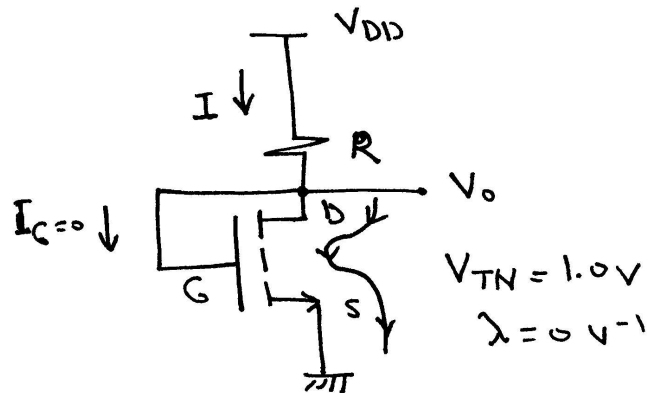


(1)



* As drain is shorted to gate

$$V_{GS} = V_{DS} \Rightarrow V_{DS} > V_{GS} - V_{TN}$$

It follows that transistor is saturated

$$I_{Ds} = \frac{K_n}{2} (V_{GS} - V_{TN})^2 \leftarrow (1)$$

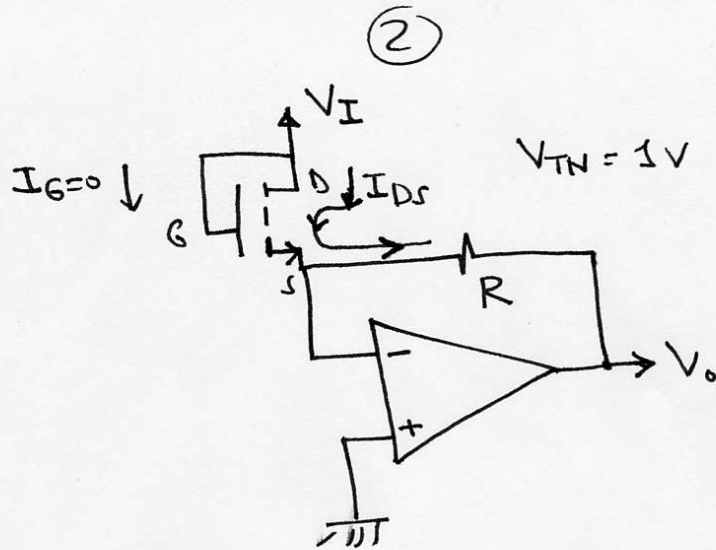
$$I = I_{Ds} = \frac{V_{DD} - V_{GS}}{R} \leftarrow (2)$$

eliminating I_{Ds} we get

$$\frac{V_{DD} - V_{GS}}{R} = \frac{K_n}{2} (V_{GS} - V_{TN})^2 \leftarrow (3)$$

(3) is then solved for V_{GS}

Check that $V_{GS} > V_{TN}$



* For the OPAMP $V^- = V^+ = 0$ because of feedback $\Rightarrow V_s = 0V$

* Drain and Gate of NMOS are shorted
 $V_D = V_G \Rightarrow V_{DS} = V_{GS} \Rightarrow V_{DS} > V_{GS} - V_T$

