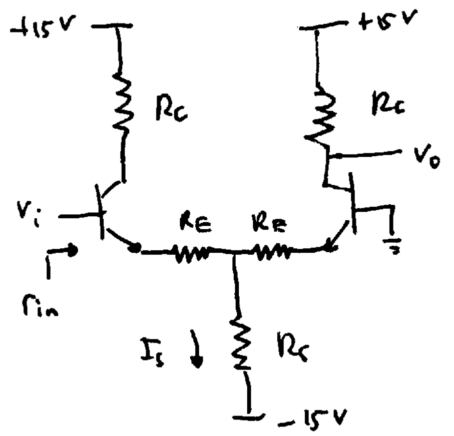
solução electrónica II exame de recurso 31/01/2005

Peter Stallinga

Pergunta 1

a)



$R_S \gg R_E \Rightarrow V_x \sim -0.7\ V$

Desenha $I_S = 6\ mA$

$I_S = \frac{14.3\ V}{R_S} \Rightarrow R_S = 2.38\ k\Omega$

escolha $\boxed{R_S = 2.2\ k\Omega} \Rightarrow$

$I_S = 6.5\ mA$

$I_E = I_S/2 = 3.25\ mA$.

$r_e = \frac{V_T}{I_E} = \frac{26\ mV}{3.25\ mA} = 8\ \Omega$

$r_{in} = (\beta+1)\,(r_e + R_E + R_S\,//\,(R_E + r_e))$

$\approx 101\ (2r_e + 2R_E)$

$r_{in} \geq 5\ k\Omega \Rightarrow 101 \times (16\ \Omega + 2R_E) \geq 5\ k\Omega$

$\Rightarrow R_E \geq 16.75\ \Omega$

escolha $\boxed{R_E = 17\ \Omega}$

$\left|\frac{V_o}{V_i}\right| = \left|-\frac{R_C}{2r_e + 2R_E}\right| = \left|\frac{-R_C}{8\ \Omega + 34\ \Omega}\right| \geq |-50|$

$\Rightarrow R_C \geq 2.1\ k\Omega$

escolha $\boxed{R_C = 2.2\ k\Omega}$

check polarization : $V_o = +15V - I_C \times R_C$

$= 15\ V - 3.25\ mA \times 2.2\ k\Omega$

$= 7.85\ V$ excellent.

b) A notar o ganho acima é o single-ended

$$\left|A_{dm}^{s.e.}\right| = \left|\frac{v_o}{v_i - 0}\right| = \left|\frac{R_C}{2r_e + 2R_E}\right|$$

o ganho em modo diferencial é

$$\left|A_{dm}\right| = \left|\frac{v_{o2} - v_{o1}}{v_{i2} - v_{i1}}\right| = 2\left|A_{dm}^{s.e}\right|$$

b) o ganho em modo comum é

$$A_{cm} = -\frac{R_C}{r_e + R_E + 2R_S} \sim \frac{R_C}{2R_S}$$

o CMRR = $\left|\frac{A_{dm}}{A_{cm}}\right| = \frac{2R_C}{2r_e + 2R_E} \Big/ R_C/2R_S = \frac{2R_S}{r_e + 2R_E} = 105$

$$\boxed{CMRR = 105}$$

Pergunta 2

Polarização: (assume $\beta = \infty$)

$$V_{B1} = \frac{100\,k\Omega}{100\,k\Omega + 100\,k\Omega} \times 10\,V = 5\,V$$

$$V_{E1} = V_{B1} - 0.7 = 4.3\,V$$

$$I_{E1} = 4.3\,V / 4.3\,k\Omega = 1\,mA \qquad \left(r_{e1} = \frac{26\,mV}{1\,mA} = 26\,\Omega\right)$$

$$V_{B2} = V_{E1} = 4.3\,V$$

$$V_{E2} = V_{B2} - 0.7 = 3.6\,V$$

$$I_{E2} = \frac{3.6\,V}{3.6\,k\Omega} = 1\,mA \qquad \left(r_{e2} = \frac{26\,mV}{1\,mA} = 26\,\Omega\right)$$

