Lecture 15 — ECE 511

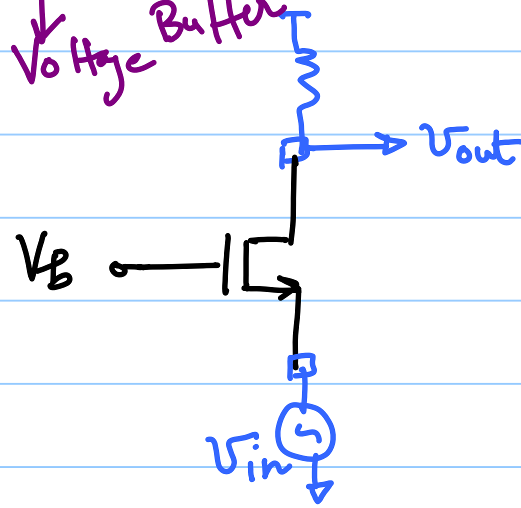
Note Title 3/13/2014

CS → gain

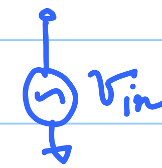
↓

SD → linearized gain

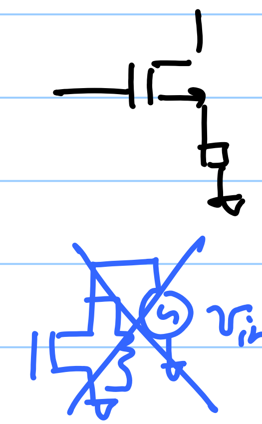
CD/SF → Voltage Buffer

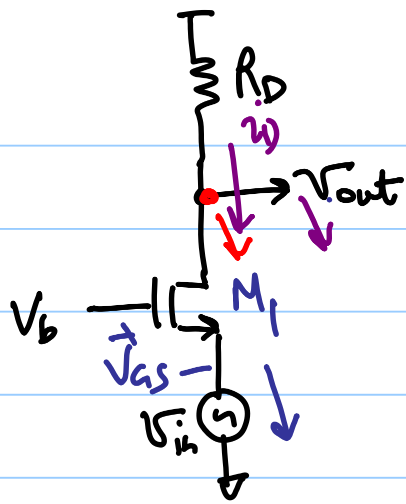


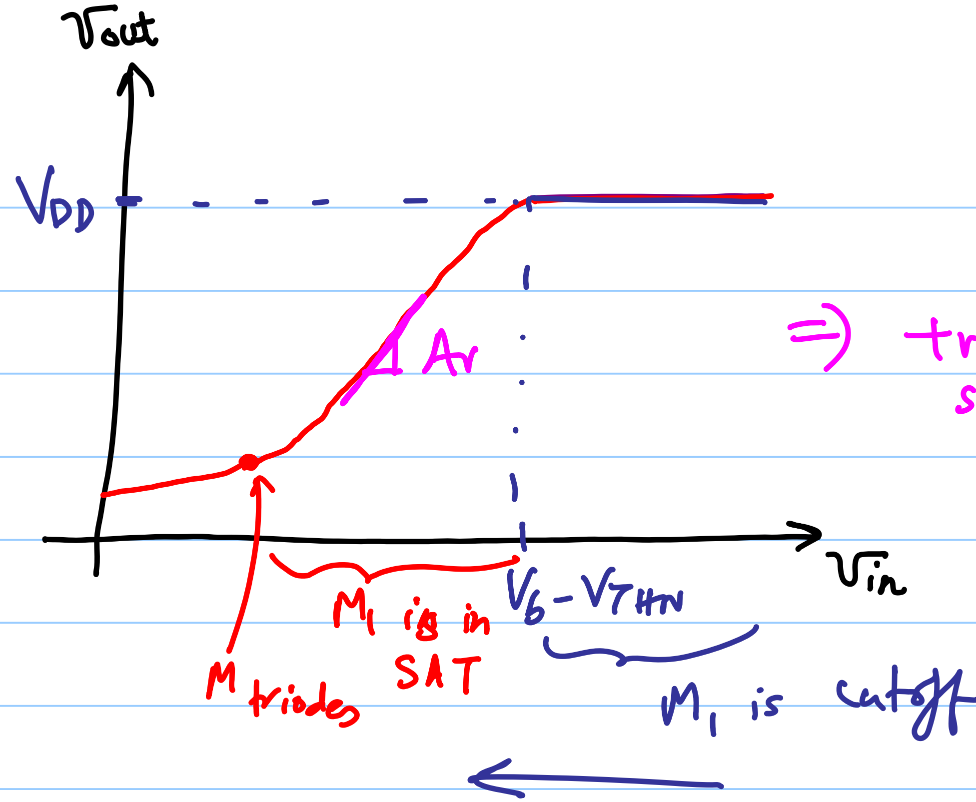
CG



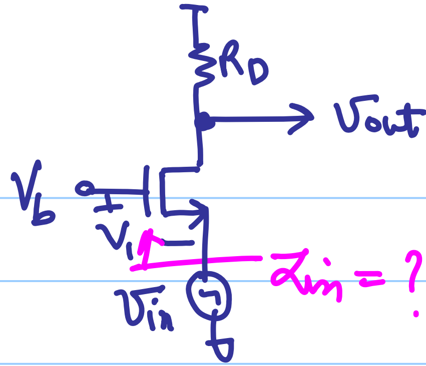
CS

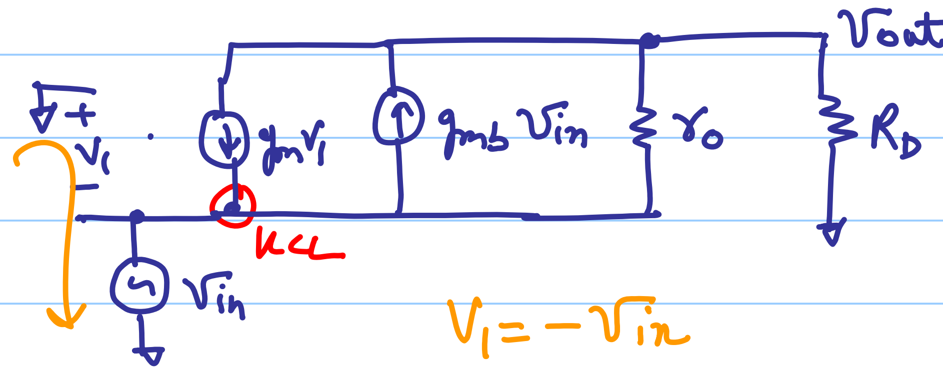






⇒ the small signal gain





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

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

