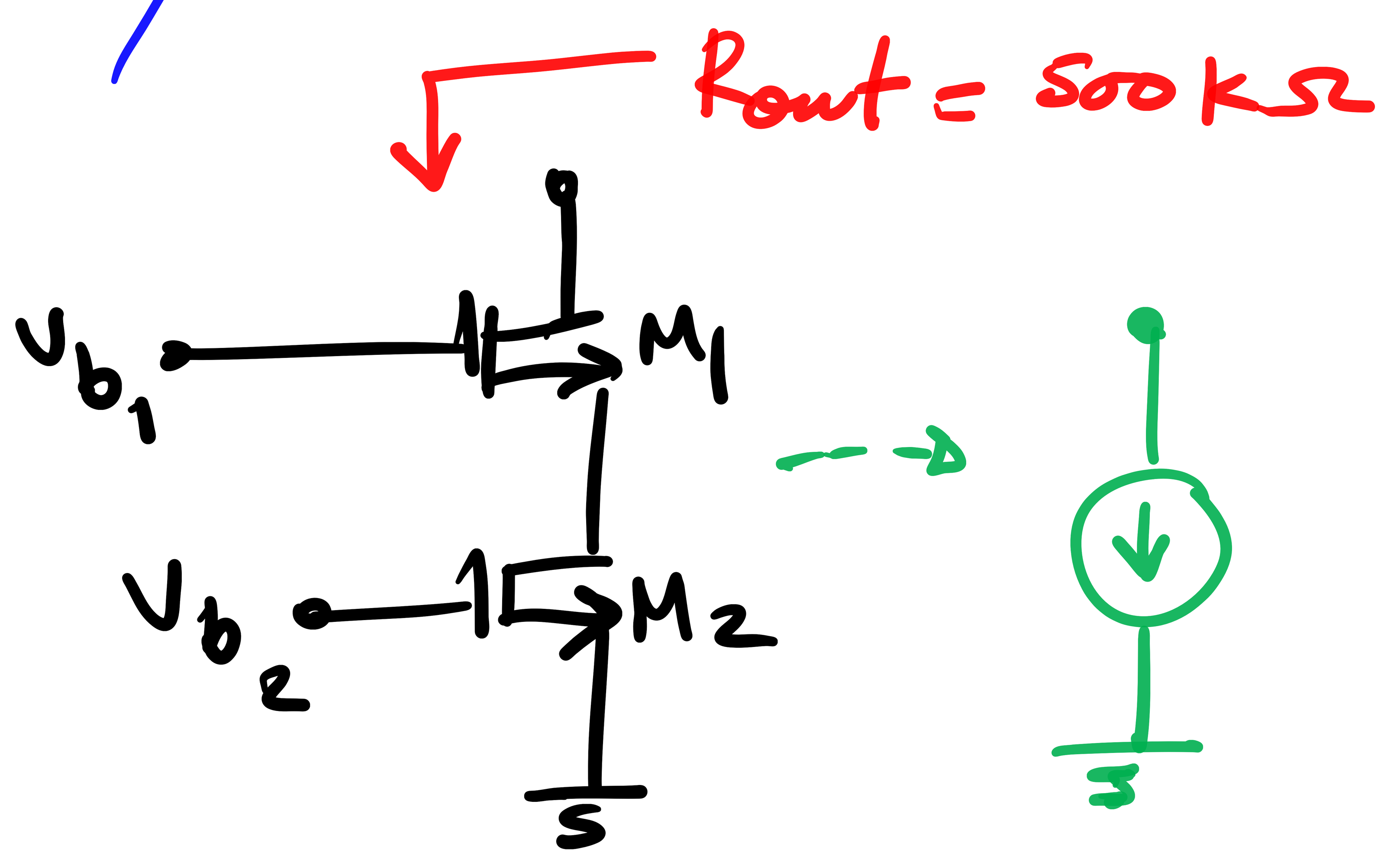
Ex: Design an NMOS cascode for an output impedance of $500\,k\Omega$ and a current of 0.5mA. For simplicity assume M_1 and M_2 are identical and $\mu_n C_{ox} = 100\,\mu A/V^2$ and $\lambda = 0.1\,V^{-1}$.



Since M_1 and M_2 are identical :-

$$r_{o1} = r_{o2}$$

$$r_{o1} = r_{o2} = \frac{1}{\lambda I_D}$$

$$r_{o1} = r_{o2} = \frac{1}{0.1 \cdot 0.5 \cdot 10^{-3}} = \boxed{20\,k\Omega}$$

$$* \quad I_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 V_{ov}^2 \rightarrow X$$

$$* \quad R_{out} = g_{m1} \cdot r_{o1} \cdot r_{o2} = g_{m1} \cdot (r_{o1})^2$$

$$\Rightarrow g_{m1} = \frac{1}{800\,\Omega} \Rightarrow \text{but } g_{m1} = \sqrt{2\mu_n C_{ox}\left(\frac{W}{L}\right)_1 I_D}$$

$$\Rightarrow \left(\frac{W}{L}\right)_1 = \frac{g_{m1}^2}{2\mu_n C_{ox} I_D} = \boxed{15.6} = \left(\frac{W}{L}\right)_2$$

$$* \quad V_{b2} \Rightarrow V_{GS2} \Rightarrow g_{m2} = \frac{2 I_D}{V_{ov}} \Rightarrow V_{ov} = \frac{2 I_D}{g_{m2}}$$

$$V_{ov} = 2 \cdot 0.5 \cdot 10^{-3} \cdot 800 = 800\,mV$$

assuming a $V_{TH} = 0.4\,V$ $\Rightarrow$

$$V_{GS} = V_{OV} + V_{TH} = \boxed{1.2\,V}$$

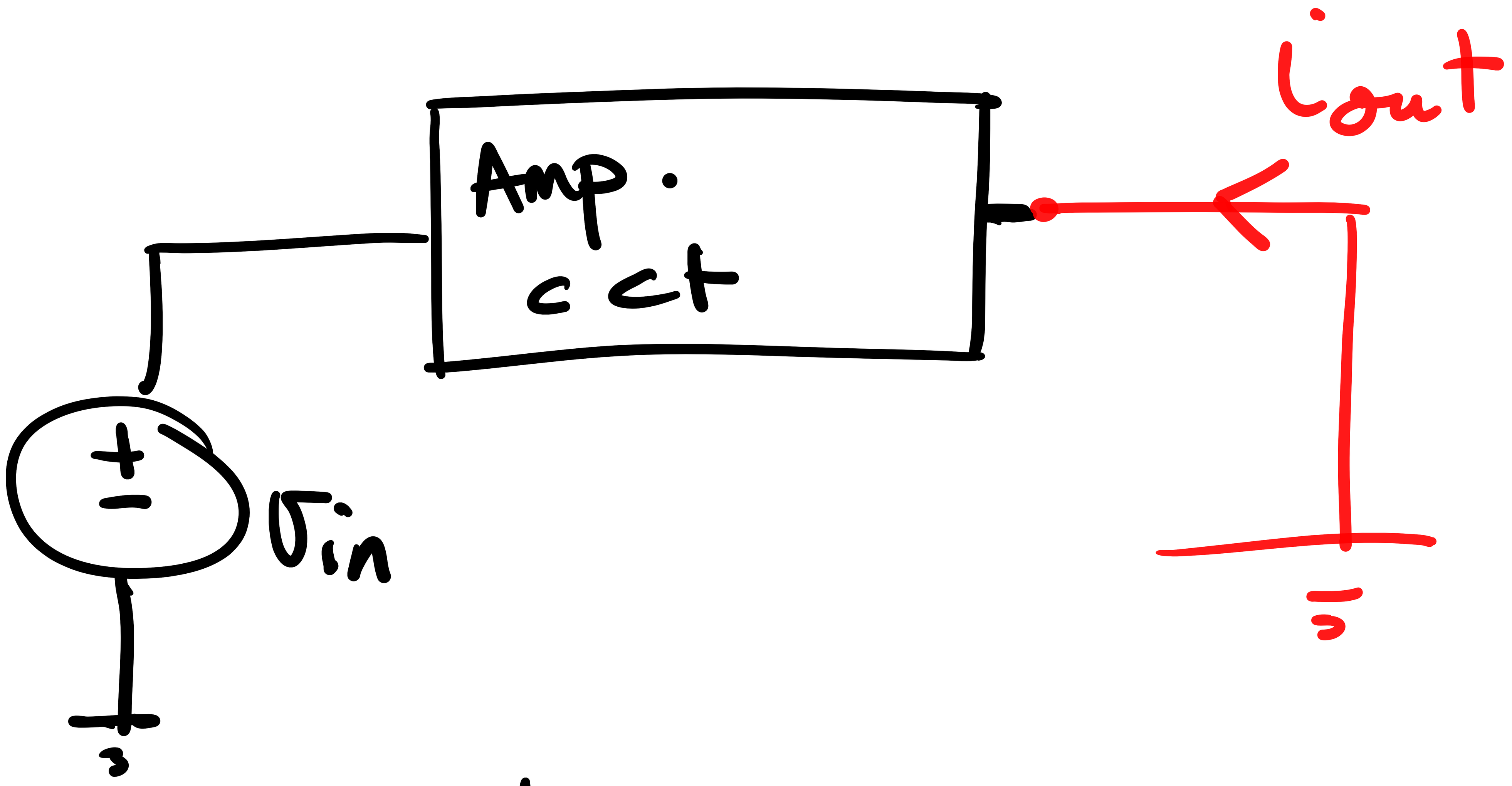
$$\Rightarrow V_{b2} = \boxed{1.2\,V}$$

Cascodes as Gain boosters:

Cascode amplifiers:-

To analyze A_v in cascode stage we can use the concept of short cct. transconductance

* Short cct. Transconductance technique:

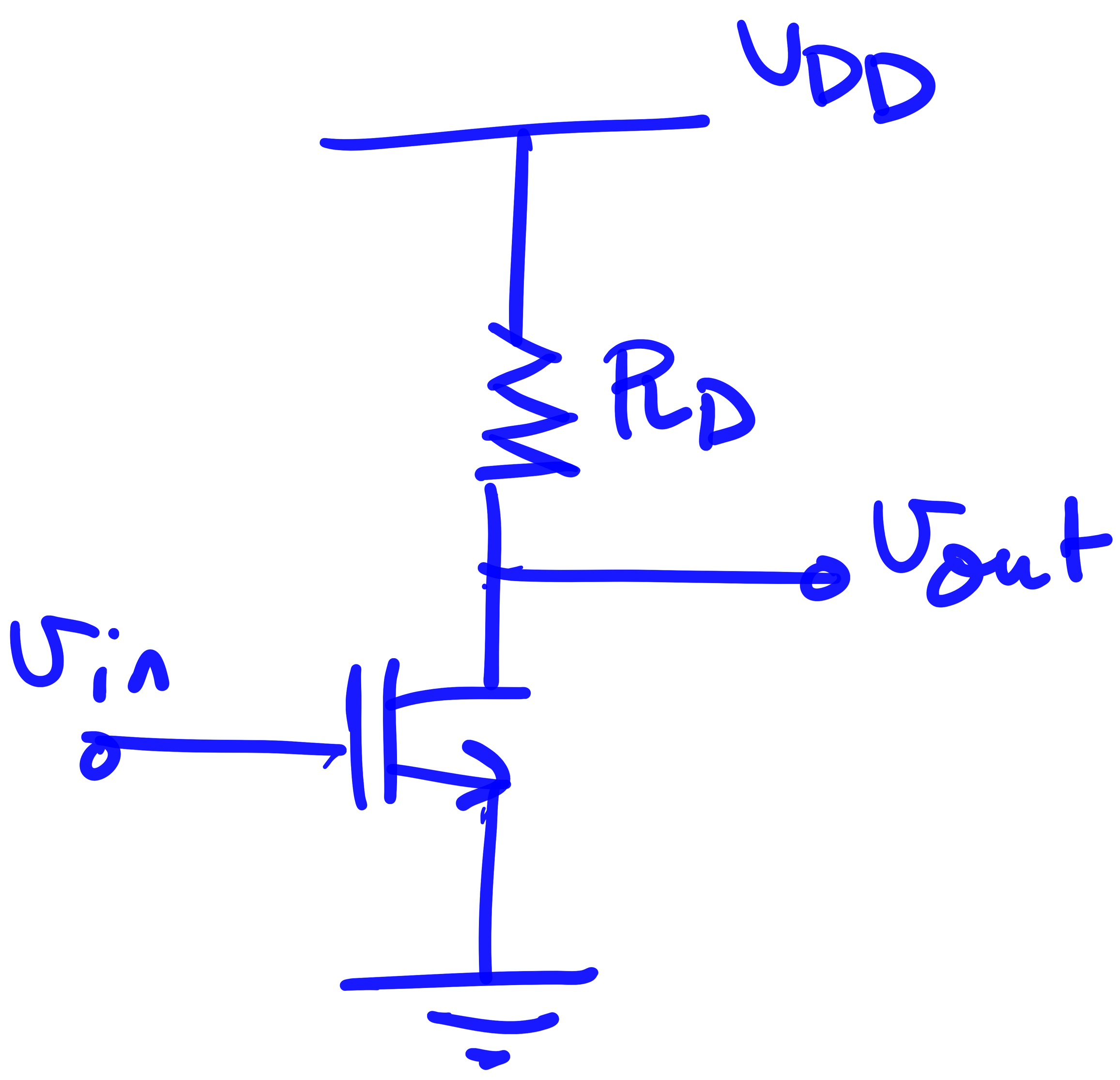


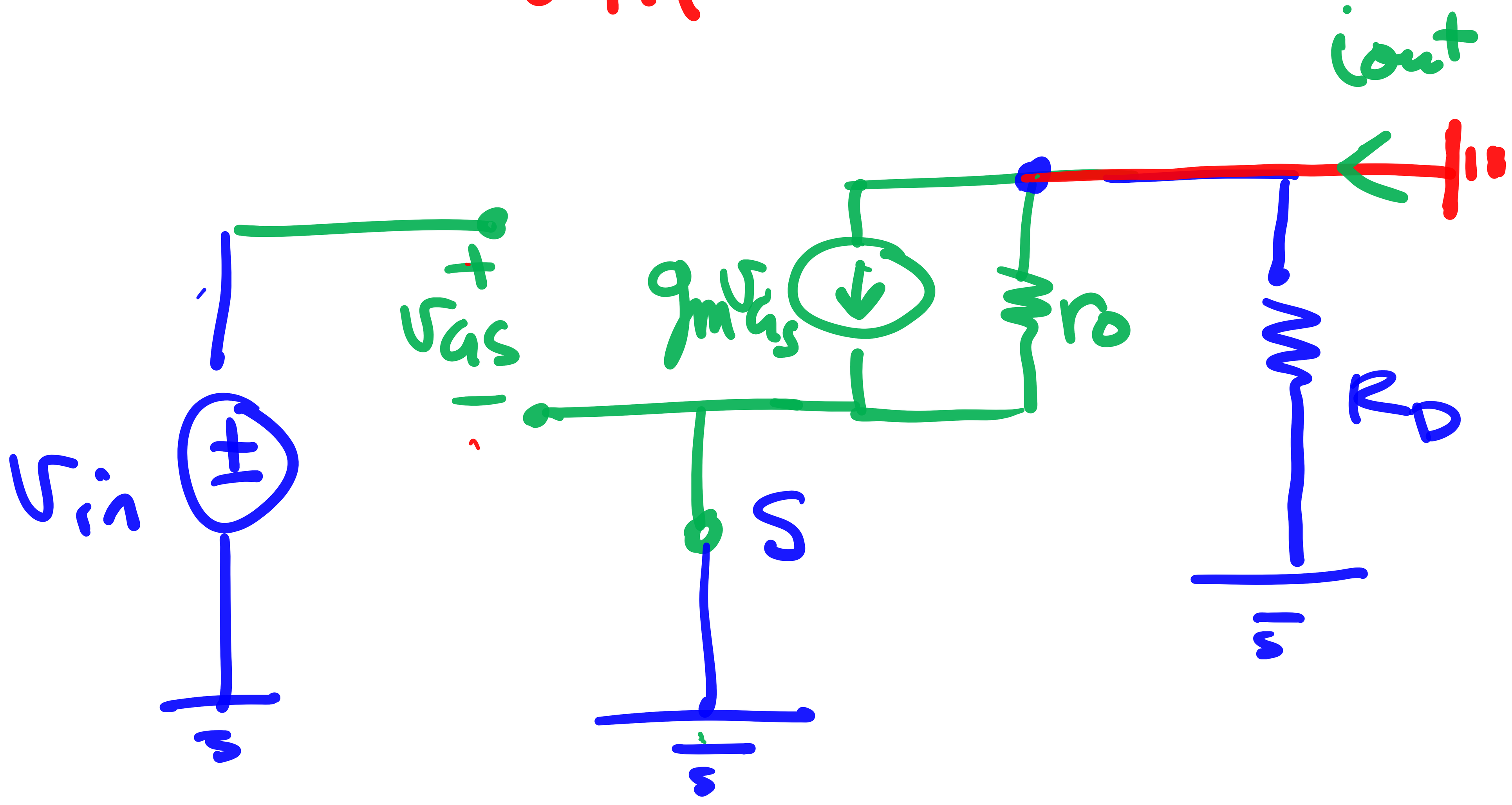
short cct. trans.

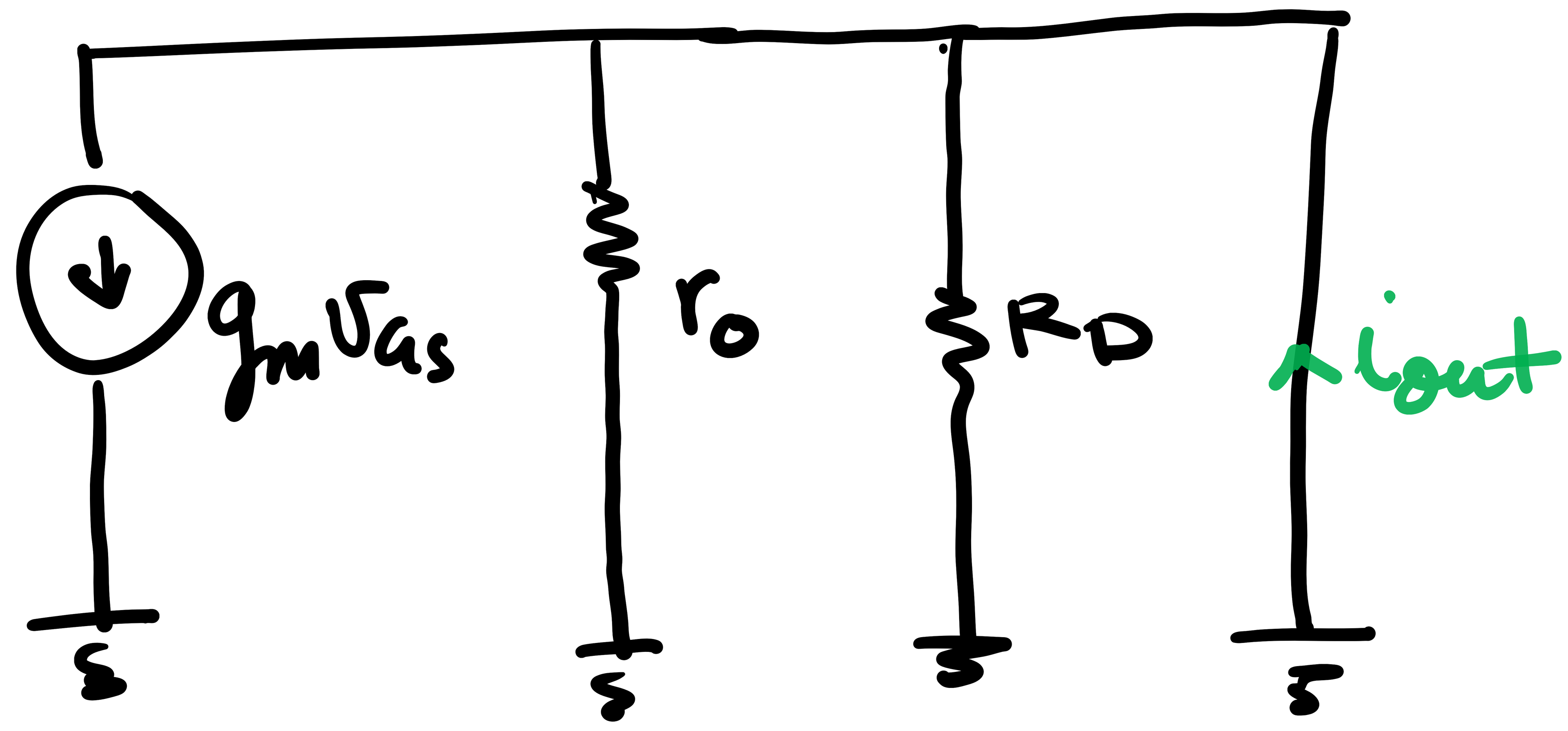
$$G_m = \left.\frac{i_{out}}{v_{in}}\right|_{v_{out}=0}$$

Ex: Calculate the short cct. transconductance for this CS stage?

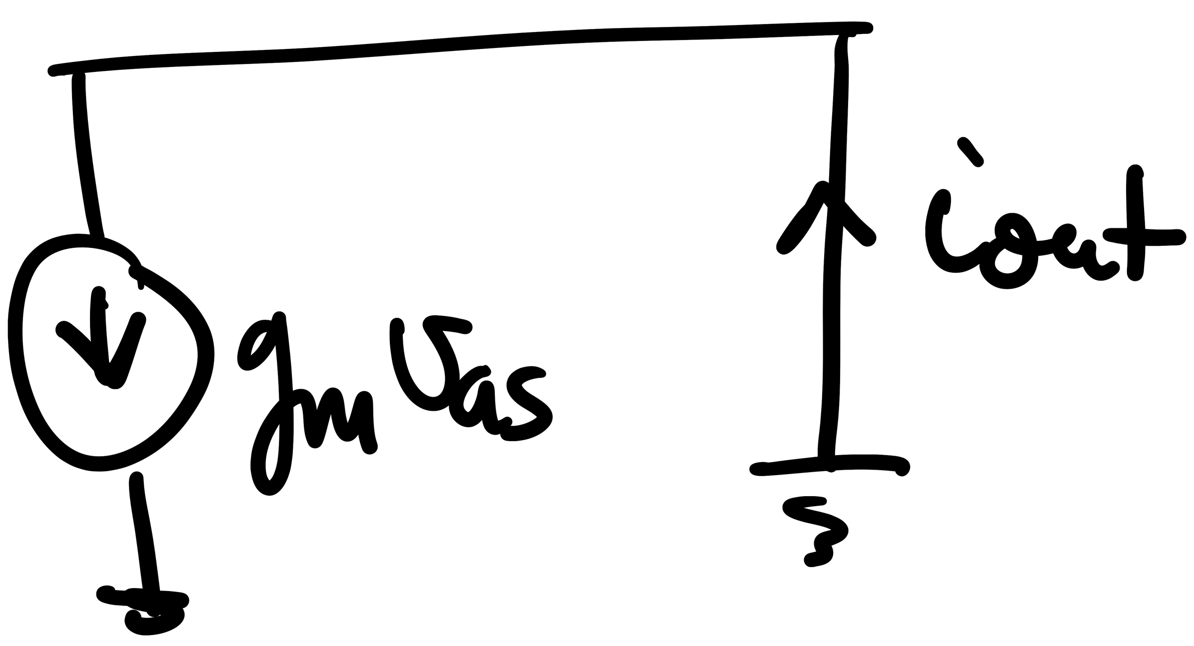
$$G_m = \frac{i_{out}}{v_{in}}$$





⇒ 

⇒ due to the shorting of the output



$$i_{out} = g_m v_{gs}$$

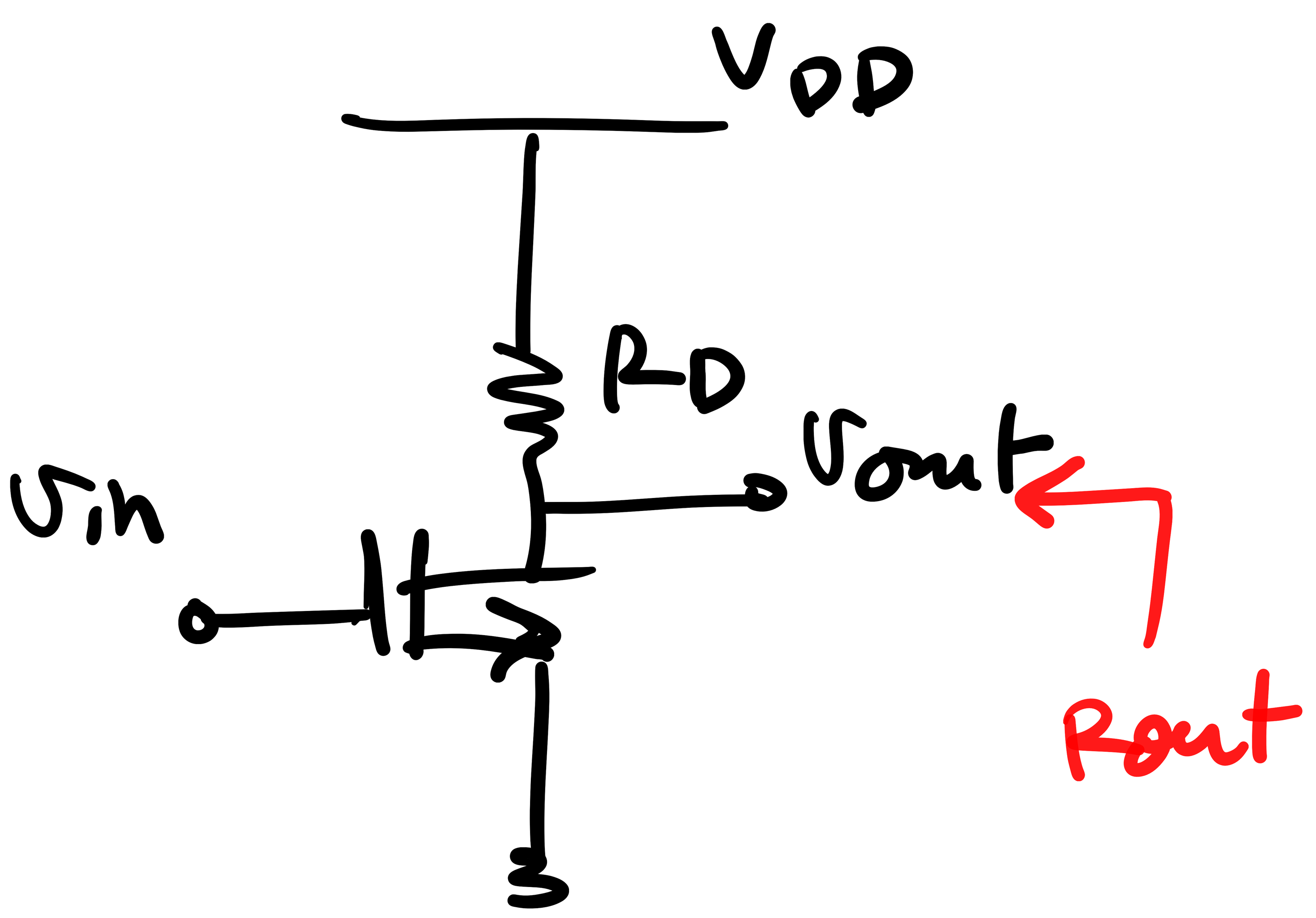
$$\Rightarrow v_{gs} = v_{in} \Rightarrow i_{out} = g_m \cdot v_{in}$$

