Lecture #16

(finish from last lecture)

Cut-off frequency

→ Frequency at which the magnitude of input current, I_i equals the load current, I_d

• From circuit with C_M:

$$I_i = j\omega(C_{gsT} + C_M)V_{gs} \quad , \quad I_d = g_m V_{gs}$$

f_T occurs at a gain of 1

Magnitude of current gain: $\left|\frac{I_d}{I_i}\right| = \frac{g_m}{2\pi f(C_{gsT} + C_M)} = 1$

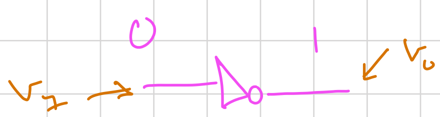
using $\omega = 2\pi f$

$$\Rightarrow \boxed{f_T = \frac{g_m}{2\pi(C_{gsT} + C_M)} = \frac{g_m}{2\pi C_G}}$$

input gate capacitance

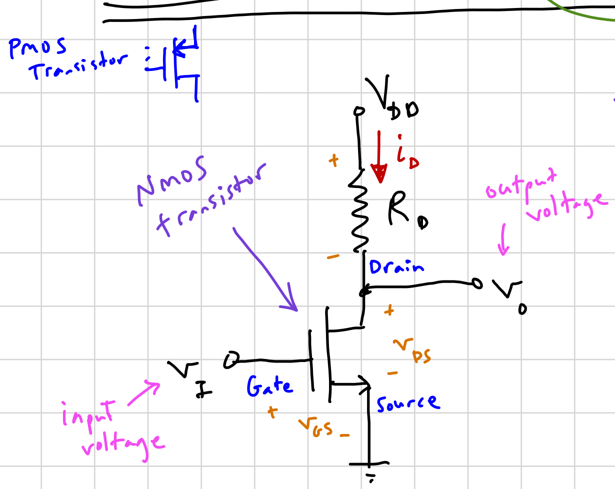
for the ideal case, where $C_G = C_{ox} W \cdot L = C_{gs}$ and $g_m = \frac{W \mu_n C_{ox}}{L}(V_{gs} - V_T)$

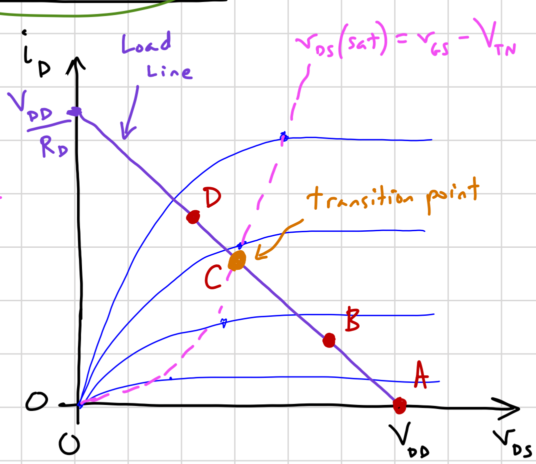
$$f_T = \frac{\mu_n(V_{GS} - V_T)}{2\pi L^2} \quad \text{(ideal MOSFET)}$$

