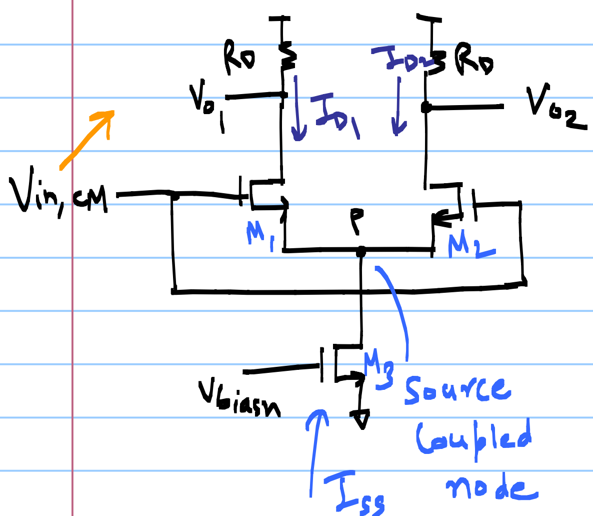
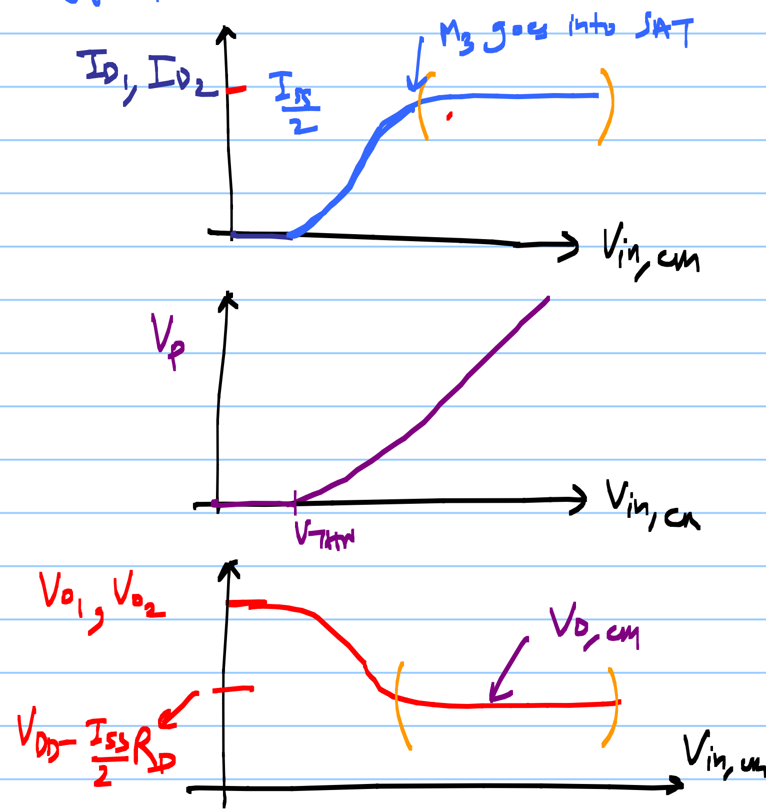
Note Title 4/2/2013

ECE 511 – Lecture 18

Commm-mode behavir of diff-pair ($\lambda = 0$)

