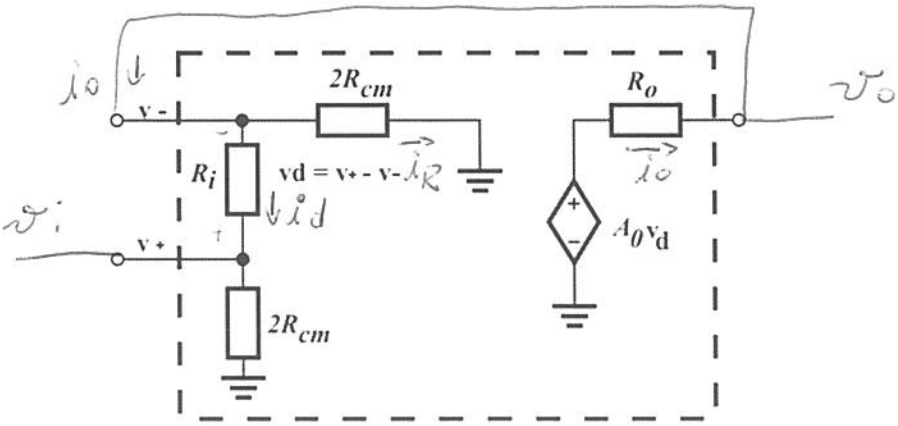
EE-530: - Eletrônica Básica I
Prova 3
Nome:____ **RA:**_______________

obs: Prova sem consulta. Pode usar calculadora. Respostas a lápis serão corrigidas, mas não aceito reclamação da correção das mesmas.

1) a) Deduza a fórmula do ganho de um buffer de tensão. Utilize o modelo do AMP. OP. não ideal da figura abaixo.

b) Dados R_i=2MΩ; $2R_{CM}$=400MΩ; R_o=75Ω; $A_0=10^5$, calcule o ganho de um buffer construído com o AMP. OP. não ideal.



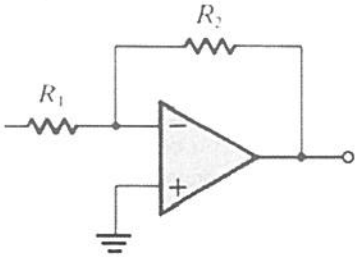
a)

- $v_+ = v_i$
- $v_- = v_o$
- ~~[illegible]~~ $v_o = A_o v_d - R_o i_o$ ($i_o \rightarrow i_d + i_R$; $v_d = v_+ - v_-$) ~~[illegible]~~
- ~~$v_o = A_o(v_+ - v_-) - R_o \frac{A_o v_d - v_o}{R_o} = A_o(v_+ - v_-) - A_o(v_+ - v_-)$ [illegible]~~
- $v_o = A_o v_d - R_o(i_d + i_R) = A_o v_d - R_o\left(-\frac{v_d}{R_i} + \frac{v_-}{2R_{cm}}\right)$ ($\rightarrow v_i$, $\rightarrow v_o$)
- $v_o = A_o(v_+ - v_-) + \frac{R_o(v_+ - v_-)}{R_i} - \frac{R_o v_-}{2R_{cm}}$
- $v_o = A_o v_i - A_o v_o + \frac{R_o}{R_i} v_i - \frac{R_o}{R_i} v_o - \frac{R_o v_o}{2R_{cm}}$
- $v_o\left(1 + A_o + \frac{R_o}{R_i} + \frac{R_o}{2R_{CM}}\right) = v_i\left(A_o + \frac{R_o}{R_i}\right)$

$$\Rightarrow \frac{v_o}{v_i} = \frac{A_o + \frac{R_o}{R_i}}{1 + A_o + \frac{R_o}{R_i} + \frac{R_o}{2R_{CM}}} \quad (\rightarrow A_v)$$

b) $A_v = \dfrac{10^5 + \frac{75}{2 \cdot 10^6}}{1 + 10^5 + \frac{75}{2 \cdot 10^6} + \frac{75}{400 \cdot 10^6}} \Rightarrow A_v = 9{,}9999 \cdot 10^{-1}$

2) Sabendo que f_0=1KHZ, determine a frequência de corte aproximada de um amplificador inversor. Dados: $A_0=10^7$; R2=100 kΩ; R1=10 kΩ.



