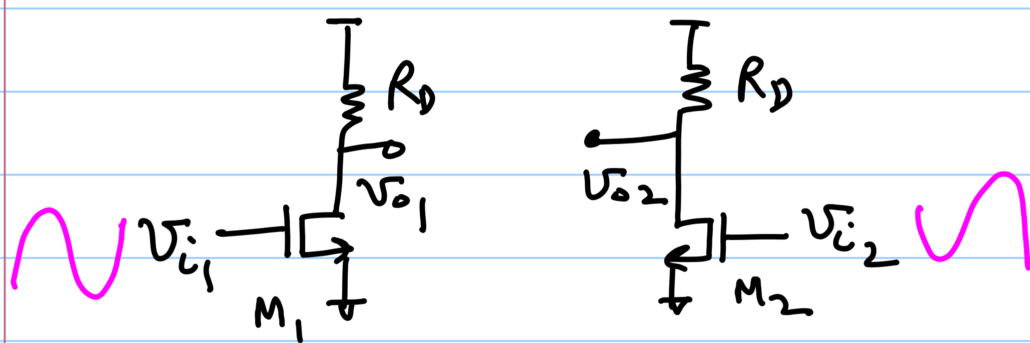
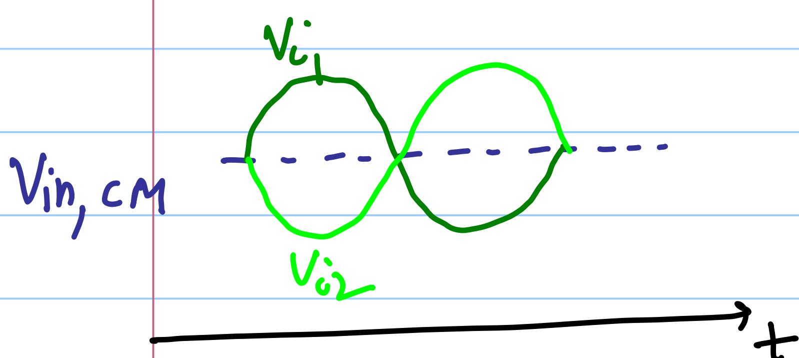
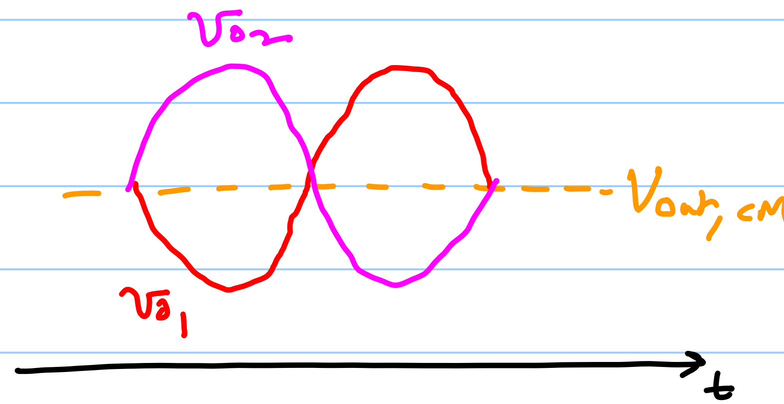
ECE511 - Lecture 20

