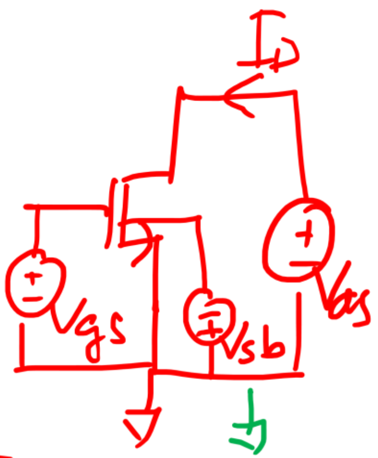
Differential Amplifier

13 June 2025



④ $V_{GS} > V_T : V_{ds} > V_{GS} - V_T$

$$I_D = \frac{\mu_n C_{ox}}{2} \cdot \frac{W}{L} (V_{GS} - V_T)^2 (1 + \lambda V_{DS})$$

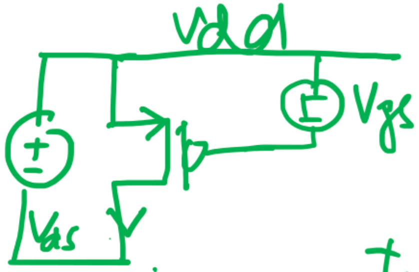
① $V_{GS} < V_T$: cut off (subthreshold)

② $V_{GS} > V_T : V_{ds} \sim 0$

$$I_D \cong \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T) \cdot V_{ds}$$

③ $V_{GS} > V_T : V_{ds} < V_{GS} - V_T$

$$I_D = \frac{\mu_n C_{ox}}{2} \frac{W}{L} \left[2(V_{GS} - V_T) V_{ds} - V_{ds}^2 \right]$$



① $V_{gs} > V_{Tp}$ cutoff (st)

② $V_{gs} < V_{tp} : V_{ds} \sim 0$

$$I_{Dp} = \mu_p C_{ox} \frac{W}{L} (V_{gs} - V_{tp}) V_{ds}$$

$V_{tp} = -0.5V$

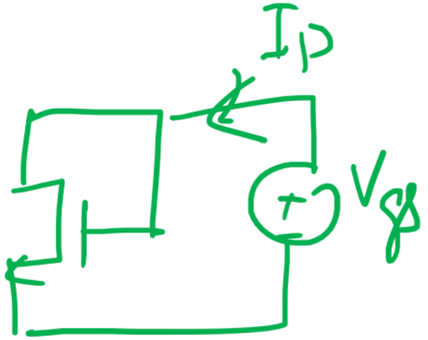
③ $V_{gs} < V_{tp} : V_{ds} > V_{dsat}$

$$I_{Dp} = \frac{\mu_p C_{ox}}{2} \frac{W}{L} \left[2(V_{gs} - V_{tp}) V_{ds} - V_{ds}^2 \right]$$

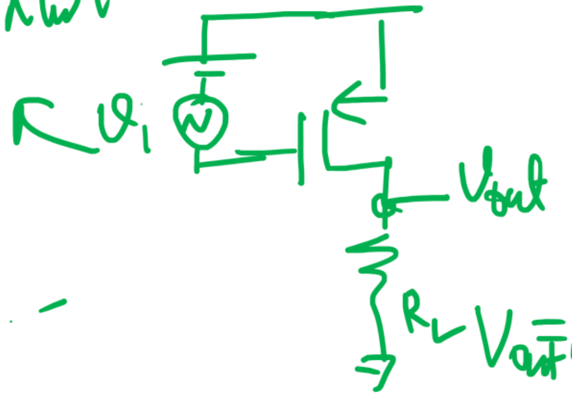
④ $V_{gs} < V_{tp} : V_{ds} < V_{dsat}$

$$I_{Dp} = \frac{\mu_p C_{ox}}{2} \frac{W}{L} (V_{gs} - V_{tp})^2 (1 + \lambda V_{ds})$$

$$\mu_n \cong (2\text{-}3) \times \mu_p$$



$v_i = V_m \cdot \sin\omega t$

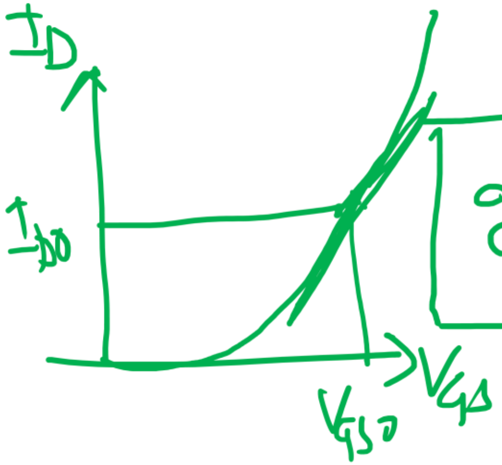


$v_{out} = I_D \times R_L$

$= \frac{\mu_p C_{ox}}{2}\frac{W}{L}(V_{GS}-V_t)^2 \times R_L$

$V_{out} = \underbrace{\frac{\mu_p C_{ox}}{2}\frac{W}{L}}_{\beta'}(\underbrace{V_{GS0}-V_t}_{V_{on}} + V_m \sin\omega t)^2 \times R_L$