$$I_{C2} = I_{E2} = 1\,mA \qquad (\alpha = 1)$$

$$V_{C2} = +10\,V - R_C \times I_{C2} = 10\,V - 4\,k\Omega \times 1\,mA = 6\,V$$

$$r_{o2} = \frac{V_A}{I_{C2}} = \frac{200\,V}{1\,mA} = 200\,k\Omega$$

Ganho $\qquad \beta = 99, \quad r_{\pi1} = r_{\pi2} = 2.6\,k\Omega$

$$\frac{v_o}{v_s} = \frac{v_{B1}}{v_s} \cdot \frac{v_{B2}}{v_{B1}} \cdot \frac{v_o}{v_{B2}}$$

$$r_{in1} = 100\,k\Omega \,//\, 100\,k\Omega \,//\, \Big(r_{\pi1} + (\beta+1)\big(R_{E1} \,//\, (r_{\pi2} + \underbrace{\cancel{(\beta+1)R_{E2}}}_{\text{bypassed by } C_E})\big)\Big)$$

$$38.4\,k\Omega$$

$$\frac{v_{B1}}{v_s} = \frac{r_{in}}{r_{in} + R_s} = \frac{38.4\,k\Omega}{38.4\,k\Omega + 4\,k\Omega} = 0.906$$

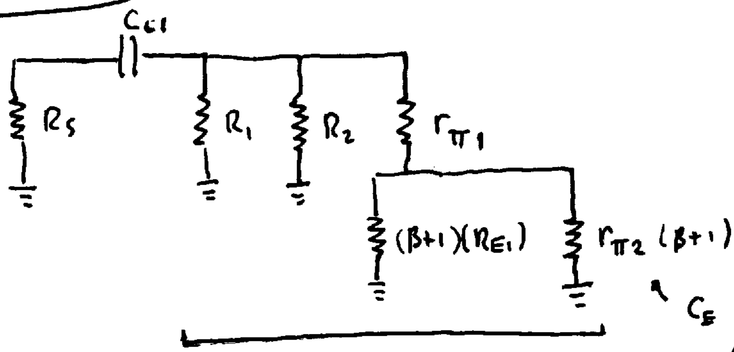
$$\frac{v_{B2}}{v_{B1}} = \frac{R_{E1} // r_{\pi2}}{R_{E1} // r_{\pi2} + r_{e1}} \approx 1$$

$$\frac{v_o}{v_{B2}} = -\frac{R_C // R_L}{r_{e2} + \underbrace{\cancel{R_{E2}}}_{\text{bypassed}}} = -\frac{2\,k\Omega}{26\,\Omega} = -76.9$$

$$\frac{v_o}{v_s} = 0.906 \times 1 \times (-76.9) = -69.7$$

b) Baixas frequências

C_{c1} :

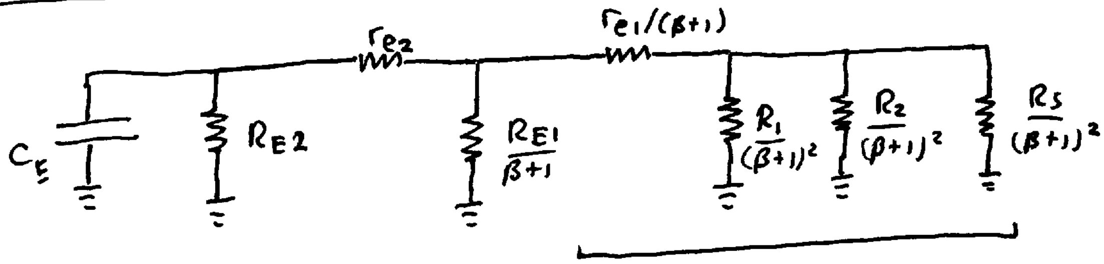


C_E em curto circuito (R_{E2} bypassed)

$r_{in} = 38.4\ k\Omega$

$$\tau_{c1} = 1\,\mu F \times (4\,k\Omega + 38.4\,k\Omega)$$
$$= 42.4\ ms \qquad (f_{c1} = 3.77\ Hz)$$

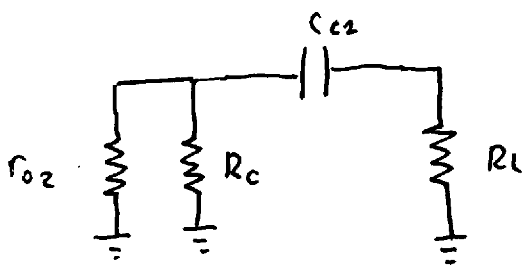
C_E :



