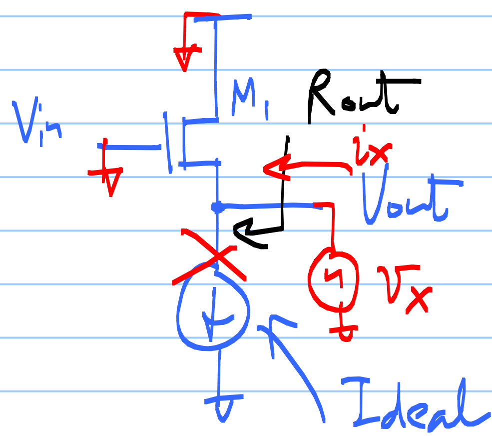
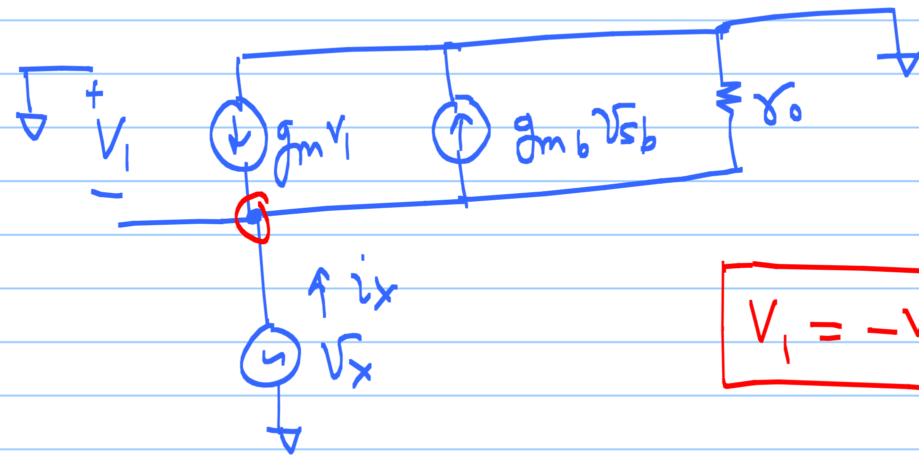
ECE 511 - Lecture 12

Note Title 3/5/2012

$\boxed{SF}$ Find R_{out} ?





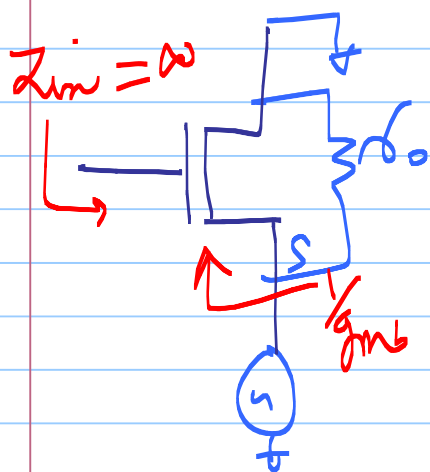
$$\boxed{V_1 = -v_x}$$

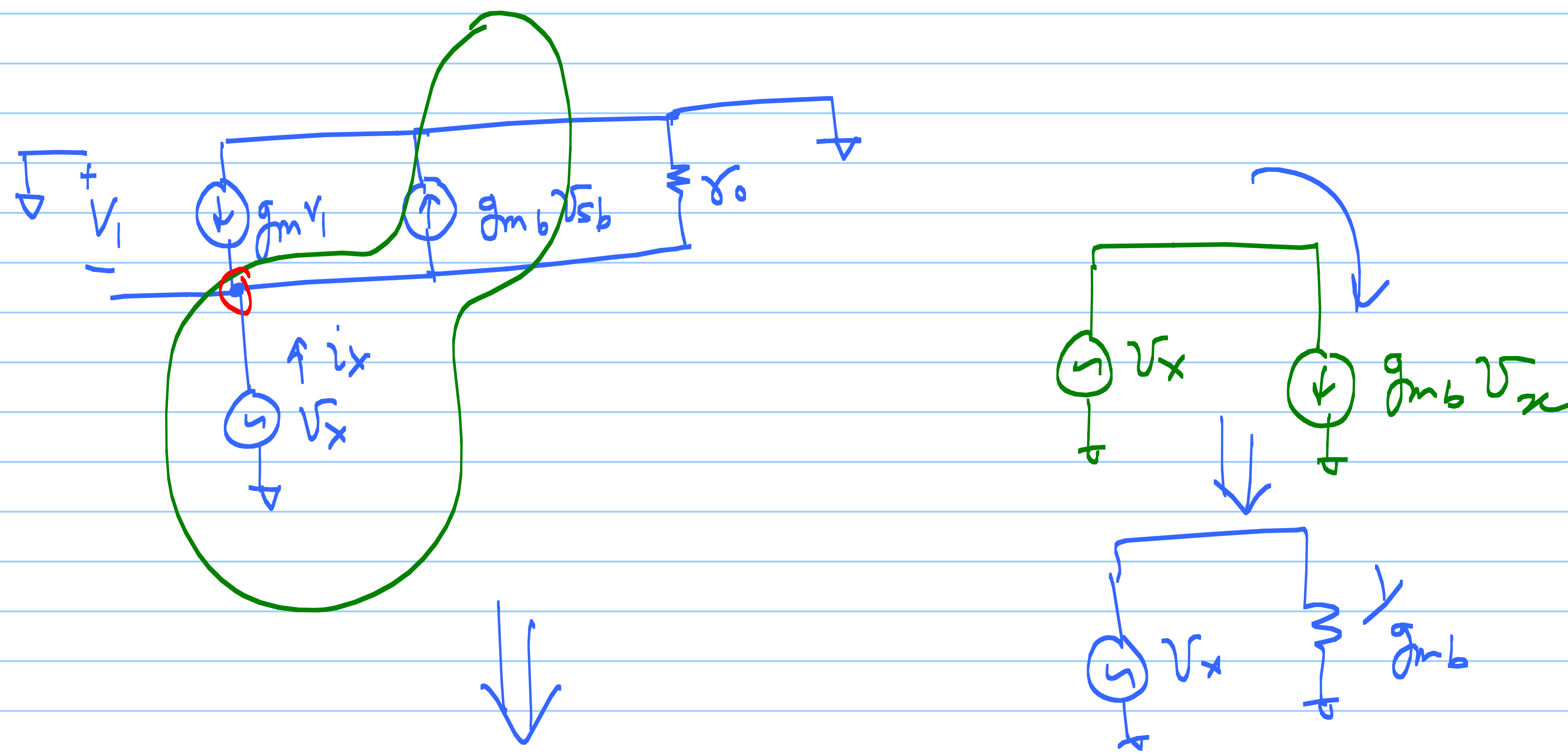
$$i_x - g_m v_x - g_{mb} v_x + \frac{v_x}{r_o} = 0$$

