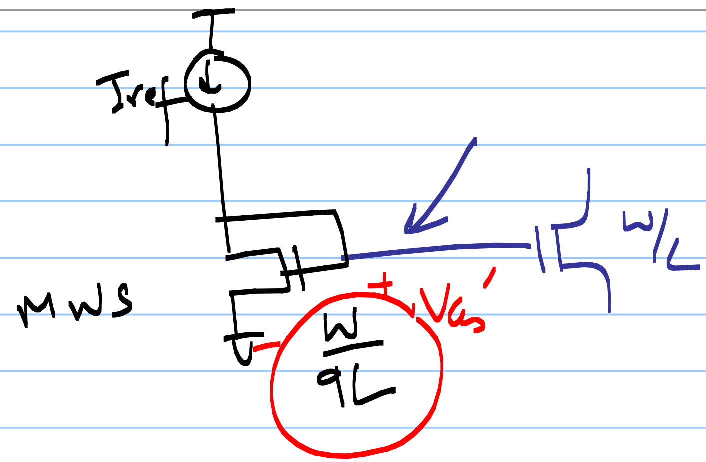
ECE 5411 – Lecture 14.

Note Title 3/14/2011

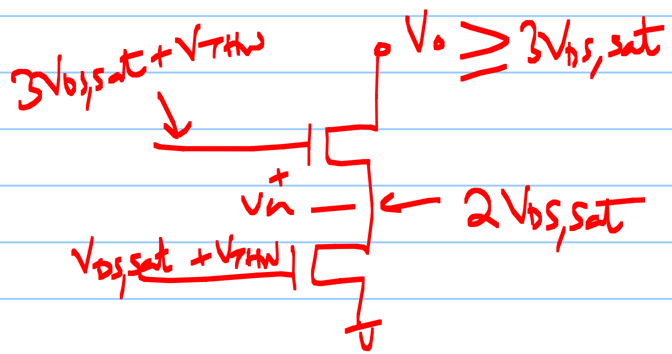


$$V_{GS}' = \sqrt{\frac{2 I_D}{\beta'}} + V_{THN}$$

$$= \sqrt{\frac{2 I_D}{\beta/9}} + V_{THN}$$

$$= 3 \underbrace{\boxed{\sqrt{\frac{2I}{\beta}}}}_{V_{DS,sat}} + V_{THN}$$

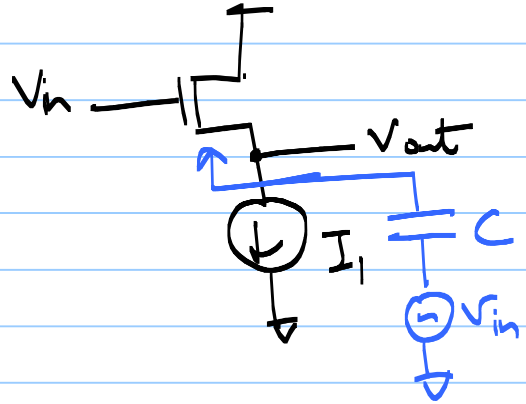
$$= \underline{3 V_{DS,sat} + V_{THN}}$$

