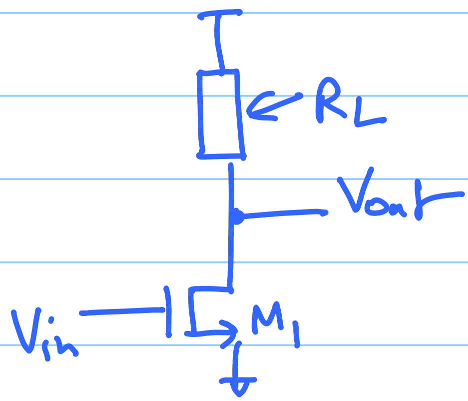
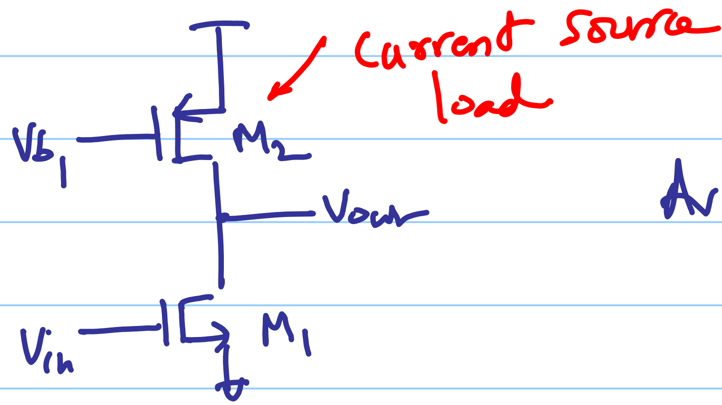
ECE 511 - Lecture 11

Note Title 2/19/2015

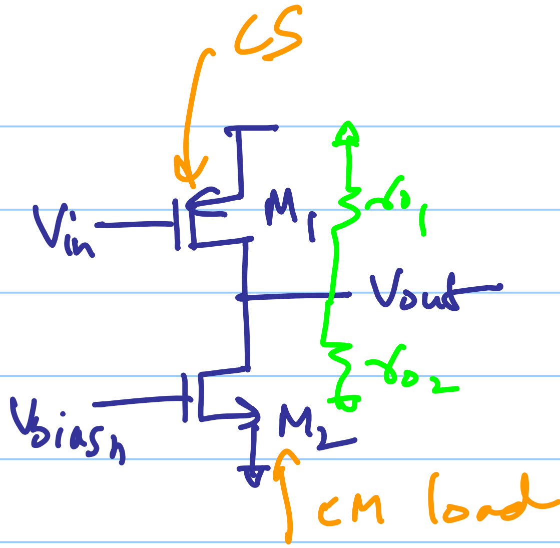
Voltage gain at DC



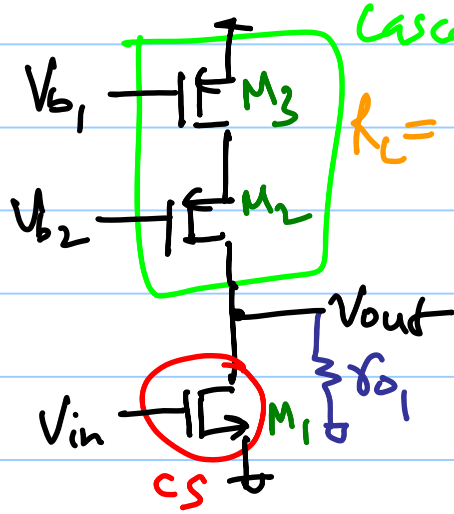
$$A_v = -g_{m_1}(R_L \| r_{o_1})$$



$$A_v = -g_{m_1} \cdot r_{o_1} \| r_{o_2}$$



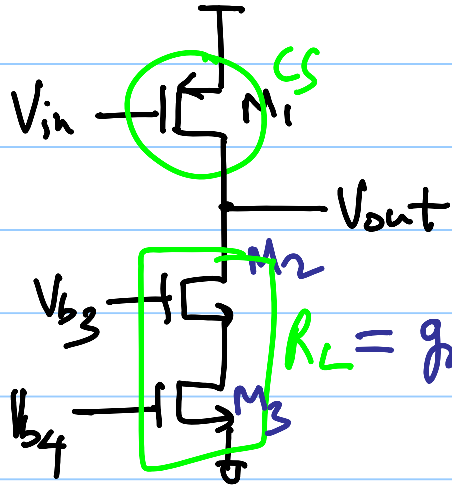
$$A_v = -g_{m_1}\cdot(r_{o_1} \| r_{o_2})$$