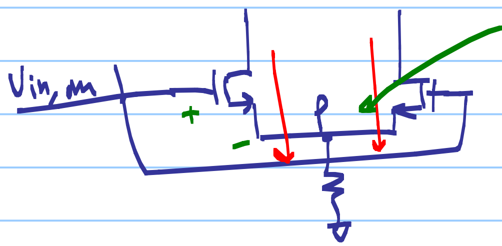




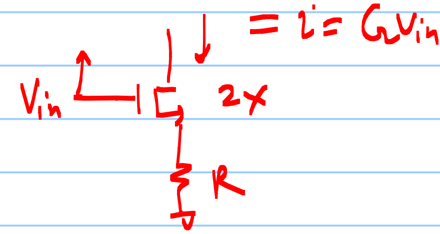
(A) $V_{in,cm} = 0$,

(B) $V_{in,cm} > V_{THN}$, M_1 & M_2 turn on in saturation

$M_3 \to$ Triode



@ P looks like a SF



(C) $V_{in,cm} \geq V_{GS_1} + V_{DS,sat_3}$

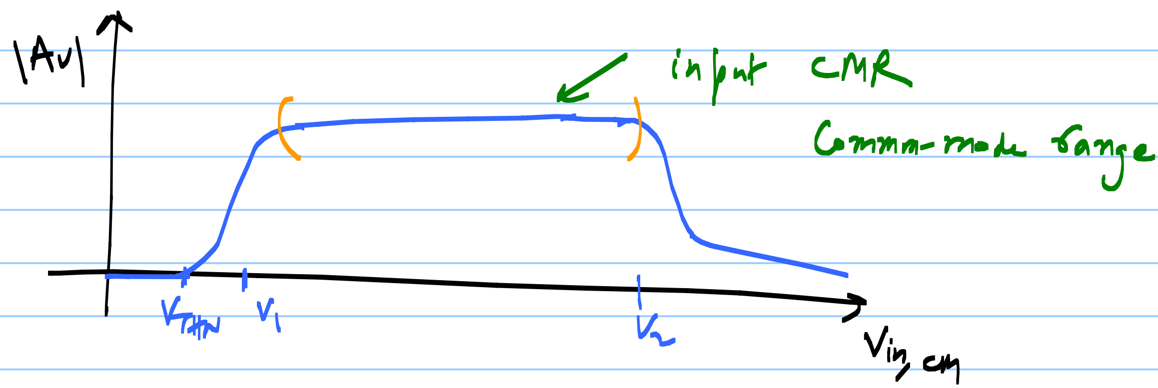
(D) $M_{1,2}$ enter into triode

$$V_{in,cm} > \underbrace{V_{out}}_{V_{o,CM}} + V_{THN}$$

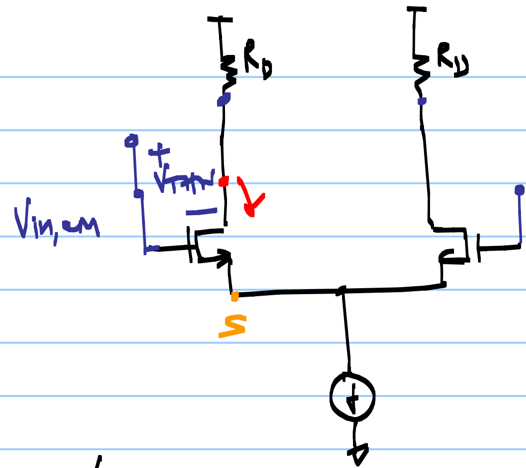
$$= \left(V_{DD} - \frac{R_D I_{SS}}{2}\right) + V_{THN}$$

Sets an upper limit on input CM-level

$$V_{in,cm} \in \Big[\underbrace{V_{GS_1} + V_{DS,sat_3}}_{V_1},\ \underbrace{V_{DD} - \frac{I_D R_{SS}}{2} + V_{THN}}_{V_2}\Big]$$



MICs bands



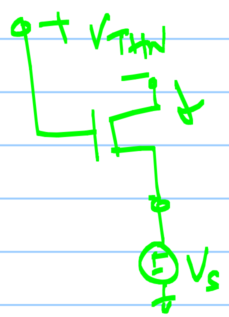
How large can be the output voltage swing?

