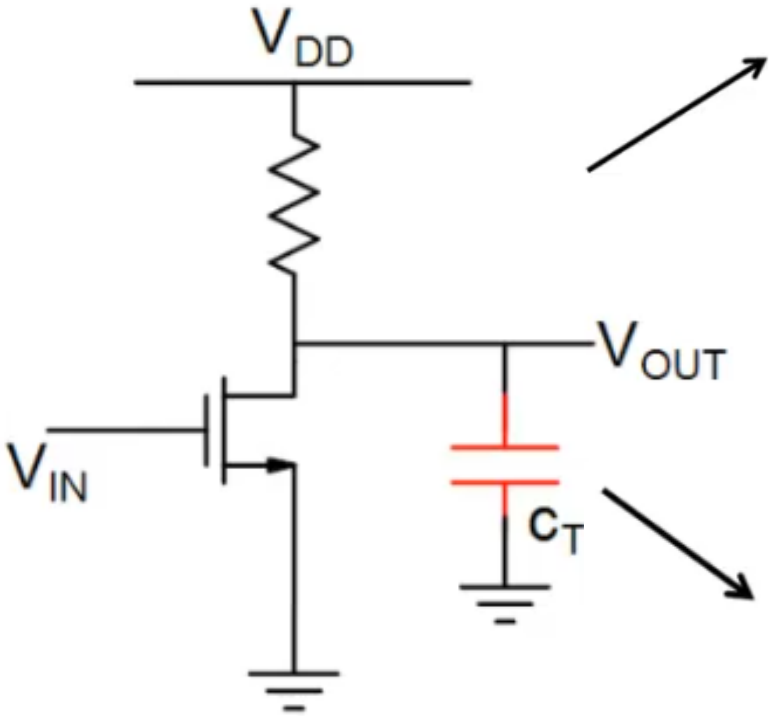
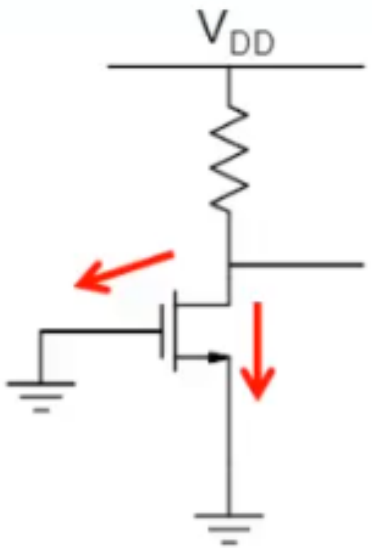
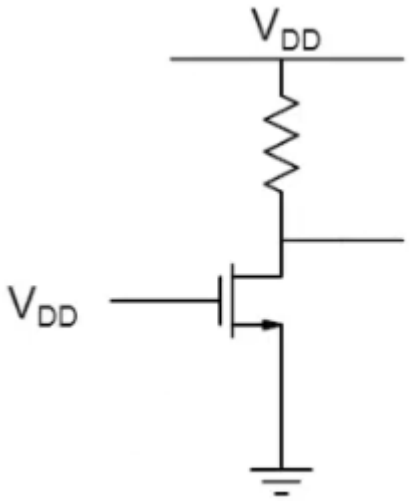
Power dissipation

