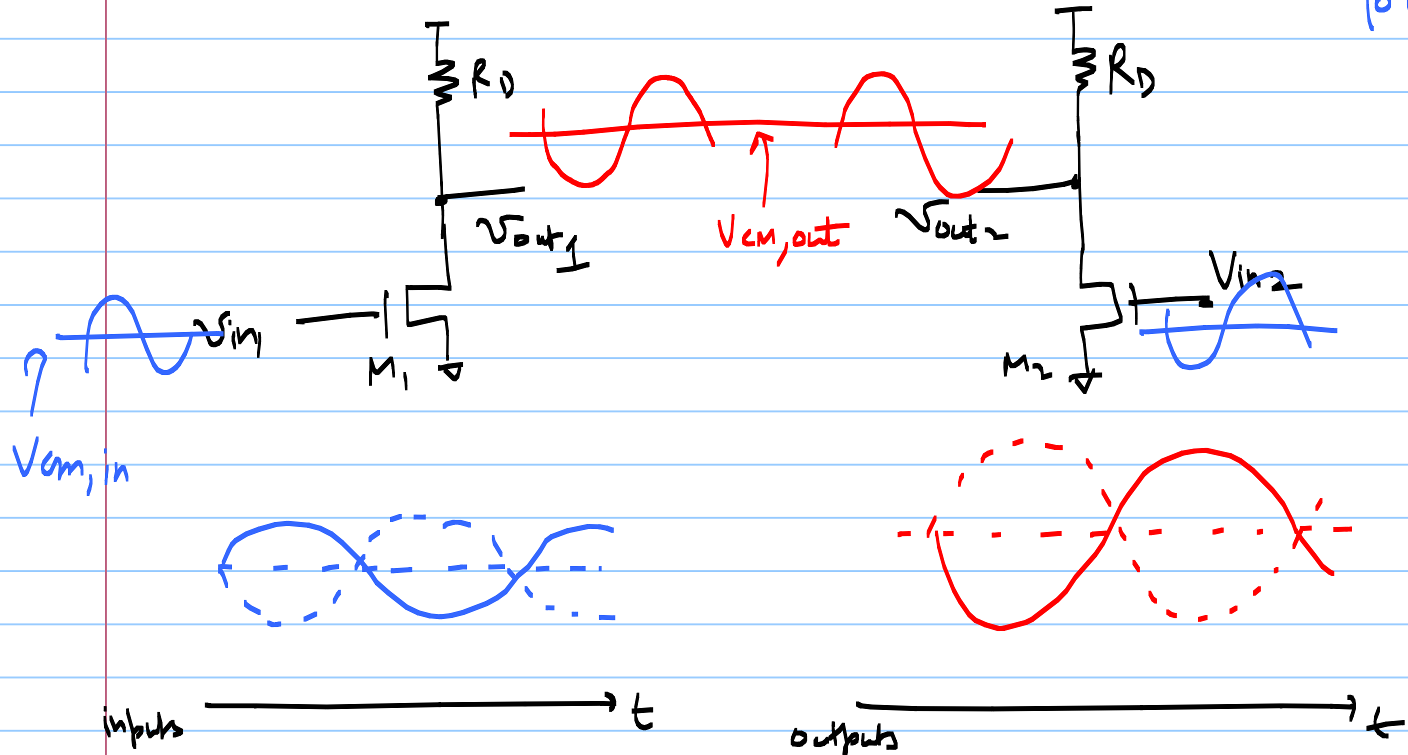
ECE 5411 – Lecture 19.

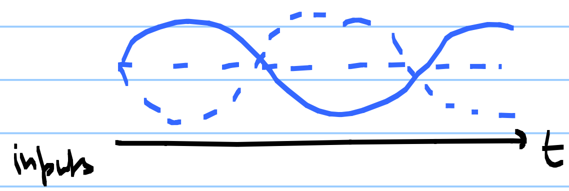
Note Title 4/6/2011

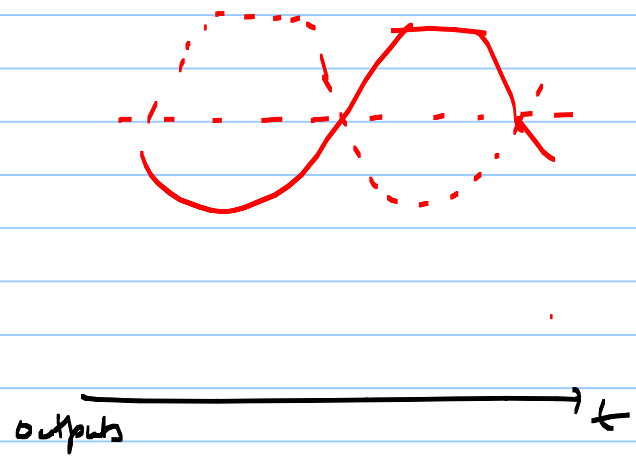
* Use two identical single-ended signal paths to process the two phases.



* rejection of CM noise
  PS noise

* 2x output swing





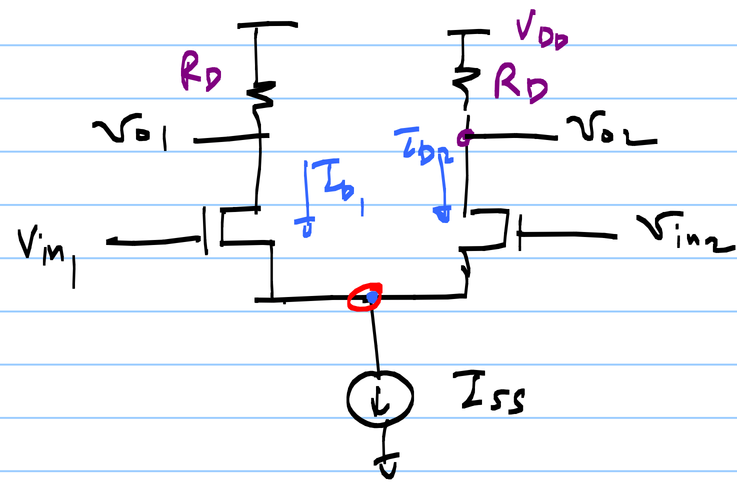
As the input CM level changes

→ bias currents in M_1 & M_2 are changing

→ g_m

→ output CM level varying

* Important for biasing that the devices have minimal dependence on input cm level.



