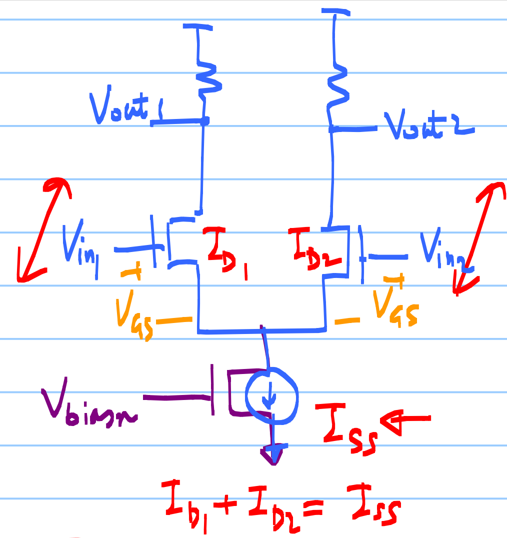
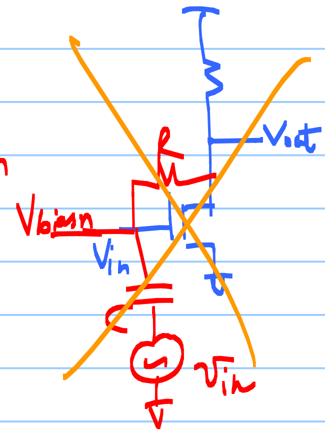
ECE 511 – Lecture 18