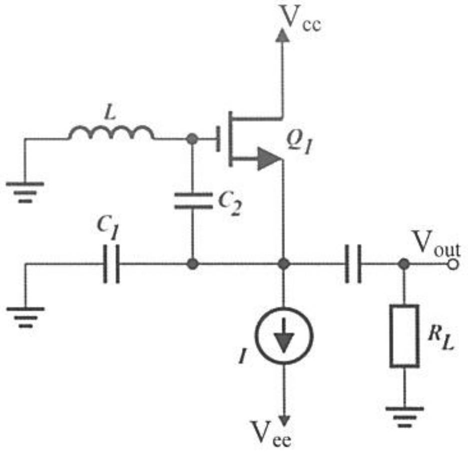
$$A_v = -\frac{R_2}{R_1} = \frac{-100}{10} \Rightarrow A_v = -10$$

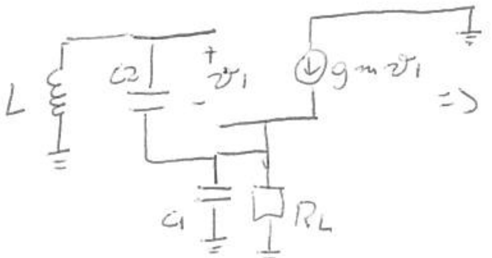
• Como a frequência é aproximada, podemos utilizar: $|A_v \cdot f_c| =$ constante

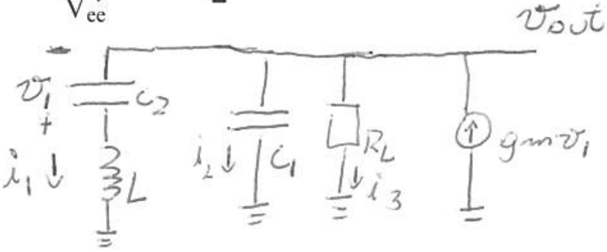
$$|A_0 \cdot f_0| = |A_v \cdot f_c|$$

$$\therefore 10^7 \cdot 10^3 = 10 \cdot f_c \Rightarrow \boxed{f_c = 10^9\ Hz}$$

3) Considere $\lambda=0$ e deduza a fórmula da frequência de oscilação e o valor de $g_m R$, de modo que ocorra oscilação.







- $i_1 = \dfrac{V_{out}(s)}{sL + \frac{1}{sC_2}} = \dfrac{V_{out}(s)}{\frac{s^2LC_2+1}{sC_2}} \Rightarrow \boxed{i_1 = \dfrac{V_{out}(s)\cdot sC_2}{s^2LC_2+1}}$

- $i_2 = \dfrac{V_{out}(s)}{\frac{1}{sC_1}} \Rightarrow \boxed{i_2 = sC_1 V_{out}(s)}$

- $\boxed{i_3 = \dfrac{v_{out}}{R_L}}$

- $v_1 = -(sC_2)^{-1} i_1 = -(sC_2)^{-1} \dfrac{V_{out}(s)\cdot sC_2}{s^2LC_2+1} \Rightarrow \boxed{\dfrac{v_1}{V_{out}(s)} = \dfrac{-1}{s^2LC_2+1}} \rightarrow B(s)$

- $g_m v_1 = i_1 + i_2 + i_3 \Rightarrow g_m v_1 = V_{out}(s)\dfrac{sC_2}{s^2LC_2+1} + sC_1 V_{out}(s) + \dfrac{v_{out}}{R_L} \Rightarrow \dfrac{v_{out}}{v_1} = g_m \dfrac{1}{\frac{sC_2}{s^2LC_2+1} + sC_1 + \frac{1}{R_L}}$

$$\Rightarrow \frac{v_{out}}{v_1} = \frac{g_m}{\frac{sR_LC_2 + sC_1R_L(s^2LC_2+1) + (s^2LC_2+1)}{R_L(s^2LC_2+1)}} \Rightarrow \frac{V_{out}(s)}{v_1} = \frac{g_m R_L(s^2LC_2+1)}{s^3LC_1C_2R_L + s^2LC_2 + s(R_LC_2+C_1R_L)}$$

$$\Rightarrow \boxed{\frac{V_{out}(s)}{v_1} = \frac{g_m R_L(s^2LC_2+1)}{s^3LC_1C_2R_L + s^2LC_2 + sR_L(C_2+C_1) + 1}} \rightarrow A(s)$$

