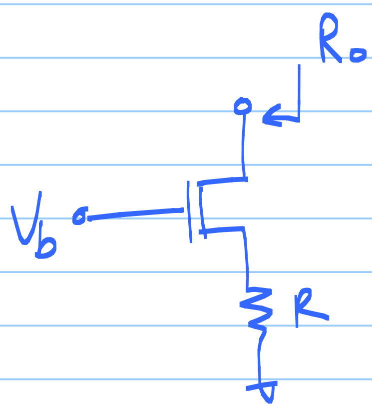
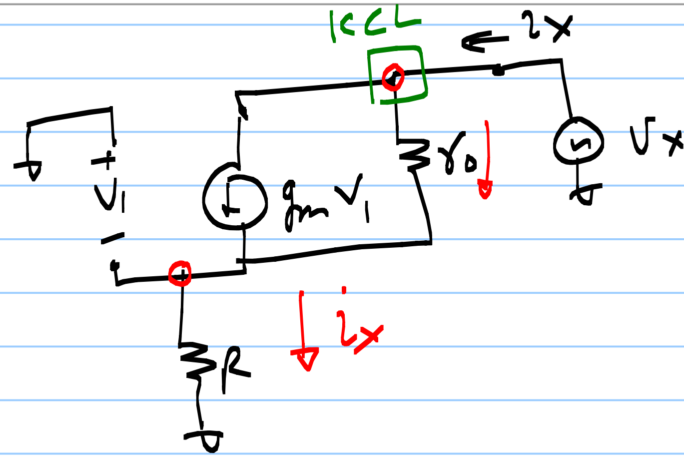
ECE 5411 – Lecture 13.

Note Title 3/7/2011





$$\frac{v_x}{i_x} = R_o$$

$$v_1 = -i_x R \longrightarrow (1)$$

KCL ⇒ $$i_x - g_m v_1 - \frac{v_x - i_x R}{r_o} = 0 \longrightarrow (2)$$

$$i_x + g_m R\, i_x - \frac{v_x}{r_o} + i_x \frac{R}{r_o} = 0$$

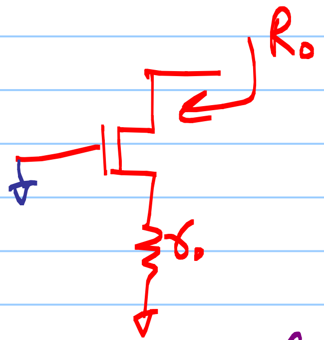
$$i_x\left[1+g_m R+\frac{R}{r_o}\right]=\frac{v_x}{r_o}$$