* Can go as high as V_{DD}

but lower limit is

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

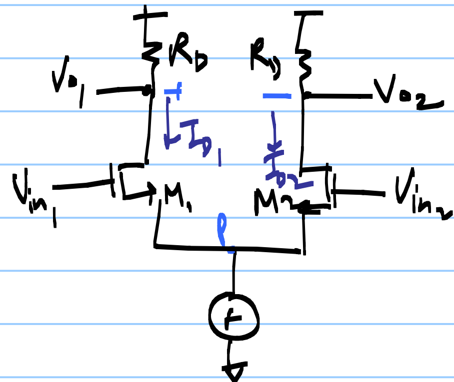
* $V_D > V_G - V_{THN}$



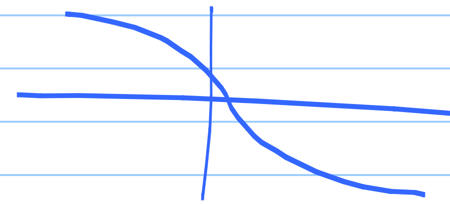
$V_{out} \in [V_{in,cm} - V_{THN},\ V_{DD}]$

don't want really high $V_{in,cm}$

Large Signal behavior:



$$V_{out} = V_{o_1} - V_{o_2} = f\left(V_{in_1} - V_{in_2}\right)$$



$$V_{o_1} - V_{o_2} = \left(I_{D_1} - I_{D_2}\right) R_D \longrightarrow (1)$$

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

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

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

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

$$\Rightarrow \quad \frac{\beta}{2}(V_{in_1} - V_{in_2})^2 - I_{ss} = -2\sqrt{I_{D_1} I_{D_2}}$$

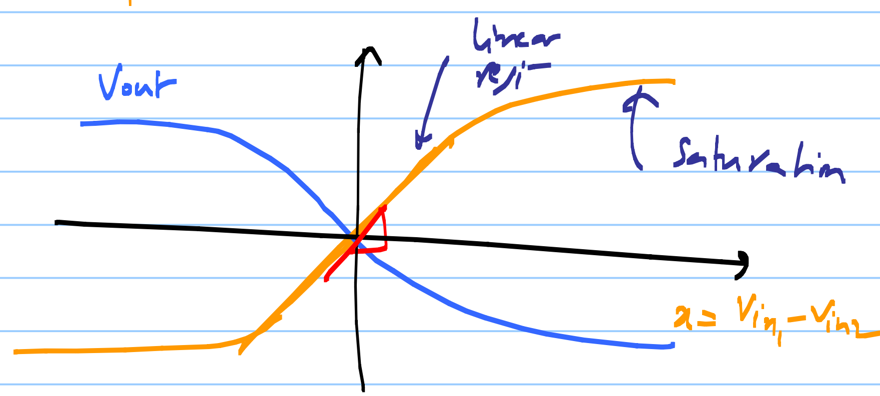
$\Rightarrow$ square both the sides again & use the identity

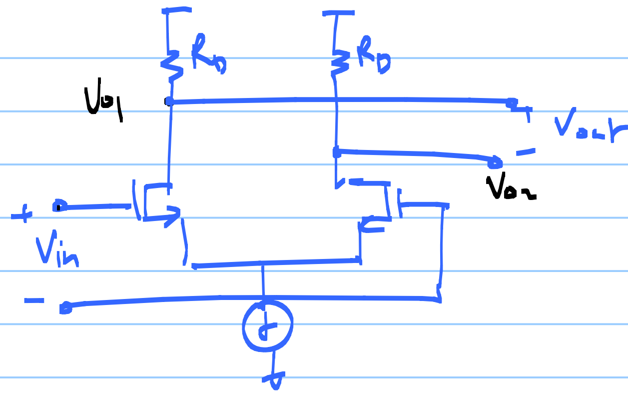
$$4 I_{D_1} I_{D_2} = (I_{D_1} + I_{D_2})^2 - (I_{D_1} - I_{D_2})^2$$

$$I_{D_1} - I_{D_2} = \frac{\beta}{2}\left(V_{in_1} - V_{in_2}\right)\sqrt{\frac{4 I_{ss}}{\beta} - (V_{in_1} - V_{in_2})^2}$$

