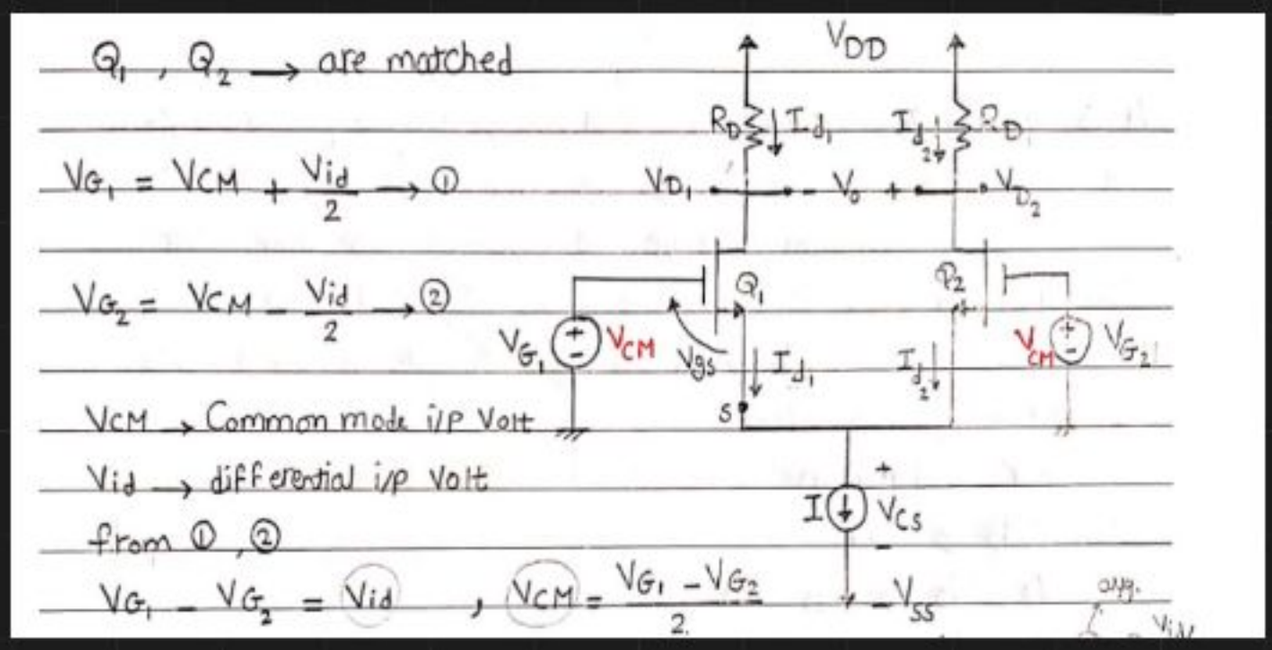
* Mos Differential Pair

- Q_1 , Q_2 are matched
- $V_{G_1} = V_{CM} + \frac{V_{id}}{2}$ ⟶ ①
- $V_{G_2} = V_{CM} - \frac{V_{id}}{2}$ ⟶ ②

- V_{CM} : Common mode input Voltage
- V_{id} : differential i/p Voltage

① - ② ⇒ $V_{G_2} - V_{G_1} = V_{id}$, $V_{CM} = \frac{V_{G_2} - V_{G_2}}{2}$



① Common mode operation:

→ $V_{G_1} = V_{G_2} = V_{CM}$

→ $i_{D_1} + i_{D_2} = I$, $i_{D_1} = i_{D_2} = \frac{I}{2}$

→ $i_{D_1} = \frac{1}{2} K_n (V_{GS} - V_t)^2$

→ $i_{D_2} = \frac{1}{2} K_n (V_{GS} - V_t)^2$

→ $V_{GS_1} = V_{GS_2}$ "matched" , $V_S = V_{CM} - V_{gs}$

→ $V_{d_1} = V_{d_2} = V_{DD} - i_d R_D$ ⟶ $V_o = V_{d_1} - V_{d_2} = 0$

- in order for the Common mode to work, V_{CM} must lay in some range

∴ $V_{DS} \geq V_{ov}$ "Saturation"

