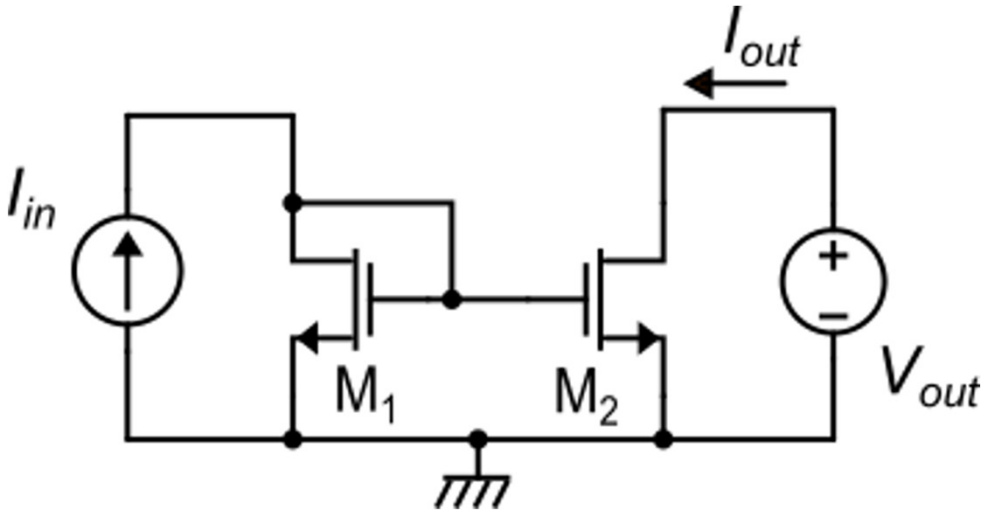
Effect of matching errors in current mirrors

CMOS simple current mirror with $k_M=1$

M1 is nominally identical to M2



$$\Delta I = I_{out} - I_{in} = I_{D2} - I_{D1} = \Delta I_D$$

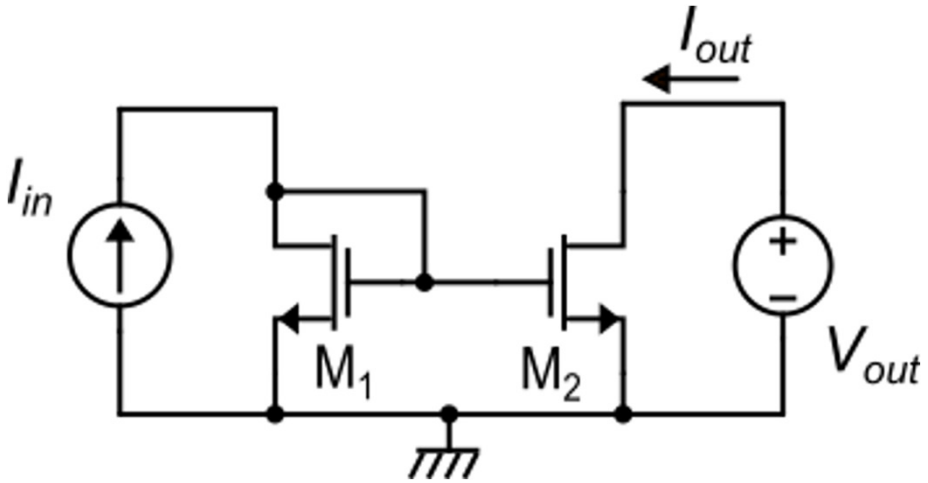
$$I_D \cong \frac{\beta}{2}\left(V_{GS} - V_t\right)^2 \qquad I_D = kA^2B$$

$$B = \beta; \quad A = \left(V_{GS} - V_t\right)$$

$$\frac{\Delta I_D}{I_D} = 2\frac{\Delta A}{A} + \frac{\Delta B}{B} \qquad \Delta A = -\Delta V_t$$

$$\frac{\Delta I}{I} = \frac{\Delta I_D}{I_D} = \frac{\Delta\beta}{\beta} - \frac{2\Delta V_t}{\left(V_{GS} - V_t\right)}$$