$R_L = g_{m_2} r_{o_2} r_{o_3}$

$$A_v = -g_{m_1}\cdot\left[r_{o_1} \| \left(g_{m_2} r_{o_2} r_{o_3}\right)\right]$$

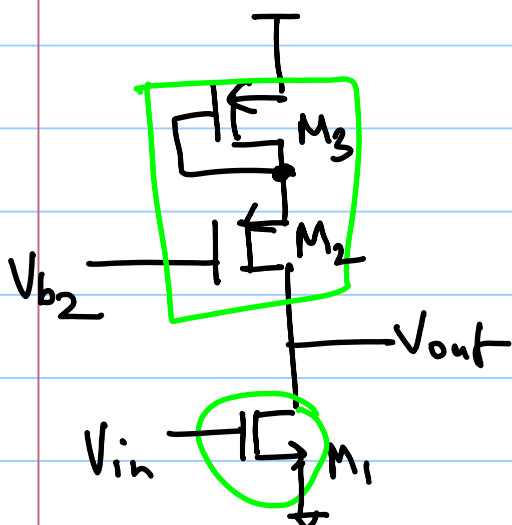
$$\simeq -g_{m_1} r_{o_1}$$



$$A_v = -g_{m_1} \cdot r_{o_1} \| R_L$$

$$R_L = g_{m_2} r_{o_2} r_{o_3}$$

$$R_L = \boxed{g_{m_2} r_{o_2} r_{o_3}} + \underbrace{r_{o_2} + r_{o_3}}$$



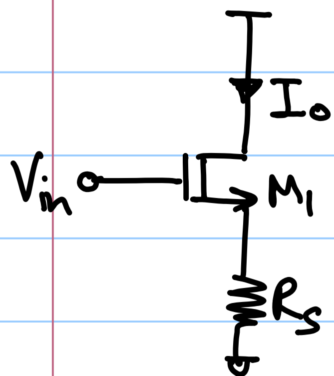
$$A_v = -g_{m_1} \cdot r_{o_1} \| R_L$$

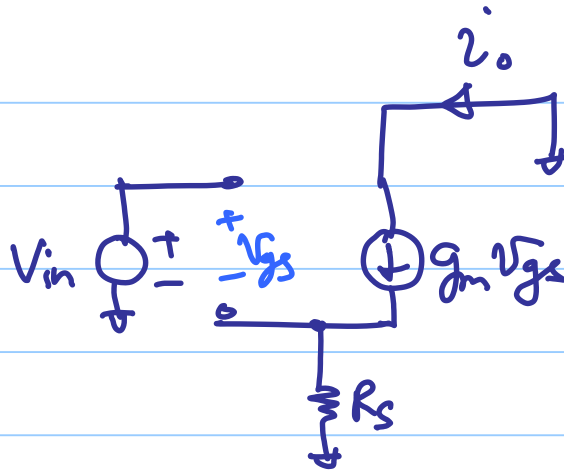
$$\downarrow$$

$$g_{m_2} r_{o_2} \cdot \frac{1}{g_{m_3}}$$

$\lambda = 0, \; \gamma = 0$

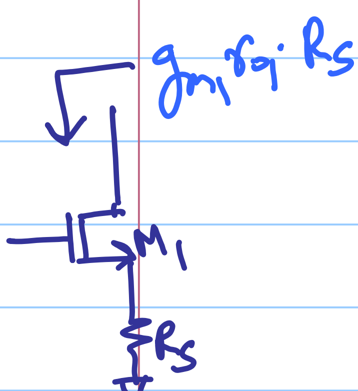
↳ Exact analysis in Razavi Book





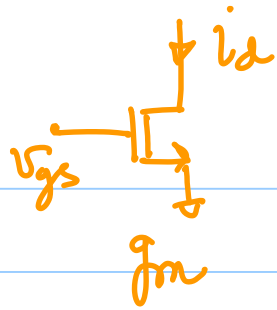
$$v_{gs} = V_{in} - i_o R_s$$

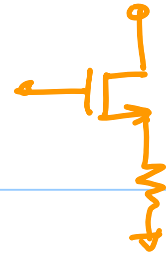
$$i_o = g_m v_{gs} = g_m (v_{in} - i_o R_s)$$



