ECE 515 – Lecture 5

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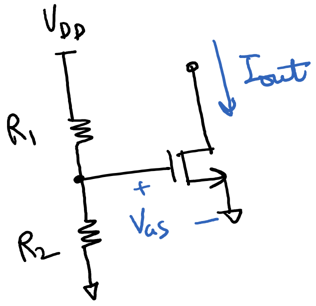
Current Mirrors :

Current Sources are widely used in IC Design



$$I_{out} \simeq \frac{k'_n}{2}\cdot\frac{W}{L}\left(\frac{R_2}{R_1+R_2}V_{DD}-V_{THN}\right)^2$$

I_{out} depends upon ⟶ V_{DD}, process (V_{THN}, k'_n).

Temperature

⇒ I_{out} is poorly defined!

→ PVT variations

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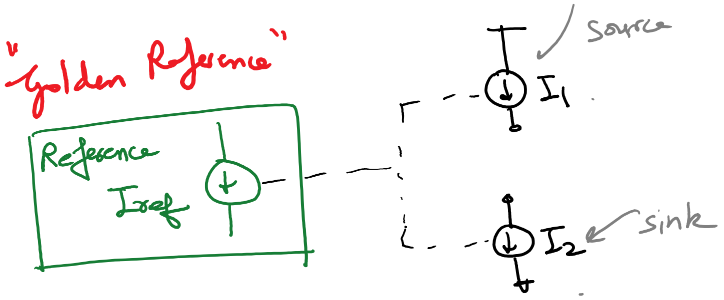
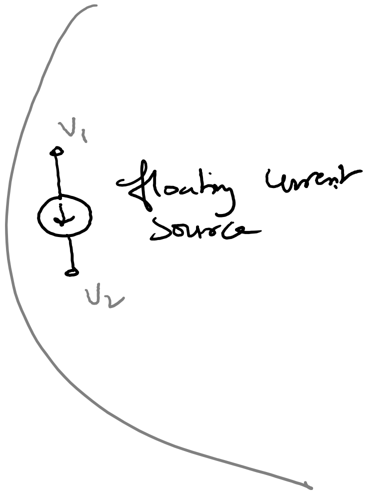
Solution: Create a stable, "precise" current reference and "copy" the currents.





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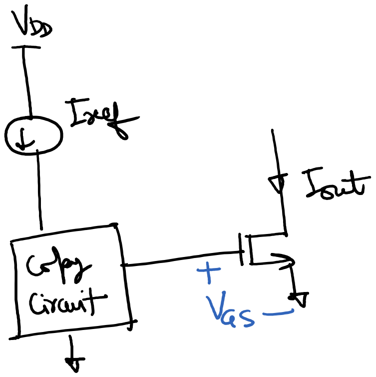
* How to generate copies of a reference current?



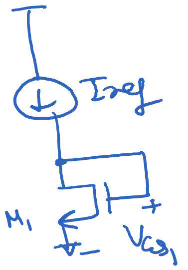
How to assure that $I_{out} = I_{ref}$?

$$I_D = f(V_{GS}, V_{DS})$$

Diode Connect

$$I_D = f(V_{GS})$$

Diode connected



$$I_{ref} = f(V_{GS_1})$$

$$V_{GS_1} = f^{-1}(I_{ref})$$

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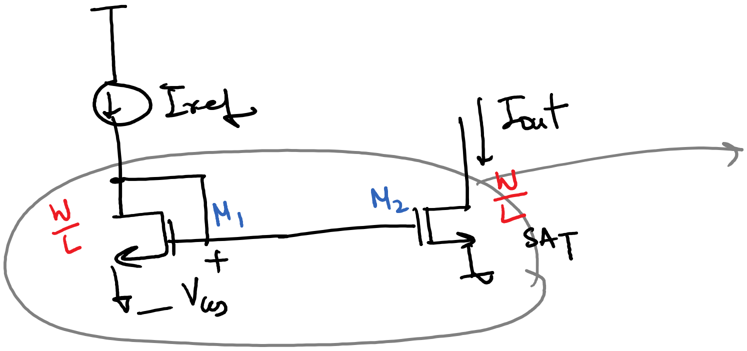
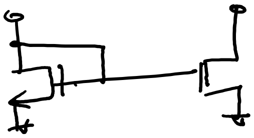