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



$\boxed{g_m = \frac{2 I_{D0}}{V_{on}}}$

$V_{out} = \beta' \cdot [V_{on}^2 + 2 \cdot V_m \cdot V_{on} \cdot \sin\omega t + V_m^2 \sin^2\omega t] R_L$

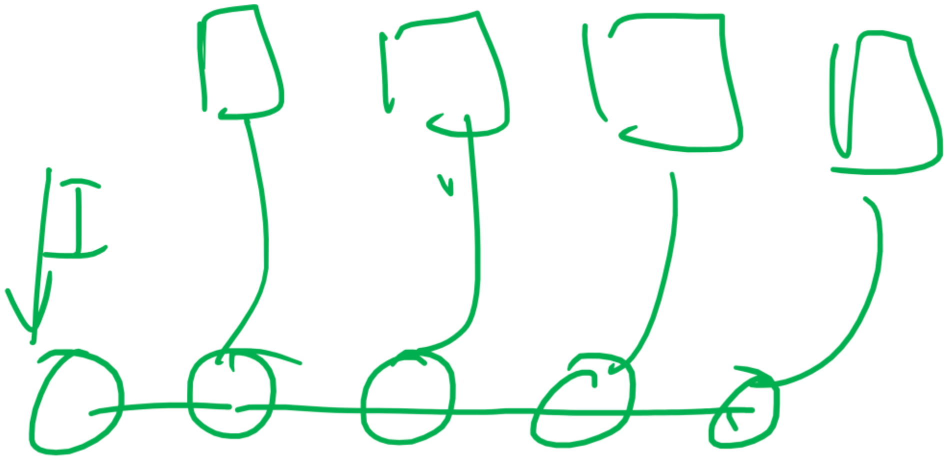
$= I_{D0} + \underbrace{\beta' \cdot 2 \cdot V_{on}}_{} V_m \sin\omega t + \beta' \frac{V_m^2}{2} - \beta' \frac{V_m^2 \cos 2\omega}{2}$

$= (I_{D0} - \frac{V_m^2}{2}\beta')R + R_L g_m V_m \sin\omega t - \beta' \frac{V_m^2}{2} \cos 2\omega t$