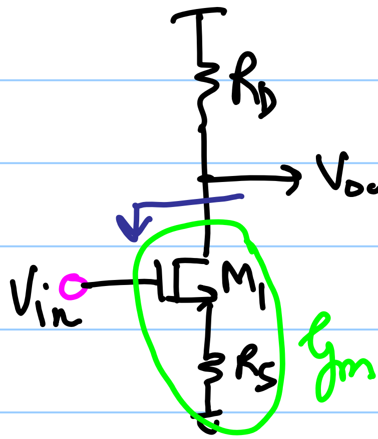
$$i_o (1 + g_m R_s) = g_m v_{in}$$

$$\Rightarrow \quad \frac{i_o}{v_{in}} = \boxed{\frac{g_m}{1 + g_m R_S} = G_m}$$





$$G_m = \frac{g_m}{1+g_m R_s}$$



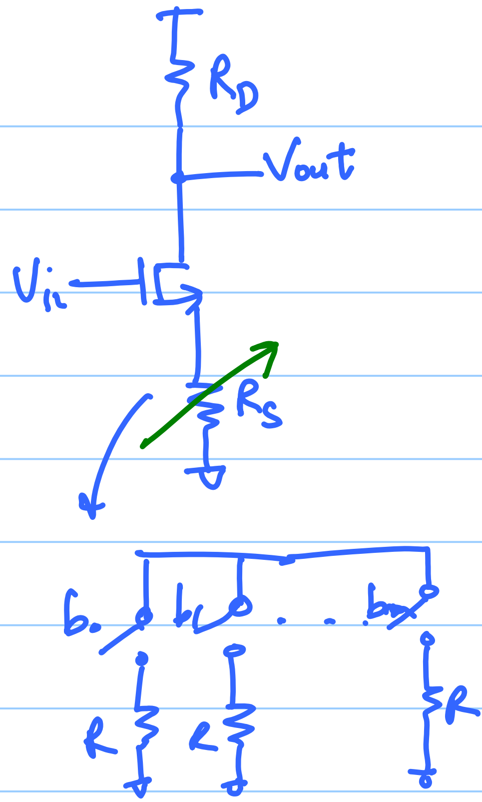
$$A_v = -G_m \cdot R_D \,||\, (g_{m1} r_o R_s)$$

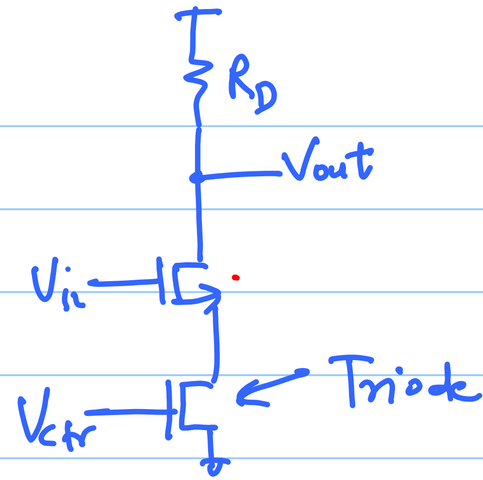
$$\simeq -G_m \cdot R_D$$

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

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

As gain is reduced by a factor of $(1+g_{m1}R_s)$





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

Let's say $g_{m1} R_S \gg 1$

$$= -\frac{\cancel{g_{m1}} R_D}{\cancel{g_{m1}} R_S} = \boxed{-\frac{R_D}{R_S}}$$

