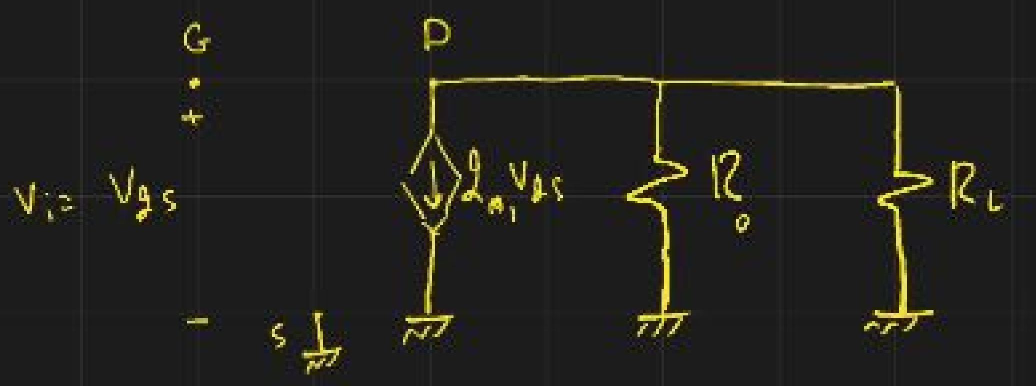
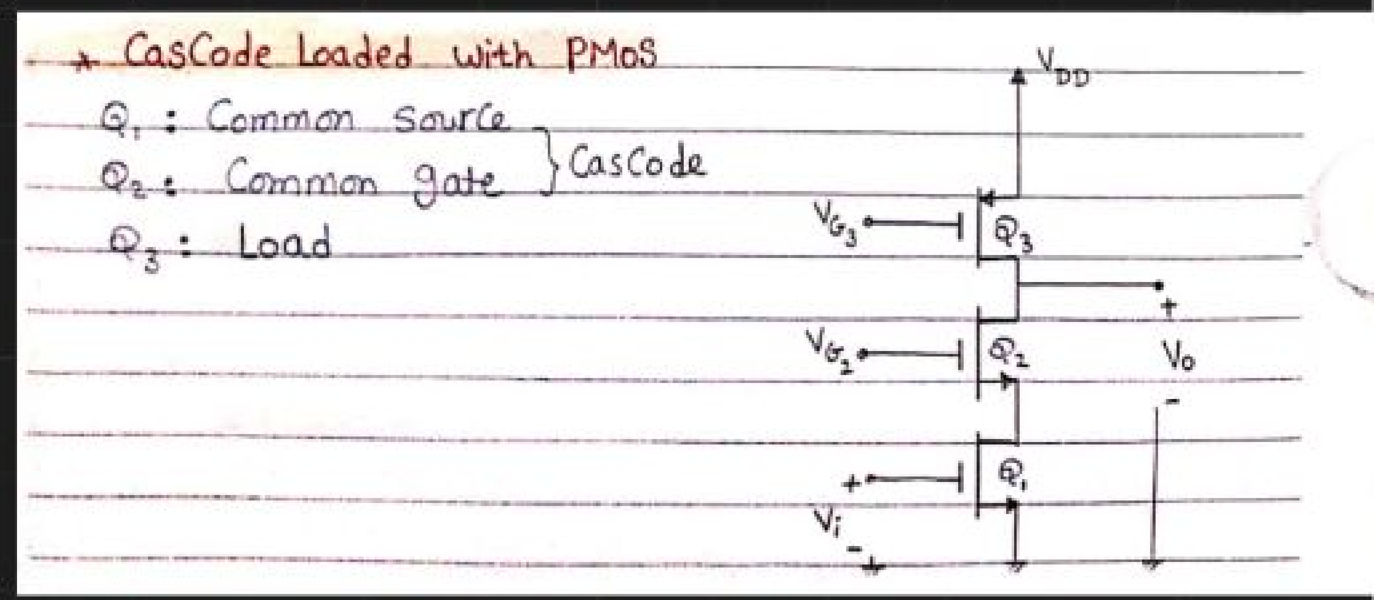
→ Remember Cascode amp with load from Lec 9