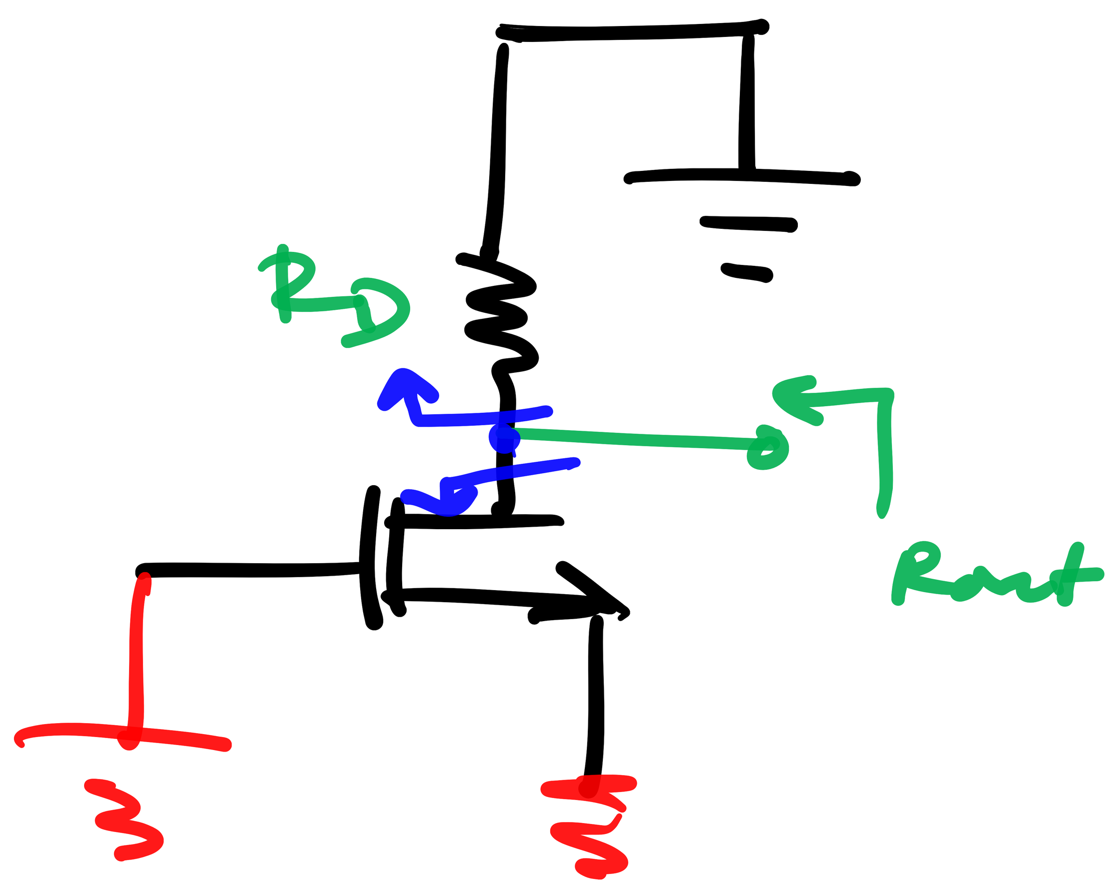
$$\Rightarrow \frac{i_{out}}{v_{in}} = g_m = G_m$$

* The gain of any stage A_V can be defined as $A_V = -G_m \cdot R_{out}$

* Using the above conclusion show that the gain for the CS stage

$$A_V = G_m \cdot R_{out}$$



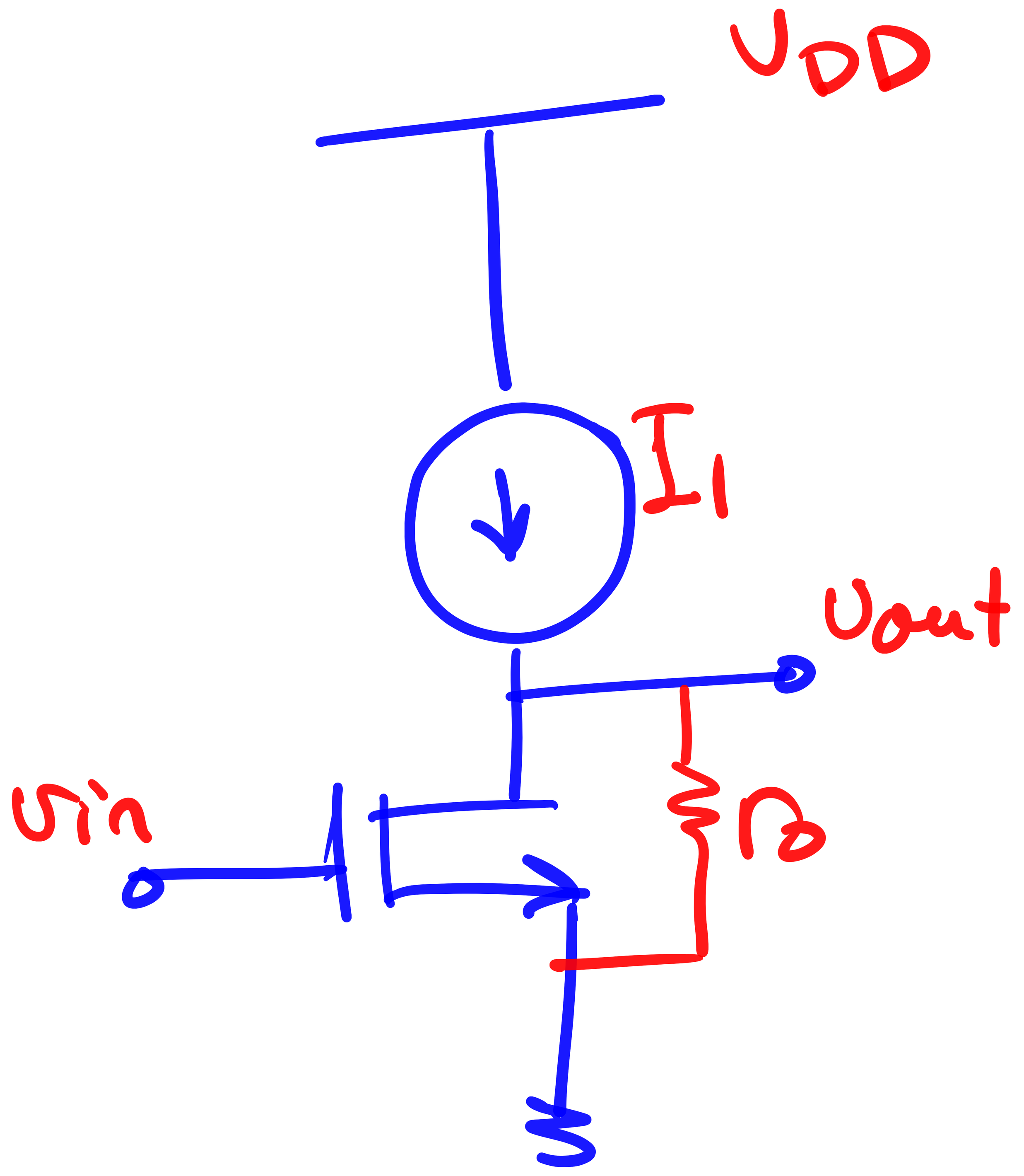


$$R_{out} = R_D // r_o$$

$$A_V = -G_m \cdot R_{out}$$

$$= -g_m \cdot (R_D // r_o)$$

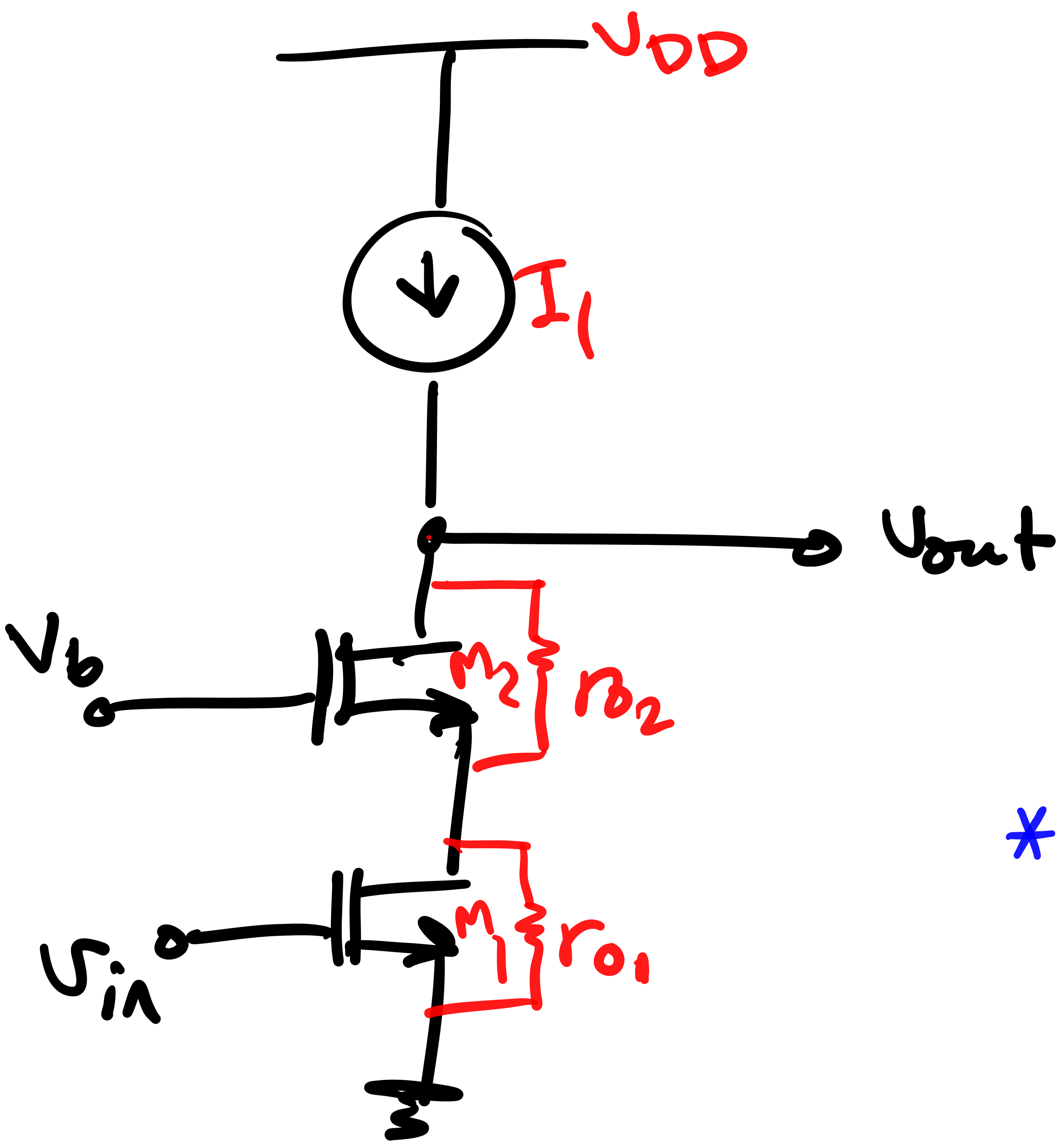
* Cascode Amplifiers :-



$$A_v = -g_m r_o$$

$$A_v = -G_m R_{out}$$

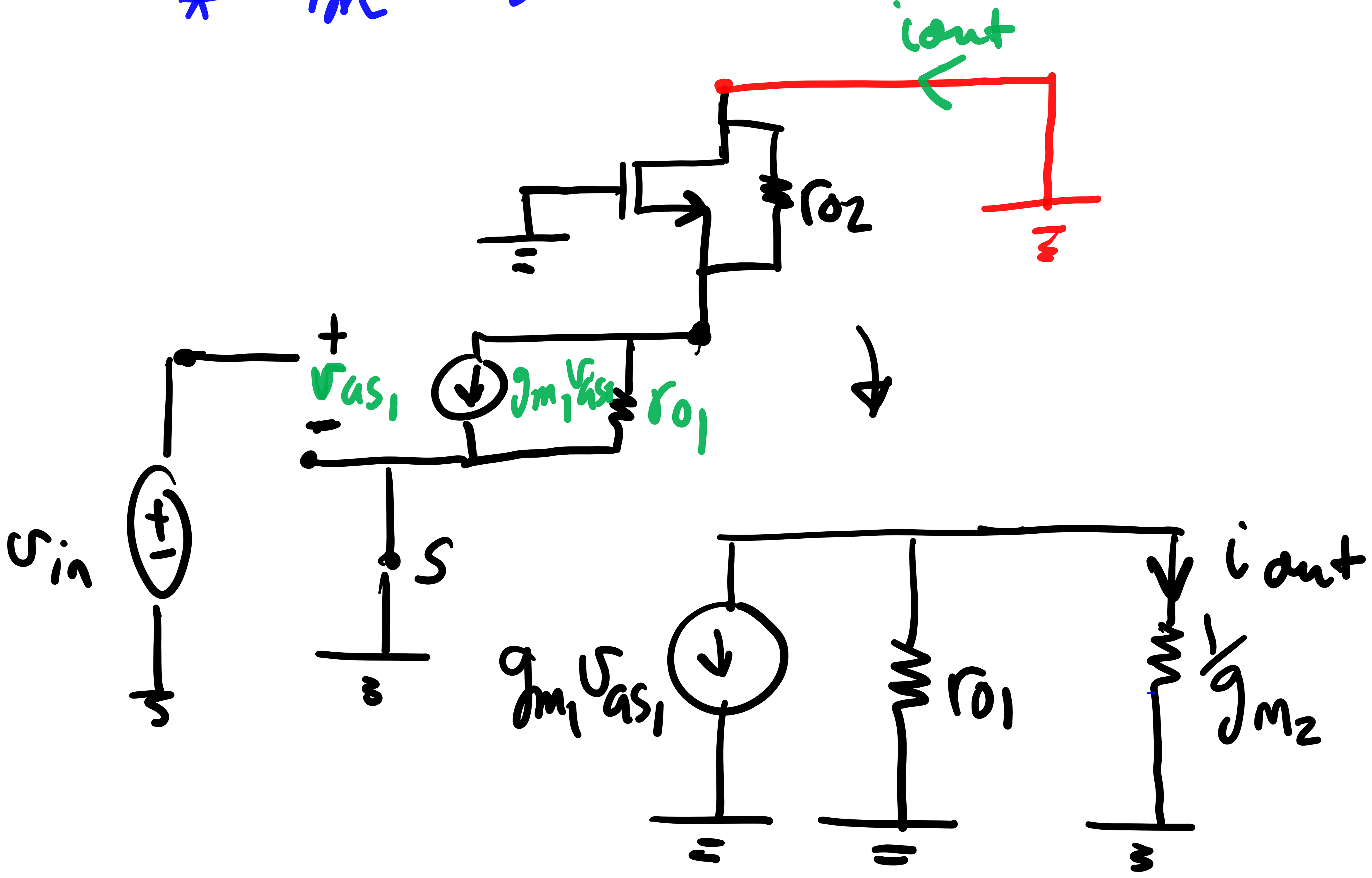
The gain can be increased as follows



* Applying small signal Analysis to find Av :-

$$A_v = -G_m \cdot R_{out}$$

* G_m → short cct. trans.