Note Title 4/2/2015

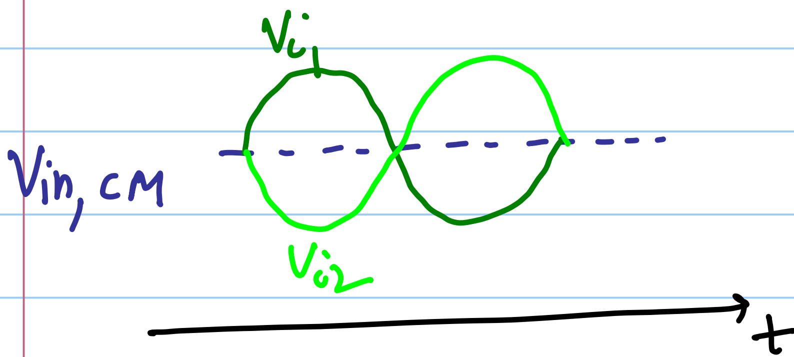
Basic Diff-pair → Diff. CS amplifier

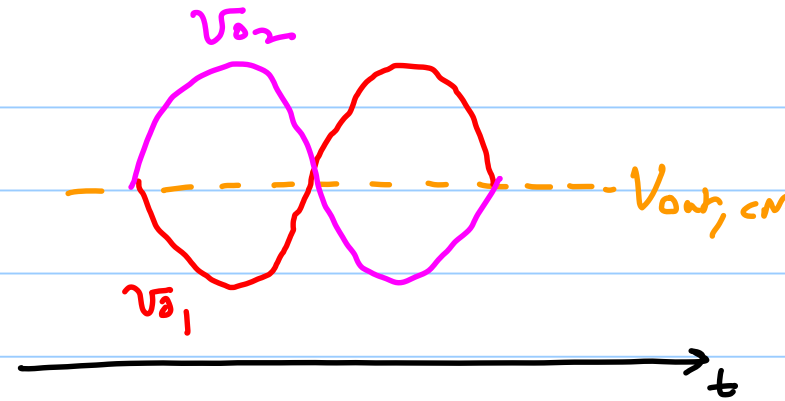


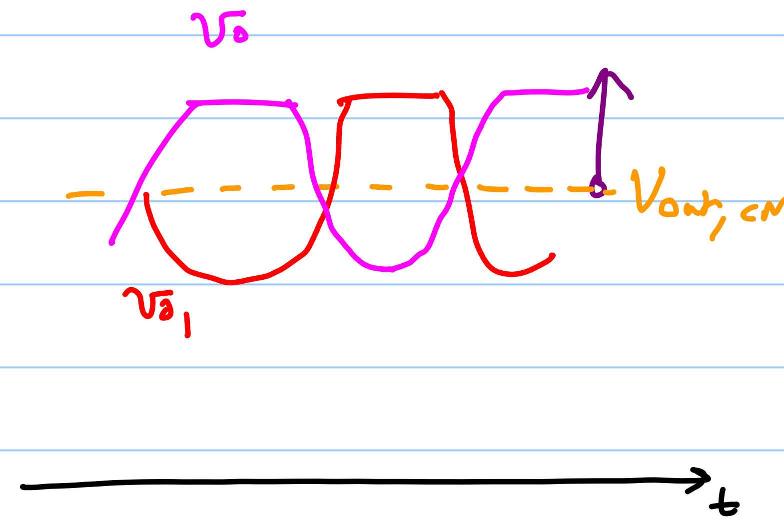


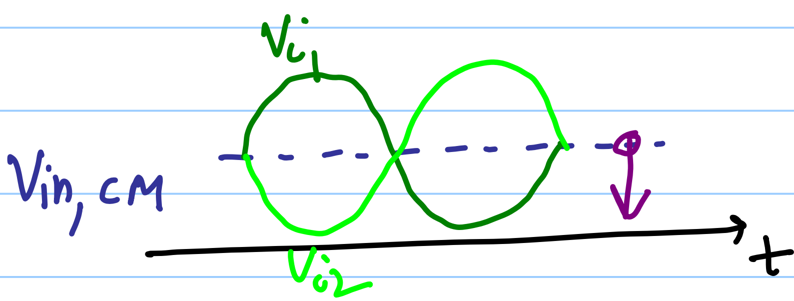


What if $V_{in,CM}$ is not well defined.



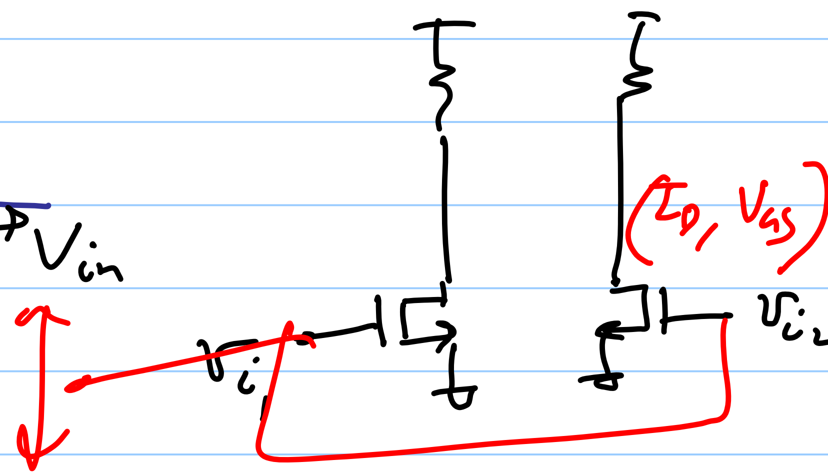






If $V_{in,CM}$ changes, I_D in M_1 & M_2 change
g_m is changed
& output CM-level varies

