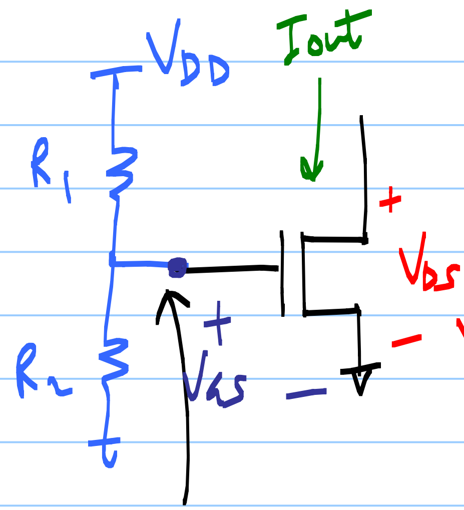
ECE 511 - Lecture 6.

Note Title 2/6/2012

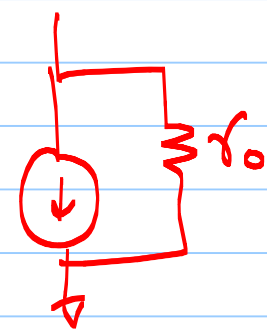
How to design stable current sources.

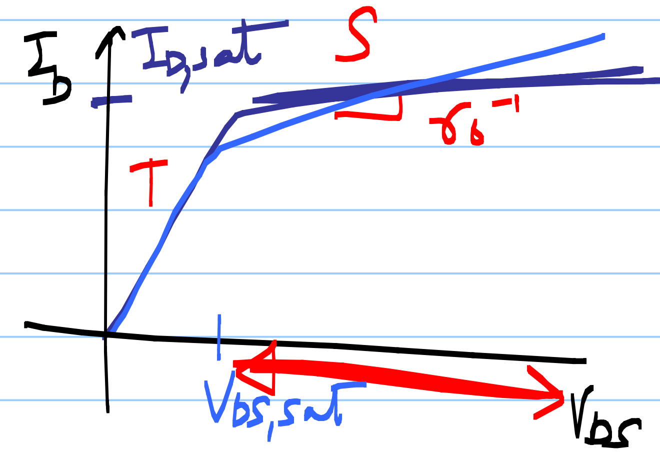
$V_{DD} = 5V$

T



$$V_{DD} \cdot \frac{R_2}{R_1 + R_2}$$





$V_{DS} > V_{DS,sat} = V_{GS} - V_{THN}$

$\lambda = 0$

$\lambda = 0$, SAT

$$\underline{\underline{I_D}} = \frac{KP_n}{2}\frac{W}{L}\left(\frac{V_{DD}\cdot R_2}{R_1+R_2} - V_{THN}\right)^2$$