≈ 0

$$\tau_E = 47\,\mu F \times (3.6\,k\Omega\ //\ 26\,\Omega)$$
$$47\,\mu F \times 26\,\Omega = 1.22\ ms \qquad (f_E = 130\ Hz)$$

C_{c2}

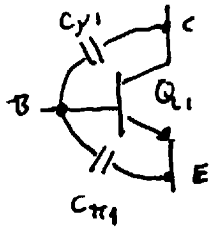


$$\tau_{c2} = (200\,k\Omega\ //\ 4\,k\Omega + 4\,k\Omega) \cdot 1\,\mu F$$
$$= 7.92\ ms \qquad (f_{c2} = 20.1\ Hz)$$

$$f_L = \frac{1}{2\pi\tau_{c1}} + \frac{1}{2\pi\tau_E} + \frac{1}{2\pi\tau_{c2}} = 154\ Hz$$

$$(= f_{c1} + f_E + f_{c2})$$

Altas frequências

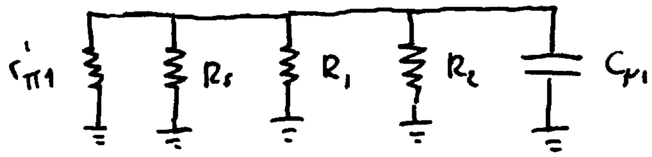


① entrada de Q1

$C_{\pi 1}$: $\frac{V_{E1}}{V_{B1}} \approx 1 \Rightarrow (1-A) \cdot C_{\pi 1} \approx 0$

$C_{\mu 1}$: $A = \frac{V_{C1}}{V_{B1}} = 0 \quad (V_{C1} = +10V)$

$\Rightarrow (1-A) \cdot C_{\mu 1} \approx C_{\mu 1}$



$r'_{\pi 1} = r_{\pi 1} + (\beta+1)(R_{E1} // r_{\pi 2})$

$\tau_{in1} = C_{\mu 1} \; (R_s // R_1 // R_2 // r'_{\pi 1})$

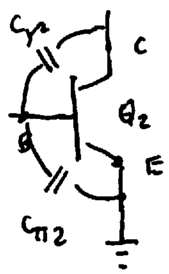
$= 5\,pF \cdot (4\,k\Omega // 100\,k\Omega // 100\,k\Omega // 165\,k\Omega)$

$= 18.11\ ns \qquad (f_{in1} = 8.79\ MHz)$

τ_{out1} : $C_{\pi 1}$, mas $\frac{V_{E1}}{V_{B1}} \approx 1 \Rightarrow (1 - \frac{1}{A})\, C_{\pi 1} \approx 0$

$\Rightarrow \tau_{out1} \approx 0 \qquad f_{out1} = \infty$

τ_{in2}

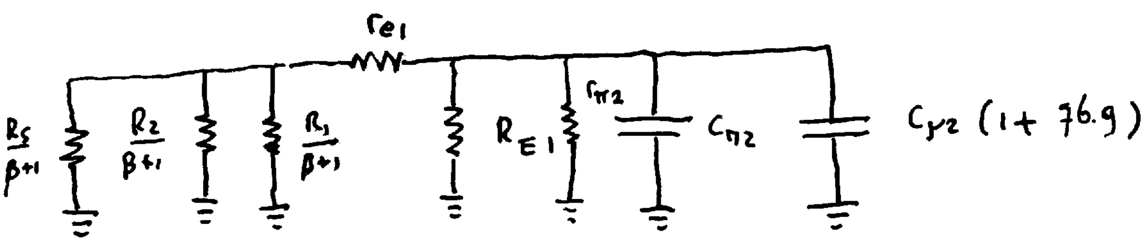


$C_{\pi 2}$: um lado ligado à terra

$(1-A)\, C_{\pi 2} = (1-0)\, C_{\pi 2} = C_{\pi 2}$

$C_{\mu 2}$: sente um ganho $\frac{V_{C2}}{V_{B2}} = -76.9$

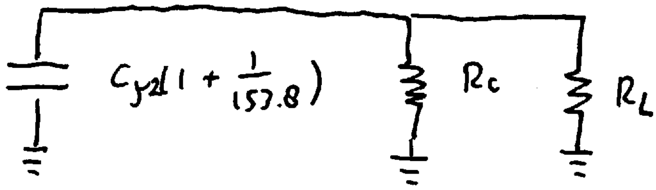
efeito Miller !



