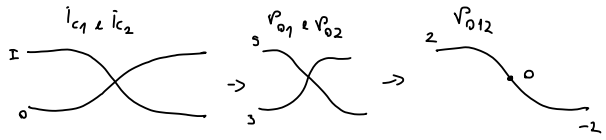
4.1) a) $\frac{i_{c_1}}{I_{EE}} = \frac{1}{1+e^{-\frac{v_D}{V_T}}}$ $\quad \frac{i_{c_2}}{I_{EE}} = \frac{1}{1+e^{\frac{v_D}{V_T}}}$ ...

b) $v_{o1}(v_I) = V_{cc} - R_c i_{c_1}$

$v_{o2}(v_I) = V_{cc} - R_c i_{c_2}$

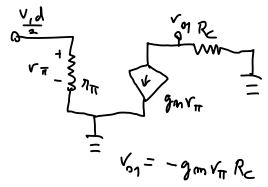
$v_{o12}(v_I) = v_{o1}(v_I) - v_{o2}(v_I) = R_c (i_{c_2} - i_{c_1}) = R_c I \tanh\left(\frac{-v_D}{2V_T}\right)$



d) $\frac{v_{o1}}{v_D} = -\frac{g_m R_c}{2}$

$\frac{v_{o2}}{v_D} = \frac{g_m R_c}{2}$

$\frac{v_{o12}}{v_D} = -g_m R_c$



$v_{o1} = -g_m v_\pi R_c$

$v_D = \frac{v_{id}}{2}$ $\rightarrow A_{d_1} = -\frac{g_m R_c}{2}$

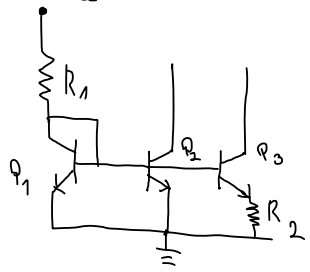
e) R_1 e R_2:

$v_{CE_1} = \underbrace{-R_c \frac{I_{EE}}{2}}_{-1V} + \underbrace{V_{cc}}_{5V} - V_C + \underbrace{V_{BE}}_{0.7V} > \underbrace{V_{CE_{SAT}}}_{0.7} \Rightarrow V_C < 4V$

R_3:

$V_C - (-V_{EE}) - V_{BE} = V_{CE_3} > V_{CE_{SAT}}$ $\quad V_C > 0.7 - 5 + 0.7 \Rightarrow V_C > -5V$

3.1)



$V_A = 100\,V$

$\beta = 100$

$V_{cc} = 6\,V$

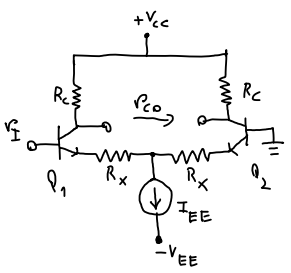
$R_1 = 20k\,\Omega$

a)

$I_{REF} = I_{C_1} + \frac{I_{C_1}}{\beta} + \frac{I_{C_2}}{\beta}$

$I_C \simeq I_S e^{\frac{V_{BE}}{V_T}} \left(1 + \frac{V_{CE}}{V_A}\right) \Rightarrow \frac{I_{C_2}}{I_1} = \frac{1 + \frac{V_{CE_2}}{V_A}}{1 + \frac{V_{CE_1}}{V_A}}$

4.2)



$I_{EE} = 100\mu A$

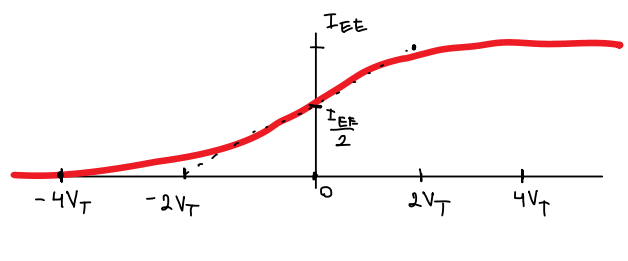
$R_c = 10\,k\Omega$

a) $i_{c_1}(v_I)$ $\quad v_{co}(v_I)$

$v_I = v_{BE_1} + R_x i_{c_1} - R_x i_{c_2} - v_{BE_2} \Leftrightarrow v_I = R_x (i_{c_1} - i_{c_2}) + v_{BE_1} - v_{BE_2}$

