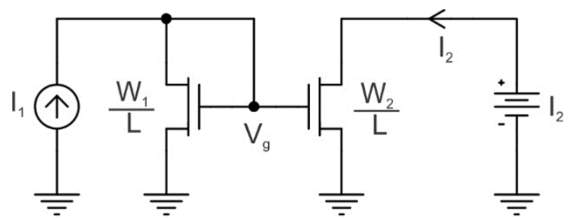
## *Descasamento do Espelho de Corrente*




### Equações do modelo EKV

$$\frac{V_G - V_{T0}}{n\phi_T} - \sqrt{1 + 4\frac{I_D}{I_{ESP}}} - \ln\left(\sqrt{1 + 4\frac{I_D}{I_{ESP}}} - 1\right) + \left(1 + \ln(2)\right) = 0$$

$$I_{ESP} = 2n\phi_T^2 k_p \frac{W}{L} \rightarrow \mathrm{IC} = \frac{I_D}{I_{ESP}}$$

$$\frac{V_G - V_{T01}}{n\phi_T} - \sqrt{1 + 4\frac{I_1}{I_{ESP1}}} - \ln\left(\sqrt{1 + 4\frac{I_1}{I_{ESP1}}} - 1\right) + \left(1 + \ln(2)\right) = 0$$

$$\frac{V_G - V_{T02}}{n\phi_T} - \sqrt{1 + 4\frac{I_2}{I_{ESP2}}} - \ln\left(\sqrt{1 + 4\frac{I_2}{I_{ESP2}}} - 1\right) + \left(1 + \ln(2)\right) = 0$$

### Calculo das variações

$$\frac{\Delta V_G}{n\phi_T} - \frac{\Delta V_{T01}}{n\phi_T} + \frac{2I_1}{I_{ESP1}^2} \frac{1}{\sqrt{1 + 4\frac{I_1}{I_{ESP1}}} - 1} \Delta I_{ESP1} = 0$$

$$\frac{\Delta V_G}{n\phi_T} - \frac{\Delta V_{T02}}{n\phi_T} + \frac{2I_2 \Delta I_{ESP2}}{I_{ESP2}^2} \frac{1}{\sqrt{1 + 4\frac{I_2}{I_{ESP2}}} - 1} - \frac{2\Delta I_2}{I_{ESP2}} \frac{1}{\sqrt{1 + 4\frac{I_2}{I_{ESP2}}} - 1} = 0$$

Valores nominais

$$\frac{I_1}{I_{ESP1}} = \frac{I_2}{I_{ESP2}} = IC$$

$$V_{T01} = V_{T02} = V_{T0}$$

$$k_{p_1} = k_{p_2} = k_p$$

$$\frac{\Delta V_G}{n\phi_T} - \frac{V_{T0}}{n\phi_T}\frac{\Delta V_{T01}}{V_{T0}} + \frac{2IC}{\sqrt{1+4IC}-1}\frac{\Delta I_{ESP1}}{I_{ESP1}} = 0$$

$$\frac{\Delta V_G}{n\phi_T} - \frac{V_{T0}}{n\phi_T}\frac{\Delta V_{T02}}{V_{T0}} + \frac{2IC}{\sqrt{1+4IC}-1}\frac{\Delta I_{ESP2}}{I_{ESP2}} - \frac{2IC}{\sqrt{1+4IC}-1}\frac{\Delta I_2}{I_2} = 0$$

$$\frac{\Delta I_2}{I_2} = \frac{\Delta I_{ESP2}}{I_{ESP2}} - \frac{\Delta I_{ESP1}}{I_{ESP1}} + \frac{V_{T0}}{n\phi_T}\frac{\sqrt{1+4IC}-1}{2IC}\left(\frac{\Delta V_{T01}}{V_{T0}} - \frac{\Delta V_{T02}}{V_{T0}}\right)$$

$$\frac{\Delta I_{ESP}}{I_{ESP}} = \frac{2n\phi_T^2 \Delta k_p \frac{W}{L}}{2n\phi_T^2 k_p \frac{W}{L}} = \frac{\Delta k_p}{k_p}$$

$$\frac{\Delta I_2}{I_2} = \frac{\Delta k_{p2}}{k_p} - \frac{\Delta k_{p1}}{k_p} + \frac{V_{T0}}{n\phi_T}\frac{\sqrt{1+4IC}-1}{2IC}\left(\frac{\Delta V_{T01}}{V_{T0}} - \frac{\Delta V_{T02}}{V_{T0}}\right)$$

