}{150} \cdot 112K + 0{,}6$$

$$\boxed{V_A = 0{,}756\,V}$$

b)



$C_\mu = 12pF = 12\times10^{-12} F$

$C_1 = C_\mu(1 + g_m r_o)$ ~800

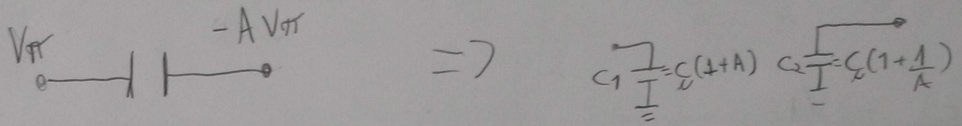
$\boxed{C_1 = 9,61\, nF}$

$C_2 = C_\mu(1 + \frac{1}{g_m r_o})$

$C_2 = 12,015\times10^{-12}\, pF$

$C_\pi = 8\, pF$

Teorema de Miller



b) Polo da entrada

$$f_c = \frac{1}{2\pi (R_s // r_\pi)(C_\pi + C_\mu(1+g_m r_o))} = \frac{1}{2\pi (15,39K)(9,618\times10^{-9})} = 1,075\,KHz$$

2,6 K

c) Polo da Saída

$$f_c = \frac{1}{2\pi\, r_o (C_2 + C_L)} = \frac{1}{2\pi (95,22K)(20,015\times10^{-12})} = \cancel{83,5\,K}\,Hz$$

250 k

D)