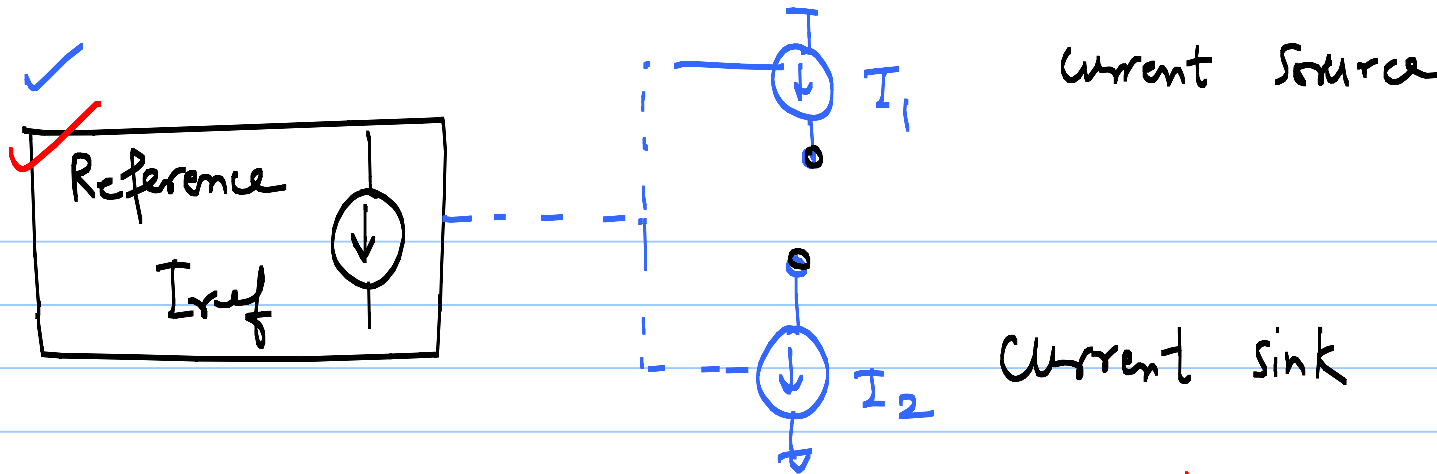
$\mu_n C_{ox}$

depend on $\boxed{V_{DD}}$, T, process

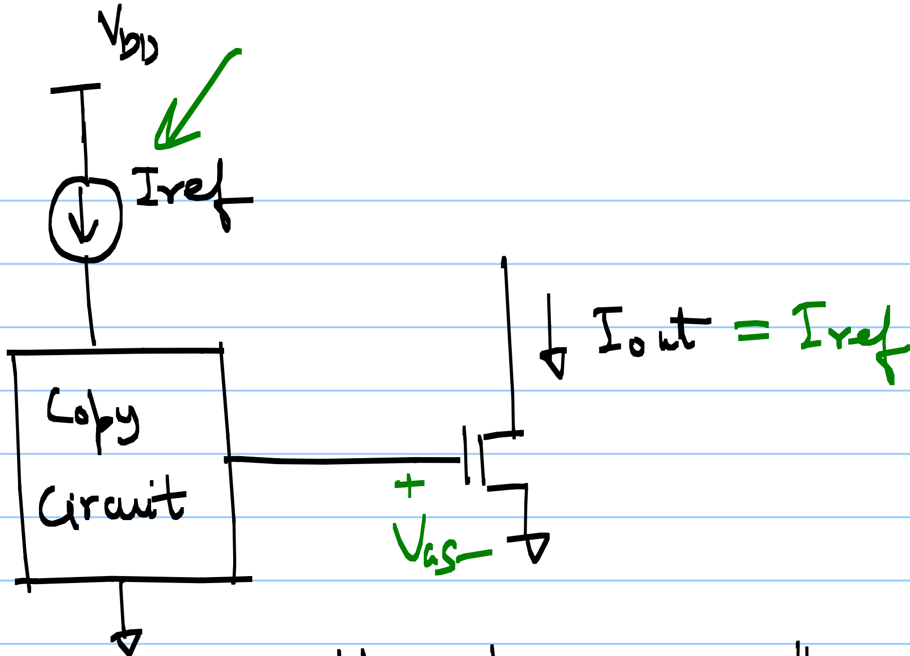
$\underline{\underline{V_{DD}}}$

Iout is poorly defined.

$\hookrightarrow$ need to get rid of V_{DD} sensitivity.



Copy the golden reference on chip

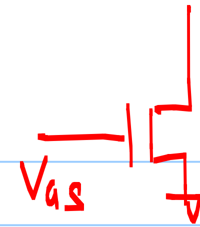


How to ensure that $I_{out} = I_{ref}$??