$$\boxed{R_{out}} = \frac{v_x}{i_x} = \frac{1}{g_m + g_{mb} + 1/r_o} = \frac{1}{g_m} \,\Big\|\, \frac{1}{g_{mb}} \,\Big\|\, r_o \approx \boxed{1/g_m}$$

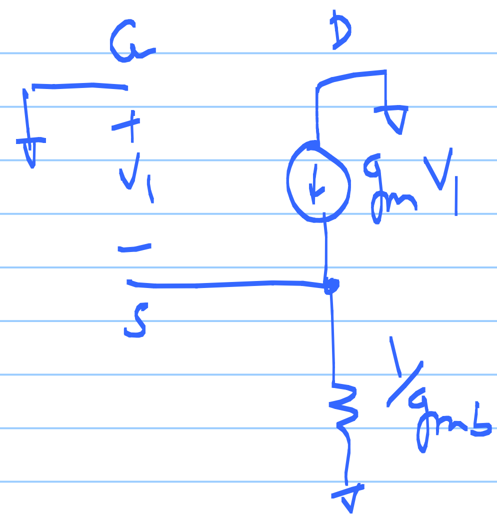
resistance looking into the source

$\Rightarrow$ Low-Z

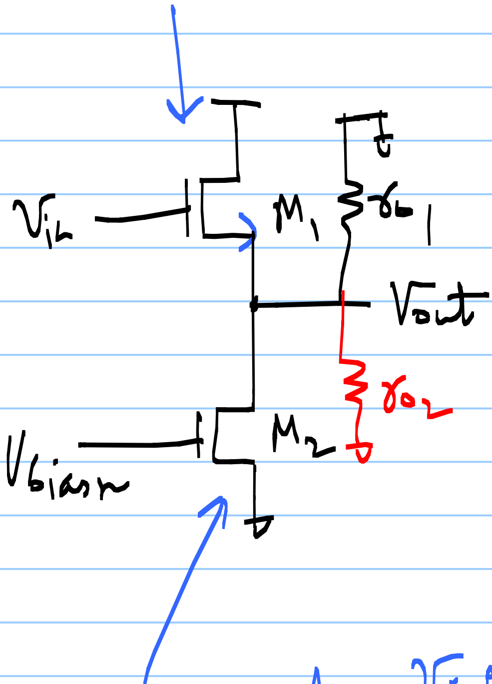


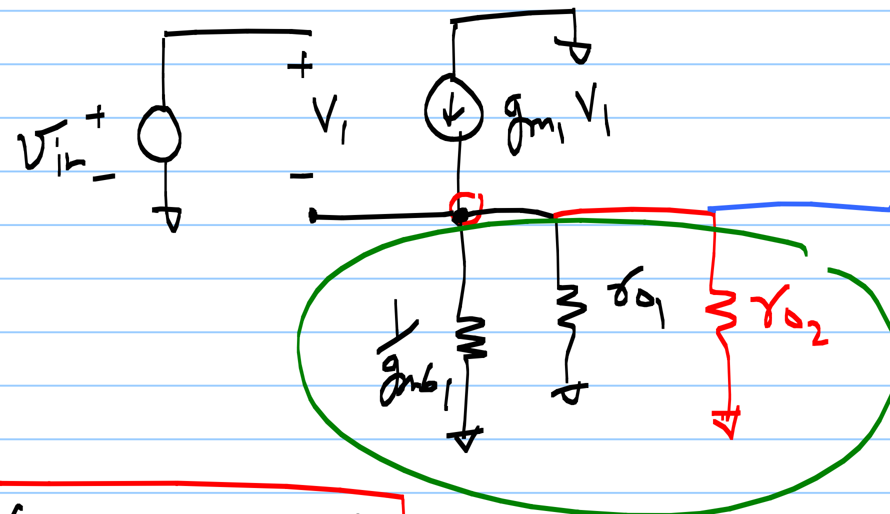


+
V_1
−
$g_m v_1$
$g_{mb} v_{sb}$
r_o
i_x
v_x
v_x
$g_{mb} v_x$
v_x
$1/g_{mb}$



G
D
+
V1
−
S
gm V1
1/gmb



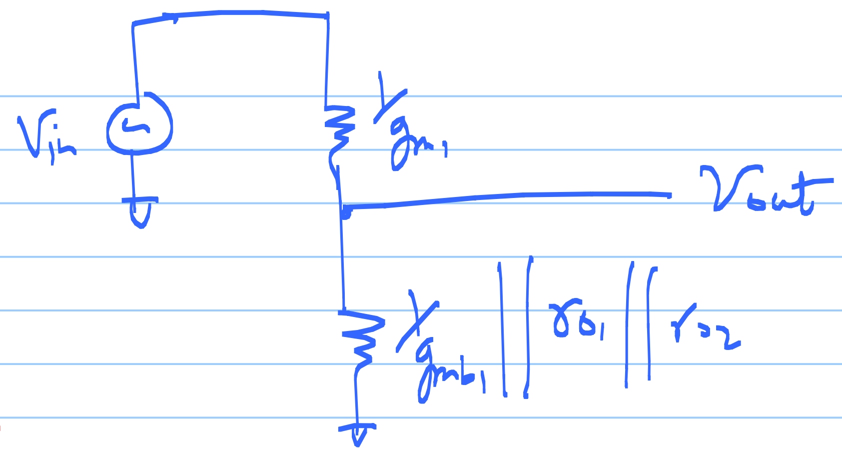


$\frac{1}{g_{mb_1}} \| r_{o_1} \| r_{o_2}$