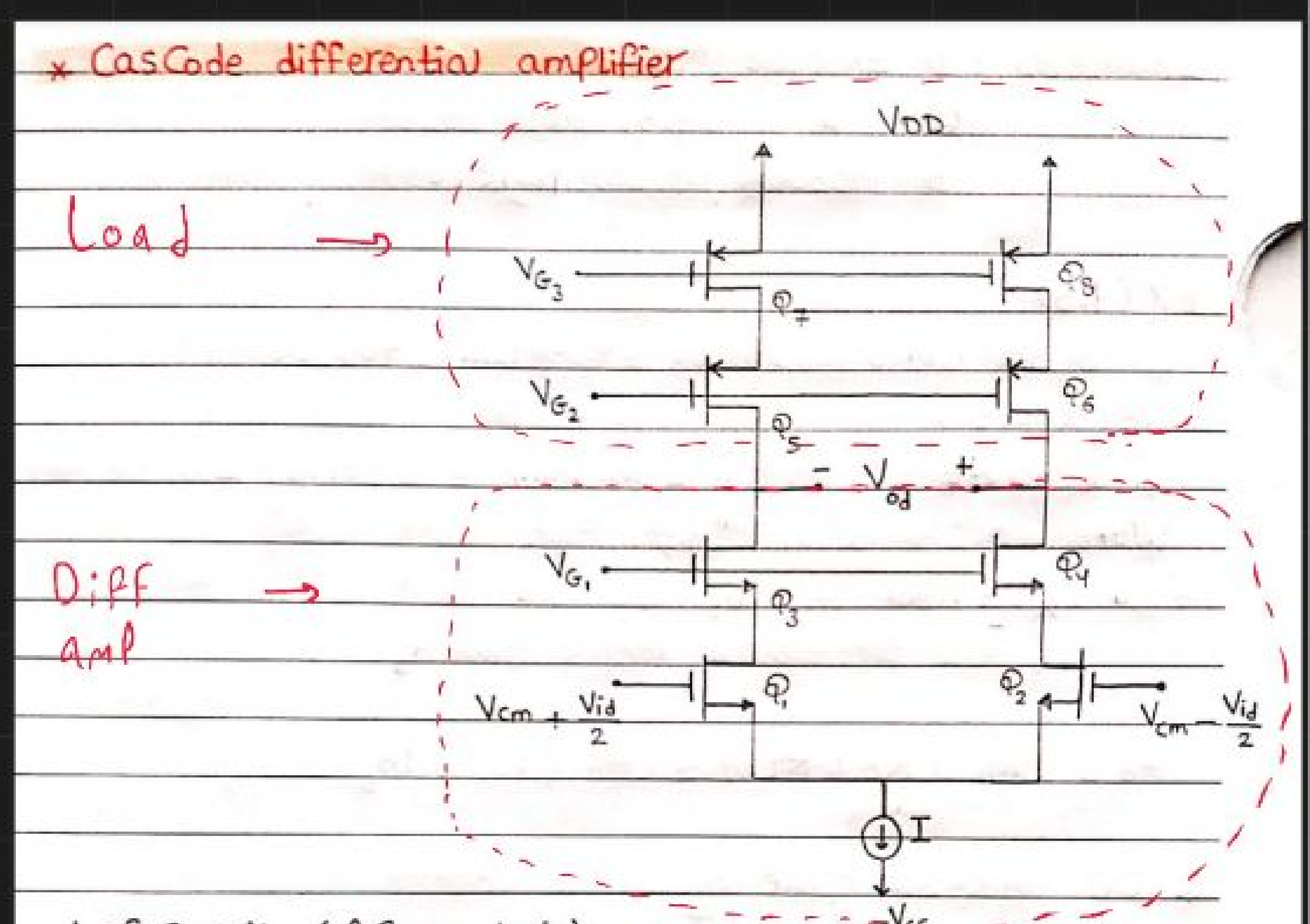
→ $R_o = R_o(Q_2) = g_{m_2} r_{o2} R_s = g_{m_2} r_{o_2} r_{o_1}$