∴ $V_D - V_S \geq V_{GS} - V_t$

∴ $V_D - \cancel{V_S} \geq V_G - \cancel{V_S} - V_t$

∴ $V_D \geq V_G - V_t$

∴ $V_D \geq V_{CM} - V_t$

∴ $V_{CM} \leq V_D + V_t$

, ∴ $V_G = V_{CM}$

∴ $V_{CM_{max}} = V_D + V_t$

∴ $V_D = V_{DD} - \frac{I}{2} R_D$

∴ $V_{CM_{max}} = V_{DD} - \frac{I}{2} R_D + V_t$

- in order for the C.S to work the voltage drop accross > 0

→ $V_S - V_{CS} + V_{SS} > 0$

∴ $V_{CS} < V_S + V_{SS}$

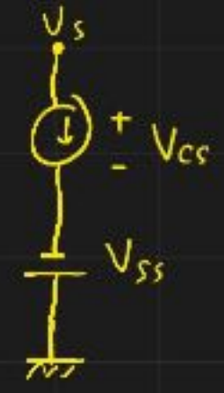
∴ $V_S = V_{CM} - V_{GS}$

∴ $V_{CS} < V_{CM} - V_{GS} + V_{SS}$

∴ $V_{CM} > V_{CS} + V_{GS} - V_{SS}$

∴ $V_{CM} > V_{CS} - V_{SS} + V_{ov} + V_t$

∴ $V_{CM_{min}} = V_{CS} + V_{ov} + V_t - V_{SS}$



∴ $V_{CM_{min}} < V_{CM} < V_{CM_{max}}$

Ex (9.1) Page (609) Very important

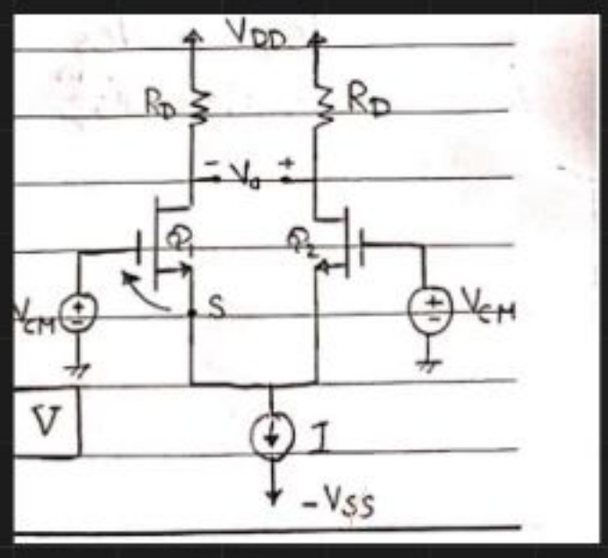
for The Mos diff. Pair with V_{CM} applied $V_{DD} = V_{SS} = 1.5V$

$K_n(\frac{W}{L}) = 4\ mA/V^2$, $V_t = 0.5\ V$, $I = 0.4\ mA$, $R_D = 2.5\ K\Omega$

neglect Channel length modulation ($\lambda = 0$). assume The C.S (I) requires min Voltage of 0.4 V ($V_{CS} = 0.4\ V$)

* ترتيب الأسئلة في الكتاب مختلف عشان زي ماقولنا المفروض نجيب ال range بتاع ال V_{CM} عشان نعرف هنكمل ولا لأ والدكتور قال هيجيبها كده في الامتحان نجيب ال range وبعد كده نبدأ نحل.

① find V_{OV}, V_{GS} for each transistor



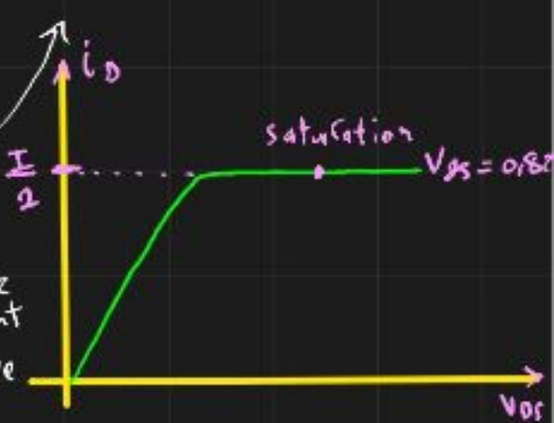
$\therefore i_{D_1} = i_{D_2} = \frac{I}{2} = \frac{0.4}{2} = 0.2\ mA$

$\therefore i_D = \frac{1}{2} K_n (V_{OV})^2$

$\therefore 0.2\ m = \frac{1}{2}(4\ m)(V_{OV})^2 \rightsquigarrow \therefore V_{OV} = 0.32\ v \rightsquigarrow V_{GS} = V_{OV} + V_t = 0.32 + 0.5 \rightsquigarrow \therefore V_{GS} = 0.82\ v$

Q_1, Q_2 matched $\rightsquigarrow V_{GS_1} = V_{GS_2}$, $V_{OV_1} = V_{OV_2}$

② for $V_{CM} = 0$, find V_S, I_{D_1}, I_{D_2}, V_{D_1}, V_{D_2}, V_O



use same V_{GS}? Yes because $I/2$ is constant ∴ same curve

$\rightarrow \therefore V_S = V_{CM} - V_{GS} \rightsquigarrow \therefore V_S = 0 - 0.82\ v \rightsquigarrow \therefore V_S = -0.82\ v$

$\rightarrow I_{D_1} = I_{D_2} = \frac{I}{2} = 0.2\ mA$

$\rightarrow V_{D_1} = V_{D_2} = V_{DD} - \frac{1}{2} I R_D \rightsquigarrow \therefore V_D = 1.5 - 0.2(2.5) \rightsquigarrow \therefore V_{D_1} = V_{D_2} = 1\ v$