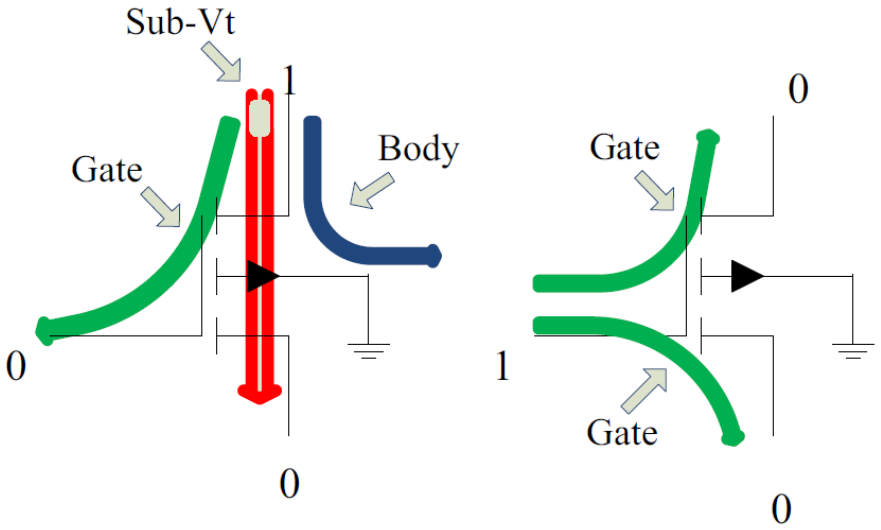


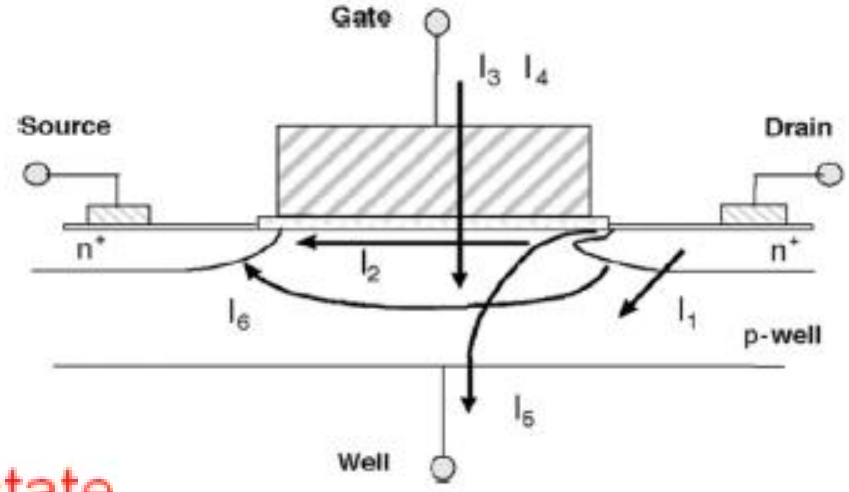


$$P = V_{DD} \times I_{leakage}$$



$$P \sim \frac{V_{DD}^2}{R_D}$$





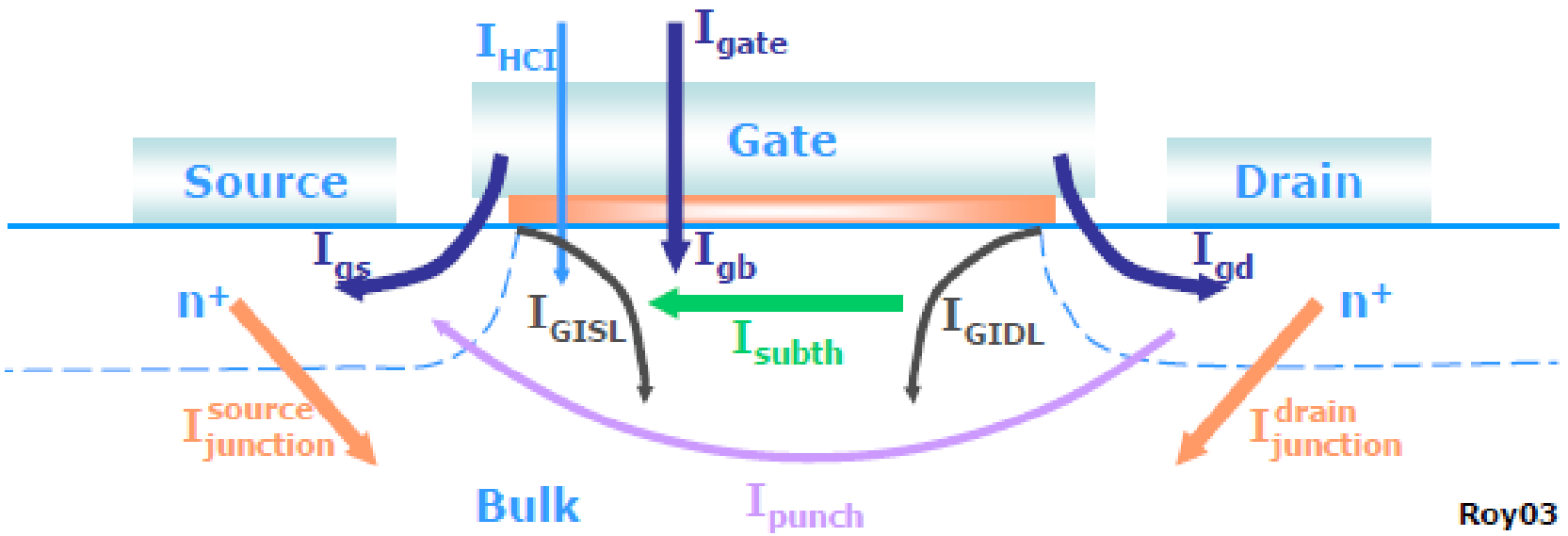
1. Static
2. Dynamic

Energy should be drawn only to change the state

- **If channel is locking:**
  - subthreshold current (I_{subth}) ≤180nm
  - gate tunnelling to S/D (I_{gate}) ≤90nm
  - pn-junction leakage ($I_{junction}$)
  - gate induced drain leakage (I_{GIDL}) ≤65nm
  - depletion punchthrough (I_{punch})

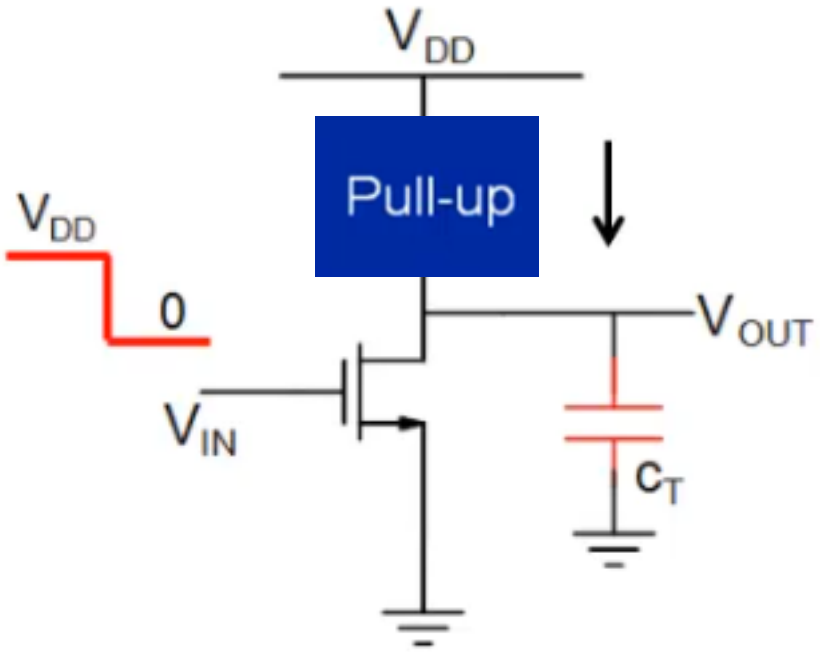
- **If channel is conducting:**
  - gate tunnelling (I_{gate})
  - pn-junction leakage ($I_{junction}$)

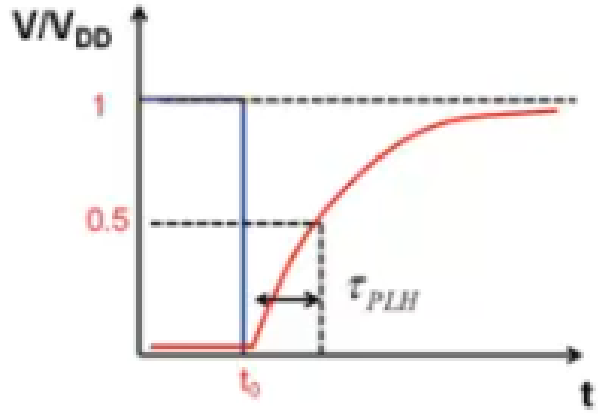
- **If channel is switching:**
  - hot carrier injection (I_{HCI})



