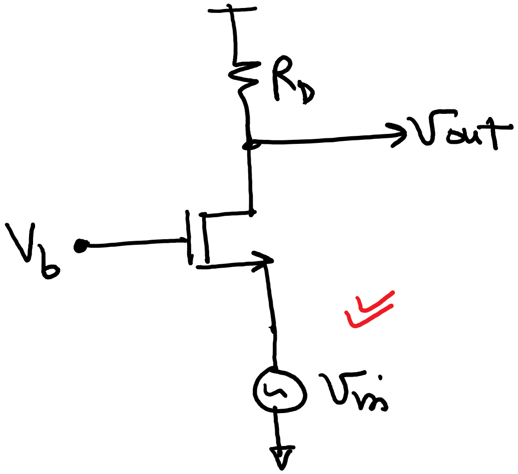
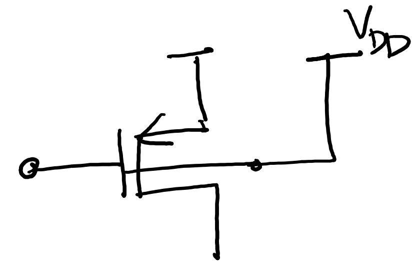
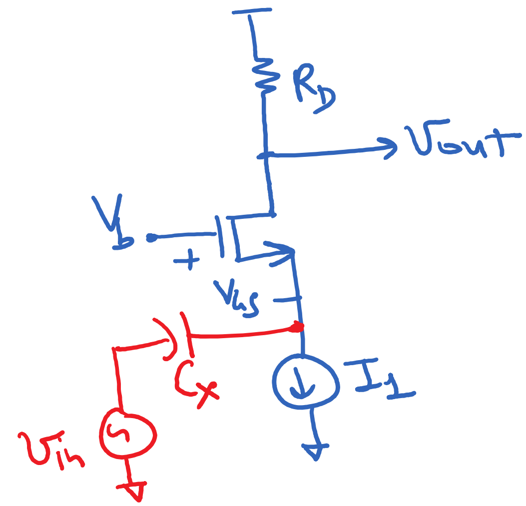
ECE 511 – Lecture 12

Tuesday, October 2, 2018 11:01 AM







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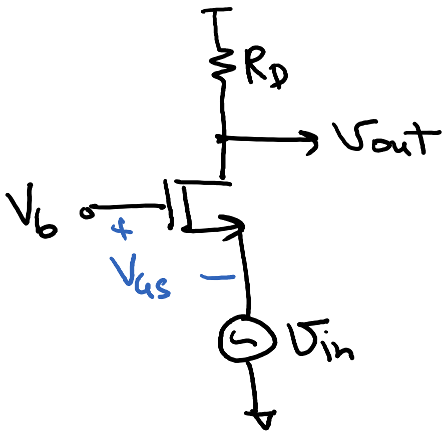

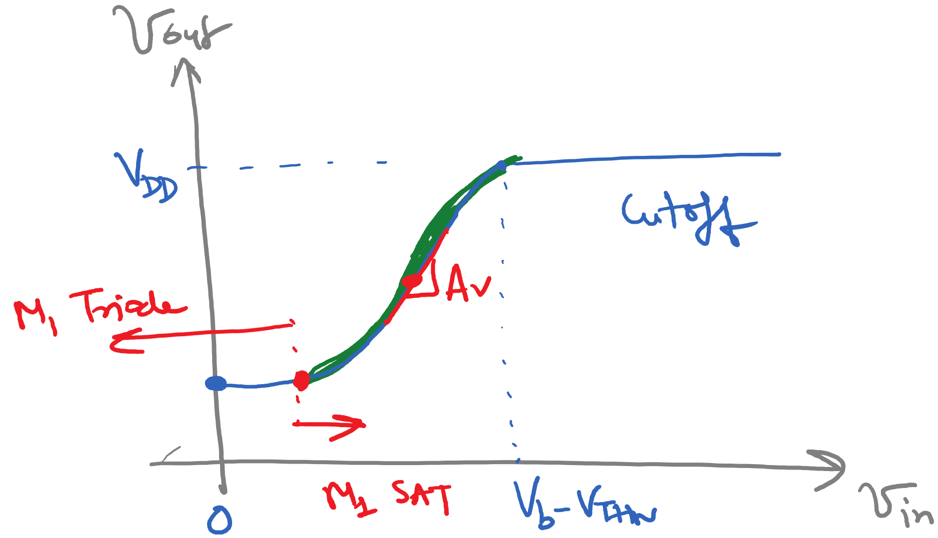

Small signal analysis:

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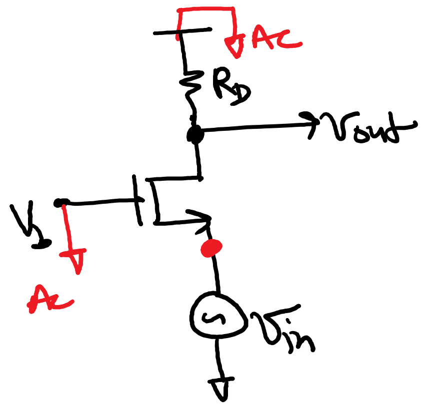

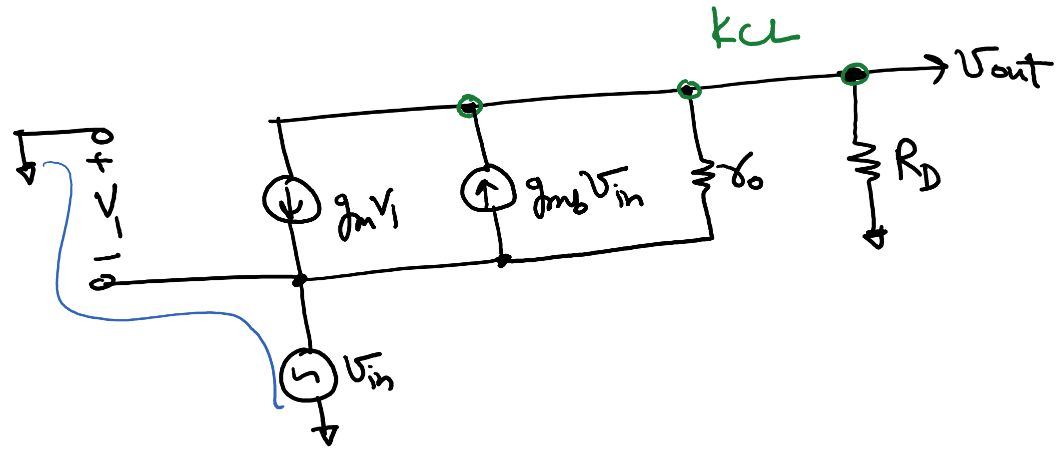

$$V_1 = -v_{in} \longrightarrow (1)$$

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

$$\Rightarrow \quad v_{in}\left[\tfrac{1}{r_o} + (g_m + g_{mb})\right] = \frac{v_{out}}{r_o \parallel R_D}$$

$$\Rightarrow \quad A_v = \frac{v_{out}}{v_{in}} = \frac{(g_m + g_{mb})\cancel{r_o} \cancel{+1}}{\cancel{R_D} + \cancel{r_o}} \cdot R_D$$

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

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

$\because\ r_o >> R_D$

$g_m r_o >> 1$

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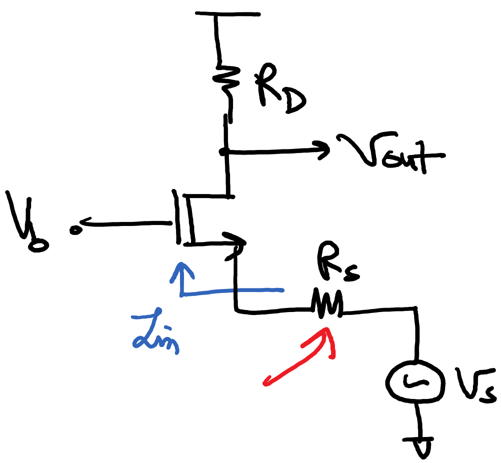
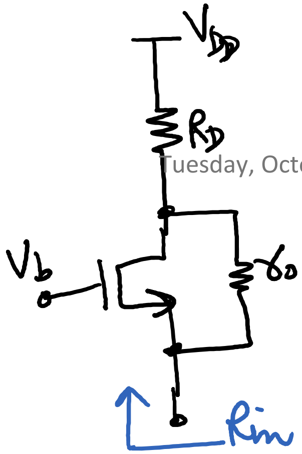
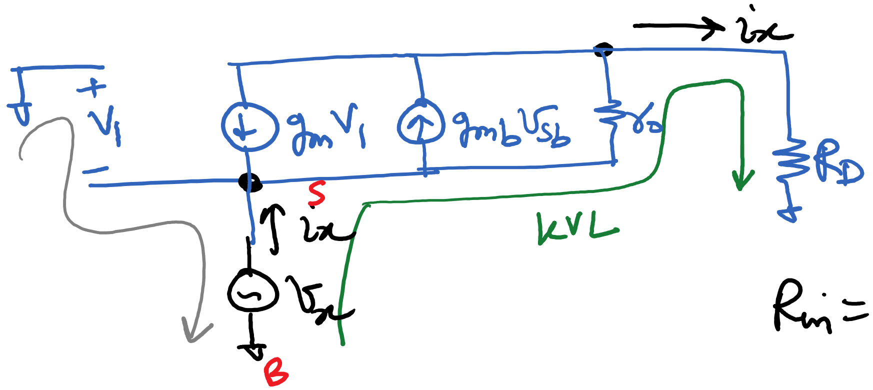