$I_{D0} = \frac{\mu_n C_{ox}}{2}\frac{W}{L}(V_{GS}-V_t)^2$

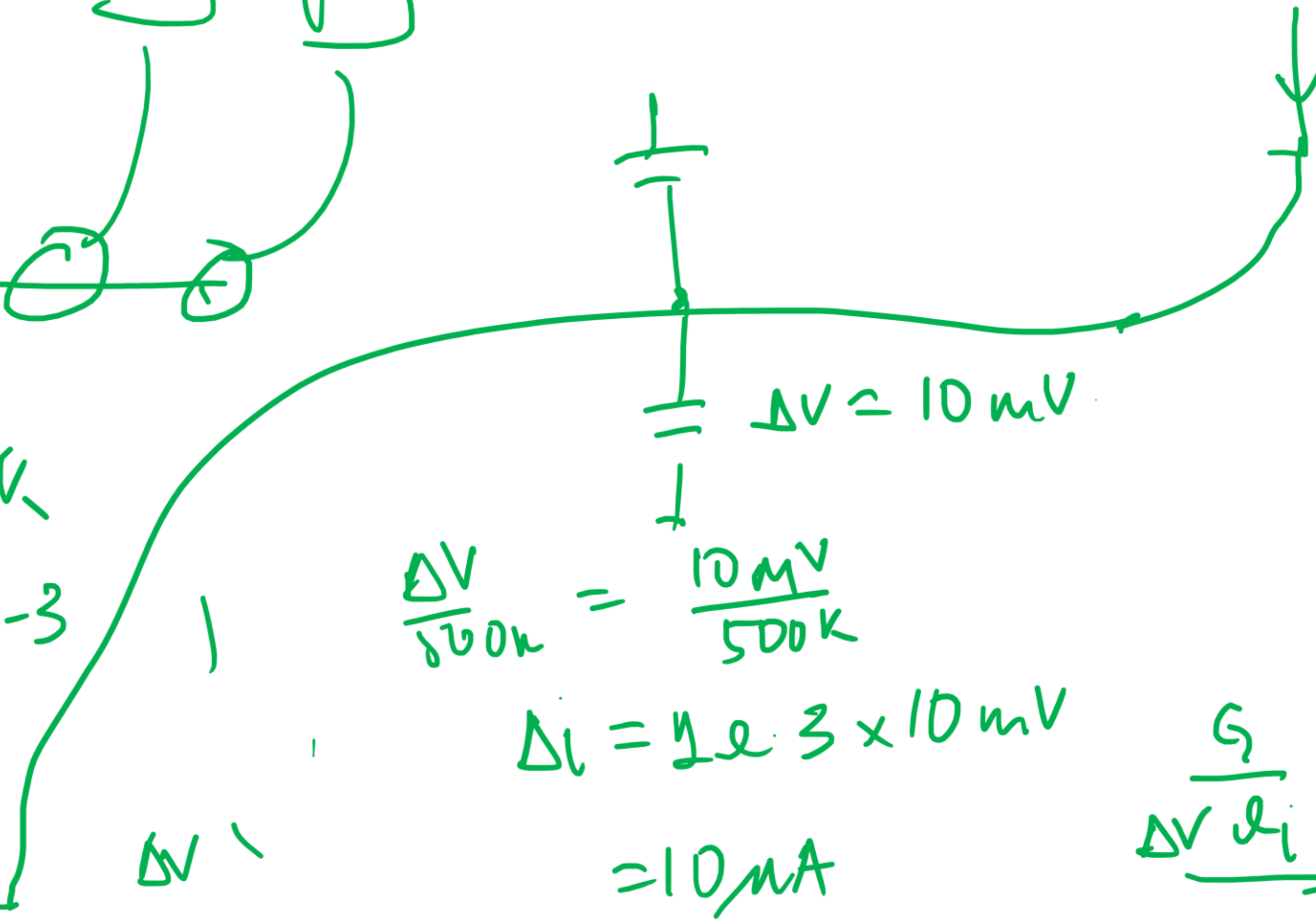
$\frac{\partial I_{D}}{\partial V_{GS}} = g_m = \mu_n C_{ox}\frac{W}{L}(V_{GS}-V_t)$

THD $= \frac{\sqrt{V_1^2 + V_2^2 + V_3^2}}{V_m} = \frac{V_m \, \beta'/2 \, \cancel{R_L}}{g_m \, \cancel{R_L}}$



$\Delta I = 10\,nA$

$= 20\,nA$



$\Delta V = 10\,mV$

$r_{ds} = 500K$

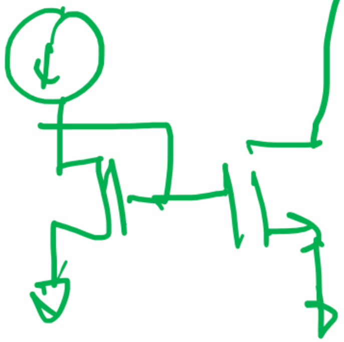
$g_m = 1e{-3}$

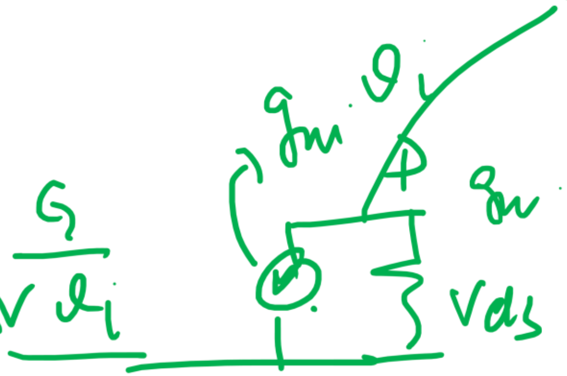
$$\frac{\Delta V}{500k} = \frac{10\,mV}{500K}$$

