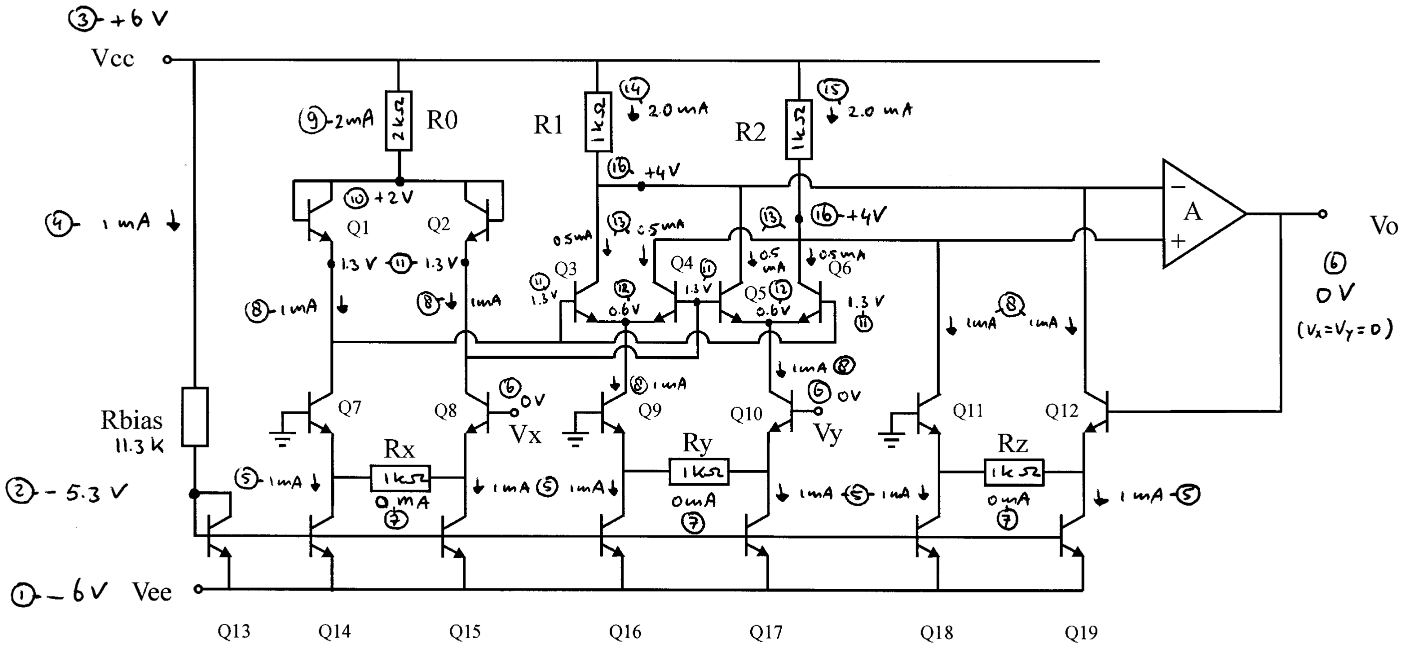
1b)



⑨ $= I_7 + I_8$

② : $V_{be13} = 0.7$ V. ④ $= 6-(-5.3)/11.3$ k ⑤ 6x espelho de corrente ⑦ simetria ⑧ $\alpha = 1$ ⑩ $= +6V - 2 \cdot 2$

⑪ $V_{be1} = V_{be2} = 0.7$ V ⑫ $V_{be3} = V_{be4} = V_{be5} = V_{be6} = 0.7$ V ⑬ simetria ⑭ $= I_3 + I_5 + I_{12}$

