Lecture 37: CMOS Inverter

- Announcements:
  - First 15 minutes of lecture for HKN course evaluations
  - HW#11 is online and due Tuesday, Dec. 10
  - Lab 6 online and due 5 p.m., Friday, Dec. 13

- Lecture Topics: (over the next few days)
  - MOS Inverter w/ Resistive Load
  - Static CMOS Inverter Behavior
    - $V_{OL}$ and $V_{OH}$
    - $V_{IL}$ and $V_{IH}$
  - Dynamic CMOS Inverter Behavior
    - Propagation Delay
    - Capacitance
  - Astable Ring Oscillator
  - CMOS Inverter Propagation Delay

- Last Time:
  - Started digital circuits
  - Now, continue with this...
$V_{OL} = V_{DD} \rightarrow \text{say } V_{OL} = V_{DD}$

$\Delta M_5 \text{ on}$

$\rightarrow \text{in steady-state:}$

For $M_5$: $V_{GS5} = V_{TH5} = V_{DD} - V_{TH5} > V_{OL}$

$\therefore M_5 \text{ is large}$

$I_D = \mu_n C_OX \frac{(V_D)}{2} (V_{DD} - V_{TH5} - \frac{V_{OL}}{2})V_{OL}$

$V_{OL} = V_{DD} - \mu_n C_OX \frac{(V_D)}{2} (V_{DD} - V_{TH5})V_{OL} + \frac{\mu_n C_OX (V_D)}{2} V_{OL}^2$

$\Rightarrow \text{solve quadratic for } V_{OL}$

$\Rightarrow \alpha \text{ can get a less accurate (but still good) value ...}$

$\Rightarrow \ldots \text{by defining an ON-resistance for the switching device:}$

$V_{OL} = \frac{V_{DD}}{R + R_{ON}} = \frac{V_{DD}}{1 + \frac{R}{R_{ON}}}$

When $V_{OL} = V_{OL}$:

$I = \frac{V_{DD}}{R + R_{ON}} = \text{in digital, any current is too much!}$

Say: $I = 100\mu A \rightarrow \text{okay for } 100 \times 10^3 \text{ siclier } = 100 \mu A$

But for $1 \text{ billion } = 1000 A \rightarrow \text{way too much}$

Thus, need lower power consumption!

$\therefore \text{CMOS.}$
The CMOS Inverter

- Introduce a complimentary device to ideally eliminate
  static power!

1. Case: $V_L < V_{IL}$
   - $M_P$ off, $M_N$ on

Get $V_{OH}$ & $V_{OL}$:

- $V_{OH} = V_{DD}$
- $V_{OL} = 0$ in steady state

2. Case: $N_P > V_{IH}$
   - $V_{PD}$
   - $R_{PMH}$
   - $C_L$
   - $N_O = 0V$
   - NMOS discharges $C_L$

Determination of the Voltage Transfer Characteristic (VTC)

- $V_N$: $V_{DD}$
- $V_{OH}$
- $V_{OL}$

$V_{OH}$
- $V_{DD}$
- $V_{PD}$

$V_{OL}$
- $V_{IL}$
- $V_{IH}$
- $V_{OL}$

Slope = -1

Slope = -1