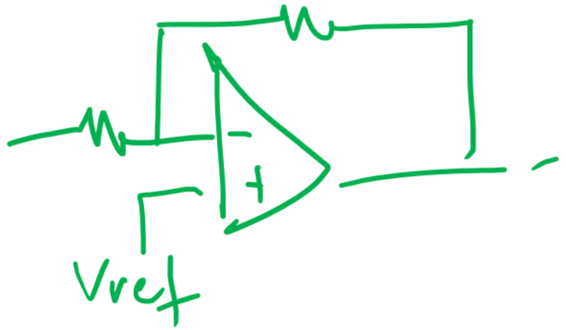
$$\Delta i = 1e{-}3 \times 10\,mV$$

$$= 10\,nA$$

ΔV

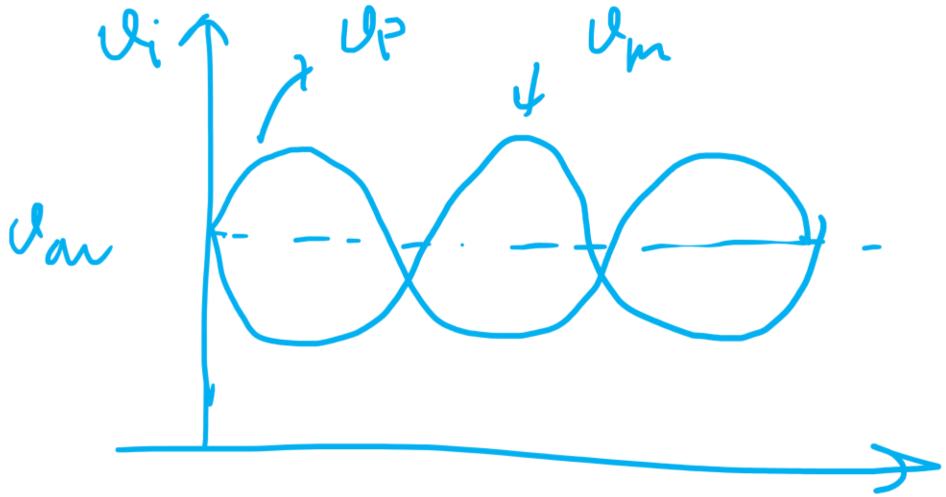


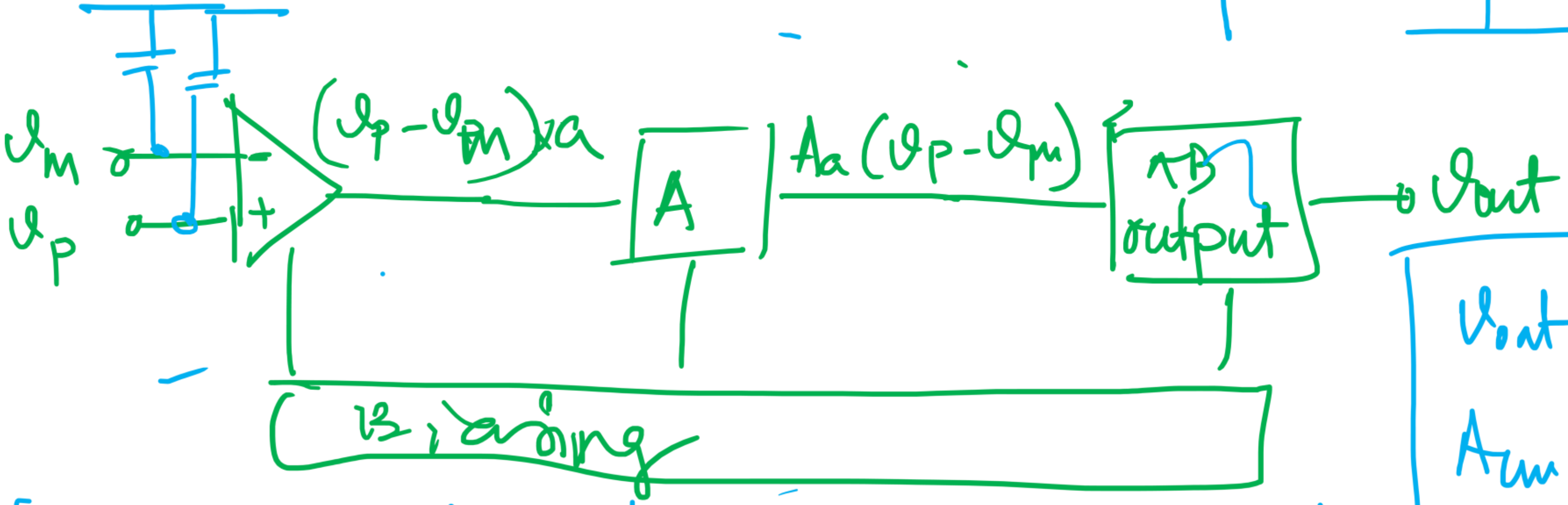




$$v_d = v_p - v_m$$

$$v_{cm} = \frac{v_p + v_m}{2}$$





$$v_p = V_p \sin\omega t$$

$$v_m = 0$$

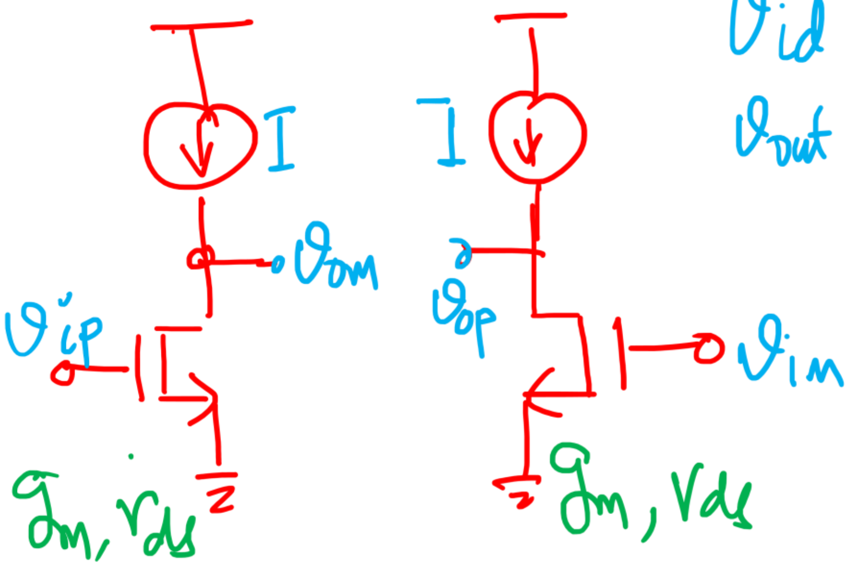
$$v_d = V_p \sin\omega t$$

$$v_{cm} = \frac{V_p}{2} \sin\omega t$$

$$v_{out} = A_{cm} \cdot v_{cm} + A_d \cdot v_d$$

$$A_{cm} \sim 0$$