Differential pair (diff pair)

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

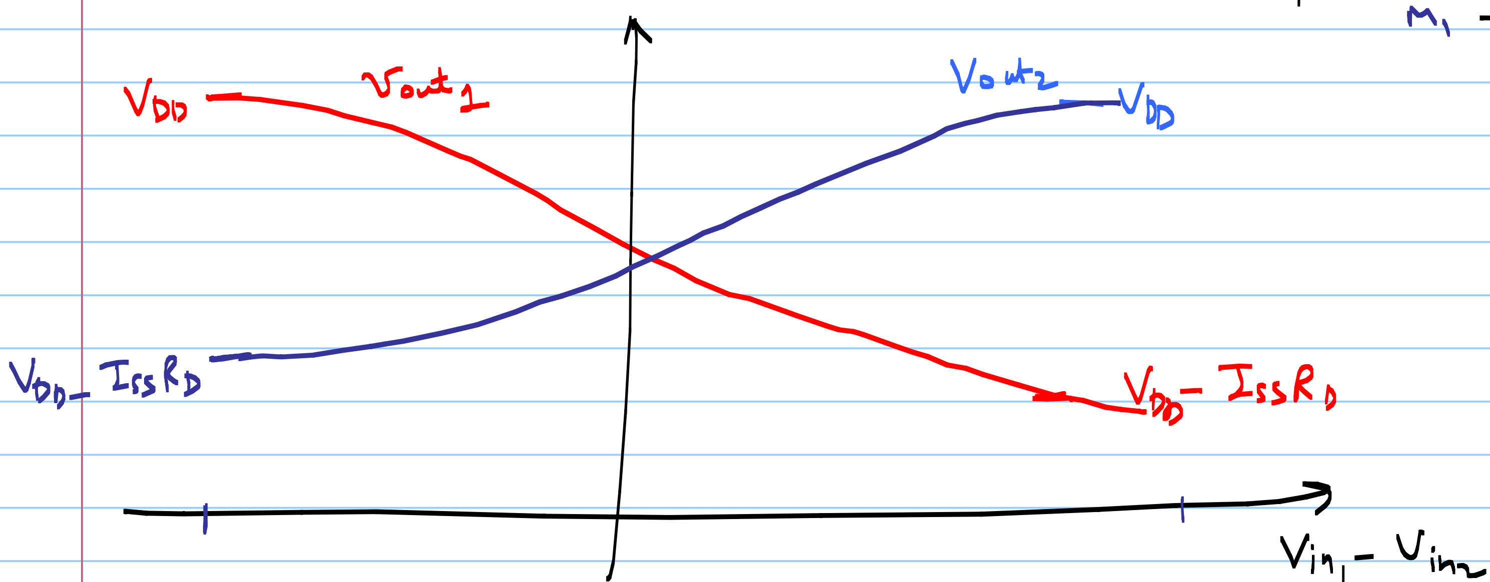
independent of the $V_{in,cm}$.

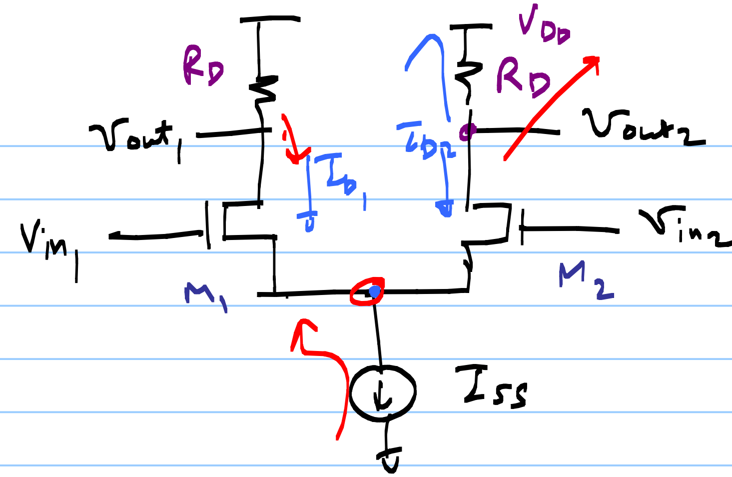
If $V_{in_1} = V_{in_2} \Rightarrow I_{D_1} = I_{D_2} = \frac{I_{SS}}{2}$

$$V_{out,cm} = V_{DD} - \frac{I_{SS}}{2} \cdot R_D$$ ← output common mode level is set

Qualitative Analysis:

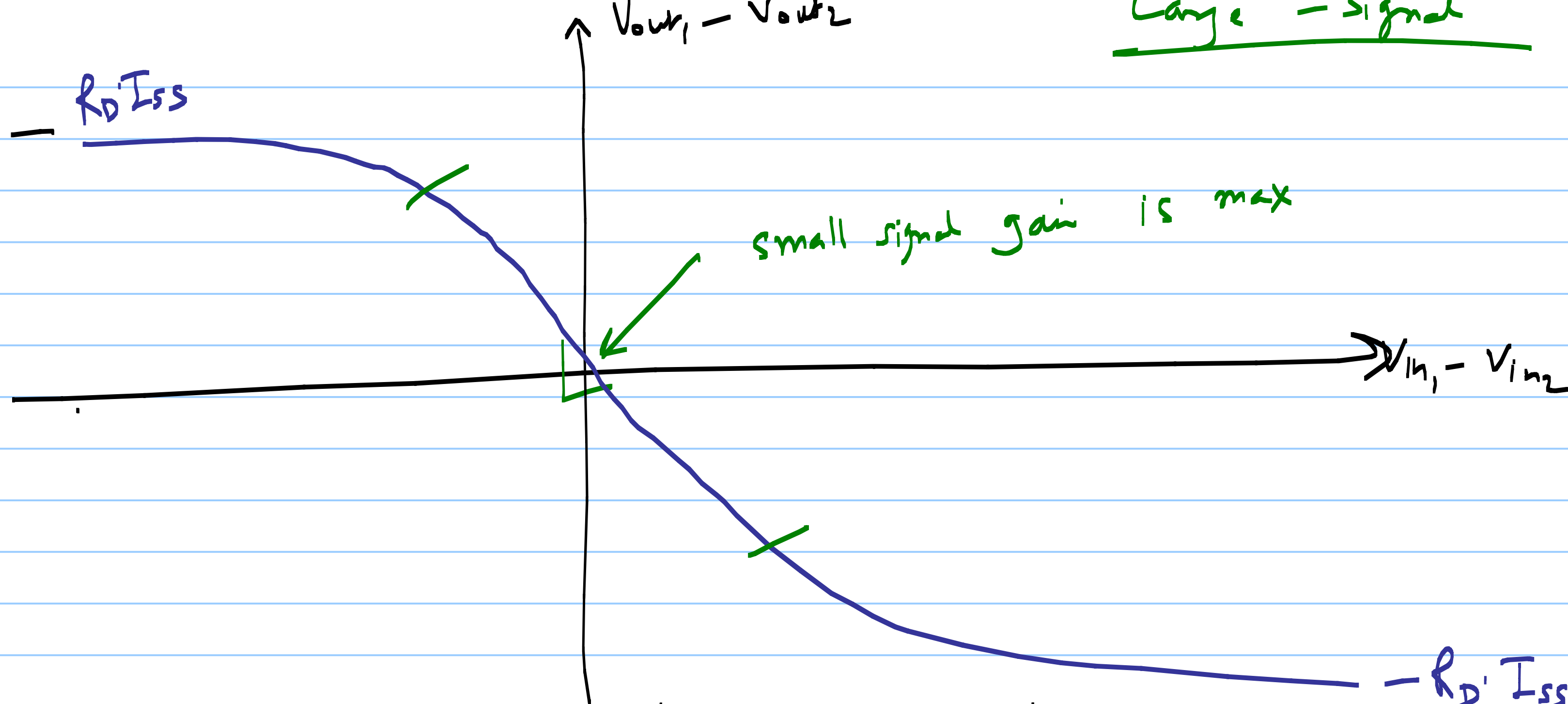
* Assume $(V_{in_1} - V_{in_2})$ varies from $-\infty$ to ∞





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

Large-signal



* Output max & min levels are well defined.
↳ independent of input CM level

* The tail current source suppress the effect of input CM level variations on the operation of M_1 & M_2 & the output level.

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

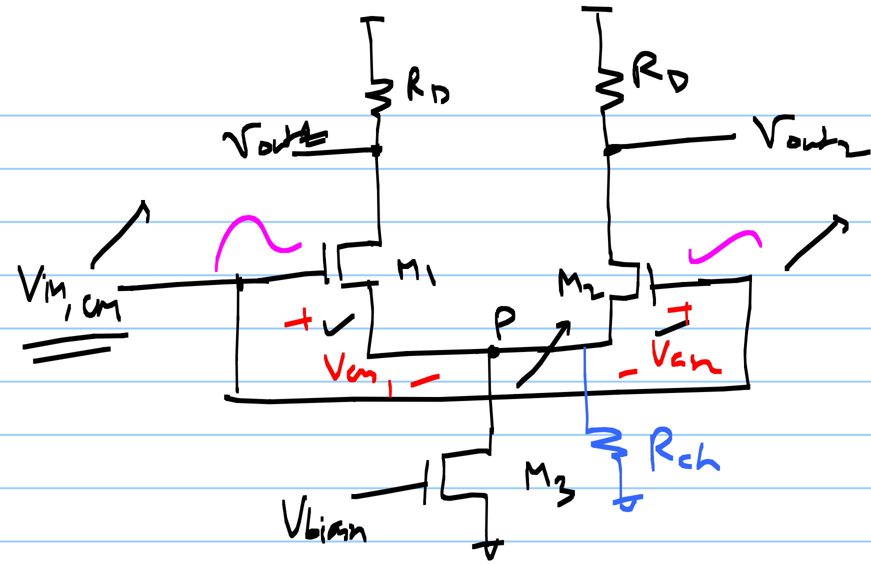
M_1 & M_2 ← cut-off

$I_{D3} = 0$

$M_3 \Rightarrow$ deep triode

$v_{out1} = v_{out2} = V_{DD}$

⇒ no amplification

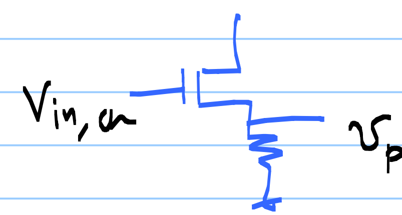


(B) $V_{in,cm} > V_{THN}$

⇒ M_3 still in triode

⇒ V_p increases and tracks $V_{in,cm}$

⇒ $v_{out1,2}$ start decreasing



(C) $V_{in,cm} \geq V_{GS,1} + V_{DS,sat3}$

↳ M_3 enters saturation

↳ total current $\frac{I_{SS}}{2}$ each → I_{SS} $(r_{o3} = \infty)$

(D) $V_{in,cm} > V_{out,1,2} + V_{THN} = \left(V_{DD} - \frac{R_D I_{SS}}{2}\right) + V_{THN}$

