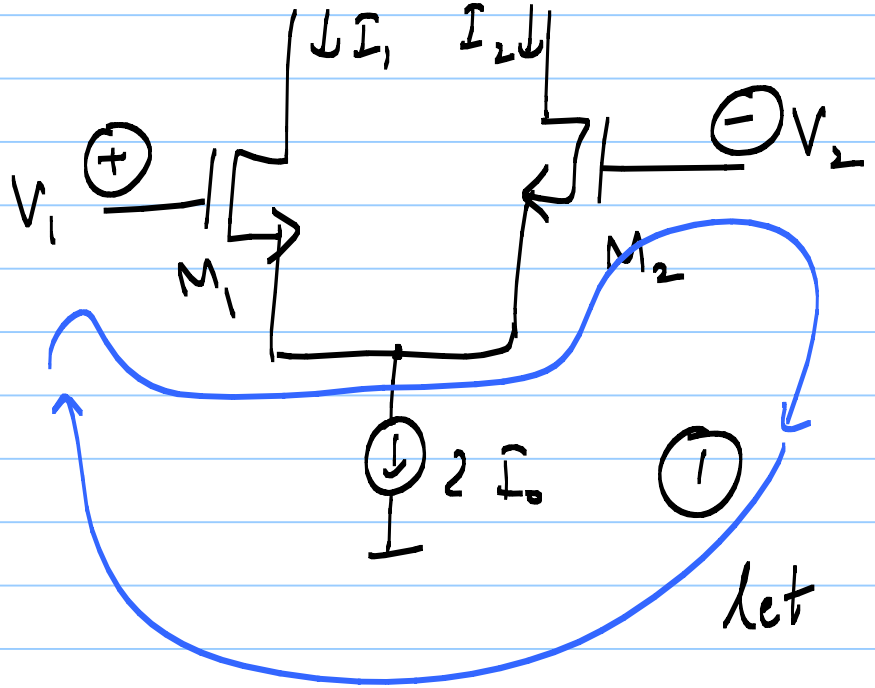
13|10|2020

Lecture 37



$V_{id} = V_1 - V_2$

$V_{id} = 0 \Rightarrow I_1 = I_2 = I_0$

$I_{od} = I_1 - I_2$

$= g_m V_{id}$ for small signals / increments

let $k' = \mu_n C_{ox}$

KVL around ①: $V_1 - V_{GS_1} + V_{GS_2} - V_2 = 0$

$$V_{id} = V_1 - V_2 = V_{GS_1} - V_{GS_2}$$

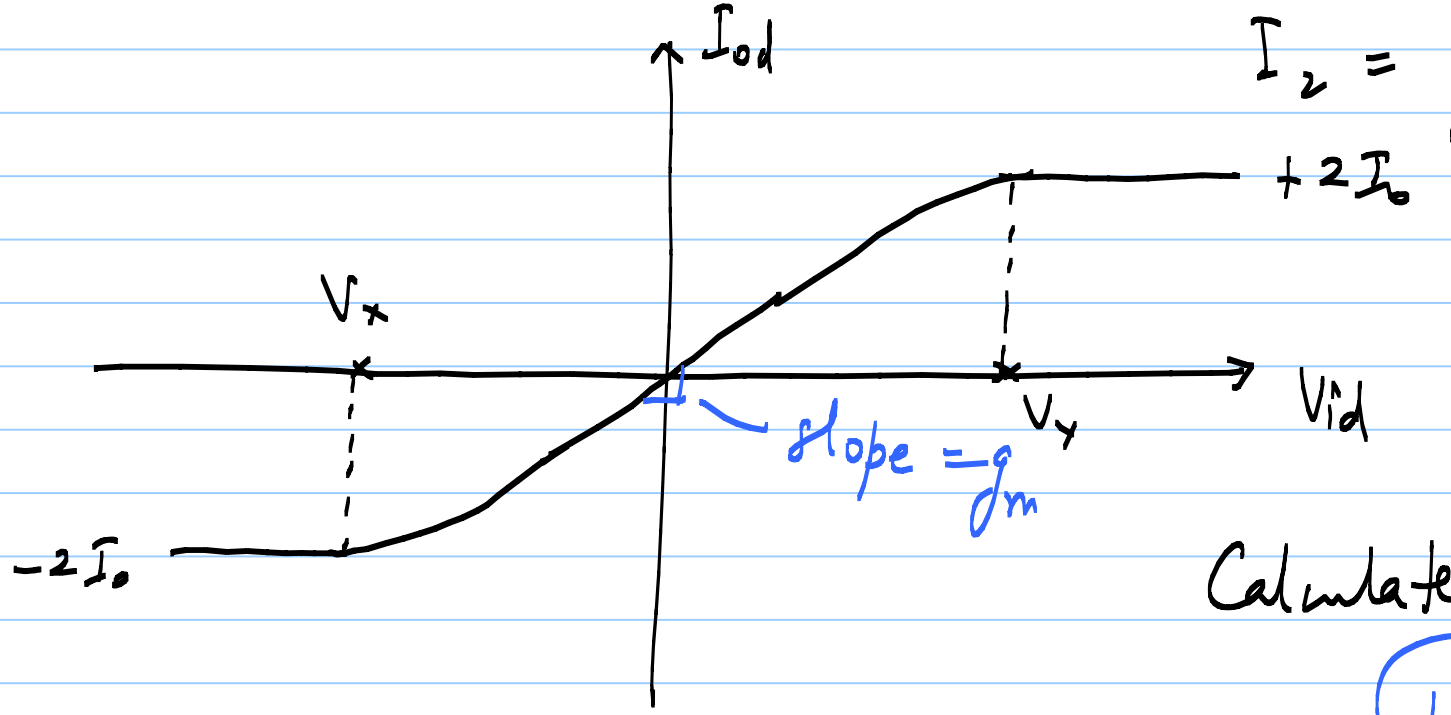
$$= \left[V_{T_1} + \sqrt{\frac{2I_1}{k'\left(\frac{W}{L}\right)_1}} \right] - \left[V_{T_2} + \sqrt{\frac{2I_2}{k'\left(\frac{W}{L}\right)_2}} \right]$$

$$V_{id} = \sqrt{\frac{2}{k'\left(\frac{W}{L}\right)}}\left[\sqrt{I_1} - \sqrt{I_2}\right] \quad \text{—— (A)}$$