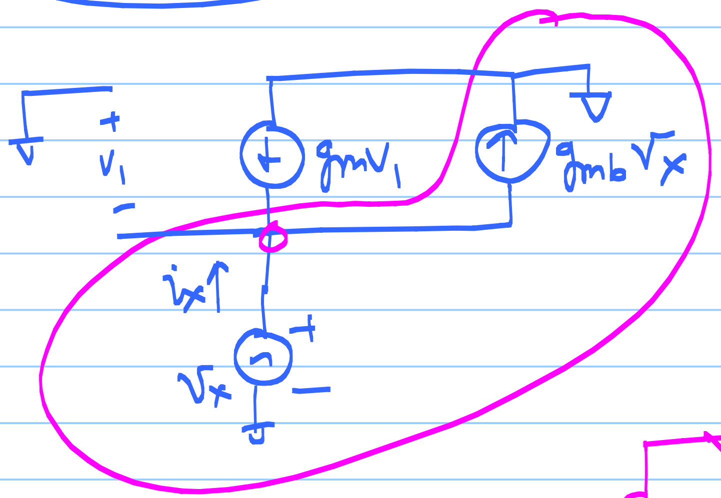


$A_v = ?$

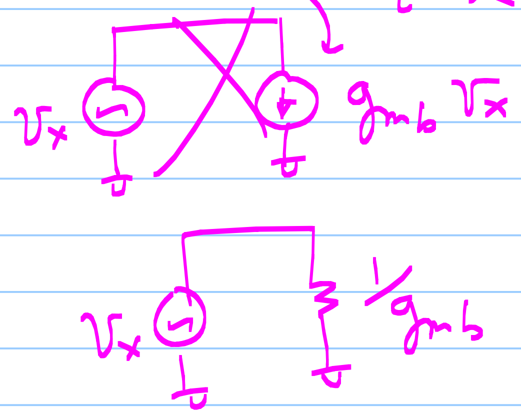
$R_{out} = ?$

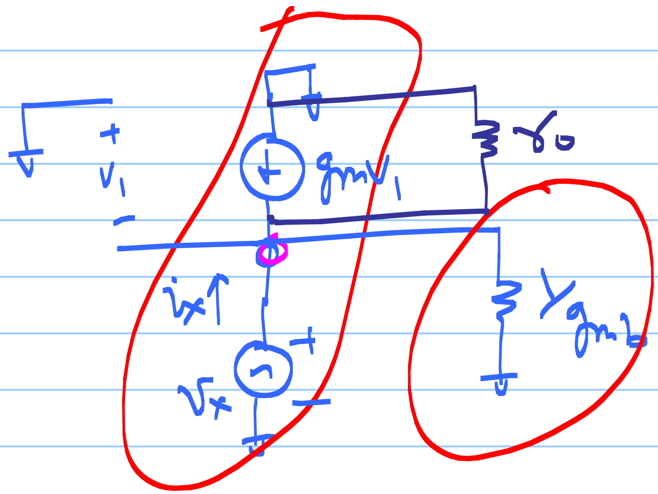
$\lambda = 0$





$i \propto v_x$





$*$ Low-impedance output

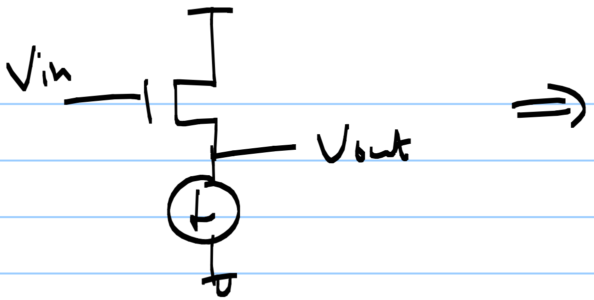
$$i_x + g_m v_1 - g_{mb} v_x = 0 \quad (v_1 = -v_x)$$

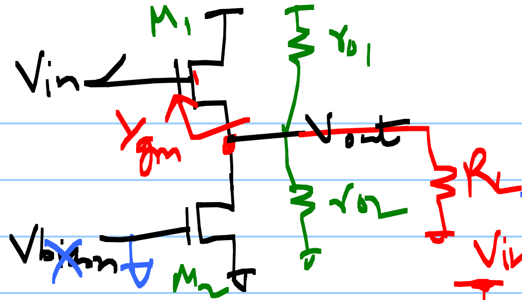
$$i_x = (g_m + g_{mb}) v_x$$

$$R_o = \frac{v_x}{i_x} = \frac{1}{g_m + g_{mb}} = \boxed{\frac{1}{g_m} \parallel \frac{1}{g_{mb}}}$$