$$\Rightarrow \quad \frac{v_x}{i_x}=\left[g_m R+1+\frac{R}{r_o}\right] r_o$$

$$=\boxed{g_m r_o R+R+r_o}$$

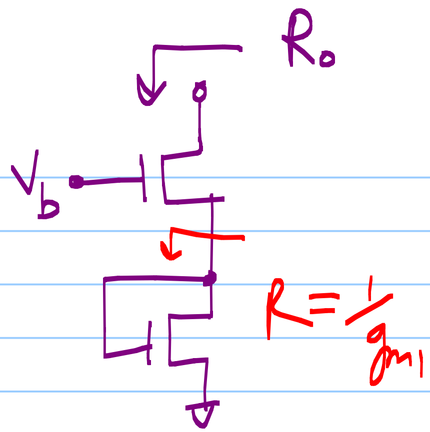
$$\simeq g_m r_o R$$

$g_m r_o >> 1$

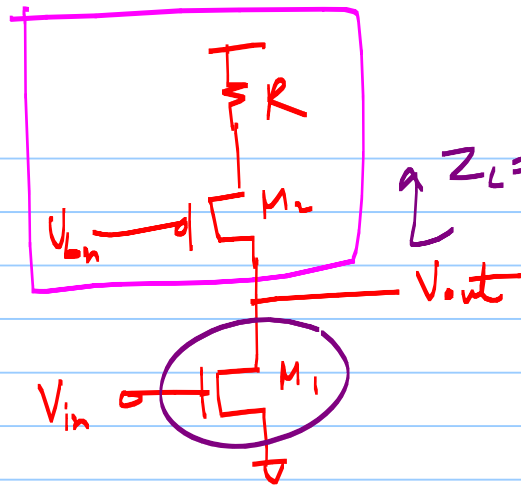


$$R_o \simeq g_m r_o^2$$

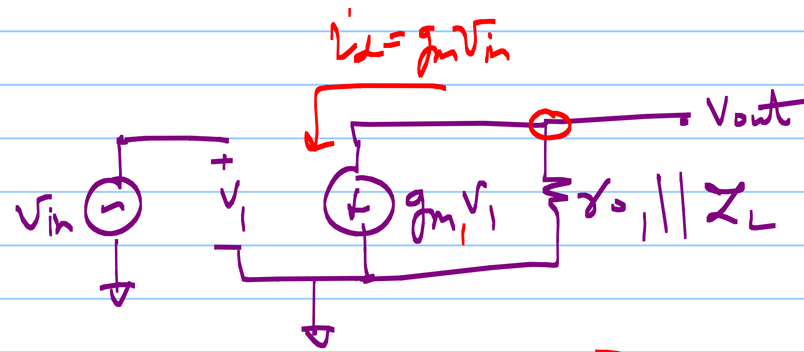
$$= g_m r_o^2 + 2r_o$$



$$R_o = g_{m2} r_{o2} \frac{1}{g_{m1}} + \frac{1}{g_{m1}} + r_o$$



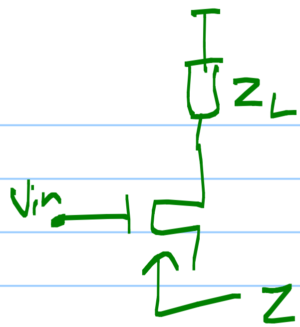
$Z_L = g_{m2} r_{o2} R$



$$v_{out} = -g_{m1} v_{in} \cdot \left[r_{o1} || (g_{m2} r_{o2} R) \right]$$

$$\Rightarrow A_v = \frac{v_{out}}{v_{in}} = -g_{m1} \times r_{o1} || (g_{m2} r_{o2} R)$$

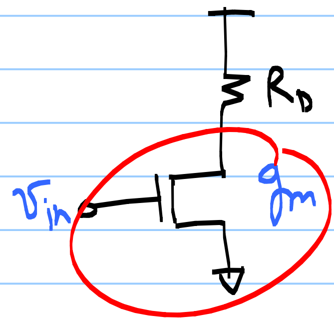
$$= - \frac{r_{o1} || (g_{m2} r_{o2} R)}{1/g_{m1}}$$