current mirror

$\underline{\underline{\lambda = 0}}$



$$V_{GS} = f^{-1}(I_{ref}) \Rightarrow I_{out} = f(V_{GS}) = f(f^{-1}(I_{ref})) = I_{ref}$$

for $\lambda = 0$,

$$I_{ref} = \frac{1}{2} k'_n \left(\frac{W}{L}\right)_1 (V_{GS} - V_{THN})^2$$

$$I_{out} = \frac{1}{2} k'_n \left(\frac{W}{L}\right)_2 (V_{GS} - V_{THN})^2$$

$$\boxed{\frac{I_{out}}{I_{ref}} = \frac{(W/L)_2}{(W/L)_1}}$$

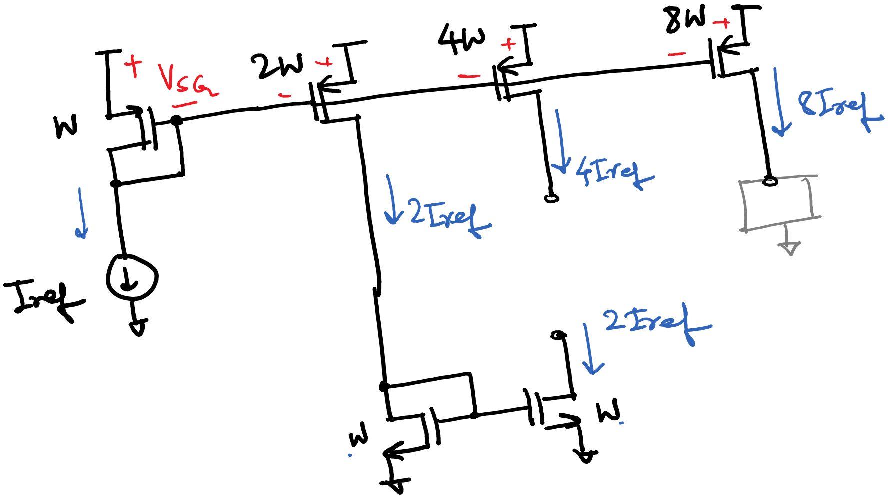
for the same L: $L_1 = L_2$

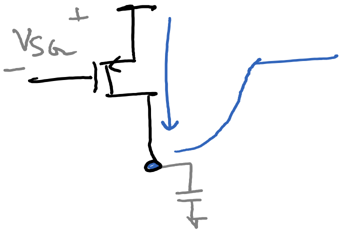
$$\frac{I_{out}}{I_{ref}} = \frac{W_2}{W_1}$$

$$\boxed{I_{out} = \left(\frac{W_2}{W_1}\right) I_{ref}}$$

× Copy and scale currents by W ratio

Same Lengths





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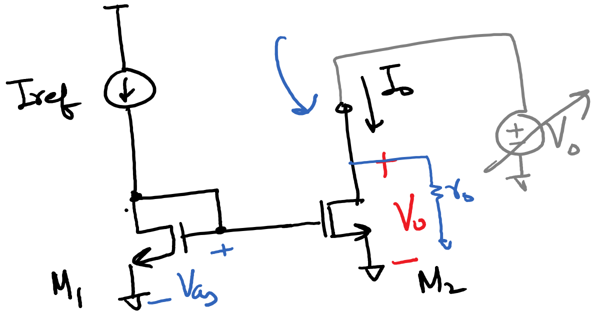
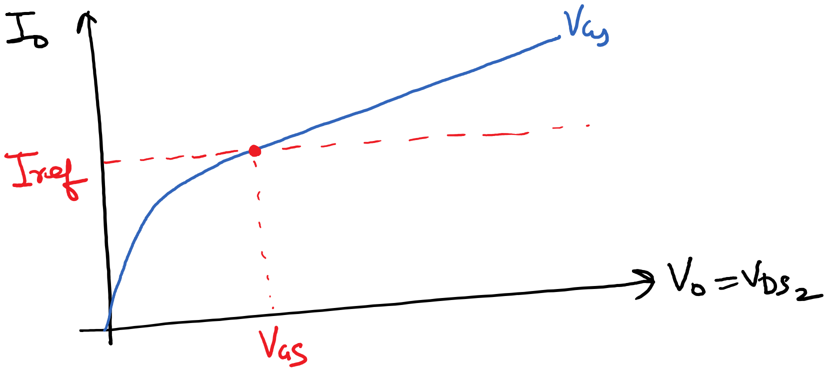
What happens when $\lambda > 0$?





