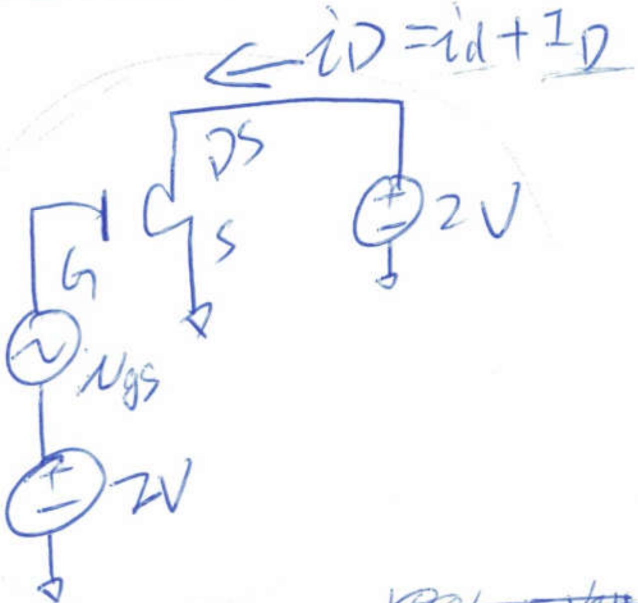
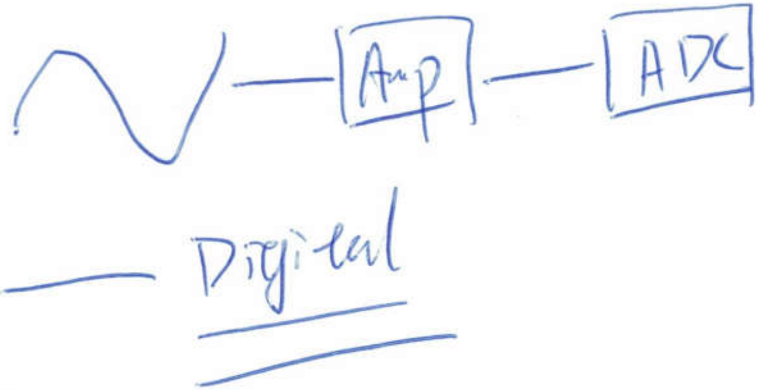
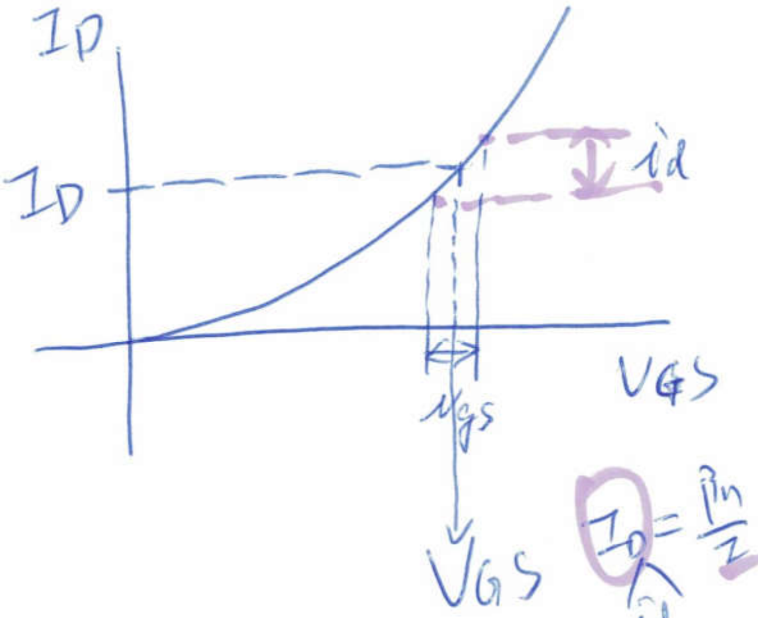
MOSFET Small Signal Models.