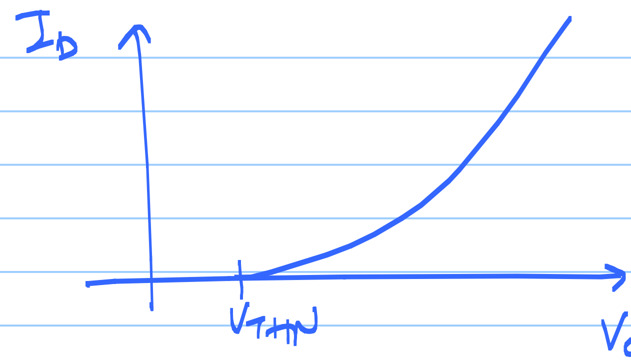


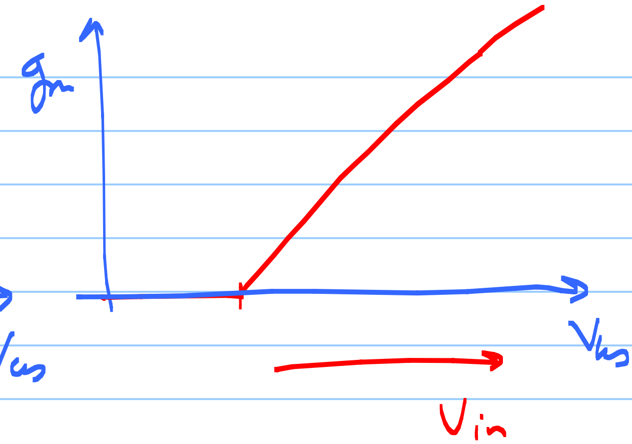
Z_{in} = depends on Z_L

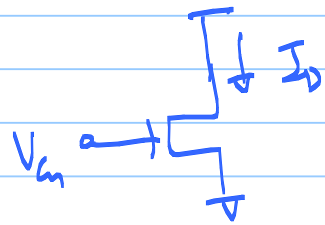
$\simeq 1/g_{m1}$ only if Z_L is small

Common-Source Amplifier with Source Degeneration



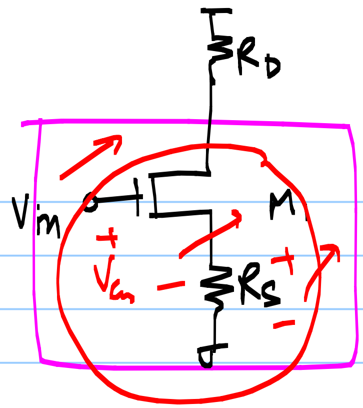






$$A_v = -g_m R_D$$

$\Rightarrow$

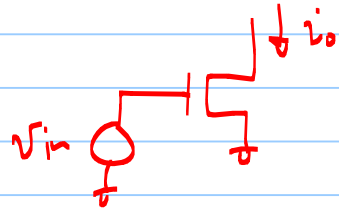


$I_D \uparrow$

V_{GS} is relatively constant

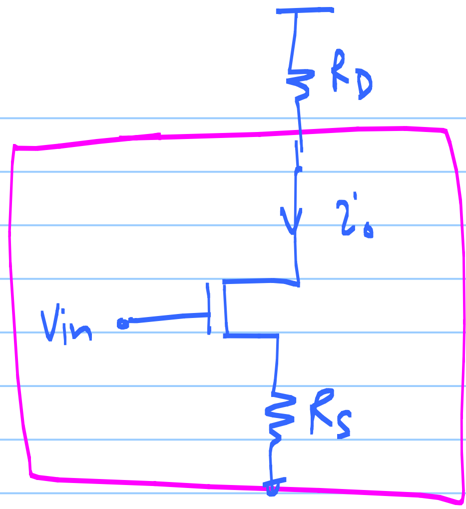
$$I_D = \frac{V_{in} - V_{GS}}{R_S}$$

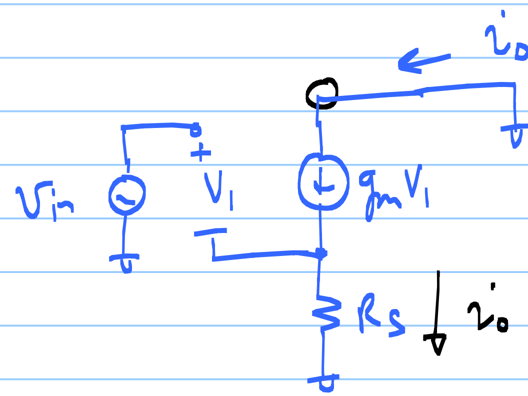
$$\Delta I_D \simeq \frac{\Delta V_{in}}{R_S}$$