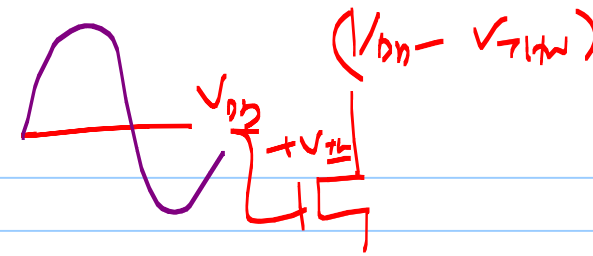
⇒ M_1 & M_2 start trioding

↳ sets upper limit on $V_{in,cm}$

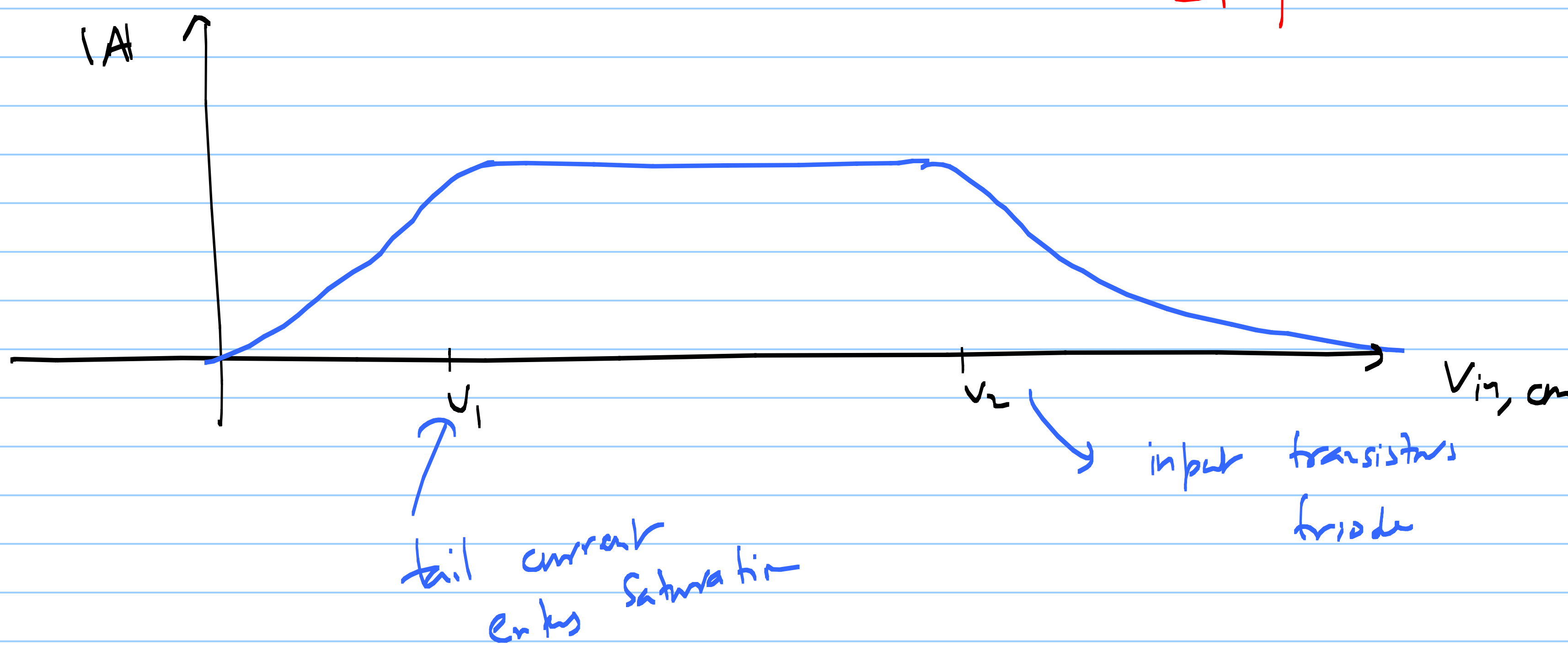
* Input common-mode range (CMR)

$$V_{GS,1} + V_{DS,sat3} \leq V_{in,cm} \leq \left(V_{DD} - \frac{R_D I_{SS}}{2}\right) + V_{THN}$$

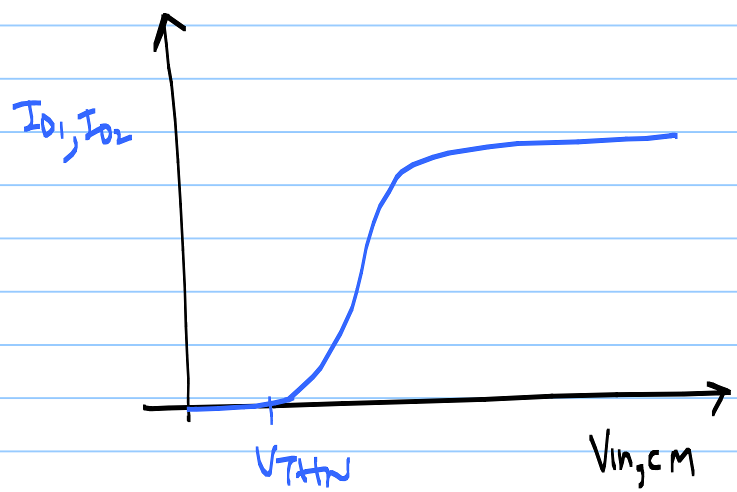
$V_{in,cm} =$ V_{on}



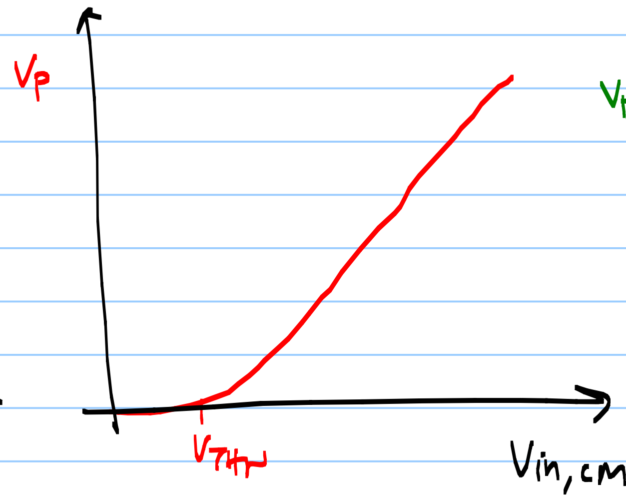
Von
+Vth
(Von − VT,tw)