Long Channels (L> 1μm)	Short Channels L > 180nm	Very Short Channels L > 90nm	Nano scale Channels L < 90nm
Leakages are very small.	t_{ox} > 3nm Sub-threshold leakage	t_{ox} > 2nm Sub-threshold leakage + Gate leakage	t_{ox} < 2nm Sub-threshold leakage + Gate leakage + Junction leakage / BTBT

Contribution of new leakage currents with scaled technologies

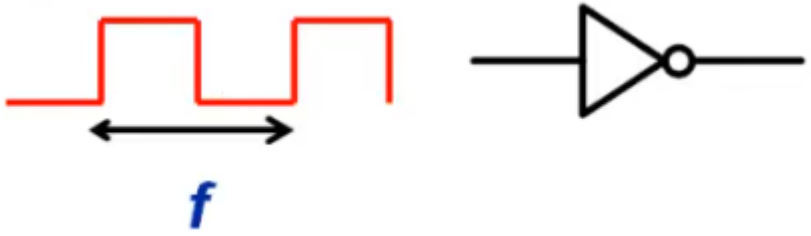




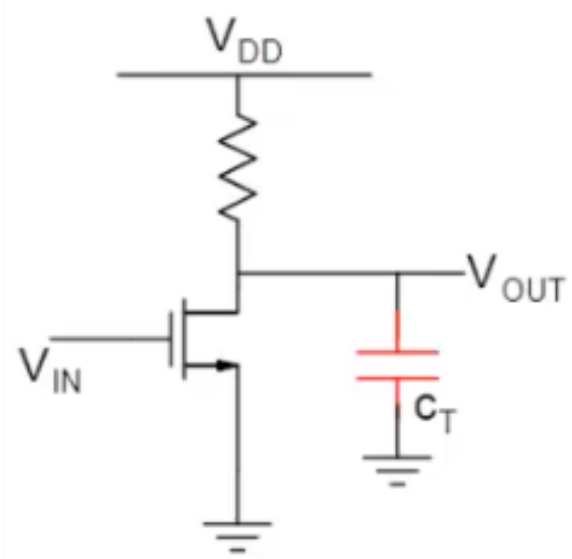
$$E_{supply} = \int V_{DD} \times I_{pu} dt = C_T \times V_{DD}^2$$

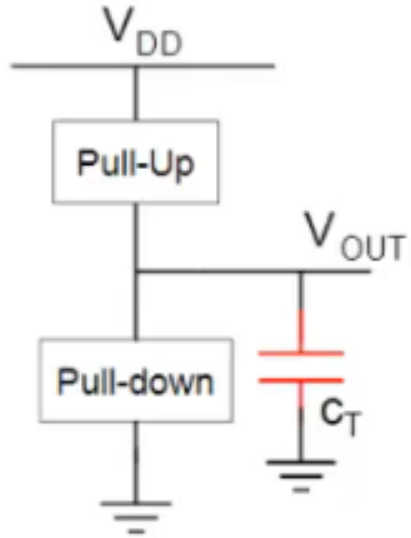
Half of it is dissipated in the resistor and the other half is stored in capacitor

When the inverter switches back to zero, the energy stored on capacitor is also dissipated

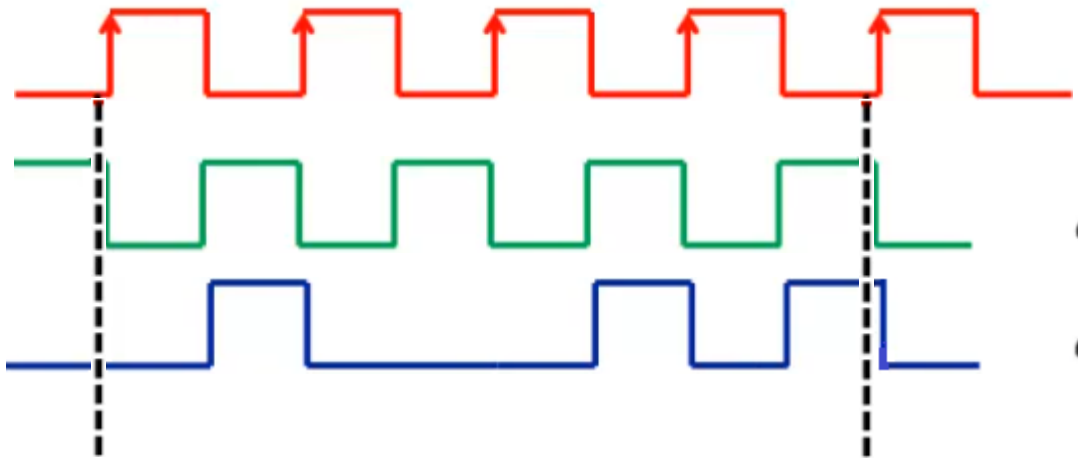


$$P_{dynamic} = \frac{0.5C_T \times V_{DD}^2 + 0.5C_T \times V_{DD}^2}{T} = C_T \times V_{DD}^2 \times f$$





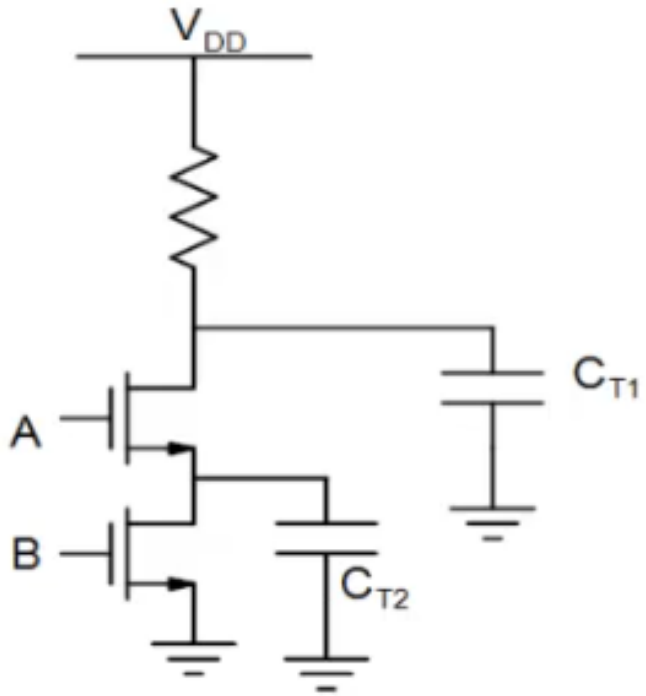
$$P_{dynamic} = C_T \times V_{DD}^2 \times f$$