$\Rightarrow V_{DS_2} = V_{DS_1} = V_{GS_1}$ for precise matching of currents

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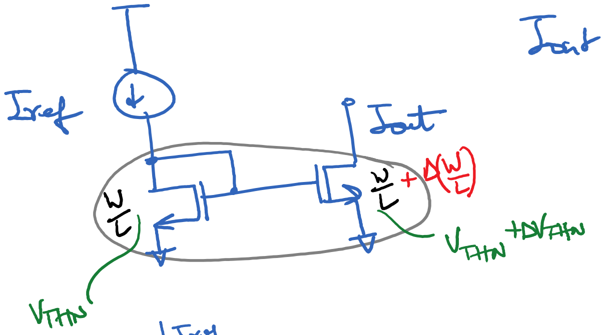
Matching in Current Mirrors:

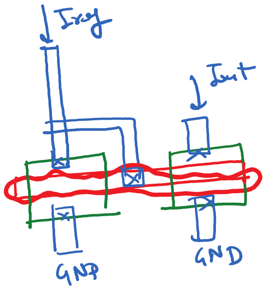
$\lambda = 0$

I_{out} can significantly differ from I_{ref} due to

$\Delta\left(\frac{W}{L}\right)$, ΔV_{THN}, t_{ox}, $\rightarrow C_{ox}'$

major factors





If $y = f(x_1, x_2, \cdots)$ then

$$\Delta y = \underbrace{\frac{\partial f}{\partial x_1}}_{\text{Sensitivity}} \cdot \underbrace{\Delta x_1}_{\text{mismatch}} + \frac{\partial f}{\partial x_2} \cdot \Delta x_2 + \cdots\cdots$$

mismatch is weighed by sensitivity

$$I_D = \frac{KP_n}{2}\left(\frac{W}{L}\right)(V_{GS} - V_{THN})^2$$

$$\Delta I_D = \frac{\partial I_D}{\partial (W/L)} \cdot \Delta\left(\frac{W}{L}\right) + \frac{\partial I_D}{\partial (V_{GS} - V_{THN})} \cdot \Delta(V_{GS} - V_{THN})$$

$$= \frac{KP_n}{2}(V_{GS} - V_{THN})^2 \cdot \Delta\left(\frac{W}{L}\right) - KP_n \cdot \frac{W}{L} \cdot (V_{GS} - V_{THN}) \cdot \Delta V_{THN}$$

normalize by I_D

$$\boxed{\frac{\Delta I_D}{I_D} = \frac{\Delta(W/L)}{W/L} - 2\frac{\Delta V_{THN}}{(V_{GS} - V_{THN})}}$$

$$\sigma^2_{\frac{\Delta I_D}{I_D}} = \frac{\sigma^2_{\Delta(W/L)}}{(W/L)^2} + \frac{4\,\overbrace{\sigma^2_{\Delta V_{THN}}}}{(V_{GS} - V_{THN})^2}$$

To minimize current mismatch

① Overdrive should be large

② $$\sigma_{\Delta V_{THN}} = \frac{A_{V_{THN}}}{\sqrt{WL}}$$

$$\sigma_{\Delta(W/L)} \propto \frac{1}{\sqrt{WL}}$$

large area → more parasitic capacitance

In subV$_T$ designs, we end up

with large 'WL' area to contain mismatch.

↳ slower speed

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Also for $\lambda > 0$

$$\frac{I_{D_2}}{I_{D_1}} = \frac{(W/L)_2}{(W/L)_1} \cdot \boxed{\frac{1+\lambda(V_{DS_2} - V_{DS,sat})}{1+\lambda(V_{DS_1} - V_{DS,sat})}}$$

↳ dominant source of mismatch

↪ cascode