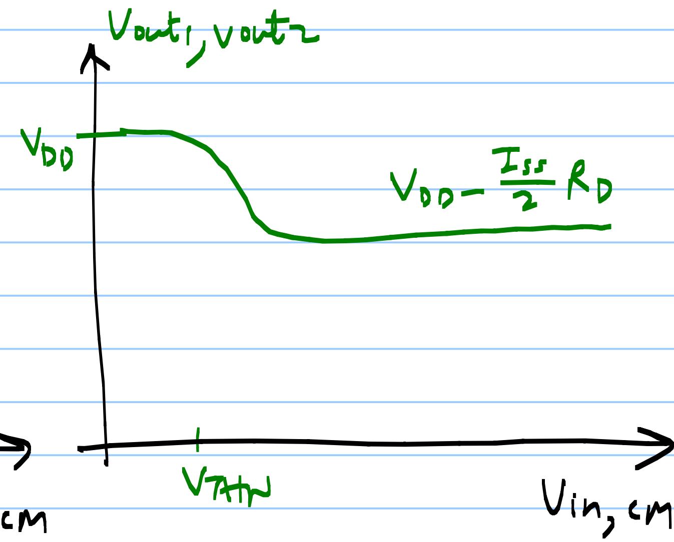
|A|
V1
V2
Vin, cm
tail current enters saturation
input transistors triode



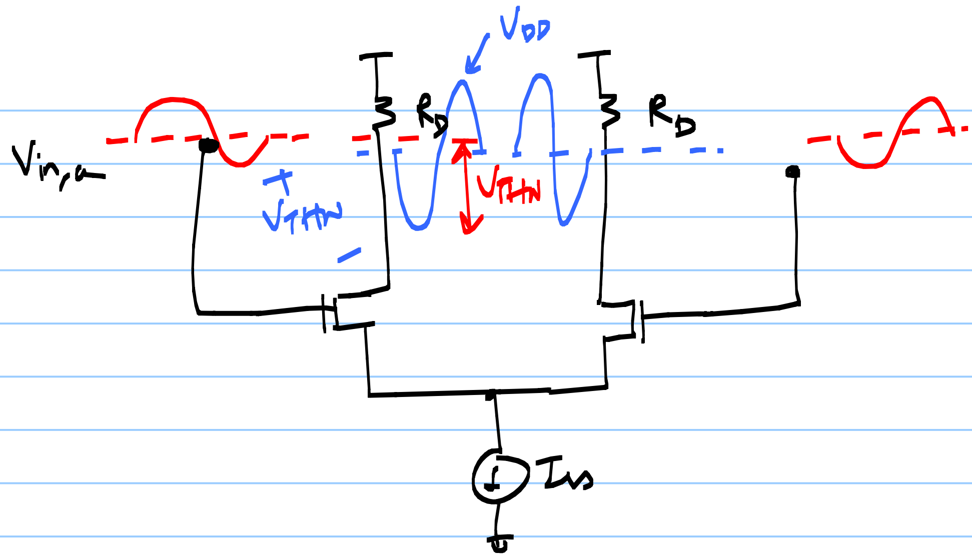
ID1, ID2
VTHN
Vin,cm



VP
VTHN
Vin,cm



Vout1, Vout2
VDD
VDD − ISS/2 RD
VTHN
Vin, cm

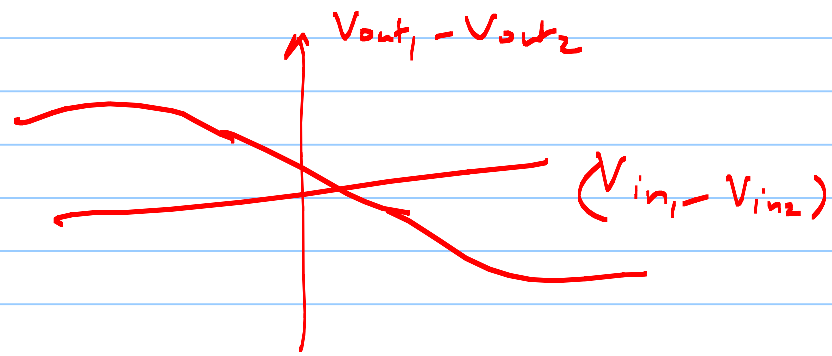


o/p can swing from $(V_{in,cm} - V_{THN})$ to V_{DD}.

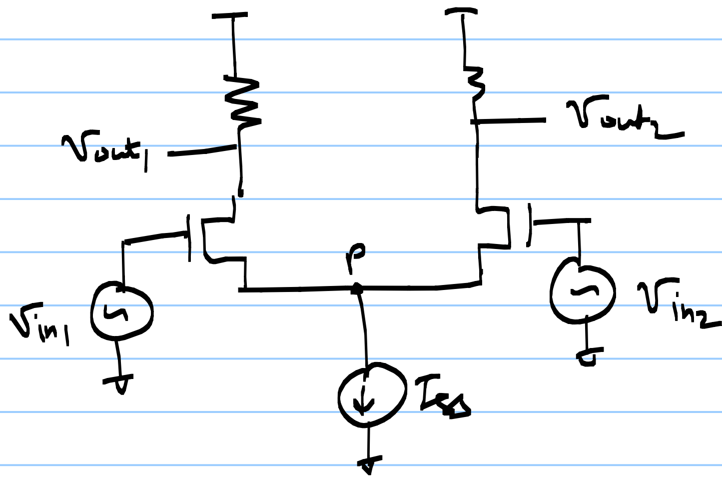
→ The higher the input cm level
↳ lower the output swing.