$$A_v = \frac{v_{out}}{v_{in}} = \frac{(g_m + g_{mb})r_o + 1}{r_o + (g_m + g_{mb})r_o R_s + R_s + R_D} \cdot R_D$$

See Razavi Book for details





$$R_{in} = \frac{v_x}{i_x}$$

$$\Rightarrow \boxed{V_1 = -v_x} \rightarrow (1)$$

Current thru r_o $\Rightarrow$ $i_x + g_m V_1 - g_{mb} v_x = i_{r_o}$

$$\Rightarrow i_{r_o} = i_x - (g_m + g_{mb}) v_x \rightarrow (2)$$

* Adding up voltages across r_o and R_D.

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

$$\Rightarrow v_x [1 + (g_m + g_{mb}) r_o] = (R_D + r_o) i_x$$

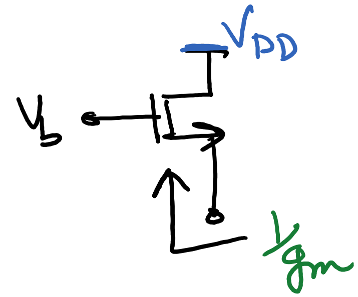
$$\Rightarrow R_{in} = \frac{v_x}{i_x} = \frac{R_D + r_o}{1 + (g_m + g_{mb}) r_o} \simeq \boxed{\frac{R_D}{(g_m + g_{mb}) r_o} + \frac{1}{(g_m + g_{mb})}}$$

R_{in}

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

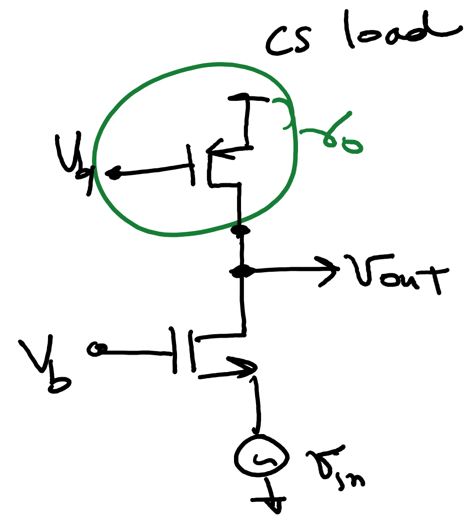
Case A: $R_D = 0$

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



Case B: $R_D \leq r_o$

$$R_{in} = \frac{2}{(g_m + g_{mb})} \simeq \frac{1}{g_m}$$



Case C: $R_D = g_m r_o^2$

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

$$\simeq r_o$$

PMOS Cascode current source load

$\because r_o >> 1/g_m$

Case D

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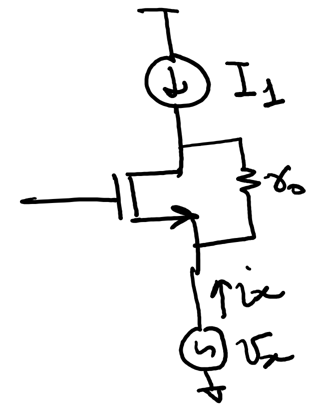
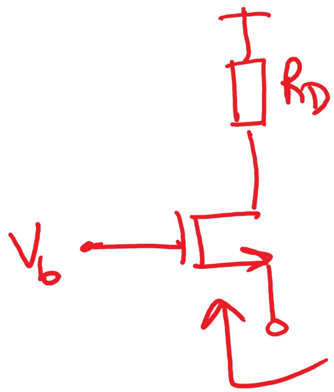
$R_D \to \infty$