$A_d \to$ high



$v_{id} = v_{ip} - v_{im}$

$v_{out} = v_{op} - v_{om}$

$$A_{cm} = \frac{v_{ocm}}{v_{icm}} \quad v_{ocm} \rightarrow \frac{v_{op}+v_{om}}{2} \quad v_{icm} \rightarrow \frac{v_{ip}+v_{im}}{2}$$

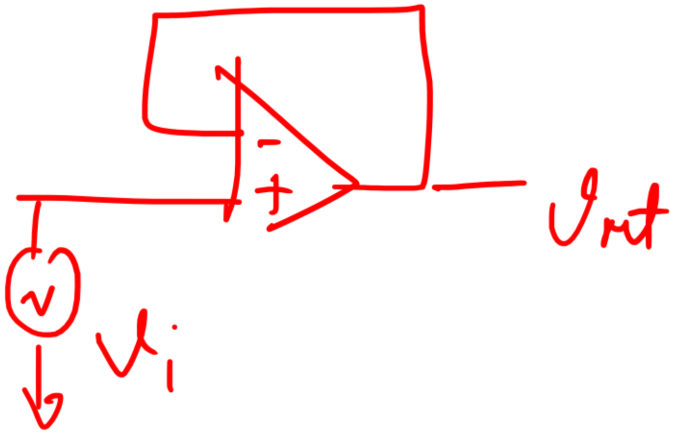
$$\frac{v_{op}+v_{om}}{2} = -\left(\frac{v_{ip}+v_{im}}{2}\right) g_m r_{ds}$$

$$\frac{v_{ocm}}{v_{icm}} = -g_m r_{ds}$$

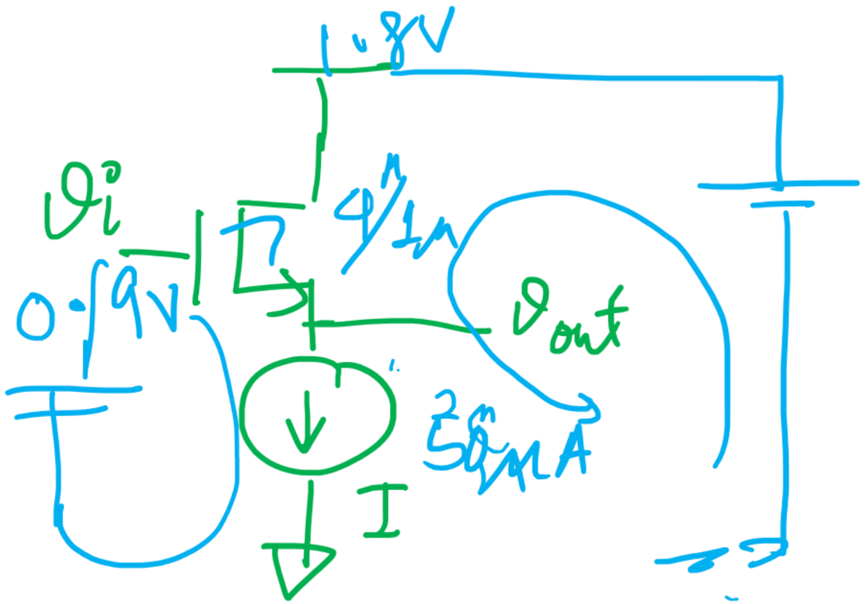
$v_{om} = -v_{ip} \cdot g_m \cdot r_{ds}$ ✓

