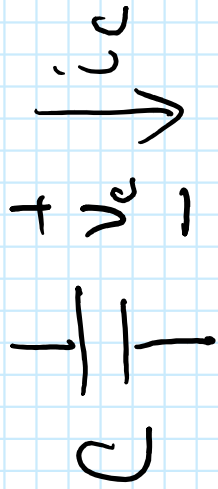


CAPACITORS

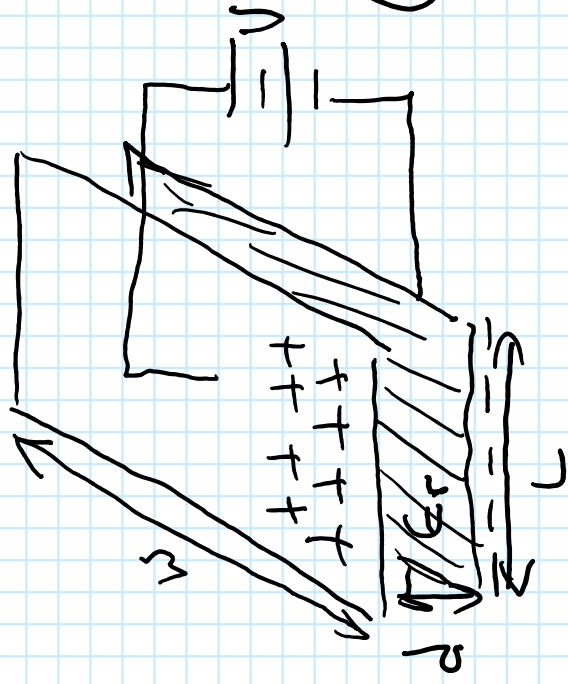


$$Q = CV$$

$$\frac{dQ}{dt} = C \frac{dV}{dt}$$

$$i_c = C \frac{dV}{dt}$$

$$A \left[\frac{C}{s} \right]$$

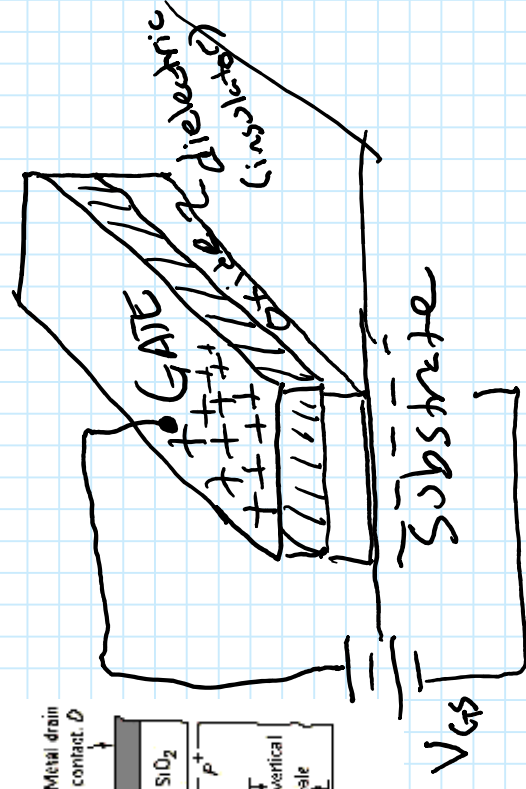
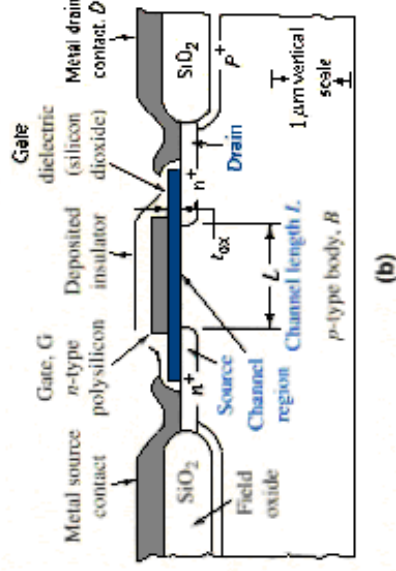
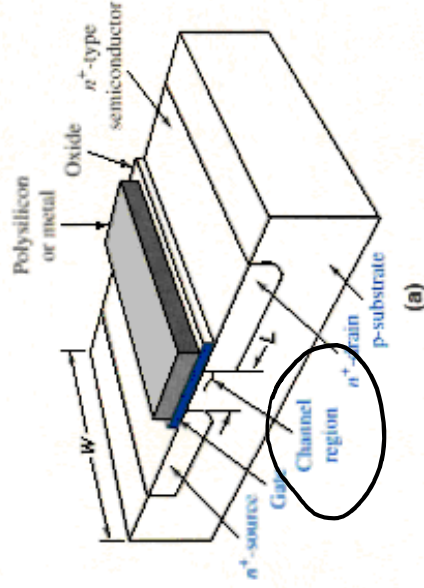