$$I_1 + I_2 = 2I_0 \quad \text{—— (B)}$$

Use (A) & (B) to get $I_1 = f(V_{id})$ HW

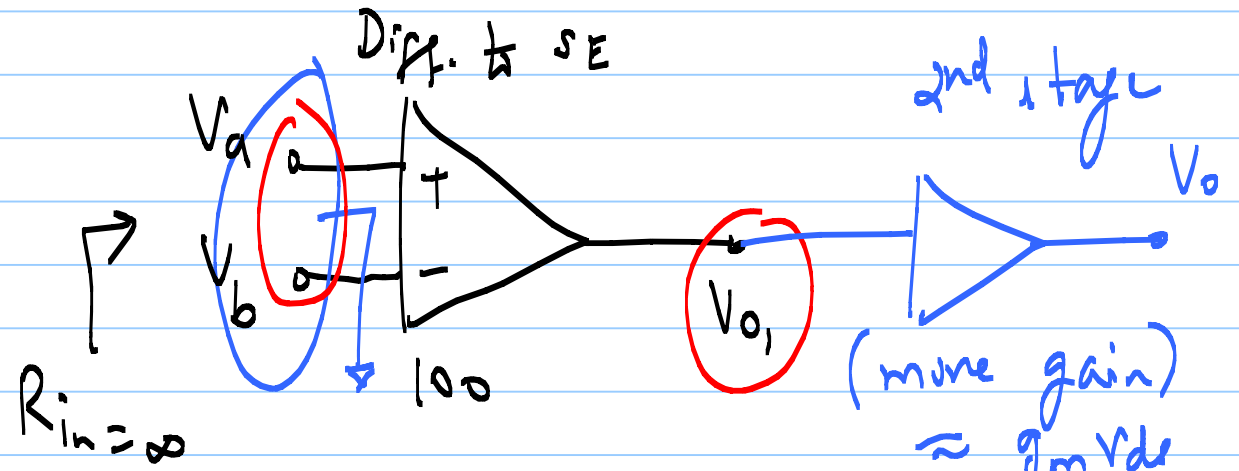
$I_2 = g(V_{id})$



Calculate V_x & V_y HW

V_x & V_y : currents become $2I_0$ & 0

One stage opamp gain $\approx g_m (r_{ds_2} \| r_{ds_4})$



2nd stage

V_o

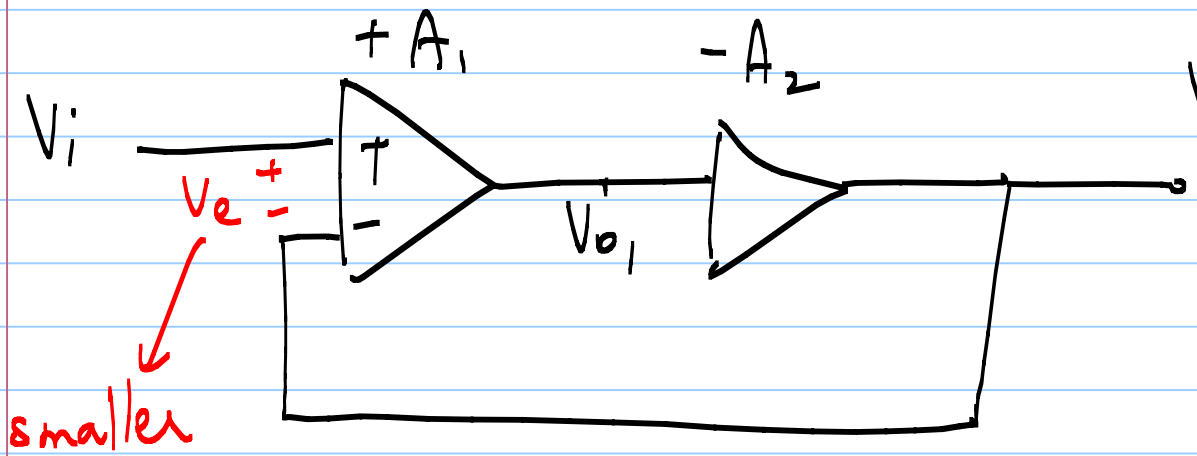
(more gain)