~~$V_{gs} - V_{TH}$~~



$$\underset{\hat{i_d}}{I_D} = \frac{\beta_n}{2}\left(\underset{+v_{gs}}{V_{GS}} - V_{THN}\right)^2$$

v_{gs} → small signal (AC

V_{GS} → DC bias (DC

v_{GS} → AC+DC

i_d → AC current

I_D → DC current

i_D → AC+DC

$$i_D = I_D + i_d = \frac{\beta_n}{2}(\underbrace{v_{gs} + V_{GS}}_{v_{GS}} - V_{THN})^2 \qquad \beta_n = \boxed{KP\frac{W}{L}}$$

$$\frac{\delta i_D}{\delta v_{GS}} = \beta_n (v_{GS} - V_{THN})$$

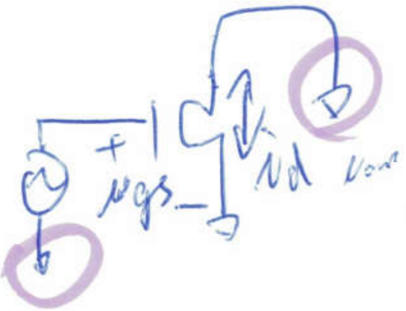
because $V_{GS} >> v_{gs}$

$$\frac{\delta i_D}{\delta v_{GS}} \approx \underline{\beta_n (V_{GS} - V_{THN}) = \boxed{g_m}}$$ Transconductance

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

$$g_m = \sqrt{2 I_D \beta_n}$$

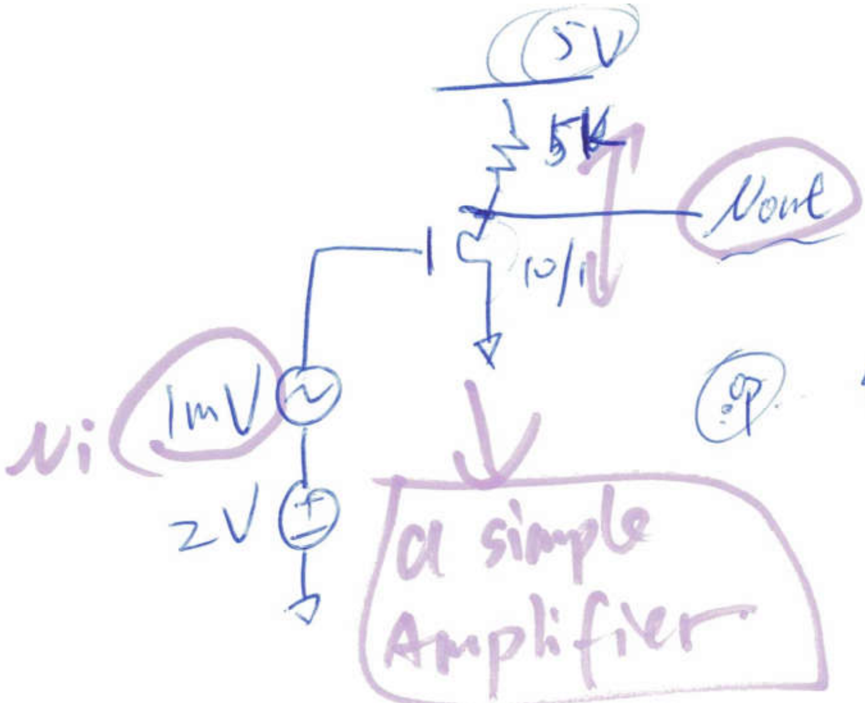
DC source is the AC ground



step1: get I_D: $I_D = \frac{\beta_n}{2}(V_{GS} - V_{THN})^2 = \dots$

step2: $g_m = \sqrt{2 I_D \beta_n} =$

step3: $\boxed{i_d = g_m v_{gs}} = \dots$



$K_p = 100\mu A/V^2$ v_{out}?