"Linear" gain

$\Rightarrow \boxed{g_{m1} R_S \gg 1}$

$\Rightarrow \frac{1}{g_{m1}} \ll R_S$ or

$\Rightarrow g_{m1} \gg \frac{1}{R_S}$

as $g_{m1} R_S >> 1$

$$G_m = \frac{g_{m1}}{1 + g_{m1} R_S} \simeq \frac{1}{R_S}$$

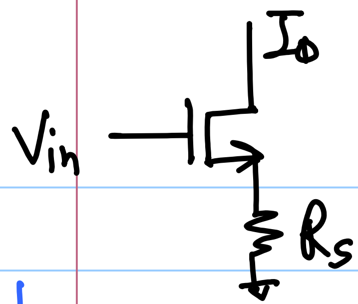
$\Rightarrow$ G_m becomes a weak function of g_m

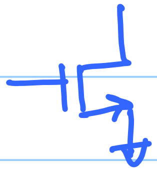
$\Rightarrow$ drain current is linearized function of the input voltage

Tradeoff b/w gain & linearity

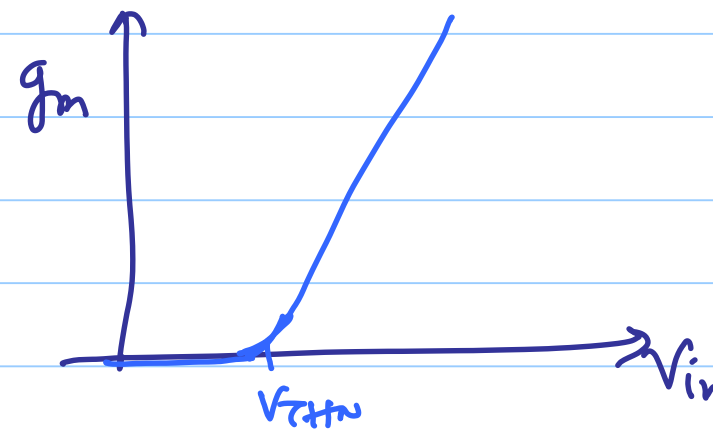
Exact analysis:

$$G_m = \frac{I_{out}}{V_{in}} = \frac{g_m r_o}{R_S + [1 + (g_m + g_{mb}) R_S] \cdot r_o} \leftarrow \text{Exercise}$$