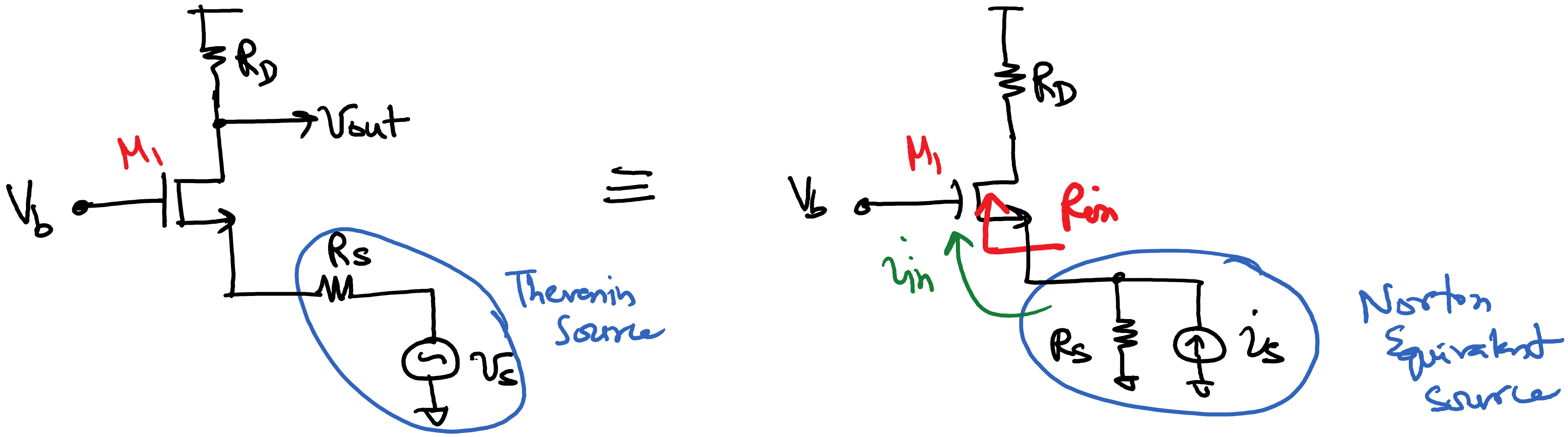
$$R_{in} = \frac{R_D}{(g_m + g_{mb}) r_o} \to \infty$$





R_{in} is $\simeq 1/g_m$ in only special cases

$R_D \leq r_o$



i_s is current divided between R_s and R_{in}

$$i_{in} = i_s \cdot \left(\frac{R_s}{R_{in}+R_s}\right)$$

for most of the current to enter M_1

$\Rightarrow R_{in} \to 0$

If $R_D \lesssim r_o \Rightarrow$ current division between $1/g_m$ & R_s

Input Impedance is low $\Rightarrow$ CG is rather a better current amplifier than a voltage amplifier

Summary :

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Amplifier	Gain	Z_{in}	Z_{out}	Application
CS	Large	∞	Moderate (r_o)	Voltage Amplifier
CS + SD	Moderate	∞	High $(g_m r_o R_S)$	Linear Voltage Amplifier
CD / SF	low <1	∞	Low $(1/g_m)$	Voltage Buffer
CG	Large	Low	Moderate/High (r_o)	Current buffer or amplifier

Cascode Amplifier:

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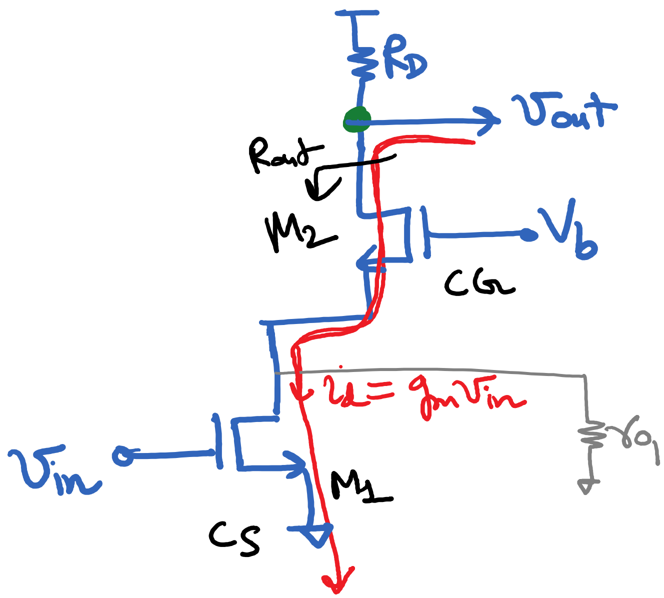