$\tau_{in2} = 62.1\ \Omega \times (50\,pF + 385\,pF)$

$= 27.0\ ns \qquad (f_{in2} = 5.90\ MHz)$

τ_{out2}



$$\tau_{out2} = 10.1 \ \text{ns} \qquad (f_{out2} = 15.8 \ \text{MHz})$$

$$= C_{\mu 2}\left(1+\frac{1}{76.9}\right)(R_c /\!/ R_L)$$

$$\tau_{tot} = \tau_{in1} + \tau_{in2} + \tau_{out1} + \tau_{out2}$$

$$= 55.21 \ \text{ns}$$

$$f_H = \frac{1}{2\pi \tau_{tot}} = 2.9 \ \text{MHz}$$

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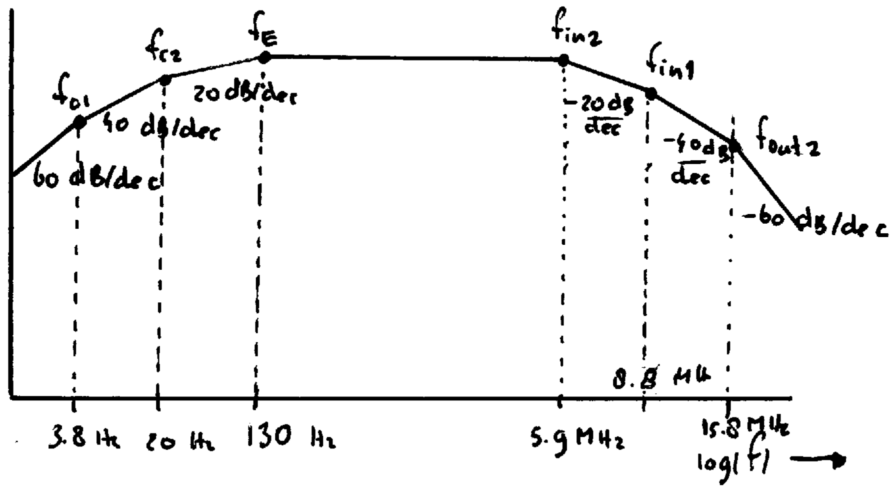
c) $20 \log\left(\frac{V_o}{V_s}\right)$



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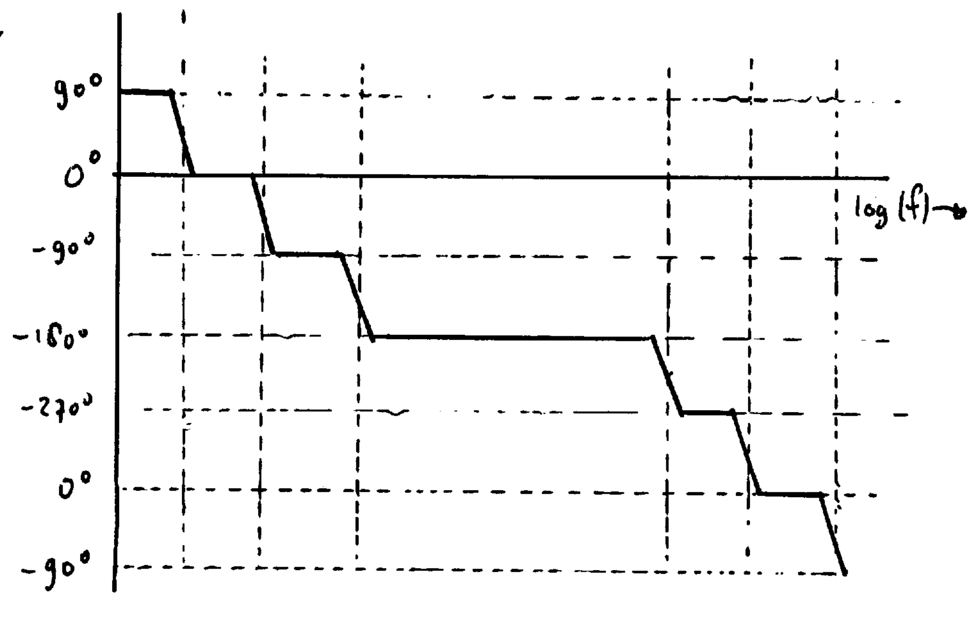
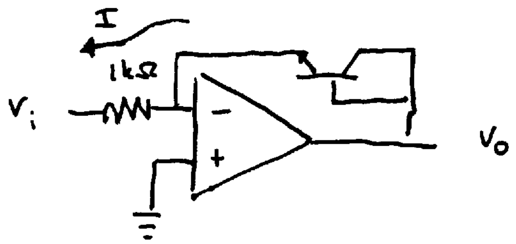