$v_{op} = -v_{im} \cdot g_m r_{ds}$ ✓

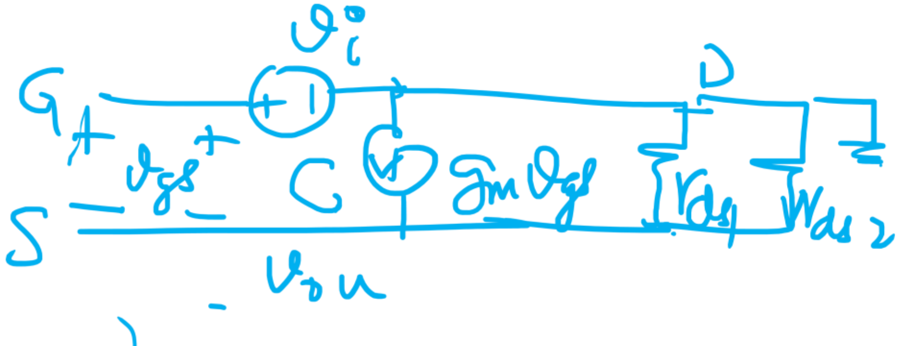
$$\underbrace{v_{op} - v_{om}}_{v_{out}} = \underbrace{g_m r_{ds}}_{A_d}(v_{ip} - v_{im})$$



Source follower



v_g	v_{out}
0.9	0.3
1.0	0.4
1.1	0.5
1.2	0.6



$$v_i + v_{gs} + v_{out} = 0$$

$$0.9 - V_{gs} - V_{out} = 0$$

$$-v_i + \frac{v_{out}}{g_m V_{ds}} + v_{out} = 0$$

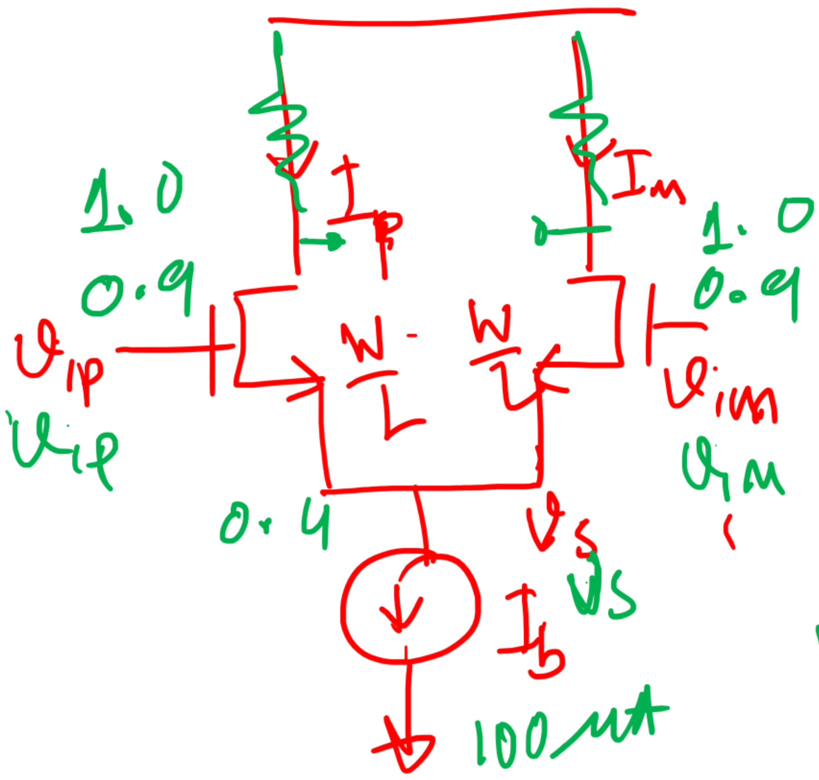
$$V_{out} = 0.9 - 0.6 = 0.3$$

$$\boxed{v_o\left(1 + \frac{1}{g_m V_{ds}}\right) = v_i}$$

$$I_D = \mu_n C_{ox} \frac{W}{L}(V_{GS} - V_T)^2$$

$$V_{GS} = V_T + \sqrt{\frac{2I_D}{\mu_n C_{ox} W/L}} = 0.5V + \sqrt{\frac{100\mu}{200\frac{\mu A}{V^2} \cdot 4}} = 0.6\,V$$