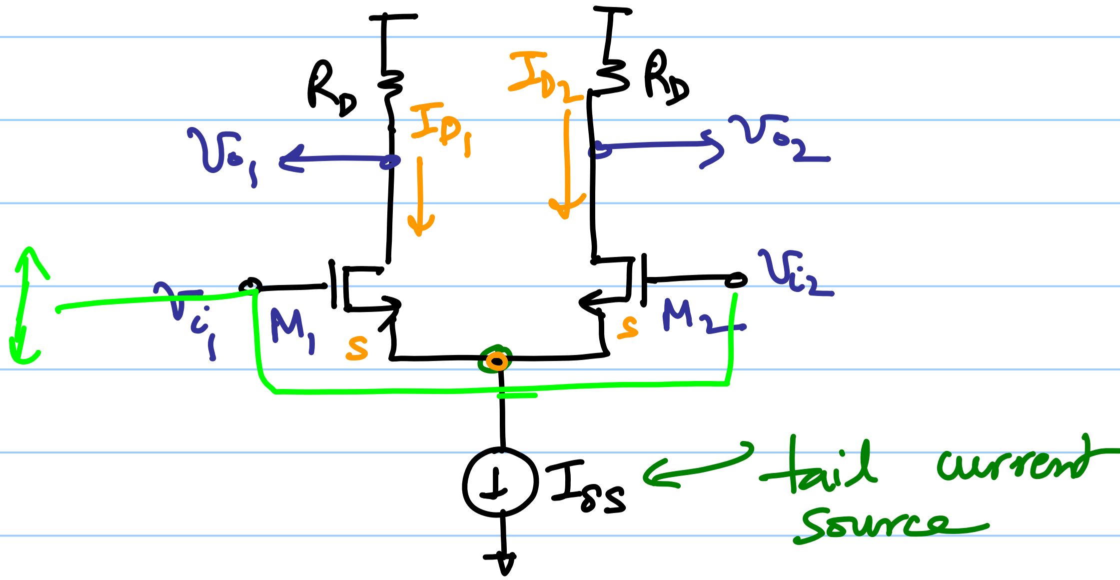
Ideally → important that the biasing (V_{GS}, I_D) of the devices has a minimal dependence on the input CM-level.

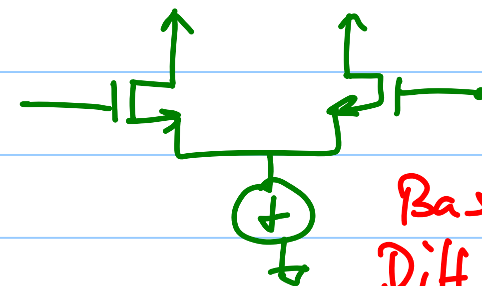


Solution

Sel

$I_{D_1} + I_{D_2} = I_{SS} = \text{const}$





Using a current source to make

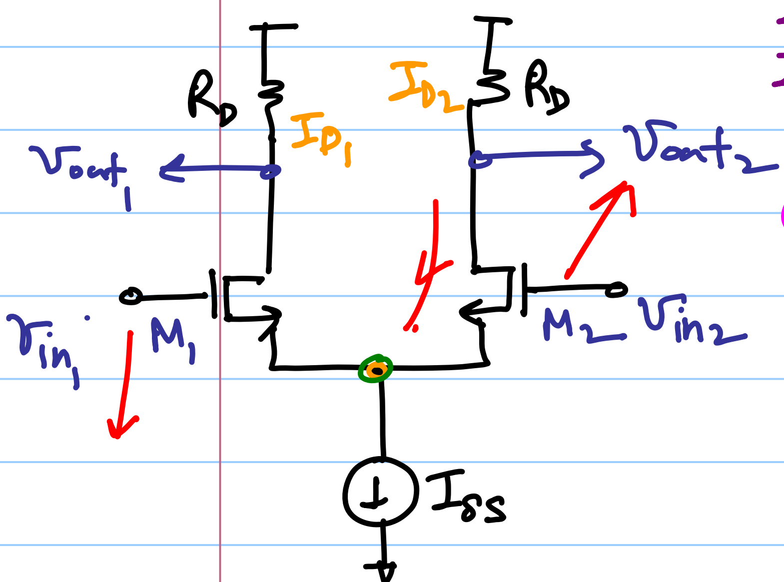
$\boxed{I_{SS} = I_{D_1} + I_{D_2}}$ independent of $V_{in,cm}$

