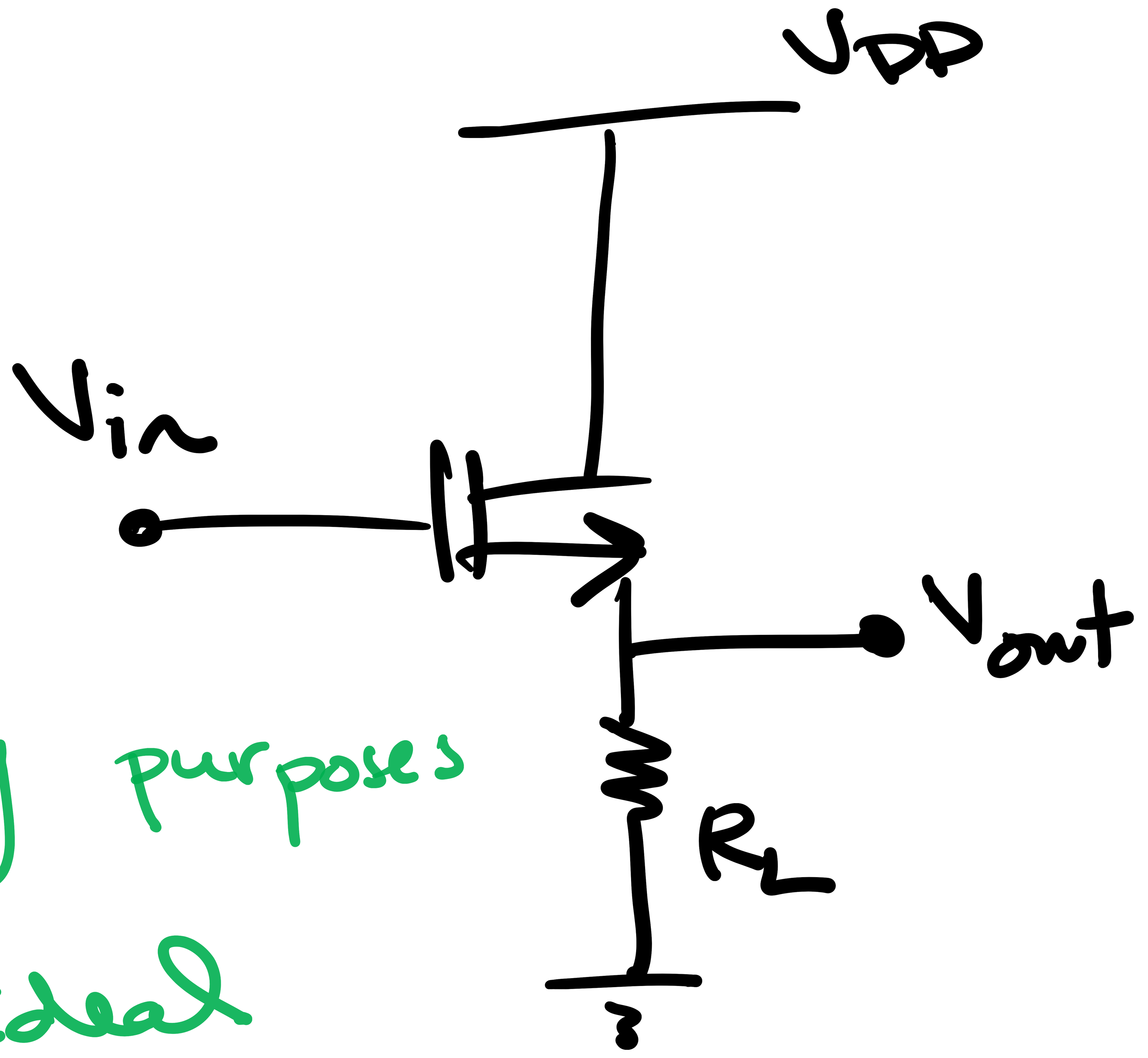
* Common Drain Stage (Source Follower):

more common.

* This stage is used for buffering purposes

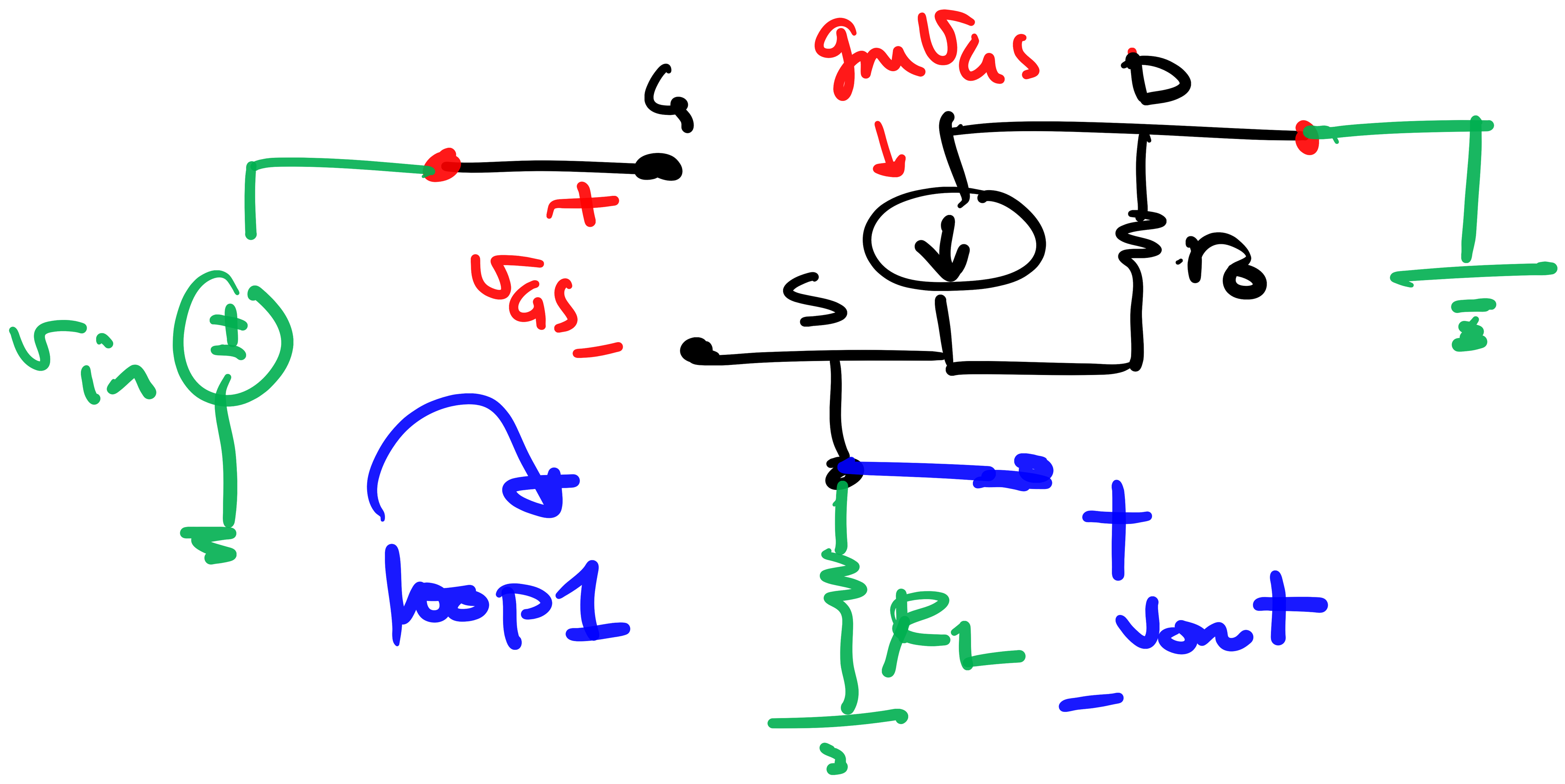


* They an ideal voltage gain of 1 ($A_V \approx 1$)