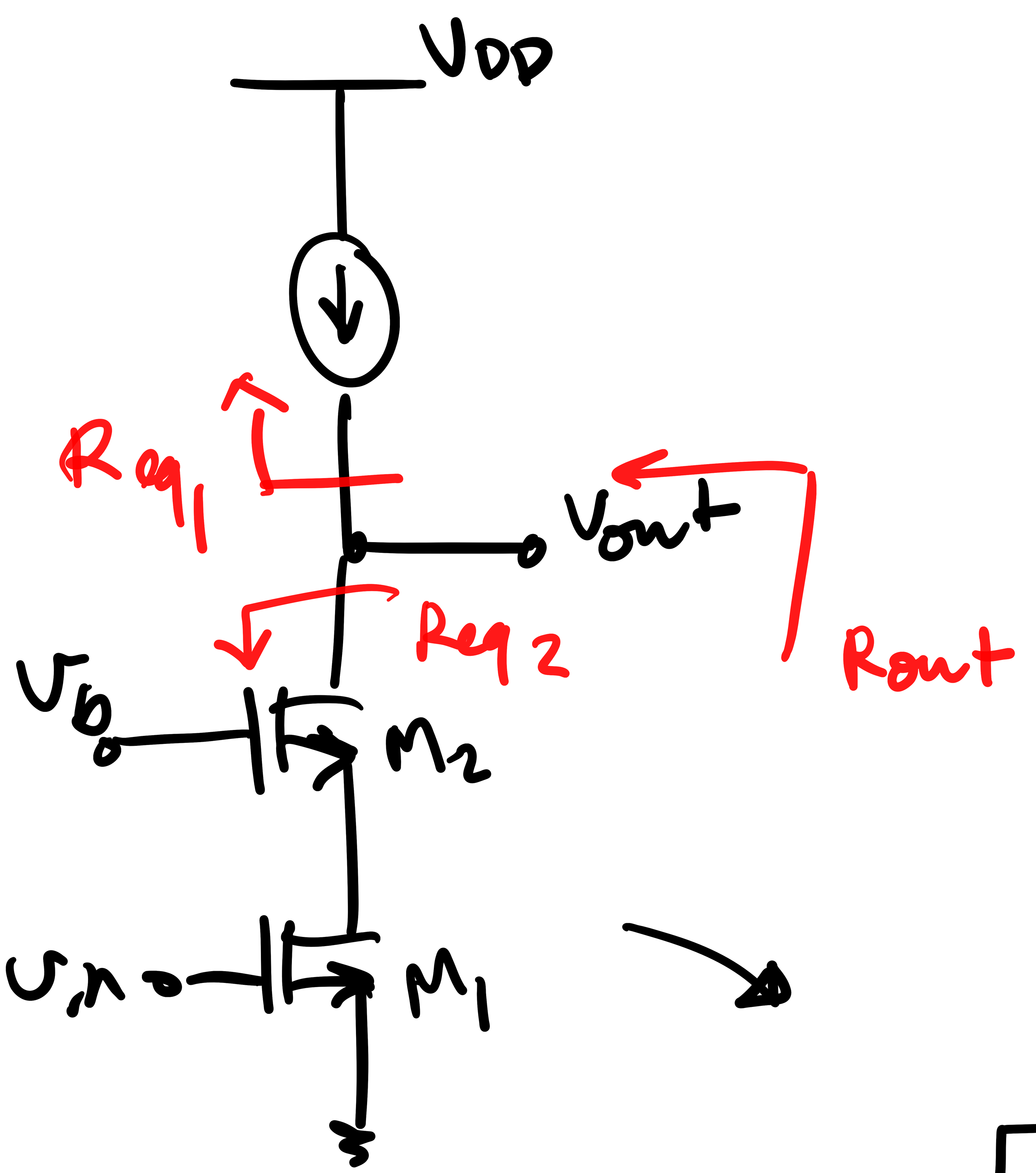
$$\boxed{G_m = \frac{i_{out}}{v_{in}}}$$

$$i_{out} = \frac{r_{o1}}{r_{o1} + 1/g_{m2}} \cdot g_{m1} \cdot v_{GS1} \Rightarrow v_{GS1} = v_{in}$$

$$i_{out} = \frac{r_{o1}}{r_{o1} + 1/g_{m2}} \cdot g_{m1} \cdot v_{in}$$

$$\Rightarrow \frac{i_{out}}{v_{in}} \cong g_{m1} \quad , \quad r_{o1} \gg 1/g_{m2}$$

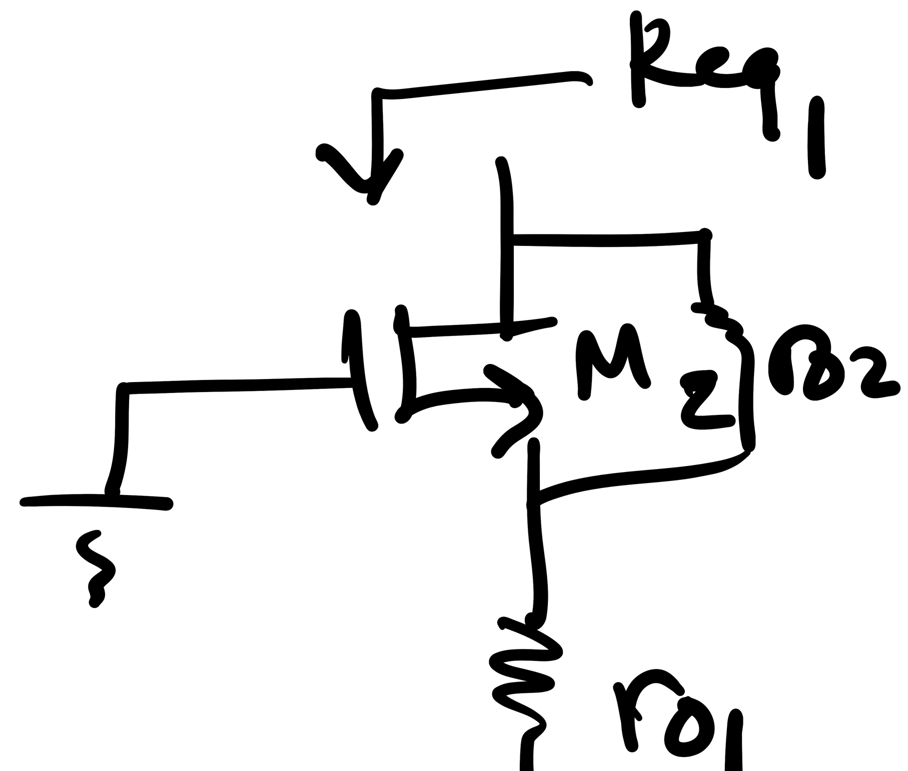
$$G_m = g_{m1} \Rightarrow R_{out} = ?$$



$$R_{out} = R_{eq1} \| R_{eq2}$$

$$\Rightarrow R_{eq1} = \infty$$

$$\Rightarrow R_{eq2} = ?$$



$$R_{eq2} = (1 + g_{m2} r_{o1}) \cdot r_{o2}$$

$$R_{eq2} \approx g_{m2} r_{o1} r_{o2} = R_{out}$$

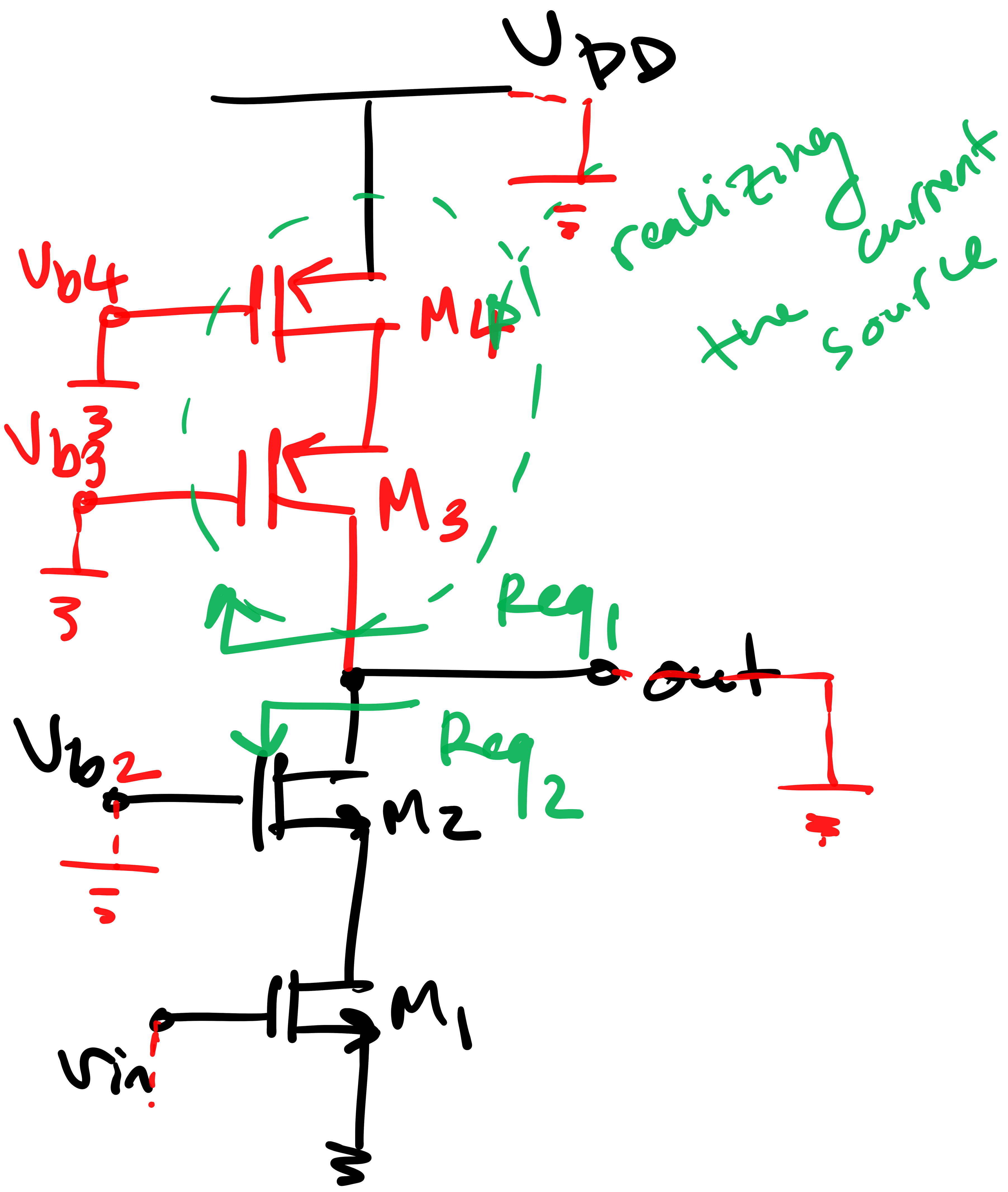
$$A_v \cong -g_{m_1} \cdot g_{m_2} r_{o_1} r_{o_2}$$

