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
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- 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
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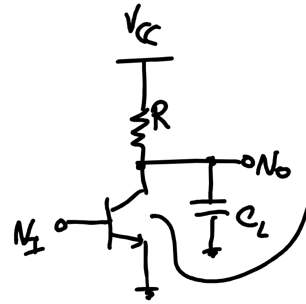
- Last Time:
- Started digital circuits
- Now, continue with this...

Transistor Inverter w/ Resistive Load

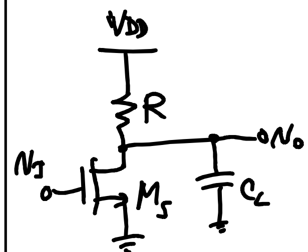
⇒ use Xsistor as a switching device → allowing it to handle large signals



bipolar Xsistor (first inverters used bipolar technology)

↳ But... not as good as MOS for digital ckts.

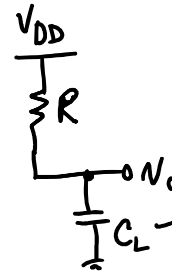
↳ reasons: cost & power consumption



Find V_{OH} & V_{OL}. (for this resistively-loaded MOS Inverter)

V_{OH}: $v_I \le V_{IL}$ → say $v_{IL} = 0V$

⇒ M_s off

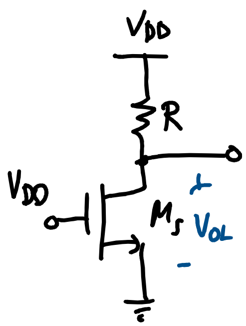


C_L charges to $v_o = V_{DD} = V_{OH}$

V_{OL}: $v_I = V_{IH}$ → say $v_I = V_{DD}$

⇒ M_S on

⇒ in steady-state:



For M_S: $V_{GSS} - V_{TNS} = V_{DD} - V_{TNS} > V_{OL}$

∴ M_S is linear

$V_{OL} \rightarrow V_{OL} = V_{DD} - I_D R$

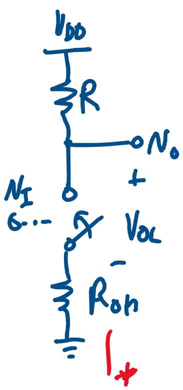
$I_D = \mu_n C_{ox} \left(\frac{W}{L}\right)_S \left(V_{DD} - V_{TNS} - \frac{V_{OL}}{2}\right) V_{OL}$

$$V_{OL} = V_{DD} - \mu_n C_{ox} \left(\frac{W}{L}\right)_S (V_{DD} - V_{TNS}) V_{OL} + \frac{\mu_n C_{ox} \left(\frac{W}{L}\right)_S}{2} V_{OL}^2$$

⇒ solve quadratic for V_{OL}

⇒ or can get a less accurate (but still good) value …

⇒ …by defining an ON-resistance for the switching device:



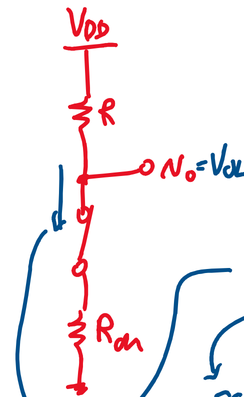
$$V_{OL} = V_{DD} \frac{R_{on}}{R + R_{on}} = V_{DD} \left(\frac{1}{1 + \frac{R}{R_{on}}} \right)$$

$$R_{on} = \frac{v_{DS}}{i_D} = \frac{V_{OL}}{\mu_n C_{ox} \left(\frac{W}{L}\right)_S \left(V_{DD} - V_{TNS} - \frac{V_{OL}}{2}\right) V_{OL}}$$

$$R_{on} = \frac{1}{\mu_n C_{ox} \left(\frac{W}{L}\right)_S \left(V_{DD} - V_{TNS} - \frac{V_{OL}}{2}\right)}$$

*

when $v_O = V_{OL}$:



$I = \frac{V_{DD}}{R + R_{on}}$ ⇒ In digital, any current is too much!

say: $I = 1\mu A$ → okay for 100 transistors = 100μA

But for 1 billion → 1000A → way too much

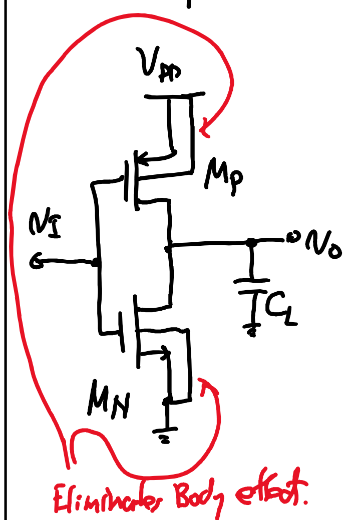
Thus, need lower power consumption!

⇓

CMOS!

The CMOS Inverter

⇒ introduce a complimentary device to ideally eliminate static power!

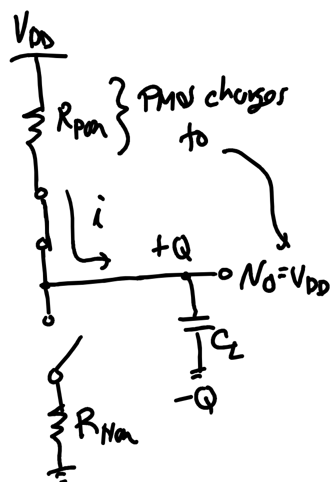


$\therefore V_{OH} = V_{DD}$ in steady-state

Get V_{OH} & V_{OL}:

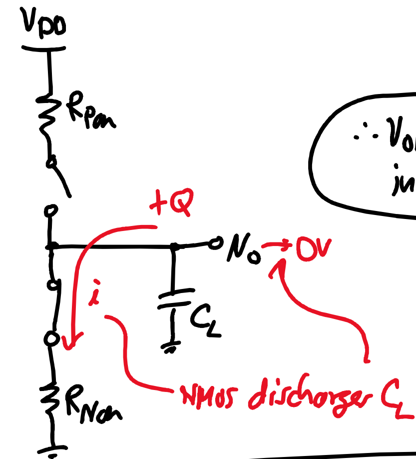
① Case: $v_I < V_{IL}$

M_P on, M_N off



② Case: $v_I > V_{IH}$

M_P off, M_N on



$\therefore V_{OL} = 0V$ in steady-state

Determination of the Voltage Transfer Characteristic (VTC)