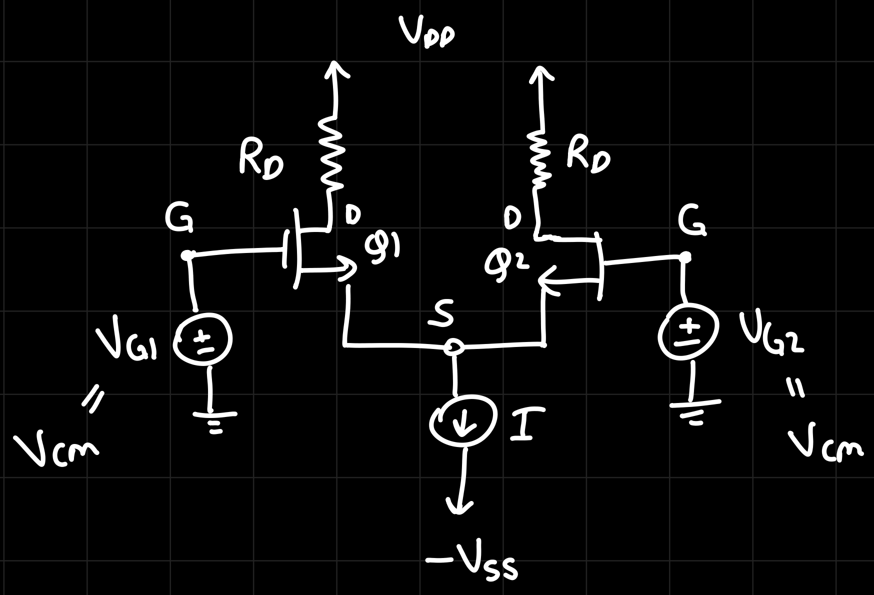
Lecture 17/04/25

→ Differential Amplifier

SNR: Signal to Noise ratio
(maximize it)



obj: to find the differential o/p given that some value of $V_{G1}, V_{G2} = V_{cm}$

Q_1 and Q_2 are in saturation

common mode voltage ← V_{cm} is the voltage applied at the 2 gate terminals V_{G1}, V_{G2}

Since Q_1, Q_2 are matched, they both will conduct a current I' i.e. $I_{D1} = I_{D2} = I'$ and since $I_{D1} + I_{D2} = I$

so → $\boxed{I' = I/2}$

Biased by the current source I

$V_S = ?$ $\quad V_{GS} = V_G - V_S = V_{cm} - V_S$

$$V_S = V_{CM} - V_{GS}$$

but $K = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}$

for $Q_1 \rightarrow$ $\frac{I}{2} = \frac{1}{2}K_n\left(\frac{W}{L}\right)(V_{GS} - V_T)^2$ $\quad K_n \rightarrow \mu_n C_{ox}$

we know $V_{GS} - V_T = V_{OV}$

$$I = K_n\left(\frac{W}{L}\right)V_{ov}^2$$

$$V_{ov} = \sqrt{\frac{I}{K_n(W/L)}} \quad \text{—} \quad (1)$$

to find the output voltage i.e. differential in nature $\rightarrow$ $V_o = V_{D2} - V_{D1}$

$$V_{D1} = V_{DD} - \frac{I}{2}R_D = V_{D2}$$

$$\boxed{V_o = 0}$$

range over which V_{cm} will give a valid outcome for $V_o = 0$?

note: Q_1 and Q_2 must remain in saturation

$\swarrow$

$$V_{DS} > V_{GS} - V_T \;\downarrow$$

$$V_D > V_G - V_T$$

$$V_{DD} - \frac{I}{2} R_D > V_{cm} - V_T$$

$$V_{cm} < V_T + V_{DD} - \frac{I}{2} R_D$$

$$\boxed{V_{cm}^{max} = V_T + V_{DD} - \frac{I}{2} R_D}$$

② for the current SRC to give current bias, we need some potential $\simeq V_{CS}$