$$A_v \cong -g_{m_1} r_{o_1} \cdot g_{m_2} r_{o_2}$$

Note that with an ideal current source

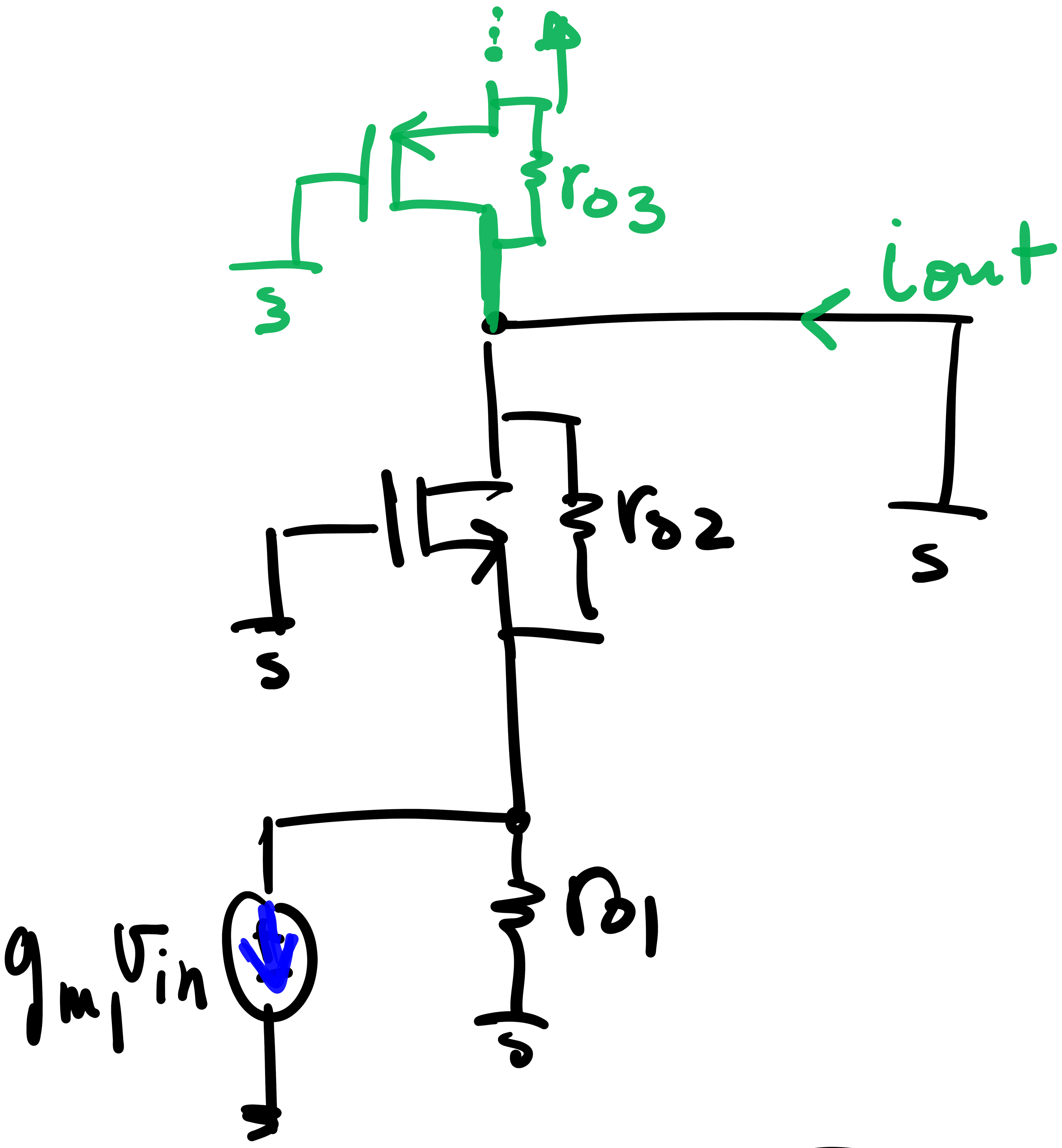
A_v = Intrinsic gain 1 × Intrinsic Gain 2

* when realizing the current source using MOS devices the gain will drop.



To analyze this stage we will repeat the above.

$$A_v = -G_m \cdot R_{out}$$



* Since v_{in} is the only ac small signal source the current i_{out} is not going to travel through M_3 and M_4 due to the short.

$$\boxed{G_m = g_{m1}}$$

$$R_{out} = R_{eq_1} // R_{eq_2}$$

$$\Rightarrow \quad R_{eq_2} = g_{m2} r_{o1} r_{o2} \quad , \quad R_{eq_1} = g_{m3} r_{o3} r_{o4}$$

$$\Rightarrow \quad A_V \approx -g_{m1}\left(g_{m2} r_{o1} r_{o2} // g_{m3} r_{o3} r_{o4}\right)$$

Ex: In the cct. above

$(W/L)_{1,2} = 30$, $(W/L)_{3,4} = 40$

$I_{D1} = I_{D2} = I_{D3} = I_{D4} = 0.5mA$.

$\mu_n C_{ox} = 100 \mu A/V^2$, $\mu_p C_{ox} = 50 \mu A/V^2$

$\lambda_n = 0.1 V^{-1}$, $\lambda_p = 0.15 V^{-1}$.

Find A_v ?

$$|A_v| = g_{m1} (g_{m2} r_{o2} r_{o1} // g_{m3} r_{o3} r_{o4})$$

$$g_{m1} = g_{m2} = \sqrt{2 \mu_n C_{ox} \left(\frac{W}{L}\right)_{1,2} \cdot I_D} = \frac{1}{577\Omega}$$

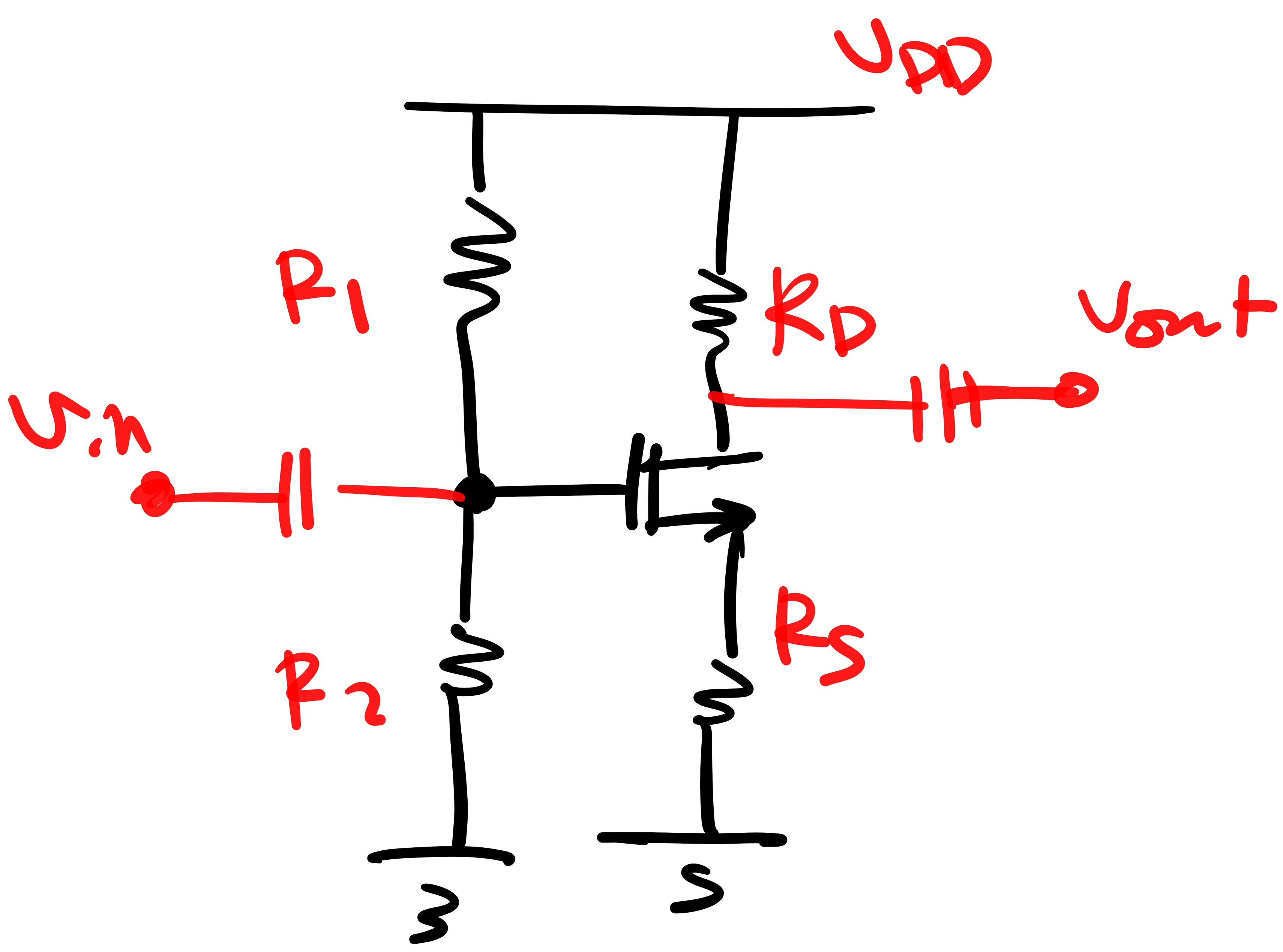
$$g_{m3} = g_{m4} = \sqrt{2 \mu_p C_{ox} \left(\frac{W}{L}\right)_{3,4} \cdot I_D} = \frac{1}{707\Omega}$$

$$r_{o1} = r_{o2} = \frac{1}{\lambda_n I_D} = 20 k\Omega$$

$$r_{o3} = r_{o4} = \frac{1}{\lambda_p I_D} = 13.3 k\Omega$$

$|A_V| = \boxed{318}$

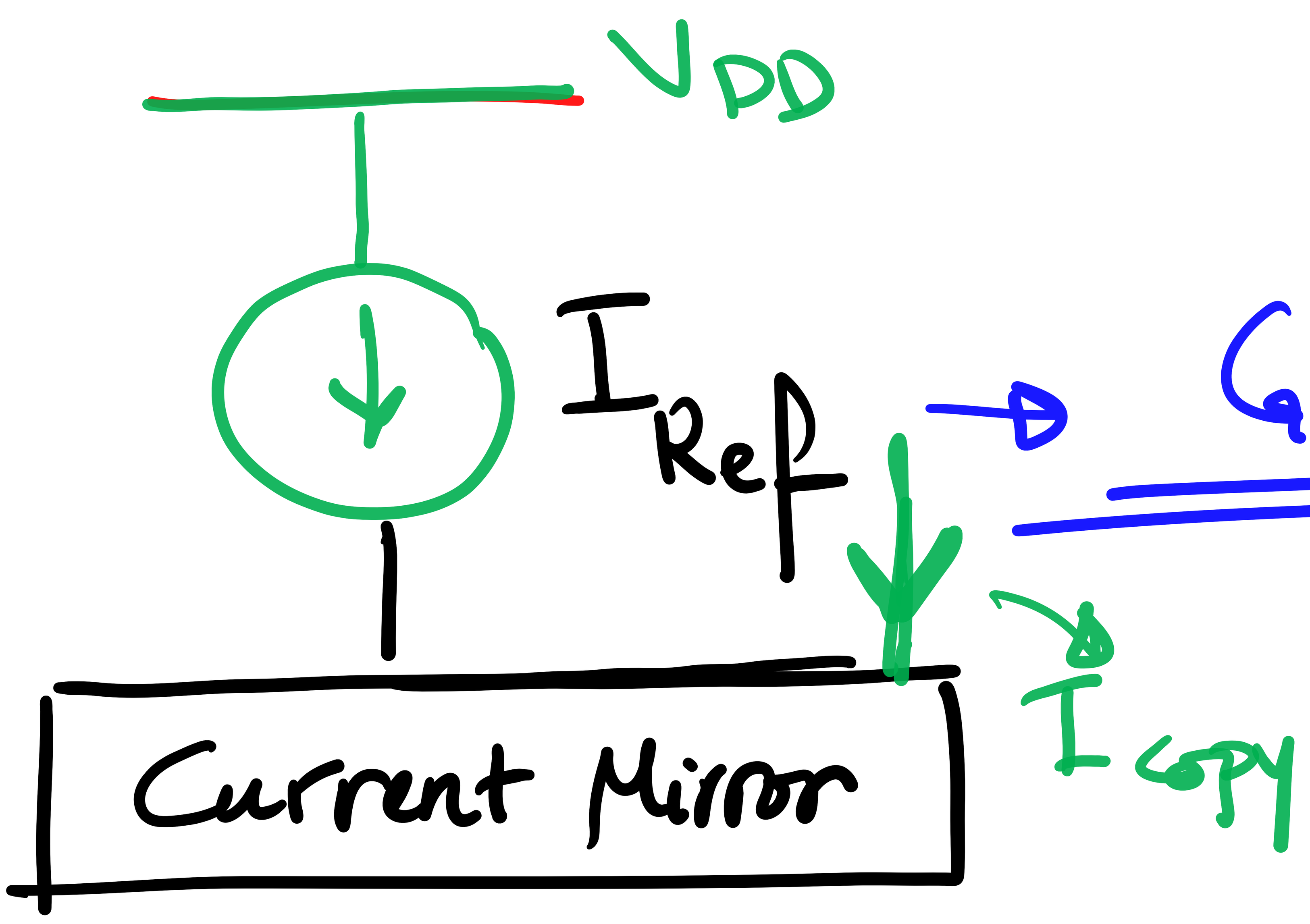
* Current Mirrors :-



* when designing an amp. we need to make sure that I_D is in sat. and is fixed regardless of temperature changes or V_{DD} drainage.

* temp. changes affect V_{TH}
* V_{DD} drainage affects biasing.