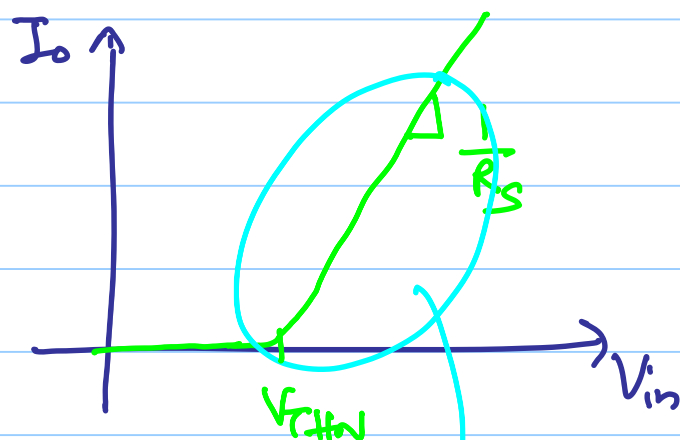


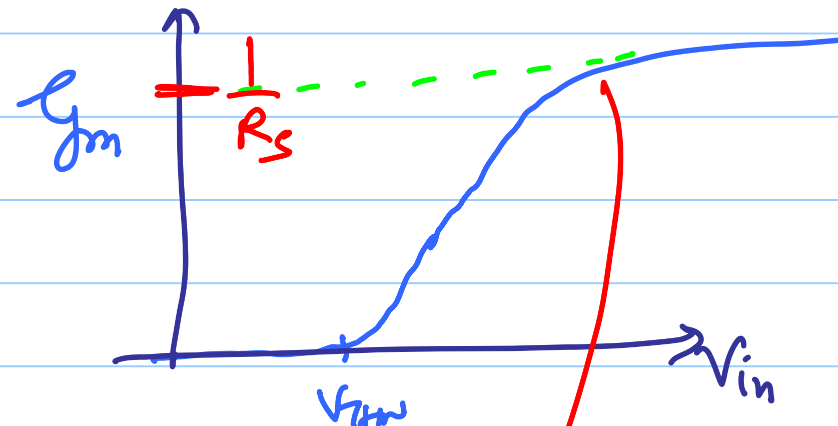


$\boxed{R_s = 0}$



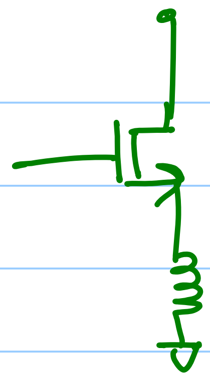
$\boxed{R_s > 0}$

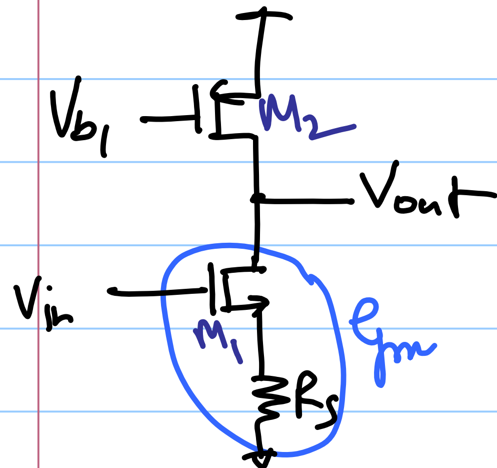




more linear behavior

@ $g_m \gg \frac{1}{R_S}$

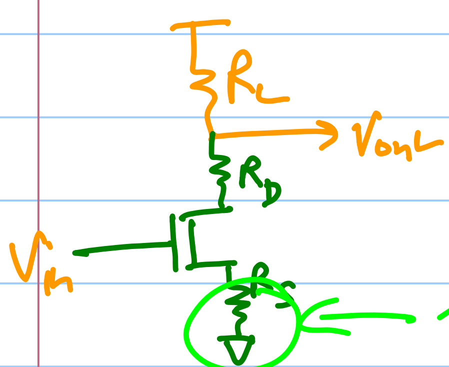




$$A_v = -G_m \cdot \Big[r_{o2} \,\|\, \underbrace{(g_{m_1} r_{o_1} R_S)}_{} \Big]$$

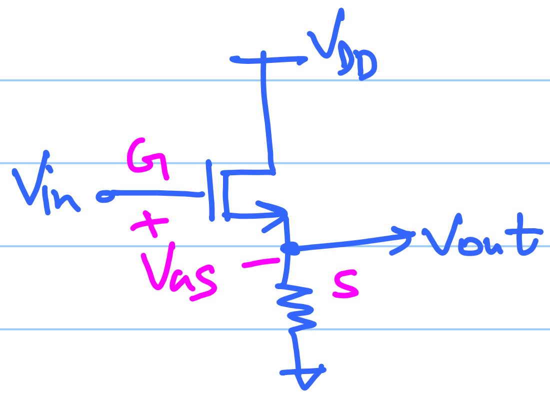
$$= -\frac{g_{m_1}}{1+g_{m_1}R_S} \cdot r_{o2} \,\|\, R_X$$