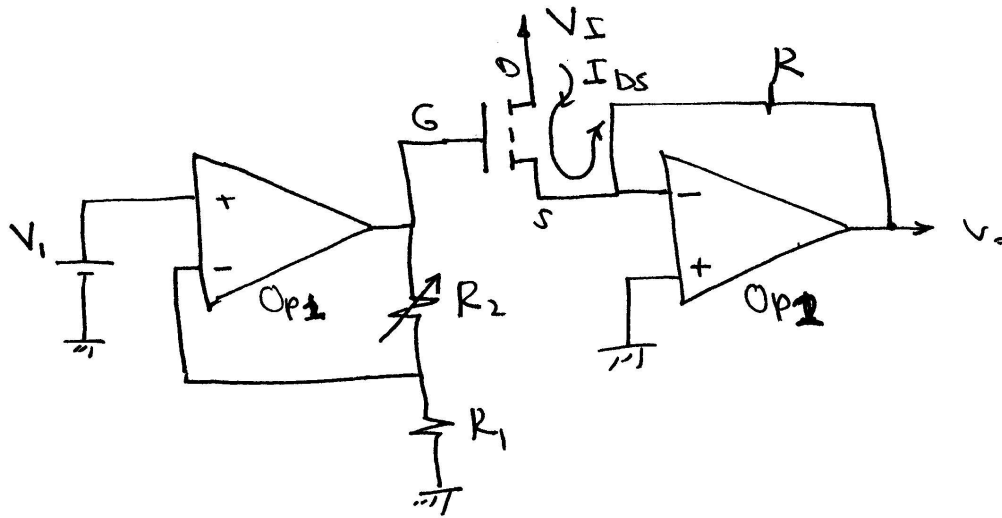
Transistor is saturated

* $V_I = V_{DS} = V_{GS}$

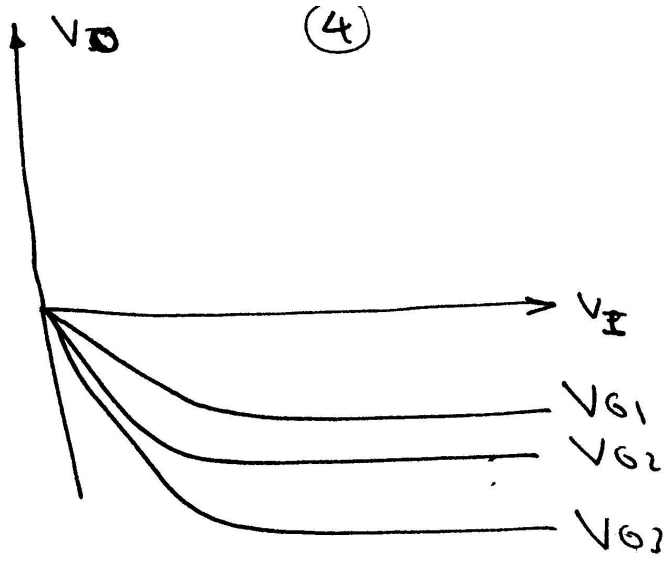
$V_o = -I_{DS}R$

By plotting V_o vs. V_I we can plot the transistor characteristics in saturation

(3)

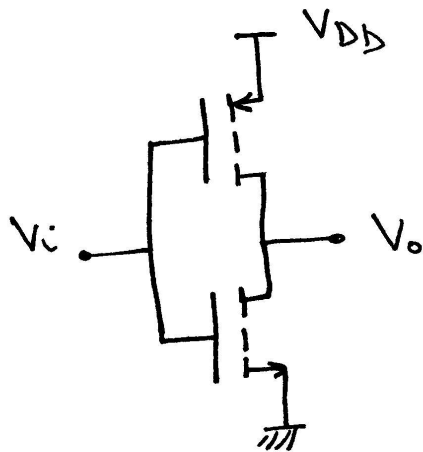


- * For Op2, $V_- = V_+ = 0 = V_S$
- * $V_I = V_{DS}$ of the NMOS transistor
- * $V_G = V_{GS} = \left(1 + \frac{R_2}{R_1}\right) V_i$
- * $V_o = -I_{DS} R$
- * by plotting V_o vs. V_I for different values of V_{GS} (by changing R_2), we get the characteristics of the NMOS



(5)

CMOS INVERTER



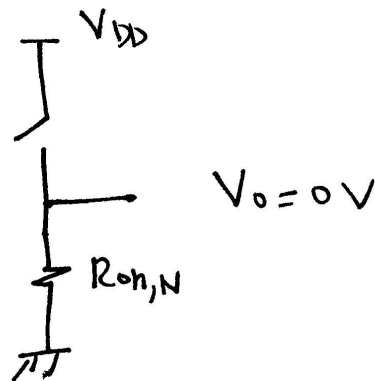
$$V_{TN} = 1V$$
$$V_{TP} = -1V$$

* if $V_i = V_{DD} \Rightarrow V_{GSN} = V_{DD} > V_{TN}$

NMOS transistor is on

$$V_{SGP} = V_{DD} - V_{DD} < -V_{TP} \Rightarrow \text{PMOS transistor is off}$$

