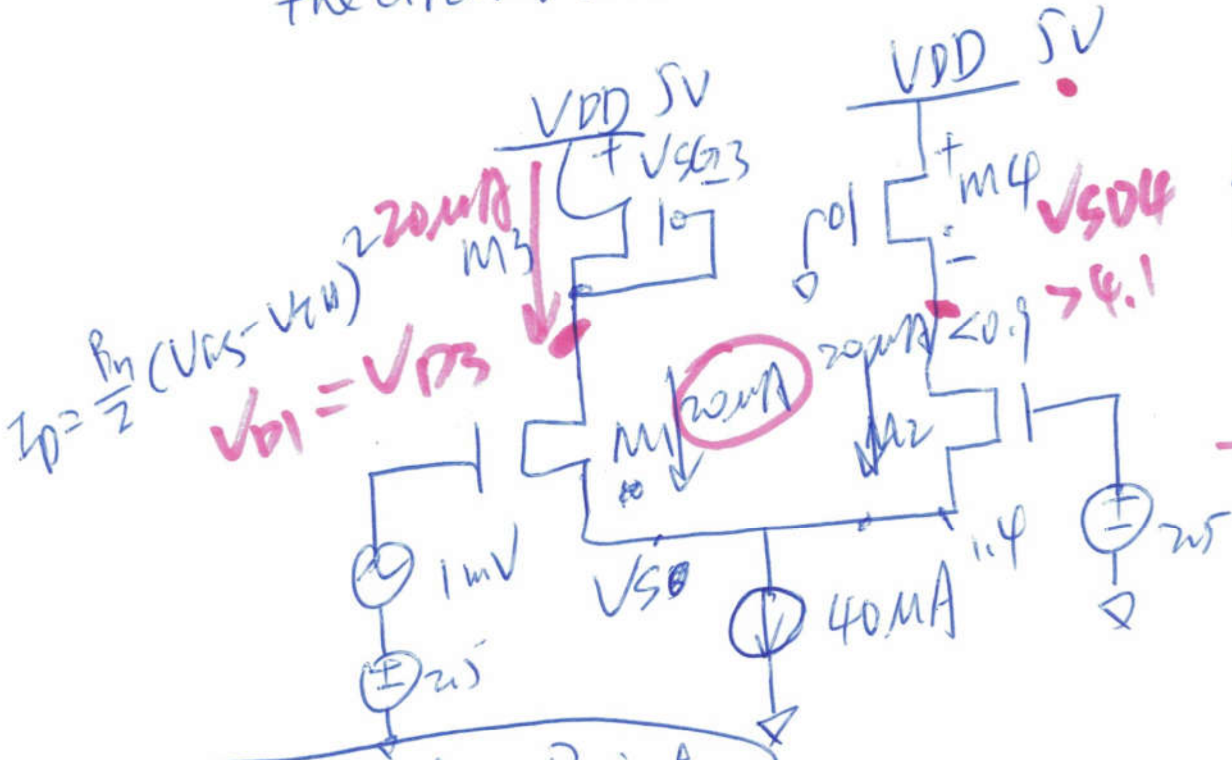
The Differential Pair

Calculate the DC and AC voltages and currents for the circuit seen below:



NMOS: 10/2
PMOS: 30/2

scale: 300nm
2 × 300nm
= 600nm
500nm

CS ON's Semiconductor.

DC Operating Point

① M_1, M_2 have the same V_{GS}.

② $V_{GS1} = \sqrt{\frac{2I_D}{\beta_n}} + V_{THN} = \sqrt{\frac{2 \cdot 20\mu A}{120\mu \cdot \frac{10}{2}}} + 0.8$

$= 1.058V$

$V_S = V_{G1} - V_{GS1} = 2.5 - 1.058 = 1.442\ V$

③ M_3 is Gate–Drain connected, operating in saturation

$V_{SG3} = \sqrt{\frac{2I_D}{\beta_p}} + V_{THP} = \sqrt{\frac{2\times 20\mu A}{40\mu \cdot \frac{30}{2}}} + 0.9 = 1.158\ V.$