$$A_v = \frac{v_{out}}{v_{in}} = \frac{\boxed{\left(\frac{1}{g_{mb_1}} \| r_{o_1} \| r_{o_2}\right)}}{\frac{1}{g_{m_1}} + \boxed{\left(\frac{1}{g_{mb_1}} \| r_{o_1} \| r_{o_2}\right)}}$$

resistance connected to the source

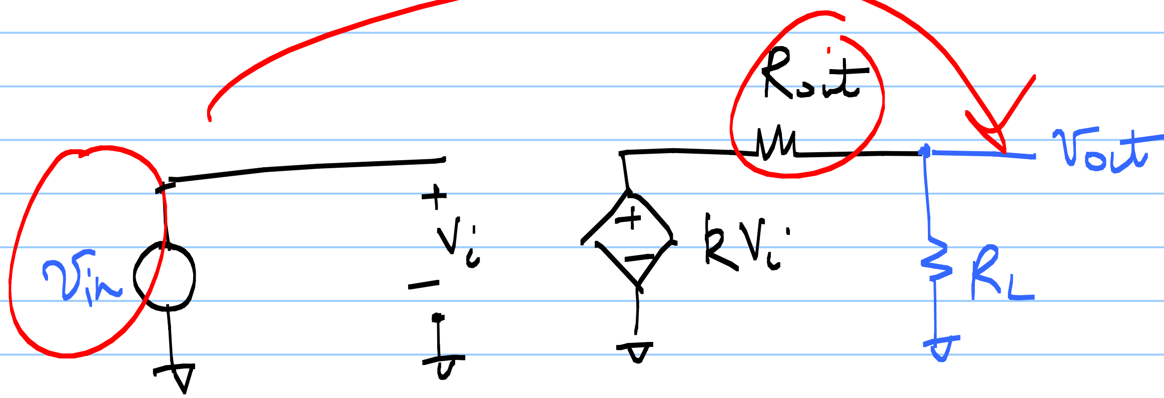
resistance looking into the source



$$\frac{1}{g_{mb1}} \,\Big|\Big|\, r_{o1} \,\Big|\Big|\, r_{o2} \simeq \frac{1}{g_{mb1}}$$

$$\Rightarrow \qquad A_v = \frac{\frac{1}{g_{mb1}}}{\frac{1}{g_{m1}} + \frac{1}{g_{mb1}}} = \frac{g_{m1}}{\underbrace{g_{mb1}}_{\eta g_{m1}} + g_{m1}} = \frac{1}{\eta + 1}$$