$$V_{o_1} - V_{o_2} = V_{out} = \boxed{-\frac{\beta R_D}{2}\left(V_{in_1} - V_{in_2}\right)} \underbrace{\sqrt{\frac{4I_{ss}}{\beta} - \left(V_{in_1} - V_{in_2}\right)^2}}$$

$$x\sqrt{\frac{4I_{ss}}{\beta} - x^2}$$





$$A_V = -g_m R_D$$

$$V_{o1} - V_{o2} = V_{out} = -\frac{\beta R_D}{2} \underbrace{(V_{in_1} - V_{in_2})}_{V_{in}} \sqrt{\frac{4 I_{SS}}{\beta} - \cancel{(V_{in_1} - V_{in_2})^2}}$$

$$= -\frac{\beta}{\cancel{2}} R_D \, V_{in} \cdot \cancel{2} \sqrt{\frac{I_{SS}}{\beta}}$$

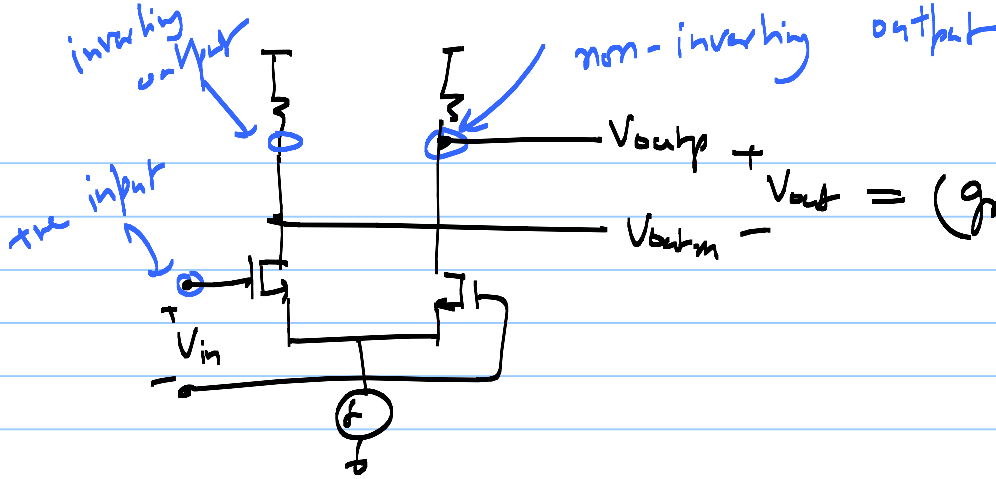
$$= -\sqrt{\beta I_{SS}} \cdot R_D \cdot V_{in}$$