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

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

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

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

for $r_o \gg R_D$

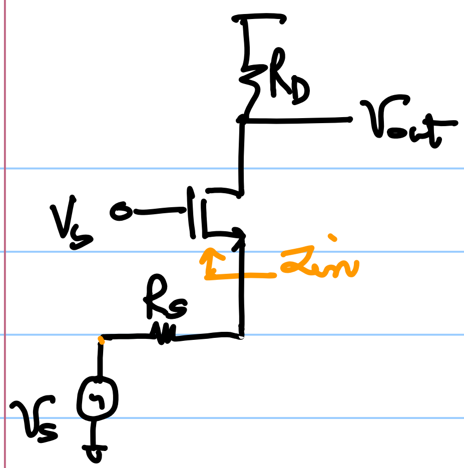
$(g_m + g_{mb})r_o \gg 1$

$$A_v = +(g_m + g_{mb})R_D$$

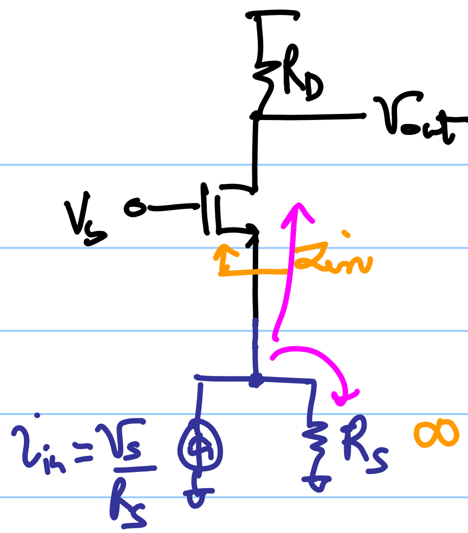
$g_{mb} = \eta g_m$

CG $\boxed{A_v = +(\eta+1) g_m R_D}$ ✓ ← Low Z_{in}

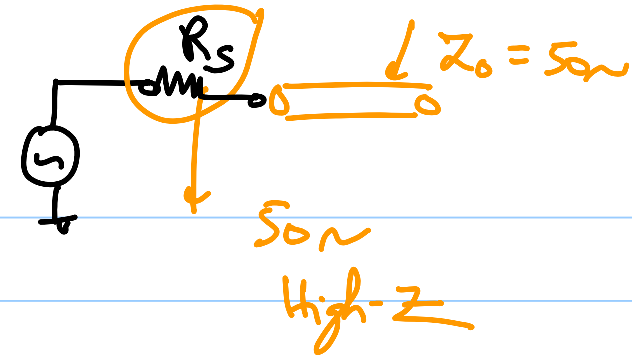
CS $A_v = -g_m R_D$ ← High Z_{in}