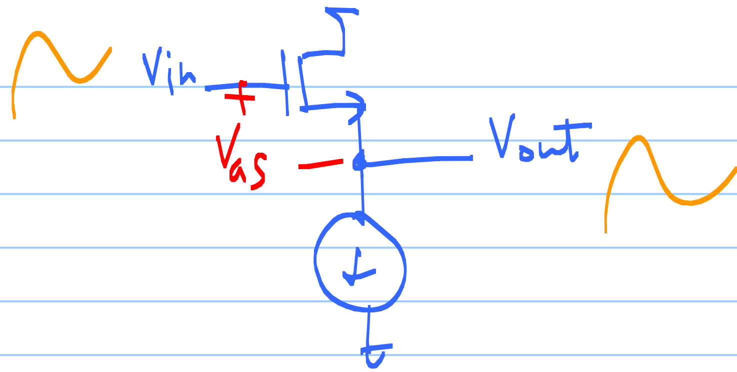
Voltage Buffer

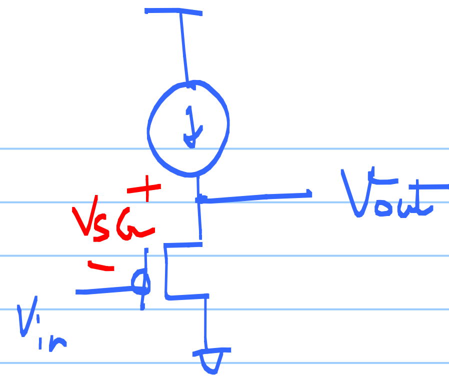


$$V_{out} \simeq V_{in}$$

$$\frac{V_{out}}{V_{in}} = \frac{R_L}{R_{out}+R_L} = \frac{1}{\left(\frac{R_{out}}{R_L}\right)+1}$$

$\rightarrow 0$





① SF ⇐ "Voltage" Buffer

② Level shifting

$A_v \cong \frac{1}{\eta + 1}$

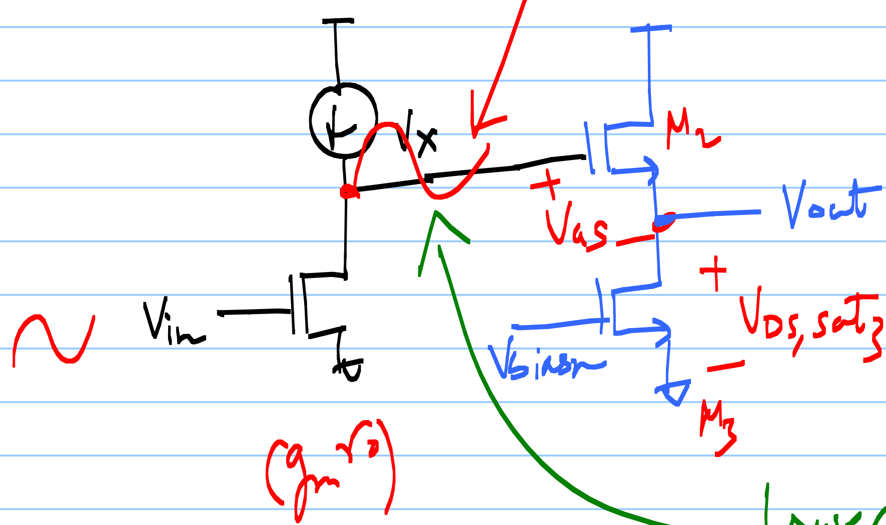
⊖ Body effect ⇒ V_{THN} depends V_{source}

⊖ low R_L

$$A_v = \frac{R_L}{R_{out} + R_L}$$

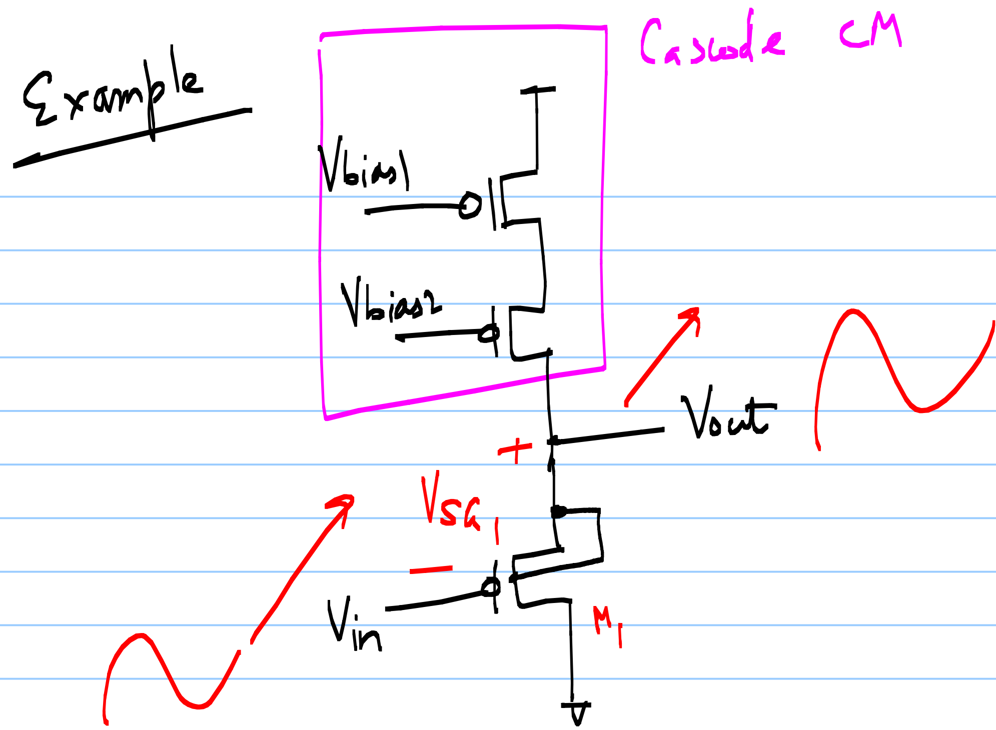
Example:

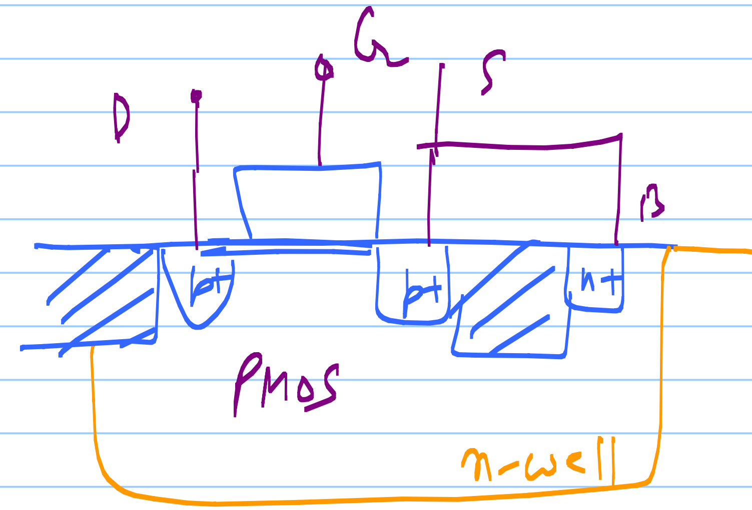
$V_x \geq V_{GS_2} + V_{DS,sat_3}$



lower voltage headroom

Example





① M_1 is in saturation as long as

$$V_{SD} = V_{out} \geq V_{SG} - V_{THP}$$

$$\Rightarrow \quad \cancel{V_{out}} \geq \cancel{V_{out}} - V_{in} - V_{THP}$$

$$\Rightarrow \quad \underline{\underline{V_{in} \geq -V_{THP}}}$$

for $V_{in} \in [0, V_{DD}]$
not a problem

② $V_{out} < V_{DD} - 2V_{SD,sat}$

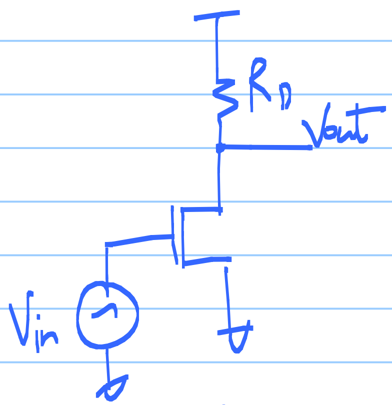
$$\Rightarrow \quad V_{in} + V_{SG_1} < V_{DD} - 2V_{SD,sat}$$