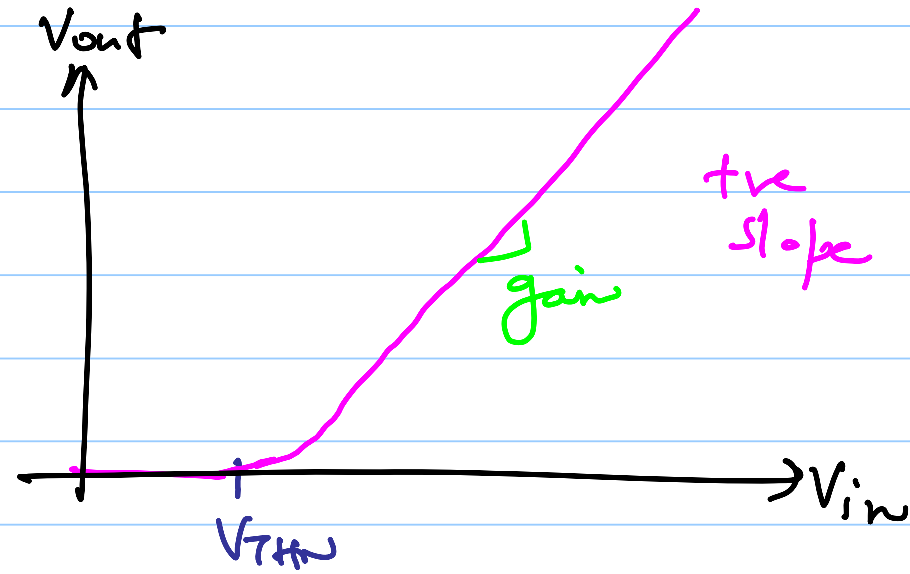
$$\simeq \frac{-g_{m_1} r_{o2}}{1+g_{m_1}R_S}$$

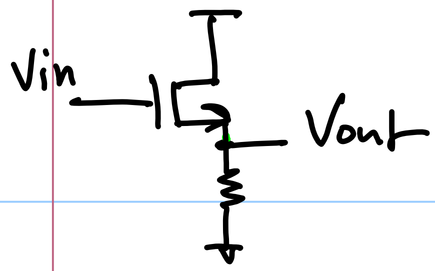


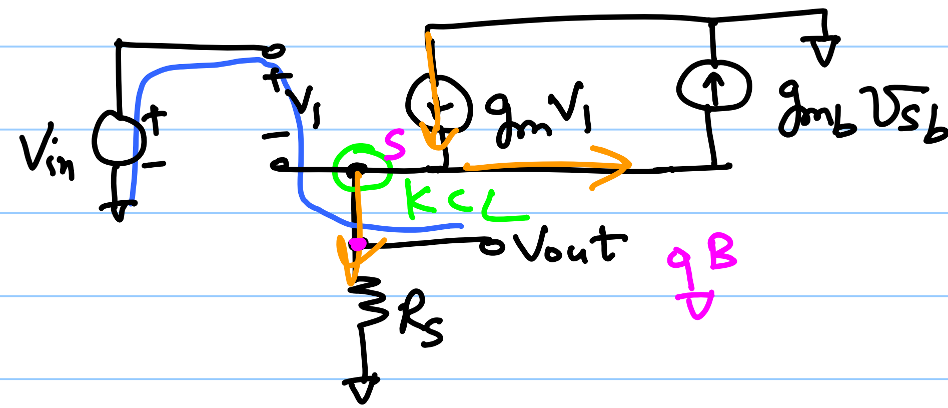
parasitics can also cause degeneration

Common Drain (Source follower)