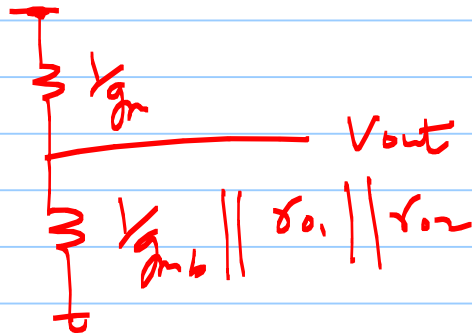
$$R_o = \frac{1}{g_m + g_{mb} + 1/r_o} = 1/g_m \parallel 1/g_{mb} \parallel r_o$$

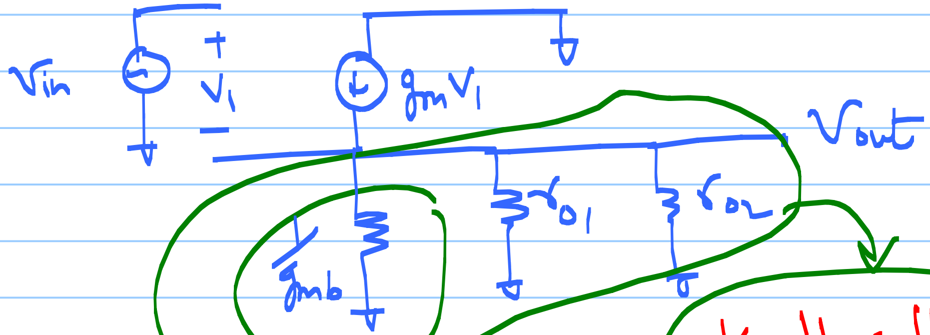
$$1/g_m \ll r_o$$





$$A_v = \frac{v_{out}}{v_{in}}$$





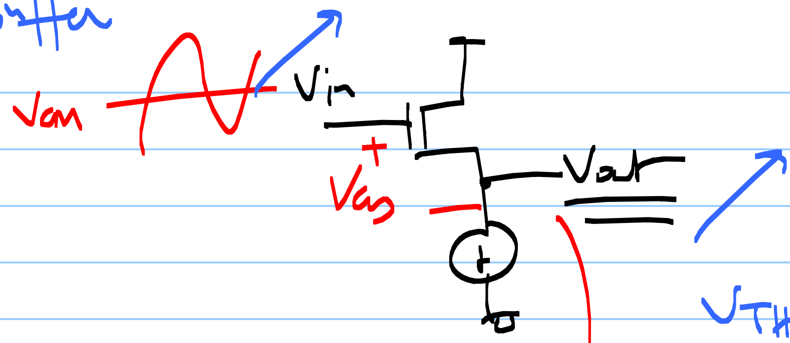
$$A_v = \frac{v_{out}}{v_{in}} = \frac{\frac{1}{g_{mb}} \| r_{o1} \| r_{o2}}{\frac{1}{g_m} + \frac{1}{g_{mb}} \| r_{o1} \| r_{o2}} =$$

$$A_v = \frac{\text{Resistance connected to the source}}{\text{Resistance looking into the source} + (\quad)}$$

→ resistance divider

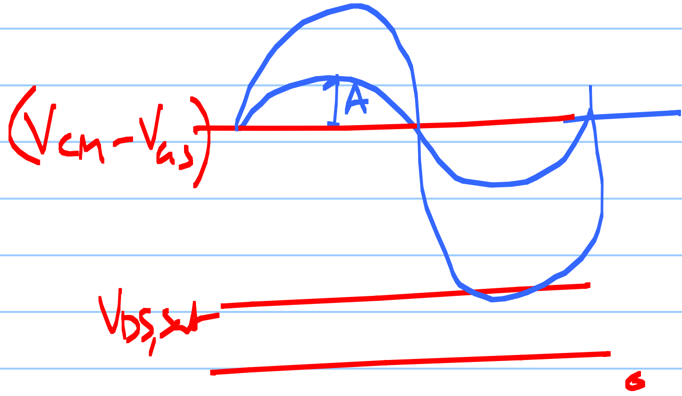
* $A_v \lesssim 1$
$R_o \to$ low
$R_{in} \to$ high