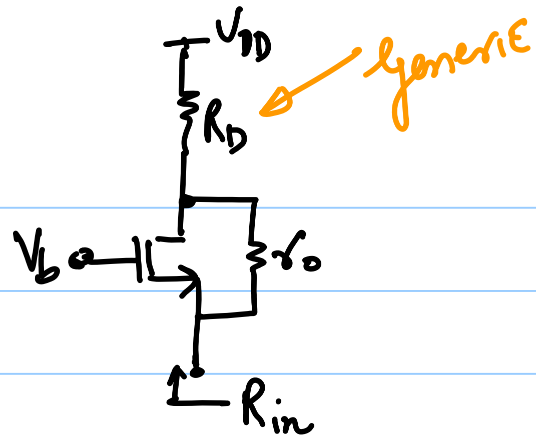
R_D
V_{out}
V_s
Z_{in}
R_s
V_s

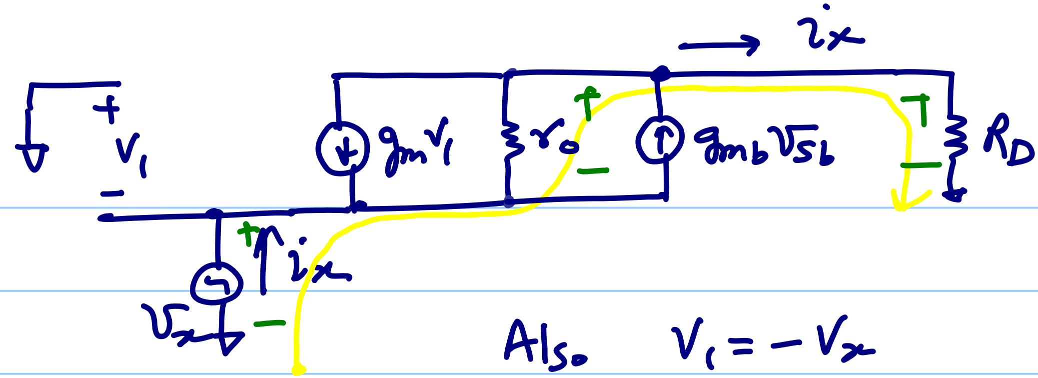


R_D
V_{out}
V_s
Z_{in}
$i_{in} = \frac{V_s}{R_s}$
R_s
∞



R_s
$Z_0 = 50\Omega$
50Ω
High-Z





Also $V_1 = -V_x$

* Current thru r_o ⇒ $i_x + g_m V_1 + g_{mb} V_1$

$$= i_x - (g_m + g_{mb}) v_x \longrightarrow (1)$$

Add up all the voltages across r_o & R_D

$$R_D i_x + r_o [i_x - (g_m + g_{mb}) v_x] = v_x$$

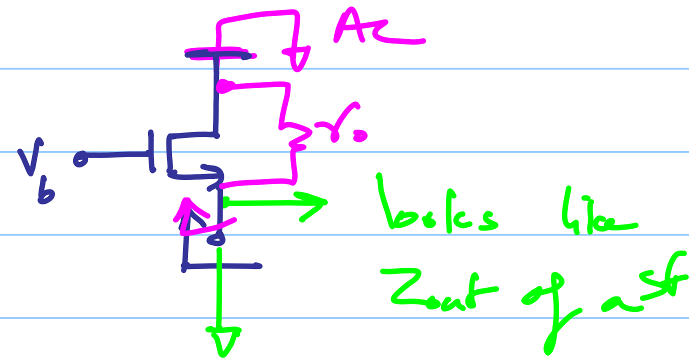
$$\Rightarrow R_{in} = \frac{v_x}{i_x} = \frac{R_D + r_o}{1 + (g_m + g_{mb}) r_o}$$