$R_x = 0 \Rightarrow v_I = v_{BE_1} - v_{BE_2}$

$i_{c_1} = I_S e^{\frac{v_{BE_1}}{V_T}}$ $\quad i_{c_2} = I_S e^{\frac{v_{BE_2}}{V_T}}$ $\quad I_{EE} = i_{c_1} + i_{c_2}$



$i_{c_1} = \frac{I_{EE}}{1 + \frac{i_{c_2}}{i_{c_1}}} \Leftrightarrow i_{c_1} = \frac{I_{EE}}{1 + e^{-\frac{v_I}{V_T}}}$

$V_{cc} - v_o = R_c i_{c_1} \Rightarrow v_o = V_{cc} - R_c i_{c_1}$ $\quad$ ou $v_o = v_{o1} - v_{o2} = R_c (i_{c_2} - i_{c_1}) = R_c I_{EE} \tanh\left(-\frac{v_I}{2V_T}\right)$

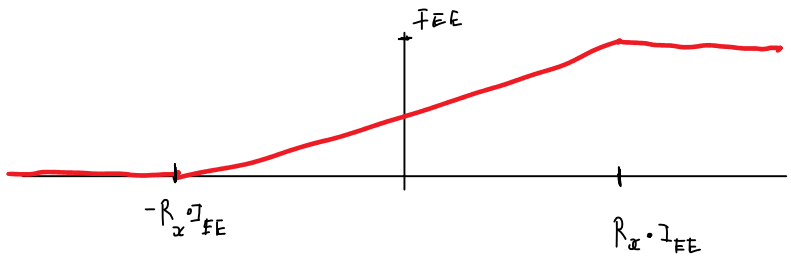
$R_x = 2\,k\Omega \Rightarrow v_I = R_x (i_{c_1} - i_{c_2}) + \underbrace{v_{BE_1} - v_{BE_2}}_{\ll}$

$I_{EE} = i_{c_1} + i_{c_2}$

$\Rightarrow \begin{cases} v_I = R_x (i_{c_1} - i_{c_2}) \\ I_{EE} = i_{c_1} + i_{c_2} \end{cases} \Leftrightarrow \begin{cases} \frac{v_I}{R_x} + i_{c_2} = i_{c_1} \\ I_{EE} = \frac{v_I}{R_x} + 2 i_{c_1} \end{cases} \Leftrightarrow \begin{cases} i_{c_1} = \frac{I_{EE}}{2} + \frac{v_I}{2R_x} \\ i_{c_2} = \frac{I_{EE}}{2} - \frac{v_I}{2R_x} \end{cases}$

$v_o = V_{cc} - R_x i_{c_1}$

$v_o = R_c I_{EE} \tanh\left(-\frac{v_I}{2V_T}\right)$



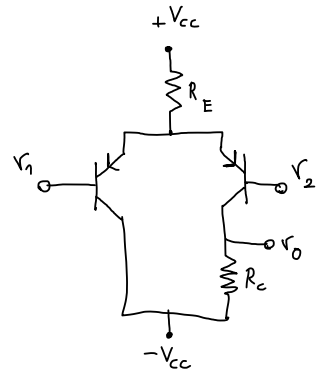
$v_D = v_{BE_1} - v_{BE_2}$ $\quad i_{c_1} = \frac{\alpha I}{1 + e^{-\frac{v_D}{V_T}}}$ $\quad i_{c_2} = \frac{\alpha I}{1 + e^{\frac{v_D}{V_T}}}$ $\quad \tanh(x) = \frac{e^{2x} - 1}{e^{2x} + 1}$

$\tanh(\theta) \approx \frac{I}{4V_T}$

Se $|v_D| \geq 4V_T$ está totalmente dessequilibrado

Se $|v_D| << 2V_T$ $(|v_D| < 10mV) \rightarrow$ amplificador linear

4.3)