$\lambda = 0$, I_D has no dependence on V_{DS}

$$I_D = f(V_{GS}) \Rightarrow V_{GS} = f^{-1}(I_D)$$

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



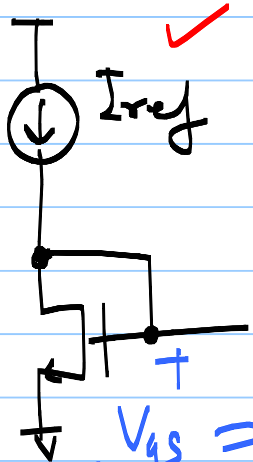
$f(\cdot)$

$$I_{out} = f(V_{GS})$$

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

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

I_{ref}

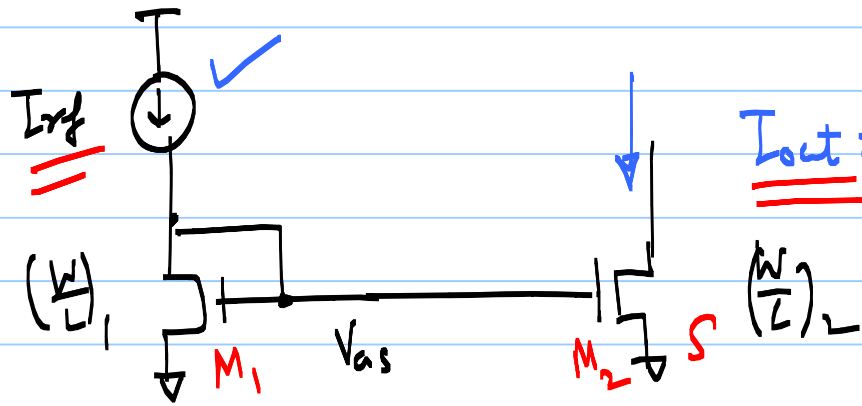


$$\underline{\underline{V_{GS} = f^{-1}(I_{ref})}}$$

$V_{DS} = V_{GS}$

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

$$\boxed{\lambda = 0}$$



$$I_{out} = f(V_{GS}) = I_{ref}$$

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

$$I_{ref} = \cancel{\frac{KP_n}{2}} \left(\frac{W}{L}\right)_1 \left(V_{GS} - \cancel{V_{THN}}\right)^2 \longrightarrow 1$$

$$I_{out} = \cancel{\frac{KP_n}{2}} \left(\frac{W}{L}\right)_2 \left(V_{GS} \cancel{-} V_{THN}\right)^2 \longrightarrow 2$$

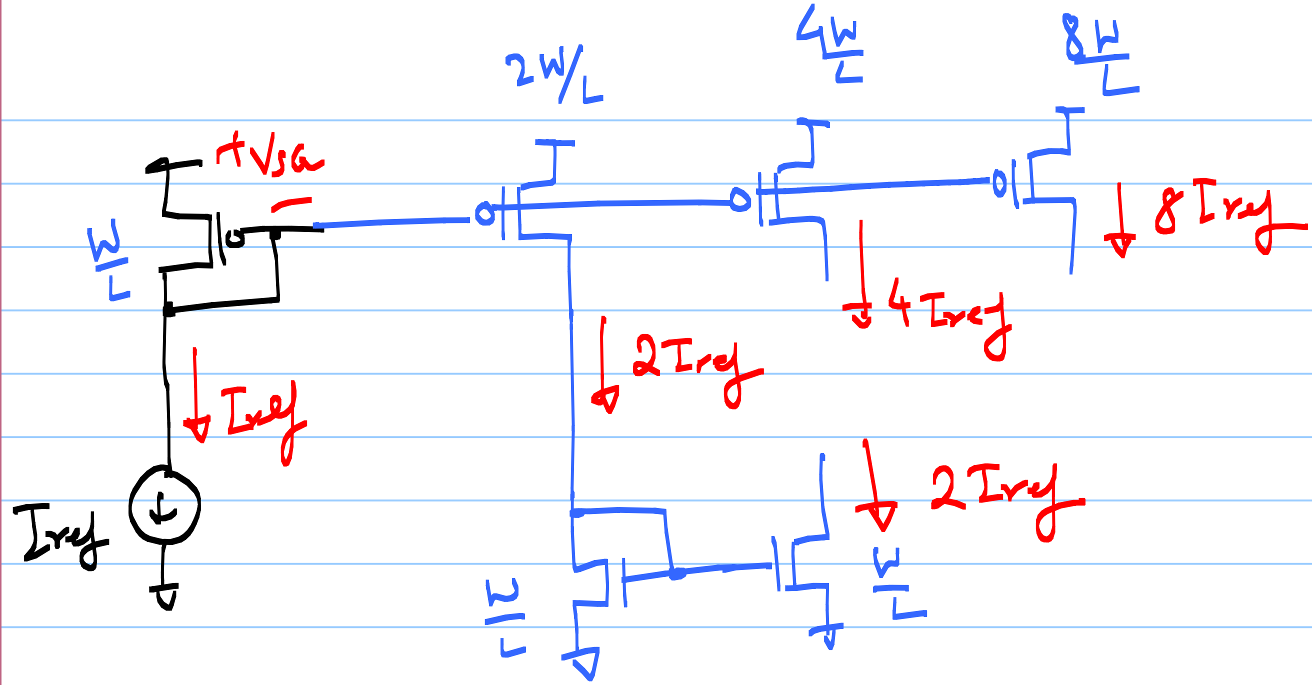
$\frac{②}{①}$

$L_1 = L_2$

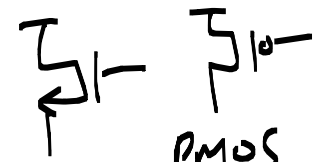
$$\frac{I_{out}}{I_{ref}} = \frac{(W/L)_2}{(W/L)_1} = \frac{W_2}{W_1} \checkmark$$