$$C = \epsilon \frac{A}{d} ; A = w \cdot l$$

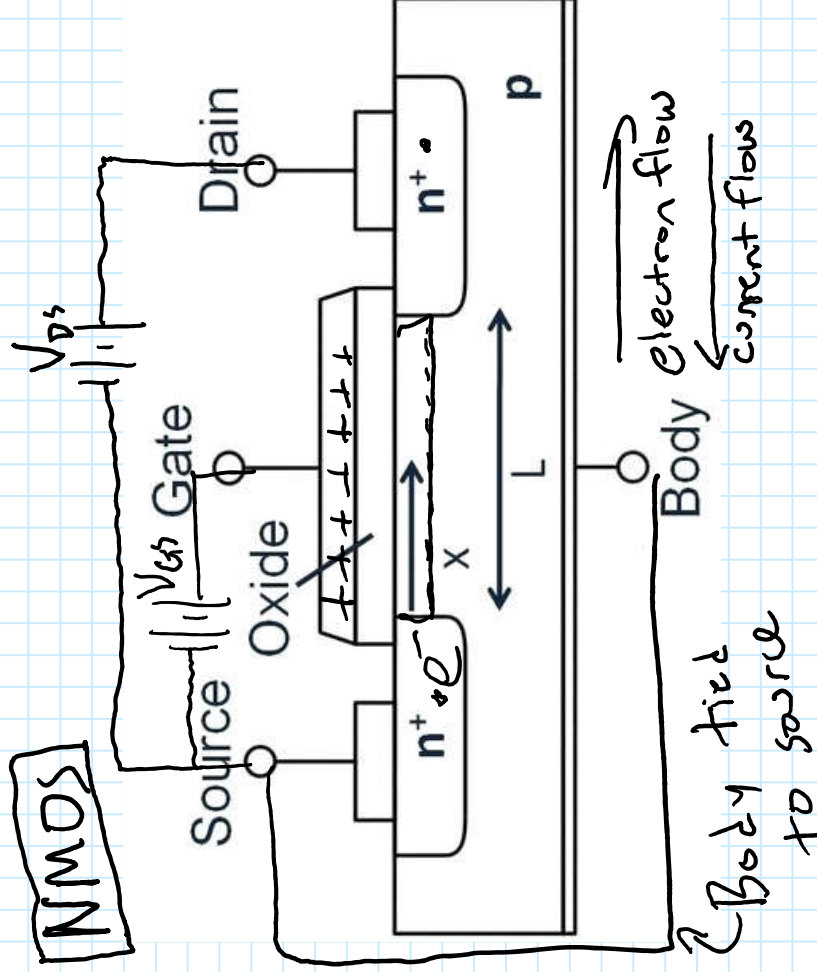
$\epsilon \Rightarrow$ Dielectric constant
 $\epsilon = \epsilon_r \epsilon_0$
 ϵ_r relative permittivity of vacuum
 ϵ_0 permittivity of vacuum