$$\frac{i_o}{v_{in}} = g_m$$

Assume $\Rightarrow$ $\lambda = 0$



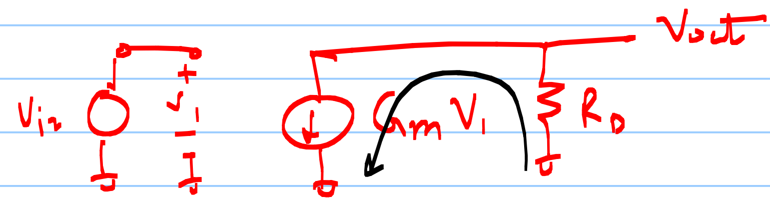


$$V_1 = V_{in} - i_o R_S \longrightarrow ①$$

$$i_o = g_m V_1 = g_m (v_{in} - i_o R_S)$$

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

$$i_o = \boxed{g_m} v_{in}$$



$$v_{out} = -i_o R_D$$
$$= -g_m v_{in} R_D$$

$$\Rightarrow A = \frac{v_{out}}{v_{in}} = -\boxed{g_m} R_D$$

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

$\hookrightarrow$ G_m is smaller

$$G_m = \frac{1}{\frac{1}{g_m} + R_S} \quad \text{if} \quad R_S >> 1/g_m$$

$$\simeq 1/R_S$$

$\hookrightarrow$ for $R_S >> 1/g_m$

$\hookrightarrow$ G_m becomes a weak function of g_m

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

$\simeq 1/R_S$

cost $\Rightarrow$ lower gain