→ R_L : is the resitance at the drain of Q_2 → which is r_{o3} → $\therefore R_L = r_{o3}$

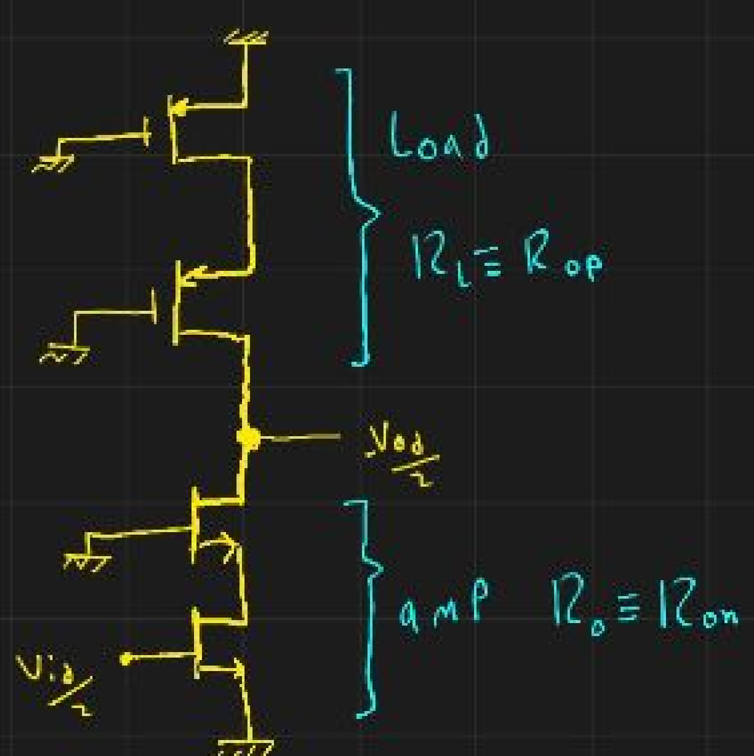
$\therefore A_v = -g_{m_1} (R_o // R_L)$

$\therefore A_v = -g_{m_1} [(g_{m_2} r_{o2} r_{o_1} // r_{o3})]$

* Cascode differintial amp:



→ half circuit (AC analsyis) :



→ $A_{v_d} = \frac{V_{od}}{V_{id}} = \frac{V_o}{V_{gs}} = -g_m (R_{on} // R_{op})$

• $R_{on} = g_{m_3} r_{o3} R_s = g_m r_{o3} r_{o1}$

• $R_L = R_{op} = g_{m5} r_{o5} r_{o7}$

$\therefore A_{v_d} = \checkmark$

EX (9.5)

0.18 μm CMOS $\mu_n C_{ox} = 4 \mu_p C_{ox} = 400\ \mu A/V^2$

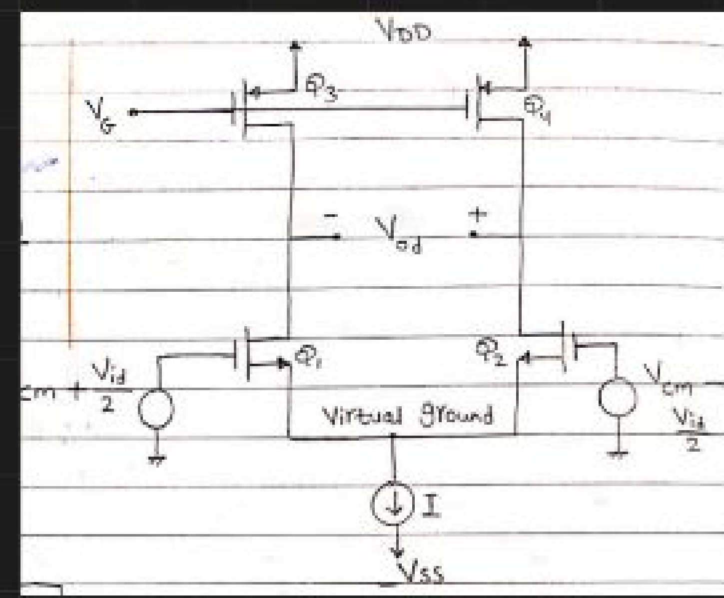
$|V_t| = 0.5$ V $|V_A'| = 10$ V/μm

$I = 200\ \mu A$ $L = 2$ minimum $= 2(0.18) = 0.36\ \mu m$

$|V_{ov}| = 0.2$ V "diff. Amp. with C.S"