$$\Rightarrow \quad \boxed{V_{in} < V_{DD} - 2V_{SD,sat} - V_{SG_1}}$$

$$\boxed{-V_{THP} \le V_{in} \le V_{DD} - 2V_{SD,sat} - V_{SG1}}$$

input range for the level-shifter

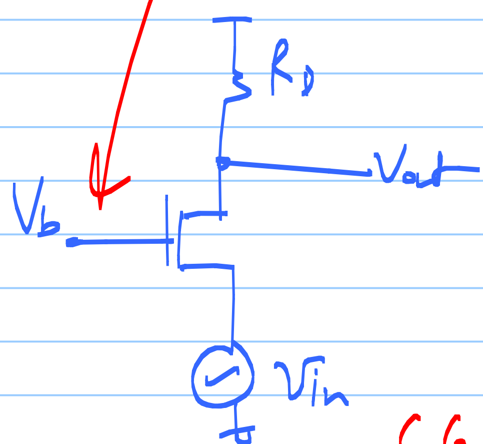
Common-Gate Stage



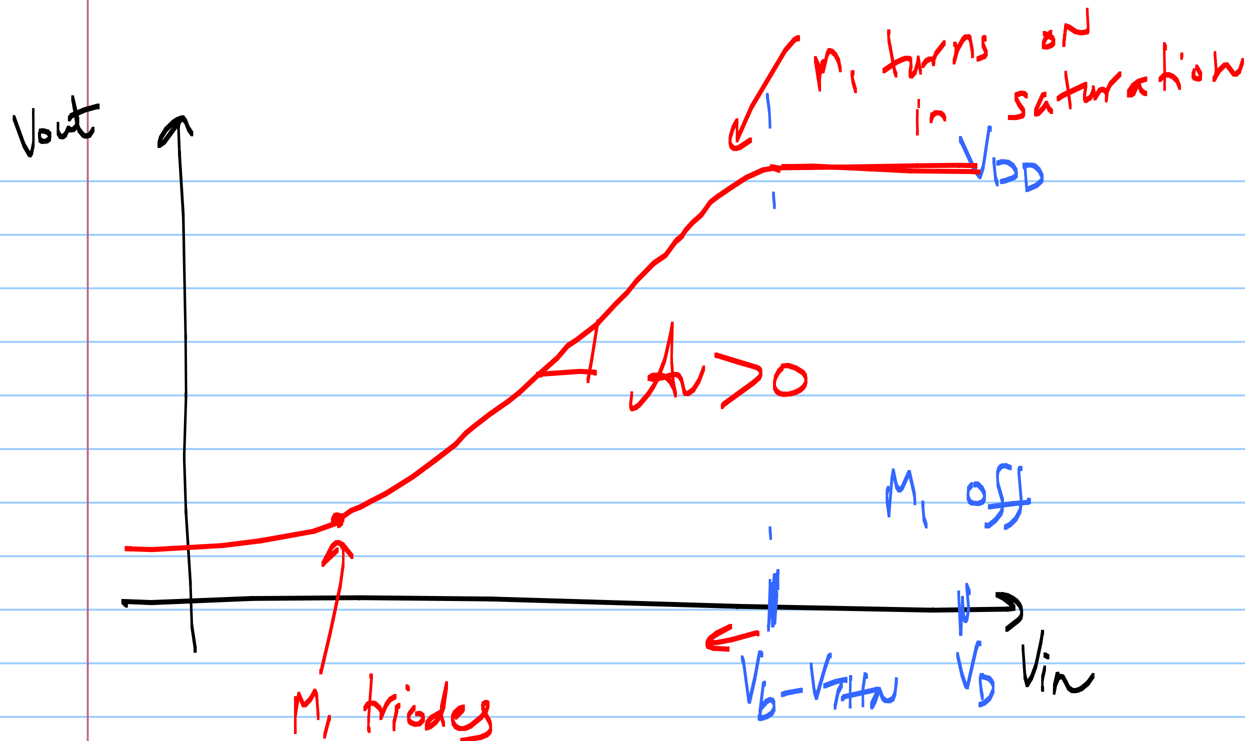
CS

$\Rightarrow$

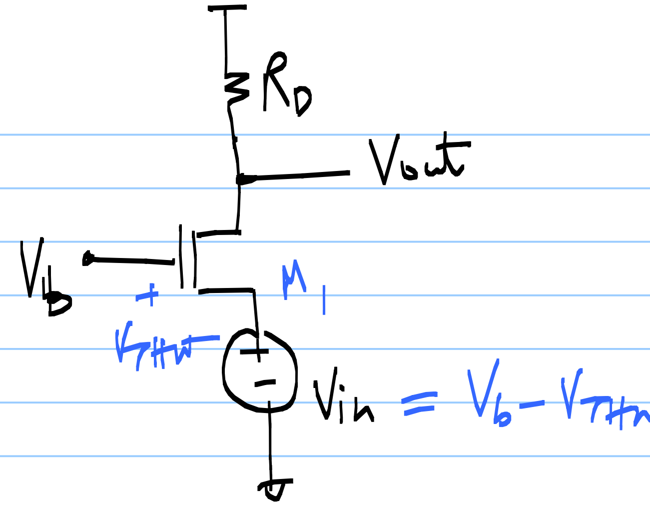
Gate is biased



CG



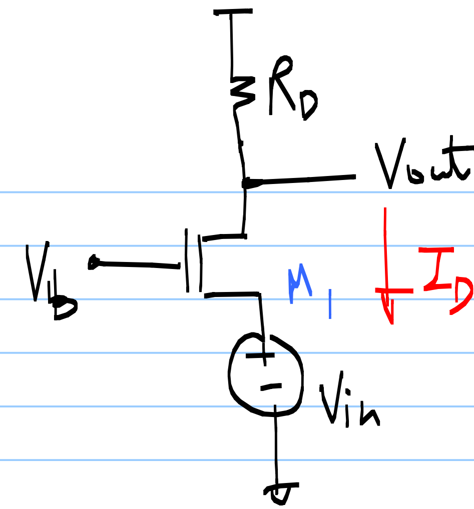
Vout
M1 turns on
in saturation
VDD
Av > 0
M1 off
M1 triodes
Vb - VTHN
VD
Vin



RD
Vout
Vb
M1
+
VTHN
Vin = Vb - VTHN

M_1 is in saturation

$$I_D = \frac{KP_n}{2}\frac{W}{L}\left(\underbrace{V_b - V_{in}}_{V_{GS}} - V_{THN}\right)^2 \longrightarrow (1)$$



$$V_{out} = V_{DD} - I_D \cdot R_D$$

$$V_{out} = V_{DD} - \frac{KP_n}{2}\frac{W}{L}\left(V_b - V_{in} - V_{THN}\right)^2 R_D$$

$$A_v = \frac{\partial V_{out}}{\partial V_{in}} = -KP_n \frac{W}{L}\left(V_b - V_{in} - V_{THN}\right)\cdot\left(-1 - \frac{\partial V_{THN}}{\partial V_{in}}\right) R_D$$

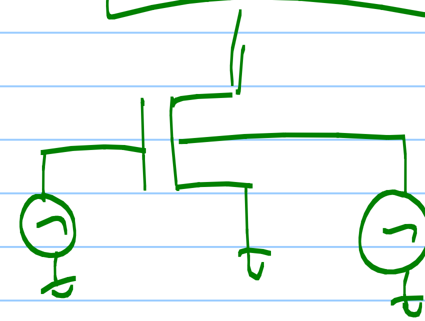
η

$$\Rightarrow \quad A_v = \underbrace{KP_n \frac{W}{L} \left(V_b - V_{in} - V_{THN} \right)}_{} (1+\eta) R_D$$