Pergunta 3

a)



$$I_i = \frac{V_i}{1k\Omega}, \quad r_{i\,opamp} = \infty \Rightarrow I = -I_i$$

Ebers Moll diodo $I = I_0\left(\exp\left(\frac{V_{BE}}{V_T}\right) - 1\right)$

$$\frac{V_i}{1k\Omega} = I_0 \exp\left(\frac{V_{BE}}{V_T}\right)$$

$$\Rightarrow V_{BE} = V_T \ln\left(\frac{V_i}{1k\Omega \times I_0}\right)$$

$$V_o = V_n + V_{BE} = 0 + V_T \ln\left(\frac{V_i}{1k\Omega \times I_0}\right)$$

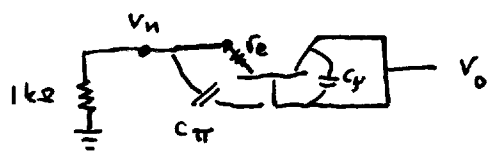
terra virtual

b) $V_i = -1\,V$, $I_i = -1\,mA$, $I = 1\,mA$

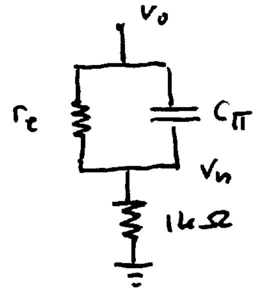
$$V_o = 26\,mV \times \ln\left(\frac{1\,mA}{10^{-14}\,A}\right) = 0.659\,V$$

$$r_e = \frac{V_T}{I_E} = 26\,\Omega$$

$$\beta \equiv \frac{V_n}{V_o}$$



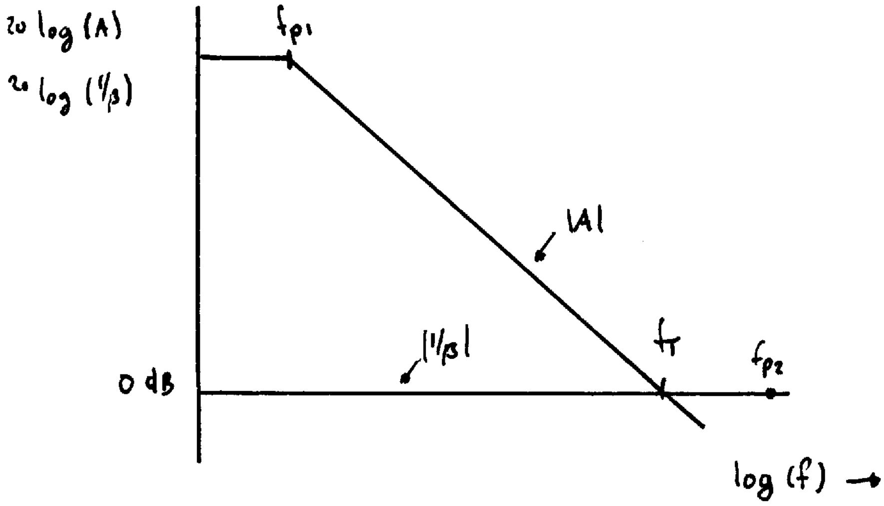
⇒



$$\beta\,(0\,Hz) = \frac{1k\Omega}{1k\Omega + 26\,\Omega} \approx 0.975$$

pólo à $f = \frac{1}{C_\pi\,(r_e \,//\, 1k\Omega)\cdot 2\pi}$

$$= 126\,MHz$$



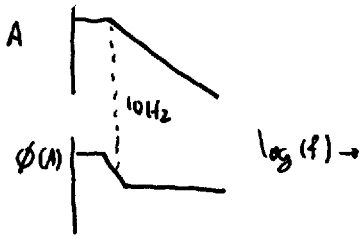
amp-op :