$\alpha = 2$

$\alpha = 5/4$

$$P_{dynamic} = \sum \left(0.5 C_j \times V_j^2 \right) \times f \times \alpha_j$$



NAND gate

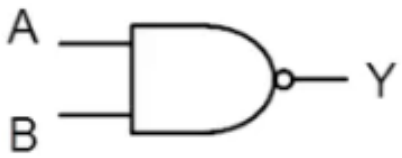
$$P_{dynamic} = \left(0.5C_{T1} \times V_{j1}^2\right) \times f \times \alpha_1 + \left(0.5C_{T2} \times V_{j2}^2\right) \times f \times \alpha_2$$

Suppose B= 1 and A switches with clock frequency

$$P_{dynamic} \cong \left(0.5C_{T1} \times V_{DD}^2\right) \times f \times 2$$

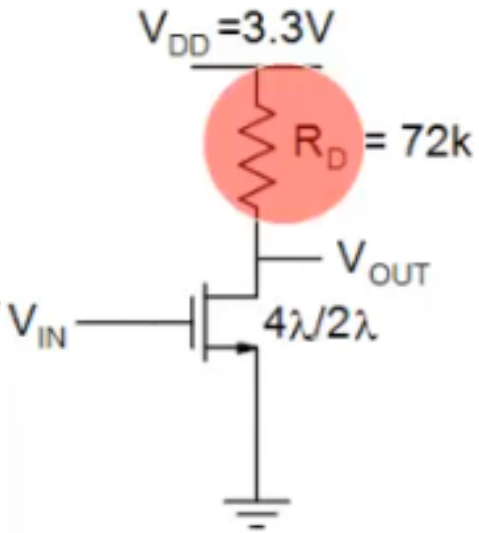
Suppose A= 1 and B switches with clock frequency

$$P_{dynamic} \cong \left(0.5C_{T1} \times V_{DD}^2\right) \times f \times 2 + \left(0.5C_{T2} \times V_{DD}^2\right) \times f \times 2$$

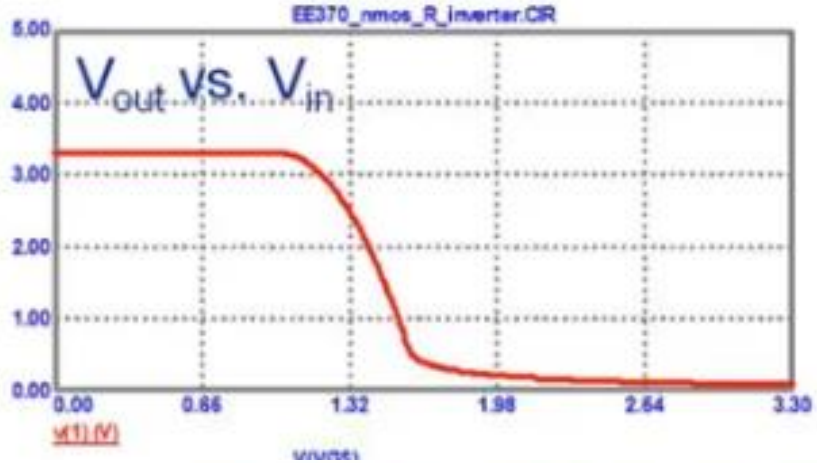


What about delays ?