higher noise

$\lambda \neq 0$, $g_{mb} \neq 0$

$$G_m = \frac{g_m r_o}{R_S + [1 + (g_m + g_{mb}) R_S] r_o}$$

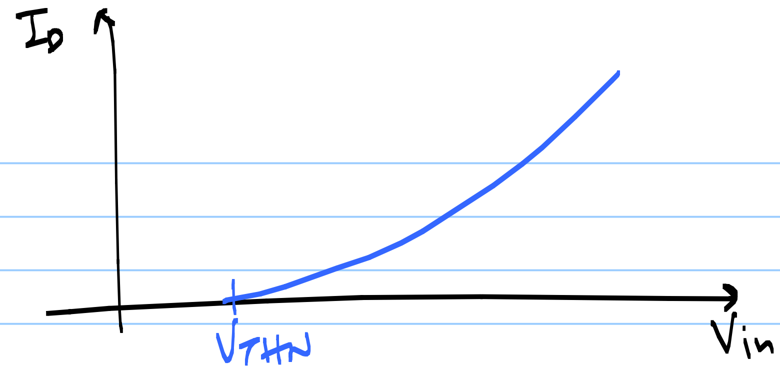
$\leftarrow$ Exercise

set $g_{mb} = 0$

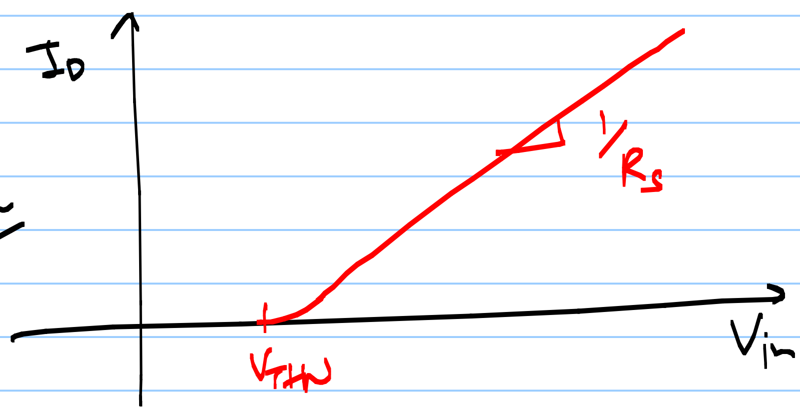
$r_o \to \infty$

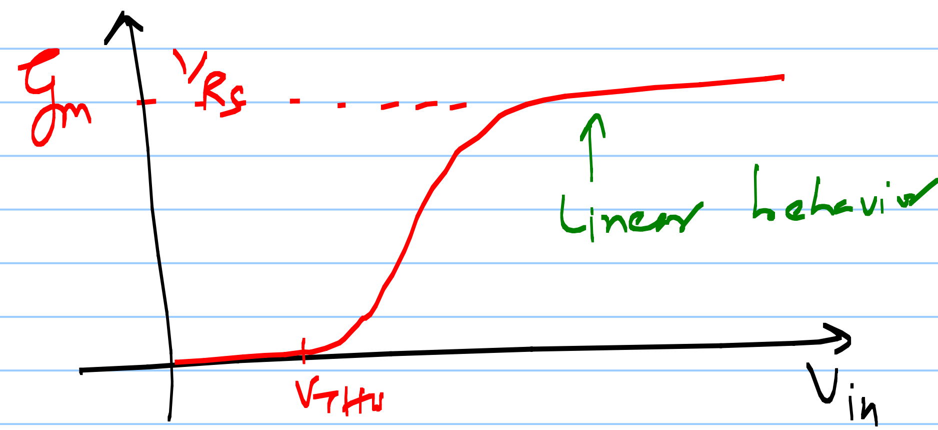
$\Rightarrow \simeq \dfrac{g_m}{1 + g_m R_S}$

$R_S = 0$



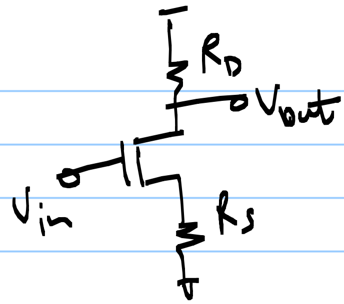
$R_S \gg 1/g_m$





At low currents

$1/g_m \gg R_S$



$$A_v = -g_m R_D$$

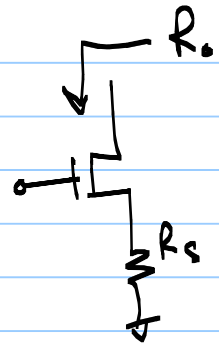
$$= -\frac{g_m R_D}{1 + g_m R_S}$$

$$= -\frac{R_D}{1/g_m + R_S}$$

if $R_S >> 1/g_m$

$$A_v \simeq -\frac{R_D}{R_S}$$

* output impedance of CS with source degeneration



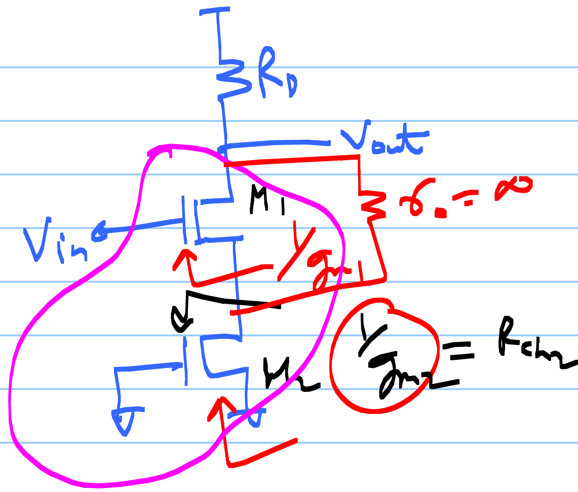
$$R_o \simeq g_m r_o R_S = \underbrace{(g_m R_S)}\, r_o$$