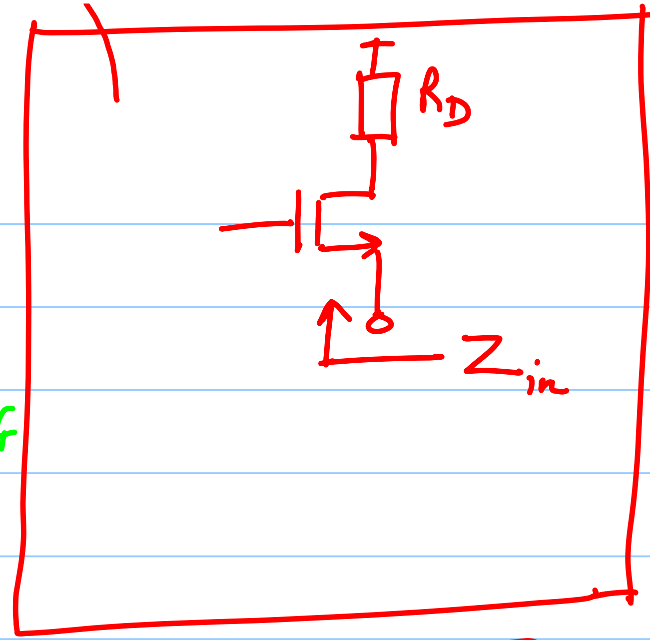
$(g_m + g_{mb}) r_o \gg 1$

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

Special cases :

(A) $R_D = 0$





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

$$= \frac{1}{1/r_o + (g_m+g_{mb})} \simeq r_o \,\|\, \frac{1}{(g_m+g_{mb})} \simeq \frac{1}{(g_m+g_{mb})}$$

$r_o >> \frac{1}{g_m}$

$\Rightarrow g_m r_o >> 1$

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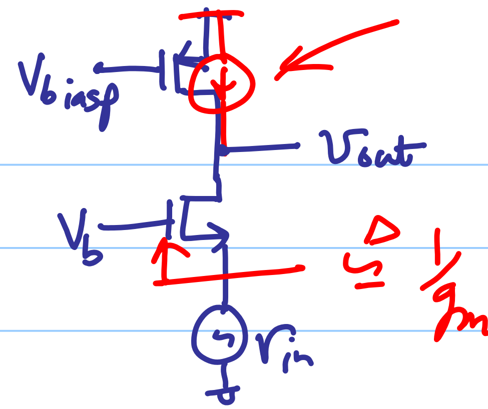
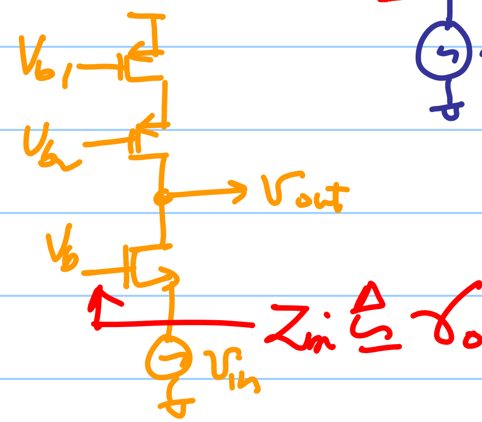
(B) $R_D \simeq r_o$