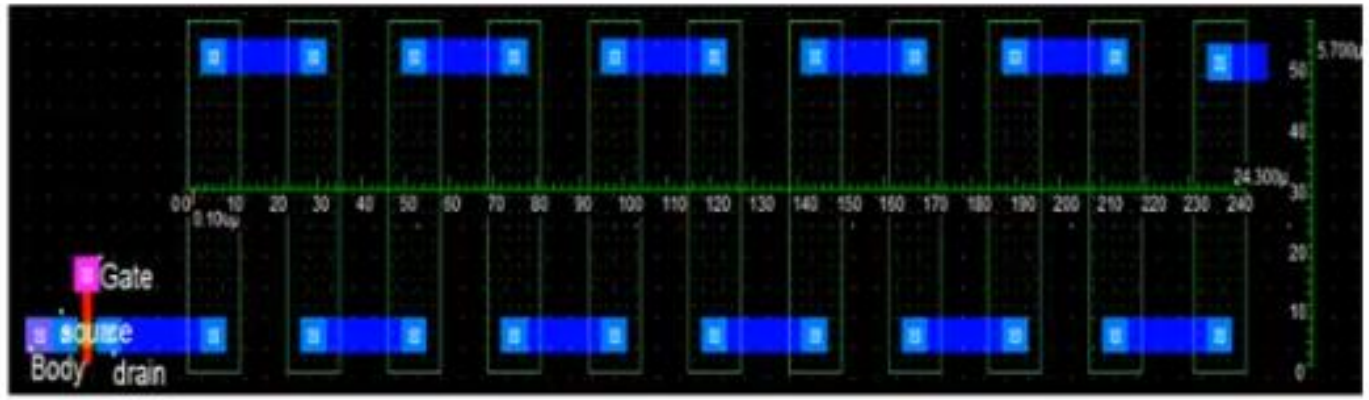
Summary

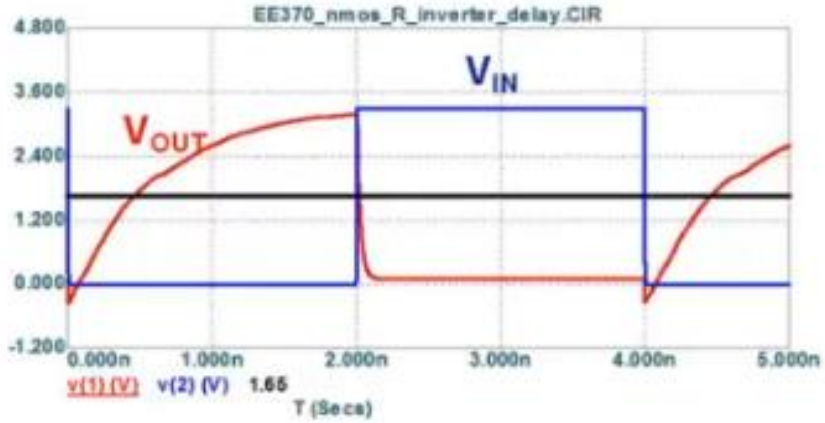


1. Noise Margins
2. Area
3. Delay
4. Power



$$R_D = 72k \Rightarrow V_{OL} = 0.1V; V_{OH} = 3.3V$$
$$V_{IL} = 1.07V; V_{IH} = 1.7V$$
$$NM_L \sim 0.97V; NM_H \sim 1.6V$$
$$V_{inv} = 1.5V$$



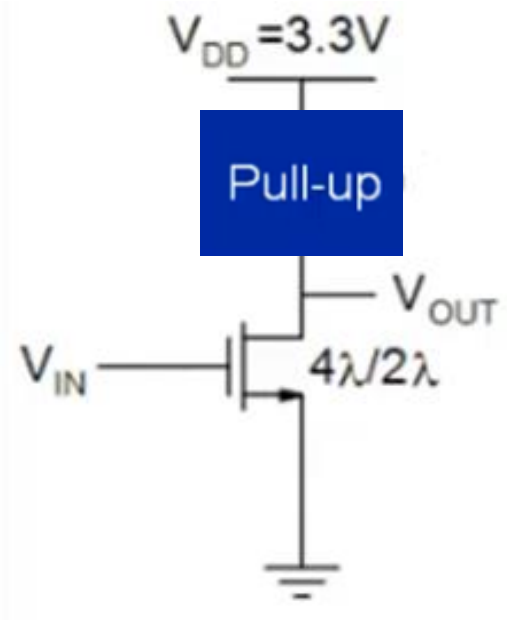


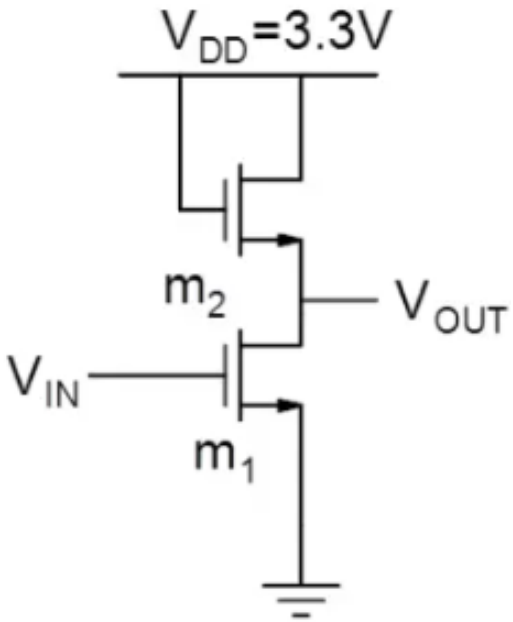
$$\tau_{PLH} \cong 424\,ps; \tau_{PHL} \sim 39\,ps$$

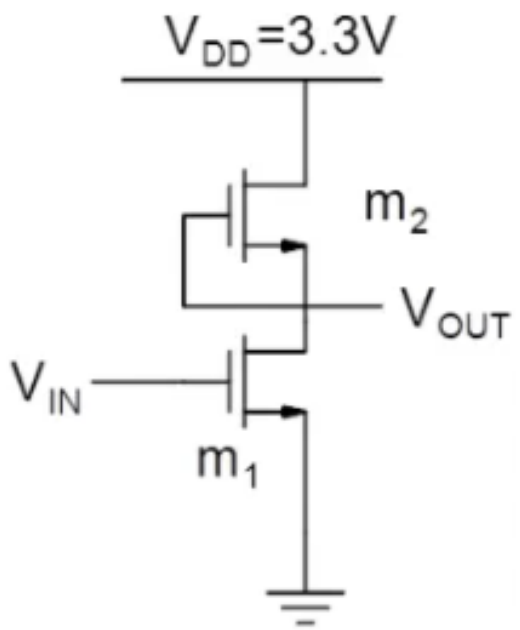
$$\tau_{PLH} \cong 0.693 \times R_D \times \tilde{C}_T$$

$$P_{static} \sim \frac{V_{DD}^2}{R_D}$$

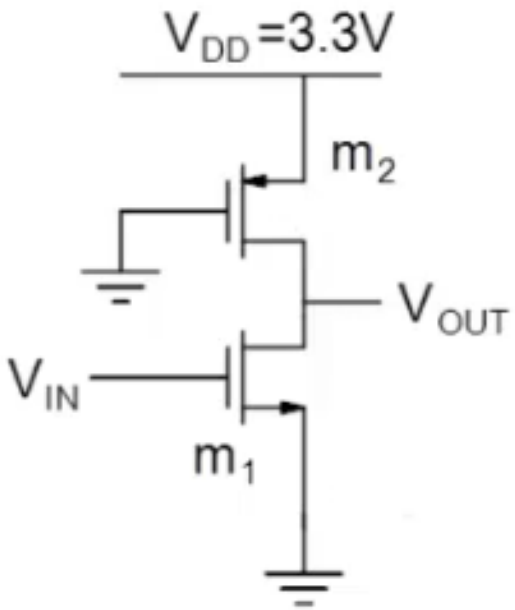
$$P_{dynamic} = C_T \times V_{DD}^2 \times f$$