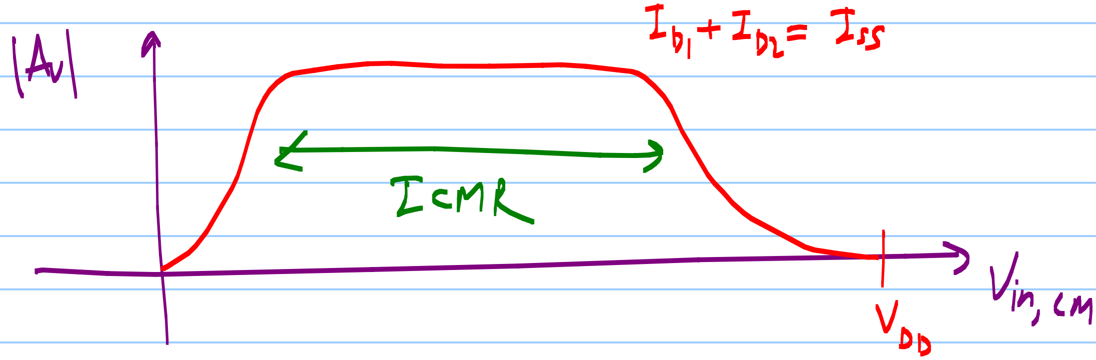
Note Title 4/4/2012

* Diffamp

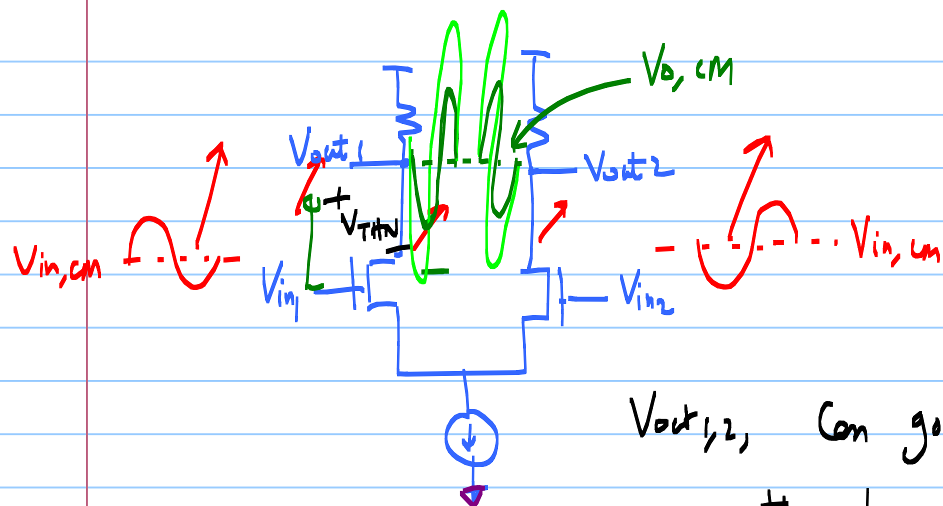


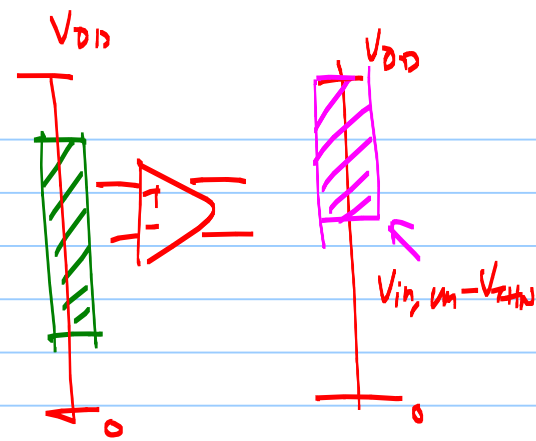


ICMR



Output Swing?

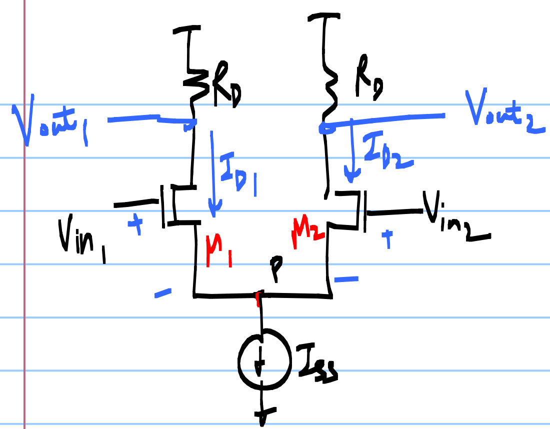




$V_{out1,2}$, can go to V_{DD}, on the high side

on the lower side

$(V_{in,cm} - V_{THN})$



Assume symmetric, & $\lambda = 0$

$$V_{out_1} - V_{out_2} = R_D\left(I_{D_2} - I_{D_1}\right) \longrightarrow ①$$

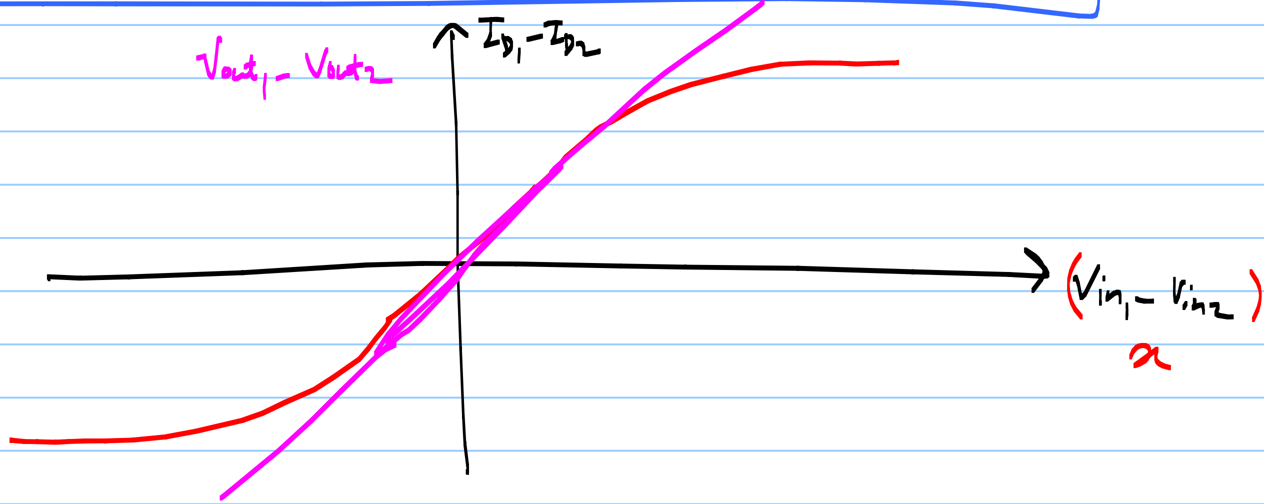
$$V_{in_1} - V_{in_2} = V_{GS_1} - V_{GS_2}$$