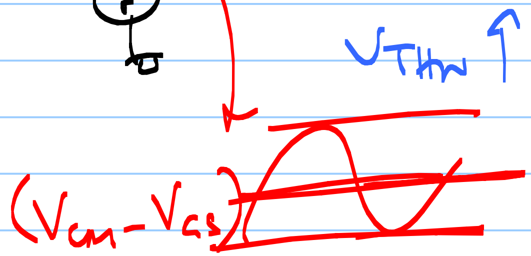
Voltage Buffer



Issues:

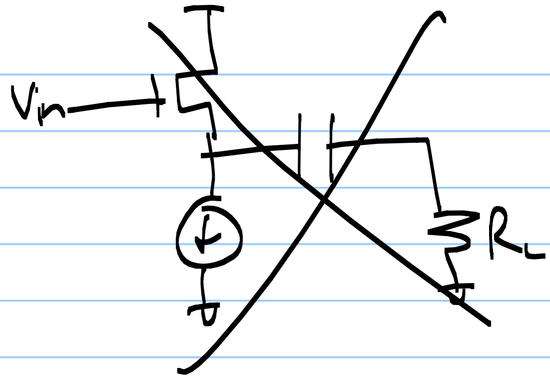
① Body





② Shift in DC value

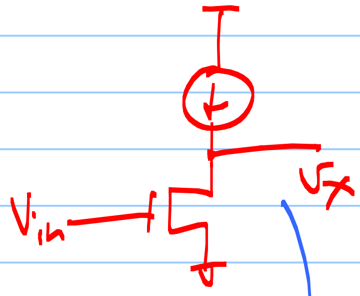
③ Loading $\Rightarrow$ $A_v = \dfrac{1/g_{mb} \| r_{o1} \| r_{o2} \| R_L}{1/g_m + 1/g_{mb} \| r_{o1} \| r_{o2} \| R_L} \simeq \dfrac{R_L}{1/g_m + R_L}$



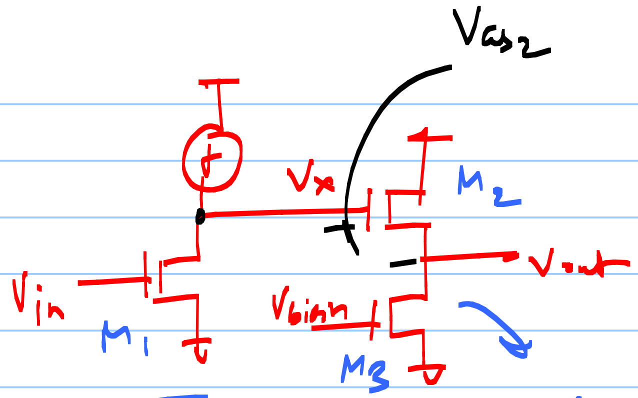
$\Rightarrow$ for low R_L, A_v can drop significantly.

$R_L \sim 1/g_m$

Example:

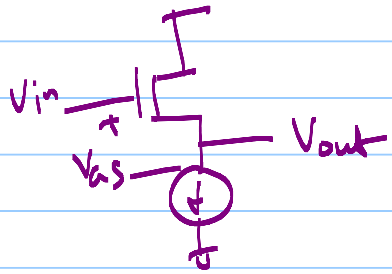


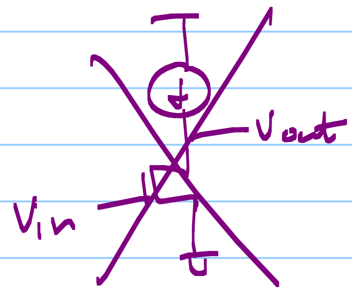
$V_x > V_{DS,sat}$



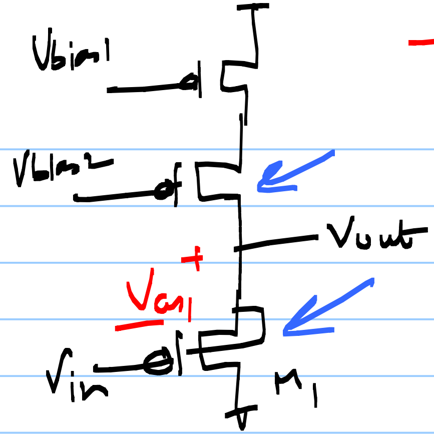
$V_{out} > V_{DS,sat_3}$

$V_x > V_{GS_1} + V_{DS,sat_3}$





Level Shifter Example.