Large Signal Analysis:

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



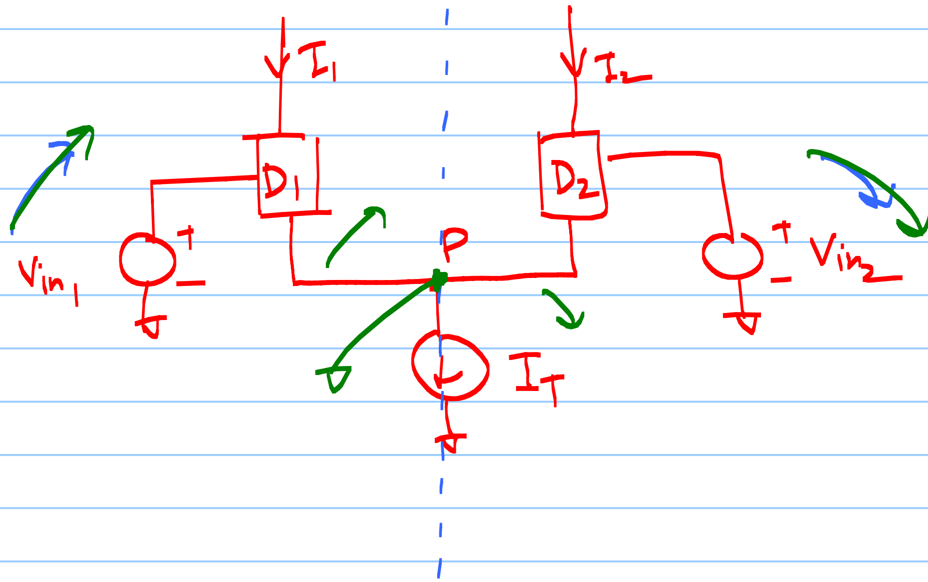
Small-Signal Analysis :



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

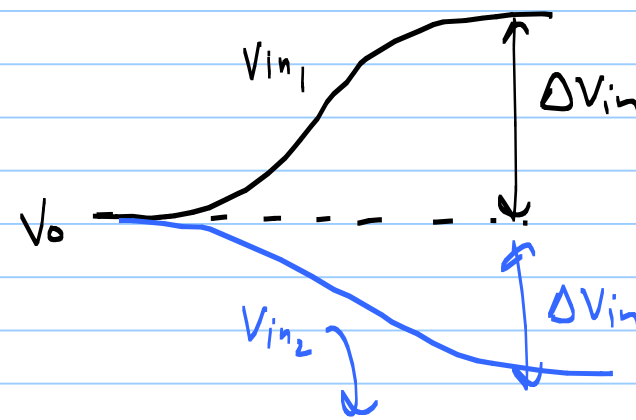
"Half-Circuit Analysis"

Lemma:



D_1 & D_2 → any 3-terminal devices

"Inputs are differential"

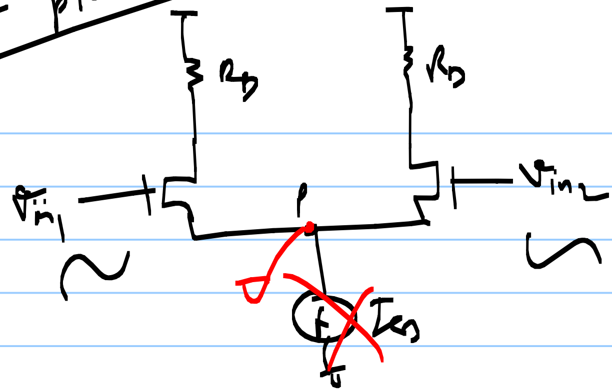


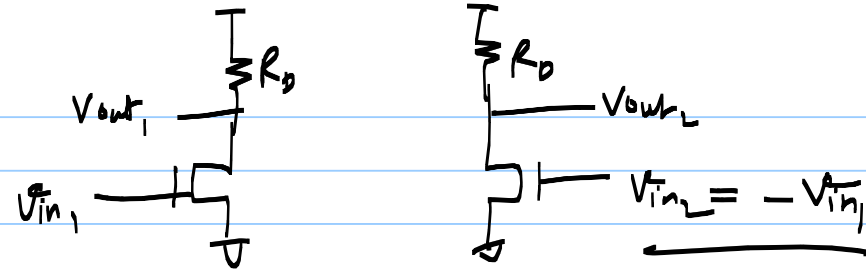
If the circuit is linear

⇒ V_P doesn't change at all. ($\lambda = 0$)

⇒ P is ac ground.