$\approx g_m r_{ds} \approx 100$

overall

2-stage gain

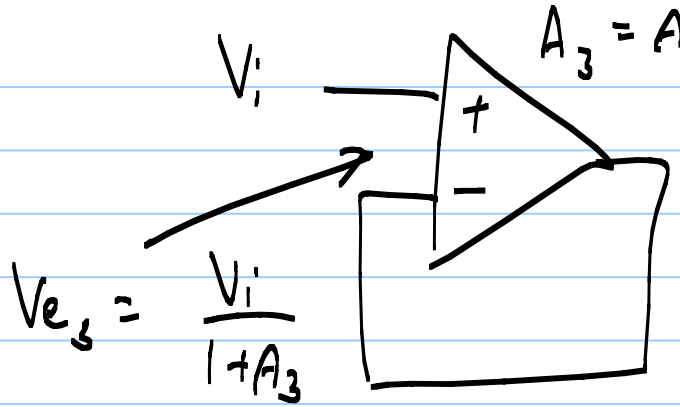
$= 10^4$



$$V_o = \frac{1}{1 + \frac{1}{A_1 A_2}} V_i$$

$$= \frac{A_1 A_2}{1 + A_1 A_2} \cdot V_i$$

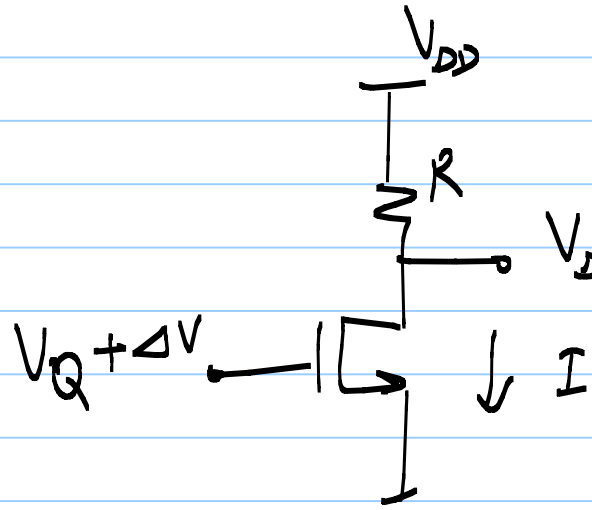
$$V_e = \frac{V_i}{1 + A_1 A_2} \quad ; \quad V_{o_1} = \frac{A_1 V_i}{1 + A_1 A_2} = \frac{V_i}{A_2 + \frac{1}{A_1}}$$