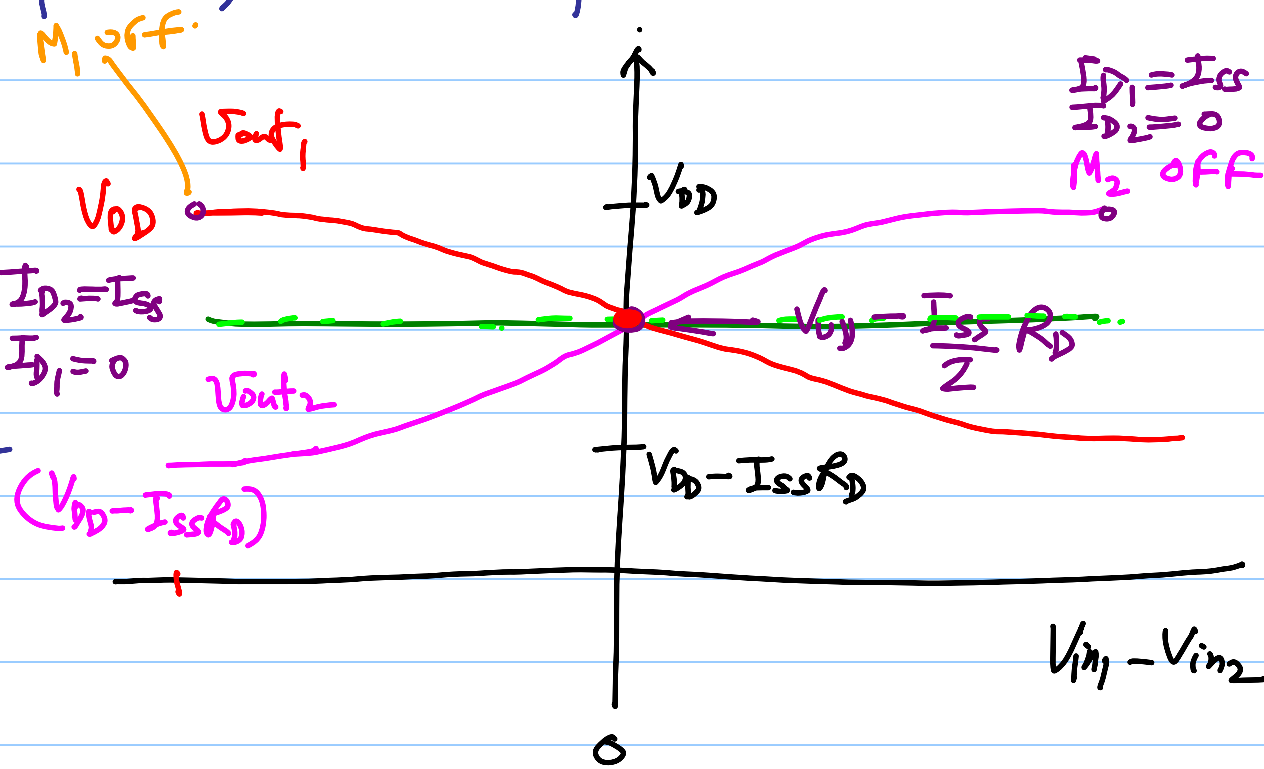
* If $\boxed{V_{i_1} = V_{i_2}}$ $\Rightarrow$ the bias current in each device $= \frac{I_{SS}}{2}$

output common mode level $= V_{DD} - \frac{I_{SS}}{2} \times R_D$

Qualitative Analysis:

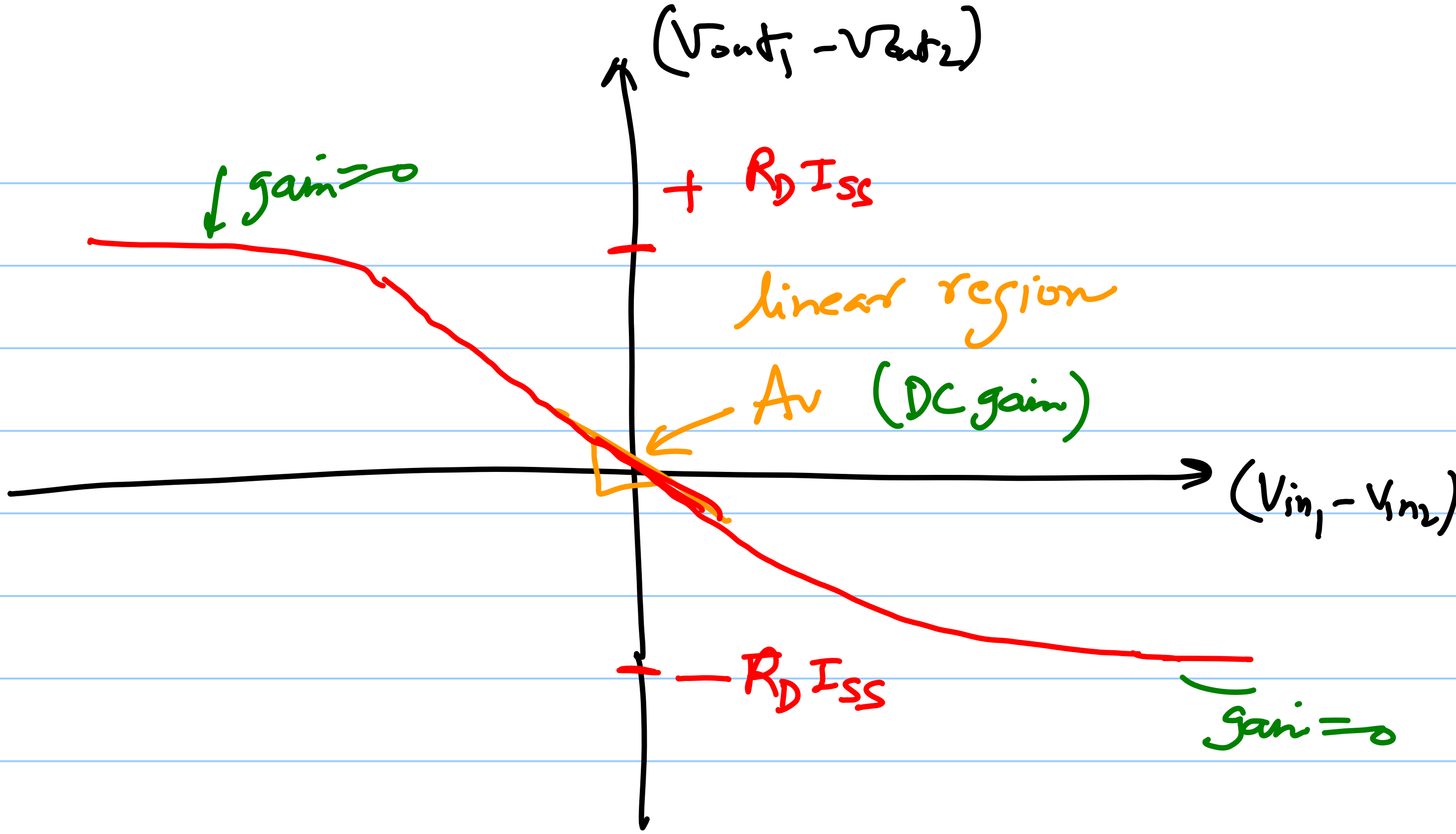
Assume that $(v_{i_1} - v_{i_2})$ varies from $-\infty$ to ∞