Start from the $\overset{DC}{\text{operating}}$ point

step1: $I_D = \frac{100\mu}{2}\cdot\frac{10}{1}(2-1)^2$ $\underline{V_{THN}=1V}$

$= 500\mu A$

$V_{out} = 5 - 5K \cdot 500\mu A = 5 - 2500 \cancel{\mu} mV$

$= 2.5V$

$= V_{DS}$

$V_{DS} \overset{?}{\geq} V_{GS} - V_{THN}$

$= 2 - 1 = 1V$ Yes. saturation!

step2: $g_m = \sqrt{2 I_D \beta_n} = \sqrt{2 \cdot 500\mu \cdot \frac{100\mu}{\cancel{2}} \cdot \frac{10}{1}}$

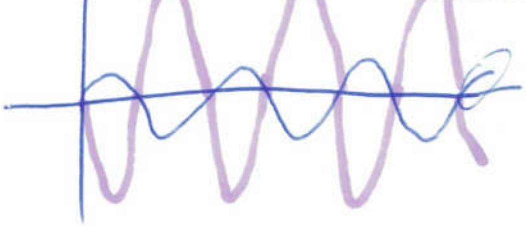
$= \sqrt{1m \cdot 1m}$

$= 1m\ A/V$

step3: $i_d = g_m v_{gs} = 1m A/V \cdot 1mV = \overset{1\mu A}{\cancel{}}$

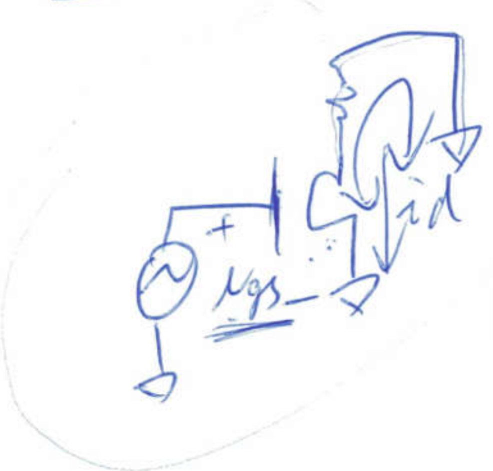
$v_{out} = -i_d \cdot 5K$

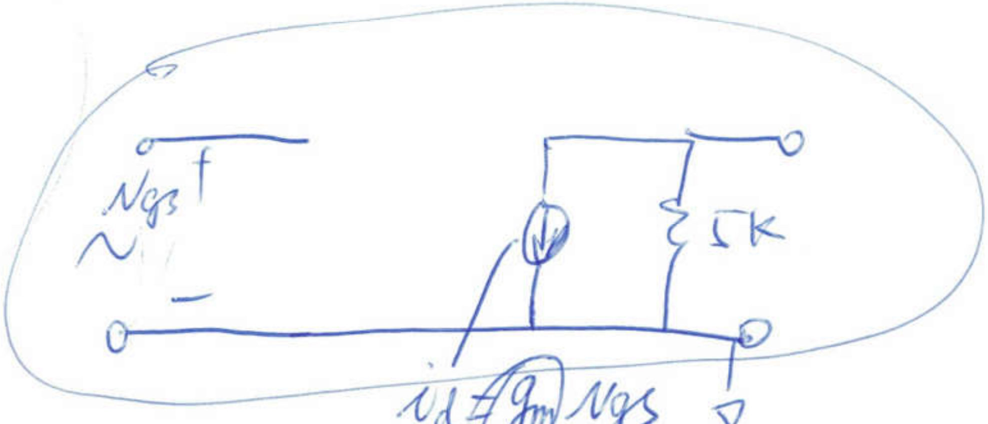
$= -5mV$



③

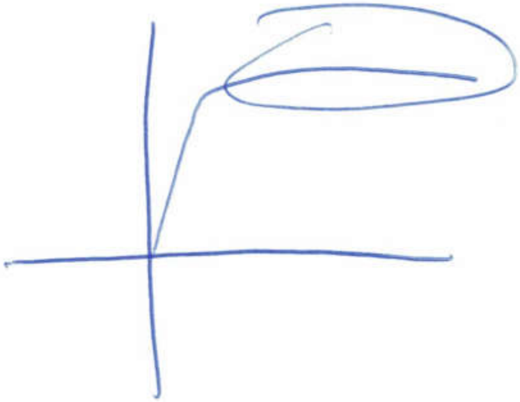
Small signal model



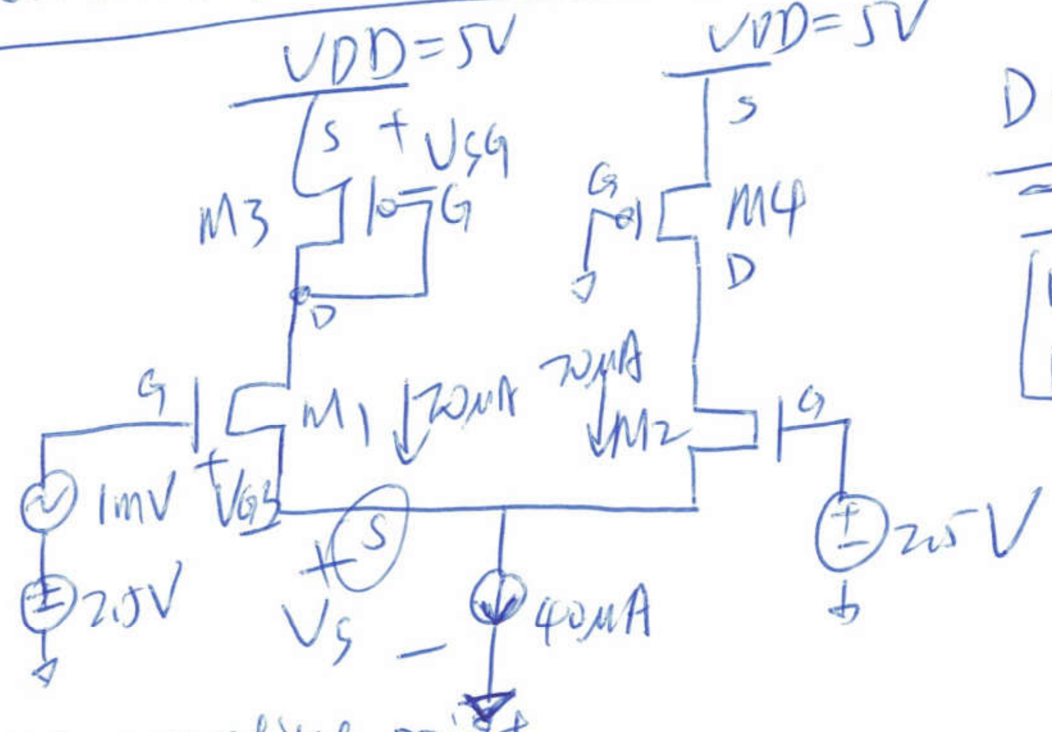


$i_d = \boxed{g_m} v_{gs}$

voltage controlled
current source



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



Differential pair.

NMOS: 10/2
PMOS: 30/2

$KP_n = 120\mu A/V$
$KP_p = 40\mu/V$.