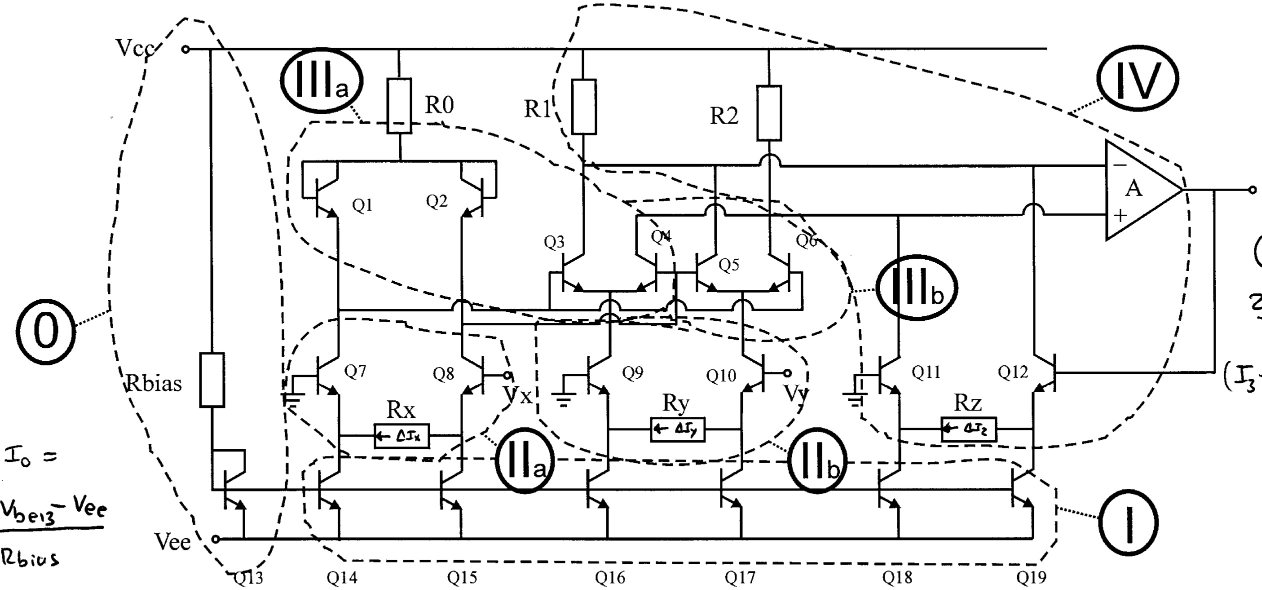
⑮ $= I_4 + I_6 + I_{11}$ ⑯ $+6V - 2 \times 1 = 4V$

* Polarização / ponto de funcionamento

Electrónica III F.P. 6

1c)

(IIIa) $I_3 - I_4 = \frac{I_3 + I_4}{I_1 + I_2}(I_2 - I_1)$ (IIIb) $I_6 - I_5 = \frac{I_6 + I_5}{I_1 + I_2}(I_2 - I_1)$



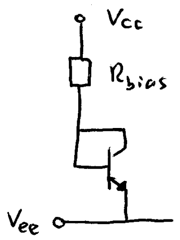
(IV) $\frac{2V_0}{R_z} = (I_3 - I_4) - (I_6 - I_5)$

(0) $I_0 = \frac{V_{cc} - V_{be13} - V_{ee}}{R_{bias}} = 1\,mA$

(IIa) : $\Delta I_x = \frac{V_x}{R_x}$ (IIb) $\Delta I_y = \frac{V_y}{R_y}$

(I) espelhos de corrente $I_0 = 1\,mA$

(0)



$$V_b = V_c = V_{ee} + 0.7\,V = -6 + 0.7\,V = -5.3\,V$$

$$I_o = (V_{cc} - V_b)/R_{bias} = \frac{6 - 0.7 + 6\ V}{11.3\,k\Omega} = 1\,mA$$

(I) 6 x espelho de corrente

$$I_x \equiv I_{14} = I_{15} = I_o = 1\,mA$$

$$I_y \equiv I_{16} = I_{17} = I_o = 1\,mA$$

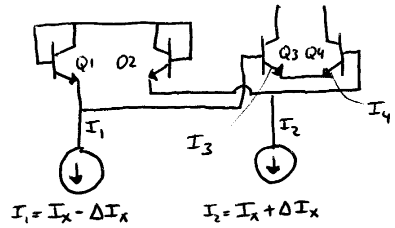
$$I_z \equiv I_{18} = I_{19} = I_o = 1\,mA$$

(IIa) igual a folha de problemas 5

$$\Delta I_x = V_x / R_x$$

(IIb) $\Delta I_y = V_y / R_y$

(IIIa)



$$I_1 + I_2 = (I_x - \Delta I_x) + (I_x + \Delta I_x)$$

$$= 2\,I_x$$

$$I_2 - I_1 = 2\,\Delta I_x$$

Malha fechada : $\sum \Delta V = 0$

$$V_{be1} + V_{be3} - V_{be4} - V_{be2} = 0$$

$$V_T \ln \frac{I_1}{I_s} + V_T \ln \frac{I_3}{I_s} - V_T \ln \frac{I_4}{I_s} - V_T \ln \frac{I_2}{I_s} = 0$$