$\lambda = 0$ for simpler analysis

$V_{in} - V_1 = V_{out} \longrightarrow (1)$

$V_{sb} = V_{out} \longrightarrow (2)$

$$g_m V_1 - g_{mb} V_{out} = \frac{V_{out}}{R_S} \longrightarrow (3)$$

$$\Rightarrow g_m (V_{in} - V_{out}) - g_{mb} V_{out} = \frac{V_{out}}{R_S}$$

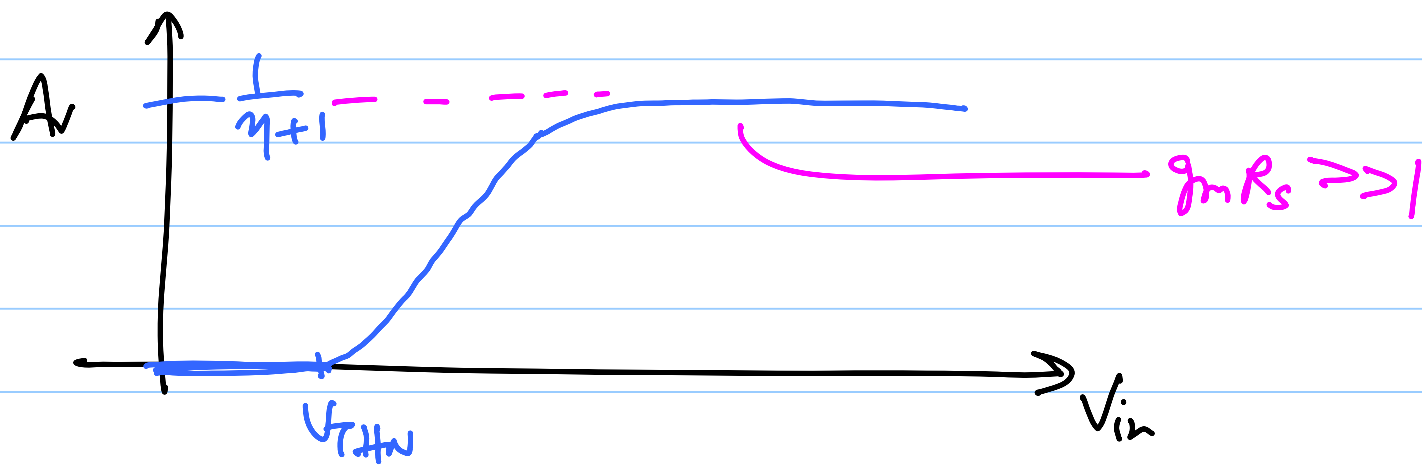
$$\Rightarrow V_{out}\left[(g_m + g_{mb}) + \frac{1}{R_S}\right] = g_m V_{in}$$

$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{g_m R_S}{1 + (g_m + g_{mb}) R_S} < 1$$

non-inverting "gain"

$$= \frac{g_m R_S}{1 + (\eta+1) g_m R_S}$$

$$= \frac{1}{(\eta+1) + \frac{1}{g_m R_S}} < 1$$



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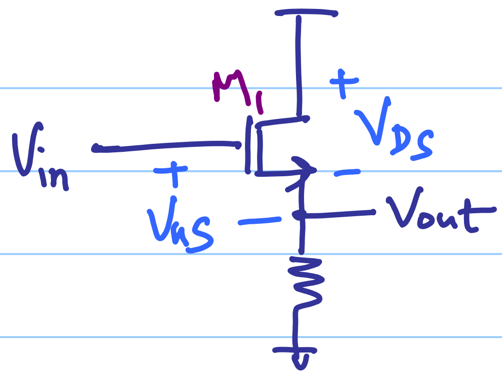


$$V_{DS} = V_{DD} - V_{out}$$
$$= V_{DD} - (V_{in} - V_{GS})$$
$$= V_{DD} - V_{in} + V_{GS}$$

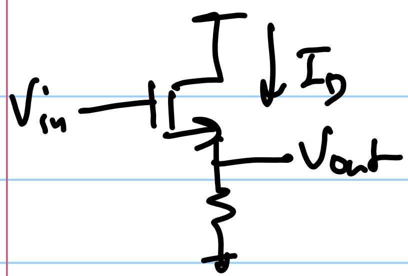
for M_1 to be in saturation

$$V_{DS} \geq V_{DS,sat}$$

$$\Rightarrow \quad V_{DD} - V_{in} + \cancel{V_{GS}} \geq \overbrace{\cancel{V_{GS}} - V_{THN}}$$

$V_{in} \leq V_{DD} + V_{THN}$ Always satisfied.