$$R_o = \left[1 + (g_m + g_{mb}) R_S\right] r_o$$

R_{out} has "increased" by a factor of

$$1 + \underbrace{(g_m + g_{mb}) R_S}$$

$\lambda = 0$



$$G_m = \frac{g_{m1}}{1 + g_{m1}\frac{1}{g_{m2}}}$$

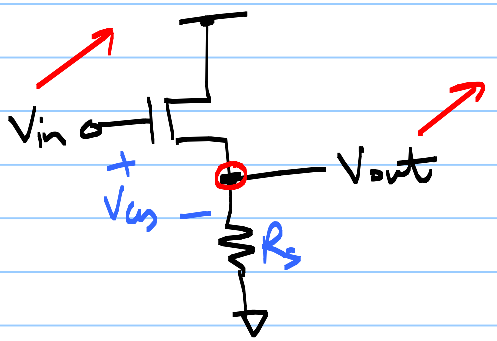
$$A_v = -G_m R_D$$

$$= -\frac{g_{m1} R_D}{1 + \frac{g_{m1}}{g_{m2}}}$$

$$= -\frac{R_D}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}}$$

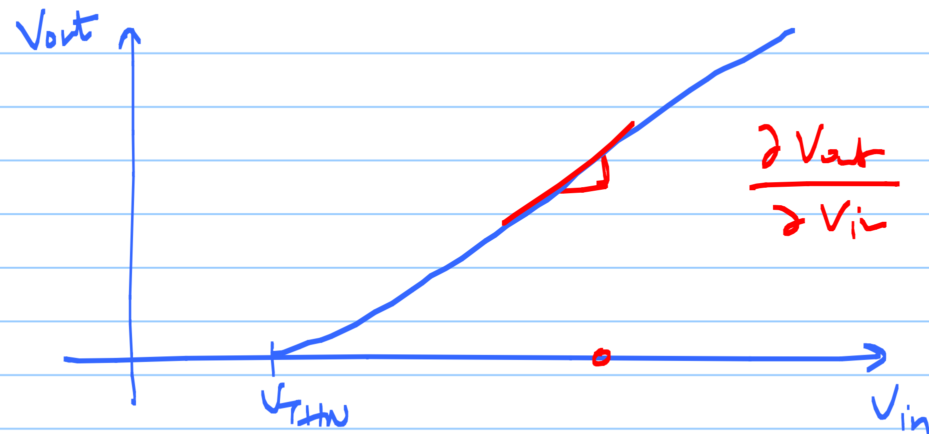
$$A_v = -\frac{\text{Resistance seen in the drain}}{\text{total resistance seen in the source path}}$$

Common Drain Amplifier (Source follower)



$V_{SB} \nearrow$

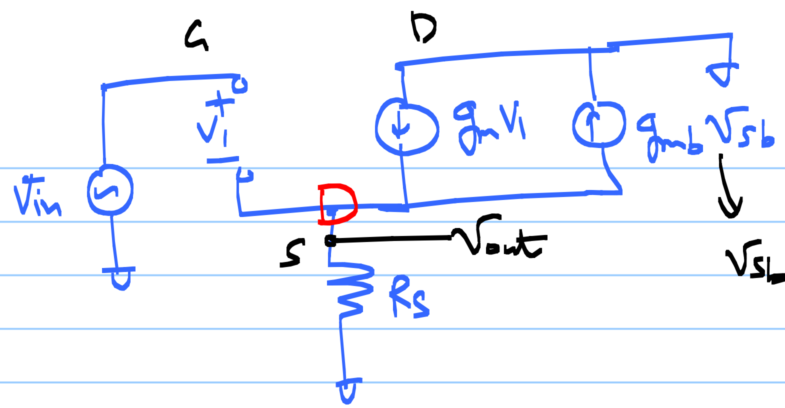
$\underline{g_{mb}}$



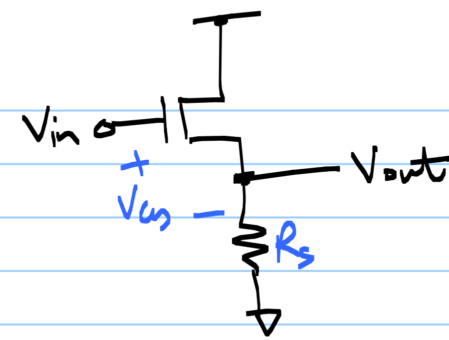
$$\frac{\partial V_{out}}{\partial V_{in}} = A_v$$

small-signal analysis

$\lambda = 0 \Rightarrow r_o \to \infty$



$v_{sb} = v_{out}$



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

KCL $\Rightarrow$ $$g_m v_1 - g_{mb} V_{out} = \frac{V_{out}}{R_S} \longrightarrow (2)$$

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

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

$$\Rightarrow \boxed{A_v = \frac{v_{out}}{v_{in}} = \frac{g_m R_s}{1 + (g_m + g_{mb}) R_s}}$$