- $L(s) = A(s)\cdot B(s) = 1 \Rightarrow L(s) = \dfrac{-1}{s^2LC_2+1} \cdot \dfrac{g_m R_L(s^2LC_2+1)}{s^3LC_1C_2R_L + s^2LC_2 + sR_L(C_2+C_1) + 1}$

$$L(s) = \frac{-g_m R_L}{s^3 L C_1 C_2 R_L + s^2 L C_2 + s R_L (C_1 + C_2) + 1} = 1$$

Critério de Oscilação

$$L(j\omega_0) = \frac{-g_m R_L}{-j\omega_0^3 L C_1 C_2 R_L - \omega_0^2 L C_2 + j \omega_0 R_L (C_1 + C_2) + 1} = 1$$

$$L(j\omega_0) = \frac{-g_m R_L}{j\left[R_L \omega_0 (C_1 + C_2) - \omega_0^3 L C_1 C_2 R_L\right] - L\omega_0^2 C_2 + 1} = 1$$

$$L(j\omega_0) = \frac{-g_m R_L}{j R_L \left[\omega_0 (C_1 + C_2) - \omega_0^3 L C_1 C_2\right] - L\omega_0^2 C_2 + 1} = 1$$

- $\angle L(j\omega_0) = 0 \Rightarrow \omega_0 (C_1 + C_2) - \omega_0^3 L C_1 C_2 = 0$

$$\omega_0 \left[C_1 + C_2 - \omega_0^2 L C_1 C_2\right] = 0$$

$$C_1 + C_2 - \omega_0^2 L C_1 C_2 = 0$$

$$\Rightarrow \boxed{\omega_0 = \sqrt{\frac{C_1 + C_2}{L C_1 C_2}}}$$

- $|L(j\omega_0)| = 1 \Rightarrow \frac{-g_m R_L}{-L \omega_0^2 C_2 + 1} = 1 \Rightarrow \frac{g_m R_L}{+L\left(\sqrt{\frac{C_1 + C_2}{L C_1 C_2}}\right)^2 C_2 \mp 1} = 1 \Rightarrow g_m R_L = + L \frac{C_1 + C_2}{L C_1 C_2} C_2 \mp 1$

$$\Rightarrow g_m R_L = \frac{+(C_1 + C_2) \mp C_1}{C_1} \Rightarrow \boxed{g_m R_L = \frac{C_2}{C_1}}$$

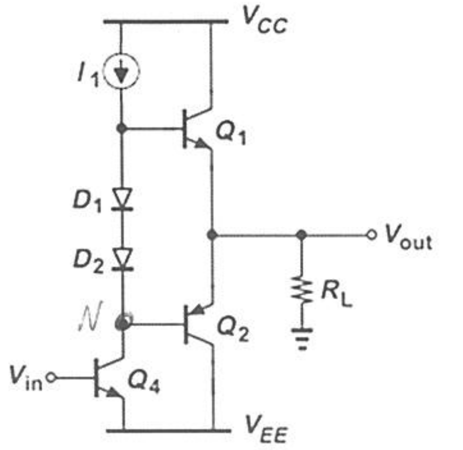
4) a) Para o circuito abaixo , despreze as resistências dos diodos e prove que:

$$A_v = -g_{m4}R_L[(g_{m1} + g_{m2})(r_{\pi1}//r_{\pi2}) + 1]$$

b) Para $g_{m1} \approx g_{m2}$, prove que (dica: comece reduzindo $r_{\pi1}//r_{\pi2}$ em função de g_m):

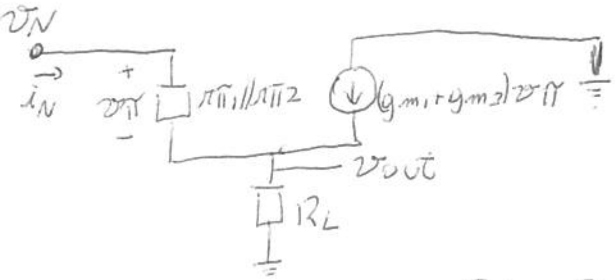
$$A_v \cong -2\frac{\beta_1\beta_2}{\beta_1 + \beta_2}g_{m4}R_L$$

c) Dados A_V=-4, β_1=40, β_2=20 e R_L= 8Ω, considere $g_{m1} \approx g_{m2}$ e calcule I_{C4}.



a)