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

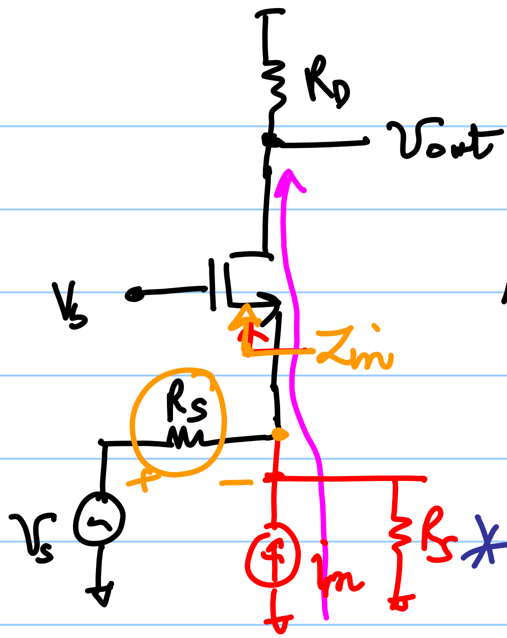
$$\simeq \frac{2}{(g_m+g_{mb})} \stackrel{\Delta}{\simeq} \frac{1}{g_m}$$



(C) $R_D \stackrel{\Delta}{=} g_m r_o^2$

$$R_{in} = \frac{g_m r_o^2}{(g_m+g_{mb})r_o} + \frac{1}{(g_m+g_{mb})} = \frac{r_o}{(\eta+1)} + \frac{1}{(\eta+1)g_m} \stackrel{\Delta}{\simeq} r_o$$

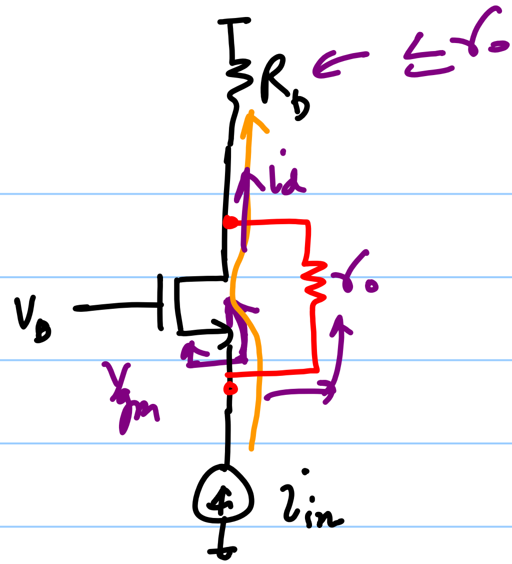
Razavi



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

* Not a great voltage amplifier

$Z_{in} \rightarrow$ low (we want high Z input)