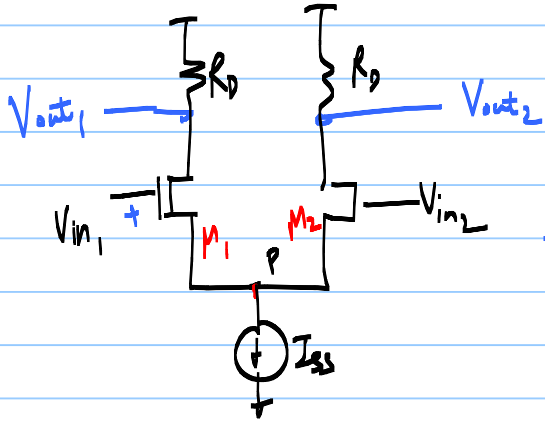
$$= \left(\sqrt{\frac{2I_{D_1}}{\beta}} + \cancel{V_{THN}}\right) - \left(\sqrt{\frac{2I_{D_2}}{\beta}} - \cancel{V_{THN}}\right)$$

$$V_{in_1} - V_{in_2} = \sqrt{\frac{2}{\beta}}\left(\sqrt{I_{D_1}} - \sqrt{I_{D_2}}\right) \longrightarrow ②$$

$$I_{D_1} + I_{D_2} = I_{SS} \longrightarrow ③$$

$$I_{D_1}-I_{D_2}=\frac{\beta}{2}\underbrace{(V_{in_1}-V_{in_2})}_{x}\sqrt{\underbrace{\frac{4I_{SS}}{\beta}}_{V_{ov}^2}-\underbrace{(V_{in_1}-V_{in_2})^2}_{x^2}}$$



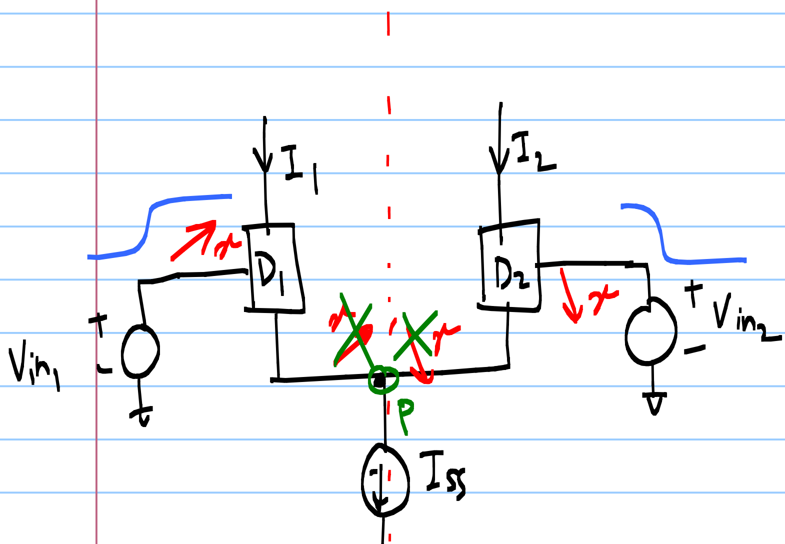


Differential Small-signal gain

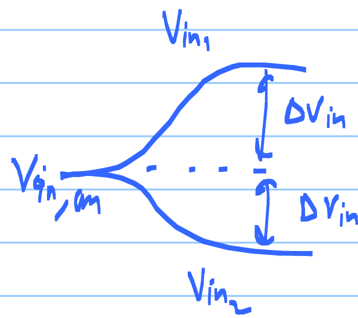
$$A_{DM} = \frac{(v_{out_1} - v_{out_2})}{(v_{in_1} - v_{in_2})}$$

