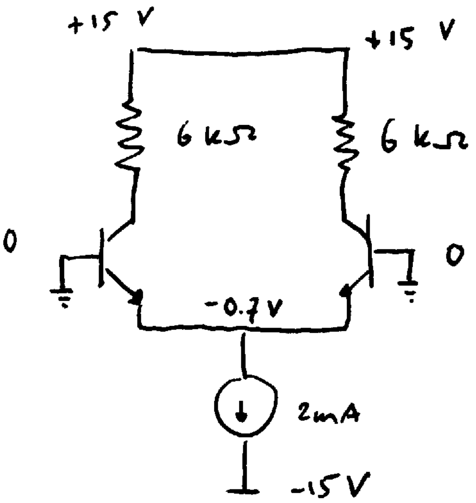
Electrónica II Exame 18-11-2009

1)



a)

$$I_{E1} = I_{E2} = 1 \text{ mA}$$

$$I_{C1} = I_{C2} = \frac{\beta}{\beta+1} \times 1 \text{ mA} \approx 1 \text{ mA}$$

$$I_{B1} = I_{B2} = \frac{1}{\beta+1} \times 1 \text{ mA} = 5 \ \mu A$$

$$V_{C1} = V_{C2} = 15 \text{ V} - 6 \text{ k}\Omega \times 1 \text{ mA}$$

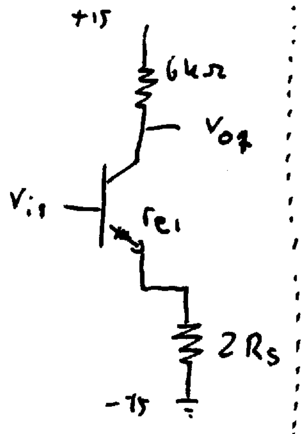
$$= 9 \text{ V}$$

$$V_{E1} = V_{E2} = V_{B1} - 0.7 = -0.7 \text{ V}$$

$$r_{e1} = r_{e2} = \frac{V_T}{I_E} = \frac{25 \text{ mV}}{1 \text{ mA}} = 25 \ \Omega$$

$$r_{o1} = r_{o2} \approx \frac{V_A}{I_C} = 100$$

b)



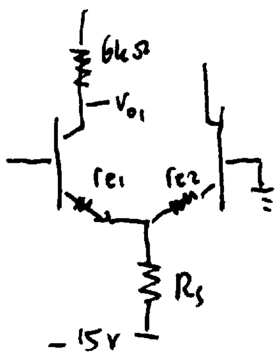
CM

Symmetry line
full circuit = 2x this half

$$\frac{V_{o1}}{V_{i1}} = -\frac{R_C}{r_e + 2R_s}$$

$$\approx -\frac{6 \text{ k}\Omega}{200 \text{ k}\Omega} = \boxed{-0.03 \text{ V/V}}$$

$$CMRR = \frac{240}{0.03} = 8000$$



DM

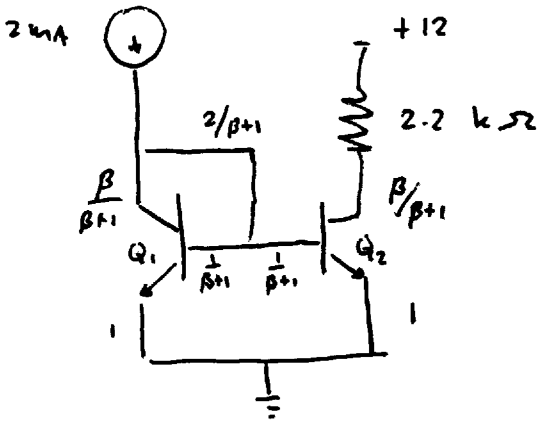
$$\frac{V_{o1}}{V_{i1}} = -\frac{R_C}{r_{e1} + r_{e2} /\!/ R_s} \approx -\frac{R_C}{2r_e} = \frac{6 \text{ k}\Omega}{50 \ \Omega}$$

$$= -120 \text{ V/V}$$

$$\frac{V_{o2}}{V_{i1}} = -\frac{V_{o1}}{V_{i1}} = +120 \text{ V/V}$$

$$A_{dm} = \left| \frac{V_{o2} - V_{o1}}{V_{i2} - V_{i1}} \right| = \left| \frac{V_{o2} - V_{o1}}{0 - V_{i1}} \right| = \left| \frac{V_{o2}}{V_{i1}} + \frac{V_{o1}}{V_{i1}} \right| = \boxed{240 \text{ V/V}}$$