* The solution for this problem is to use a current_source for biasing that does not get affected by temp. or V_{DD} changes. This current source is called "Band-gap-reference-cct"



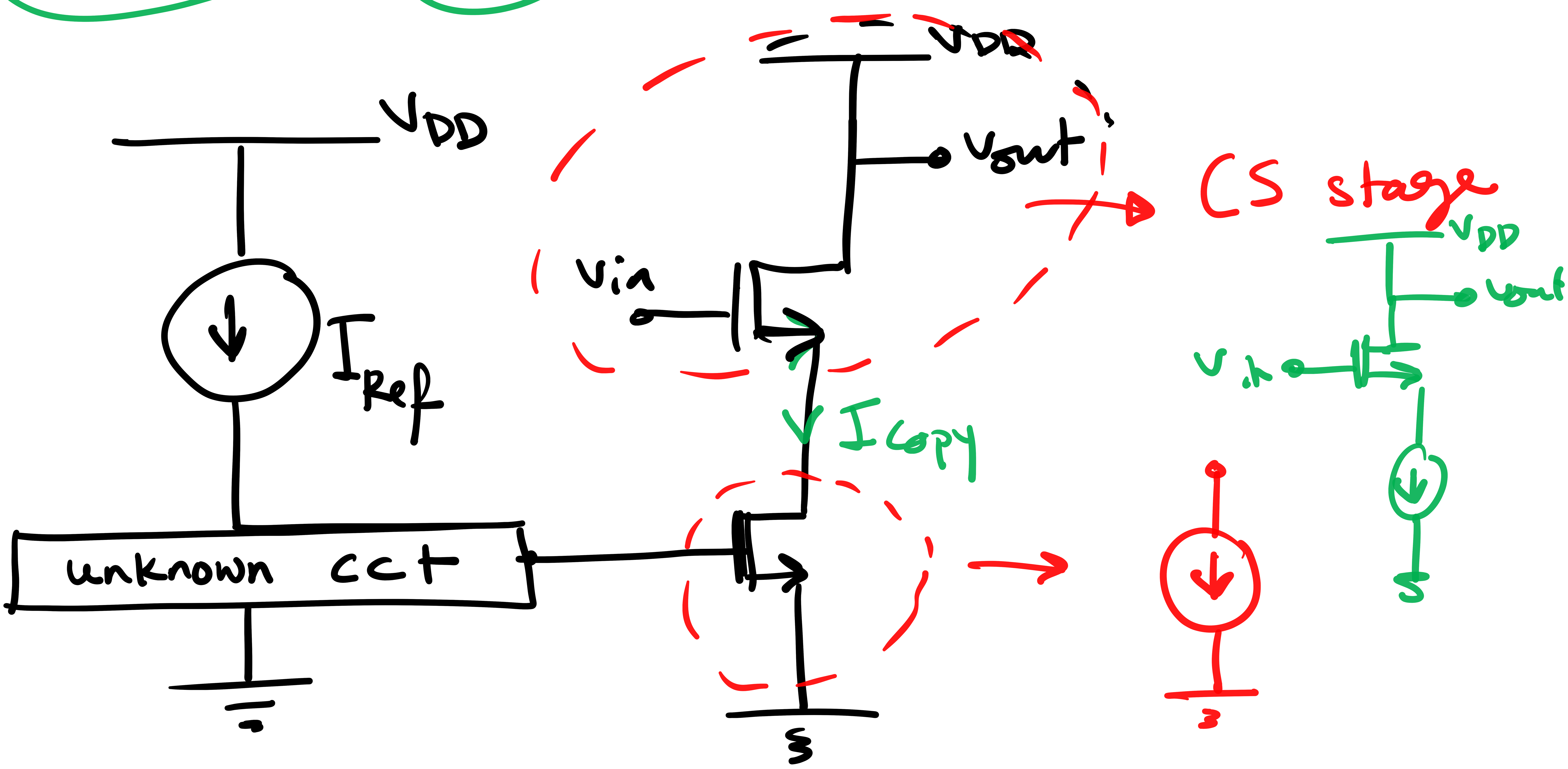
Golden current.

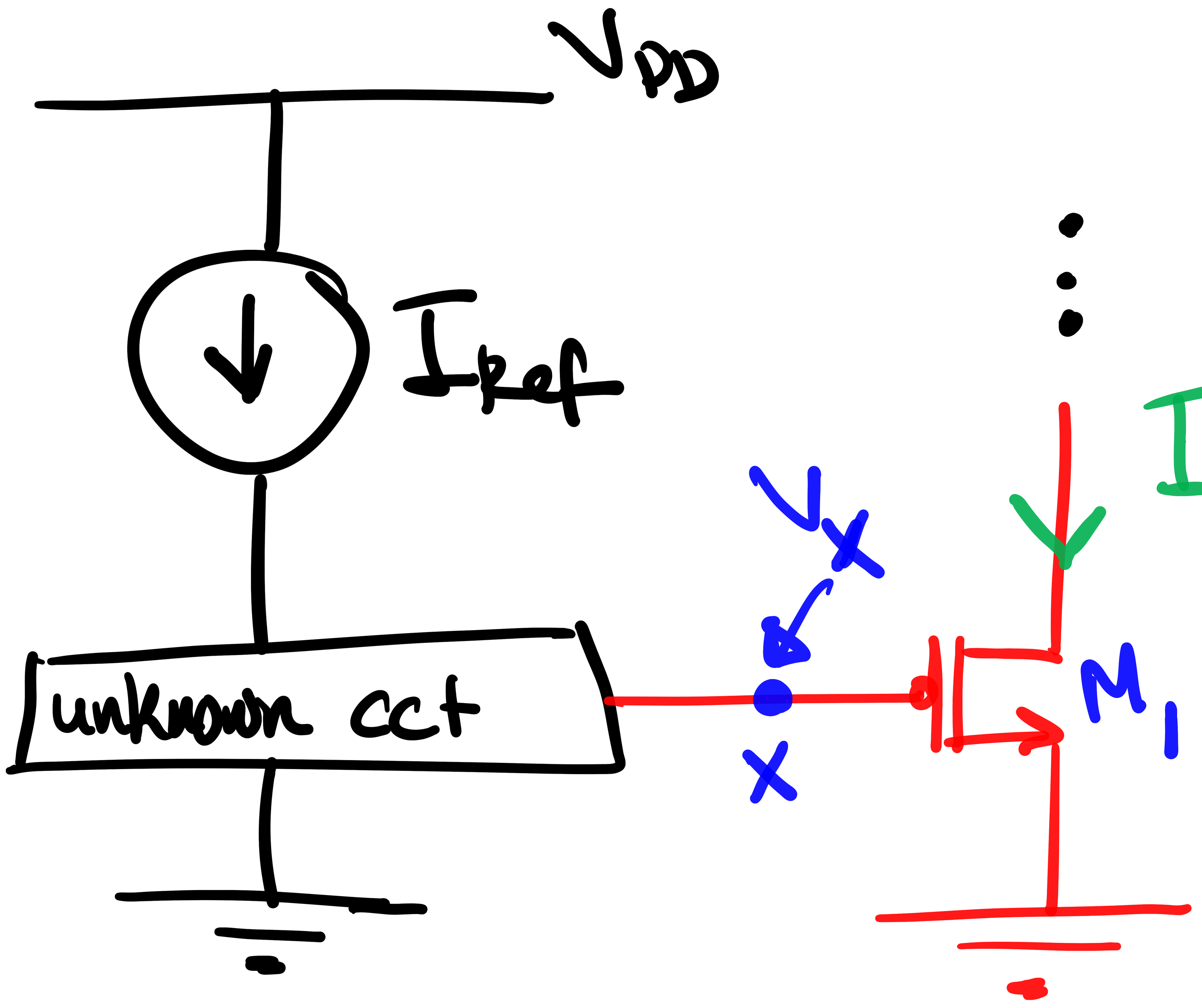
* To manipulate I_{Ref} and get different I_D values out of it we use current Mirrors.

$$I_{copy} = \alpha \cdot I_{ref}$$

$0 < \alpha < 1$ either $\alpha \geq 1$

* The Design of current Mirrors:





* V_X is V_{GS_1}

$$I_{copy} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 \cdot (V_{GS_1} - V_{TH})^2$$

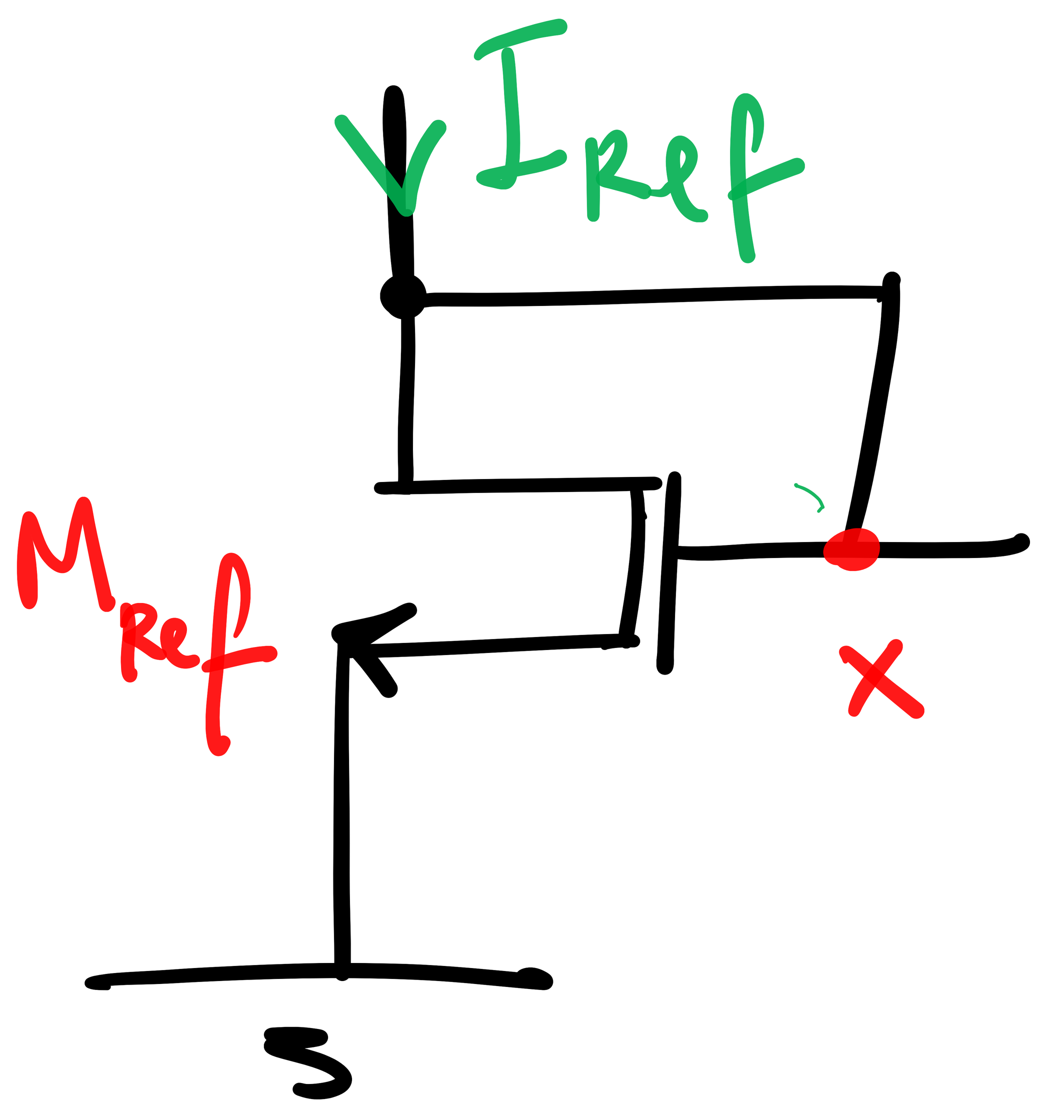
$$I_{copy} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 \cdot (V_X - V_{TH})^2$$

$I_{copy} = I_{Ref}$

This unknown cct is responsible for generating V_X that eventually controls I_{copy}.

$$V_X = \sqrt{\frac{2 I_{Ref}}{\mu_n C_{ox} \left(\frac{W}{L}\right)_1}} + V_{TH}$$

* we want a cct. that take $\sqrt{\ }$ of I_{Ref}.

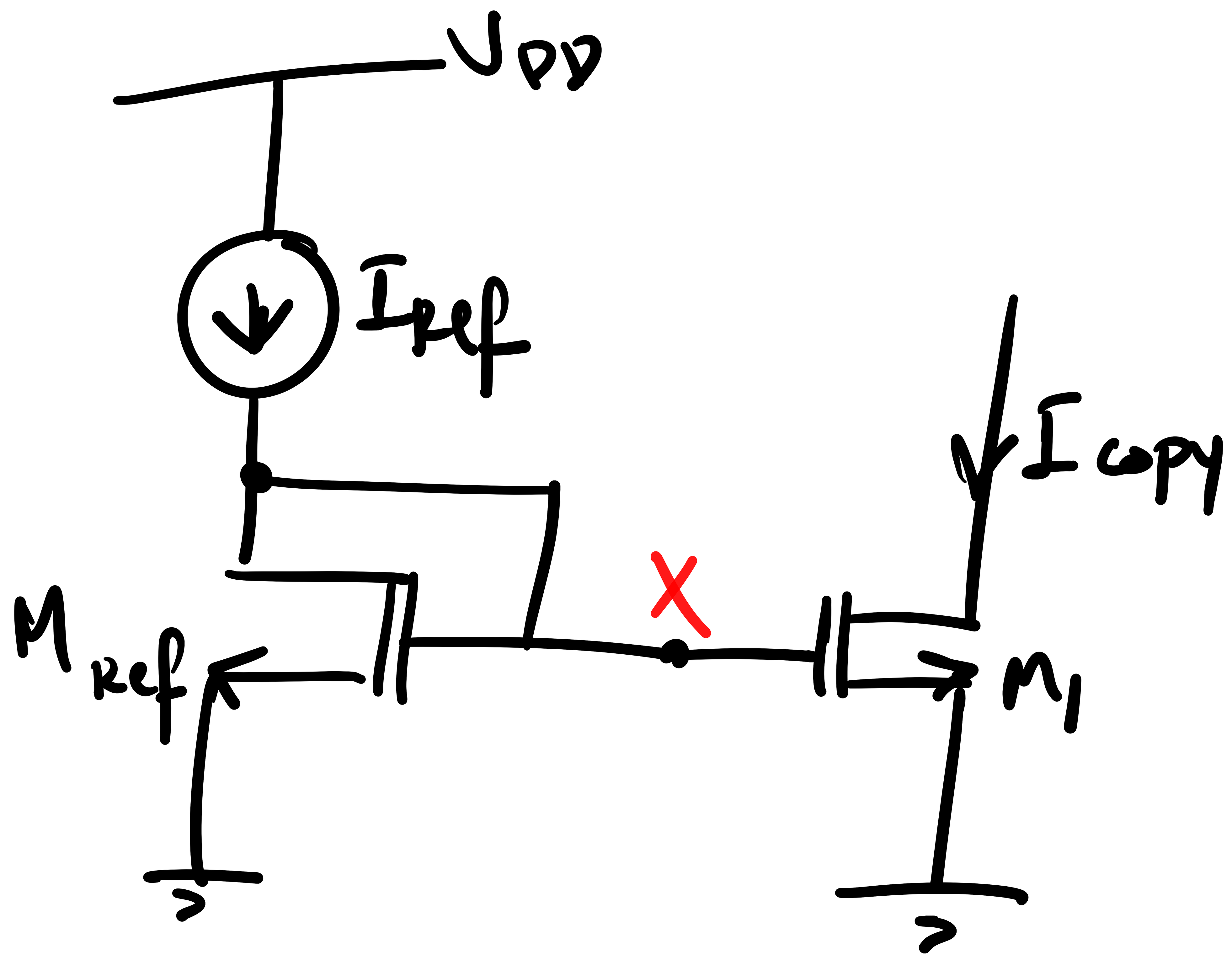


$$I_{Ref} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_{Ref} \cdot (V_X - V_{TH})^2$$

$$V_X = \sqrt{\frac{2 I_{Ref}}{\mu_n C_{ox} \left(\frac{W}{L}\right)_{Ref}}} + V_{TH}$$