Half-Circuit Method

Symmetric Circuit

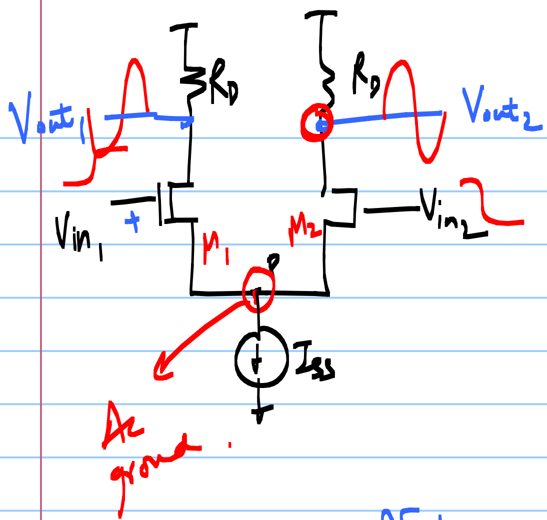


$I_1 + I_2 = I_{SS}$

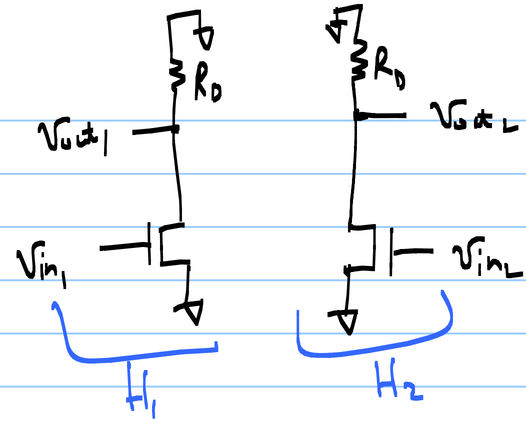


By symmetry node P ← fixed DC voltage

↳ Node "P" is an "AC ground"



Ac Picture



Two Half Circuits

$$H_1: \quad \frac{V_{out_1}}{V_{in_1}} = -g_{m_1}(R_D \| r_{o_1})$$

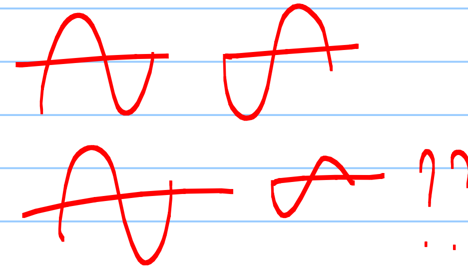
$$H_2: \quad \frac{V_{out_2}}{V_{in_2}} = -g_{m_2}(R_D \| r_{o_2})$$

$$g_{m_1} = g_{m_2}$$
$$r_{o_1} = r_{o_2}$$

$$\frac{V_{out_1} - V_{out_2}}{V_{in_1} - V_{in_2}} = -g_m(R_D \| r_o)$$ ← Differential mode gain

$$= \frac{v_{out2}}{v_{in1} - v_{in2}} = \frac{g_m (R_D \| r_o)}{2}$$

* what if the inputs are not differential



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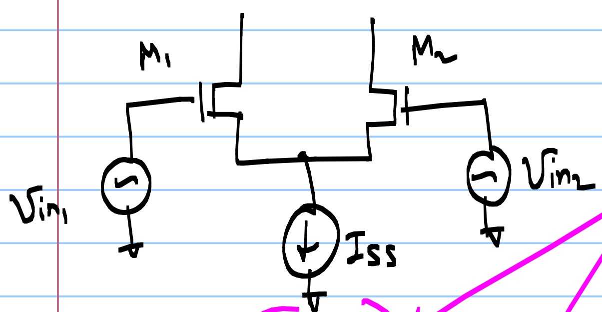