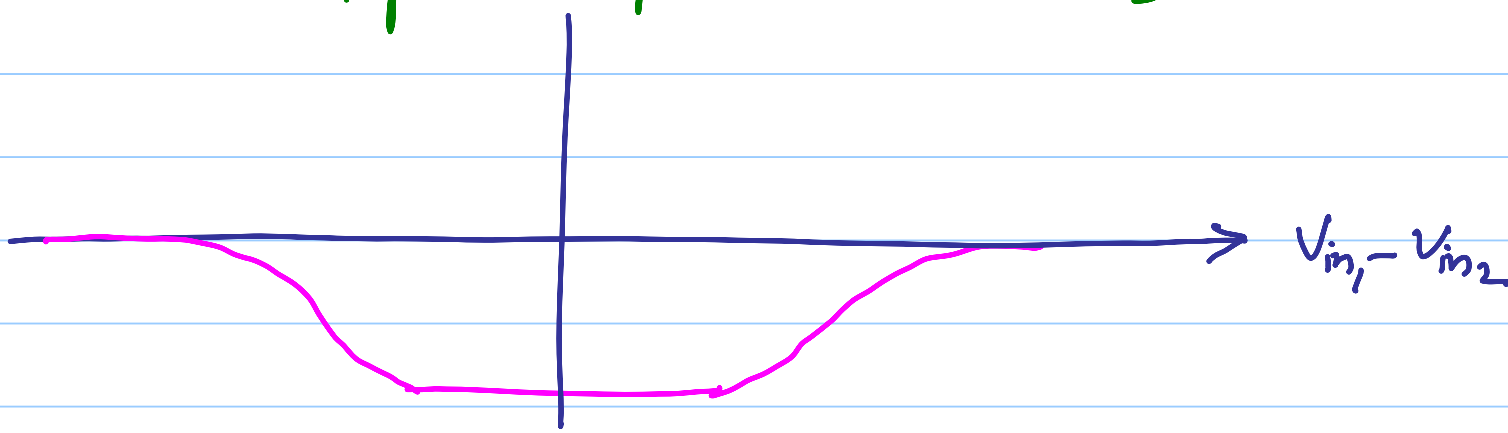
M_1 & M_2 are SAT

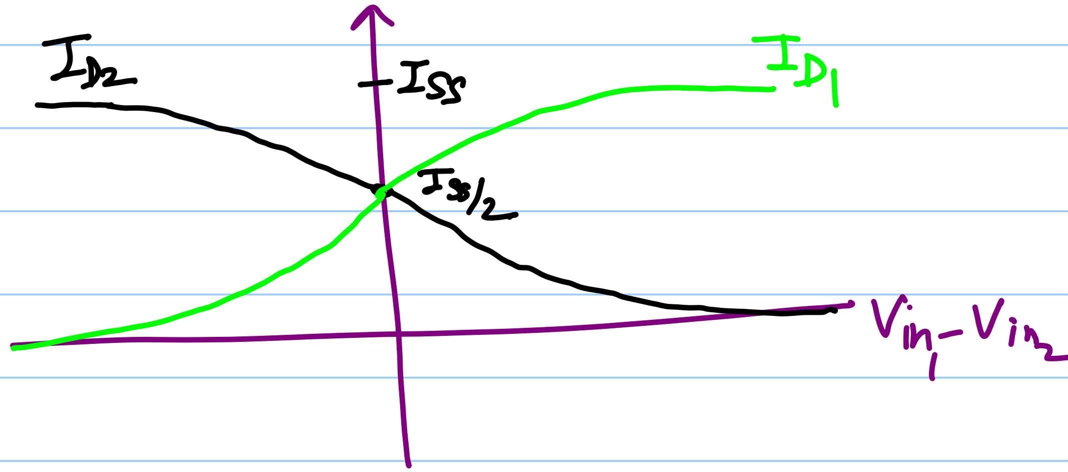
I_{SS} is ideal



input - output characteristics

$$\frac{d(V_{out_1} - V_{out_2})}{d(V_{in_1} - V_{in_2})}$$

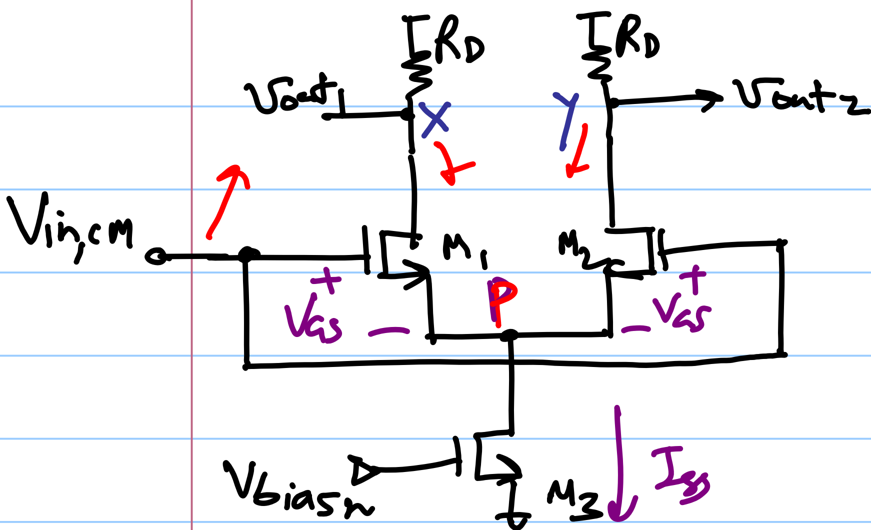


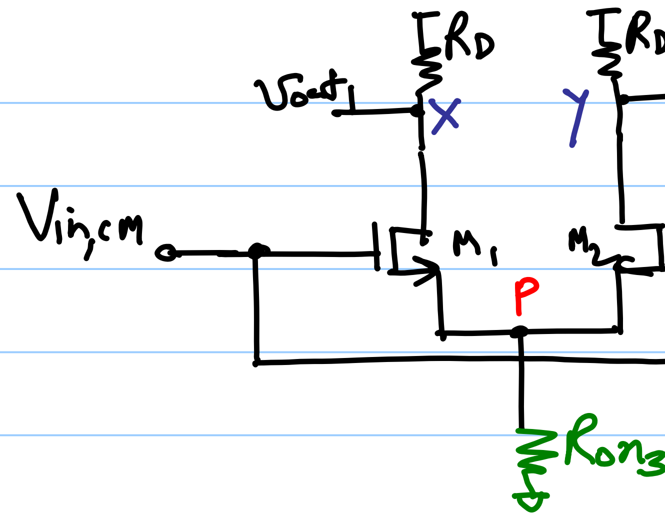


$$v_{out} = -\left(A_1 v_{in} - A_3 v_{in}^3 - \cdots\right)$$