$V_{out} = V_{in} + V_{SG_1}$

for M_1 to be saturation

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

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

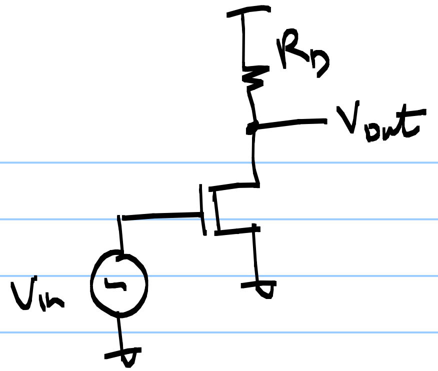
$\Rightarrow \boxed{V_{in} \geq -V_{THP}}$

$V_{out} < V_{DD} - 2V_{SD,sat}$

$V_{in} + V_{SG}$

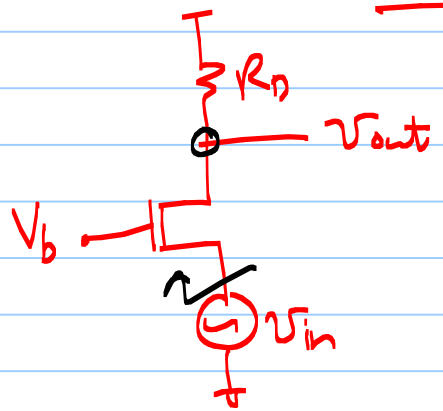
$\Rightarrow \boxed{V_{in} < V_{DD} - 2V_{SD,sat} - V_{SG}}$ Current mirror in saturation

