To do : Transistors & RC Models

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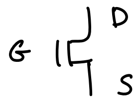
① PMOS, NMOS, & Transistors

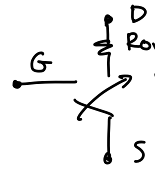
② Introduction to RC circuits and Differential equations

Transistors - PMOS / NMOS

Motivating Q : Why can't our computers go any faster?

NMOS

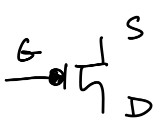


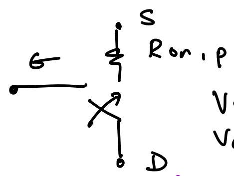


$V_{gs} \geq V_{th,n}$ — NMOS threshold voltage

Treat these devices as black boxes

PMOS





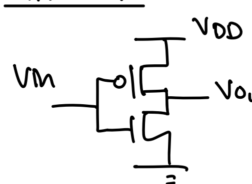
$V_{sg} \geq |V_{th,p}|$

$V_{gs} \leq -|V_{th,p}|$ — PMOS threshold values

★ It is possible for both the PMOS and NMOS to turn on at the same time, or be off at the same time

★ 16B Assumption $0 \leq V_{th,p}, V_{th,n} \leq V_{DD}$

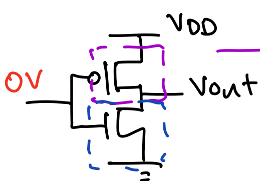
Inverter

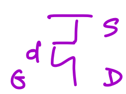


if $V_{in} = V_{DD}$, $V_{out} = 0V$

if $V_{in} = 0V$, $V_{out} = V_{DD}$

→ Lets check the conditions :



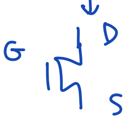


$V_{gs} \leq -|V_{th,p}|$

$0 - V_{DD} \leq -|V_{th,p}|$

$-V_{DD} \leq -|V_{th,p}|$ ✓ Yes!

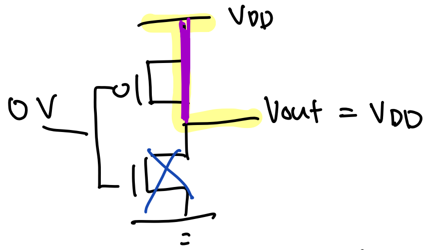
∵ condition is satisfied, the PMOS turns "on"



$V_{gs} \geq V_{th,n}$

$0 - 0 \geq V_{th,n}$ ✗ No!

∵ condition is NOT satisfied, the NMOS turns "off"

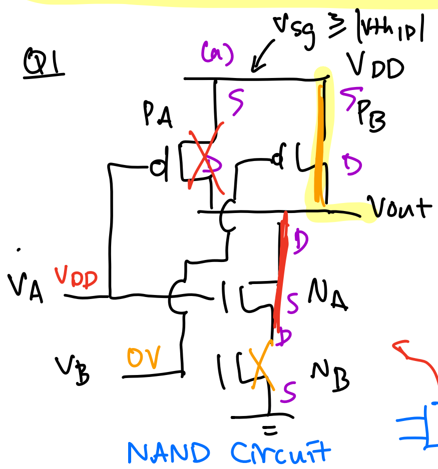


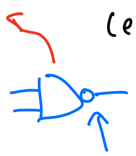
Trick : To solve for NMOS / PMOS (Vout) in circuits quickly, just remember the inverter. It only works if we know our inputs are high / low (VDD / 0)

input low → output high [PMOS on, NMOS off]

input high → output low [PMOS off, NMOS on]

Q1





$V_{DD} - V_{DD} \geq |V_{th,p}|$ ✗

(b) $V_A = V_{DD}$, $V_B = V_{DD}$, $V_{out} = 0V$

(c) $V_A = V_{DD}$, $V_B = 0V$, $V_{out} = V_{DD}$

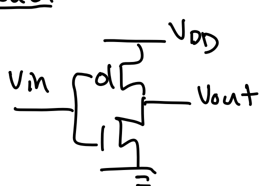
(d) $V_A = 0V$, $V_B = V_{DD}$, $V_{out} = V_{DD}$