$A_0 = 200.000$

$f_{p1} = 10 \text{ Hz}$

$f_T = 200000 \times 10 \text{ Hz} = 2 \text{ MHz}$

$(A(f_T) \equiv 1)$

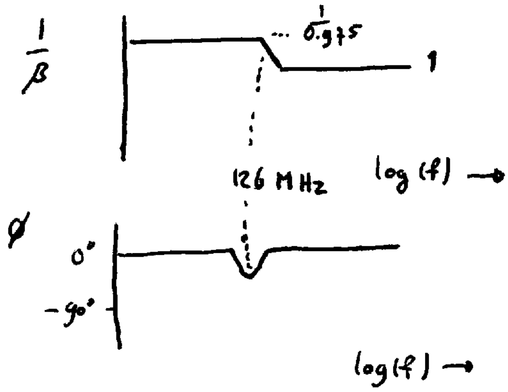


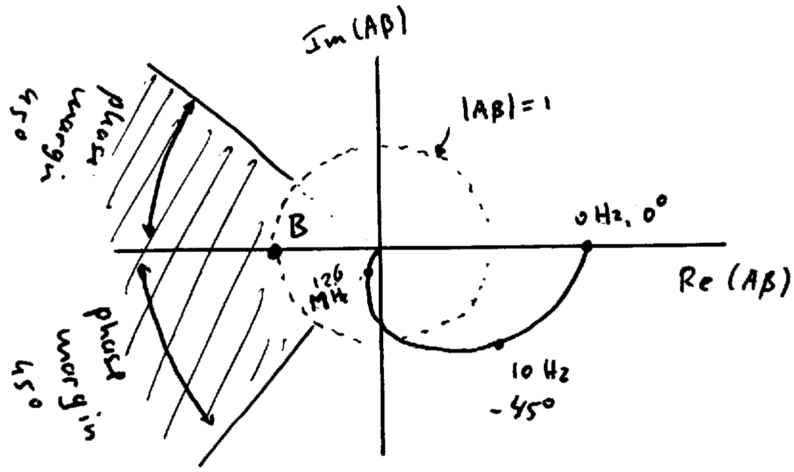
β :