④ $V_{D3} = V_{D1} = 5 - V_{SG3} = 5 - 1.158 = 3.842\ V.$

⑤ $V_{G4} = 0.\quad V_{SG4} = 5\ V.$

$V_{SD4} > V_{SG4} - V_{THP}$

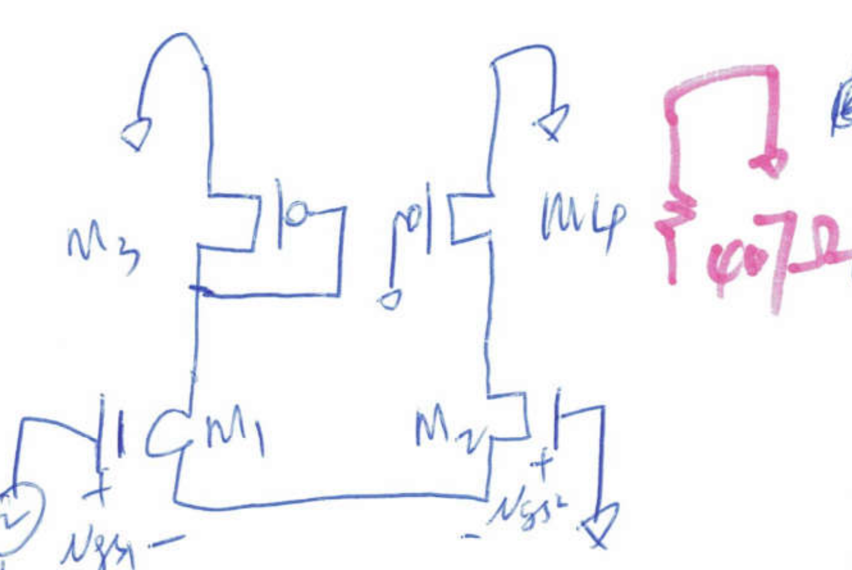
$= 5 - 0.9 = 4.1\ V$

$\Rightarrow V_{D4} = V_{D2} < 0.9$ to make M_4 operates in saturation region.

⑥ M_4 is not in saturation, M_4 is not off } M_4 is operating in the linear region.

(2)

AC Analysis



DC source is the AC ground

$V_{GS} = \sqrt{\frac{2I_D}{\beta_n}} + V_{TH}$

① $g_{m1} = g_{m2} = \sqrt{2\beta_n I_D}$

$= \sqrt{2 \cdot 100\mu \frac{10}{2} \cdot 20\mu} = 150\,\mu A/V$

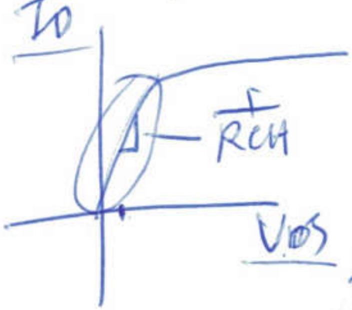
$I_D = \frac{\beta_n}{2}(V_{GS} - V_{THN})^2$

$g_m = \frac{\delta I_D}{\delta V_{GS}} = \beta_n(V_{GS} - V_{THN})$

$\frac{\Delta I_D}{\Delta V_{GS}} = g_m$

② $g_{m3} = \sqrt{2\beta_p I_D} = \sqrt{2 \cdot 40\mu \frac{30}{2} \cdot 20\mu A}$

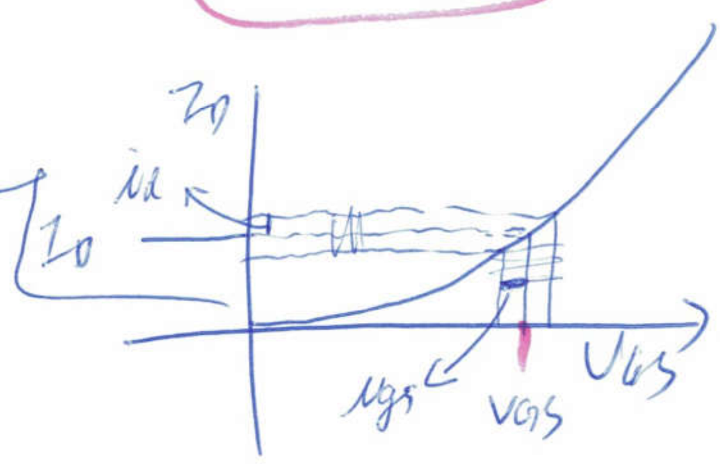
$= 150\,\mu A/V$



③ M4: $I_D = \beta_n\left[(V_{GS} - V_{THP})V_{SD} - \frac{V_{SD}^2}{2}\right]$

$\frac{1}{R_{CH}} = \frac{\delta I_D}{\delta V_{SD}} = \beta_p(V_{GS} - V_{THP} - V_{SD})$

$\approx \beta_p(V_{SG} - V_{THP})$



②

$$\frac{1}{R_{CH}} = 40\mu \cdot \frac{30}{2}(1.159 - 0.9)$$

$$R_{CH} = 407\,\Omega$$

(4) M_3. $\dfrac{g_{m3} \cdot v_{sg3}}{v_{sg3}} = g_{m3} \cdot v_{sd3}$

$= i_d$

$g_m = \beta_p (V_{SG3} - V_{THP})$

$g_{m3} = \dfrac{i_d}{v_{sd3}}$