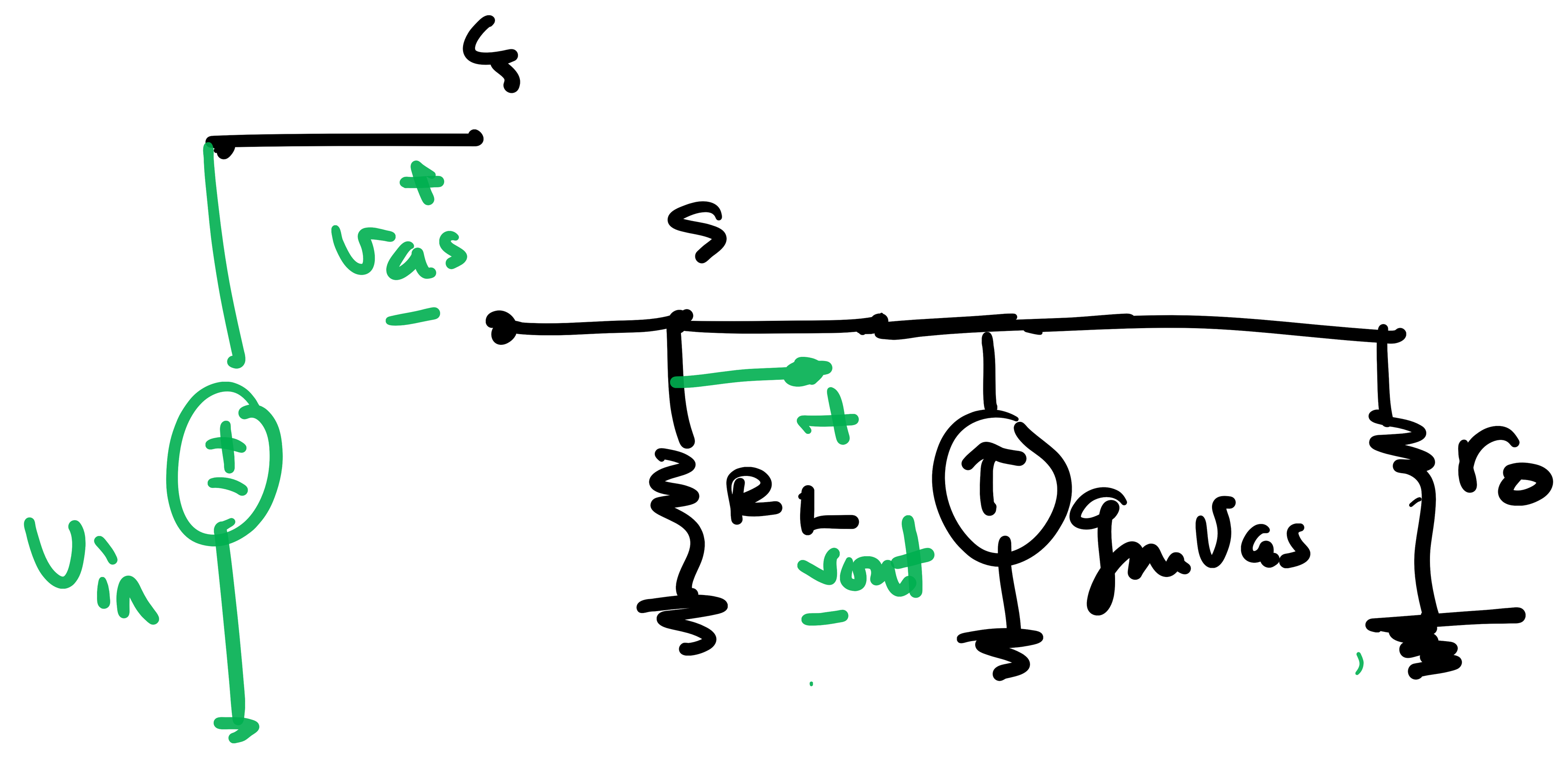
* a high input impedance
* a Low output impedance

* Gain Analysis A_V: $\lambda \neq 0$

$$A_V = \frac{V_{out}}{v_{in}}$$



$v_{out} = g_m v_{gs} (R_L \| r_o)$



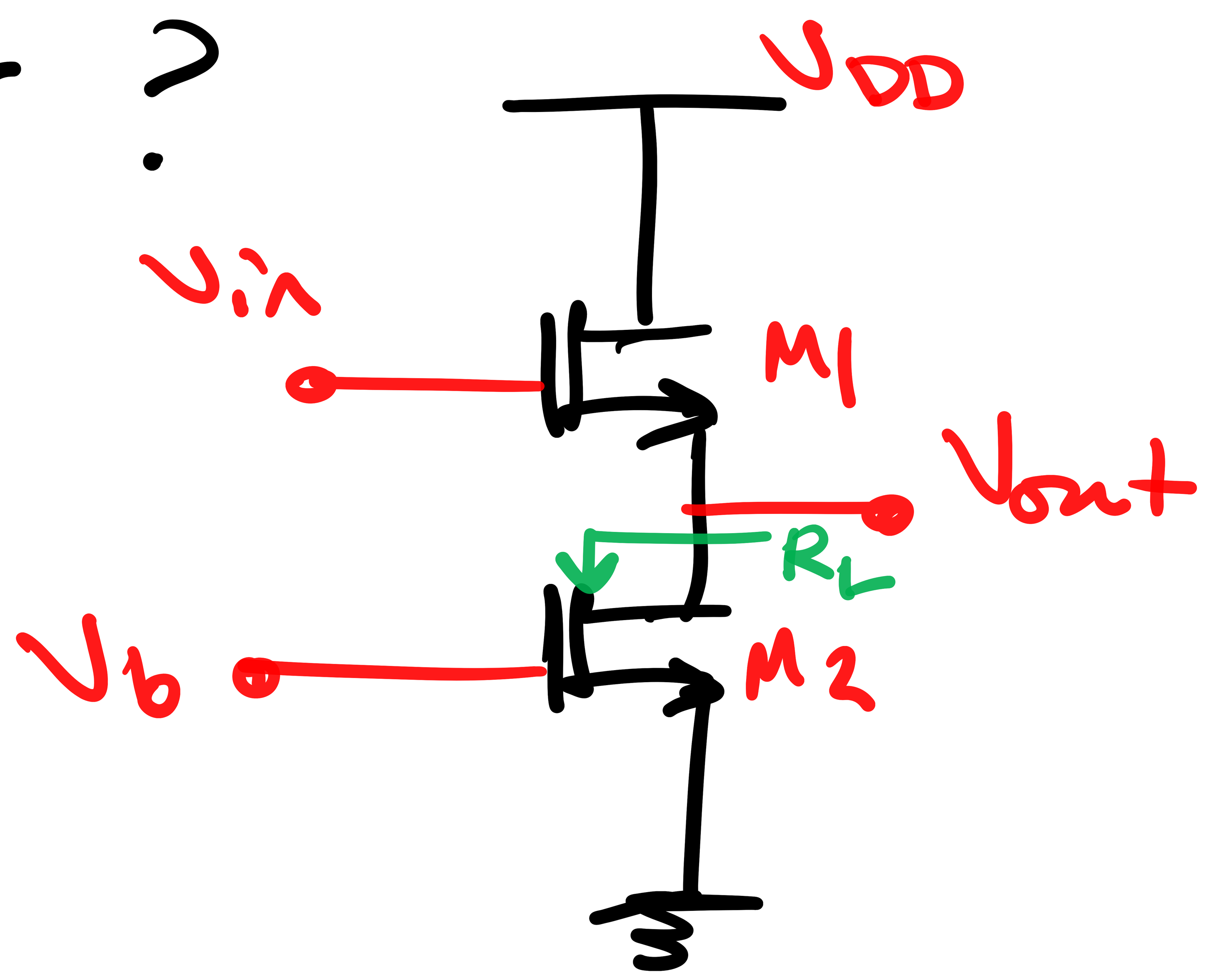
applying KVL @ loop 1 :-

$$V_{gs} = V_{in} - V_{out}.$$

$$A_v = \frac{V_{out}}{v_{in}} = \boxed{\frac{R_L \| r_o}{R_L \| r_o + 1/g_m}}$$

if $R_L \| r_o \gg 1/g_m \Rightarrow \boxed{A_v \approx 1}$

Ex: a S.F. is ~~realized~~ as follows, calculate A_v ?