find : * $\frac{W}{L}$ for Q_1, Q_2, Q_3, Q_4

* the differential voltage gain A_d



- $I_{D_1} = I_{D_2} = \frac{I}{2} = \frac{200}{2} = 100\ \mu A$
- $I_D = \frac{1}{2} k_{n_1}' \left(\frac{W}{L}\right)_1 (V_{ov})^2$

$\therefore 100\mu = \frac{1}{2}(400\mu)\left(\frac{W}{L}\right)_1 (0.2)^2$

$\therefore \boxed{\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2 = 12.5}$

$I_D = \frac{1}{2} k_{n_3}' \left(\frac{W}{L}\right)_3 (V_{ov})^2$

$100\mu = \frac{1}{2}(100\mu)\left(\frac{W}{L}\right)_3 (0.2)^2$

$\therefore \boxed{\left(\frac{W}{L}\right)_3 = \left(\frac{W}{L}\right)_4 = 50}$

- $A_d = -g_m (r_{o_1} \parallel r_{o_3})$

$\rightarrow r_{o_1} = \frac{V_A}{I_D} = \frac{V_A' L}{I_D} = \frac{(10)(0.36)}{100\mu} = 36\ K\Omega$

$\rightarrow r_{o_3} = \text{-------} = \frac{(10)(0.36)}{100\mu} = 36\ K\Omega$

$\rightarrow g_{m_1} = \frac{2 I_D}{V_{ov}} = \frac{I}{V_{ov}} = \frac{200\mu}{0.2} = 1\ mA/V$

$\therefore A_d = -(1)\left(\frac{1}{2} \times 36\right) \rightarrow \therefore \boxed{A_d = -18}$