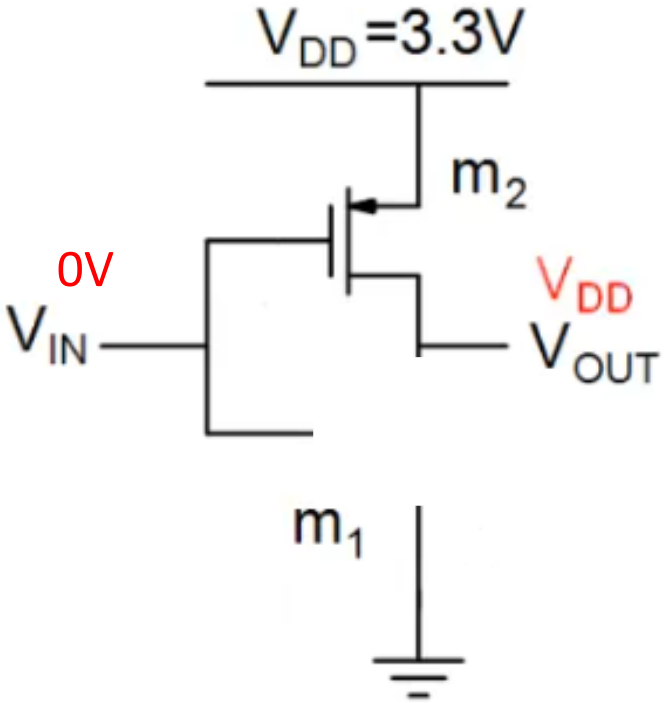


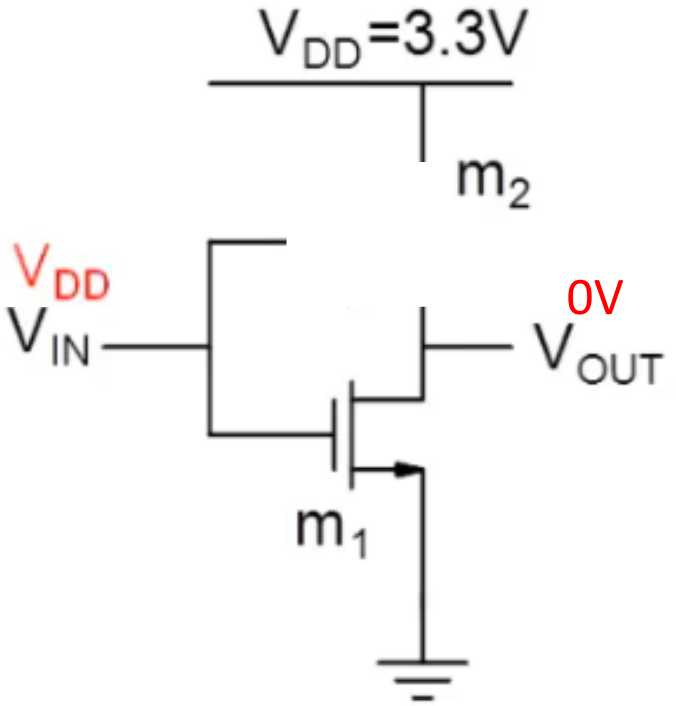
Make m2 depletion mode



They all have static power dissipation when output is low.

Pseudo-NMOS logic

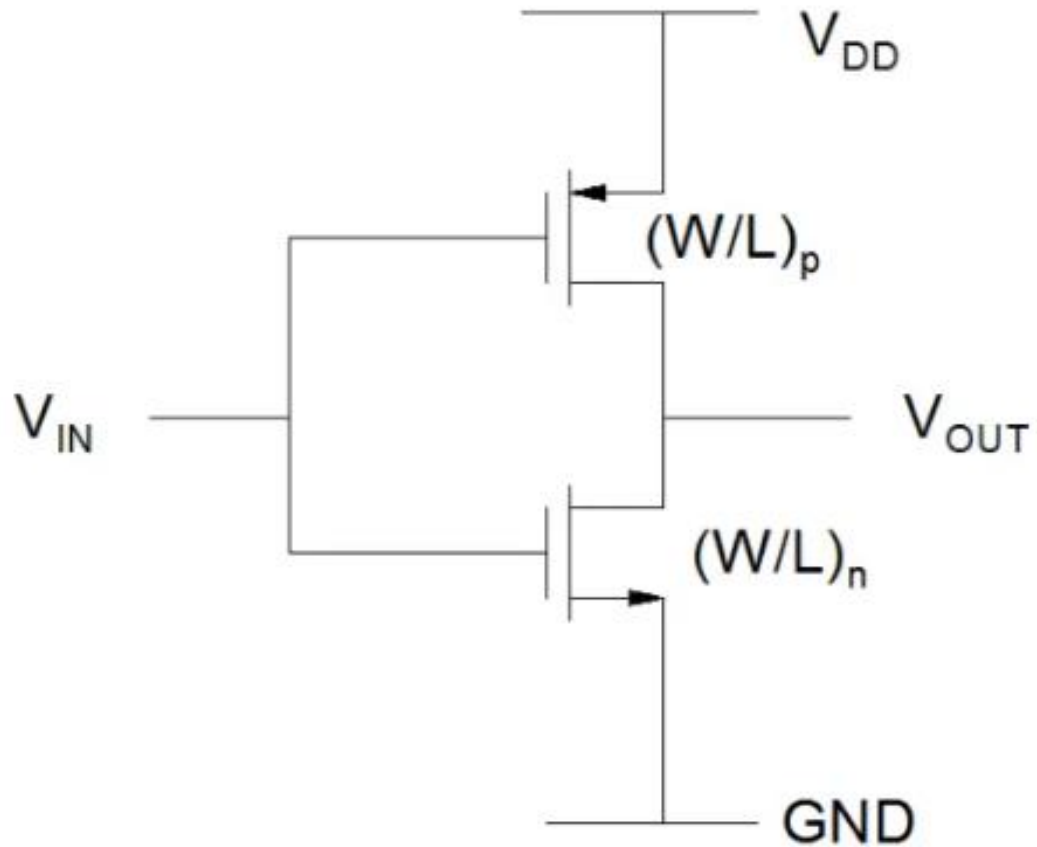




Logic "1" is VDD and "logic "0" is GND independent of size of transistors.