DC operating point

① M_1, M_2 have the same V_{GS}, the same $I_D = 40\mu A/2 = 20\mu A$

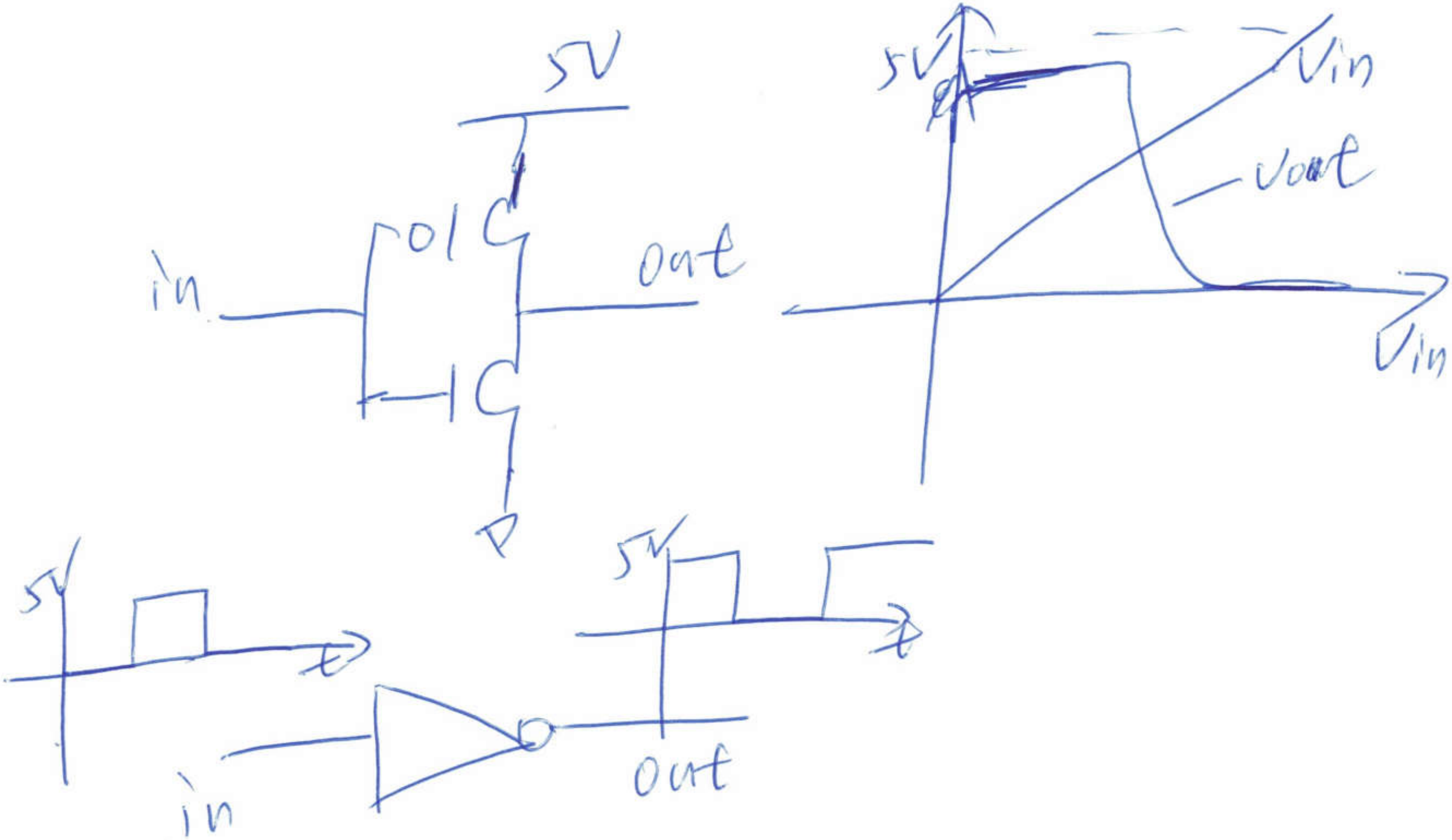
② $V_{GS} = \sqrt{\frac{2 I_D}{\beta_n}} + V_{THN} = \sqrt{\frac{2 \cdot 20\mu}{120\mu \cdot \frac{10}{2}}} + 0.8 = 1.058$.

$V_G = 2.5V$. $V_{GS} = 1.058V$. $V_S = V_G - V_{GS} = 1.442V$.

③ $V_{SG3} = \sqrt{\frac{2 \cdot I_D}{\beta_P}} + V_{THP} = \sqrt{\frac{2 \cdot 20\mu}{40 \cdot \frac{30}{2}}} + 0.9 = 1.158V$.

$V_{G3} = 5 - 1.158 = 3.842V = V_{D3} = V_{D1}$

$\boxed{CP3}$


5V
in
out
5V
Vin
Vout
Vin
5V
t
5V
t
in
out