$\Rightarrow$ standard def. for a S.F. A_v

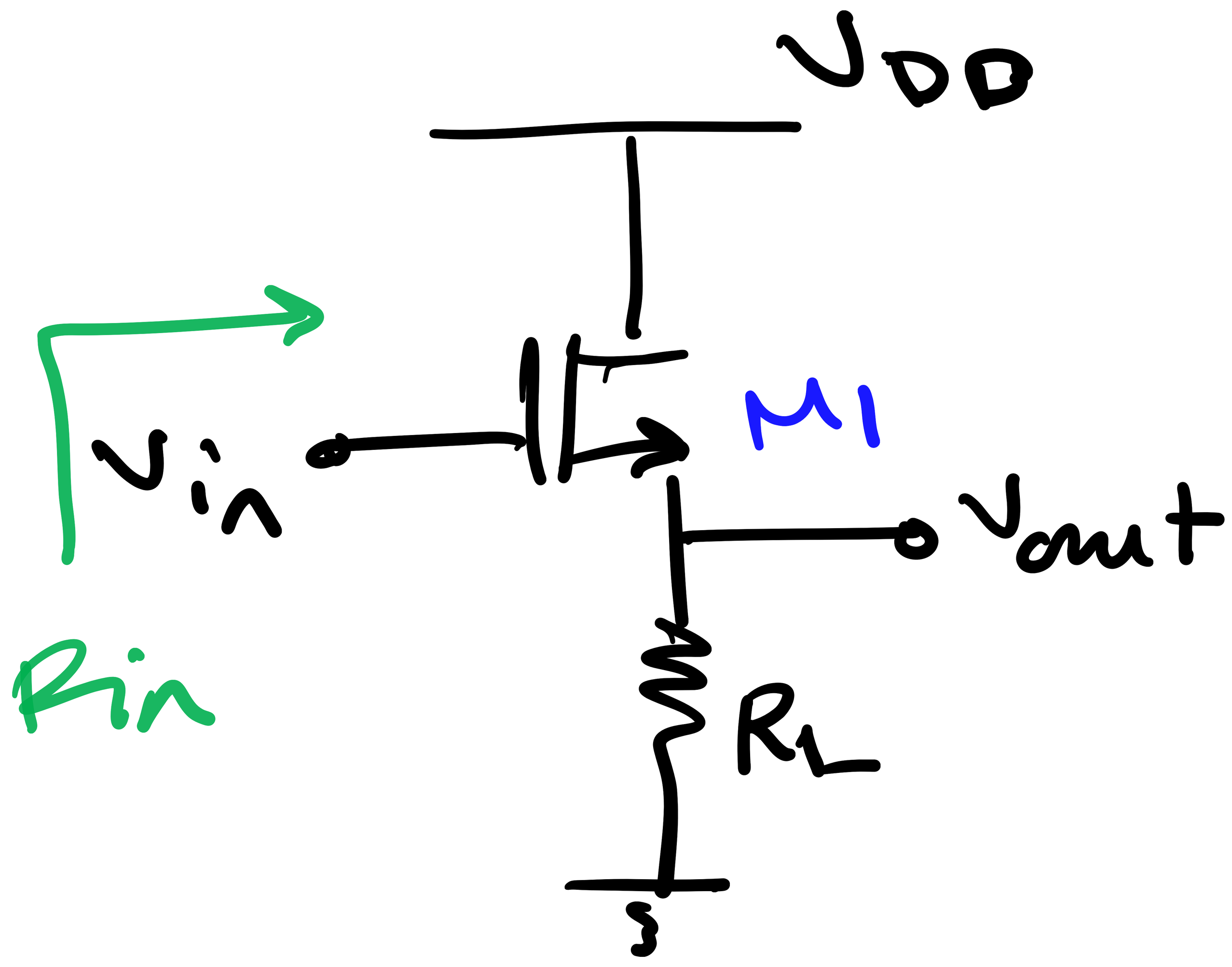
$$\boxed{= \frac{R_L \| r_o}{R_L \| r_o + 1/g_m}}$$

if $\lambda \neq 0 \Rightarrow R_L = r_{o2}$

$$\Rightarrow A_v = \frac{r_{o2} \| r_{o1}}{r_{o2} \| r_{o1} + 1/g_{m1}}$$

* Input Impedance Analysis :-

$R_{in} = \infty$

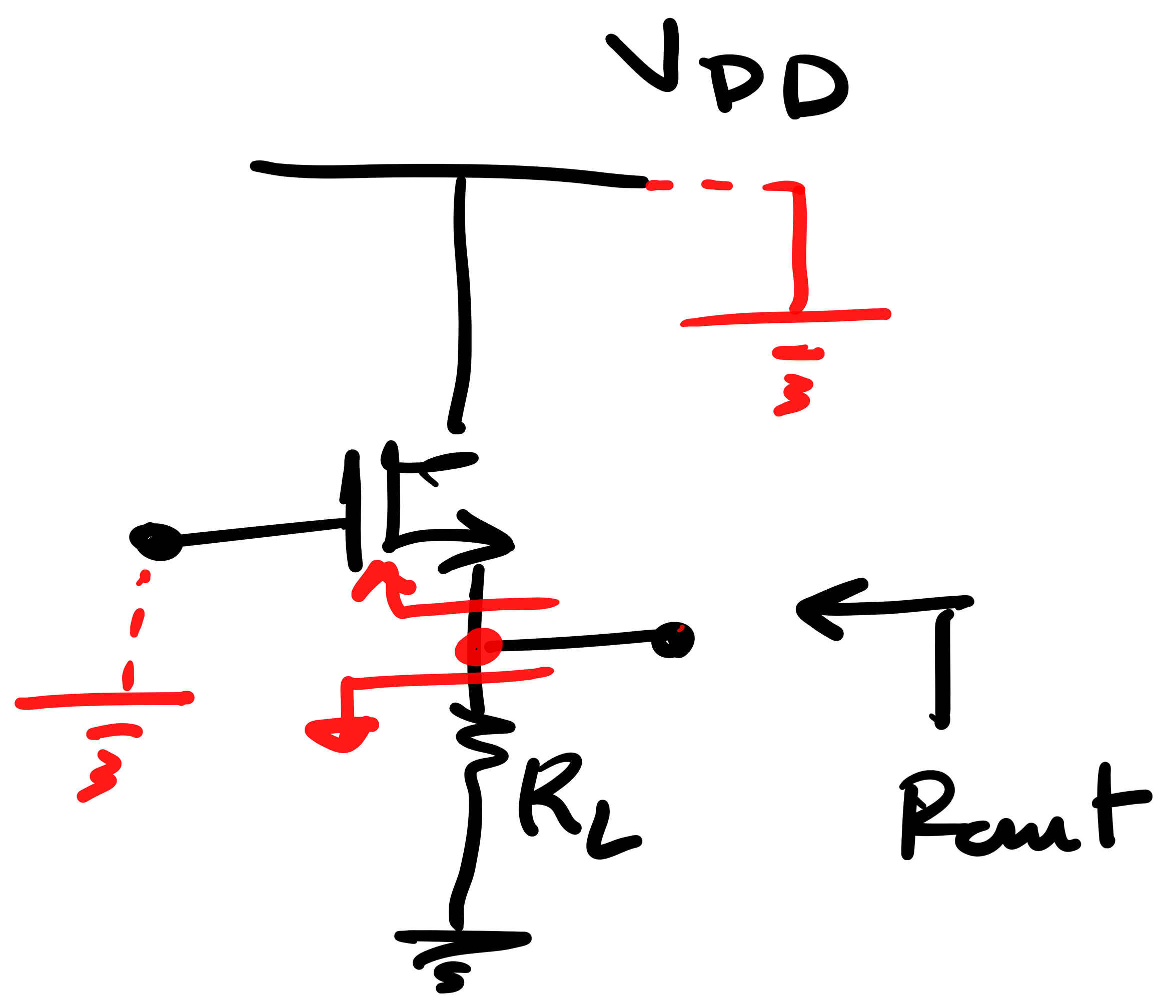


* Remember that

Rin will drop when we bias M_1 using resistors.