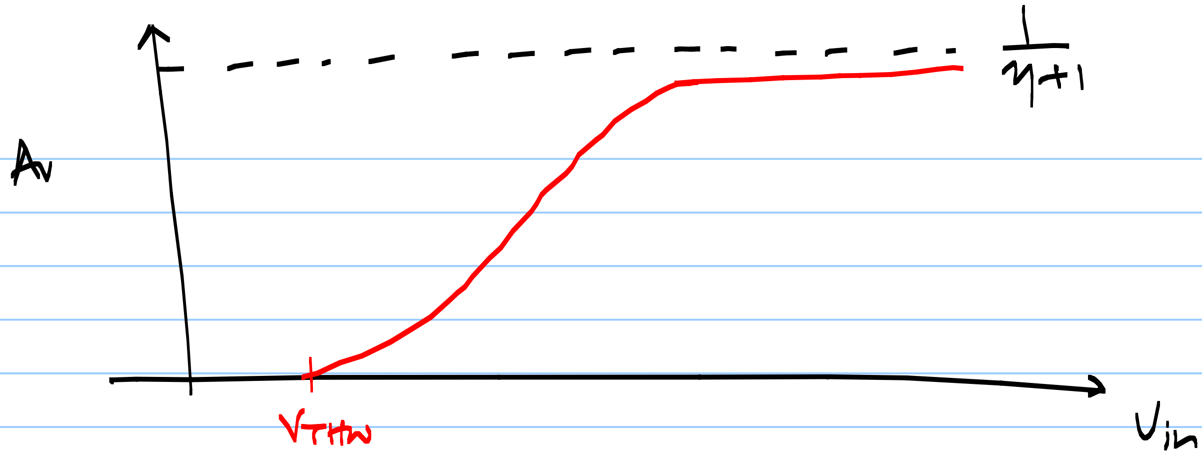
$\Rightarrow$ non-inverting gain

$$\boxed{g_{mb} = \eta \, g_m}$$

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

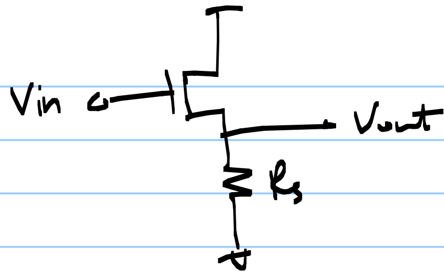
$$A_v = \frac{1}{(\eta+1) + \frac{1}{g_m R_s}} < 1$$

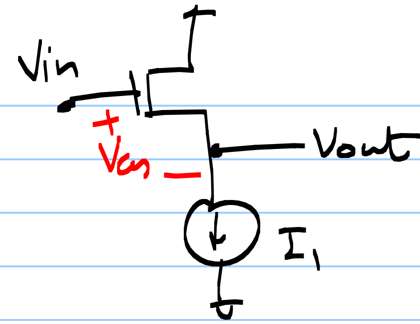
$$\simeq \frac{1}{\eta + 1} \quad \text{when } g_m R_s \gg 1$$

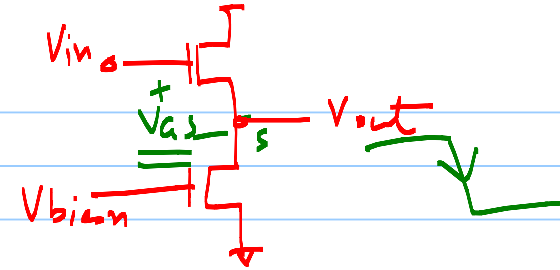


$\Rightarrow$ gain monotonically increases with $V_{in} \Rightarrow g_m \uparrow \Rightarrow g_m R_s \uparrow$

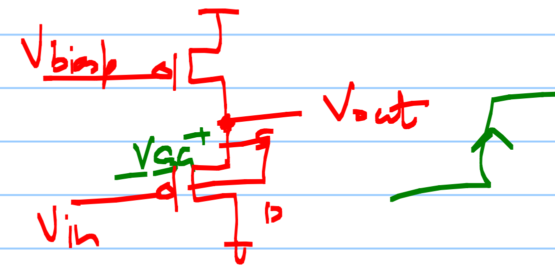
gain $\longrightarrow \frac{1}{\eta+1} \lesssim 1.0$