MOSFET PHYSICAL STRUCTURE

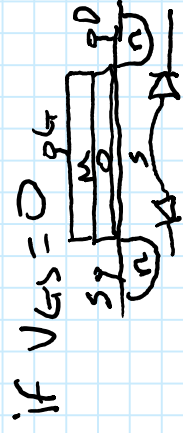
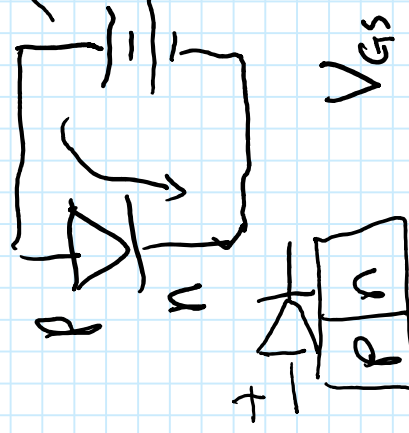
$$\text{MOSFET} = \text{Metal Oxide Semiconductor Field Effect Transistor}$$



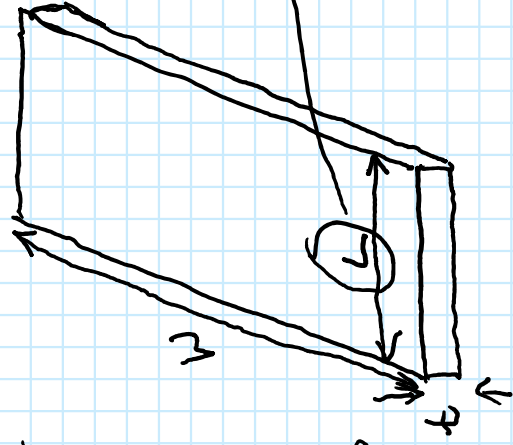
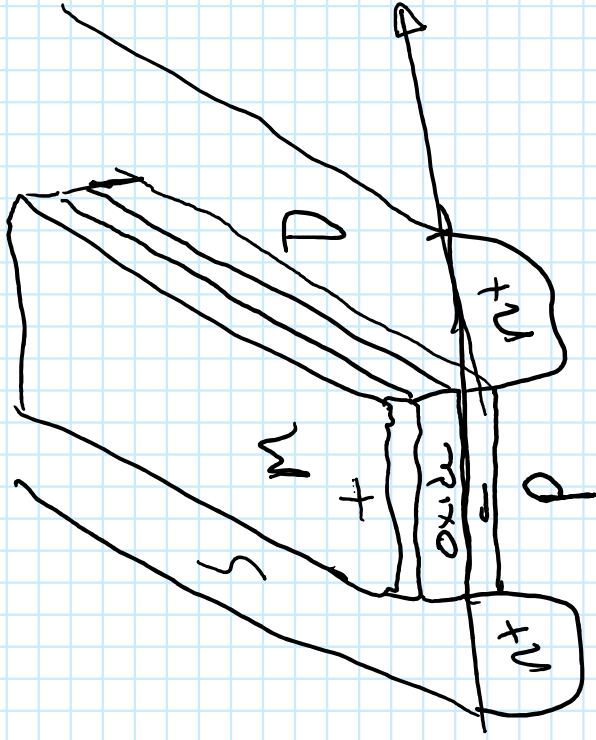
NMOS



Diode - current flows in one direction



MOSFET PHYSICAL STRUCTURE 2



Think of channel as a resistor $\sigma = \frac{1}{\rho} \propto \# \text{ electrons in channel} \propto Q$