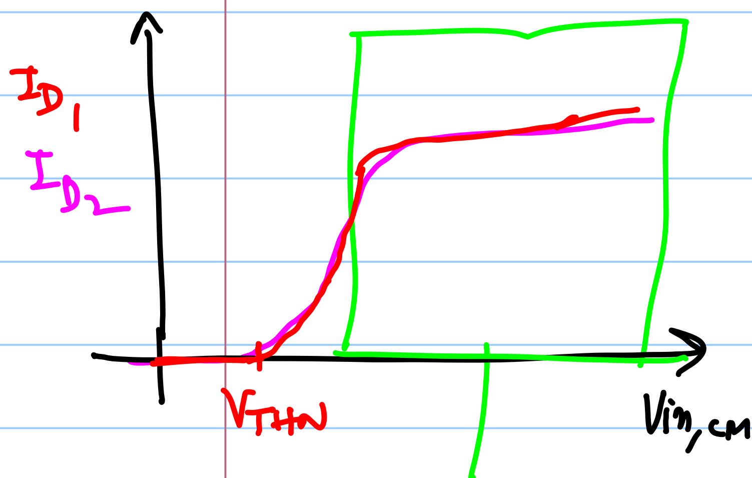
for large signal operation

Common-mode behavior of the Diff-Pair

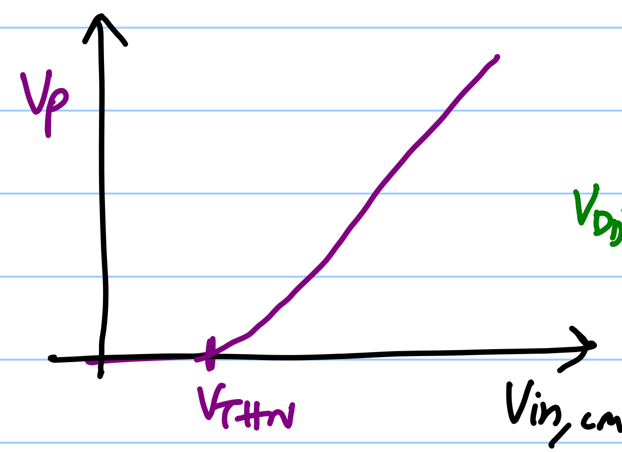


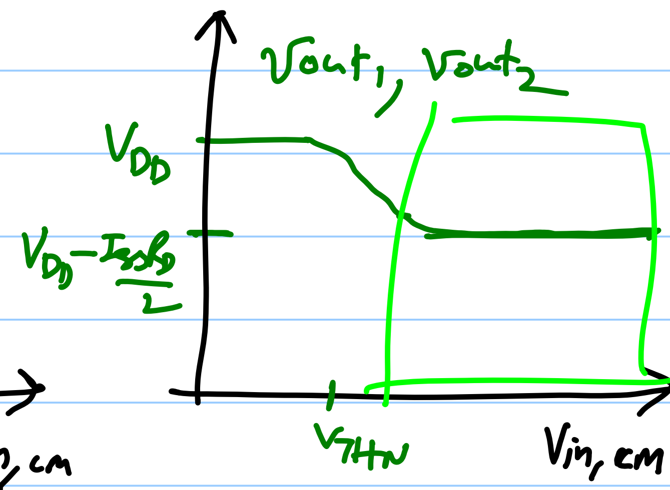


M_3 is in Triode



Input CM-range





Ⓐ $V_{in,cm} = 0$, M_3 is in deep Triode
M_1 & M_2 are cut off

Ⓑ $V_{in,cm} > V_{THN}$, M_3 is in triode

V_p increases with $V_{in,cm}$
(acts like a SF)