## Cálculo da variância relativa

$$E\left[\left(\frac{\Delta I_2}{I_2}\right)^2\right] = E\left[\left(\frac{\Delta k_{p2}}{k_{p2}} - \frac{\Delta k_{p1}}{k_{p1}} + \frac{V_{T0}}{n\phi_T}\frac{\sqrt{1+4IC}-1}{2IC}\left(\frac{\Delta V_{T01}}{V_{T0}} - \frac{\Delta V_{T02}}{V_{T0}}\right)\right)^2\right]$$

$$\hat{\sigma}^2_{\Delta I_2} = \left(\frac{1}{W_1 L} + \frac{1}{W_2 L}\right)\hat{A}^2_{k_p} + \left(\frac{V_{T0}}{n\phi_T}\frac{\sqrt{1+4IC}-1}{2IC}\right)^2\left(\frac{1}{W_1 L} + \frac{1}{W_2 L}\right)\hat{A}^2_{V_{T0}}$$

$$W_1 = N_1 W$$

$$W_2 = N_2 W$$

## Variância

$$\hat{\sigma}^2_{\Delta I_2} = \left(\frac{N_1 + N_2}{N_1 N_2}\right)\left(\frac{\hat{A}^2_{k_p}}{WL} + \frac{V^2_{T0}}{n^2\phi^2_T}\left(\frac{\sqrt{1+4IC}-1}{2IC}\right)^2\frac{\hat{A}^2_{V_{T0}}}{WL}\right)$$

## Desvio padrão

$$\hat{\sigma}_{\Delta I_2} = \sqrt{\left(\frac{N_1 + N_2}{N_1 N_2}\right)\left(\frac{\hat{A}^2_{k_p}}{WL} + \frac{V^2_{T0}}{n^2\phi^2_T}\left(\frac{\sqrt{1+4IC}-1}{2IC}\right)^2\frac{\hat{A}^2_{V_{T0}}}{WL}\right)} \longrightarrow$$

Distribuição normal

$$\pm 3\sigma = 99.7\%$$

## *Limites para a Inversão Forte e Fraca*

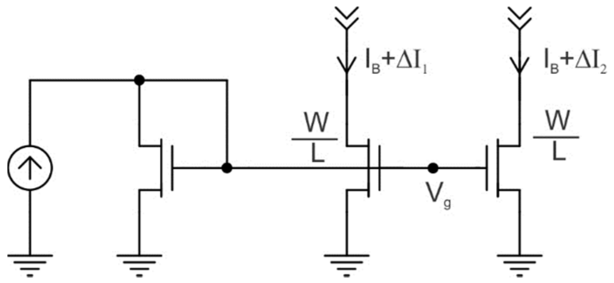
$$\hat{\sigma}_{\Delta I_2} = \sqrt{\left(\frac{N_1 + N_2}{N_1 N_2}\right)\left(\frac{\hat{A}_{k_p}^2}{WL} + \frac{V_{T0}^2}{n^2\phi_T^2}\left(\frac{\sqrt{1+4IC}-1}{2IC}\right)^2 \frac{\hat{A}_{V_{T0}}^2}{WL}\right)}$$

Inversão Fraca $\xrightarrow{\text{IC<<1}}$ $$\hat{\sigma}_{\Delta I_2} = \sqrt{\left(\frac{N_1 + N_2}{N_1 N_2}\right)\left(\frac{\hat{A}_{k_p}^2}{WL} + \left(\frac{V_{T0}}{n\phi_T}\right)^2 \frac{\hat{A}_{V_{T0}}^2}{WL}\right)}$$

Inversão Forte $\xrightarrow{\text{IC>>1}}$ $$\hat{\sigma}_{\Delta I_2} = \sqrt{\left(\frac{N_1 + N_2}{N_1 N_2}\right)\left(\frac{\hat{A}_{k_p}^2}{WL} + \frac{V_{T0}^2}{n^2\phi_T^2 IC}\frac{\hat{A}_{V_{T0}}^2}{WL}\right)}$$

*Descasamento do Espelho de Corrente Duplo*

O espelho de corrente duplo é usado na saída de OpAmps e OTAs. Neste caso não importa a variação da tensão $V_g$, mas somente a diferença entre as duas correntes espelhadas.




$$\frac{V_G - V_{T01}}{n\phi_T} - \sqrt{1+4\frac{I_1}{I_{ESP1}}} - \ln\left(\sqrt{1+4\frac{I_1}{I_{ESP1}}} - 1\right) + \left(1+\ln\left(2\right)\right) = 0$$

$$\frac{V_G - V_{T02}}{n\phi_T} - \sqrt{1+4\frac{I_2}{I_{ESP2}}} - \ln\left(\sqrt{1+4\frac{I_2}{I_{ESP2}}} - 1\right) + \left(1+\ln\left(2\right)\right) = 0$$

$$I_{ESP} = 2n\phi_T^2 k_p \frac{W}{L} \rightarrow \mathrm{IC} = \frac{I_D}{I_{ESP}}$$