Conductivity \uparrow

$R = \rho \frac{L}{A}$

resistivity

Channel length - critical parameter

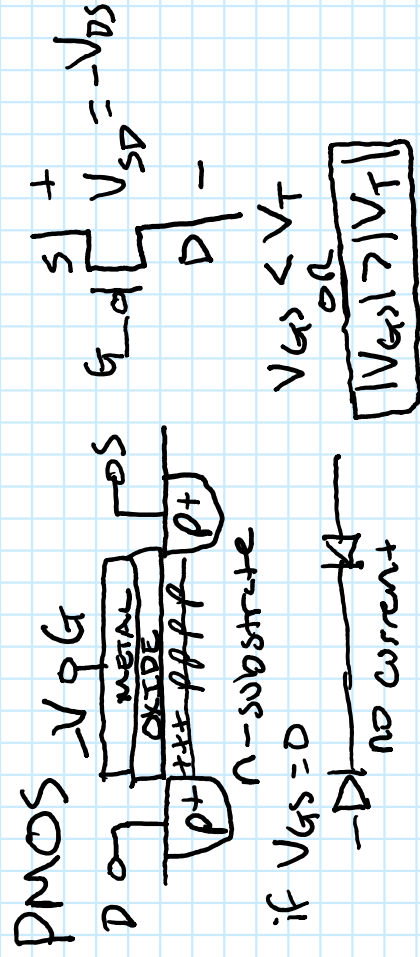
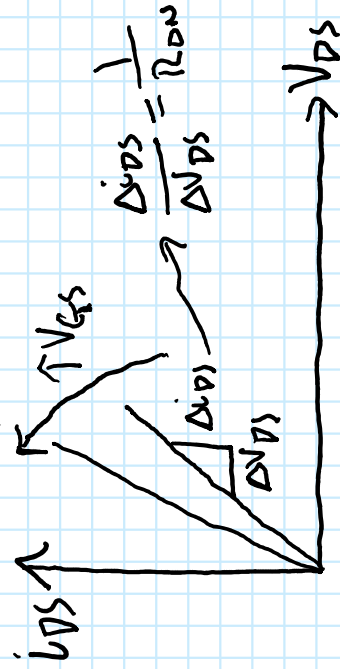
$A = t \cdot w$

$Q = CV$

$I_{GS} = 0$ ALWAYS

$V_{GS} < V_T$ $I_{DS} = 0$ CUTOFF MODE

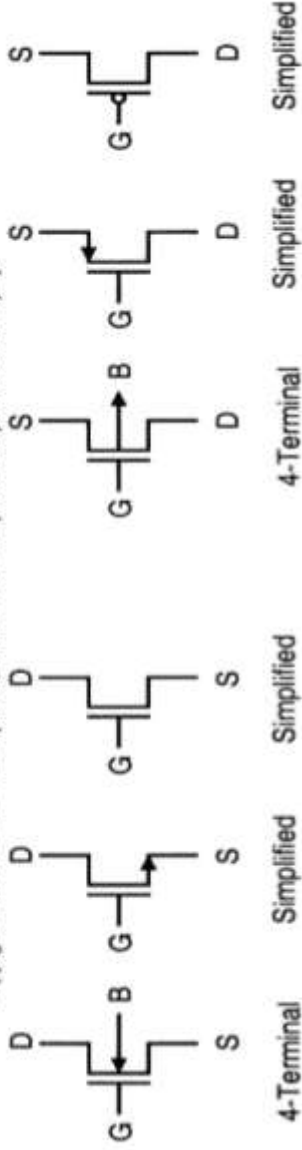
$V_{GS} > V_T$ TRIODE (S-R MODE)