Ac picture





$$\frac{v_{out_1}}{v_{in_1}} = -g_{m_1}(R_D \| r_{o_1})$$

$$g_{m_1} = g_{m_2}$$

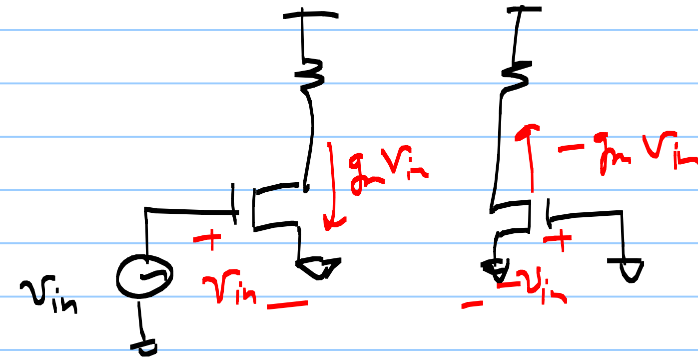
$$r_{o_1} = r_{o_2}$$

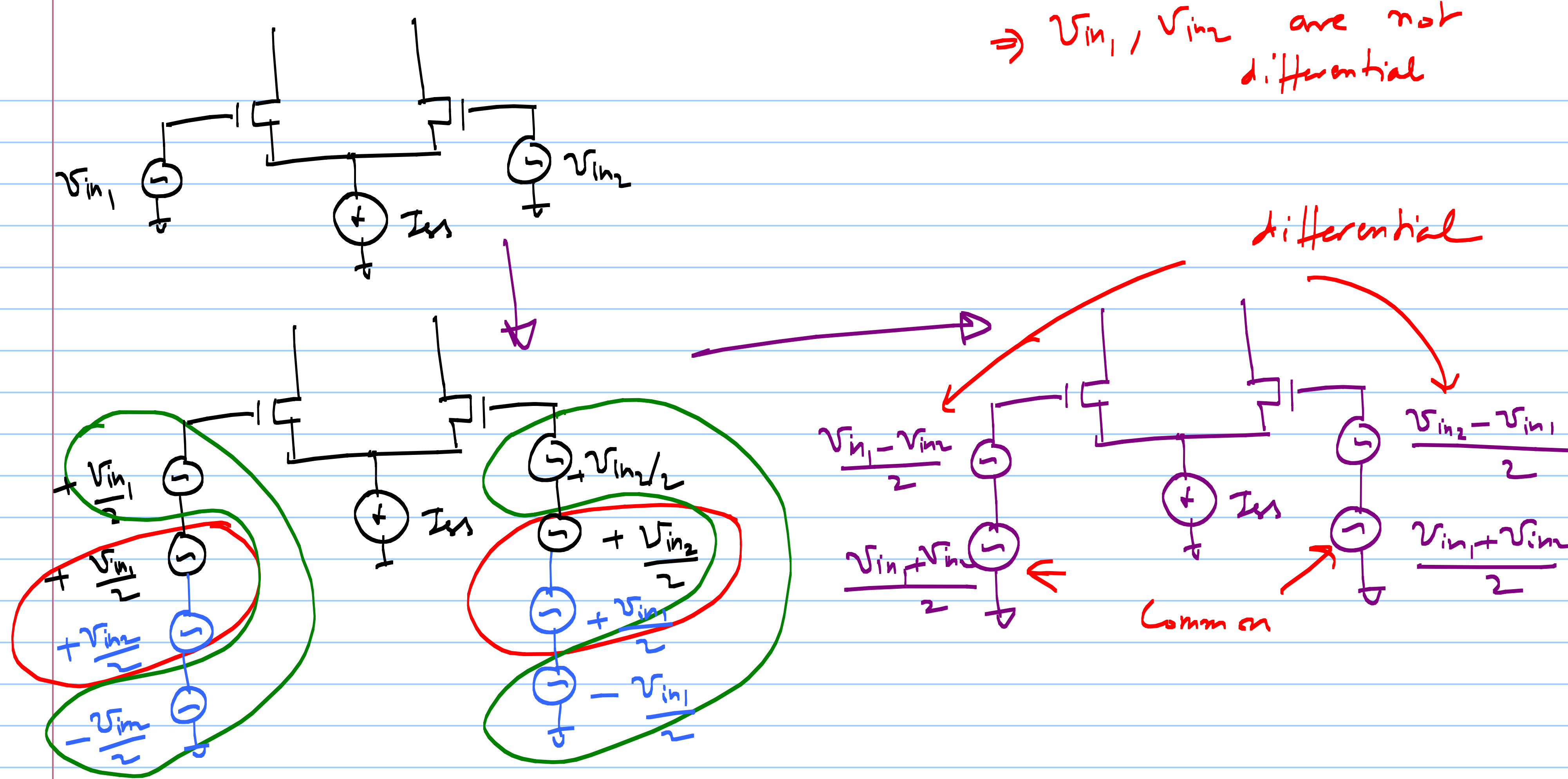
$$\frac{v_{out_2}}{v_{in_2}} = g_{m_2}(R_D \| r_{o_2})$$