I_{out} precisely copies I_{ref}

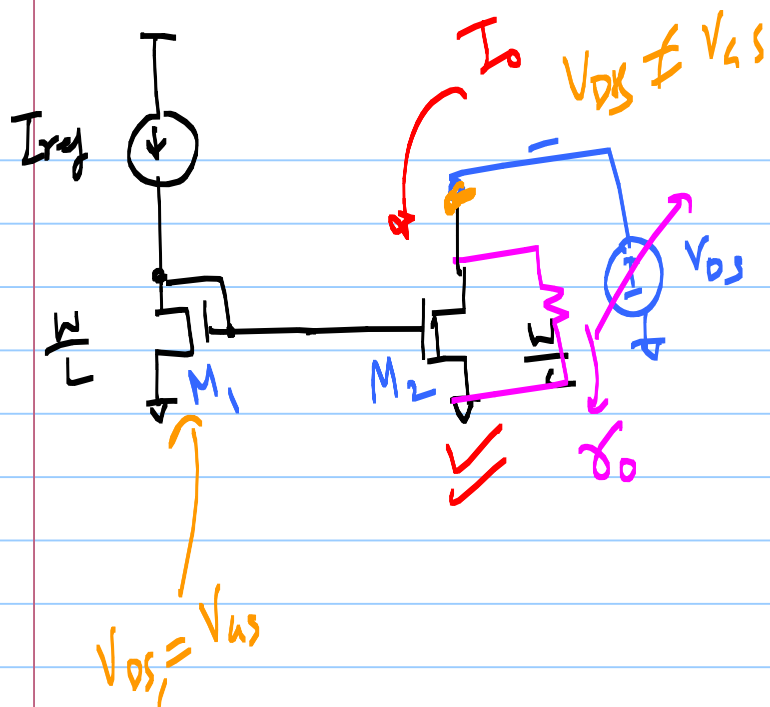
Scale

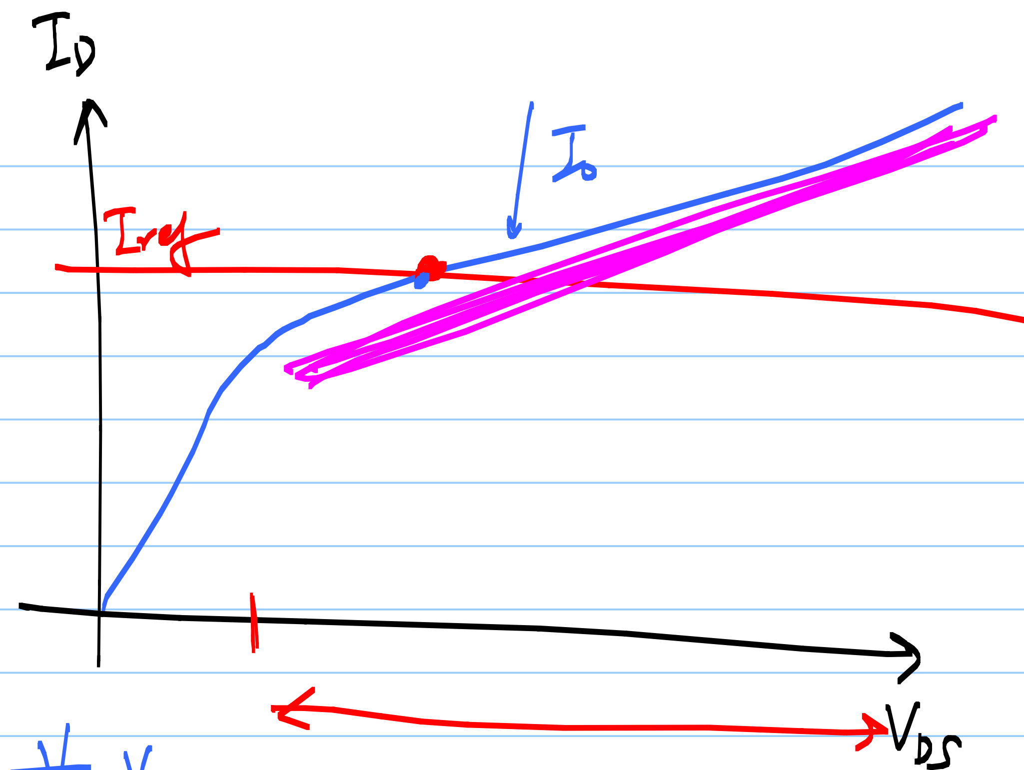


$\boxed{\lambda = 0}$



PMOS

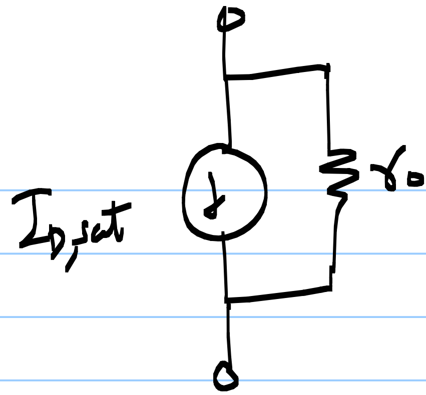


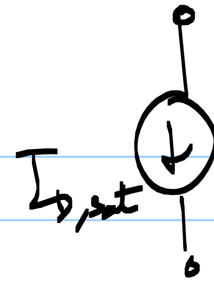


$I_o \neq I_{ref}, \ \forall \ V_{DS}$

for precise matching of currents

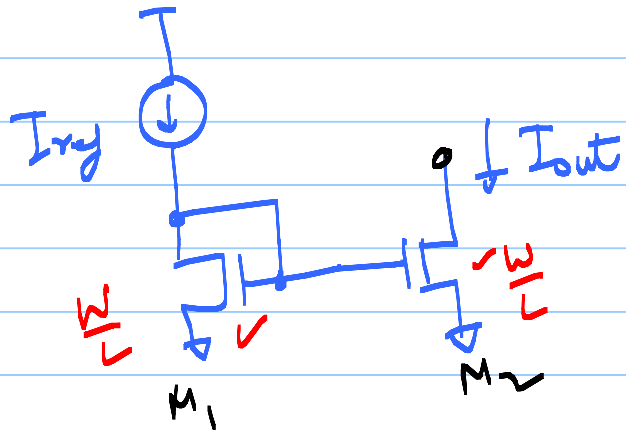
$V_{DS_2} = V_{DS_1} = V_{GS}$





A good current source should have large r_o

Matching in Current Mirrors.



$I_{out} \triangleq I_{ref}$

V_{DS}

$\Delta\left(\frac{W}{L}\right)$ ✓

$\Delta V_{THN} \leftarrow$ doping, tox

✓

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

$$y = f(x_1, x_2, \ldots)$$

$$\Delta y = \left(\frac{\partial f}{\partial x_1}\right) \Delta x_1 + \frac{\partial f}{\partial x_2} \Delta x_2 + \cdots$$

sensitivity

mismatch

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

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

$$\boxed{\frac{\Delta I_D}{I_D} = \left|\frac{\Delta (W/L)}{W/L}\right| + \left|\frac{2\,\Delta V_{THN}}{(V_{GS}-V_{THN})}\right|}$$