CIRCUIT SYMBOLS

Circuit symbols

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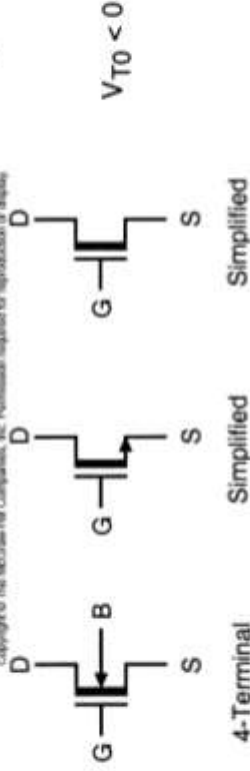


n-channel MOSFET

p-channel MOSFET

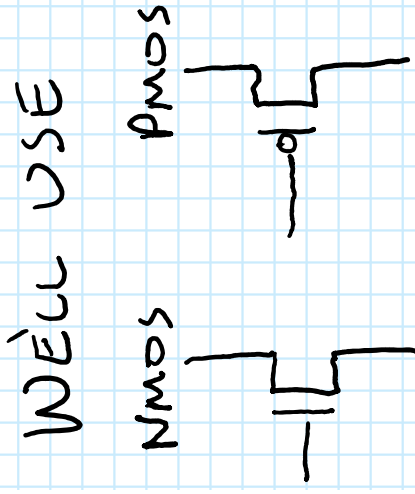
Circuit symbols for n-channel and p-channel enhancement-type MOSFETs

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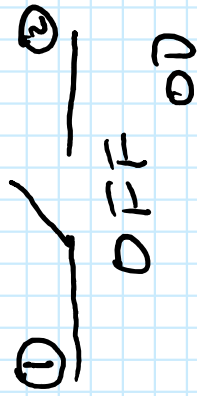
$V_{T0} < 0$

Circuit symbols for n-channel depletion-type MOSFETs

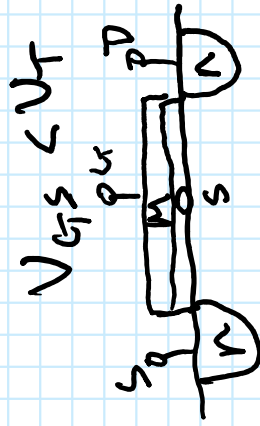


S-R MODEL

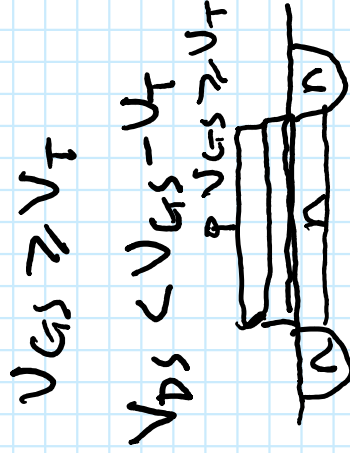
Switch - Resistor (Triode mode)