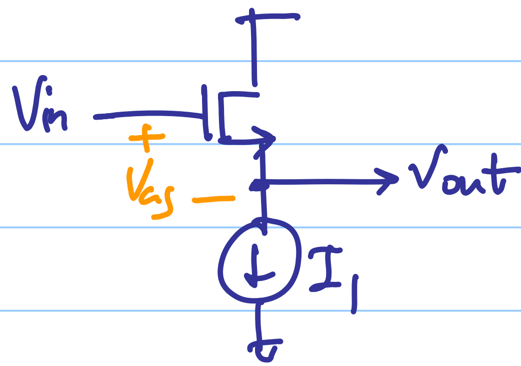
M_1 never triodes

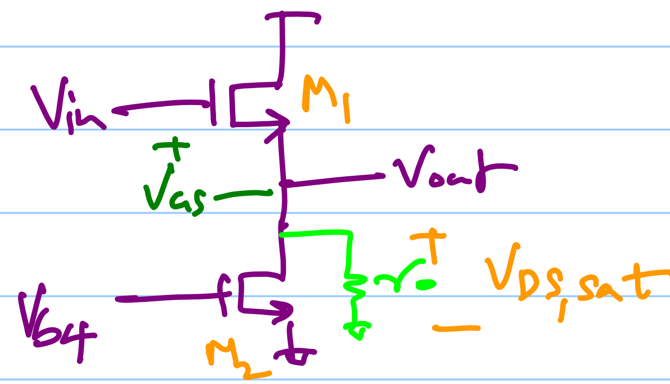


$V_{in} \uparrow \Rightarrow I_D \uparrow \Rightarrow g_m \uparrow$

$\Rightarrow$ non-linearity with larger input amplitude

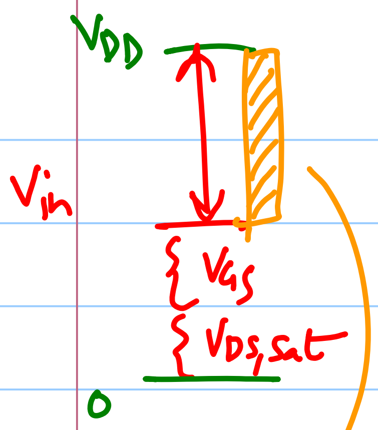
$\Rightarrow$ fix the bias current



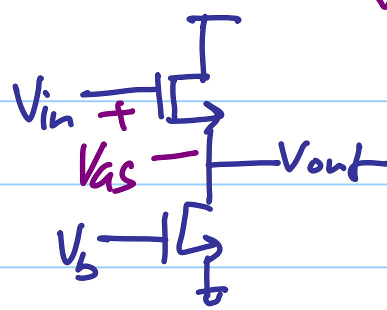


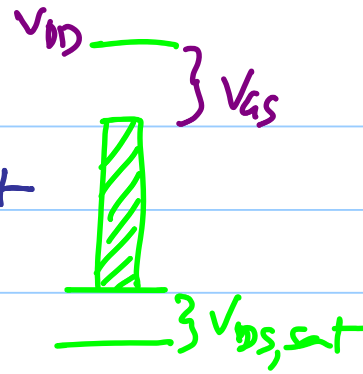
M_2 must be in SAT

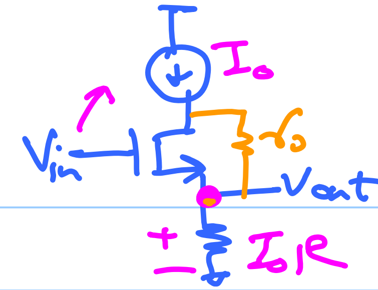
$\Rightarrow V_{in} > V_{GS} + V_{DS,sat}$



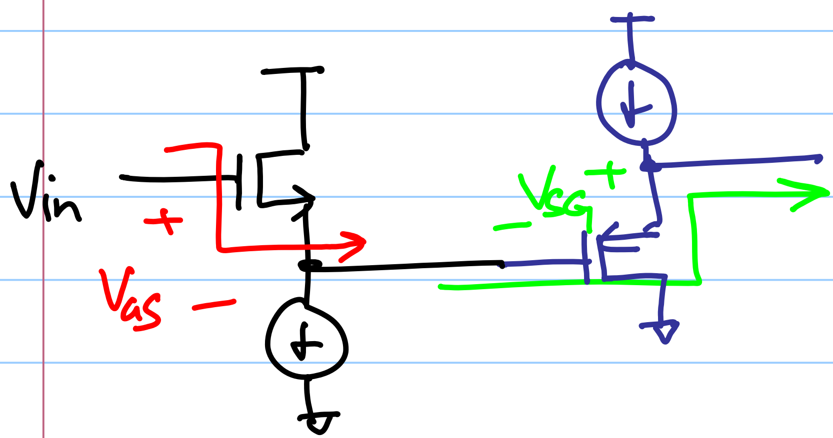
input headroom is reduced







level shifting by V_{GS}



⇒ Can use for DC
level shifter