$\rightarrow V_O = V_{O_2} - V_{O_1} = 0$

. to make sure in Saturation

$\rightarrow V_{DS} = V_D - V_S = 1 + 0.82$

$\therefore V_{DS} = 1.82 > V_{OV}$ ✓

. to make sure C.S works

$V_{GS} = V_S + V_{SS} = -0.82 + 1.5$

$\therefore V_{GS} = 0.68\ v > V_{CM_{min}} = 0.4$ ✓

③ Repeat ② @ $V_{CM} = 1V$

. $V_S = V_{CM} - V_{GS} = 1 - 0.82 \rightsquigarrow \therefore V_S = 0.18\ v$

. $V_{D_1} = V_{D_2} = V_{DD} - \frac{I}{2} R_D = 1.5 - 0.2(2.5) \rightsquigarrow \therefore V_{D_1} = V_{D_2} = 1\ v$

→ check Saturation

↳ $V_{DS} = V_D - V_S = 1 - 0.18 \rightsquigarrow \therefore V_{DS} = 0.82\ v > V_{OV}$ ✓

→ no need to check V_{GS} here, because we increased $V_{CM} \uparrow \rightsquigarrow V_S \uparrow \rightsquigarrow V_{GS} \uparrow$ and it was already working.

④ @ $V_{CM} = -0.2\ V$

→ We decleased $V_{cm}\downarrow \rightsquigarrow V_s\downarrow \rightsquigarrow V_{cs}\downarrow$ might not work needs to check

$\rightsquigarrow V_{DS}\uparrow$ no need to check satalation

- $V_s = V_{CM} - V_{GS} = -0,2 - 0,82 \rightsquigarrow \therefore V_s = -1,02v$
- $V_{cs} = V_s + V_{SS} = -1,02 + 1,5 \rightsquigarrow \therefore V_{cs} = 0,48\ v > V_{cs_{min}}$ ✓
- $V_{D_1} = V_{D_2} = 1\ v$
- $I_{D_1} = I_{D_2} = 0,2\ mA$

⑤ highest permitted Value of V_{CM} ($V_{CM\,max}$)

→ $V_{DS} \geq V_{ov}$

$\therefore V_{DS} \geq V_{GS} - V_t$

$\therefore V_D - V_S \geq V_G - V_S - V_t$

$\therefore V_D \geq V_G - V_t$

$\therefore V_D \geq V_{CM} - V_t$

$\therefore V_{CM} \leq V_D + V_t$

$\therefore V_{CM_{max}} = V_D + V_t$

$= 1 + 0,5$

$\therefore \boxed{V_{CM_{max}} = 1,5}$

⑥ Lowest Value of V_{CM} ($V_{CM_{min}}$)

→ $V_s - V_{cs} + V_{SS} > 0$

$\therefore V_{cs} < V_s + V_{SS}$

$\therefore V_{cs} < V_{CM} - V_{GS} + V_{SS}$

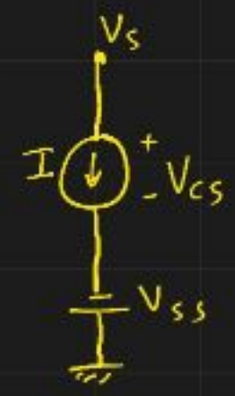
$\therefore V_{CM} > V_{cs} + V_{GS} - V_{SS}$

$\therefore V_{CM_{min}} = V_{cs_{min}} + V_{GS} - V_{SS}$

$\therefore = 0,4 + 0,82 - 1,5$

$\therefore \boxed{V_{CM_{min}} = -0,28\ v}$

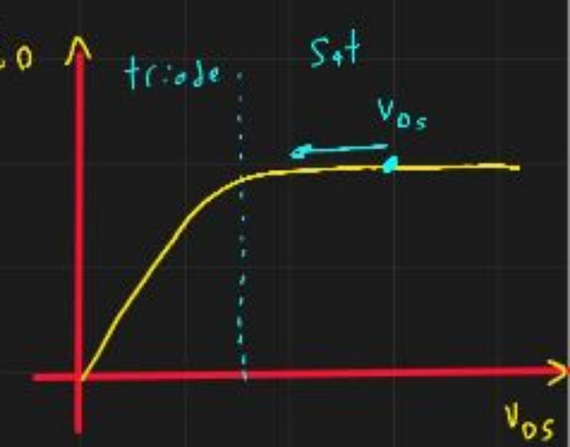
$\therefore \boxed{-0,28 < V_{CM} < 1,5}$



• Notes:

→ if $V_{CM} > V_{CM_{max}}$ ⟶ Mosfet won't be in saturation and will enter triod

→ V_{CM} ↑↑ V_S ↓↓ V_{DS} ↓↓



→ as V_{cm} changes while $V_{cm_{min}} < V_{cm} < V_{cm_{max}}$ ⟶ V_{GS} remains constant,

V_S changes, $I_{D_1} = I_{D_2} = \frac{I}{2}$ no change because I and V_{GS}.