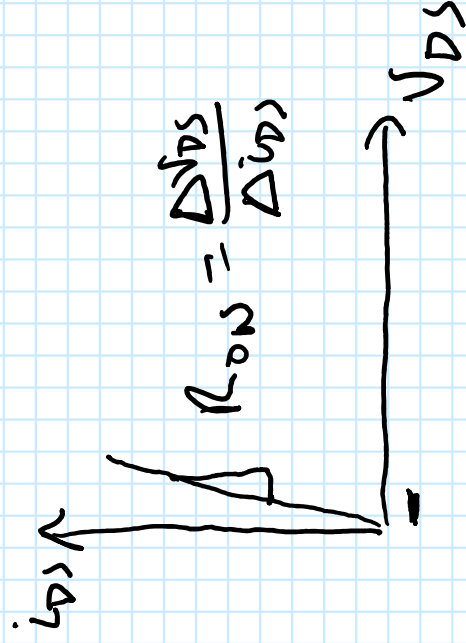
$V_{GS} < V_T$



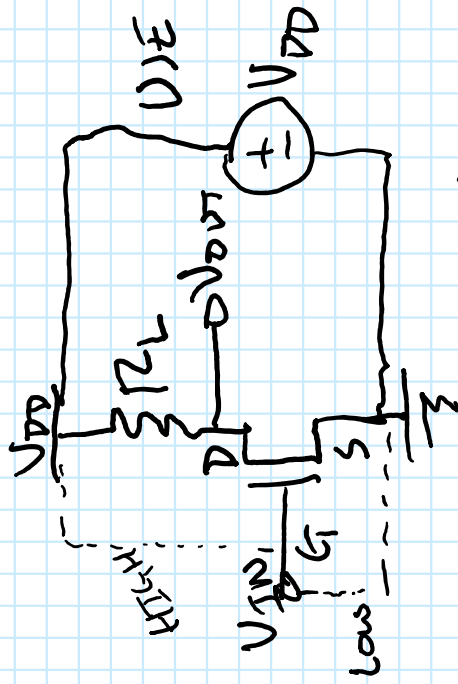
$V_{GS} \geq V_T$



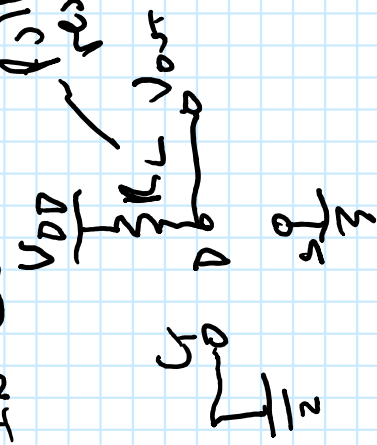
NMOS $-I_{DS}$



INVERTER CIRCUITS



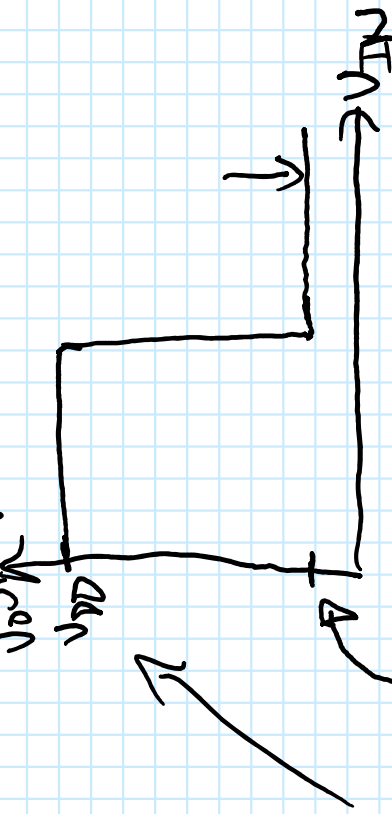
$V_{IN} < V_T$
 $V_{IN} < V_T$
 full-on resistor



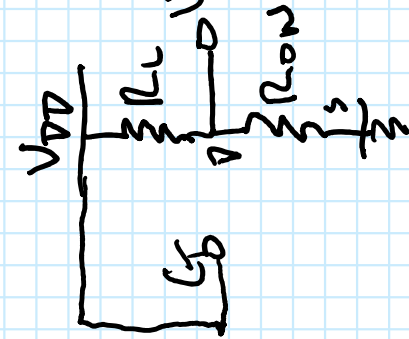
\Rightarrow

S-R MODEL

NMOS



$V_{IN} > V_T$



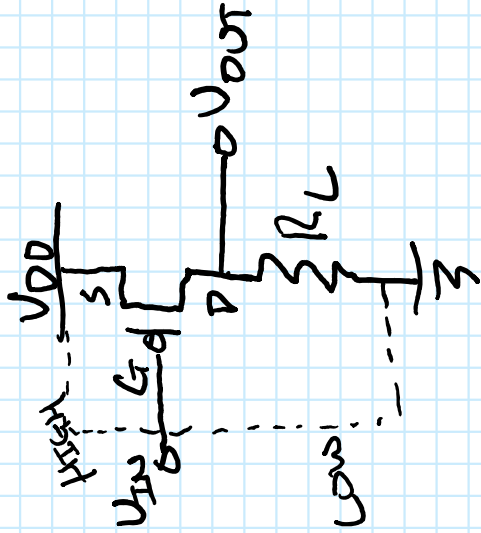
$$V_{OUT} = V_{DD} \left(\frac{R_{ON}}{R_{ON} + R_L} \right)$$