V_{dsat}
V_{on}
V_{eff}



$$I_p = \frac{\mu_n C_{ox}}{2} \frac{W}{L} \left(V_{gs_p} - V_T\right)^2$$

$$I_m = \frac{\mu_n C_{ox}}{2} \frac{W}{L} \left(V_{gs_m} - V_T\right)^2$$

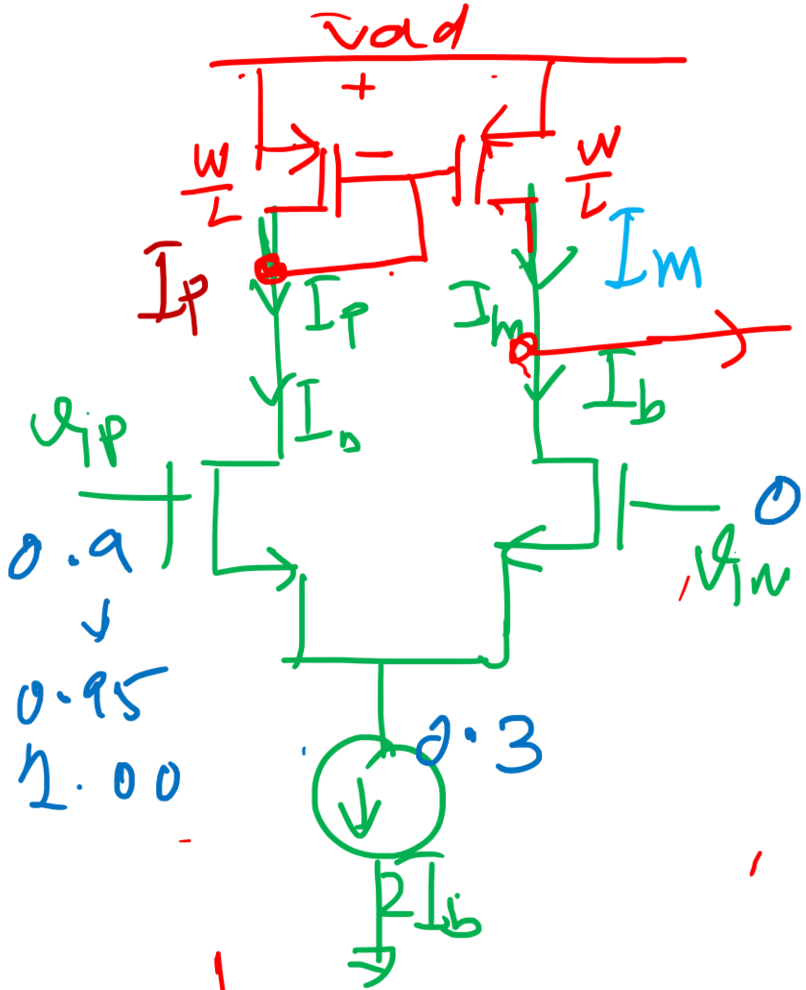
$$I_p + I_m = I_b$$

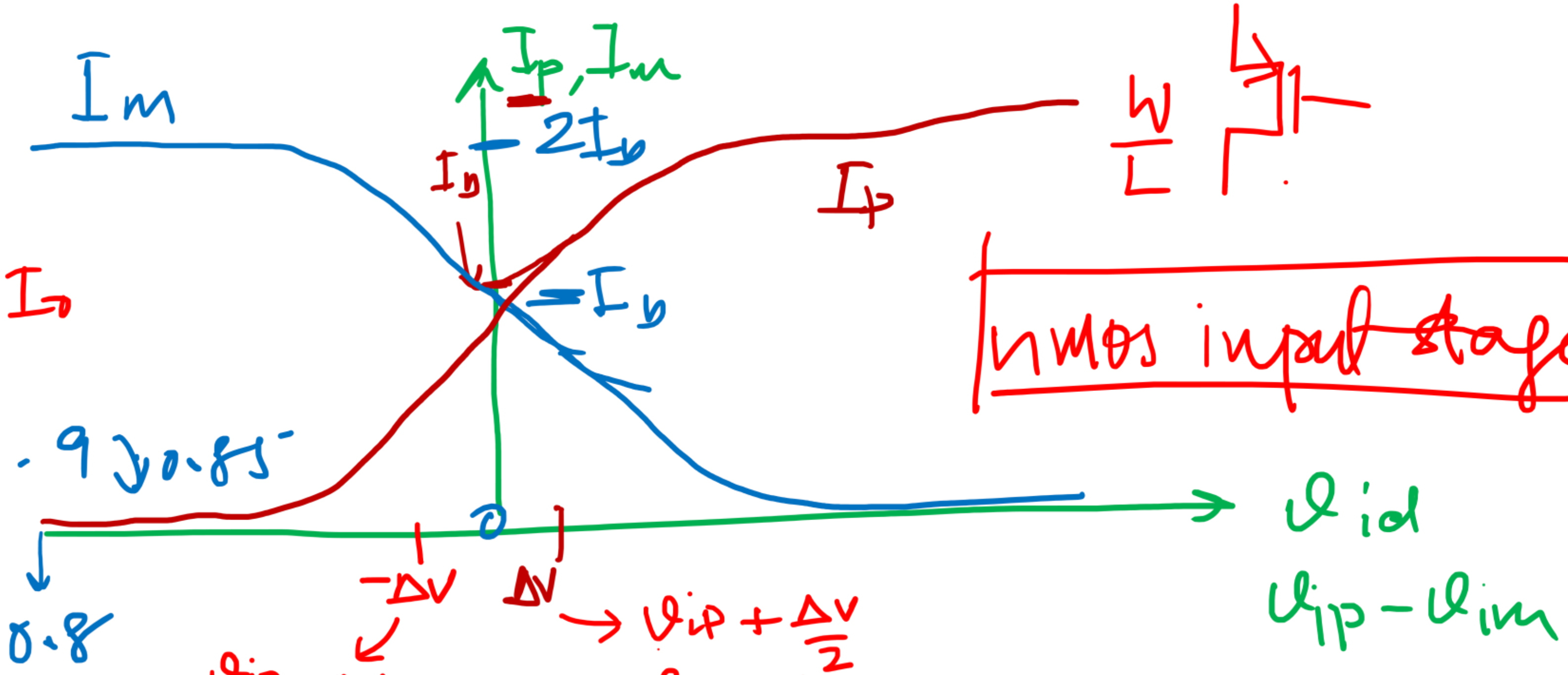
$$V_{gs_p} = v_{ip} - v_s$$

$$V_{gsm} = v_{im} - v_s$$

$$v_{ip} = v_{im}$$

$$\Rightarrow I_p = I_m = \frac{I_b}{2}$$





~~nmos input stage~~ → $\boxed{\text{nmos input } \cancel{\text{stage}}}$

$$\underbrace{\begin{matrix} v_{ip} - \frac{\Delta V}{2} \\ v_{im} + \frac{\Delta V}{2} \end{matrix}}$$

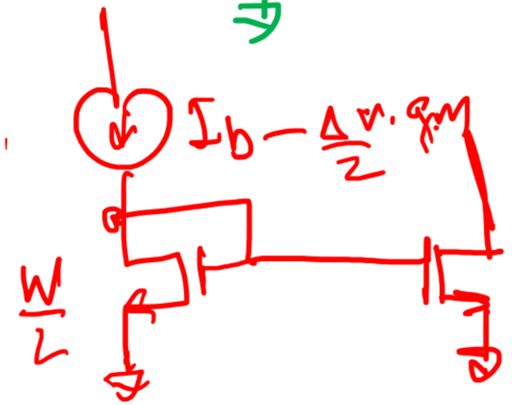
$$\underbrace{\begin{matrix} I_p = I_b - g_m \cdot \frac{\Delta V}{2} \\ I_m = I_b + g_m \cdot \frac{\Delta V}{2} \end{matrix}}$$

$$I_{out} = I_p - I_m = -g_m \Delta V$$

$$\underbrace{\begin{matrix} v_{ip} + \frac{\Delta V}{2} \\ v_{im} - \frac{\Delta V}{2} \end{matrix}}$$

$$\underbrace{\begin{matrix} I_p = I_b + g_m \cdot \frac{\Delta V}{2} \ \checkmark \\ I_m = I_b - g_m \cdot \frac{\Delta V}{2} \end{matrix}}$$

$$I_{out} = I_p - I_m = +g_m \times \Delta V$$



$$I_0 = I_b + g_m \cdot \frac{\Delta V}{2} - I_b + g_m \frac{\Delta V}{2} = g_m \cdot \Delta V \times \frac{r_{ds}}{2}$$

pmos input