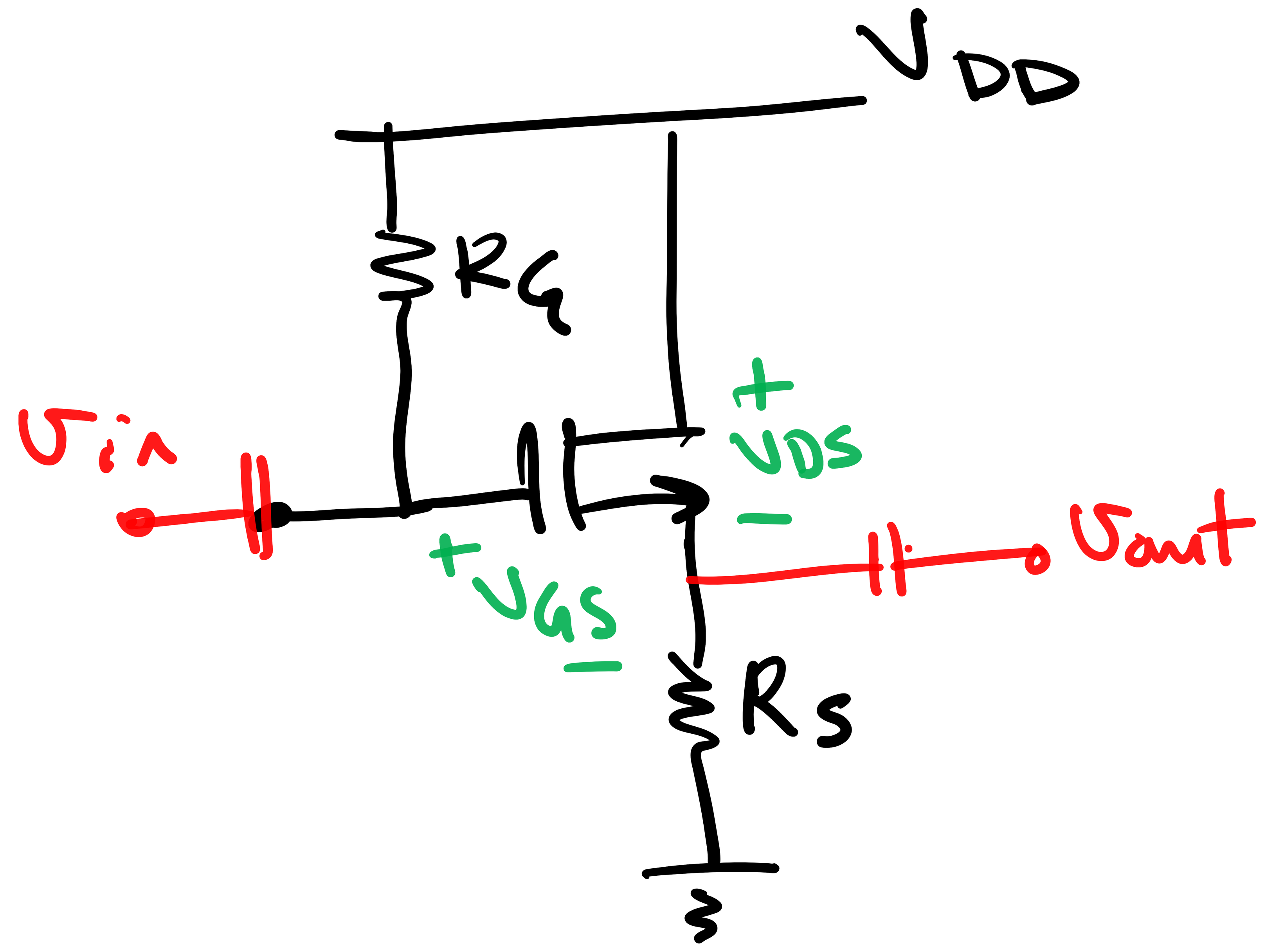
* Output Impedance Analysis :-

$R_{out} = \boxed{\frac{1}{g_m} \parallel R_L}$



Notice that Rout is low compared to CS and CG stages.

* Source Follower biasing :-



Since $I_G = 0$

$\Rightarrow \quad V_G = V_D = V_{DD}$

$\Rightarrow \quad V_{GS} = V_{DS}$

hence $V_{DS} > V_{GS} - V_{TH}$

$\longrightarrow$ always in saturation.

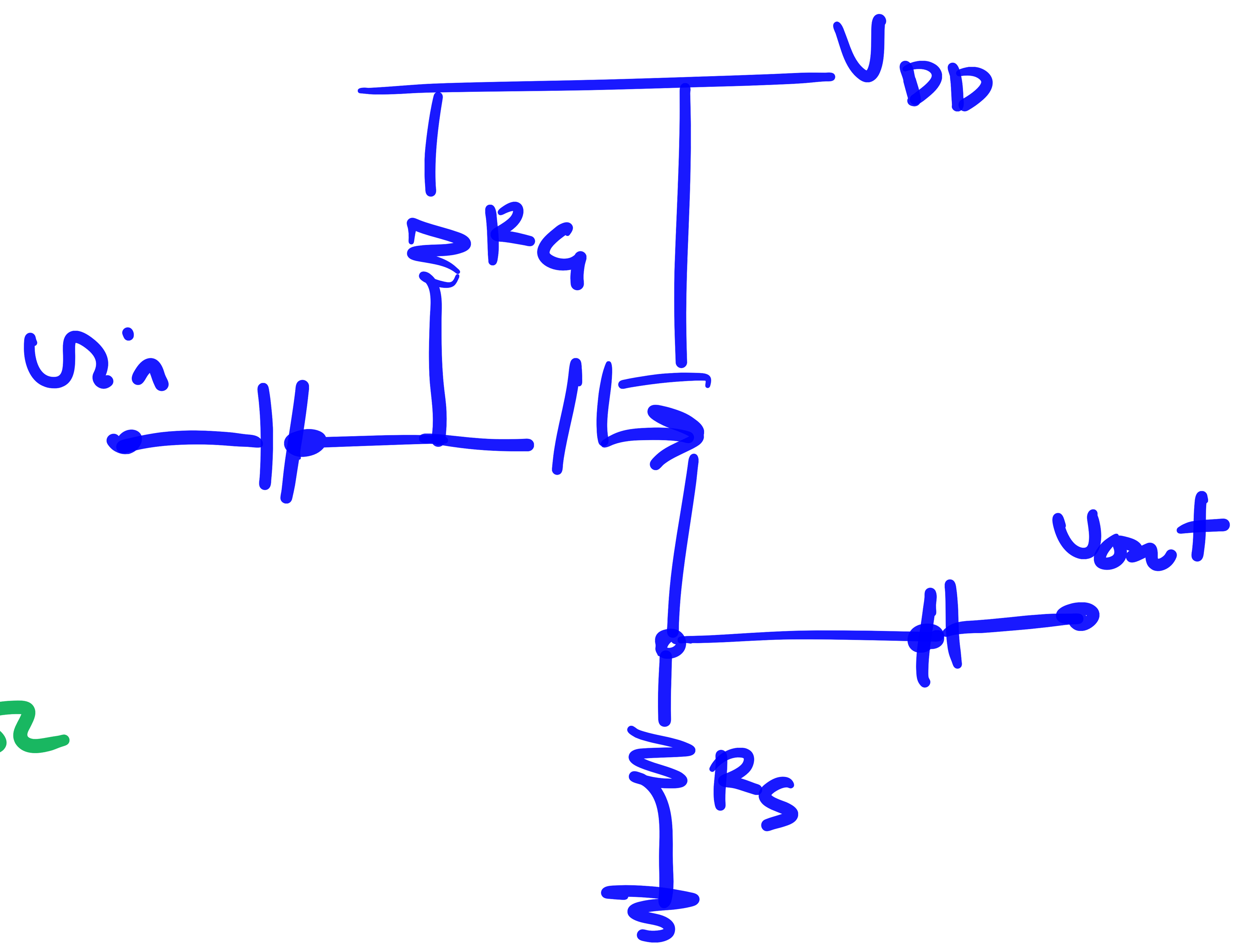
$$I_D = \frac{1}{2}\mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})^2$$

$\Rightarrow \quad V_{DS} = V_{DD} - I_D R_S \Rightarrow V_{GS} = V_{DD} - I_D R_S$

$$\boxed{I_D = \frac{1}{2}\mu_n C_{ox} \frac{W}{L} \left(V_{DD} - I_D R_S - V_{TH} \right)^2}$$

& solve for I_D then define V_{GS}, V_{DS}

Ex: Design a S.F. for a Drain current of 1mA and an A_v of 0.8. Assume $\mu_n C_{ox} = 100\mu A/V^2$, $V_{TH} = 500mV$, $\lambda = 0$, $V_{DD} = 1.8V$ and and $R_G = 50k\Omega$.



Sol: $I_D = 1mA$

$A_v = 0.8$, $R_G = 50k\Omega$

$$A_v = \frac{R_S \| r_o}{R_S \| r_o + 1/g_m} = \frac{R_S}{R_S + 1/g_m} = 0.8$$

$\Rightarrow$ but $g_m = \dfrac{2I_D}{V_{GS} - V_{TH}}$ $\rightarrow$ $V_{GS} = V_{DD} - I_D R_S$

$$g_m = \frac{2I_D}{(V_{DD} - I_D R_S - V_{TH})}$$

$$\rightarrow A_v = 0.8 = \frac{R_S}{R_S + \frac{(V_{DD} - I_D R_S - V_{TH})}{2I_D}}$$

