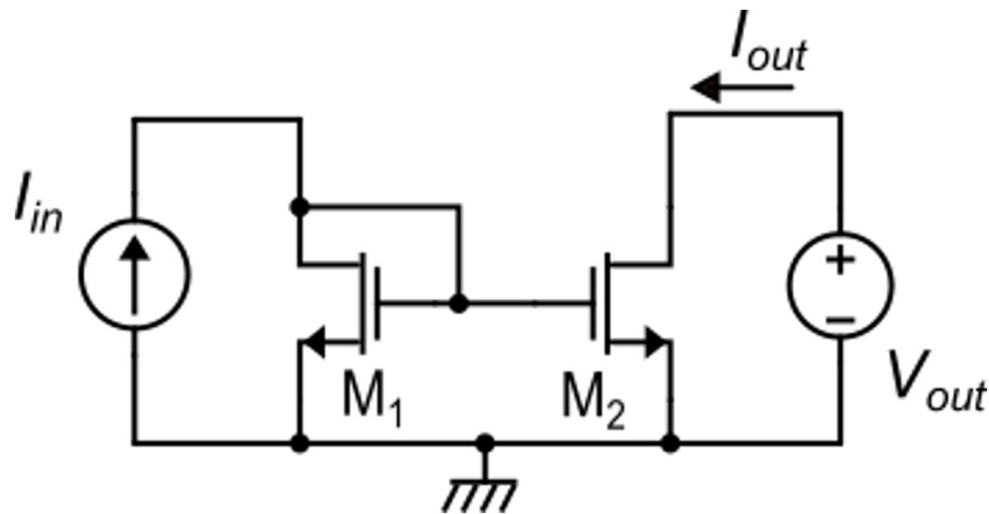


# Effect of matching errors in current mirrors

CMOS simple current mirror  
with  $k_M=1$

M1 is nominally identical to M2



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

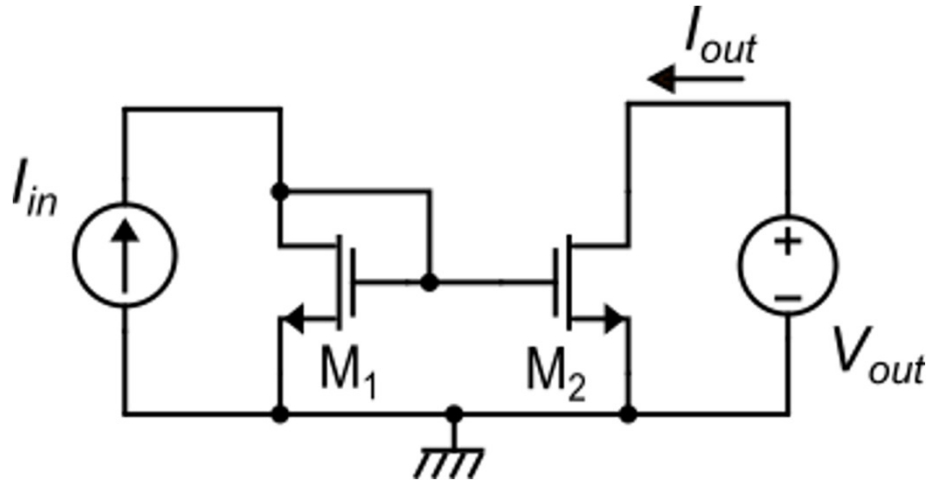
$$I_D \cong \frac{\beta}{2} (V_{GS} - V_t)^2 \quad I_D = kA^2B$$

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

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

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

## Standard deviations

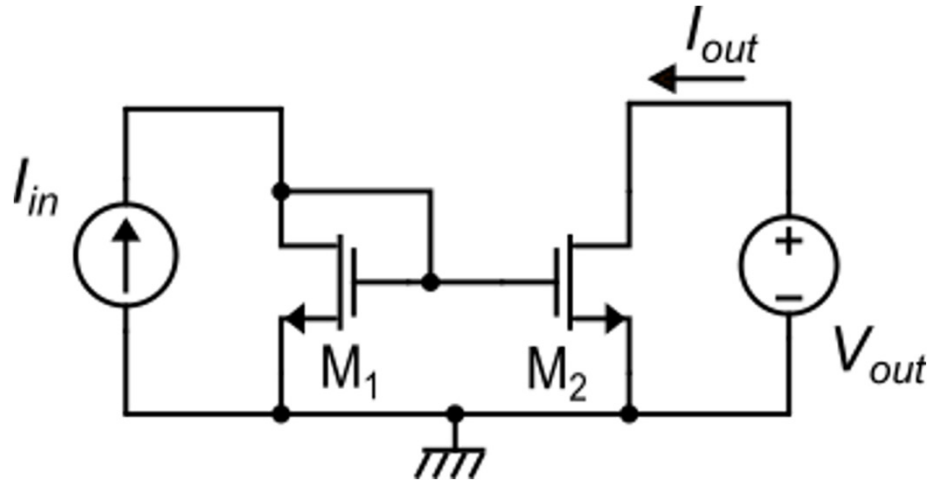


$$\sigma \frac{\Delta I_D}{I_D} = \sqrt{\sigma \frac{\Delta \beta}{\beta}^2 + \left( \frac{2\sigma_{\Delta V_t}}{V_{GS} - V_t} \right)^2}$$