$$= -\sqrt{2\beta I_D} \cdot R_D \cdot v_{in}$$

g_m

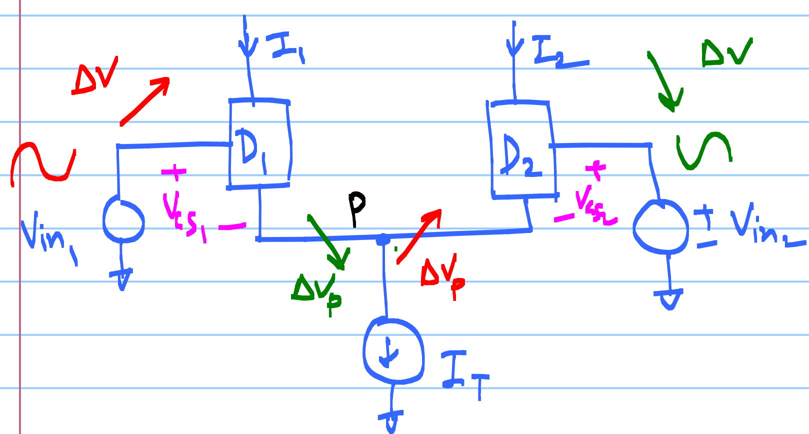
$$= -g_m R_D \, v_{in}$$

$$\Rightarrow \boxed{A_v = -g_m R_D}$$



$$V_{out} = (g_m R_D)\, V_{in}$$

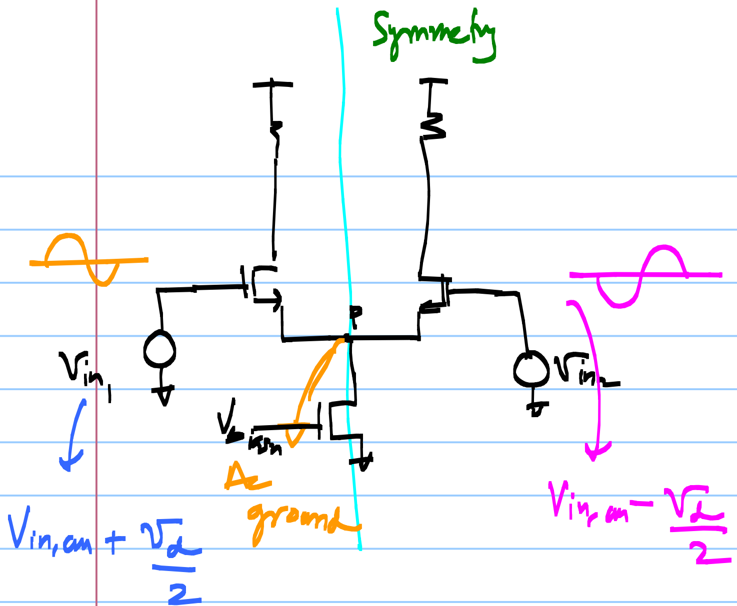
Half-Circuit Analysis / Method



$V_p = V_{in,cm} - V_{GS_{1,2}}$

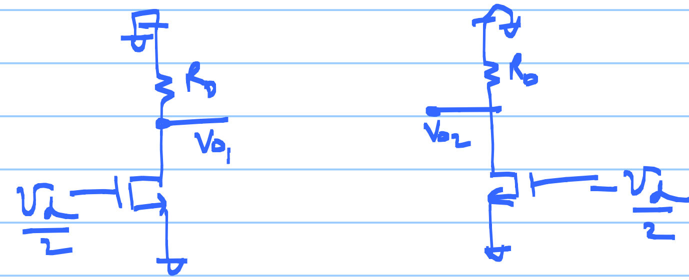
"D_1 & D_2 are identical linear circuits"

⇒ by superposition
V_p is constant
↳ V_p is AC ground



AC picture

↘ decomposes into two half circuits



$$V_{o_1} = -g_m R_D \frac{V_d}{2}$$

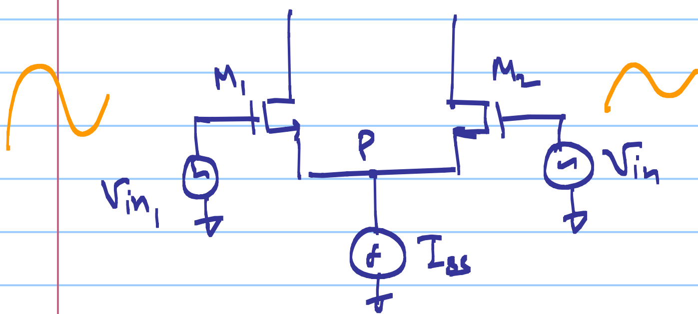
$$V_{o_2} = g_m R_D \frac{V_d}{2}$$

$$V_{out} = V_{o_1} - V_{o_2} = -g_m R_D V_d$$

$$\boxed{A_v = -g_m R_D}$$

* what if the inputs are not FD, but single-ended.

Caveat: can't apply the theorem yet!



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

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

$$f(x) = f_{odd}(x) + f_{even}(x)$$

$$\frac{f(x) - f(-x)}{2} \qquad \frac{f(x) + f(-x)}{2}$$