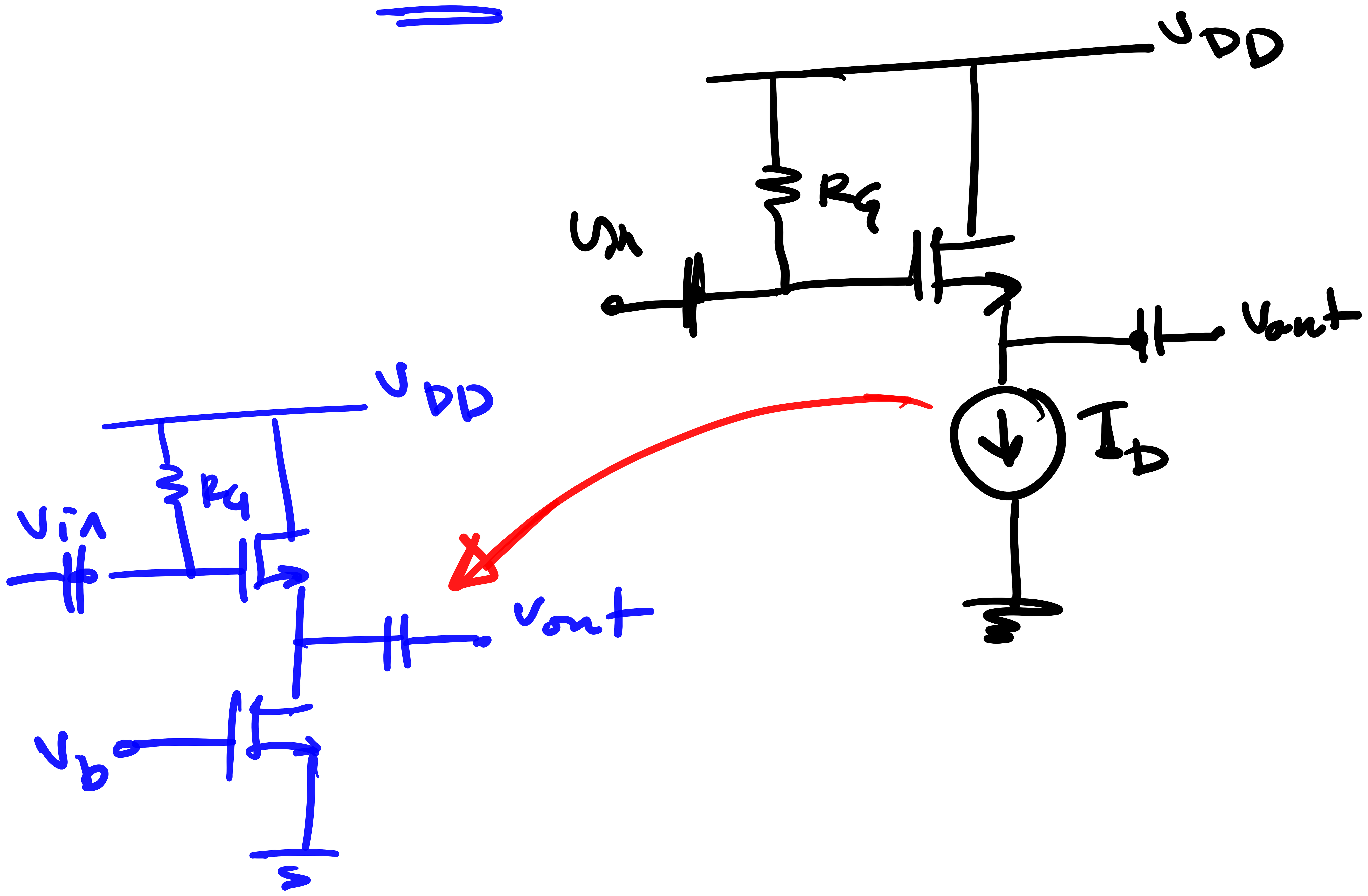
$\rightarrow$ solving for R_S $\Rightarrow$ $\boxed{R_S = 867\Omega}$

$$\Rightarrow \frac{W}{L} = \frac{2I_D}{\mu_n C_{ox}(V_{GS}-V_{TH})^2}, \quad \text{but } V_{GS} = V_{DD} - I_D R_S = \boxed{0.933\,V}$$

$$\Rightarrow \boxed{\frac{W}{L} = 207} \; ? \quad 107$$

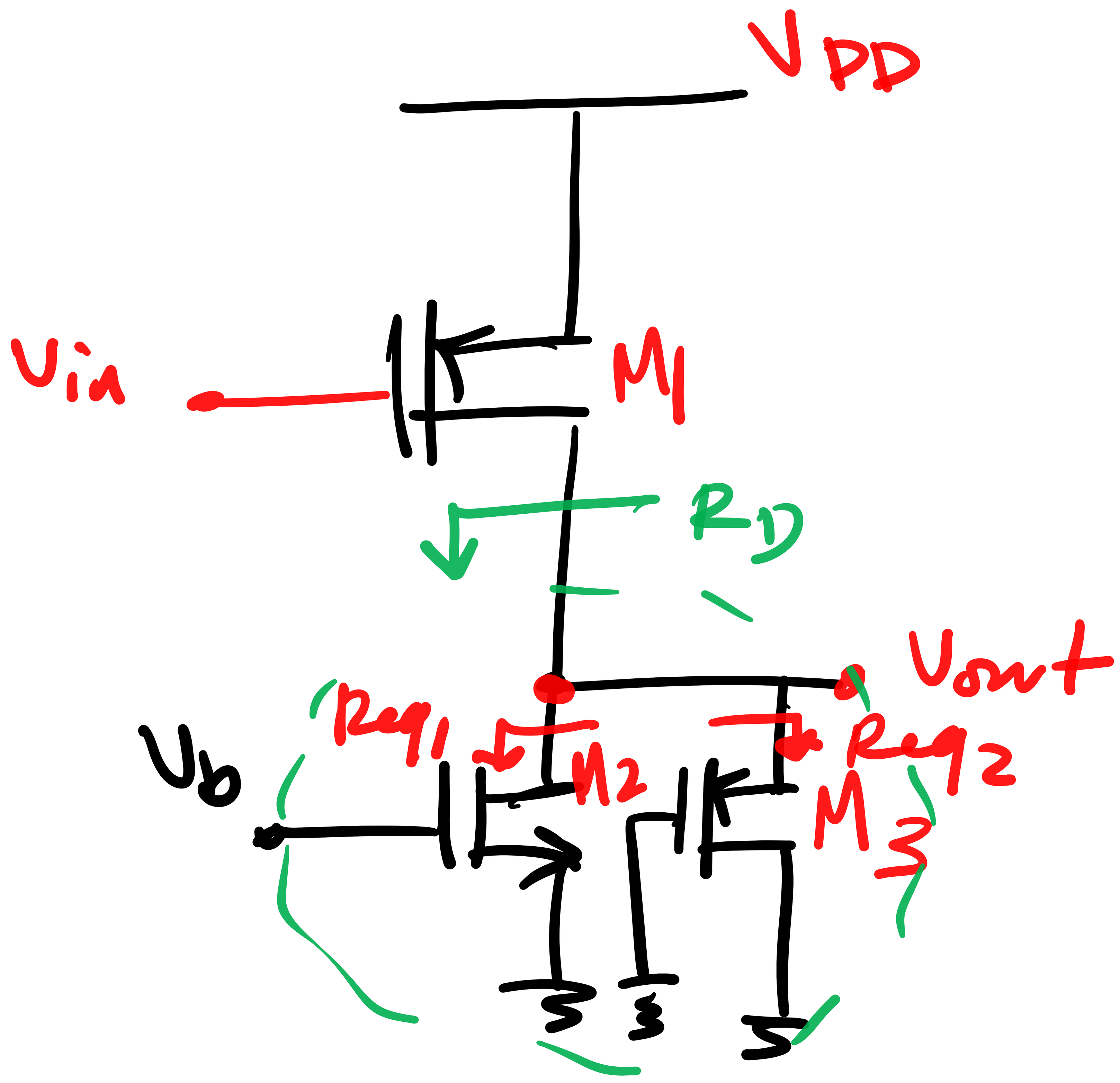
Since V_{GS} depends on R_S and I_D pay attention to the increase in either R_S or I_D as it may turn the transistor OFF.

* To solve the above issue we can bias the S.F. using a current source realized as a MOS.