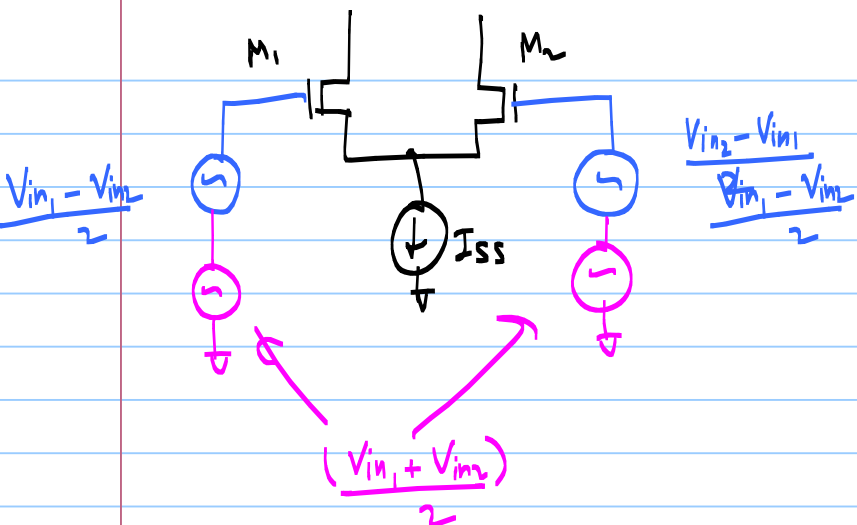
Differential mode term

$$V_{in_1} = \frac{(V_{in_1} - V_{in_2})}{2} + \frac{(V_{in_1} + V_{in_2})}{2}$$

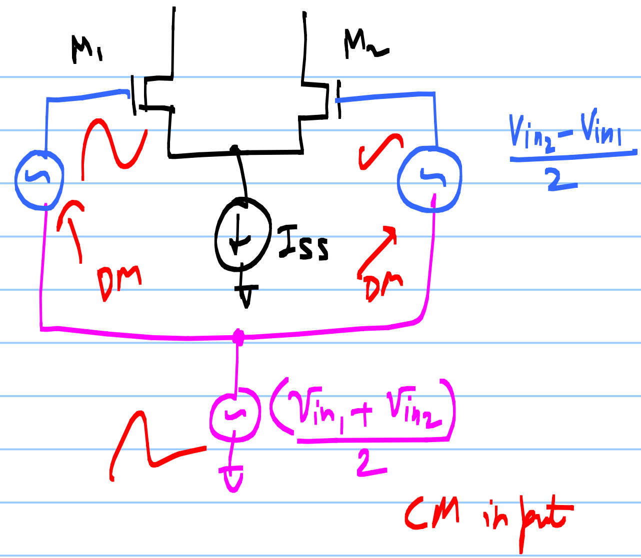
$$V_{in_2} = \frac{(V_{in_2} - V_{in_1})}{2} + \frac{(V_{in_1} + V_{in_2})}{2}$$

Common mode term ⟸ NOT DC here

$$f(x) = \underbrace{\left(\frac{f(x) + f(-x)}{2}\right)}_{\text{Even}} + \underbrace{\left(\frac{f(x) - f(-x)}{2}\right)}_{\text{Odd}}$$