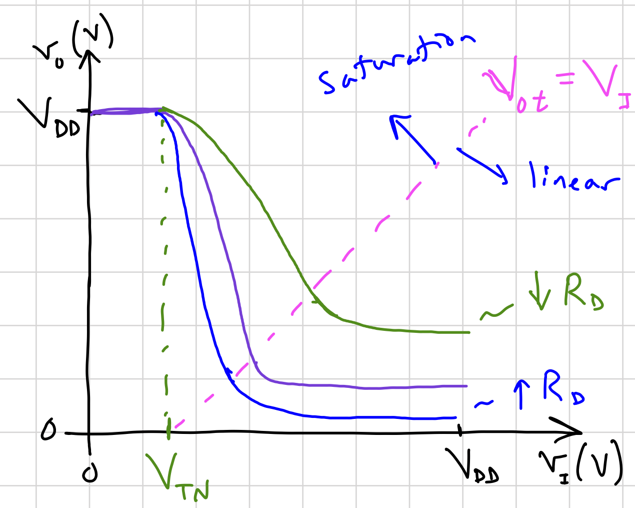


NMOS Inverter with Resistive Load

→ a resistor fabricated in Si substrate







A: $v_I \leq V_{TN}$

→ transistor is OFF

$i_D = 0$

$v_O = V_{DD}$

LOGIC "1"

B: v_I just $> V_{TN}$

→ Transistor is in saturation

$v_O = V_{DD} - i_D R_D$

$i_D(sat) = K_n(v_I - V_{TN})^2$ (v_{GS})

$v_O = V_{DD} - K_n R_D (v_I - V_{TN})^2$

C: v_I at transition point

$V_{Ot} = V_{It} - V_{TN}$

v_{DS} v_{GS} at trans. pt.

$K_n R_D (V_{It} - V_{TN})^2 + (V_{It} - V_{TN}) - V_{DD} = 0$

D: $v_I > V_{It}$

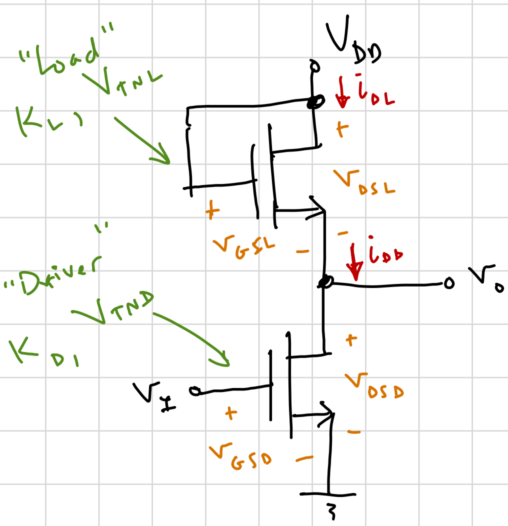
→ transistor in linear

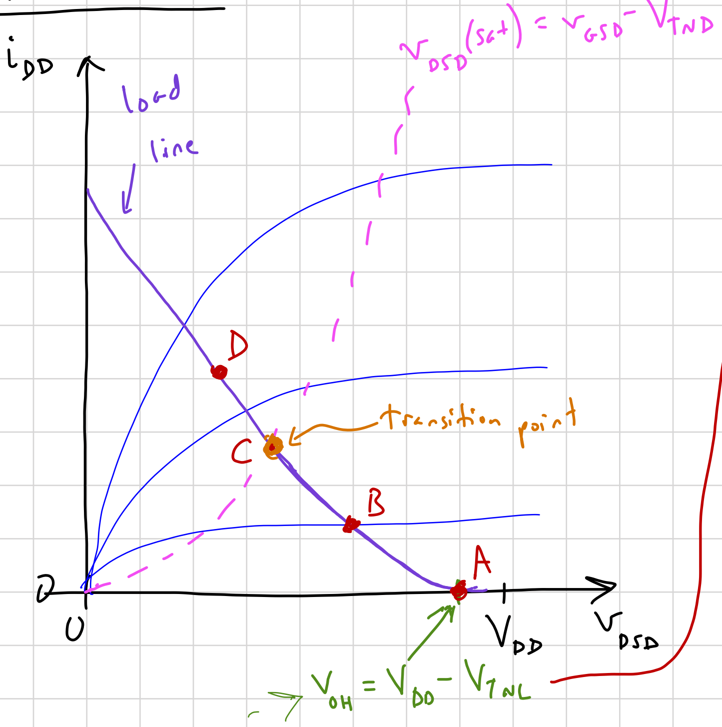
$i_D = K_n\left[2(v_I - V_{TN})v_O - v_O^2\right]$