* Examples on different MOS amp stages :-

Ex: Calculate A_v and R_{out} for this stage



$$A_v = -g_m R_D$$

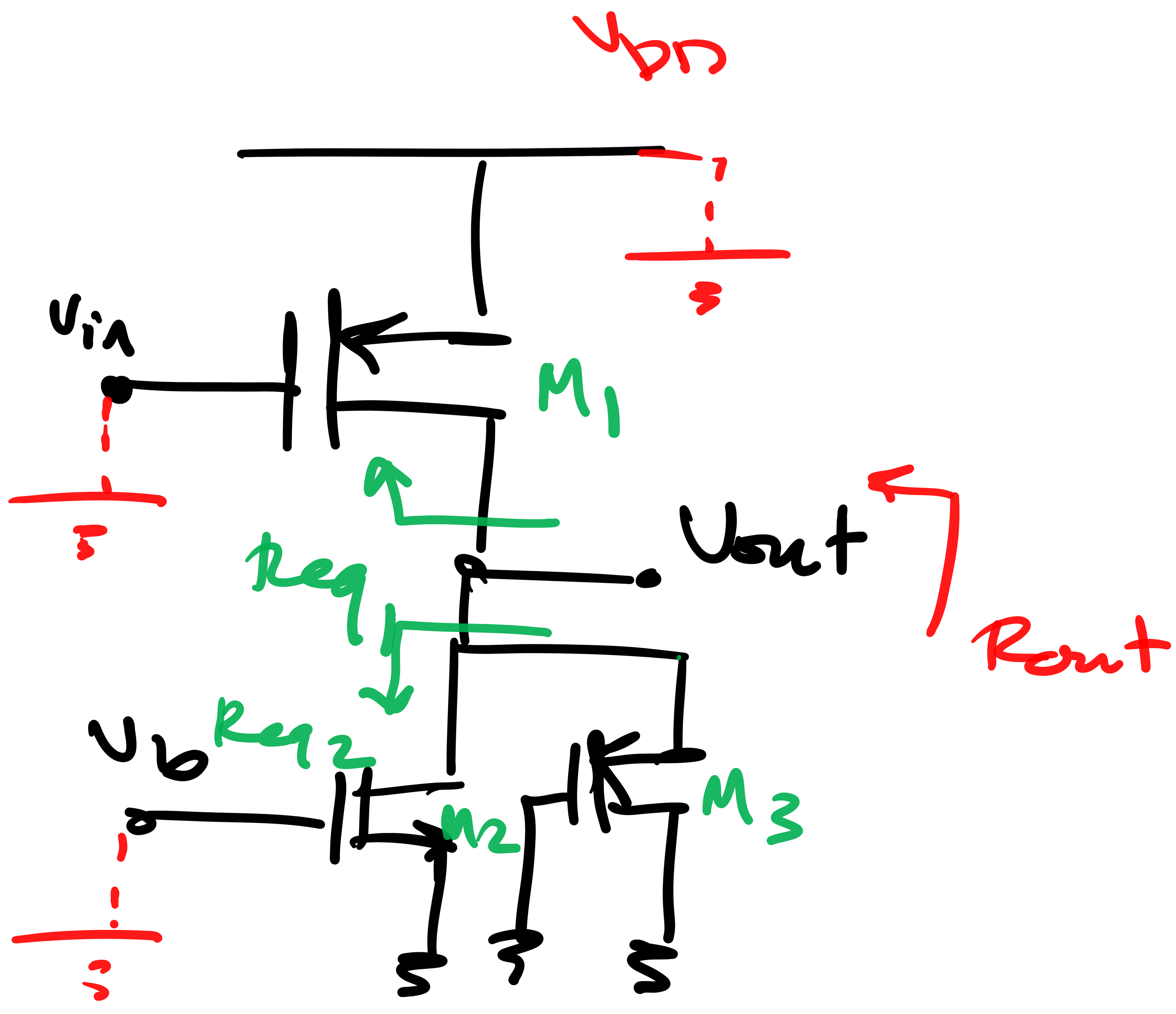
$$R_D = R_{eq_1} \,//\, R_{eq_2}$$

$$R_{eq_1} = r_{o2}$$

$$R_{eq_2} = 1/g_{m3}$$

$$A_v = -g_{m_1} \cdot r_{o2} \,//\, 1/g_{m3} \approx \frac{-g_{m1}}{g_{m3}}$$

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



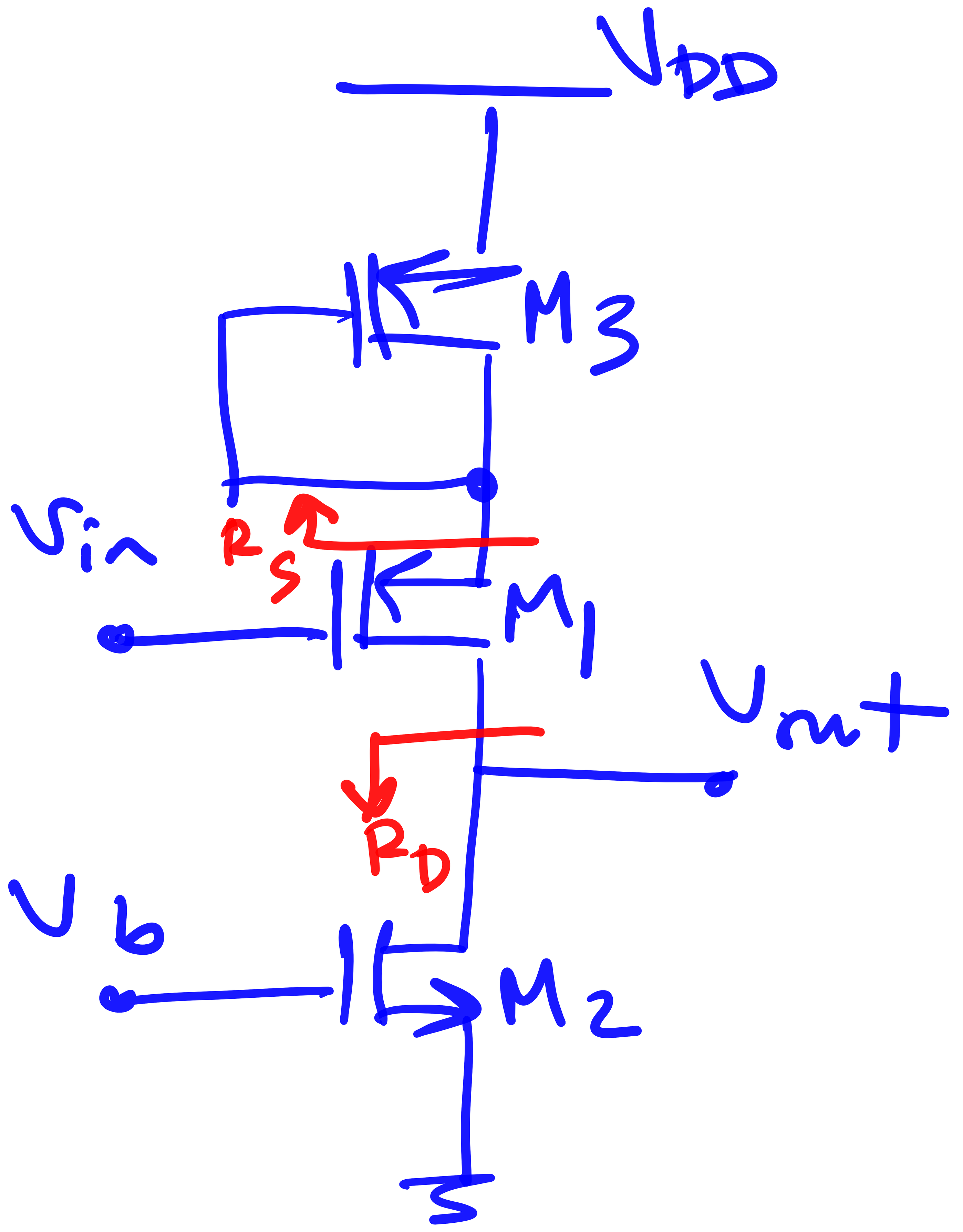
$$R_{out} = R_{eq_1} \,//\, R_{eq_2}$$

$$R_{eq_1} = r_{o1}$$

$$R_{eq_2} = r_{o2} \,//\, 1/g_{m3}$$

$$R_{out} = r_{o1} \,//\, r_{o2} \,//\, 1/g_{m3} \rightarrow \approx \frac{1}{g_{m3}}$$

Ex: Calculate A_v for this cct assuming $\lambda \neq 0$.



→ This is a degenerate CS core

$$A_v = \frac{-R_D}{1/g_{m1} + R_S}$$

$$R_S = \frac{1}{g_{m3}}$$

$$R_D = r_{o2}$$

$$A_v = \frac{-r_{o2}}{\frac{1}{g_{m1}} + \frac{1}{g_{m3}}}$$

* Chapter 9: Cascode Stages and Current Mirrors:

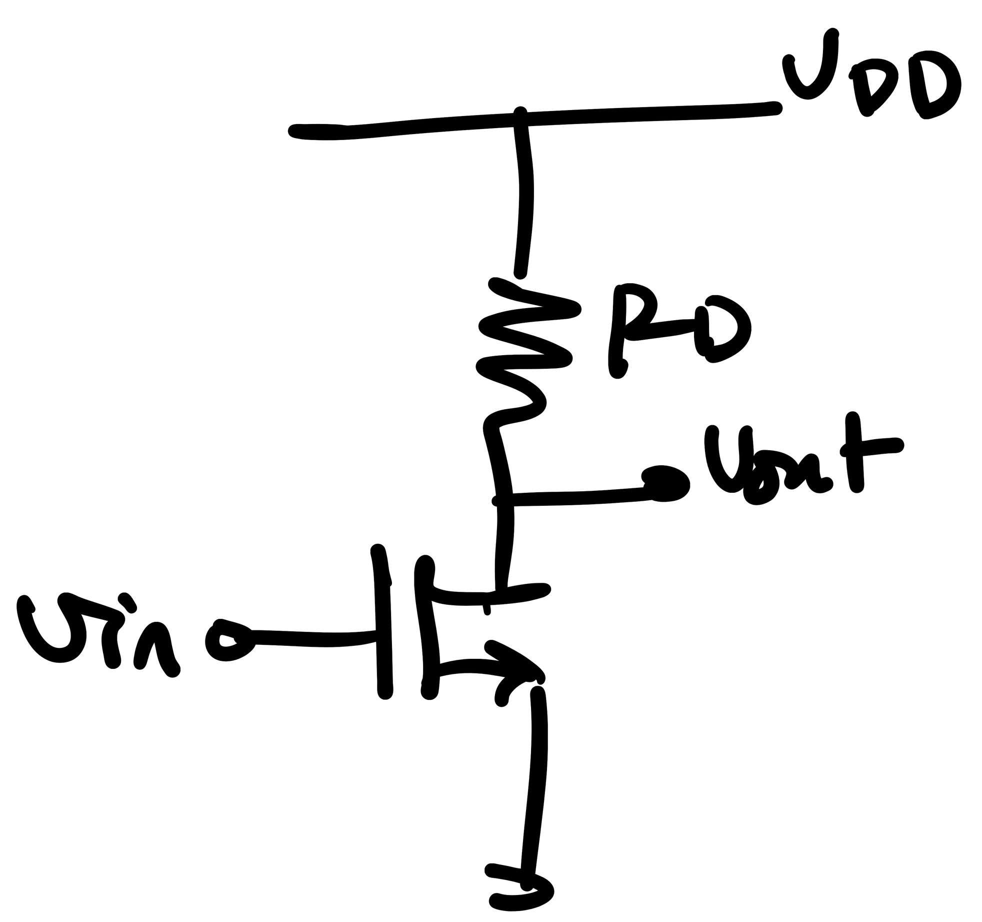
* Cascode Amplifiers:-

Impedance Boosters

Gain Boosters

* Impedance Boosters:-

$\lambda = 0$



$\Rightarrow$ The gain $|A_v| = +g_m R_D$

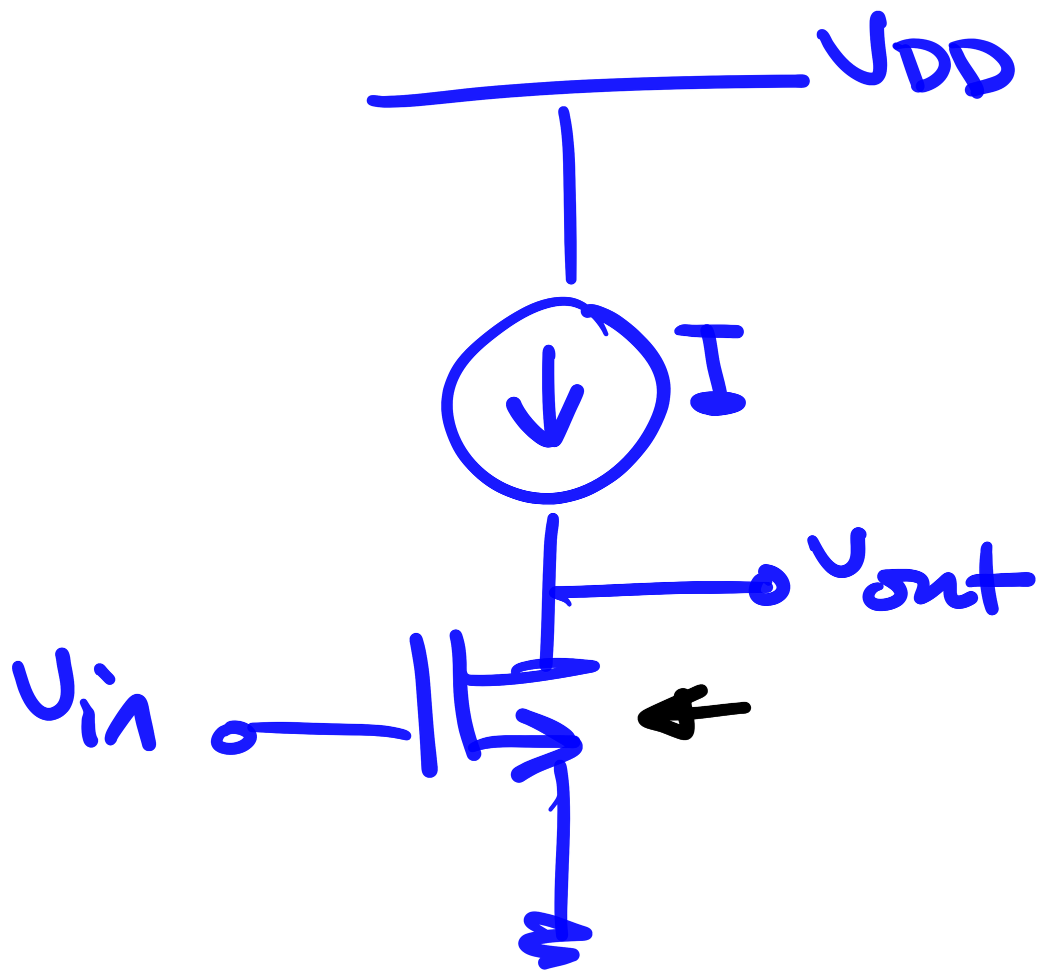
to increase $|A_v| \uparrow \rightarrow g_m \uparrow$ or $R_D \uparrow$

when $g_m \uparrow \rightarrow I_D \uparrow \rightarrow$ Consuming more power

$I_D \uparrow \rightarrow V_{DS} \downarrow \rightarrow$ placing the Q point closer to the triode region.

$R_D \uparrow \rightarrow V_{DS} \downarrow \rightarrow$ same as above

* Cascodes solve the above problem as follows:



if the current source is ideal

assume $\lambda = 0$

$$|A_v| = g_m \cdot \infty$$

current source acts as an open

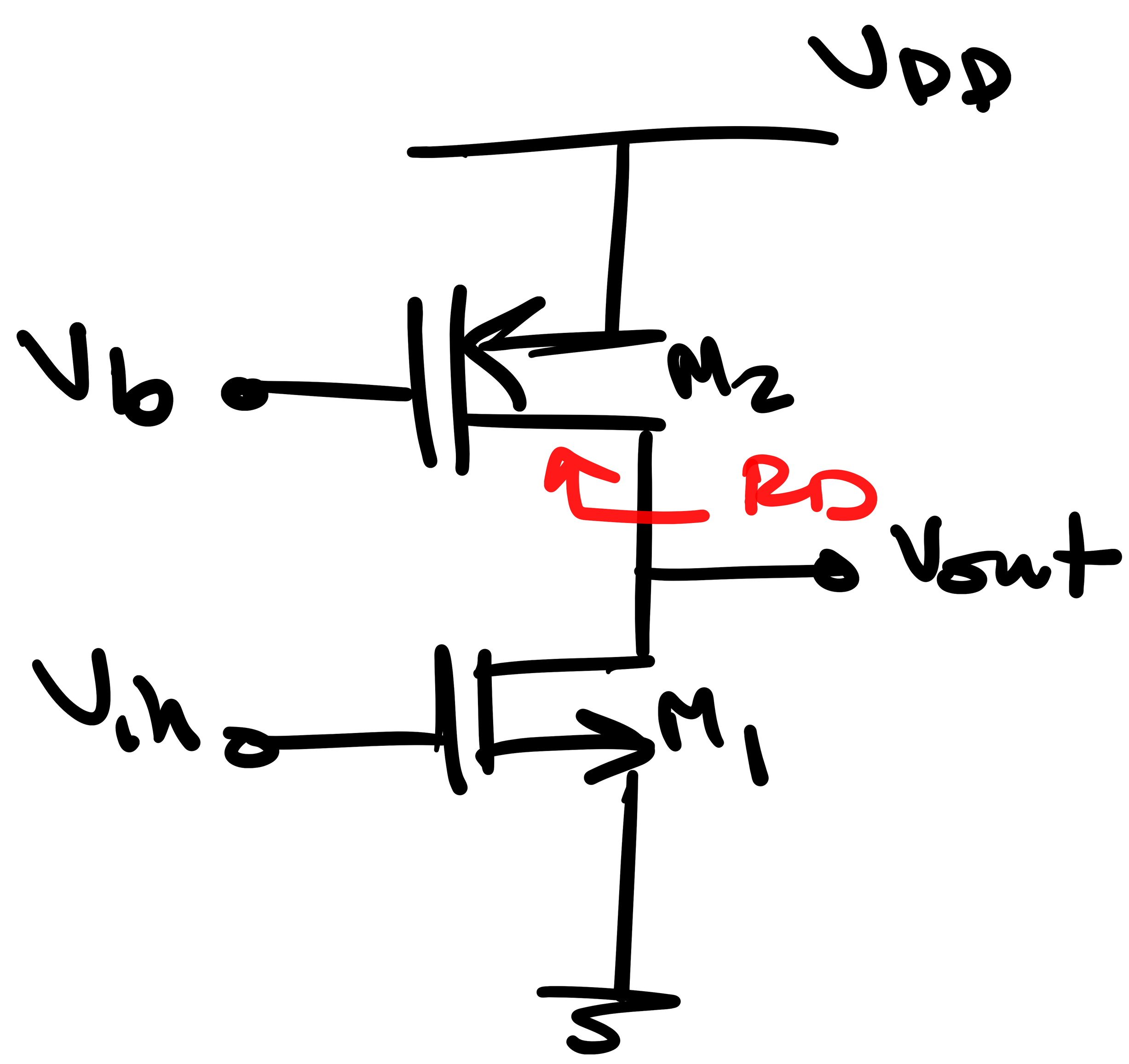
but if $\lambda \neq 0$

$$|A_v| = g_m \cdot r_o$$

⇒ The ideal current source is assumed to have an infinite small signal resistance allowing

$$|A_v| = g_m \cdot (r_o // \infty) = (g_m r_o)$$

⇒ Let us see what happens when the current source is realized using MOS devices?