V_{GS}

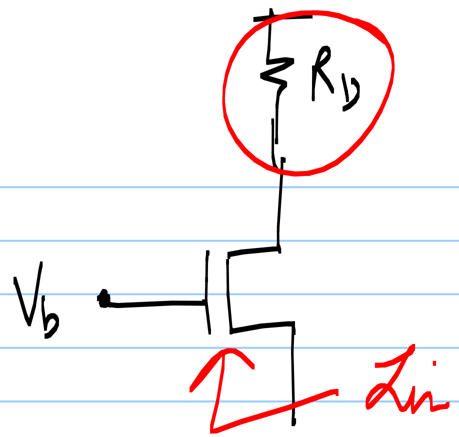
$$\boxed{A_v = + \, g_m R_D (1+\eta)}$$

$V_{DD} < 0.5V$



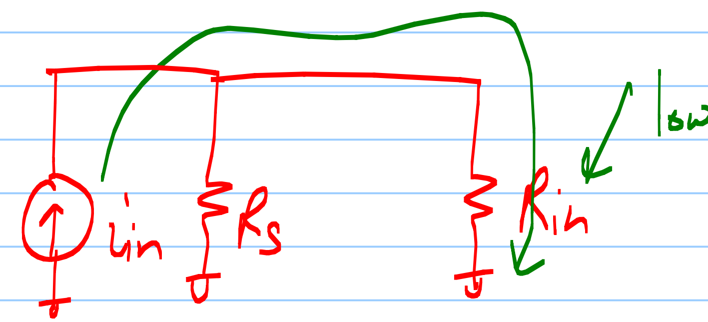
+ve gain

$(\eta+1) \leftarrow$ more gain due to body effect



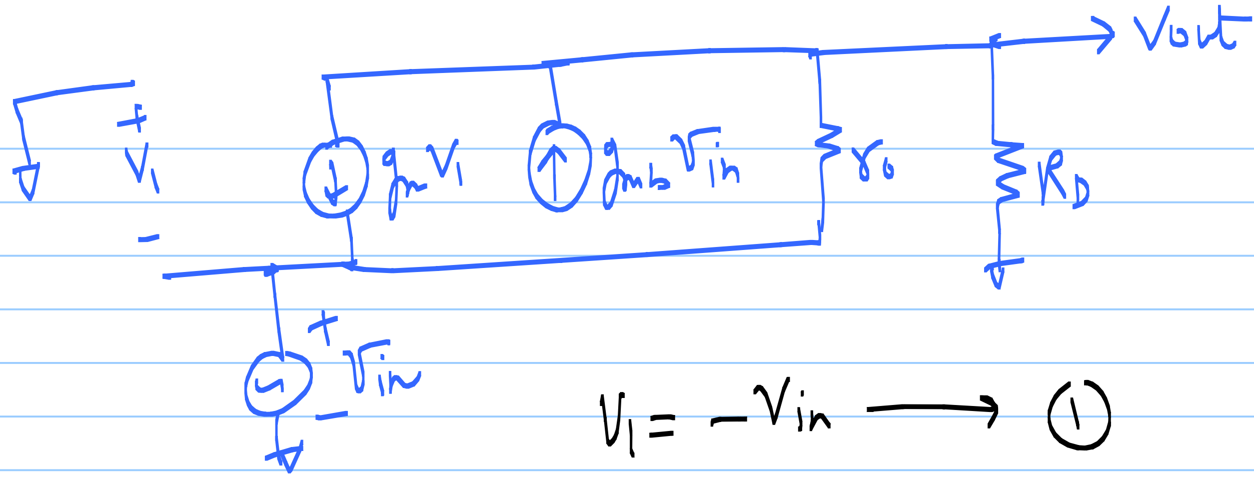
$R_D \sim r_o$

$Z_{in} \approx \frac{1}{g_m}$



$R_{in} \ll R_s$

* CG makes a good current input stage



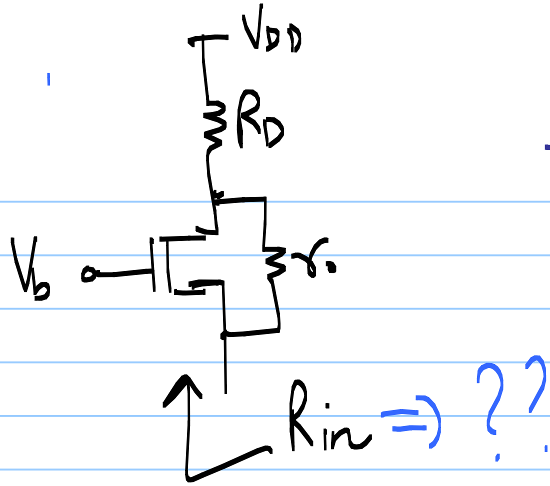
$$V_1 = -V_{in} \longrightarrow (1)$$

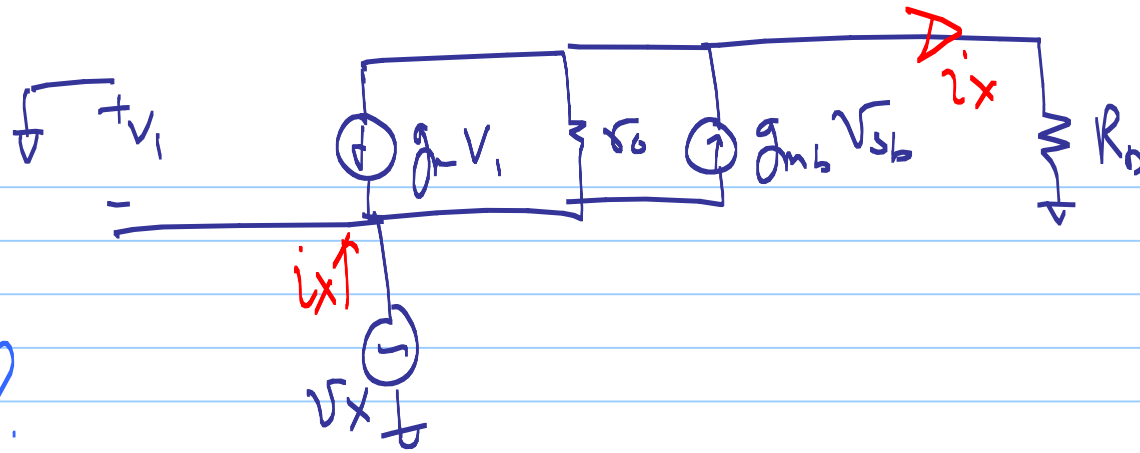
$$-g_m V_1 + g_{mb} V_{in} - \frac{(V_{out} - V_{in})}{r_o} - \frac{V_{out}}{R_D} = 0$$

$$A_v = \left[(g_m + g_{mb}) + \frac{1}{r_o}\right] \cdot (R_D \| r_o)$$

for $r_o >> R_D$

$$\boxed{A_v \simeq (\mu+1)\, g_m R_D}$$





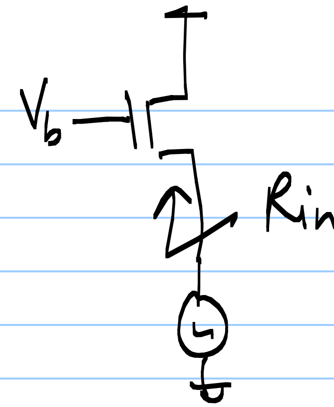
$$R_{in} = \frac{v_x}{i_x} = \frac{R_D + r_o}{1 + (g_m + g_{mb})\, r_o}$$

for $(g_m + g_{mb})\, r_o \gg 1$