• Push-Pull (Av_2)



$$v_{out} = R_L \cdot \left[(g_{m1}+g_{m2})v_\pi + \frac{v_\pi}{r_{\pi1}//r_{\pi2}}\right]$$

$$v_{out} = v_\pi R_L \left[(g_{m1}+g_{m2}) + \frac{1}{r_{\pi1}//r_{\pi2}}\right]$$

$$v_N = v_\pi + v_{out} \Rightarrow v_N = v_\pi \left[1 + R_L\left(g_{m1}+g_{m2}+\frac{1}{r_{\pi1}//r_{\pi2}}\right)\right]$$

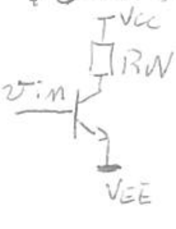
$$\boxed{Av_2 = \frac{v_{out}}{v_N} = \frac{R_L\left[g_{m1}+g_{m2}+\frac{1}{r_{\pi1}//r_{\pi2}}\right]}{1 + R_L\left[g_{m1}+g_{m2}+\frac{1}{r_{\pi1}//r_{\pi2}}\right]}}$$

※ R_N

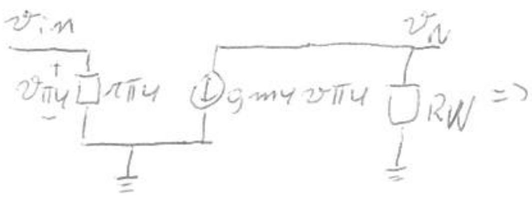
$$i_N = \frac{v_\pi}{r_{\pi1}//r_{\pi2}} \Rightarrow R_N = \frac{v_N}{i_N} = \frac{1 + R_L\left[g_{m1}+g_{m2}+\frac{1}{r_{\pi1}//r_{\pi2}}\right]}{\frac{1}{r_{\pi1}//r_{\pi2}}}$$

$$\boxed{R_N = r_{\pi1}//r_{\pi2}\left\{1 + R_L\left[g_{m1}+g_{m2}+\frac{1}{r_{\pi1}//r_{\pi2}}\right]\right\}}$$

• Emissor comum (Q_4, Av_1)



⇒



⇒ $\rightarrow Av_1$

$$\frac{v_N}{v_{in}} = \frac{-g_{m4}v_\pi R_N}{v_{\pi4}}$$

$$\boxed{Av_1 = -g_{m4}R_N}$$

- Ganho total (A_v)

$$A_v = A_{v_1} \cdot A_{v_2} = -g_{m4} \cdot \overbrace{r_{\pi_1} \| r_{\pi_2} \left\{ 1 + R_L \left[g_{m1} + g_{m2} + \frac{1}{r_{\pi_1} \| r_{\pi_2}} \right] \right\}}^{R_N} \cdot \frac{R_L \left[g_{m1} + g_{m2} + \frac{1}{r_{\pi_1} \| r_{\pi_2}} \right]}{1 + R_L \left(g_{m1} + g_{m2} + \frac{1}{r_{\pi_1} \| r_{\pi_2}} \right)}$$

$$\boxed{A_v = -g_{m4} R_L \left[(g_{m1} + g_{m2}) r_{\pi_1} \| r_{\pi_2} + 1 \right]} \quad \text{c.q.d.}$$

b) $$r_{\pi_1} \| r_{\pi_2} = \frac{r_{\pi_1} r_{\pi_2}}{r_{\pi_1} + r_{\pi_2}} = \frac{\frac{\beta_1}{g_m} \cdot \frac{\beta_2}{g_m}}{\frac{\beta_1}{g_m} + \frac{\beta_2}{g_m}} = \boxed{\frac{1}{g_m} \frac{\beta_1 \beta_2}{\beta_1 + \beta_2}}$$

$$A_v = -g_{m4} R_L \left[2 \cdot g_m \cdot \frac{1}{g_m} \frac{\beta_1 \beta_2}{\beta_1 + \beta_2} + 1 \right]$$

$$\frac{2 \cdot \beta_1 \beta_2}{\beta_1 + \beta_2} \gg 1 \Rightarrow \boxed{A_v \cong -g_{m4} R_L \cdot \frac{2 \beta_1 \beta_2}{\beta_1 + \beta_2}} \quad \text{cqd}$$

c) $$-4 = -g_{m4} \cdot 8 \cdot 2 \frac{40 \cdot 20}{20 + 40} \Rightarrow \boxed{g_{m4} = 0{,}0187\,S}$$

$$g_{m4} = \frac{I_{C4}}{V_T \approx 26\,mV} \Rightarrow \boxed{I_{C4} = 487{,}5\,\mu A}$$