Read from Razavi on CB

$\frac{1}{g_m} \ll r_o$

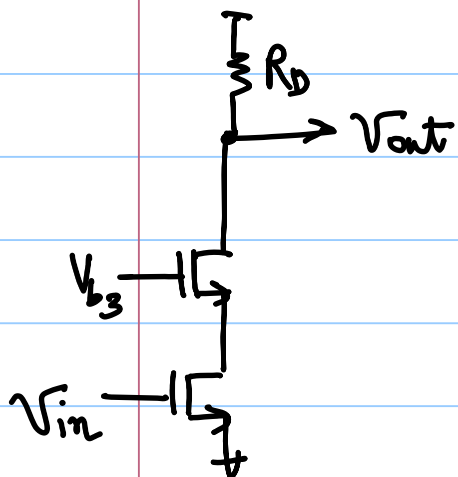
$\Rightarrow \quad i_d \simeq i_{in}$

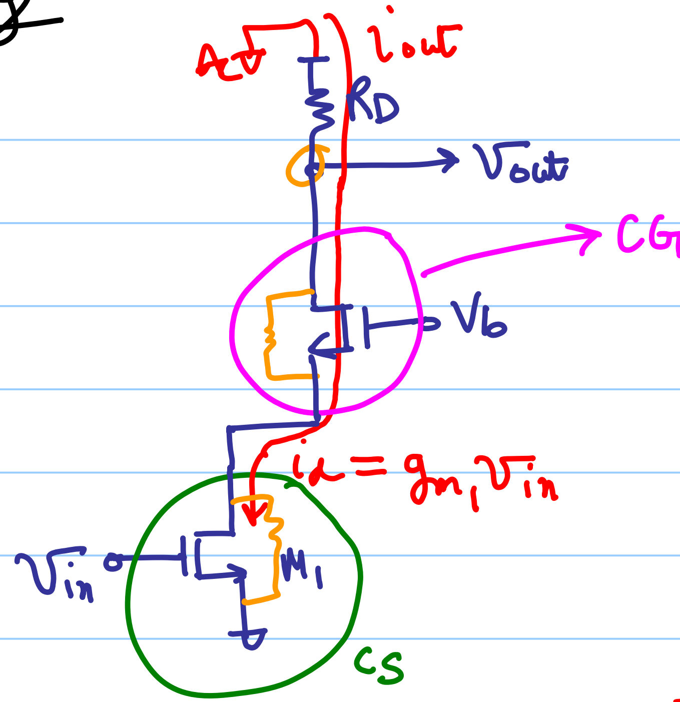
"acts like a current conveyor"

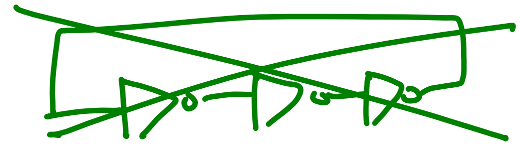
"current buffer"

Amplifier Type	Gain	R_{in}	R_{out}	Application
CS	Large ($g_m r_o$)	∞	Moderate	Amplifier stage
↳ CS+SD	Moderate	∞	High/moderate	Linear Amplifier
CD/SF	low (<1)	∞	Low $(1/g_m)$	Voltage Buffer
CG	Medium/high	Low	moderate/High	Current Buffer

Cascode stage







$r_o = \infty$

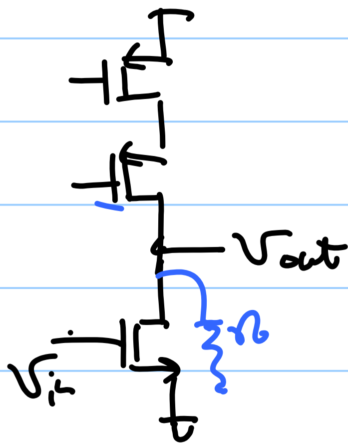
$\lambda = 0$

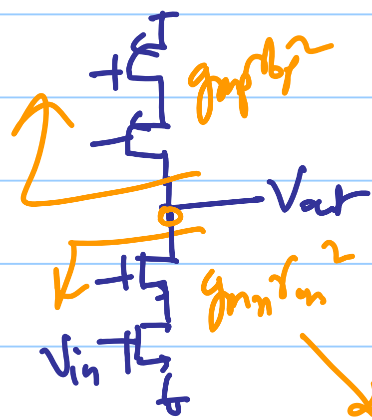
$$V_{out} \simeq -i_{out} \cdot R_D$$
$$= -g_{m1} v_{in} R_D$$