$R_D \leq r_o$

i_d sees current division between $1/g_{m2}$ & r_{o1}

Lets say most of i_d goes into M_2

$\Rightarrow 1/g_{m2} \ll r_{o1}$

$R_{out} = g_{m2} r_{o2} r_{o1}$

$v_{out} = -i_d (R_D || R_{out}) = -g_m v_{in} (R_D || R_{out})$

$A_v = (-g_m) R_{out} = -(g_m r_o)^2$

$\downarrow$

$(g_m r_o^2)$

if $R_D \to \infty$

* Need a better analysis method

Lemma: In a linear circuit voltage gain $= -G_m R_{out}$

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where

$G_m \Rightarrow$ transconductance of the circuit when the output is shorted to ground (output short circuit transconductance)

$R_{out} \Rightarrow$ output resistance of the circuit when the input is set to zero.

* See the proof in Razavi Book

Example: CS

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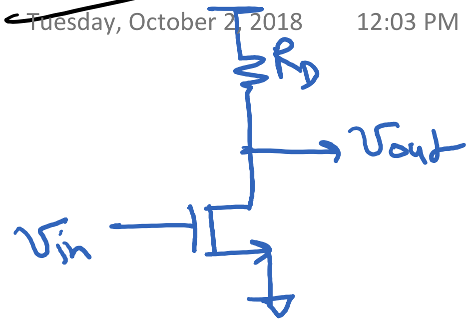

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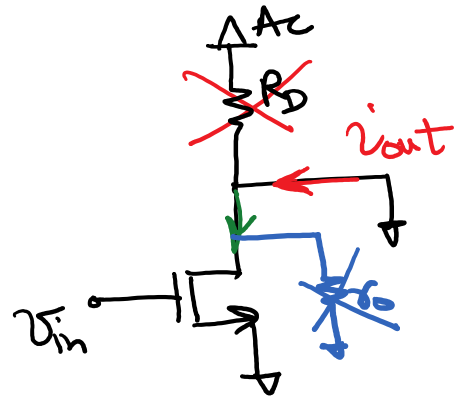
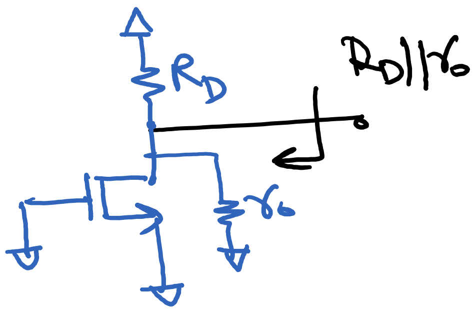


$$i_{out} = i_d = g_m v_{in}$$

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



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

$$= -g_m (R_D \| r_o)$$

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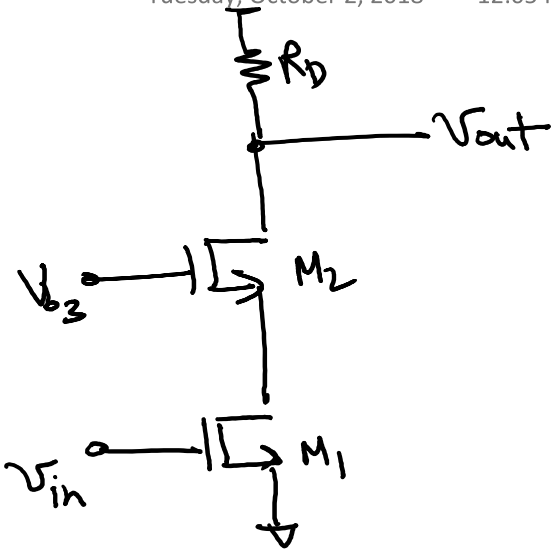
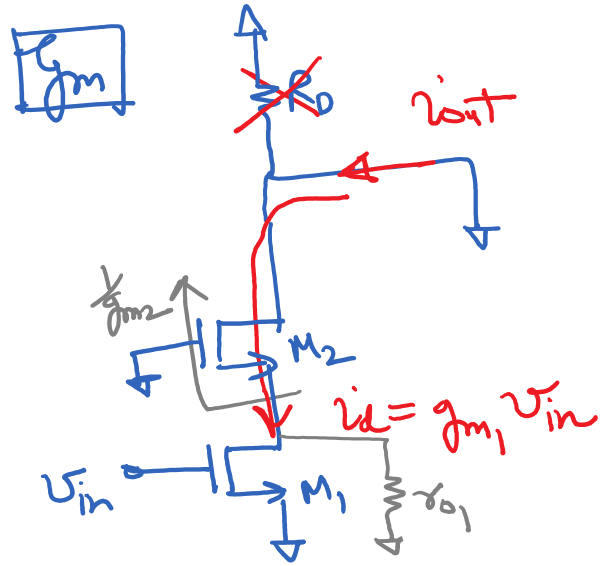