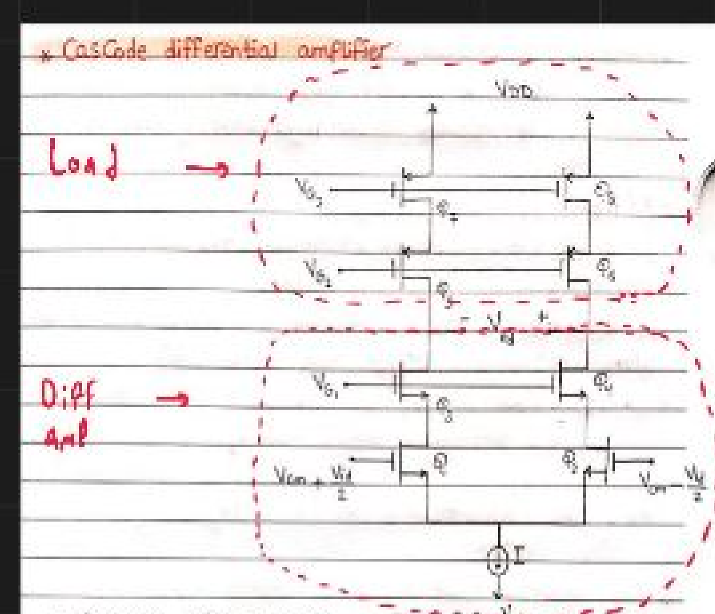
EX (9.6) Cascode diff. amplifier

$\mu_n C_{ox} = 4 \mu_p C_{ox} = 400\ \mu A/V^2$ $|V_t| = 0.5$ V

$|V_A'| = 10$ V/μm $I = 200\ \mu A$ $L = 0.36\ \mu m$

$|V_{ov}| = 0.2$ V

find : ① $\frac{W}{L}$ for each of $Q_1 \rightarrow Q_8$ ② A_d



- $I_{D_1} = \frac{1}{2} k_{n_1}' \left(\frac{W}{L}\right)_1 (V_{ov})^2$

$100\mu = \frac{1}{2}(400\mu)\left(\frac{W}{L}\right)_1 (0.2)^2$

$\therefore \boxed{\left(\frac{W}{L}\right)_{1,2,3,4} = 12.5}$

- $I_{D_5} = \frac{1}{2} k_{n_2}' \left(\frac{W}{L}\right)_5 (V_{ov})^2$

$100\mu = \frac{1}{2}(100)\left(\frac{W}{L}\right)_5 (0.2)^2$

$\therefore \boxed{\left(\frac{W}{L}\right)_{5,6,7,8} = 50}$

- $A_d = -g_{m_1} (R_{on} \parallel R_{op})$

$R_{on} = g_{m_3} r_{o_3} r_{o_1}$

$R_{op} = g_{m_5} r_{o_5} r_{o_7}$

- $r_o = \frac{V_A}{I_D} = \frac{V_A' L}{I_D} = 36\ K\Omega$
- $g_m = \frac{2 I_D}{V_{ov}} = \frac{I}{V_{ov}} = 1\ m\Omega^{-1}$

$\therefore R_{on} = 36^2\ K\Omega$

$\therefore R_{op} = 36^2\ K\Omega$

$\therefore \boxed{A_d = g_{m_1} \frac{36^2}{2} = 648}$

Prob. (9.20)

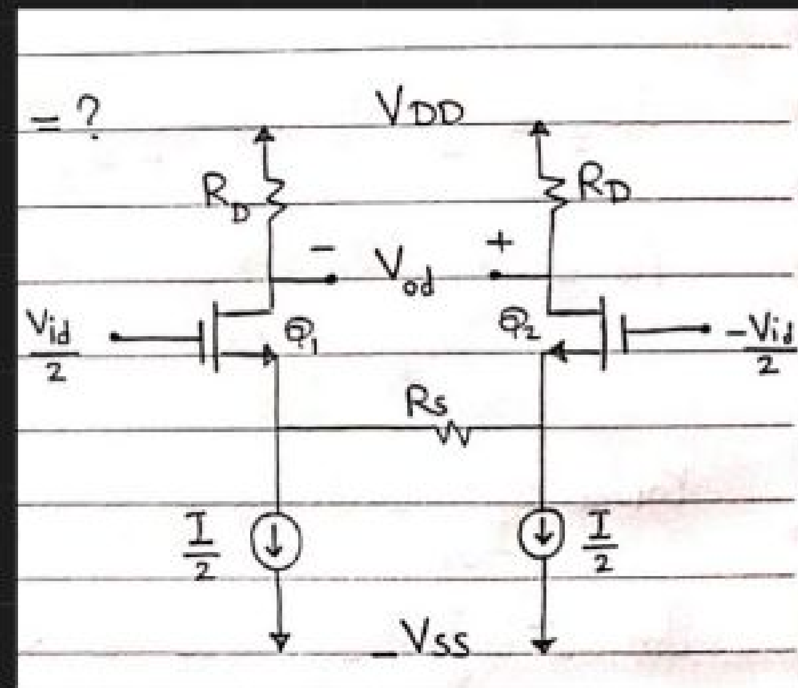
find the diff. half Circuit, derive an expression for A_d

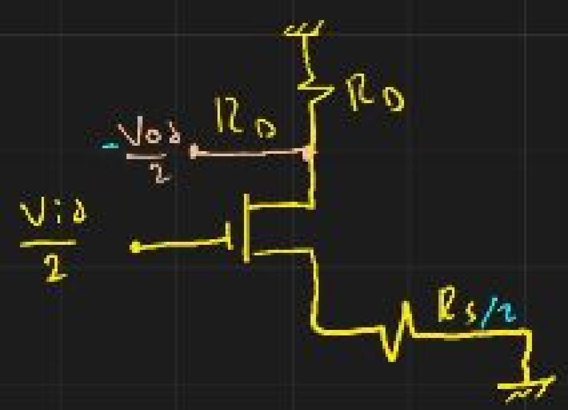
$A_d = \frac{V_{od}}{V_{id}} = f(g_m, R_D, R_s)$, neglect early effect.