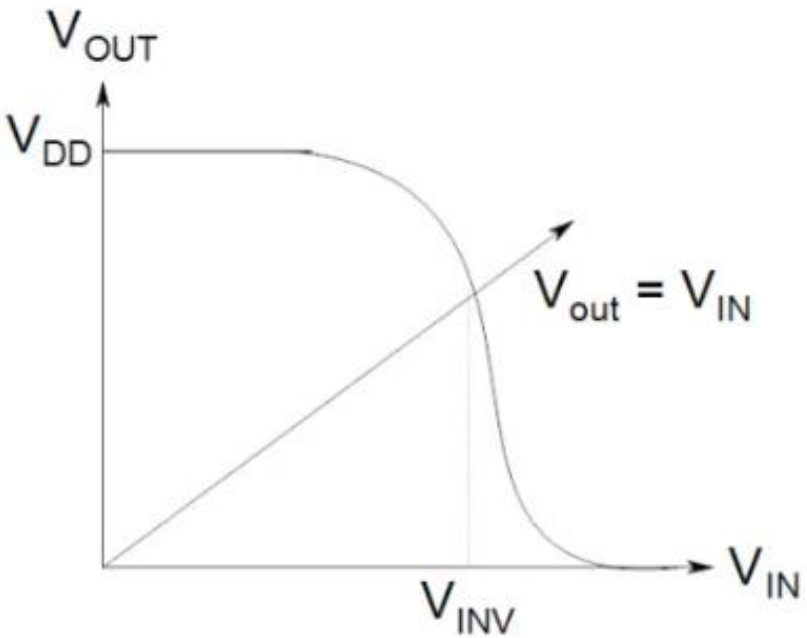
There is "no" static power dissipation in the circuit

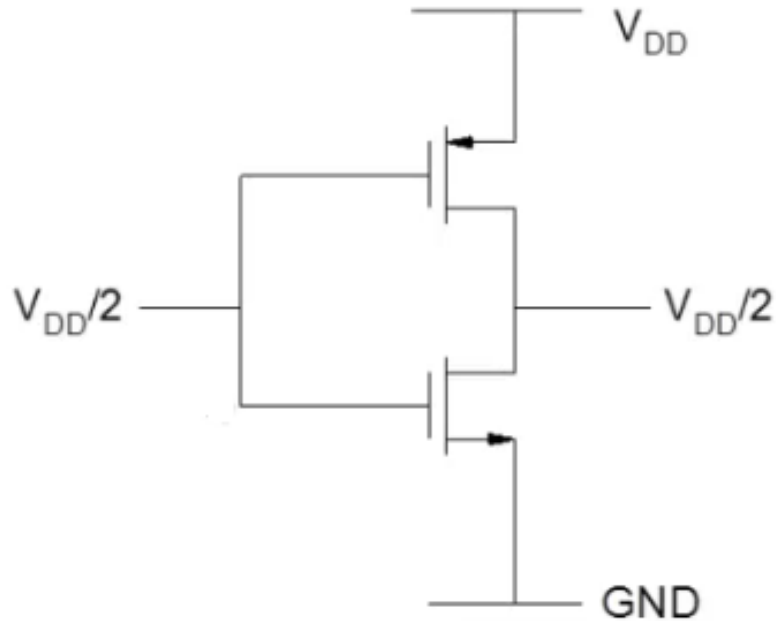
CMOS Inverter



How should we size to obtain symmetrical VTC ?

CMOS Inverter : VTC

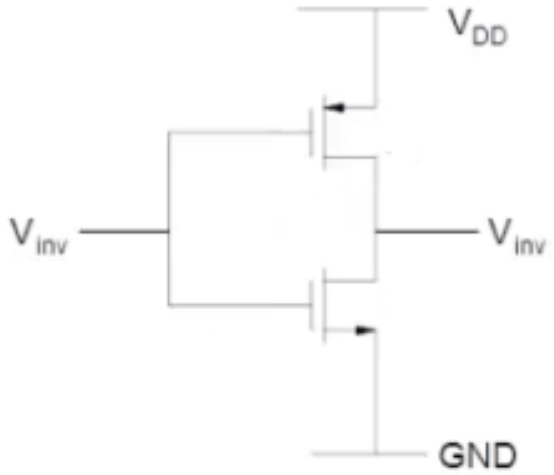




Both NMOS and PMOS are in saturation region

CMOS Inverter : VTC

$$I_{DSN} = I_{SDP}$$



$$\frac{\beta_N}{2}(V_{inv} - V_{THN})^2 = \frac{\beta_P}{2}(V_{SGP} + V_{THP})^2$$

$$V_{SGP} = V_{DD} - V_{inv}$$

$$\beta_N = W_N / L_N KP_N$$

$$\beta_P = W_p / L_P KP_P$$

$$V_{INV} = \frac{V_{THN} + \frac{1}{\sqrt{\beta_R}}(V_{DD} + V_{THP})}{1 + \frac{1}{\sqrt{\beta_R}}}$$

$$\beta_R = \frac{\beta_N}{\beta_P} = \left(\frac{W_N / L_N}{W_P / L_P}\right) \times \left(\frac{KP_N}{KP_P}\right)$$

CMOS Inverter : VTC

$$V_{INV} = \frac{V_{THN} + \frac{1}{\sqrt{\beta_R}}(V_{DD} + V_{THP})}{1 + \frac{1}{\sqrt{\beta_R}}}$$