2)



$$2\,mA = \left(\frac{\beta}{\beta+1} + \frac{2}{\beta+1}\right) \times I_{E2}$$

$$I_{E2} = \frac{\beta+1}{\beta+2} \times 2\,mA$$

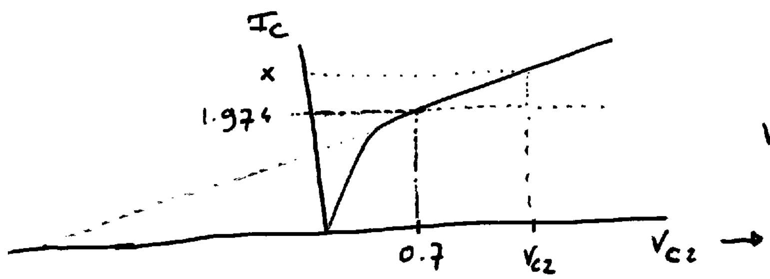
$$I_{C2} = \frac{\beta}{\beta+1} I_E = \frac{\beta}{\beta+1} \times \frac{\beta+1}{\beta+2} \times 2\,mA$$

$$= \frac{\beta}{\beta+2} \times 2\,mA$$

$$= 1.974 \quad mA$$

$$V_{C2} \approx 12 - 2.2\,k\Omega \times I_{C2} = 7.657\ V$$

$$r_o = \frac{V_A}{I_{C2}} \approx 50\,k\Omega$$



1.974 mA seria quando $V_{C2} = V_{C1} = 0.7\ V$

$$\left.\begin{aligned} V_{C2} &= +12\,V - 2.2\,k\Omega \times I_{C2} \\ I_{C2} &= 1.974\,mA + \frac{V_{C2} - 0.7\,V}{V_A / I_{C2}} \end{aligned}\right\}$$ non-linear system...

aproximation

$$I_{C2} = 1.974\,mA + \frac{V_{C2} - 0.7}{50\,k\Omega}$$

$$V_{C2} = +12\,V - 2.2\,k\Omega \times \left[1.974\,mA + \frac{V_{C2} - 0.7}{50\,k\Omega}\right]$$

$$V_{C2} + \frac{2.2\,k\Omega}{50\,k\Omega} V_{C2} = 12\,V - 2.2\,k\Omega \times 1.974\,mA + \frac{2.2\,k\Omega}{50\,k\Omega} \times 0.7\,V$$

$$\boxed{\begin{aligned} V_{C2} &= 7.365\ V \\ I_{C2} &= (12 - V_{C2})/2.2\,k\Omega = 2.107\ mA \end{aligned}}$$

3) a)

$$A_v \equiv \frac{V_o}{V_i} = \frac{V_o}{V_{out}} \cdot \underbrace{\frac{V_{out}}{V_{in}}}_{A} \cdot \frac{V_{in}}{V_i} \qquad A = -100$$

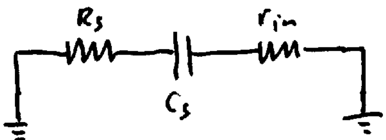
$$\frac{V_{in}}{V_i} = \frac{r_{in}}{r_{in}+R_s} = \frac{5\,k\Omega}{5\,k\Omega + 1\,k\Omega} = \frac{5}{6}$$

$$\frac{V_o}{V_{out}} = \frac{R_L}{R_L + r_{out}} = \frac{3\,k\Omega}{3\,k\Omega + 1\,k\Omega} = \frac{3}{4}$$

$$A_v = \frac{3}{4} \times (-100) \times \frac{5}{6} = -62.5$$

b) baixas frequências / low frequencies

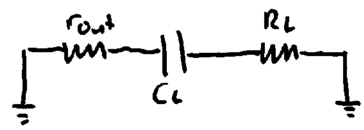
τ_s :



$$\tau_s = (R_s + r_{in})\,C_s = (1k\Omega + 5k\Omega) \times 10\mu$$

$$= 60\ \text{ms}, \quad f_s = \frac{1}{2\pi\tau_s} = 2.65\ \text{Hz}$$

τ_L :