Standard deviations

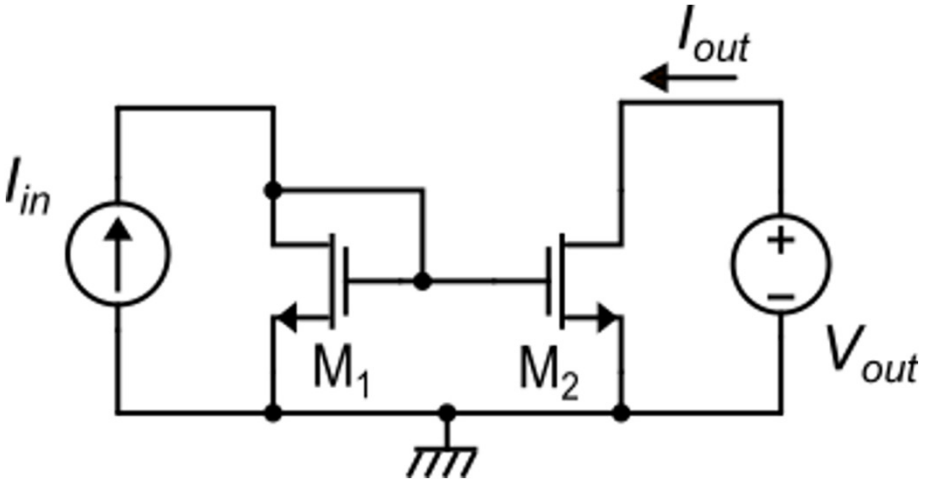


$$\sigma_{\frac{\Delta I_D}{I_D}} = \sqrt{\sigma^2_{\frac{\Delta\beta}{\beta}} + \left(\frac{2\sigma_{\Delta V_t}}{V_{GS} - V_t}\right)^2}$$

$$\frac{\Delta I}{I} = \frac{\Delta I_D}{I_D} = \frac{\Delta\beta}{\beta} - \frac{2\Delta V_t}{(V_{GS} - V_t)}$$

$$\sigma_{\frac{\Delta\beta}{\beta}} = \frac{C_\beta}{\sqrt{WL}}$$

$$\sigma_{V_t} = \frac{C_{V_t}}{\sqrt{WL}}$$



Examples

$$\sigma_{\frac{\Delta\beta}{\beta}} = \frac{C_\beta}{\sqrt{WL}} \quad \sigma_{V_t} = \frac{C_{V_t}}{\sqrt{WL}}$$

$$\sigma_{\frac{\Delta I_D}{I_D}} = \sqrt{\sigma^2_{\frac{\Delta\beta}{\beta}} + \left(\frac{2\sigma_{\Delta V_t}}{V_{GS} - V_t}\right)^2}$$

$$C_\beta = 0.03\ \mu\text{m}$$

$$C_{V_t} = 8.5\ \text{mV}\cdot\mu\text{m}$$

Case 1: L=W=1µm
V_{GS}-V_t =100 mV

$$\sigma_{\frac{\Delta\beta}{\beta}} = 0.03 \quad \frac{2\sigma_{\Delta V_t}}{V_{GS} - V_t} = 0.17 \quad \sigma_{\frac{\Delta I_D}{I_D}} = 0.173\ \ (17.3\%)$$

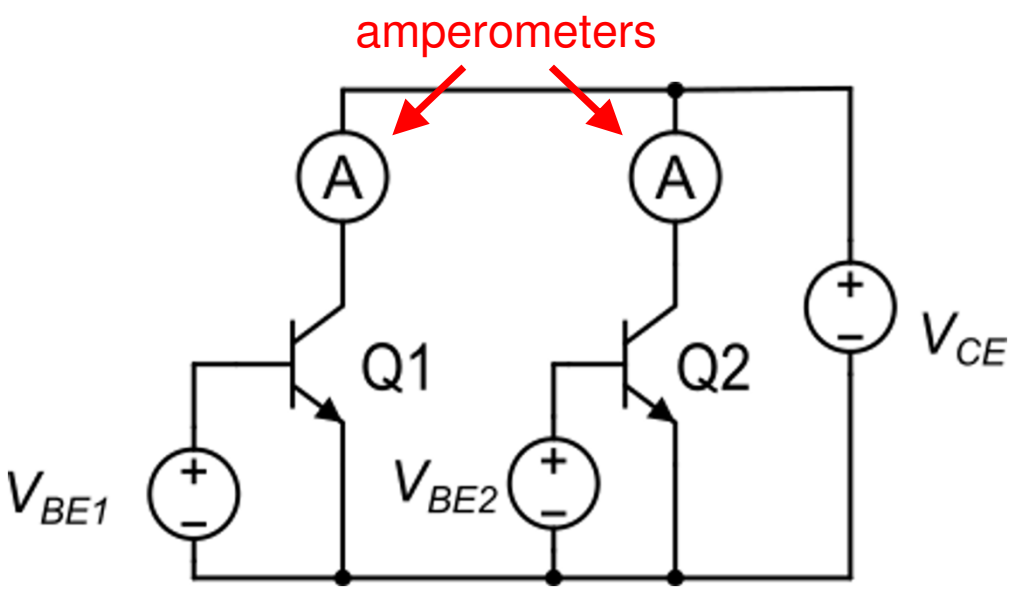
Case 1: L=W=1µm
V_{GS}-V_t =500 mV

$$\sigma_{\frac{\Delta\beta}{\beta}} = 0.03 \quad \frac{2\sigma_{\Delta V_t}}{V_{GS} - V_t} = 0.034 \quad \sigma_{\frac{\Delta I_D}{I_D}} = 0.0453\ \ (4.53\%)$$