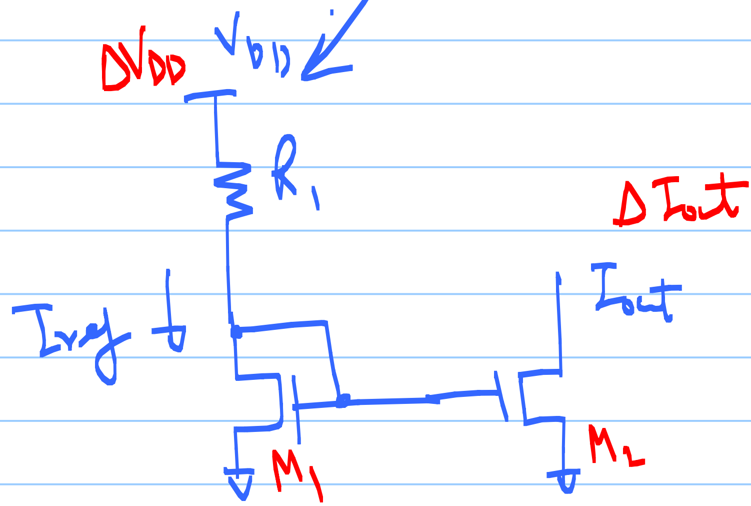
Subthresholds

$V_{GS} \simeq V_{THN}$

To minimize current mismatch

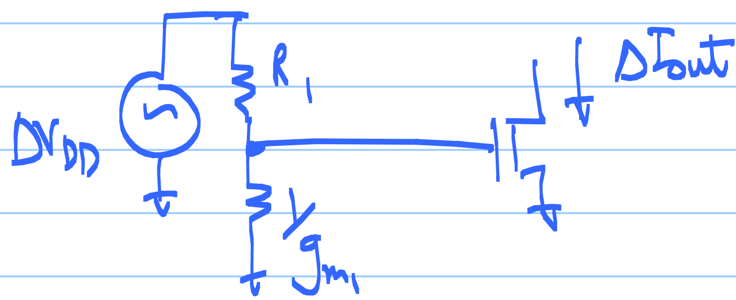
$\Rightarrow$ 1 overdrive should be sufficiently large

* How to generate I_{ref}?



small signal analysis

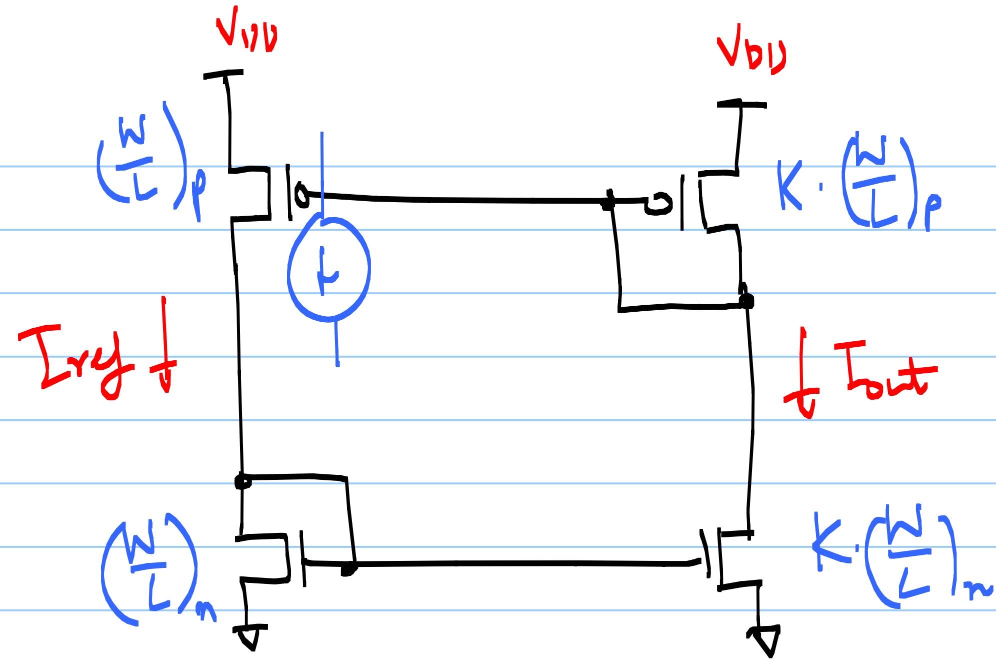
$$\underline{\underline{\Delta I_{out}}} = \frac{\Delta V_{DD}}{R_1 + 1/g_{m1}} \frac{(W/L)_2}{(W/L)_1}$$



Supply independent Biasing

I_{ref} should not be derived from V_{DD}.

I_{ref} should be derived from I_{out}.