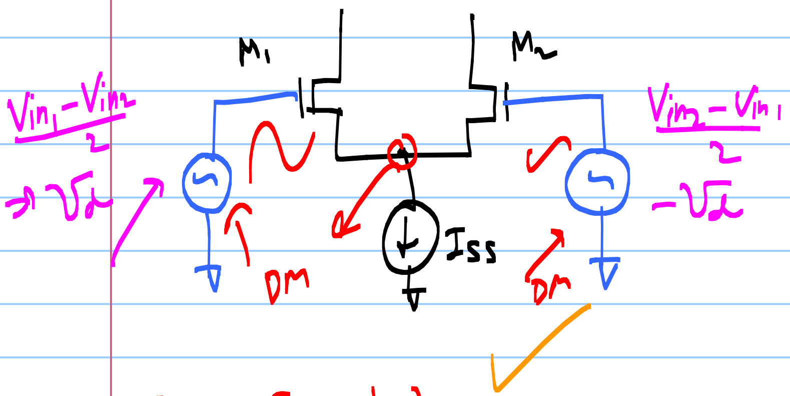


M_1
M_2
$\frac{V_{in_1} - V_{in_2}}{2}$
I_{SS}
$\frac{(V_{in_1} + V_{in_2})}{2}$
$\frac{V_{in_2} - V_{in_1}}{2}$
$\frac{V_{in_1} - V_{in_2}}{2}$



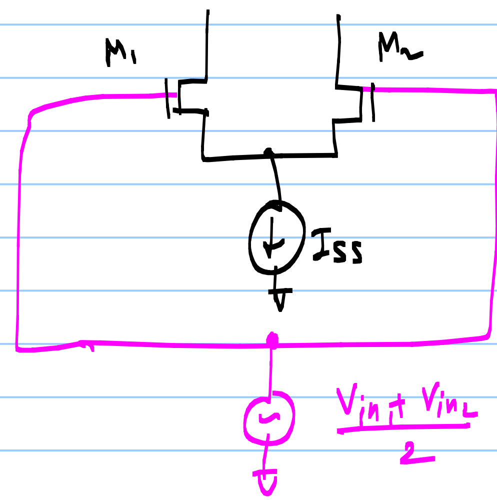
M_1
M_2
I_{SS}
DM
DM
$\frac{V_{in_2} - V_{in_1}}{2}$
$\frac{(V_{in_1} + V_{in_2})}{2}$
CM input