$\beta_0 = 0.975$

$f_{p2} = 126 \text{ MHz}$

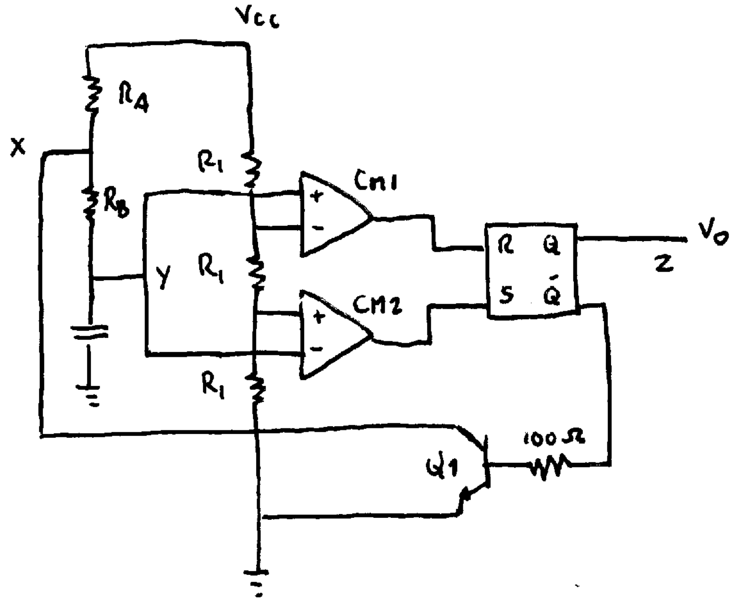
$\beta_\infty = 1$

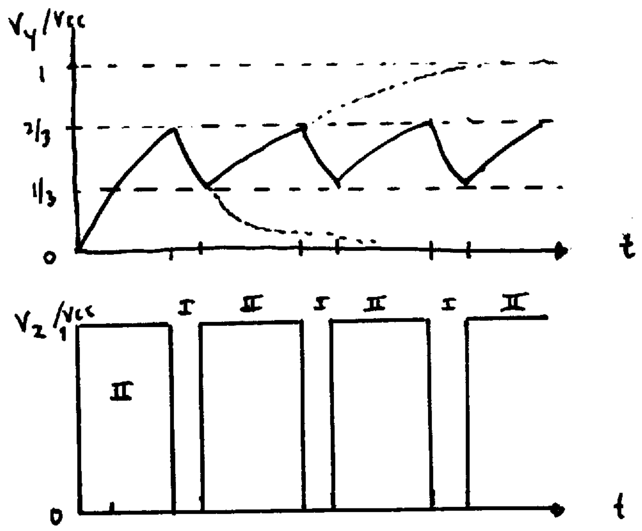


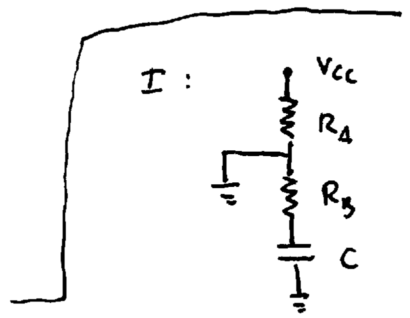


o circuito é estável !

Pergunta 4



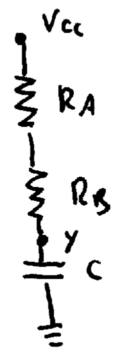




I : $V_z = 0$ V, $Q = 0$ V, $\bar{Q} = 5$ V, Q_1 curto circuito. V_x ligada a terra. vai descarregar o C com tempo característica $\tau_I = R_B C$, com tendência à 0 V.

Quando chega a $V_y = 1/3\,V_{cc}$, o CM2 comuta e faz o Q (set) e o $\bar{Q}$. A segunda fase do período começa

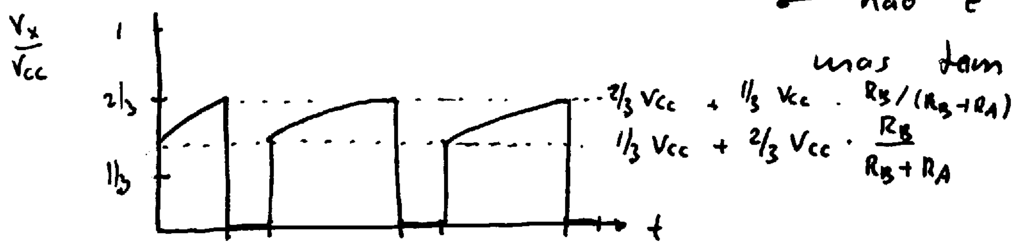
II $V_2 = V_{cc}$, $Q = V_{cc}$, $\bar{Q} = 0\,V$. O transistor está em circuito aberto. Temos a seguinte situação



O C é carregado com tempo característica $\tau_{II} = (R_A + R_B) C$ com tendência $(I(t=\infty) = 0)$ $V_y(t=\infty) = V_{cc}$.

Quando chega à $V_y = \frac{2}{3} V_{cc}$ o CM1 comuta ⎍ e faz o Q ⎍ ("reset") e o $\bar{Q}$ ⎍ . Isto abre o transístor e a fase I começa de novo

← não é interessante, mas também foi pedido.



T_I : $V_y(t) = \frac{2}{3} V_{cc} \exp(-t/\tau_I)$

$V_y(T_I) = \frac{1}{3} V_{cc}$

$\Rightarrow \frac{2}{3} V_{cc} \exp(-T_I/\tau_I) = \frac{1}{3} V_{cc}$

$T_I = \tau_I \ln(2) = R_B C \ln(2)$

T_{II} : $V_y(t) = V_{cc} - \frac{2}{3} V_{cc} \exp(-t/\tau_{II})$

$V_y(T_{II}) = \frac{2}{3} V_{cc}$

$\Rightarrow T_{II} = \tau_{II} \ln(2) = (R_A + R_B) C \ln(2)$

c)

$f = 10 \text{ kHz}$

$T = 100 \ \mu s = T_I + T_{II}$

$$(2R_B + R_A)\, C \ln(2) = 100 \ \mu s$$

por exemplo

$C = 10 \text{ nF}$

$R_A = 3.3 \text{ k}\Omega$

$R_B = 3.3 \text{ k}\Omega$