for $V_{in,cm} \geq V_{GS_{1,2}} + V_{DS,sat_3}$
M_3 enters saturation

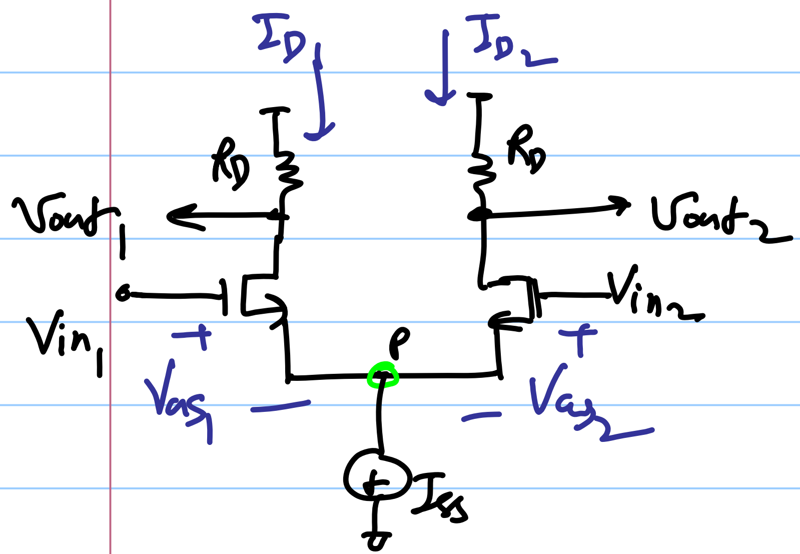
① M_1 & M_2 enter triode when

$$V_{in,cm} > V_{out_1} + V_{THN} = \left(V_{DD} - \frac{R_D I_{SS}}{2}\right) + V_{THN}$$

sets an upper limit on $V_{in,cm}$

$$\underbrace{V_{GS_{1,2}} + V_{DS,sat_3}}_{V_1} \le V_{in,cm} \le \min\left\{ \underbrace{V_{DD} - \frac{R_D I_{SS}}{2} + V_{THN}}_{V_2},\ V_{DD} \right\}$$

Large Signal Analysis



$$\boxed{I_{D_1} + I_{D_2} = I_{SS}}$$

$$\left.\begin{aligned} V_{out_1} &= V_{DD} - R_D I_{D_1} \\ V_{out_2} &= V_{DD} - R_D I_{D_2} \end{aligned}\right\}$$

$$(V_{out_1} - V_{out_2}) = R_D\,(I_{D_2} - I_{D_1})$$

Assume symmetry, $\lambda = 0$

voltage @ node P $= V_{in_1} - V_{GS_1} = V_{in_2} - V_{GS_2}$

$$\Rightarrow \quad (V_{in_1} - V_{in_2}) = V_{GS_1} - V_{GS_2}$$

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

$$\Rightarrow \quad V_{in} - V_{in_2} = \sqrt{\frac{2}{\beta}}\left[\sqrt{I_{D_1}} - \sqrt{I_{D_2}}\right]$$

Square both sides & use $I_{D_1} + I_{D_2} = I_{SS}$

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

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

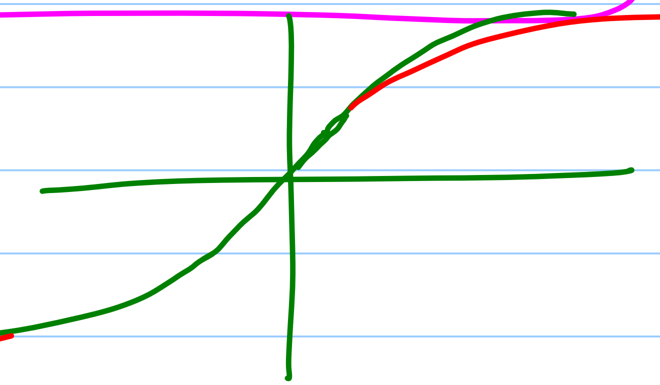
Square both sides & use the identity

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

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

$$\boxed{\underbrace{I_{D_1}-I_{D_2}}_{\Delta I_D} = \frac{\beta}{2}\underbrace{\left(V_{in_1}-V_{in_2}\right)}_{\Delta V_{in}} \times \sqrt{\frac{4I_{ss}}{\beta} - \left(V_{in_1}-V_{in_2}\right)^2}}$$

$$\left(V_{in_1}-V_{in_2}\right)^2 \ll \frac{4I_{ss}}{\beta}$$



$I_{D_1}-I_{D_2}$ is more linear with $V_{in_1}-V_{in_2}$

$$\frac{\partial \Delta I_D}{\partial \Delta V_{in}} = \frac{\beta}{2}\,\frac{\frac{4I_{ss}}{\beta} - 2\Delta V_{in}^2}{\sqrt{\frac{4I_{ss}}{\beta} - \Delta V_{in}^2}}$$

$\Delta V_{in} \stackrel{\Delta}{=} 0$

$$= \frac{\beta}{2}\sqrt{\frac{4I_{ss}}{\beta}} = \sqrt{\beta I_{ss}} = \sqrt{2\beta\left(\frac{I_{ss}}{2}\right)} = g_m \text{ of } M_1 \,\&\, M_2$$

Small signal gain $= \underline{\underline{-g_m R_D}}$