(e) $V_A = 0V$, $V_B = 0V$, $V_{out} = V_{DD}$

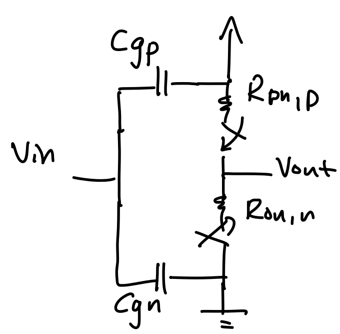
(f)

V_A	V_B	V_{out}
0	0	V_{DD}
0	V_{DD}	V_{DD}
V_{DD}	0	V_{DD}
V_{DD}	V_{DD}	0

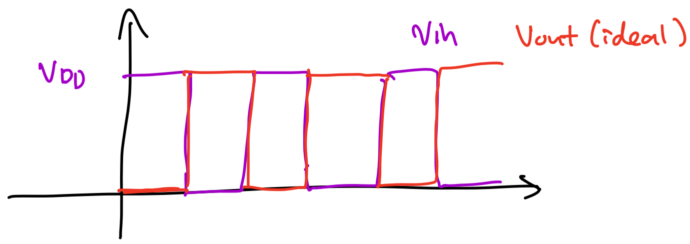
RC Model



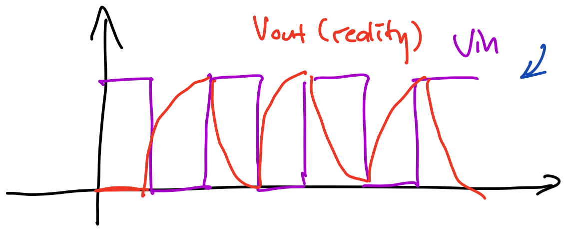
⟹



Ideally



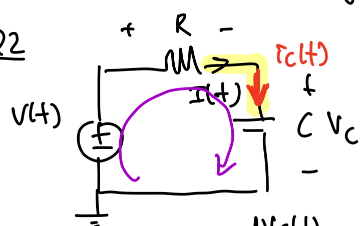
Reality



how fast it rises/falls depends on the RC time constant (τ)

To answer our motivating question: Because we are limited by capacitors!

Q2



(b), (c)

KCL: $I(t) = i_c(t)$

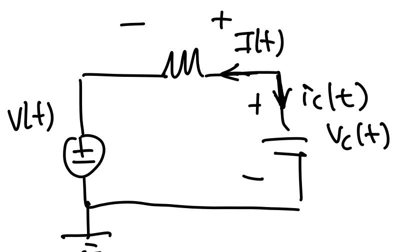
$$\frac{V_R(t)}{R} = C\frac{dV_c(t)}{dt}$$

$$\frac{V(t) - V_c(t)}{R} = C\frac{dV_c(t)}{dt}$$

$$\therefore \frac{dV_c(t)}{dt} = \frac{V(t) - V_c(t)}{CR}$$

(a) $I_C(t) = C\frac{dV_C(t)}{dt}$

$$I(t) = C\frac{dV_c(t)}{dt}$$



KCL: $0 = I(t) + i_c(t)$

$$= I(t) + C\frac{dV_c}{dt}$$

$$= \frac{V_R(t)}{R}$$

$$= \frac{V_c(t) - V(t)}{R} + C\frac{dV_c}{dt}$$

KVL: $V(t) - V_R(t) - V_c(t) = 0$

$$V(t) - i(t)\cdot R - V_c(t) = 0$$

$$V(t) - C\frac{dV_c(t)}{dt}\cdot R - V_c(t) = 0$$

$$\frac{V(t) - V_c(t)}{R} = C\frac{dV_c}{dt}$$