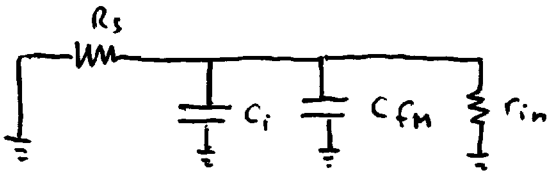
$$\tau_L = (R_L + r_{out})\,C_L = (1k\Omega + 1k\Omega) \times 10\mu F$$

$$= 20\ \text{ms}, \quad f_L = \frac{1}{2\pi\tau_L} = 7.96\ \text{Hz}$$

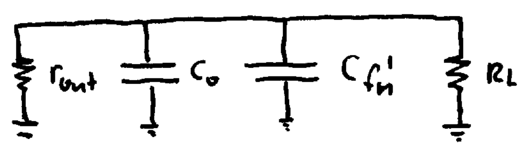
$$\omega_{tot} = \omega_s + \omega_L = \frac{1}{\tau_s} + \frac{1}{\tau_L} = 66.67\ \text{rad/s}$$

$$f_{Ltot} = \frac{1}{2\pi}\,\omega_{tot} = 10.6\ \text{Hz} = f_s + f_L$$

altas frequências / high frequencies



τ_{in}



τ_{out}

$$C_{fM} = (1-A) \times C_f = 101 \times 10\ pF$$
$$= 1{,}01\ nF$$

$$C_{fM}' = \left(1 - \frac{1}{A}\right) \times C_f = 1.01 \times 10\ pF$$
$$= 10.1\ pF$$

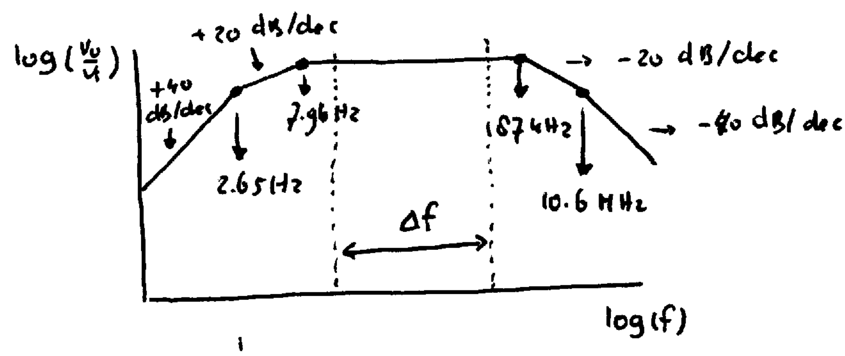
$$\tau_{in} = (R_S // r_{in}) \times (C_i + C_{fM})$$
$$= (1k\Omega // 5k\Omega) \times (10\ pF + 1010\ pF)$$
$$= 8.50\ \ 10^{-7}\ s$$
$$f_{in} = \frac{1}{2\pi \tau_{in}} = 187\ kHz$$

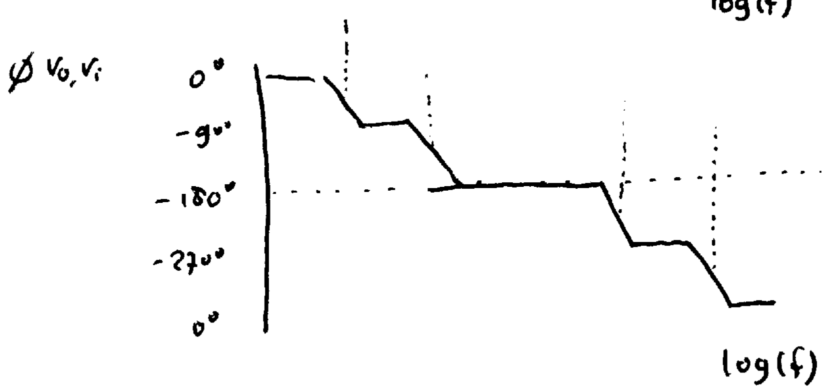
$$\tau_{out} = (R_L // r_{out}) \times (C_o + C_{fM}')$$
$$= (3k\Omega // 1k\Omega) \times (10\ pF + 10.1\ pF)$$
$$= 1.51\ \ 10^{-8}\ s$$
$$f_{out} = \frac{1}{2\pi \tau_{out}} = 10.6\ MHz$$