$$V_S - (-V_{SS}) > V_{CS}$$

$$V_S = V_{cm} - V_{GS}$$

$$V_{cm} - V_{GS} + V_{SS} > V_{CS}$$

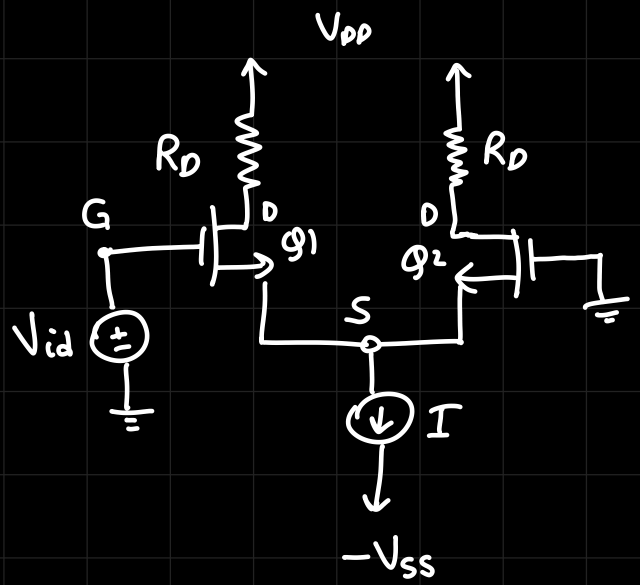
$$V_{cm} > V_{CS} + V_{GS} - V_{SS}$$

we know, $V_{GS} = \underbrace{V_{GS} - V_T}_{V_{OV}} + V_T$

$$V_{cm} > V_{CS} + V_{OV} + V_T - V_{SS}$$

So, range of V_{cm}:

$$V_{CS} + V_{OV} + V_T - V_{SS} < V_{cm} < V_T + V_{DD} - \frac{I}{2} R_D$$



for V_{id}^{max}, current will flow through Q_1 only and through Q_2 for V_{id}^{min}

So, now find range for V_{id} such that: $V_{id}^{min} \leq V_{id} \leq V_{id}^{max}$

$V_{id} \Rightarrow$ potential at which the bias current (I) will flow through Q_1 and no current will flow through Q_2.

for Q_1: $$I = \frac{1}{2} k_n \left(\frac{W}{L}\right)_{Q_1} (V_{GS1} - V_T)^2$$

$$V_{GS1} = V_T + \sqrt{\frac{2I}{k_n (W/L)_{Q_1}}} =$$

from ①: $$V_{ov} = \sqrt{\frac{I}{k_n (W/L)_{Q_1}}}$$

$$\boxed{V_{GS1} = V_T + \sqrt{2}\, V_{ov}} \text{ — ②}$$

for Q_2: $I = 0$

$$0 = K(V_{GS2} - V_T)^2$$

$$\rightarrow V_{GS2} = V_T$$

$$\cancel{V_{G2}}^{0} - V_{S2} = V_T$$

$$-V_{S2} = -V_S = V_T$$

$$\boxed{V_S = -V_T} \text{ — } ③$$

from ②, ③

$$V_{GS1} = V_T + \sqrt{2}V_{ov}$$

$$V_{G1} + V_T = V_T + \sqrt{2}V_{ov}$$

$$V_{G1} = \sqrt{2}V_{ov}$$

so, $\boxed{V_{id}^{max} = \sqrt{2}V_{ov}}$

for V_{id}^{min}: for $Q_1 \rightarrow I = 0$

$$V_{GS1} = V_T \rightarrow V_{G1} - V_T = V_S \quad ④$$

for $Q_2 \rightarrow$ $I = \frac{1}{2}K_n\frac{W}{L}(V_{GS2} - V_T)^2$

$$V_{GS2} = V_T + \sqrt{\frac{2I}{K_n(W/L)_{Q2}}} =$$

$\swarrow$

$$-V_S = V_T + \sqrt{\frac{2I}{k_n(W/L)_{Q_2}}}$$

$$-V_S = V_T + \sqrt{2}V_{ov}$$

$$V_S = -\sqrt{2}V_{ov} - V_T$$

$$V_{G1} - \cancel{V_T} = -\sqrt{2}V_{ov} - \cancel{V_T} \quad \} \text{ from } ①$$