$$\frac{R_{ON}}{R_{ON} + R_L} \approx 0$$

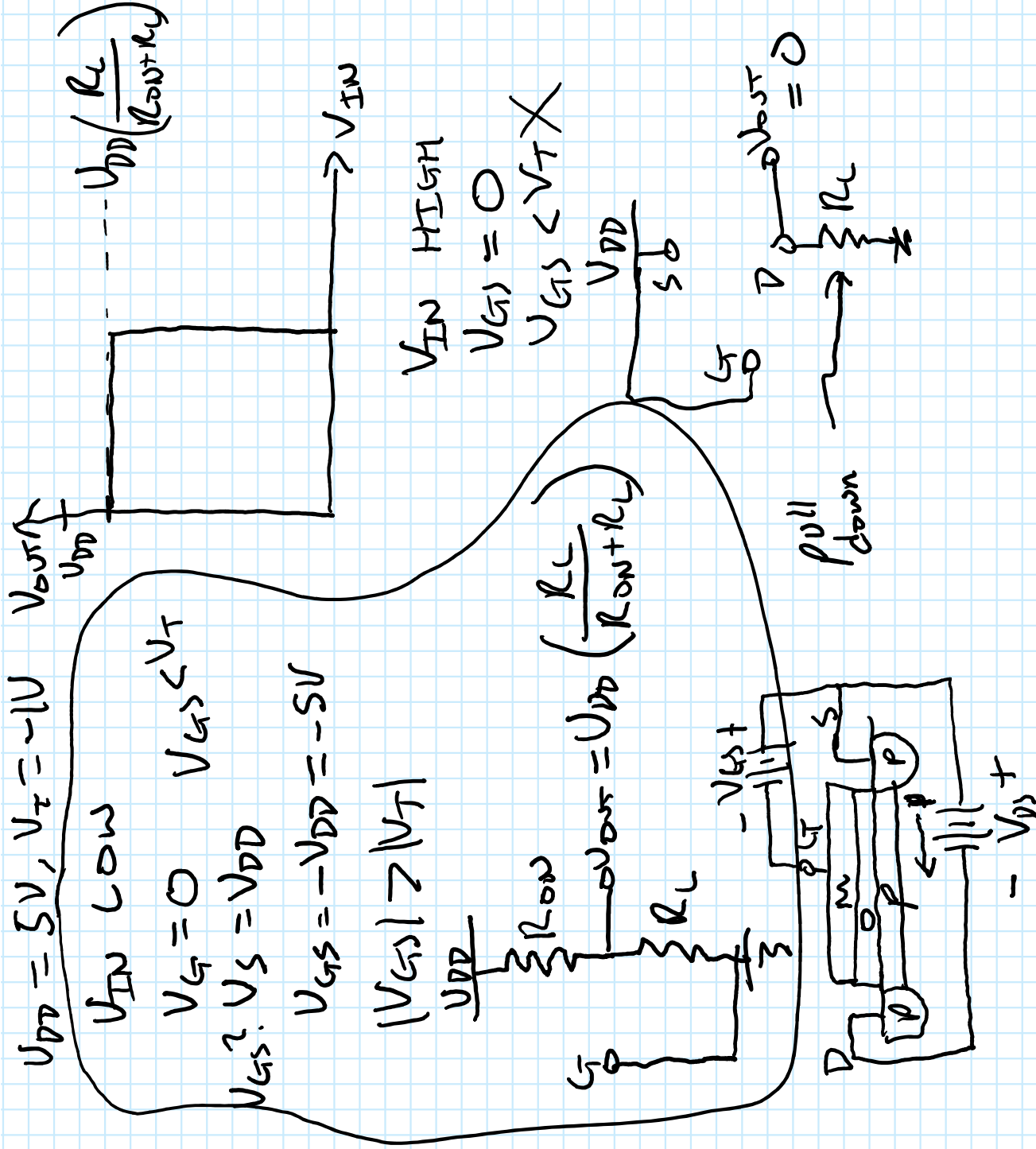
$$\frac{1}{1 + R_L/R_{ON}}$$

$$\frac{R_L}{R_{ON}} \gg 1$$

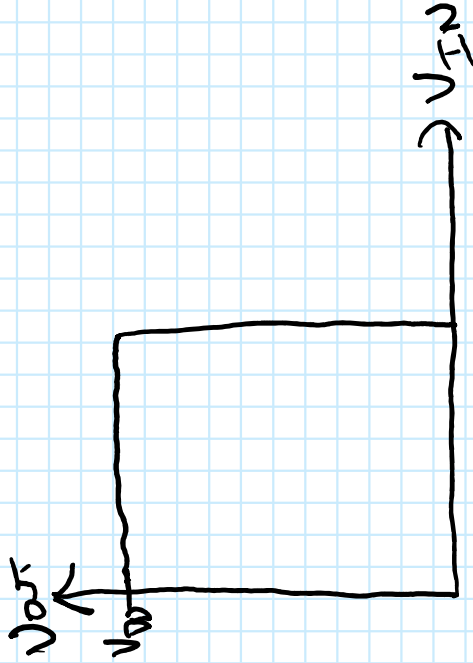
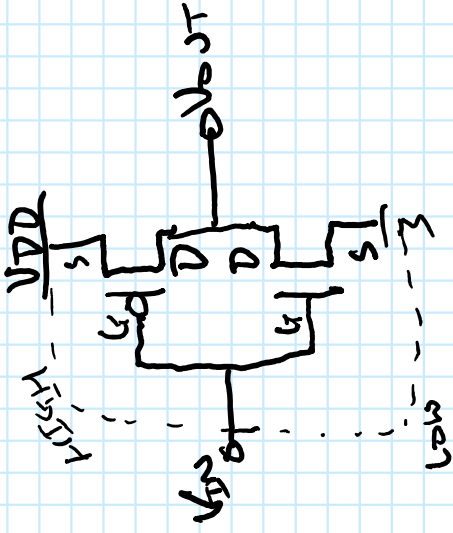
PMOS INVERTER



$$V_{DD} \left(\frac{R_L}{R_{on} + R_L} \right) \approx \left(\frac{1}{\frac{R_{on}}{R_L} + 1} \right) V_{DD} \ll V_{DD}$$