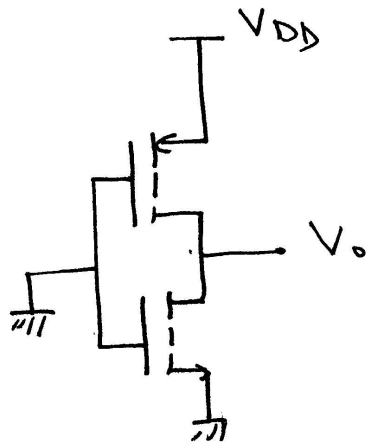
equivalent circuit



for this case $V_o = 0V$

(6)

x if $V_i = 0V$

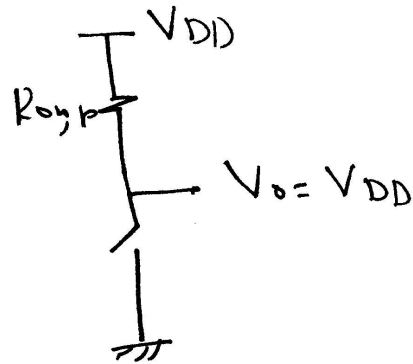


$V_{GSN} = 0V \Rightarrow$ NMOS transistor is off

$V_{SGP} = V_{SP} - V_{GP} = V_{DD} - 0 = V_{DD} > -V_{TP} = 3.0V$

PMOS transistor is on $\Rightarrow V_o = V_{DD}$

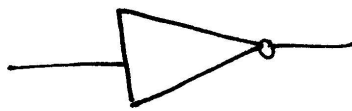
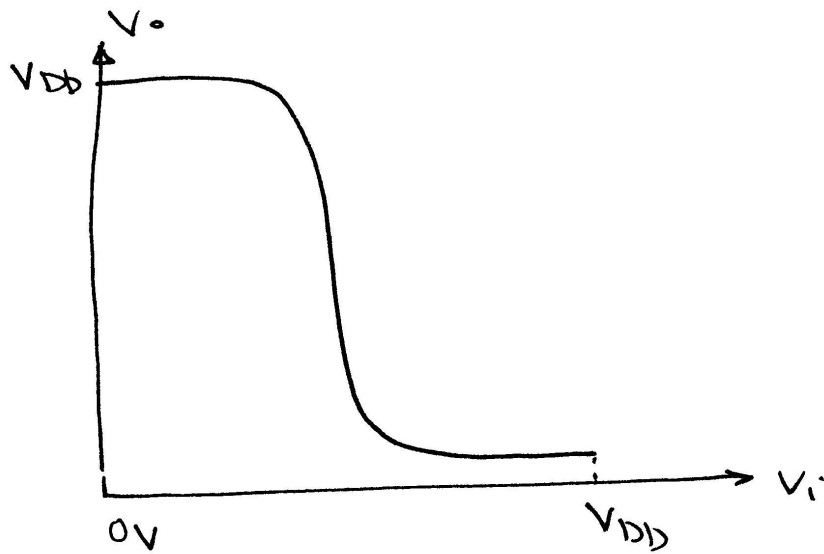
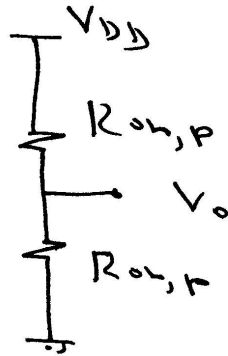
equivalent circuit



In this case $V_o = V_{DD}$

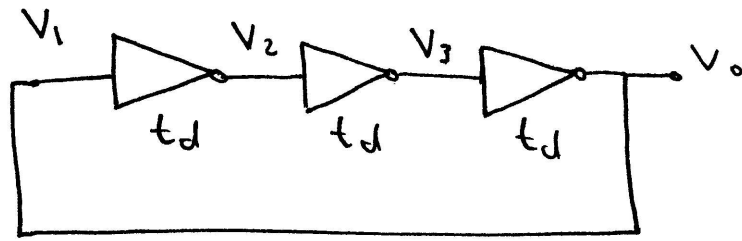
⑦

For any voltage $0 < V_i < V_{DD}$, the equivalent circuit looks like



Inverter symbol

8



Assume at time $t=0$, the voltage V_1 changed from 0V to 5V. After t_d seconds V_2 becomes 0V. After $2t_d$ seconds V_3 becomes 5V. After $3t_d$ seconds V_0 becomes 0V, i.e., $V_1=0$ and the cycle is repeated.