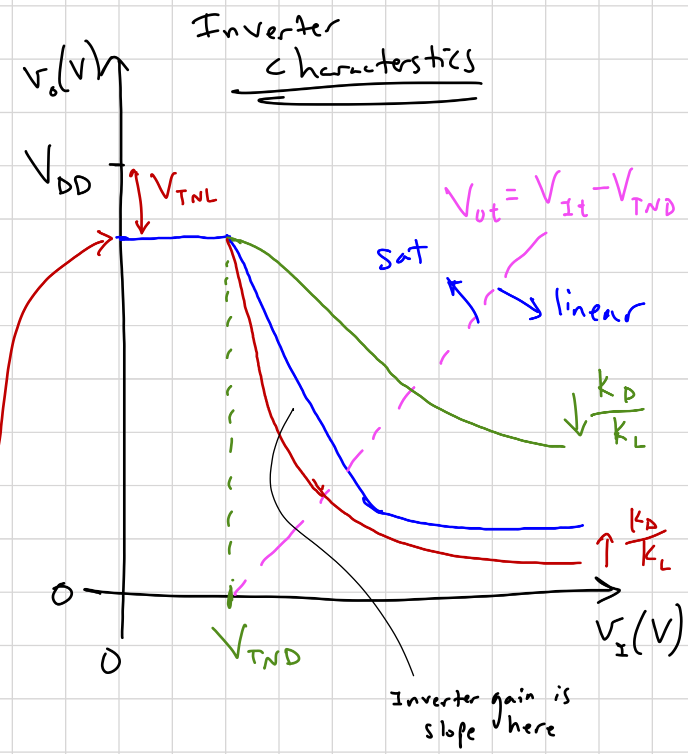
then: $v_O = V_{DD} - R_D i_D$

☆ $\uparrow R_D$ gives much better inverter characteristics, but difficult to make in Si (takes a lot of space)

NMOS Inverter with NMOS Load







A: $v_I < V_{TND}$

→ Driver is off

$$i_{DL} = 0 = K_L(v_{DSL} - V_{TNL})^2$$

→ Load transistor always operates in saturation when $v_{GSL} = v_{DSL} \geq V_{TNL}$

Since : $V_{DSL} = V_{DD} - v_o$

$$v_{DSL} - V_{TNL} = V_{DD} - v_o - V_{TNL} = 0$$

→ and max. output voltage of:

$$v_{o,max} = V_{OH} = V_{DD} - V_{TNL}$$

B: v_I just $> V_{TND}$

→ At steady-state, $i_{DL} = i_{DD}$

$$K_D(v_{GSD} - V_{TND})^2 = K_L(v_{GSL} - V_{TNL})^2$$

→ expressed in terms of input/output:

$$K_D(v_I - V_{TND})^2 = K_L(V_{DD} - v_o - V_{TNL})^2$$

Giving:

$$☆\ v_o = V_{DD} - V_{TNL} - \sqrt{\frac{K_D}{K_L}}(v_I - V_{TND})$$

C: v_I at transition point

$$v_{DSD}(sat) = v_{GSD} - V_{TND}$$

OR

$$V_{ot} = V_{It} - V_{TND}$$

$$V_{It} = \frac{V_{DD} - V_{TNL} + V_{TND}\left(1 + \sqrt{\frac{K_D}{K_L}}\right)}{1 + \sqrt{\frac{K_D}{K_L}}}$$

D: $v_I > V_{It}$

→ still have $i_{DD} = i_{DL}$

→ Driver now in linear region

$$K_D\left[2(v_I - V_{TND})v_o - v_o^2\right] = K_L(V_{DD} - v_o - V_{TNL})^2$$

Inverter Gain: Slope in the transition region:

$$\frac{dv_o}{dv_I} = -\sqrt{\frac{K_D}{K_L}}$$

☆ Want to be ↑