* $I_{copy} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_X - V_{TH})^2$

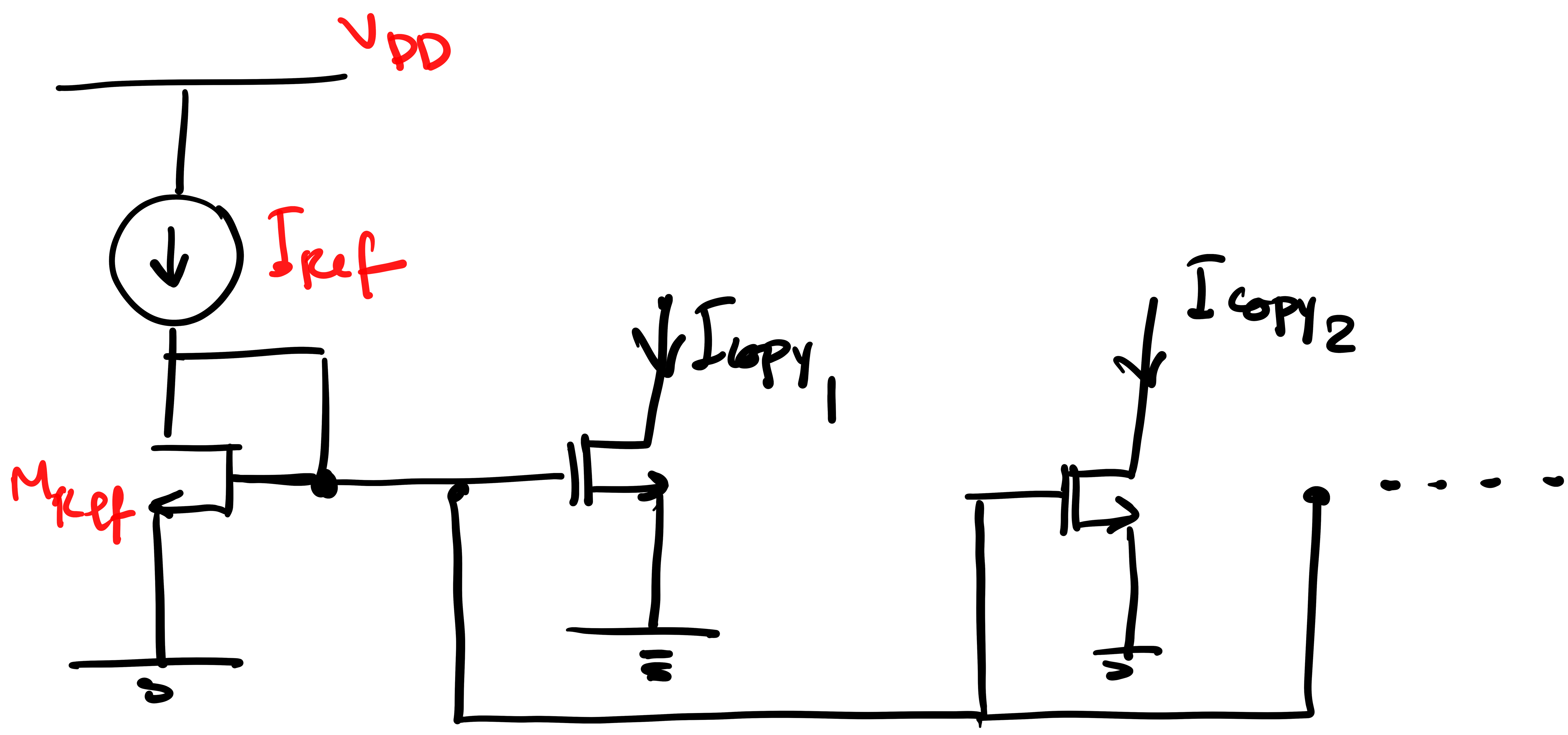
* $I_{Ref} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_{Ref} (V_X - V_{TH})^2$

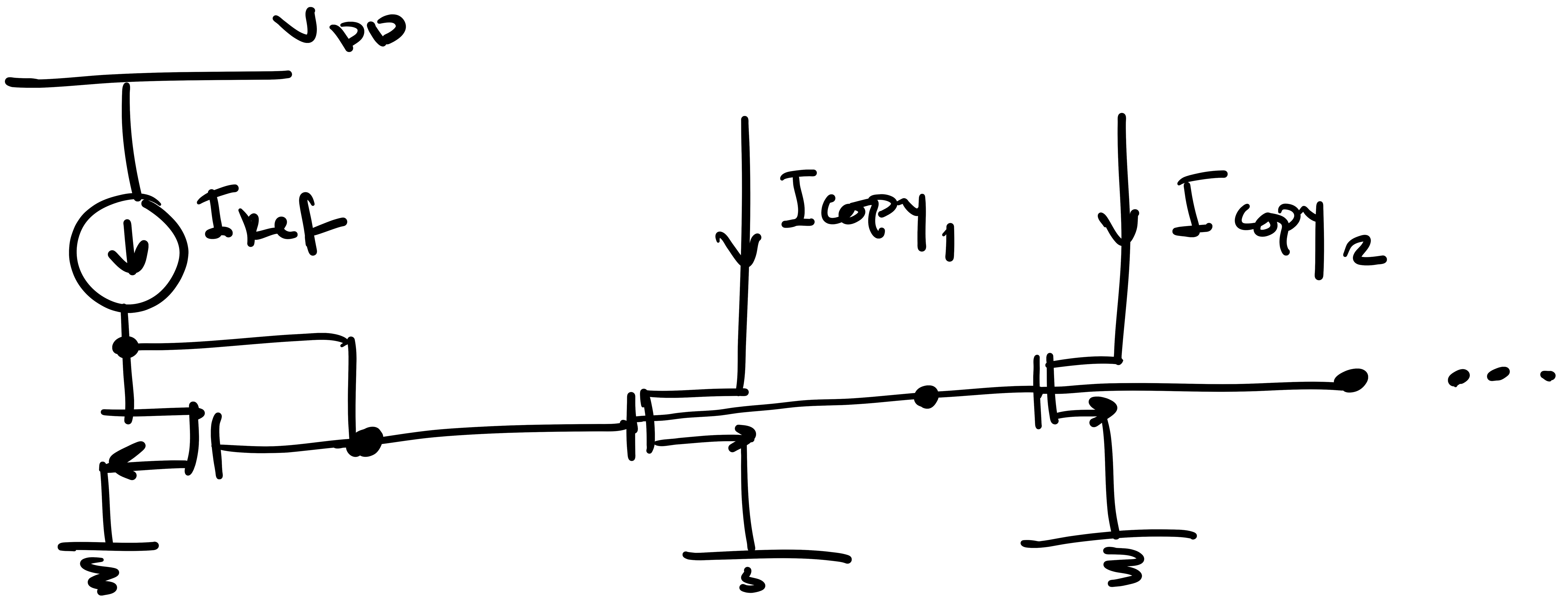


$$\frac{I_{copy}}{I_{Ref}} = \frac{(W/L)_1}{(W/L)_{Ref}}$$

$$\boxed{I_{copy} = \frac{(W/L)_1}{(W/L)_{Ref}} \cdot I_{Ref}}$$

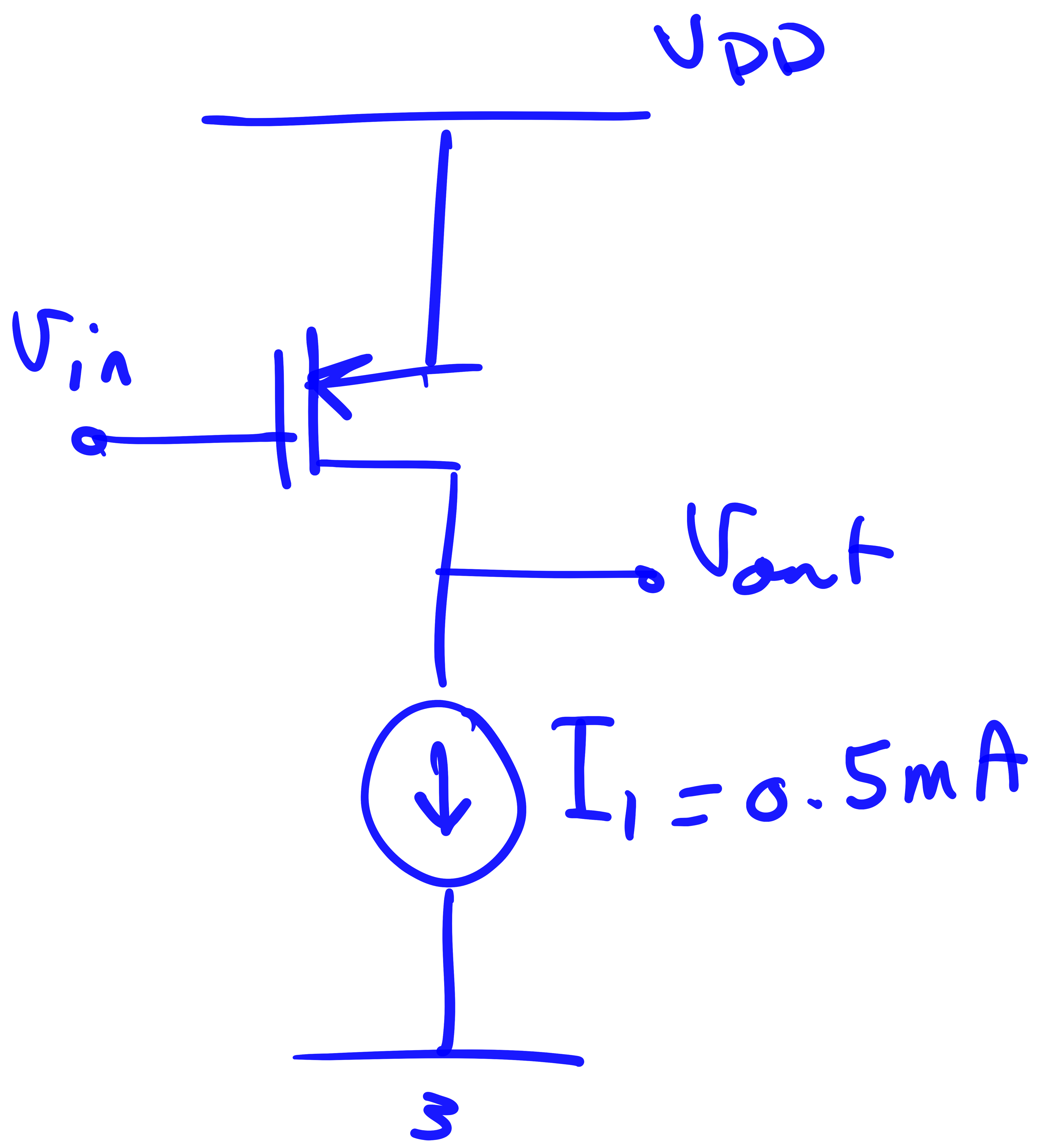
* Generating multiple currents in a cct. using I_{Ref} :-