$\beta = 100$

$V_{cc} = 6\,V$

$R_E = 100k\,\Omega$

$R_c = 10K\,\Omega$

a) $V_{cc} - v_1 = V_{R_4} + v_{EB}$

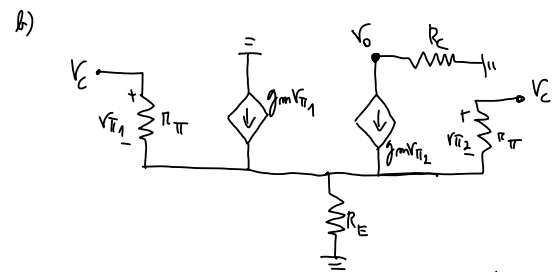
$V_{RE} = V_{cc} - V_1 - V_{EB} = 6 - 0,7 = 5,3\,V$

$2 \cdot I_{E_1} = \frac{V_{R_E}}{R_E} \Leftrightarrow I_{E_1} = I_{E_2} = 26,5\mu A$

$V_{EC_1} = -V_{R_E} + V_{cc} - (-V_{cc}) = 6,7\,V$

$V_{EC_2} = -V_{R_E} + 2 \cdot V_{cc} - R_c i_{c_2} = 6,435\,V$

b)



D:

$v_o = -R_c g_m v_{\pi_2}$

$v_{\pi_1} = \frac{v_d}{2}$

$v_{\pi_2} = -\frac{v_d}{2}$

$A_d = \frac{v_o}{v_d} = \frac{R_c g_m}{2} = -5,3$

C: $v_o = -g_m v_{\pi_2} R_c$

$\begin{cases} \frac{v_{\pi_1}}{r_\pi} + g_m v_{\pi_1} + g_m v_{\pi_2} + \frac{v_{\pi_2}}{r_\pi} = \frac{v_c - v_{\pi_1}}{R_E} \\ v_{\pi_1} = v_{\pi_2} = v_\pi \end{cases} \Rightarrow v_\pi = \frac{v_c}{2R_E\left(\frac{1}{r_\pi} + g_m\right) + 1}$

$A_c = \frac{v_o}{v_c} = -\frac{g_m R_c}{2R_E\left(\frac{1}{r_\pi} + g_m\right) + 1} \simeq -\frac{R_c}{R_E} = -0,05$

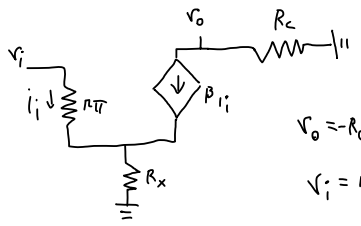
$CMRR = \left|\frac{A_d}{A_c}\right| = 106$

$CMRR_{dB} = 40 \cdot 5\,dB$

c) C: $R_{ic} = \frac{v_c}{i_{b_1} + i_{b_2}} = \frac{v_c}{\frac{v_{\pi_1}}{r_\pi} + \frac{v_{\pi_2}}{r_\pi}} = \frac{v_c}{\frac{v_c}{2R_E\left(\frac{1}{r_\pi} + g_m\right) + 1}\left(\frac{2}{r_\pi}\right)} = \frac{\left(2R_E\left(\frac{1}{r_\pi} + g_m\right) + 1\right) r_\pi}{2} \approx 10,1M\Omega$

D: $R_{id} \simeq 2r_\pi$

b)



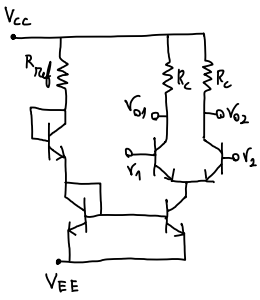
$v_o = -R_c \beta i$

$v_i = r_\pi i_i + R_x (1+\beta) i_i$

$A_{d_1} = \frac{v_o}{v_i} = -\frac{R_c \beta}{r_\pi + R_x (1+\beta)} \simeq -\frac{R_c}{R_x} = -5$

$A_{d_1} = \frac{v_o}{v_i} = -\frac{R_c \beta}{\frac{\beta}{g_m}} = -R_c g_m = -20$

1)



$V_{CC} = -V_{EE} = 4V$
$R_C = 2K\Omega$
$V_{BE\,on} = 0{,}7V$
$\beta = 80$
$V_A = 50V$