CMOS INVERTERS



COMPLEMENTARY

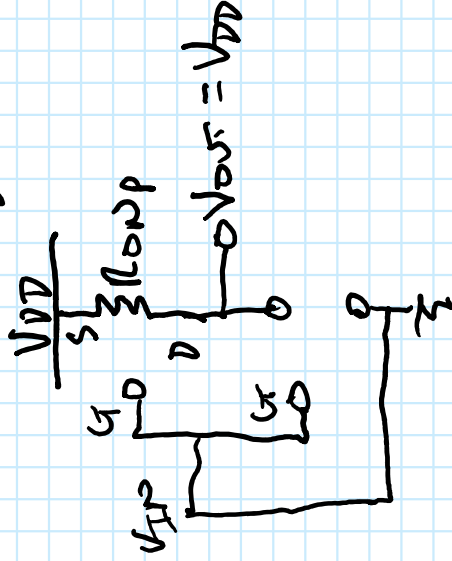
V_{IN} LOW

$$V_{GSN} = 0 \Rightarrow \text{OFF}$$

$$V_{GSP} =$$

$$V_{GSP} = V_G - V_S$$

$$V_{GSP} = 0 - V_{DD} \Rightarrow \text{ON}$$



V_{IN} HIGH

$$V_{GSN} = V_{DD} \Rightarrow \text{ON}$$

$$V_{GSP} = 0 \Rightarrow \text{OFF}$$

$$\frac{1}{4} C V^2 f$$