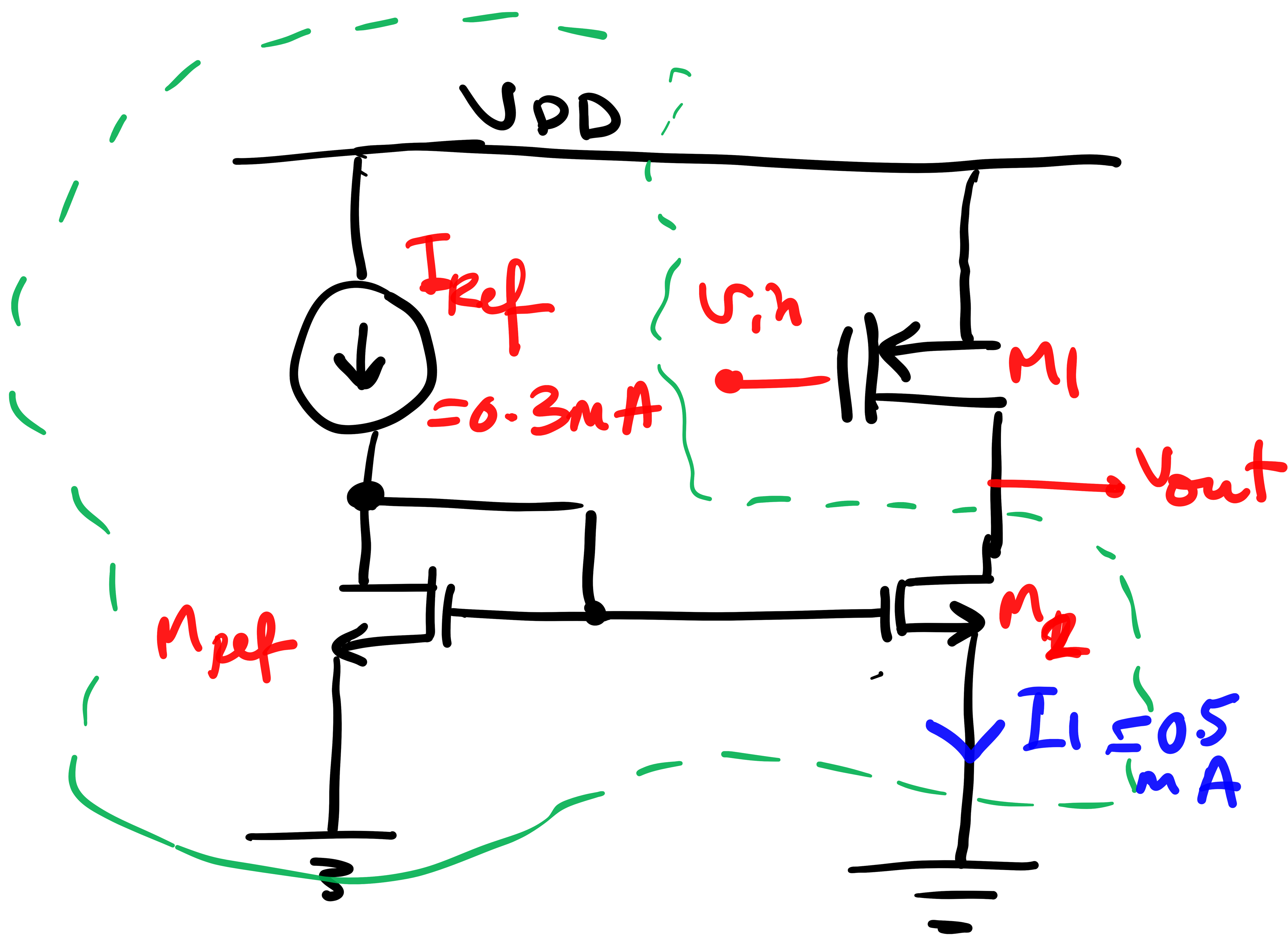




$$I_{copy_j} = \frac{(W/L)_j}{(W/L)_{REF}}$$

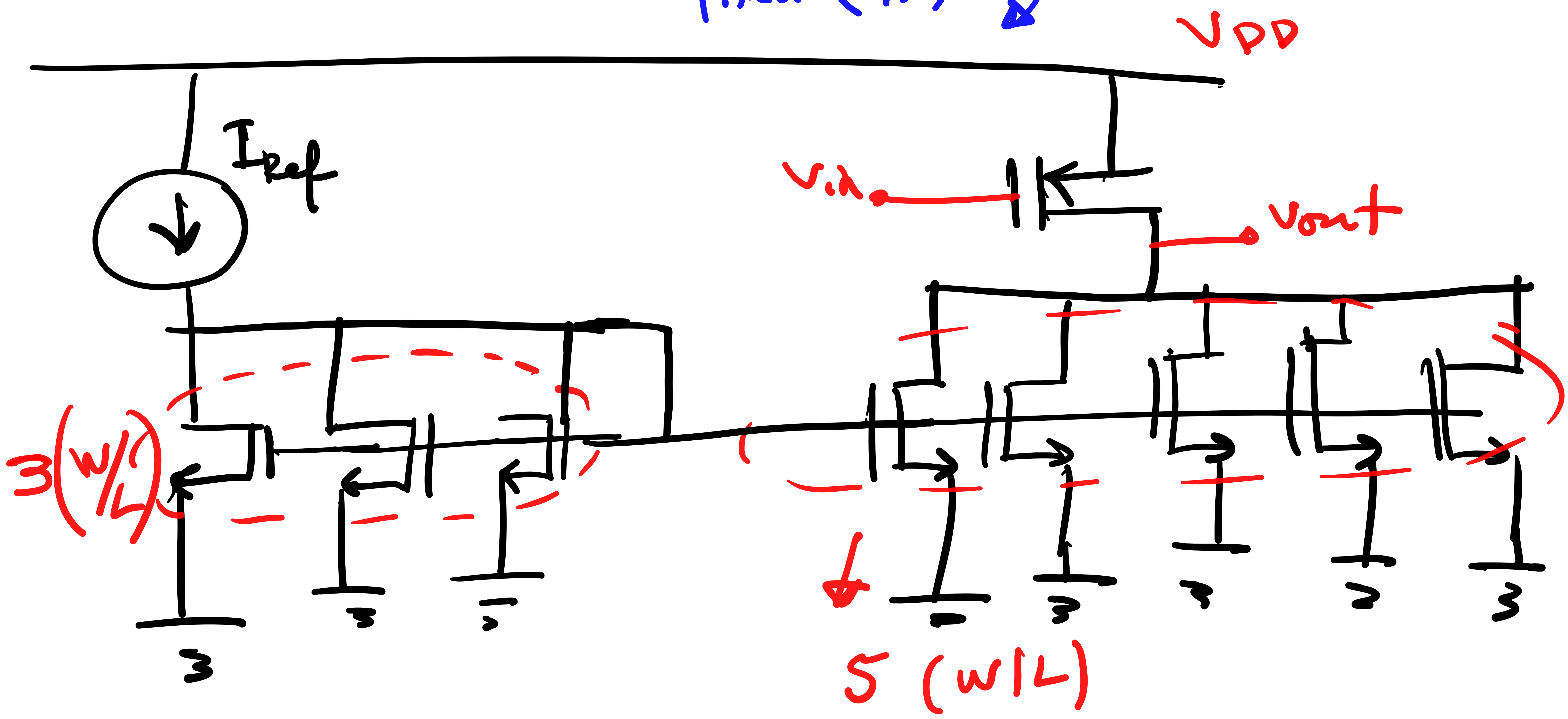
Ex: An Integrated cct. employs a CS stage, design a current mirror that produces $I_1 = 0.5mA$ from a $I_{ref} = 0.3mA$



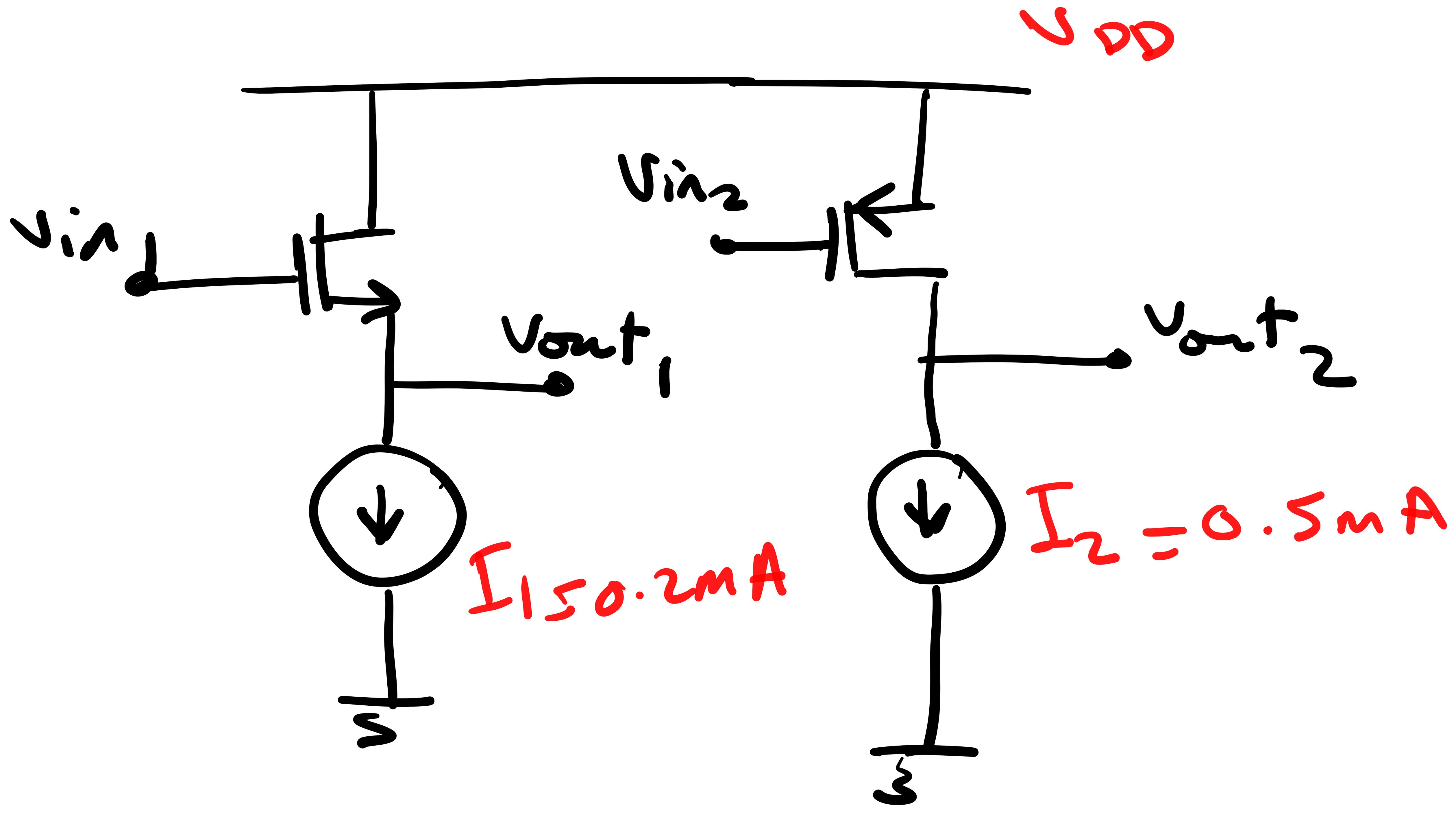


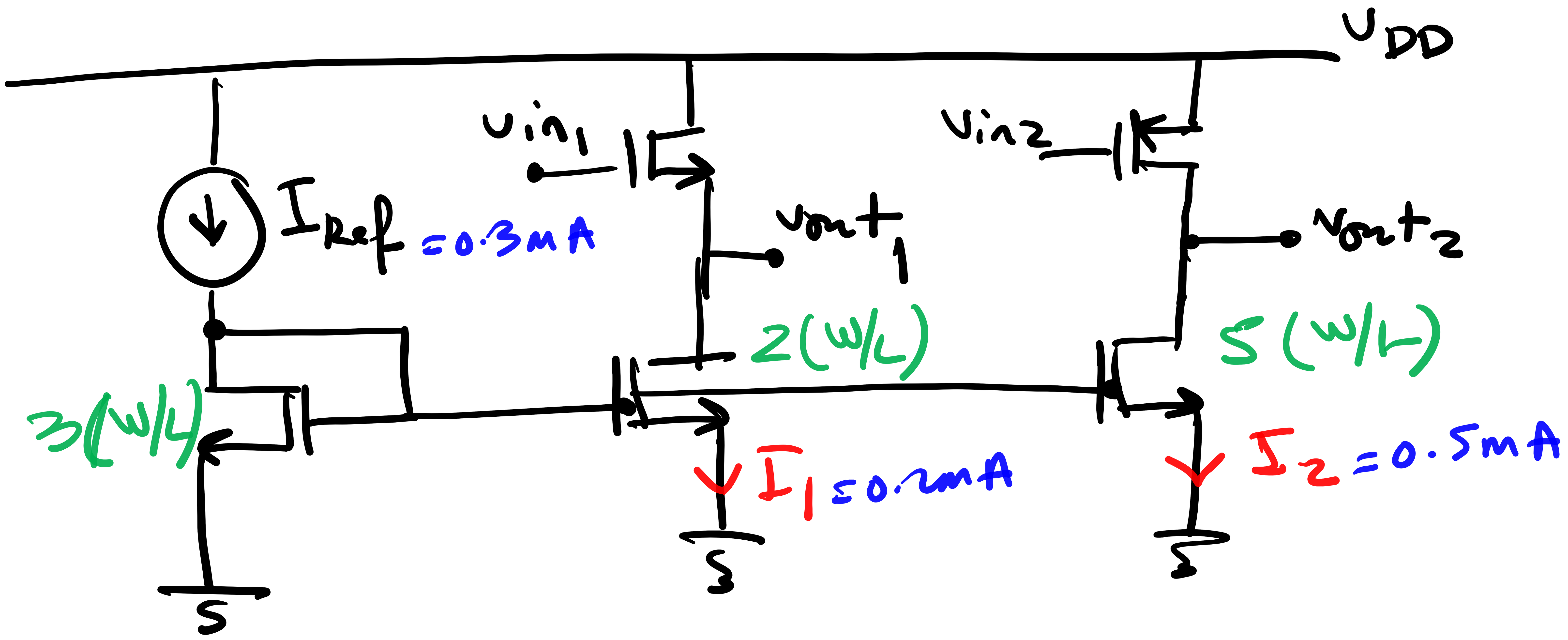
$$\frac{I_1}{I_{ref}} = \frac{(W/L)_2}{(W/L)_{ref}} = \frac{0.5\,mA}{0.3\,mA} = \frac{5}{3}$$

using unit transistor of fixed (W/L)



Ex: Design this cct. using an $I_{Ref} = 0.3mA$?





$$\frac{I_1}{I_{Ref}} = \frac{0.2}{0.3} = \frac{2}{3} \quad , \quad \frac{I_2}{I_{Ref}} = \frac{0.5}{0.3} = \frac{5}{3}$$

* PMOS current Mirrors :-