$$\frac{I_1 I_3}{I_4 I_2} = 1 \qquad \frac{I_3}{I_4} = \frac{I_2}{I_1}$$

$$\frac{I_3}{I_4} = \frac{I_2}{I_1}$$

$$\frac{I_3}{I_4} - 1 = \frac{I_2}{I_1} - 1$$

$$\frac{I_3 - I_4}{I_4} = \frac{I_2 - I_1}{I_1}$$

$$I_3 - I_4 = \frac{I_4}{I_1}(I_2 - I_1)$$

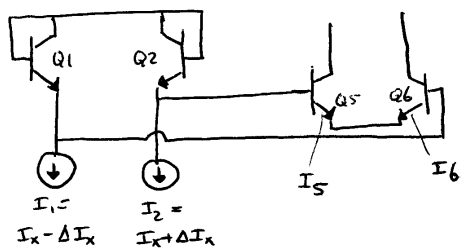
$$\frac{I_3}{I_4} + 1 = \frac{I_2}{I_1} + 1$$

$$\frac{I_3 + I_4}{I_4} = \frac{I_2 + I_1}{I_1}$$

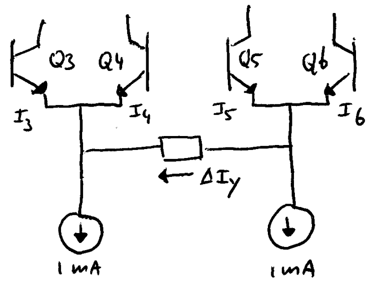
$$\frac{I_4}{I_1} = \frac{(I_3 + I_4)}{(I_1 + I_2)}$$

$$\boxed{(I_3 - I_4) = \left(\frac{I_3 + I_4}{I_1 + I_2}\right)(I_2 - I_1)}$$

III b



$$\boxed{(I_6 - I_5) = \frac{(I_5 + I_6)}{(I_1 + I_2)}(I_2 - I_1)}$$



$$I_3 + I_4 = I_y - \Delta I_y$$

$$I_5 + I_6 = I_y + \Delta I_y$$

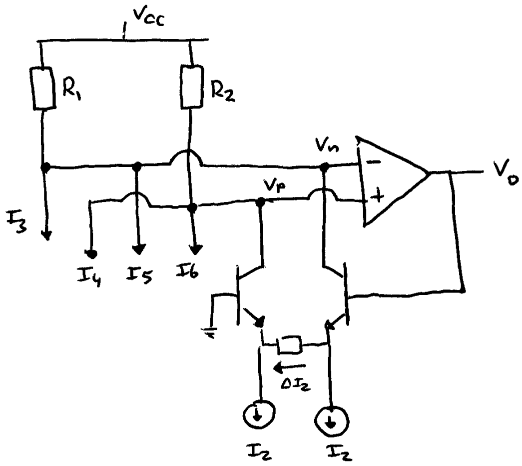
$$\left(\begin{array}{l} I_1 + I_2 = 2 I_x \\ I_2 - I_1 = 2 \Delta I_x \end{array}\right)$$

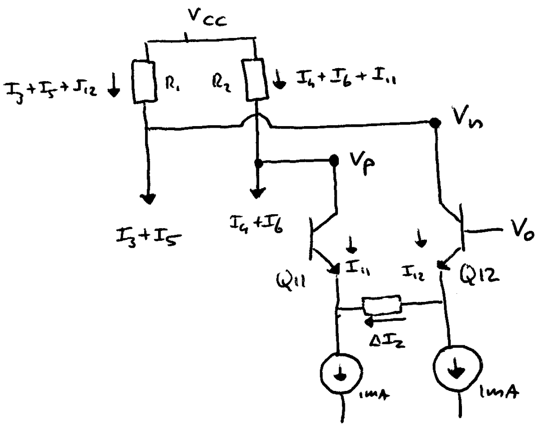
$$(I_3 - I_4) = \frac{I_y - \Delta I_y}{2 I_x} \cdot 2 \Delta I_x$$

$$(I_6 - I_5) = \frac{I_y + \Delta I_y}{2 I_x} \cdot 2 \Delta I_x$$

$$(I_3 - I_4) - (I_6 - I_5) = - 2 \frac{\Delta I_y}{I_x} \cdot \Delta I_x$$

IV





$$\Delta I_2 = \frac{V_o}{R_2}$$

$$\Downarrow$$

$$(I_{11} - I_{12}) = 2 \Delta I_2 = 2 \frac{V_o}{R_2}$$

$$V_n = V_{cc} - (I_3 + I_5 + I_{12}) \cdot R_1$$

$$V_p = V_{cc} - (I_4 + I_6 + I_{11}) \cdot R_2$$

$R_1 = R_2$

opamp ideal : $V_n = V_p$

$V_n = V_p \Rightarrow I_3 + I_5 + I_{12} = I_4 + I_6 + I_{11}$

$\Rightarrow (I_3 - I_4) - (I_6 - I_5) = (I_{11} - I_{12})$

$\Rightarrow -2 \frac{\Delta I_y}{I_x} \cdot \Delta I_x = 2 \Delta I_z$

$\Delta I_y = \frac{V_y}{R_y}, \quad \Delta I_x = \frac{V_x}{R_x}, \quad \Delta I_z = \frac{V_o}{R_z}$