$$\frac{v_{out_1} - v_{out_2}}{v_{in_1} - v_{in_2}} = -g_m(R_D \| r_o)$$

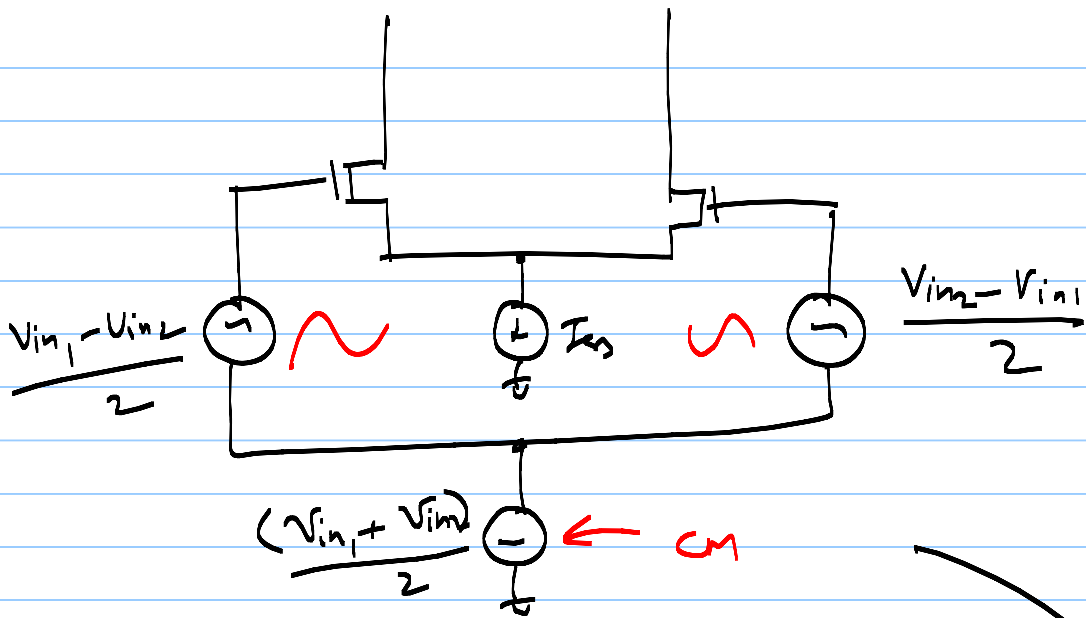
$+ v_{in_1}$

$$\frac{v_{out_1}}{v_{in_1} - v_{in_2}} = -\frac{g_m (R_D \| r_o)}{2}$$

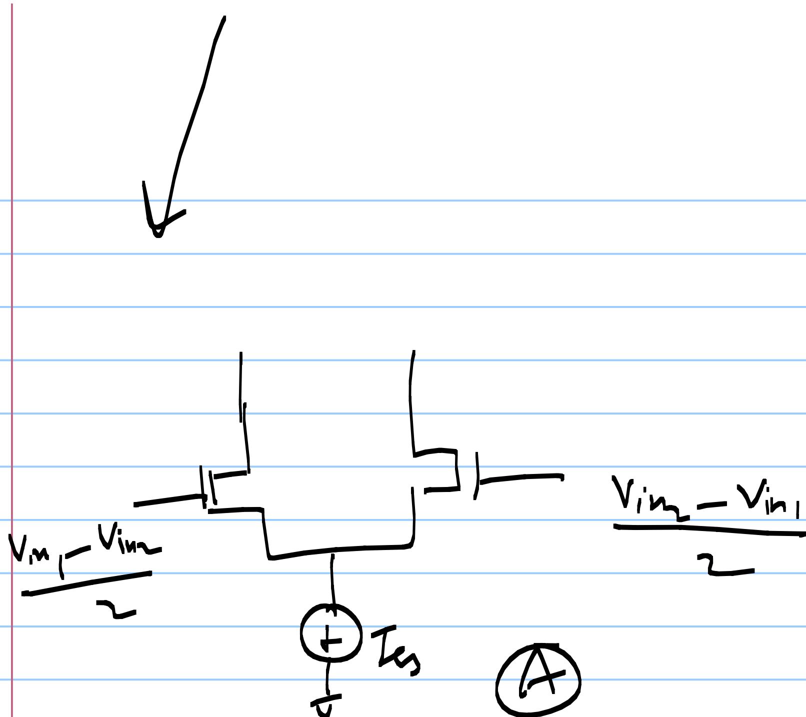




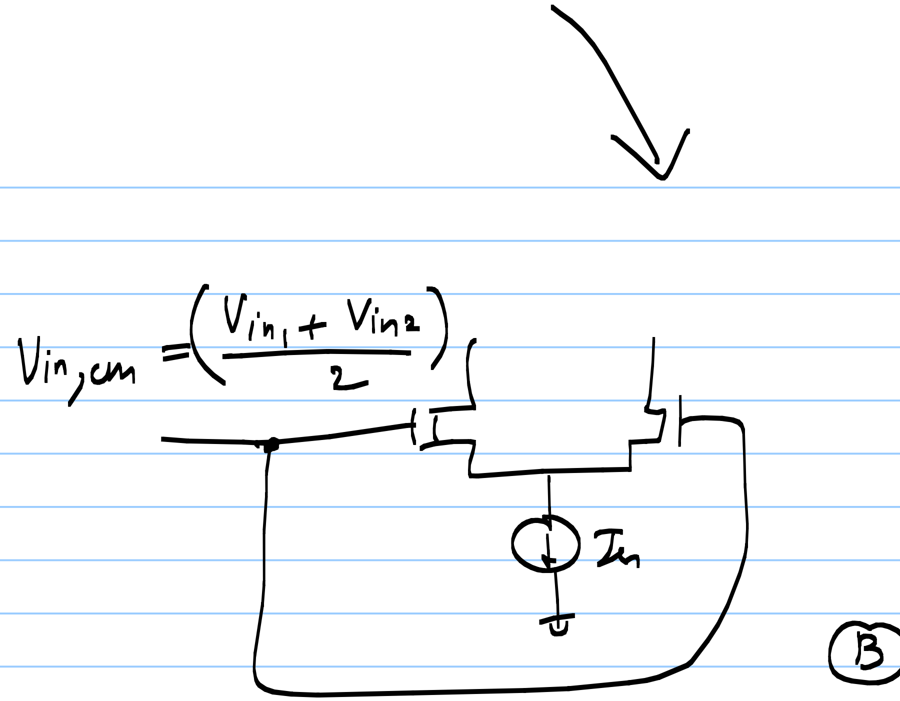
⇒ v_{in_1}, v_{in_2} are not differential
v_{in_1}
v_{in_2}
I_{SS}
$+\frac{v_{in_1}}{2}$
$+\frac{v_{in_1}}{2}$
$+\frac{v_{in_2}}{2}$
$-\frac{v_{in_2}}{2}$
$+v_{in_2}/2$
$+\frac{v_{in_2}}{2}$
$+\frac{v_{in_1}}{2}$
$-\frac{v_{in_1}}{2}$
differential
$\frac{v_{in_1}-v_{in_2}}{2}$
$\frac{v_{in_1}+v_{in_2}}{2}$
$\frac{v_{in_2}-v_{in_1}}{2}$
$\frac{v_{in_1}+v_{in_2}}{2}$
Common



"Linear Superposition"



Differential Mode



Common Mode

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

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

Dm

cm