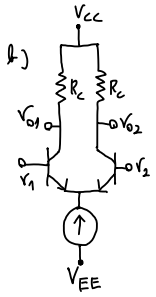
a) $V_{CC} - V_{EE} = V_{R_{ref}} + 0.7 + 0.7 \Leftrightarrow$

$\Leftrightarrow 8 - 1.4 = V_{R_{ref}} \Leftrightarrow$

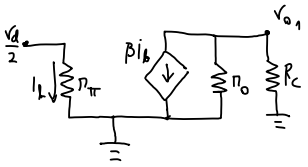
$\Leftrightarrow 6.6 = R_{ref} \cdot I_{C_3} \Leftrightarrow$

$\Leftrightarrow \frac{6.6}{I_{C_1} + I_{C_2}} = R_{ref} \Leftrightarrow R_{ref} \simeq 3.3\,k\Omega$

b)



É simétrico!



$r_o = \frac{V_A}{I_C} = 50k\Omega$

$R_O = r_o // R_C$

$V_1 = i_{b_1} r_\pi \Rightarrow \frac{V_1}{r_\pi} = i_{b_1}$

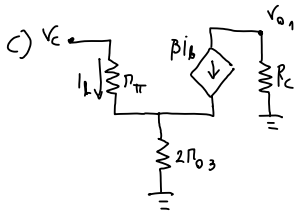
$R_O = -\frac{V_{o1}}{\beta i_b} \Leftrightarrow -R_O \cdot \beta \cdot \frac{V_1}{r_\pi} = V_{o1}$

$A_{d_1} = \frac{V_{o1}}{V_d} = -\frac{R_O \beta}{2 \cdot r_\pi} = -38.46$

$A_{d_2} = \frac{V_{o2}}{V_d} = \frac{R_O \beta}{2 \cdot r_\pi} = 38.46$

$A_d = \frac{V_{o12}}{V_d} = -\frac{R_O \beta}{r_\pi} = -76.923$

c)



$r_{o3} = \frac{V_A}{I_{C_3}} = 25\,k\Omega$

$V_C = i_b r_\pi + (1+\beta) i_b \cdot 2 r_{o3}$

$V_{o1} = -\beta i_b R_C$

$\Rightarrow \frac{V_{o1}}{V_C} = -\frac{\beta R_C}{r_\pi + (1+\beta) \cdot 2 \cdot r_{o3}} = -0.039$

$\frac{V_{o1}}{V_C} = -0.039 \Rightarrow A_{C_{12}} = 0$

d)

Max

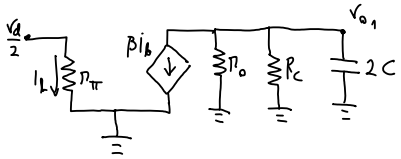
Q_1 e Q_2: $V_{C\,Max} = \overbrace{V_{CC} - R_C I_{C_1}}^{\text{Para não saturar}} = 2V$

Min

Q_3: $V_{C\,Mim} = V_{EE} + \overbrace{V_{CE_3}}^{\text{Assumindo limite da saturação}} + V_{BE_1} = -2.6V$

$V_{CE_3} = 0.7V$

e) T. Bissecção



$\Delta = j\omega$

$V_{o1} = -(r_o // R_C // \frac{1}{2C\Delta}) \beta i_b$

$i_b = r_\pi \frac{V_d}{2}$

$\left(\frac{1}{r_o} + \frac{1}{R_C} + 2C\Delta\right)^{-1} = \left(\frac{R_C + r_o + 2C r_o R_C \Delta}{r_o R_C}\right)^{-1}$

$A_{d_1} = -\frac{r_\pi \beta}{2} \cdot \frac{r_o R_C}{R_C + r_o + 2C r_o R_C \Delta}$

$A_d = -\frac{\beta r_\pi r_o R_C}{1 + \frac{2C r_o R_C}{R_C + r_o}\Delta}$ $\Rightarrow$ freq. corte -3dB = freq. polo

$\omega_p = \frac{R_C + r_o}{2C r_o R_C} \Rightarrow f_C = \frac{R_C + r_o}{4\pi C r_o R_C} = 41\,MHz$