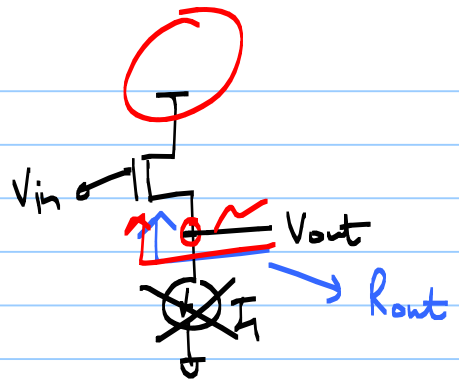
NMOS SF

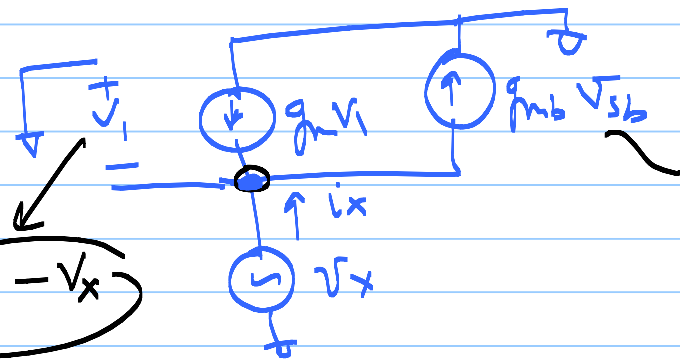


PMOS SF

"Level-shifting"

$\lambda = 0$





$v_{sb} = v_x$

$V_1 = -V_x$

$$i_x + g_m v_1 - g_{mb} v_x = 0$$

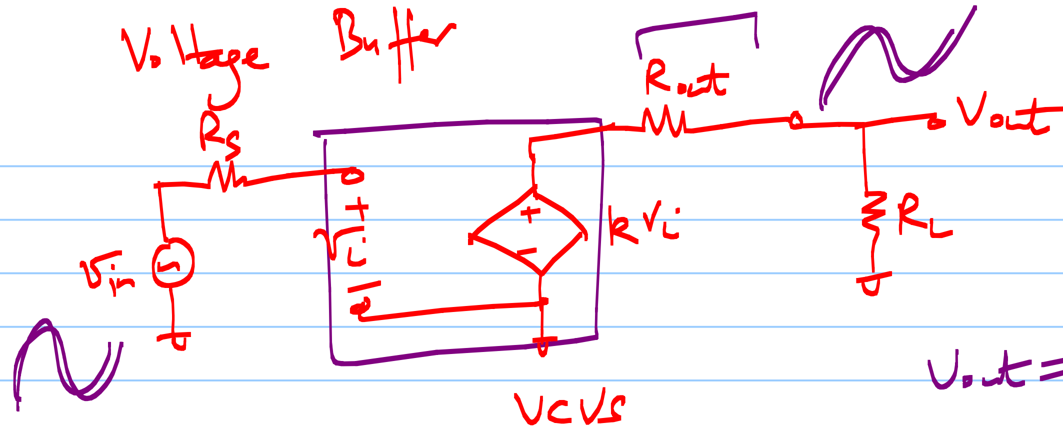
$$\Rightarrow i_x - g_m v_x - g_{mb} v_x = 0$$

$$\boxed{R_{out} = \frac{v_x}{i_x} = \frac{1}{g_m + g_{mb}}} = \frac{1}{g_m(\eta+1)}$$

$\Rightarrow$ Low-Z output for a SF.

Digression.

Voltage Buffer



$$V_{out} = kV_i \cdot \frac{R_L}{R_L + R_{out}}$$

$k = 1$

$\Rightarrow$ for good quality VB, we want $R_{out} \to 0$