$$\boxed{-V_{THP} \leq V_{in} \leq V_{DD} - 2V_{SD,sat} - V_{SG}}$$

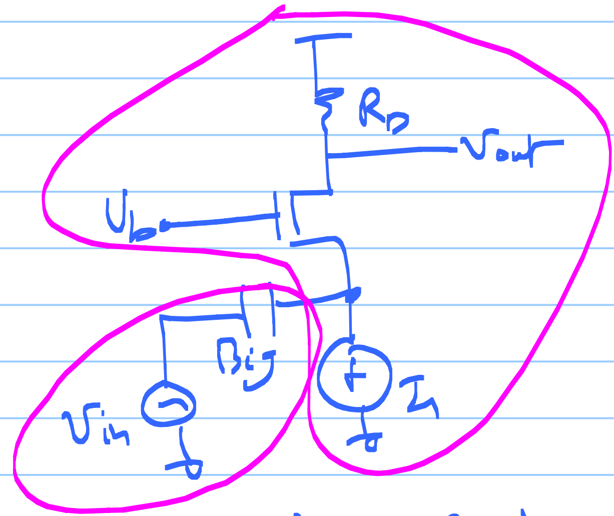


$\Rightarrow \quad -g_m R_D$

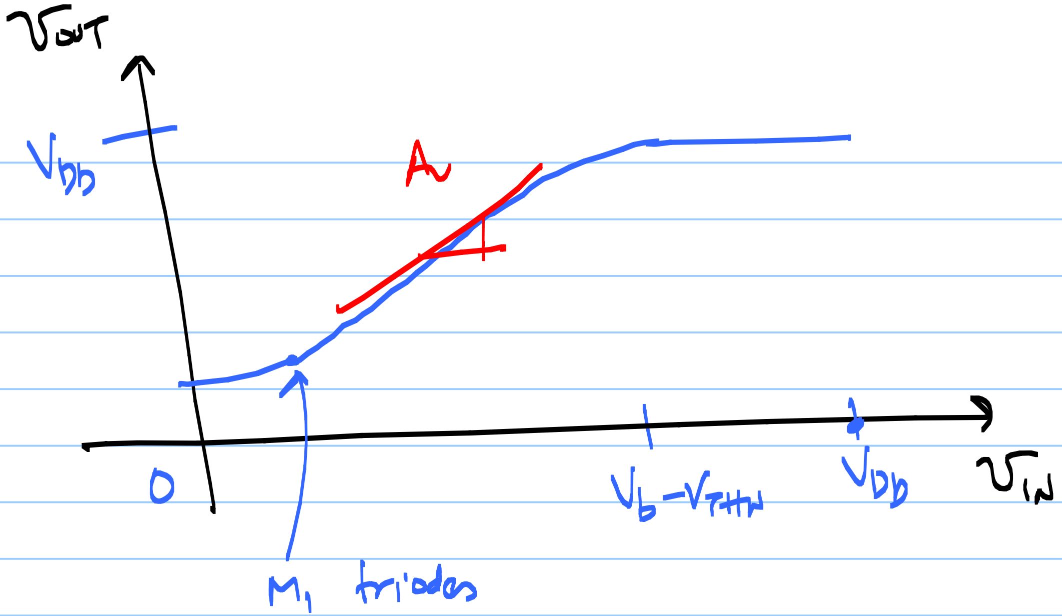
Common-Gate Amplifier/Stage.

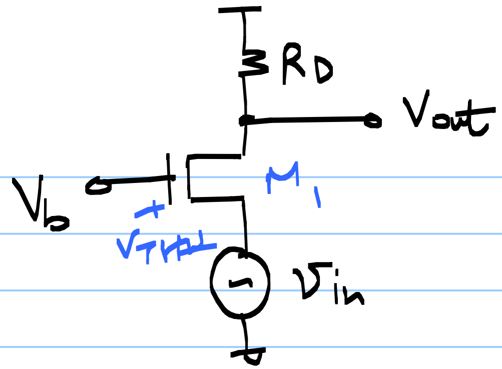


Direct coupling

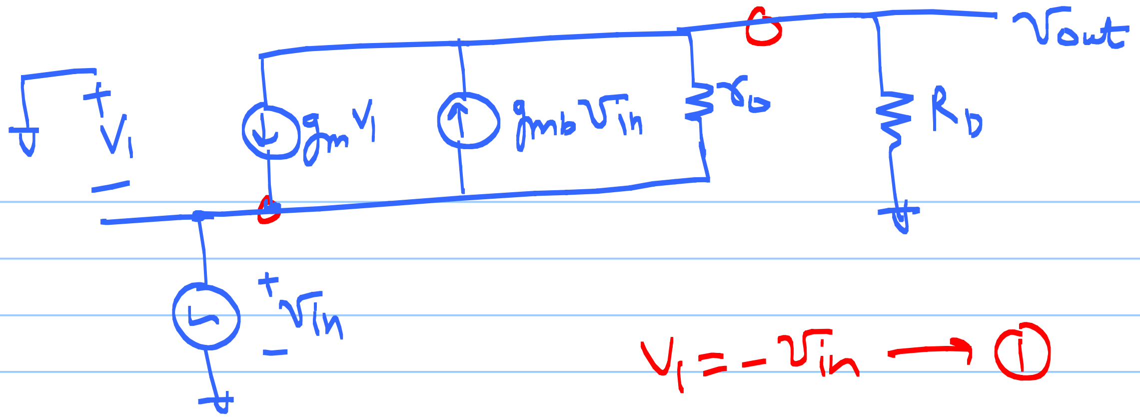


Capacitive Coupling.