By Superposition

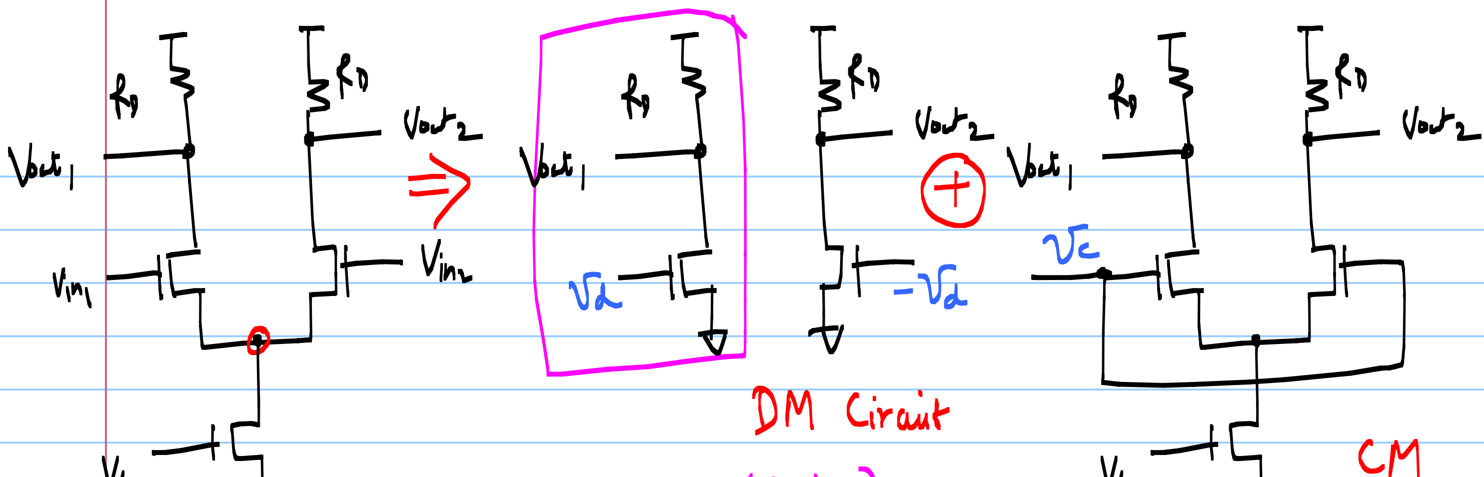


DM Equivalent

(Half Circuit Method)



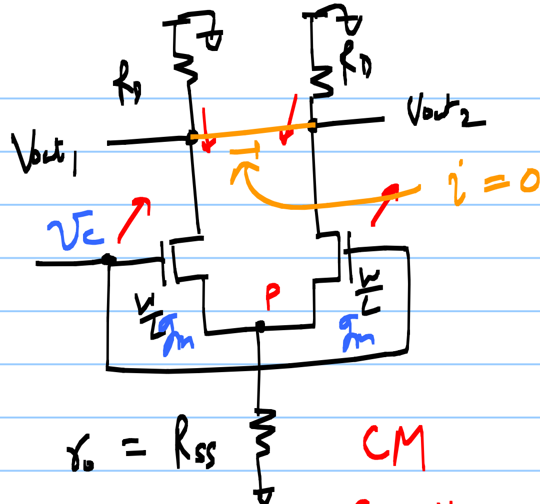
CM Equivalent circuit



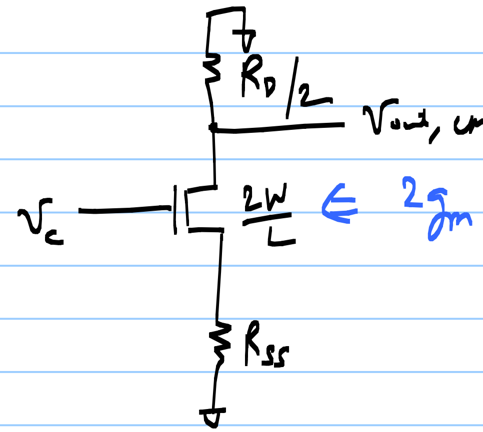
$A_{V,DM} = -g_m(R_D || r_o)$

$v_d = v_{in_1} - v_{in_2} \Leftarrow$ differential input

$$v_c = \left(\frac{v_{in_1} + v_{in_2}}{2}\right)$$



CM Circuit



Equivalent CM circuit

Common mode gain $A_{v,cm} = \dfrac{V_{out,cm}}{V_c} = \dfrac{-R_D/2}{1/2g_m + R_{SS}}$

$$A_{v,DM} = -g_m(R_D \| r_o)$$ Maximize

$$A_{v,CM} = -\frac{R_D/2}{(1/2g_m) + R_{SS}}$$ Minimize

Ideal tail CM

$R_{SS} \to \infty$

$A_{v,CM} = 0$

At output

$$V_{out_2} = V_{out_2,DM} + V_{out_2,CM}$$

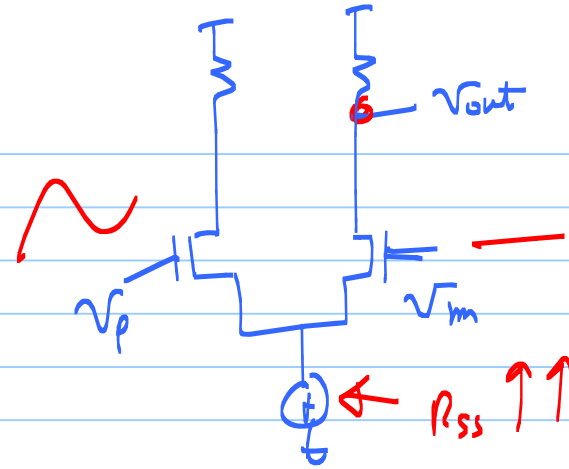
$$= A_{v,DM}\left(\frac{V_d}{2}\right) + A_{v,CM} \cdot (V_c)$$