$$V_o = \frac{A_3}{1+A_3} V_i$$

$$V_{e_3} = \frac{V_i}{1+A_3}$$

$$= \frac{V_i}{1+A_1}$$

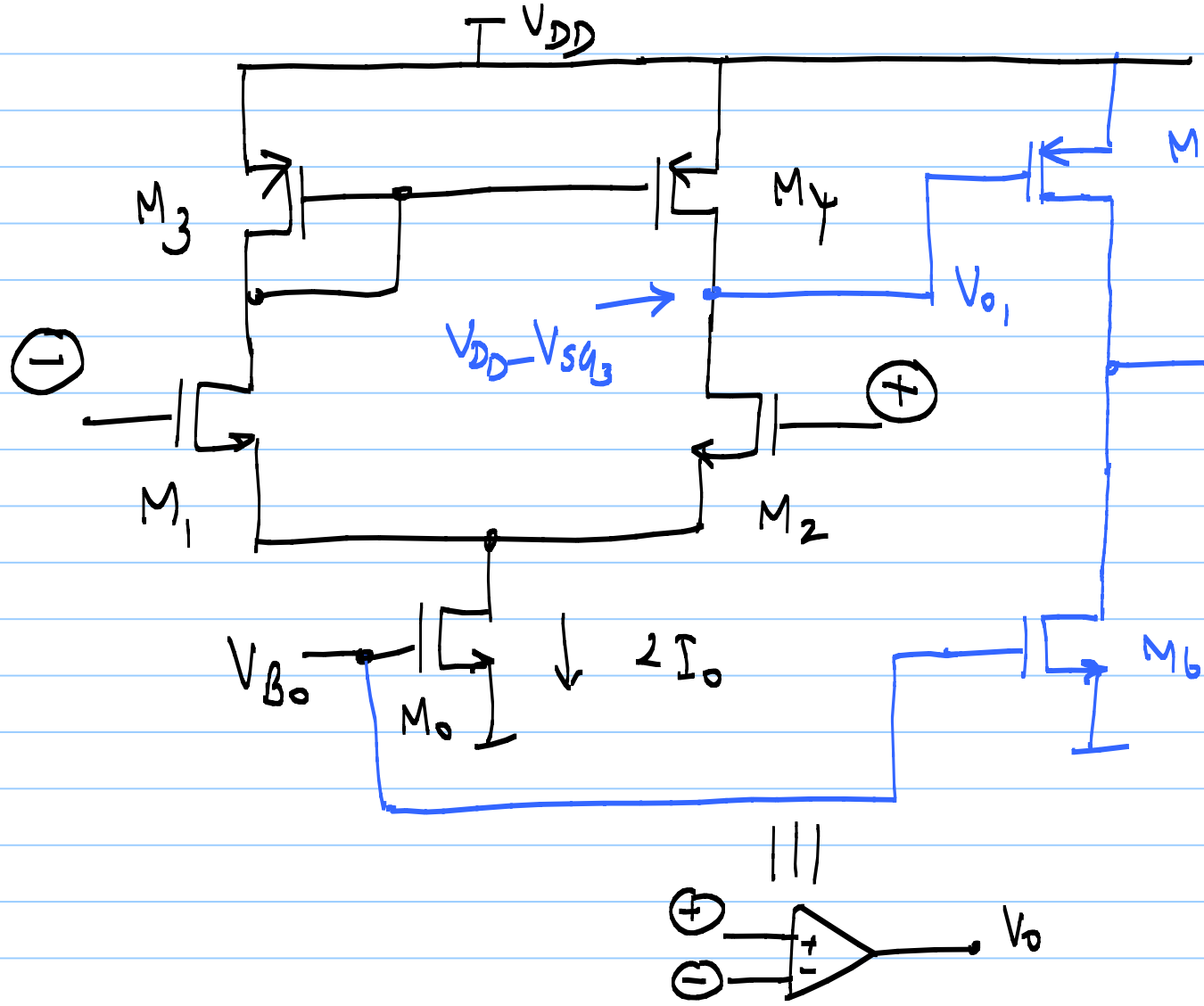


$$g_m = f(V_Q \text{ or } I_Q)$$

$$V_{DD} - I_Q R - g_m R \Delta V$$

$$\downarrow I_Q + g_m \Delta V$$

2-stage opamp:

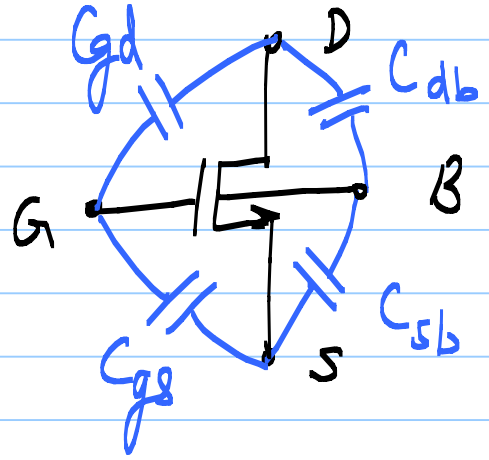


$$A_1 = g_{m_1}\left(r_{ds_2} \| r_{ds_4}\right)$$

$$A_2 = -g_{m_5}\left(r_{ds_5} \| r_{ds_6}\right)$$

$$V_{o_1} = -g_{m_1}\left(r_{ds_2} \| r_{ds_4}\right)$$

* Every MOSFET has a speed limitation / delay

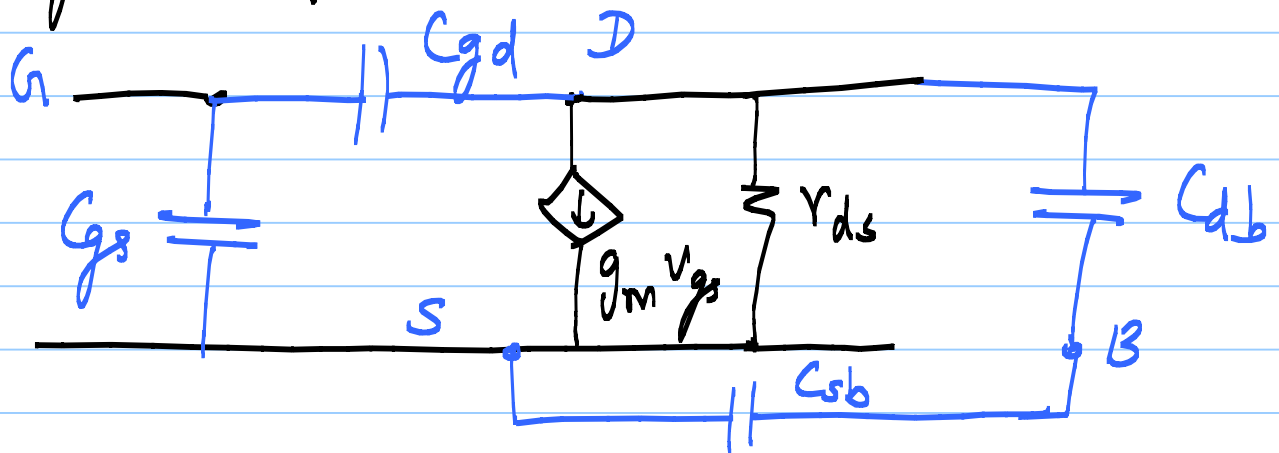


← bulk / substrate terminal { normally signal ground }

B = gnd for NMOS

B = Vdd for PMOS

AC small signal eq. cir.:



* In sat.: $C_{gs} \gg C_{gd}, C_{db}, C_{sb}$ (smallest cap.; largest cap.)

* $C_{gs} \simeq \frac{2}{3} W \cdot L \cdot C_{ox}$ in saturation

C_{gs}: fF; W, L: μm; C_{ox}: $fF/\mu m^2$

$V_1 = 3\,V \qquad V_2 = 4\,V$

$V_{CM} = 3.5\,V$

$V_{DM} = -0.5\,V$