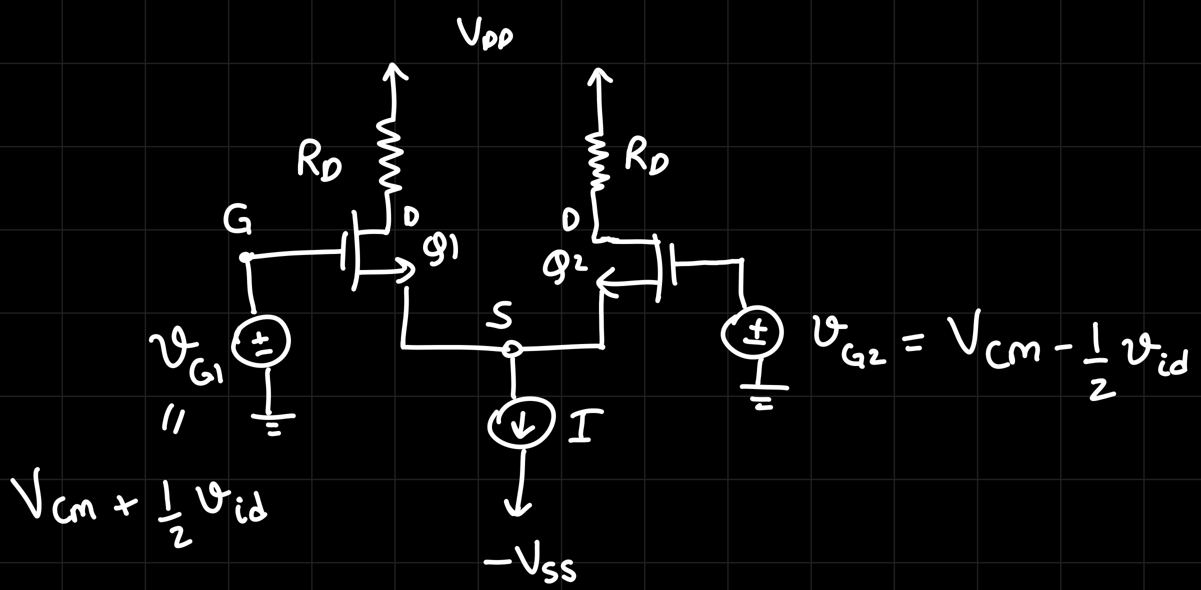
$$V_{G1} = -\sqrt{2}V_{ov}$$

$$V_{id}^{min} = -\sqrt{2}V_{ov}$$

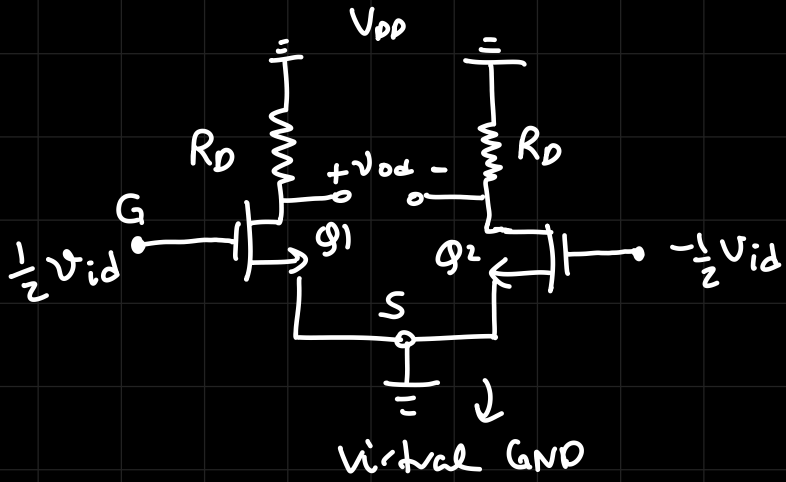
So, range for V_{id} :

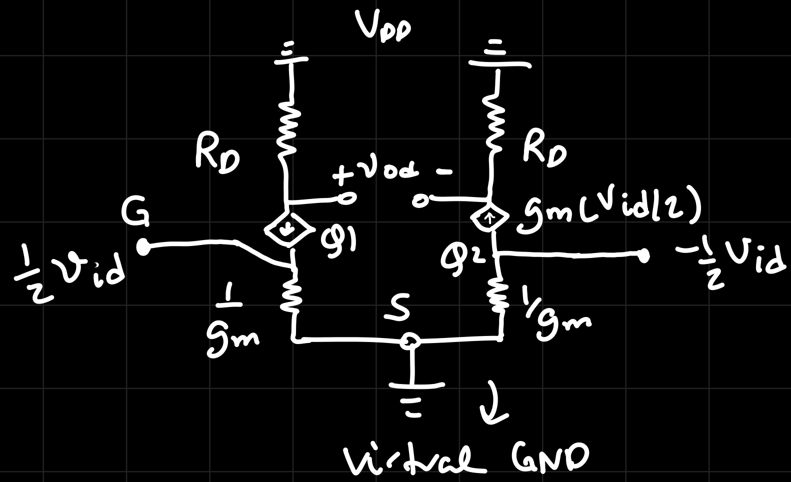
$$\boxed{-\sqrt{2}V_{ov} < V_{id} < \sqrt{2}V_{ov}}$$

assuming Q_1 and Q_2 are in saturation



AC analysis → Remove DC SRC





$$I_D = g_m \frac{V_{id}}{2}$$

70% project

Filter

V amp

P amp

aux out

$$V_{o1} = -g_m \frac{V_{id}}{2} R_d$$

$$V_{o2} = g_m \frac{V_{id}}{2} R_D$$

$$A_{v1} = \frac{V_{o1}}{V_{id}} = -\frac{1}{2} g_m R_D$$ } 1st branch

$$A_{v2} = \frac{V_{o2}}{V_{id}} = \frac{1}{2} g_m R_D$$ } 2nd branch

$$A_D = \frac{V_o}{V_{id}} = \frac{V_{o2} - V_{o1}}{V_{id}} = \underline{g_m R_d}$$ } Differential gain

↳ double of that of individual branch gain