1 → What is the gain $R_s = 0$ ⟶ $A_{d\,max}$

2 → " " " Value of R_s $f(\frac{1}{g_m})$ that reduce gain to half Value

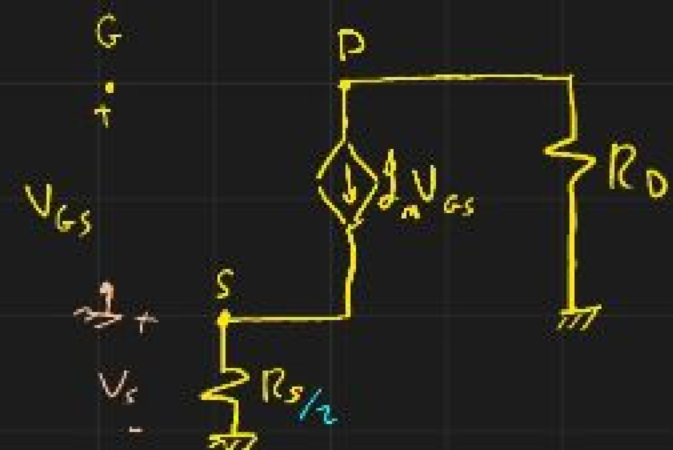
= ?





→ at first glance (R_s ussually very small) → $A_d = -g_m(R_D)$

→ Small signal model:



$A_{vd} = \frac{V_{od}}{V_{id}} = \frac{V_{od}/2}{V_{id}/2} = \frac{V_D}{V_G}$

→ $V_D = -g_m V_{GS}(R_D)$ → ① , $V_{GS} = V_G - V_s = \frac{V_{id}}{2} - V_s$

∴ $V_D = -g_m\left(\frac{V_{id}}{2} - V_s\right)(R_D)$

∴ $V_s = g_m V_{GS} R_s = g_m\left(\frac{V_{id}}{2} - V_s\right) R_s$

∴ $V_s = g_m \frac{V_{id}}{2}\frac{R_s}{2} - g_m V_s \frac{R_s}{2}$ ⟶ ∴ $V_s\left(1 + g_m \frac{R_s}{2}\right) = g_m \frac{V_{id}}{2}\frac{R_s}{2}$ ⟶ ∴ $V_s = \frac{g_m \frac{V_{id}}{2} R_{s/2}}{1 + g_m R_{s/2}}$

∴ $V_{GS} = V_G - V_s = \frac{V_{id}}{2} - \frac{g_m (V_{id}/2) R_{s/2}}{1 + g_m R_{s/2}} = \frac{V_{id} + \cancel{V_{id} g_m R_{s/2}} - \cancel{V_{id} g_m R_{s/2}}}{2(1 + g_m R_{s/2})} = \frac{V_{id}/2}{1 + g_m R_{s/2}}$

∴ ① → $V_D = -g_m\left(\frac{V_{id}/2}{1 + g_m R_s}\right)(R_D)$

∴ $A_{vd} = \frac{V_D}{V_{id}/2}$ ⟶ ∴ $\boxed{A_{vd} = -g_m\left(\frac{1}{1 + g_m R_{s/2}}\right)(R_D)}$

→ $A_{d\,max}$ @ $R_s = 0$ ⟶ ∴ $\boxed{A_{d\,max} = -g_m(R_D)}$

→ R_s when $A_d = \frac{1}{2} A_{d\,max}$

↳ $-\cancel{g_m}\left(\frac{1}{1 + g_m R_{s/2}}\right)(\cancel{R_D}) = -\frac{1}{2}\cancel{g_m}(\cancel{R_D})$

∴ $1 + g_m \frac{R_s}{2} = 2$

∴ $g_m \frac{R_s}{2} = 1$

∴ $\boxed{R_s = \frac{2}{g_m}}$