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

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

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



## Examples

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

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

$C_{\beta} = 0.03 \mu\text{m}$   
 $C_{V_t} = 8.5 \text{ mV} \cdot \mu\text{m}$

Case 1:  $L=W=1\mu\text{m}$   
 $V_{GS}-V_t=100 \text{ mV}$

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

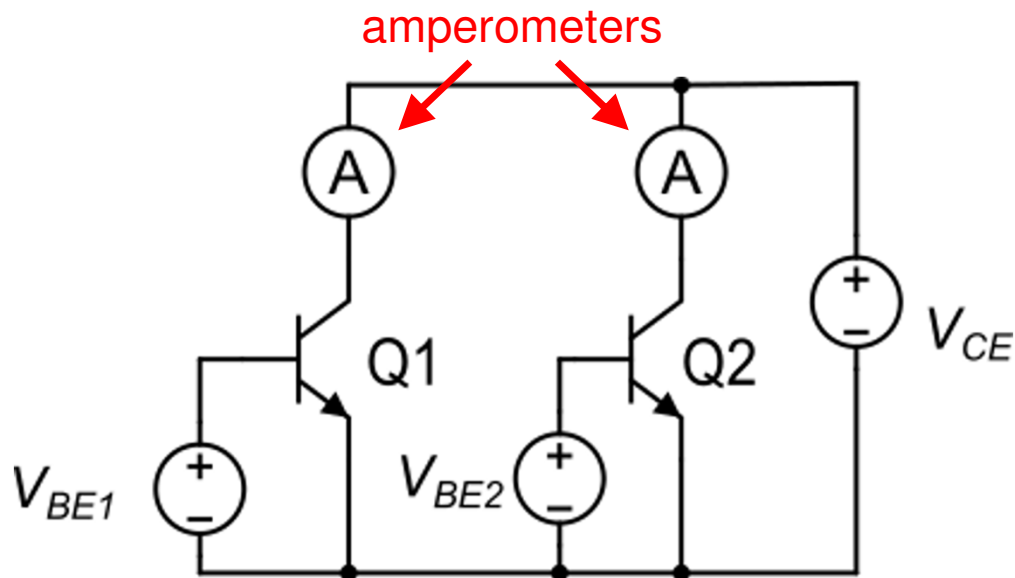
Case 1:  $L=W=1\mu\text{m}$   
 $V_{GS}-V_t=500 \text{ mV}$

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

Case 1:  $L=W=10 \mu\text{m}$   
 $V_{GS}-V_t=500 \text{ mV}$

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

## 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  $V_{CE} \gg V_{CE_{SAT}}$  and individual  $V_{BE}$  voltage such that Q1 and Q2 carry the same collector current

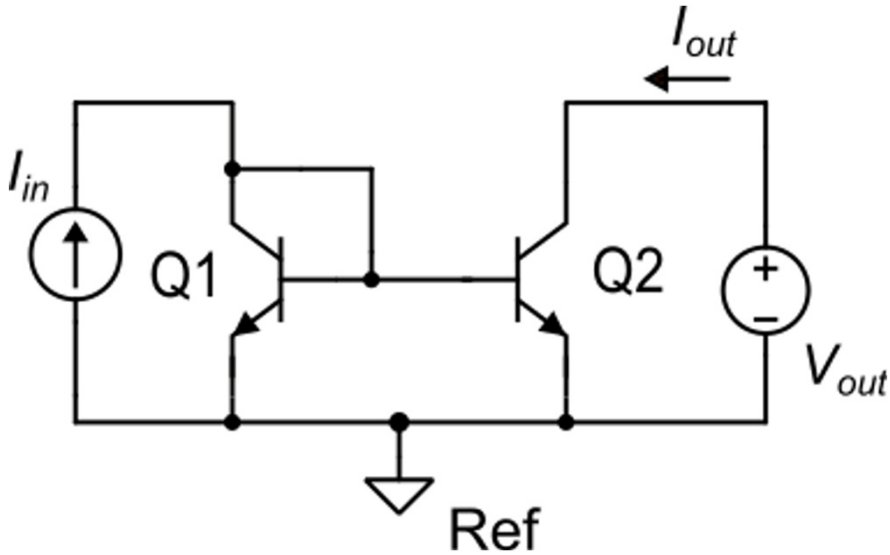
$$I_C = I_S e^{\frac{V_{BE}}{V_t}} \left( 1 + \frac{V_{CB}}{V_A} \right) \cong I_S e^{\frac{V_{BE}}{V_t}} \quad \Rightarrow \quad V_{BE} = V_T \ln \left( \frac{I_C}{I_S} \right)$$

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

generically

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

## Matching errors in BJT current mirrors



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

$$\Delta I_C = I_{C2} - I_{C1}$$

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

$$\frac{\Delta I_C}{I_C} = \frac{\Delta I_S}{I_S}$$

$$\frac{\Delta I_S}{I_S} = -\frac{\Delta V_{BE}^*}{V_T}$$

$$\sigma \frac{\Delta I_C}{I_C} = \sigma \frac{\Delta I_S}{I_S} = \frac{\sigma \Delta V_{BE}^*}{V_T}$$

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

$$\sigma \frac{\Delta I_C}{I_C} = 0.4 \times 10^{-2} - 1.2 \times 10^{-2}$$

Note:  $\sigma_{\Delta V_{BE}^*} = \frac{\sigma_{\Delta V_{BE}^*}}{\sqrt{\text{area}}}$