Case 1: **L=W=10 µm**
V_{GS}-V_t =500 mV

$$\sigma_{\frac{\Delta\beta}{\beta}} = 0.003 \quad \frac{2\sigma_{\Delta V_t}}{V_{GS} - V_t} = 0.0034 \quad \sigma_{\frac{\Delta I_D}{I_D}} = 0.00453\ \ (0.453\%)$$

Matching in BJT: process parameters



Q1 and Q2 are nominally identical and placed in the same chip. They are affected by matching errors

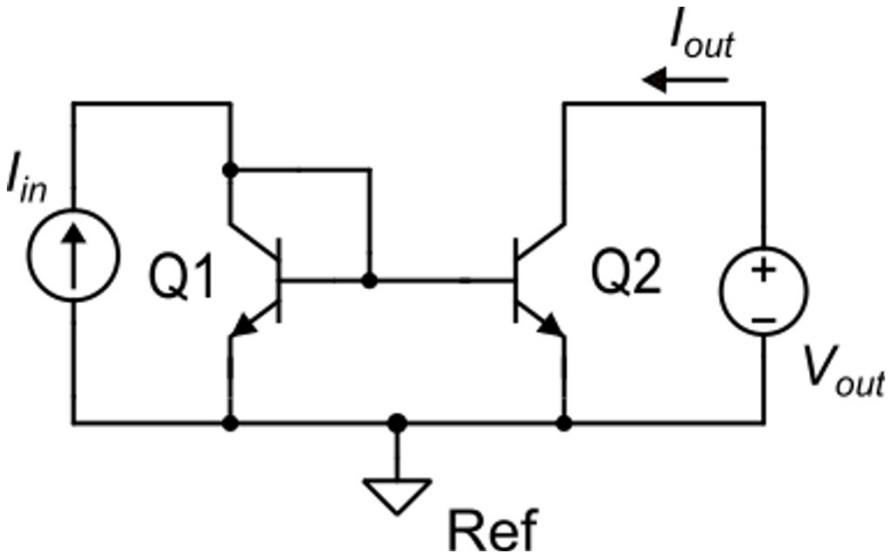
Q1 and Q2 are biased with identical V_{CE}>> V_{CESAT} and individual V_{BE} voltages such that Q1 and Q2 carry the same collector current

$$I_C = I_S e^{\frac{V_{BE}}{V_t}}\left(1+\frac{V_{CB}}{V_A}\right) \cong I_S e^{\frac{V_{BE}}{V_t}} \Rightarrow V_{BE} = V_T \ln\left(\frac{I_C}{I_S}\right)$$

$$\Delta V_{BE} = V_T\left(\frac{\Delta I_C}{I_C} - \frac{\Delta I_S}{I_S}\right) \qquad I_{C1} = I_{C2} \Rightarrow \Delta I_C = 0 \qquad \Delta V_{BE}^* \triangleq \Delta V_{BE}\big|_{\Delta I_C = 0} = -V_T\left(\frac{\Delta I_S}{I_S}\right)$$

generically The foundry provides $\sigma_{\Delta V_{BE-e}^*}$ (of the minimum size BJT)

Matching errors in BJT current mirrors



$$I_C = I_S e^{\frac{V_{BE}}{V_t}}\left(1+\frac{V_{CB}}{V_A}\right) \cong I_S e^{\frac{V_{BE}}{V_t}}$$

$$\Delta I_C = I_{C2} - I_{C1} \qquad \frac{\Delta I_C}{I_C} = \frac{\Delta I_S}{I_S}$$

$$\Delta V^*_{BE} = -V_T\left(\frac{\Delta I_S}{I_S}\right) \qquad \frac{\Delta I_S}{I_S} = -\frac{\Delta V^*_{BE}}{V_T}$$

$$\sigma_{\frac{\Delta I_C}{I_C}} = \sigma_{\frac{\Delta I_S}{I_S}} = \frac{\sigma_{\Delta V^*_{BE}}}{V_T}$$

typical values: $\sigma_{\Delta V^*_{BE-e}} = 100\ \mu V - 300\ \mu V$

$$\sigma_{\frac{\Delta I_C}{I_C}} = 0.4\times10^{-2} - 1.2\times10^{-2}$$

Note: $\sigma_{\Delta V^*_{BE}} = \frac{\sigma_{\Delta V^*_{BE-e}}}{\sqrt{area}}$