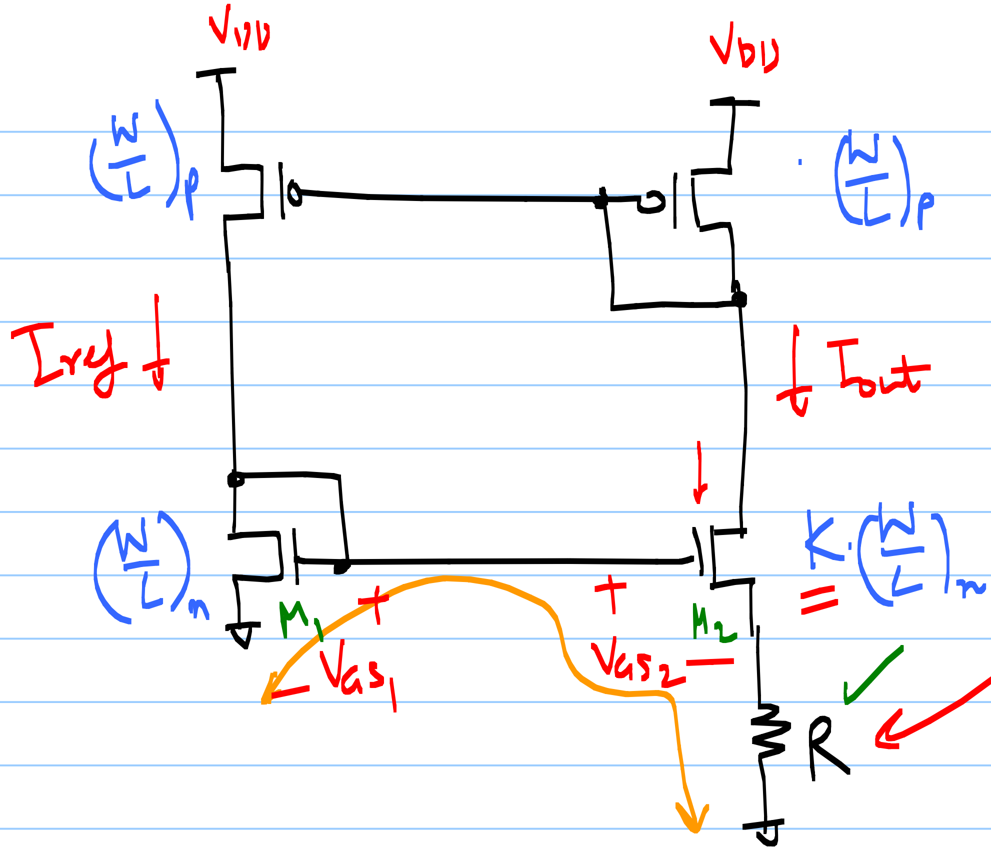
$\underline{\underline{\lambda = 0}}$

$x = y$

$I_{out} = K \cdot I_{ref}$

Circuit admits any solution for I_{ref} & I_{out}.

↳ fix the value of I_{ref} & I_{out}



Due to PMOS devices

$$\boxed{I_{ref} = I_{out}}$$

add a constant element to the circuit

$$V_{GS_1} = V_{GS_2} + I_{out} \cdot R$$

$$\sqrt{\frac{2I_{out}}{Kp_n(W/L)}} + \cancel{V_{THN_1}} = \sqrt{\frac{2I_{out}}{Kp_n\left(\frac{W}{L}\right)K}} + \cancel{V_{THN_2}} + I_{out}\cdot R$$

$$V_{GS} = \sqrt{\frac{2I_D}{\beta}} + V_{THN}$$

neglecting body effect $\underline{\underline{V_{THN_1} = V_{THN_2}}}$

$$\sqrt{\frac{2I_{out}}{Kp_n\left(\frac{W}{L}\right)}}\left(1 - \frac{1}{\sqrt{K}}\right) = I_{out}\cdot R$$

$$I_{out} = 0, \quad \boxed{\frac{2}{Kp_n\left(\frac{W}{L}\right)}\frac{1}{R^2}\left(1 - \frac{1}{\sqrt{K}}\right)^2}$$

$$I_{Ref} = I_{out} = \frac{2}{K\mu_n\left(\frac{W}{L}\right)} \cdot \frac{1}{R^2}\left(1 - \frac{1}{\sqrt{K}}\right)^2$$

independent of V_{DD}

(assuming saturation)

Beta Multiplier Circuit (BMR)

$$g_m \text{ of } M_1 = g_{m_1} = \sqrt{2\beta I_{REF}}$$

$$\boxed{g_m = \frac{2}{R}\left(1 - \frac{1}{\sqrt{K}}\right)}$$

* Constant-g_m Biasing

for $K = 4$

$$g_m = 1/R$$

on-chip $R \rightarrow \pm 15\%$