$$\simeq \frac{R_D}{(g_m + g_{mb})\, r_o} + \frac{1}{(g_m + g_{mb})}$$

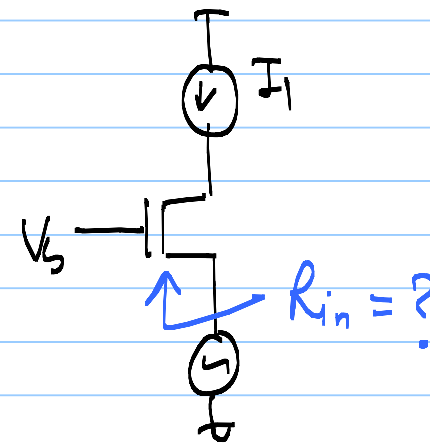
Special Case (A) $R_D = 0$

$$R_{in} \simeq \frac{1}{g_m + g_{mb}}$$



(B) $R_D \leftarrow$ Ideal Current Source

$$R_{in} \simeq \frac{R_D}{(g_m + g_{mb}) r_o} \longrightarrow \infty$$



(c) $R_D = g_{m_2} r_{o_2}^2$ ← Cascode Current Source

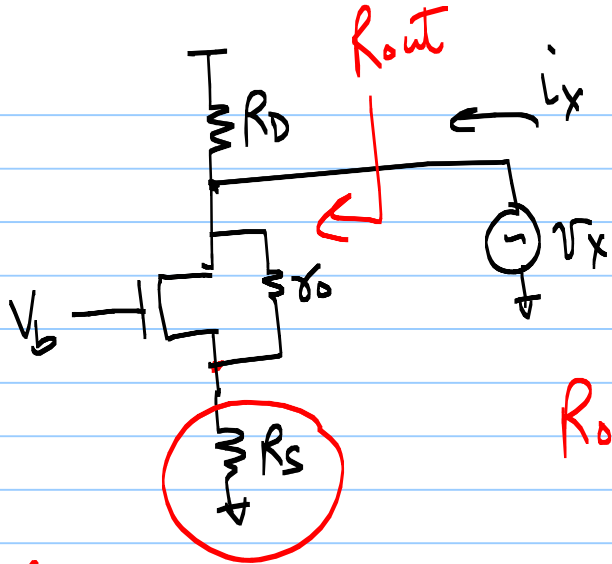
$$R_{in} = \frac{\cancel{g_{m_2}} r_{o_2}^{\cancel{2}}}{\cancel{(g_m + g_{mb})} \cancel{r_o}} + \frac{1}{(g_m + g_{mb})}$$

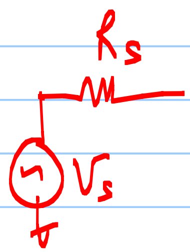
$g_{m_2} \simeq g_m$

$r_{o_2} \simeq r_o$

$$\simeq r_o + \frac{1}{g_m + g_{mb}}$$

$$\simeq \underline{\underline{r_o}}$$





looks similar to the Rout of SD-CS

$$R_{out} = \{ \underbrace{[1 + (g_m + g_{mb}) r_o] R_s}_{g_m r_o R_s} + r_o \} \,||\, R_D$$

$R_{out} \Rightarrow$ moderate to high impedance

$R_{in} \Rightarrow$ Low if $R_D \approx r_o$