## Cálculo das variações

$$-\frac{\Delta V_{T01}}{n\phi_T} + \frac{2I_1\Delta I_{ESP1}}{I_{ESP1}^2}\frac{1}{\sqrt{1+4\frac{I_1}{I_{ESP1}}} - 1} - \frac{2\Delta I_1}{I_{ESP1}}\frac{1}{\sqrt{1+4\frac{I_1}{I_{ESP1}}} - 1} = 0$$

$$-\frac{\Delta V_{T02}}{n\phi_T} + \frac{2I_2\Delta I_{ESP2}}{I_{ESP2}^2}\frac{1}{\sqrt{1+4\frac{I_2}{I_{ESP2}}} - 1} - \frac{2\Delta I_2}{I_{ESP2}}\frac{1}{\sqrt{1+4\frac{I_2}{I_{ESP2}}} - 1} = 0$$

Valores nominais

$$I_1 = I_B$$
$$I_2 = I_B$$
$$I_{ESP1} = I_{ESP}$$
$$I_{ESP2} = I_{ESP}$$
$$IC = \frac{I_B}{I_{ESP}}$$

$$\longrightarrow$$

$$-\frac{\Delta V_{T01}}{n\phi_T} + \frac{2IC}{\sqrt{1+4IC}-1}\frac{\Delta I_{ESP1}}{I_{ESP}} - \frac{2IC}{\sqrt{1+4IC}-1}\frac{\Delta I_1}{I_B} = 0$$

$$-\frac{\Delta V_{T02}}{n\phi_T} + \frac{2IC}{\sqrt{1+4IC}-1}\frac{\Delta I_{ESP2}}{I_{ESP}} - \frac{2IC}{\sqrt{1+4IC}-1}\frac{\Delta I_2}{I_B} = 0$$

$$\frac{\Delta I_1 - \Delta I_2}{I_B} = \left(\frac{\sqrt{1+4IC}-1}{2IC}\right)\left(\frac{\Delta V_{T02}}{V_{T0}} - \frac{\Delta V_{T01}}{V_{T0}}\right)\frac{V_{T0}}{n\phi_T} + \left(\frac{\Delta I_{ESP1}}{I_{ESP}} - \frac{\Delta I_{ESP2}}{I_{ESP}}\right)$$

$$\hat{\sigma}^2_{\Delta I} = E\left[\left(\frac{\Delta I_1 - \Delta I_2}{I_B}\right)^2\right]$$

$$\frac{\Delta I_{ESP}}{I_{ESP}} = \frac{\Delta k_p}{k_p}$$

$$\hat{\sigma}^2_{\Delta I} = \frac{V_{T0}^2}{2n^2\phi_T^2}\left(\frac{\sqrt{1+4IC}-1}{IC}\right)^2\frac{\hat{A}^2_{V_{T0}}}{WL} + 2\frac{\hat{A}^2_{k_p}}{WL}$$

$$\hat{\sigma}_{\Delta I} = \sqrt{\frac{V_{T0}^2}{2n^2\phi_T^2}\left(\frac{\sqrt{1+4IC}-1}{IC}\right)^2\frac{\hat{A}^2_{V_{T0}}}{WL} + 2\frac{\hat{A}^2_{k_p}}{WL}} \longrightarrow$$

Distribuição normal

$$\pm 3\sigma = 99.7\%$$

## *Limites para a Inversão Forte e Fraca*

$$\hat{\sigma}_{\Delta I} = \sqrt{\frac{V_{T0}^2}{2n^2\phi_T^2}\left(\frac{\sqrt{1+4IC}-1}{IC}\right)^2 \frac{\hat{A}_{V_{T0}}^2}{WL} + 2\frac{\hat{A}_{k_p}^2}{WL}}$$

Inversão Fraca $\xrightarrow{\text{IC<<1}}$ $\hat{\sigma}_{\Delta I} = \sqrt{\frac{2\hat{A}_{k_p}^2}{WL} + \frac{2V_{T0}^2}{n^2\phi_T^2}\frac{\hat{A}_{V_{T0}}^2}{WL}}$

Inversão Forte $\xrightarrow{\text{IC>>1}}$ $\hat{\sigma}_{\Delta I} = \sqrt{\frac{2V_{T0}^2}{n^2\phi_T^2 IC}\frac{\hat{A}_{V_{T0}}^2}{WL} + 2\frac{\hat{A}_{k_p}^2}{WL}}$

# Final deste Tópico