$$\tau_{tot} = \tau_{in} + \tau_{out} = 8.65\ \ 10^{-7}\ s$$
$$f_{H\,tot} = \frac{1}{2\pi \tau_{tot}} = 184\ kHz$$

c) Bandwidth

$\Delta f = 184\ kHz - 10.6\ H$

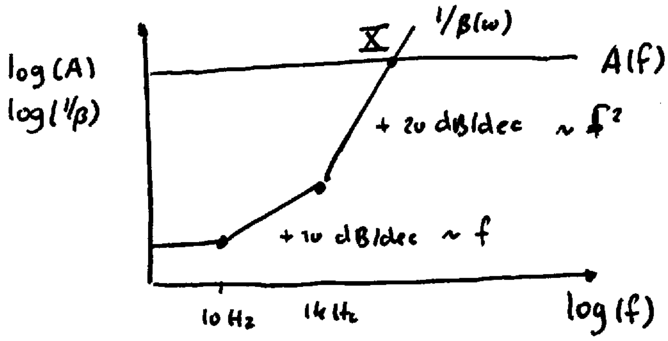


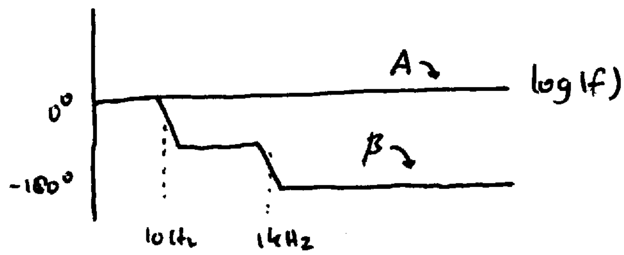


4) a) $$A_v = \frac{A}{1+A\beta} = \frac{A(\omega)}{1+A(\omega)\,\beta(\omega)} = \frac{A(f)}{1+A(f)\,\beta(f)}$$

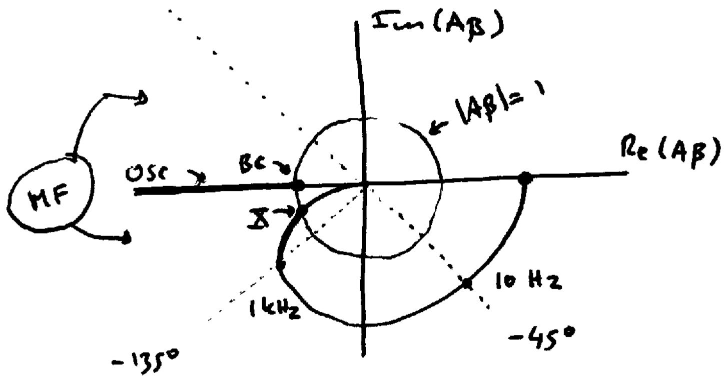
b)

Bode plots of A, $1/\beta$ and β

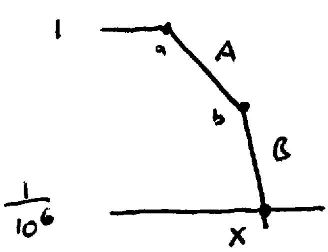




Nyquist plot of $A\beta$



The circuit does not oscillate with guarantee, but has the risk to oscillate between 1kHz, where it enters the phase margin zone (MF); and X, where it enters the zona $|A\beta| < 1$ that is safe.



a : 10 Hz , $|\beta| = 1$

A : $|\beta| = 1 \times 10\ \text{Hz}/f$

b : 1 kHz , $|\beta| = 1 \times 10\ \text{Hz}/1\text{kHz} = 0.01$

B : $|\beta| = 0.01 \times (1\ \text{kHz})^2/f^2$

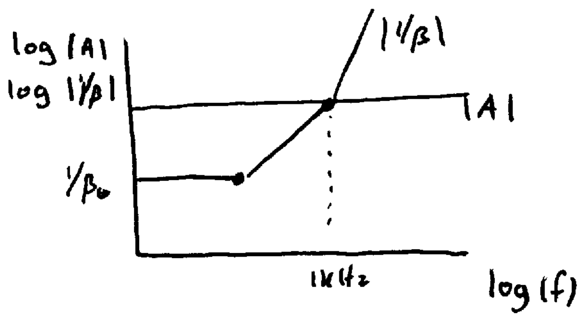
X : $|A\beta| = 1 \Rightarrow |\beta| = \frac{1}{A} = 10^{-6} = 0.01 \times \frac{(1\ \text{kHz})^2}{f^2}$