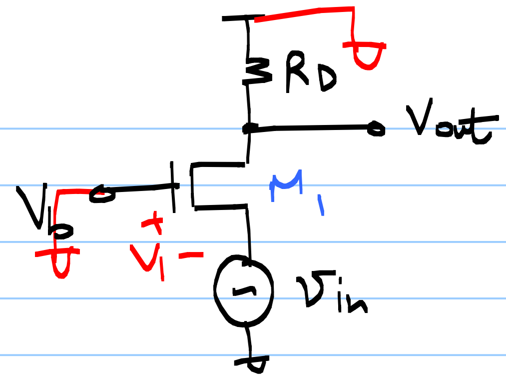




$V_{DD} > V_b$



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



KCL :

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

$$A_v = \frac{v_{out}}{v_{in}} = \left[(g_m + g_{mb}) + 1/r_o\right] \times (R_D \| r_o)$$

$$\simeq \boxed{(g_m + g_{mb})R_D}$$

$R_D \ll r_o$

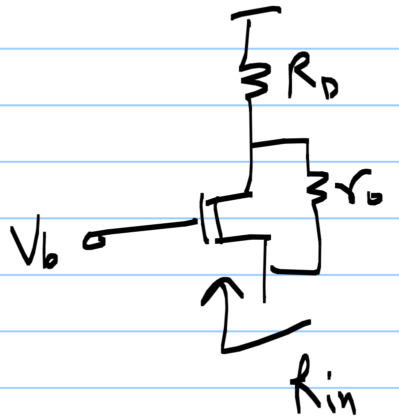
$r_o \gg 1/g_m$

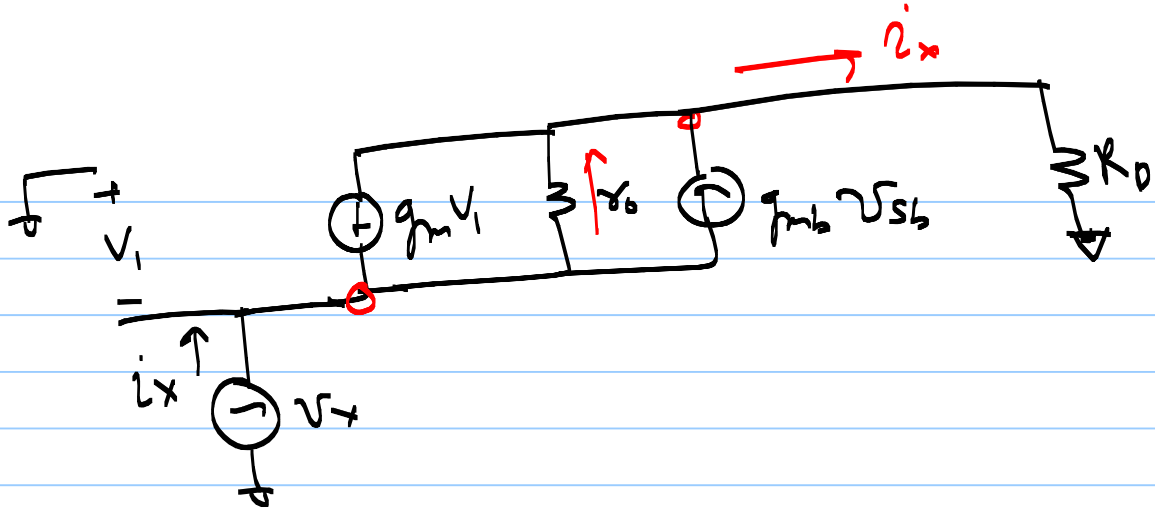
$$= (\eta + 1) g_m R_D$$

* Body effect effectively increases $\underline{g_m}$.