assume $\lambda \neq 0$

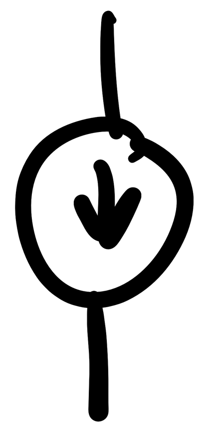
and M_1 and M_2 are identical

$$|A_v| = g_{m_1} (R_D // r_{o1})$$

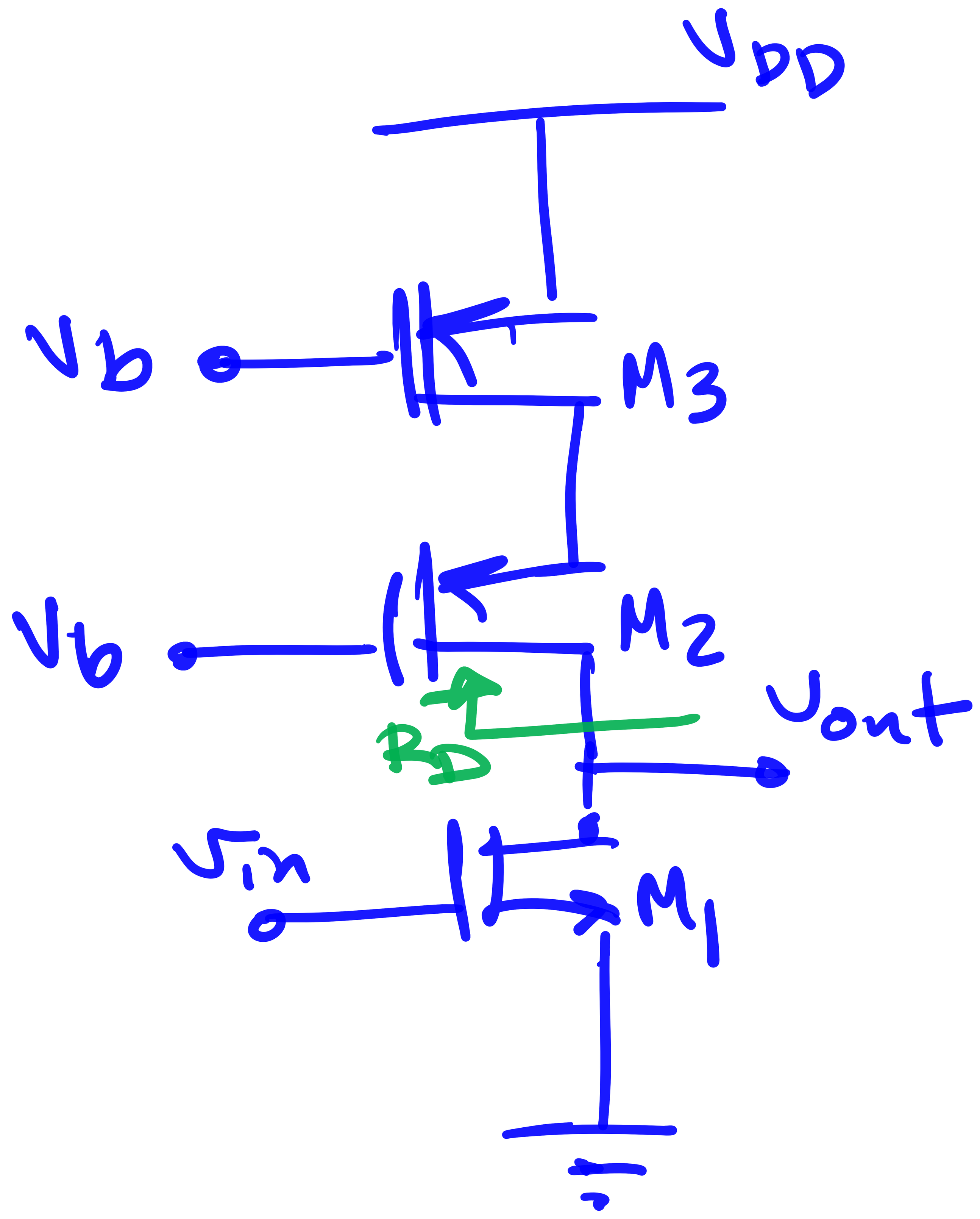
$$= g_{m_1} (r_{o2} // r_{o1})$$

$$\Rightarrow |A_v| = g_{m_1} r_o / 2$$

[M_1 and M_2 are identical $r_{o1} = r_{o2}$]

realizing  with one MOS will drop $|A_v|$,

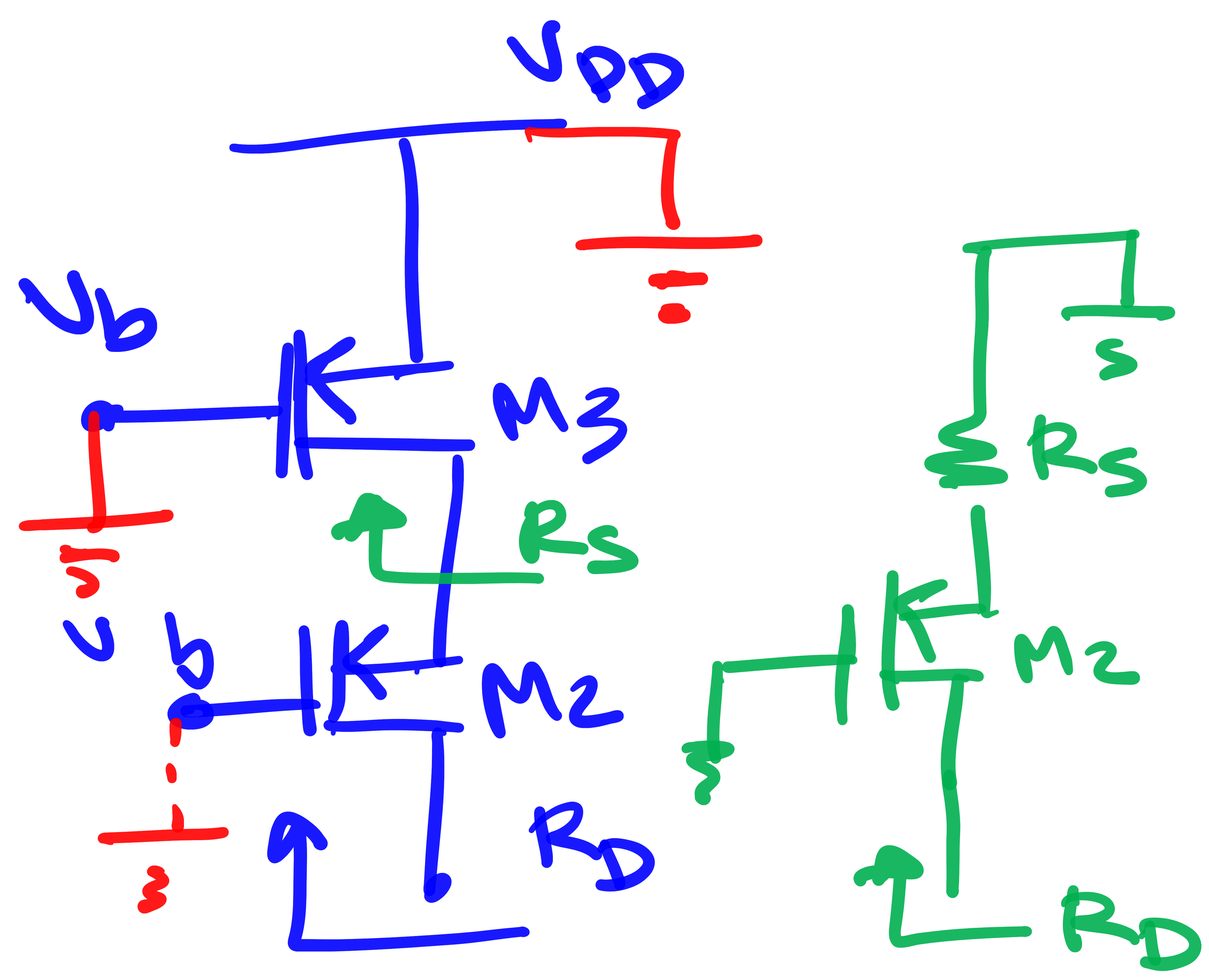
solution is use a cascode:



$\lambda \neq 0$

$|A_v| = g_{m_1}(R_D // r_{o1})$

$\Rightarrow R_D$?



$R_D = (1 + g_{m_2} R_S) \cdot r_{o2}$

$\Rightarrow R_S = r_{o3}$

$R_D = (1 + g_{m_2} r_{o3}) \cdot r_{o2}$

$R_D \approx g_{m_2} r_{o3} \cdot r_{o2}$

$\Rightarrow |A_v| = g_{m_1}(r_{o1} // g_{m_2} r_{o2} r_{o3})$