$$\frac{V_{in_1} + V_{in_2}}{2}$$

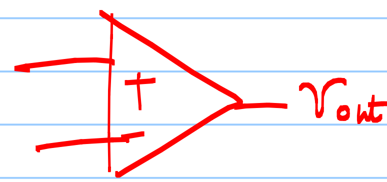
$$\frac{V_{in_1} - V_{in_2}}{2}$$

Common-mode rejection ratio

$$CMRR = \left| \frac{A_{v,DM}}{A_{v,CM}} \right| \rightarrow \infty$$



$$= \frac{g_m R_D/2}{\left(\frac{g_m R_D}{1+2g_m R_{SS}} \right)}$$

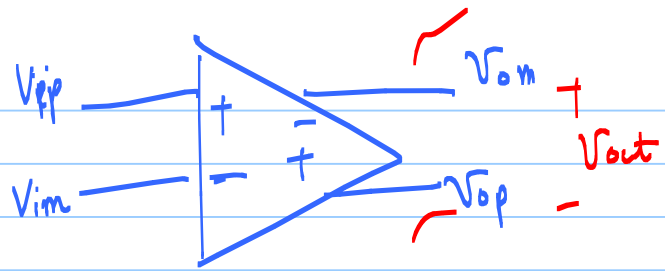


Single-ended

$$\simeq \frac{1}{2} + g_m R_{SS}$$

$$\simeq \underline{\underline{g_m R_{SS}}}$$

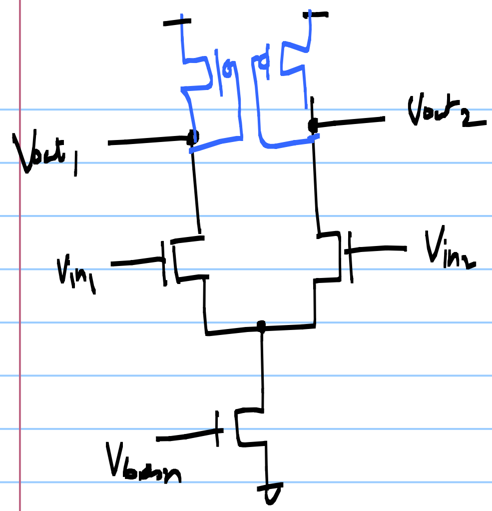
R_{SS} should be as large as possible



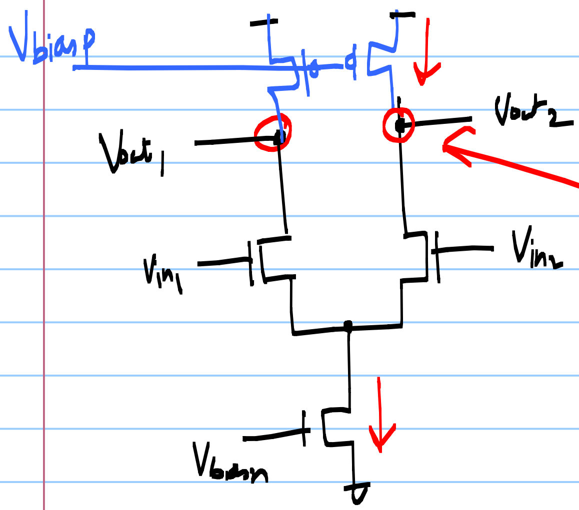
Vip
Vim
+
-
-
+
Vom
Vop
+
Vout
-

Diode Connected PMOS load

↳ low gain



$g_m(r_{o_1} || r_{o_3})$



output CM-level is not defined