* Gain is +ve

Input impedance





$V_1 = -V_x$

$\Rightarrow$ current through $r_o \Rightarrow i_x + g_m V_1 + g_{mb} V_1$

$= i_x - (g_m + g_{mb}) V_x$

$\Rightarrow$ Adding up the voltages across r_o and R_D

$$R_D i_x + r_o \left(i_x - (g_m + g_{mb}) v_x \right) = v_x$$

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

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

$\times$ if $(g_m + g_{mb}) r_o \gg R_D \leftarrow$ R_D is low impedance

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

$*$ $R_D = g_{m2} r_{o2}{}^2$

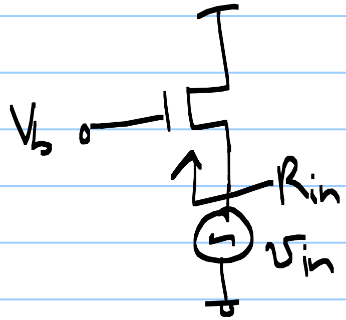
$$\Rightarrow \quad R_{in} = \frac{\cancel{g_{m2} r_{o2}}\,{}^{\cancel{2}}\, r_{o2}}{\cancel{(g_{m1} + g_{mb1}) r_{o1}}} + \frac{1}{(g_{m1} + g_{mb1})}$$

lets say
$g_{m1} r_{o1} \triangleq g_{m2} r_{o2}$

$$\simeq r_{o_2} + \underbrace{\frac{1}{g_{m_1}}}_{\text{if } R_D \simeq r_o}$$

Special cases

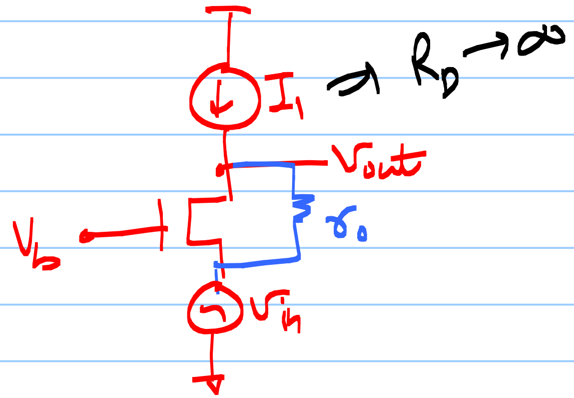
① $R_D = 0$



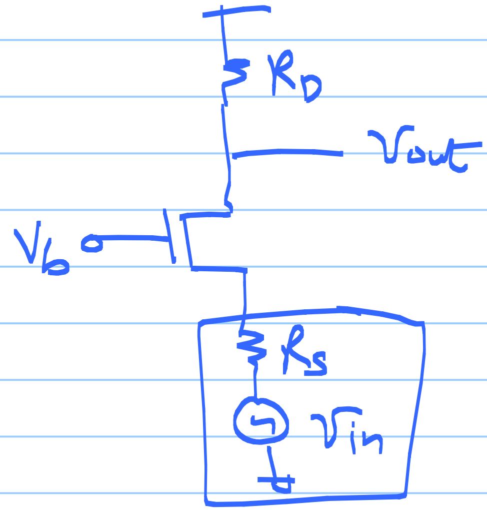
$$R_{in} \simeq \frac{R_D}{(g_m + g_{mb}) r_o} + \frac{1}{(g_m + g_{mb})}$$

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

② R_D is replaced by an Ideal current source



$R_{in} \to \infty$

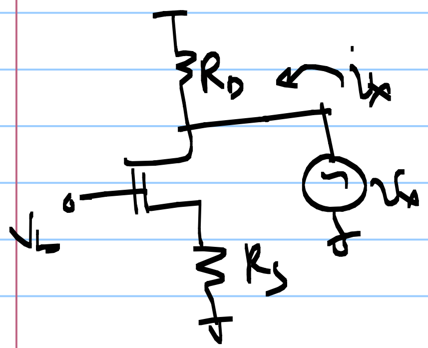


$$A_v = \frac{(g_m+g_{mb})r_o+1}{r_o+(g_m+g_{mb})r_oR_S+R_S+R_D} \cdot R_D$$

$R_D \to \infty$

$$\Rightarrow A_v \simeq (g_m+g_{mb})r_o+1 \simeq g_m r_o$$

Output impedance of CG stage.



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

→ same as CS with source degeneration