$$\Rightarrow \boxed{A_v \simeq -g_{m1} R_D}$$

$$\downarrow$$

$$(g_{mp} r_{op}^2) \| (g_{mn} r_{on}^2)$$





$$A_v = -g_{m1} \cdot (g_m r_{op}^2) \| (g_m r_{on}^2)$$

$$A_v = -g_{m1}(r_{o1} \| g_m r_o^2) \simeq -g_m r_{o1}$$

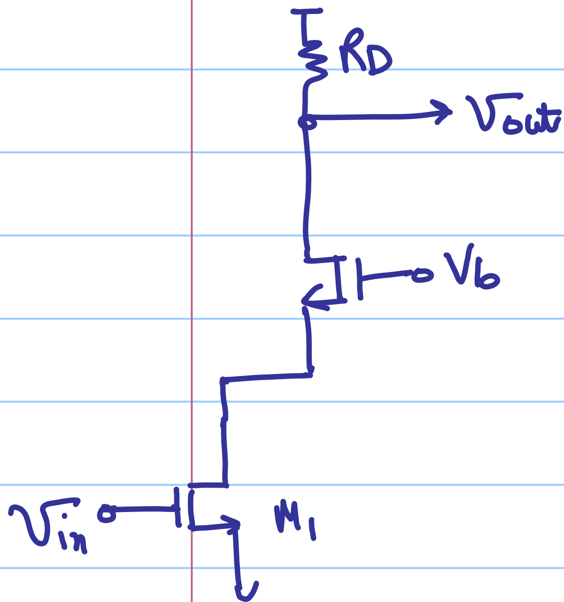
Razavi

Lemma

In a linear circuit voltage gain $= -G_m \cdot R_{out}$

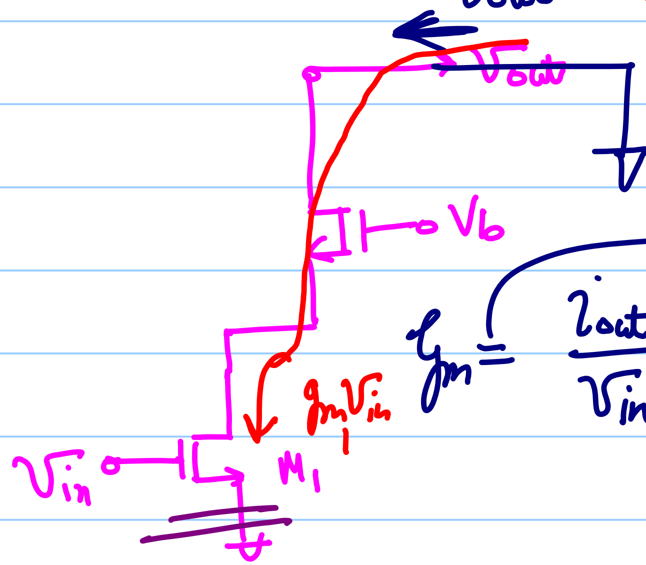
where $G_m \Rightarrow$ transconductance when the o/p is shorted to ground.

and $R_{out} \Rightarrow$ o/p resistance of the circuit when the i/p is set to zero.



$$A_v = -G_m \times R_{out}$$

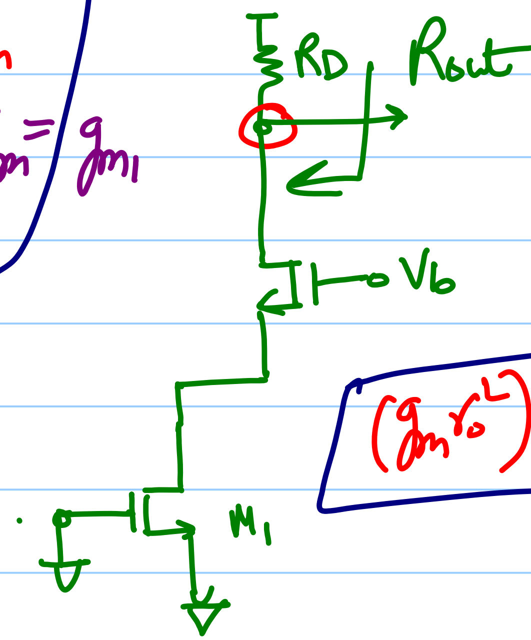
$G_m \Uparrow g_{m1}$



$i_{out} = g_{m1} v_{in}$

$\Rightarrow G_m = g_{m1}$

$$G_m = \frac{i_{out}}{v_{in}}$$



$$R_{out} = (g_m r_o^2) \| R_D$$