$\Rightarrow f_X = 100\ \text{kHz}$

c) 1 kHz - 100 kHz

possible solutions: - reduce β_0

- reduce A



make $|A|$ and $|1/\beta|$ cross at 1 kHz

- reduce β_0 : $\beta = \dfrac{\beta_0}{(1+jf/10\,\text{Hz}) \times (1+jf/1\,\text{kHz})}$

At 1 kHz $|\beta| = |1/A| = 10^{-6}$

$\Rightarrow \beta_0 \times 10\,\text{Hz}/1\,\text{kHz} = 10^{-6}$

$\Rightarrow \beta_0 = 10^{-4}$

- reduce A : At 1 kHz $|\beta| = |1/A|$

$1 \times \dfrac{10\,\text{Hz}}{1\,\text{kHz}} = 1/A \Rightarrow A = 10^2$

5) $V_A = \infty$

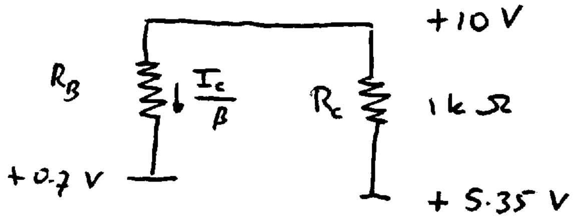
$r_{out} = R_C \parallel r_o = 1\,\text{k}\Omega$

$R_L = 1\,\text{k}\Omega \rightarrow$ max power transfer

a) class A : the complete wave appears on the output, albeit with offset ($v_i = 0 \Rightarrow V_o \neq 0$)

b) we want V_o to be halfway between $+V_{CC}$ and V_B

let's say between +10 V and +0.7 V $\rightarrow V_o = +5.35\,\text{V}$

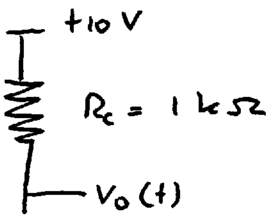


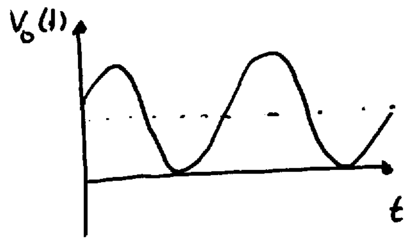
$$I_c = \frac{(10\text{ V} - 5.35\text{ V})}{1\text{ k}\Omega} = 4.65\text{ mA}$$

$$I_B = \frac{1}{\beta} I_c = 46.5\ \mu A$$

$$I_B = \frac{(10\text{ V} - 0.7\text{ V})}{R_B} = 46.5\ \mu A \Rightarrow R_B = 200\text{ k}\Omega$$

c) ignoring I_B and P_B, and using $V_{c\emptyset} = +5$ V





$$V_o(t) = 5V(1 + \sin\omega t)$$

$$P_L(t) = V_L(t) \cdot I_L(t)$$

$$= \left[10\text{ V} - 5\text{ V}(1+\sin\omega t)\right] \times \frac{\left[10\text{ V} - 5\text{ V}(1+\sin\omega t)\right]}{R_c}$$

$$= \frac{25\text{ V}^2}{R_c}\left[1 - \sin\omega t\right]^2$$

$$\bar{P}_L = \frac{1}{T}\int_0^T P_L(t)\,dt = 25\text{ mW}\ \frac{1}{T}\int_0^T (1-\sin\omega t)^2\,dt$$

$$= 25\text{ mW} \times \left(1 + \tfrac{1}{2}\right) = \underline{37.5\text{ mW}}$$

$$P_S(t) = V_S(t) \cdot I_S(t) = +10\text{ V} \times I_L(t)$$

$$= 10\text{ V} \times \left[10\text{ V} - 5\text{ V}(1+\sin\omega t)\right] / R_c$$

$$= 50\text{ mW} - 50\text{ mW}\sin\omega t$$

$$\bar{P}_S = 50\text{ mW}$$

$$\eta = \frac{37.5\text{ mW}}{50\text{ mW}} = 75\%$$

d) 12.5 mW (50 - 37.5) in transistor

$T_J = 40^\circ + 12.5\ \text{mW} \times 40^\circ\text{C}/\text{W}$

$= 40.5^\circ\text{C}$