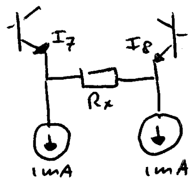
$\Rightarrow -\frac{V_y}{R_y} \cdot \frac{1}{I_x} \cdot \frac{V_x}{R_x} = \frac{V_o}{R_z}$

$\Rightarrow V_o = -\frac{R_z}{R_x R_y I_x} \cdot V_x V_y$

$R_x = 1k\Omega, \quad R_y = 1k\Omega, \quad R_z = 1k\Omega, \quad I_x = 1mA$

$V_o = -V_x V_y \quad (V)$

1d:) Veja folha de problemas 5



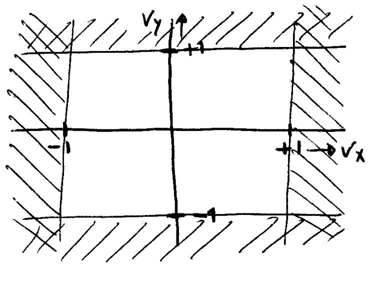
$I_7 > 0$ e $I_8 > 0 \Rightarrow$

$|\Delta I_x| < 1mA$

$\left|\frac{V_x}{R_x}\right| < 1mA \qquad R_x = 1k\Omega$

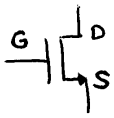
$-1V < V_x < 1V$

V_y: igual : $-1V < V_y < 1V$



2) transístor FET em zona linear / triod:

$$I_D = \beta \left((V_{GS} - V_T) V_{DS} - \frac{V_{DS}^2}{2} \right)$$



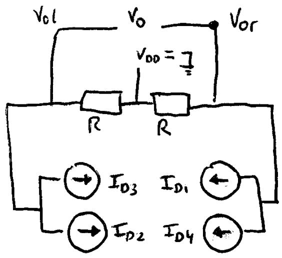
(nota: em saturação: $I_D = \frac{\beta}{2} (V_{GS} - V_T)^2$)

$$\left.\begin{aligned}
I_{D1} &= \beta_1 \left[\left(V_{GS} - \frac{V_y}{2} - V_{T1}\right)\left(\frac{V_x}{2}\right) - \frac{1}{2}\left(\frac{V_x}{2}\right)^2 \right] \\
I_{D2} &= \beta_2 \left[\left(V_{GS} - \frac{V_y}{2} - V_{T2}\right)\left(-\frac{V_x}{2}\right) - \frac{1}{2}\left(\frac{V_x}{2}\right)^2 \right] \\
I_{D3} &= \beta_3 \left[\left(V_{GS} + \frac{V_y}{2} - V_{T3}\right)\left(\frac{V_x}{2}\right) - \frac{1}{2}\left(\frac{V_x}{2}\right)^2 \right] \\
I_{D4} &= \beta_4 \left[\left(V_{GS} + \frac{V_y}{2} - V_{T4}\right)\left(-\frac{V_x}{2}\right) - \frac{1}{2}\left(-\frac{V_x}{2}\right)^2 \right]
\end{aligned}\right\} \Rightarrow$$

$$\begin{cases}
I_{D1} + I_{D4} = \beta \cdot \left[-\frac{V_x V_y}{2} - \frac{V_x V_x}{4} \right] \\
I_{D2} + I_{D3} = \beta \cdot \left[+\frac{V_x V_y}{2} - \frac{V_x V_x}{4} \right]
\end{cases}$$

$\beta_1 = \beta_2 = \beta_3 = \beta_4$

$V_{T1} = V_{T2} = V_{T3} = V_{T4}$



modelo pequenas sinais

$$V_{or} = R\,(I_{D1} + I_{D4})$$

$$V_{ol} = R\,(I_{D2} + I_{D3})$$

$$V_o = V_{ol} - V_{or} = R\,(I_{D1} + I_{D4} - I_{D2} - I_{D3})$$

$$= -\beta\, V_x V_y\, R$$