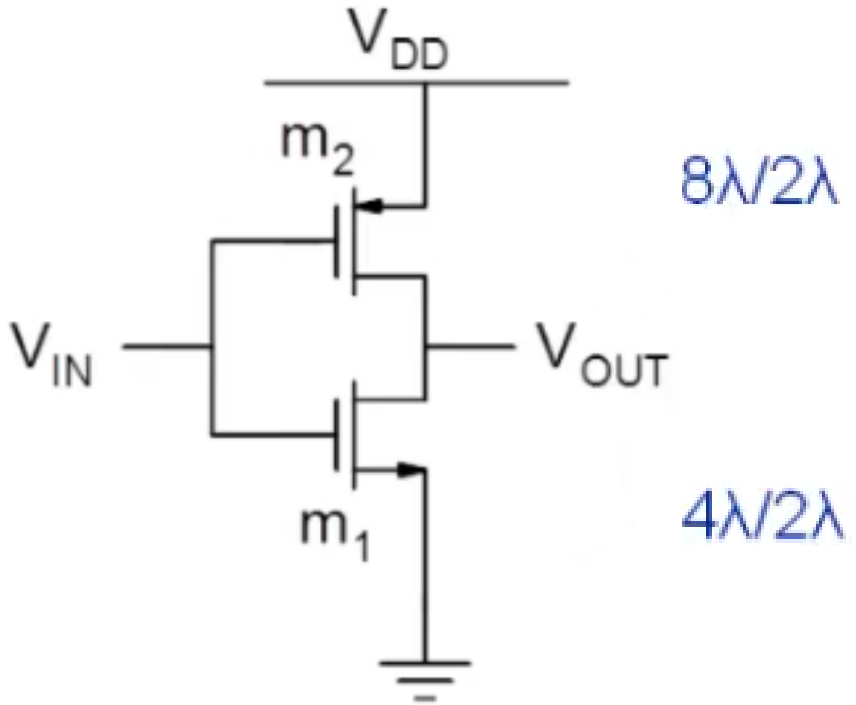
$$V_{INV} = 0.5V_{DD}$$

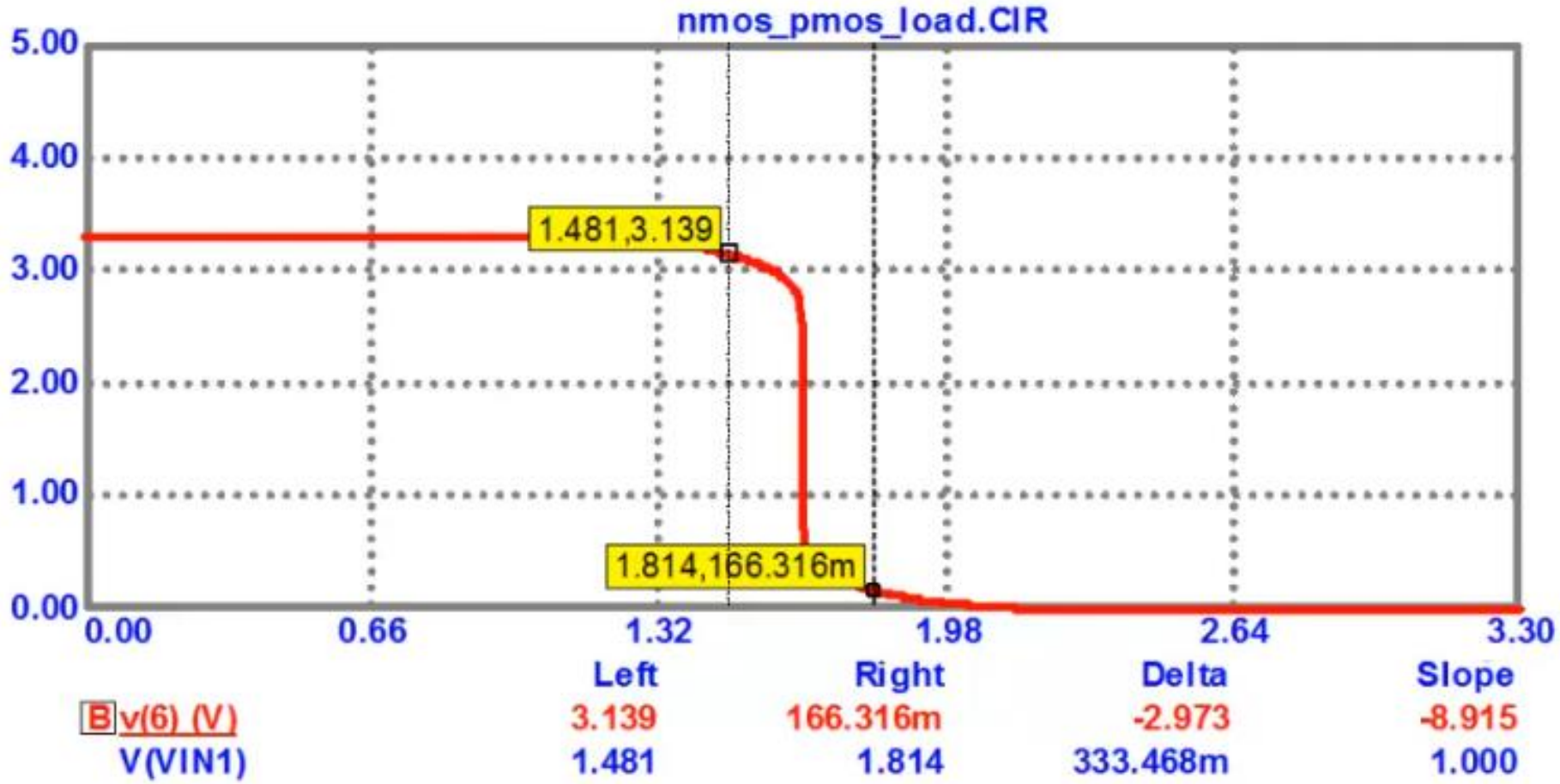
$$\beta_R = \frac{0.5V_{DD} + V_{THP}}{0.5V_{DD} - V_{THN}}$$

$$\Rightarrow \beta_R = 1$$

$$\frac{W_P/L_P}{W_N/L_N} = \frac{KP_N}{KP_P}$$

2.0





$$V_{IL} = 1.48V; v_{ol} = 0V$$

$$V_{IH} = 1.814V; v_{oh} = 3.3V$$

$$NM_H = 1.48V; NM_L = 1.48V$$

$$\frac{NM_H}{0.5V_{DD}} = 0.9$$