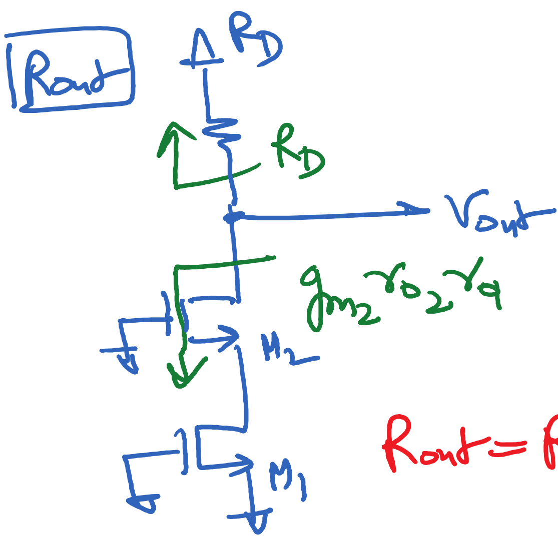
Approximation:

$$\frac{1}{g_{m2}} \ll r_{o1}$$

* M_2 acts as a current buffer

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

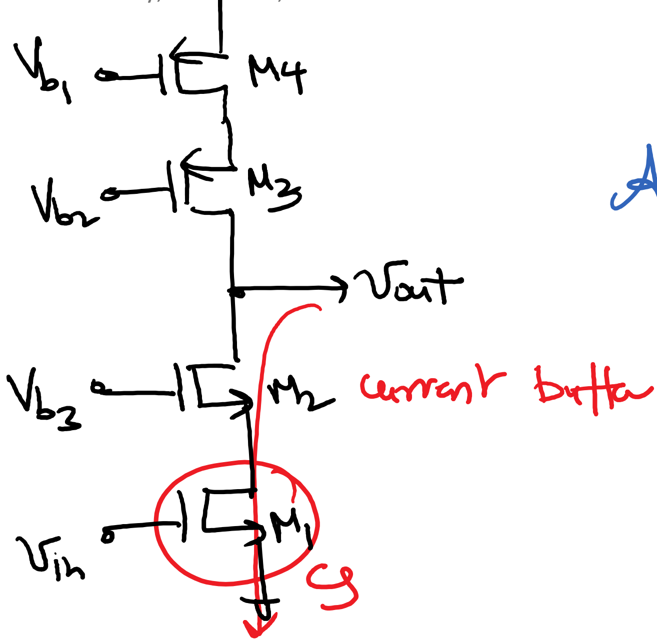
$$\Rightarrow \boxed{G_m = g_{m1}}$$



$$R_{out} = R_D \| (g_{m2} r_{o2} r_{o1})$$

$$A_v = -G_m R_{out} = \boxed{-g_{m1} R_D \| (g_{m2} r_{o2} r_{o1})}$$

$$\simeq -g_{m1} R_D$$



$$A_v = -g_{m_1} \cdot R_{out}$$

g_{m_1}

$R_{out} = R_{pcas} \| R_{ncas}$

$R_{pcas} = g_{m_3} r_{o3} r_{o4} = g_{mp} r_{op}^2$

$R_{ncas} = g_{m_2} r_{o2} r_{o1} = g_{mn} r_{on}^2$

* Biasing is not shown only conceptual

$$A_v = -g_{m_n} \cdot \left[(g_{mn} r_{on}^2) \| (g_{mp} r_{op}^2) \right]$$

$$= -g_m \cdot \frac{g_m r_o^2}{2} = -\frac{(g_m r_o)^2}{2}$$

all transistors have same g_m r_o