Symmetric CMOS Inverter

→ book derives equations for Noise Margin

$$NM_H = \frac{V_{DD} - V_{TN} - 3V_{TP}}{4}$$

$$NM_L = \frac{V_{DD} + 3V_{TN} + V_{TP}}{4}$$

Note: For the case where $K_R = \frac{K_n}{K_p}$ $K_n = K_p$. see Fig 7.9, p.366 otherwise

for $V_{DD} = +2.5V$, $V_{TN} = +0.6V$, $V_{TP} = -0.6V$

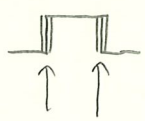
$$NM_H = NM_L = 0.93V$$

∴ the device can tolerate a noise voltage up to 0.93V on top of our desired signal and still generate the correct output signal

2. <u>Jitter</u> – "noise" – unwanted variation in switching time

ideal :

with jitter:



pulse train: pulse width / switching time varies from pulse to pulse

→ another type of noise encountered in digital systems

→ may or may not be important

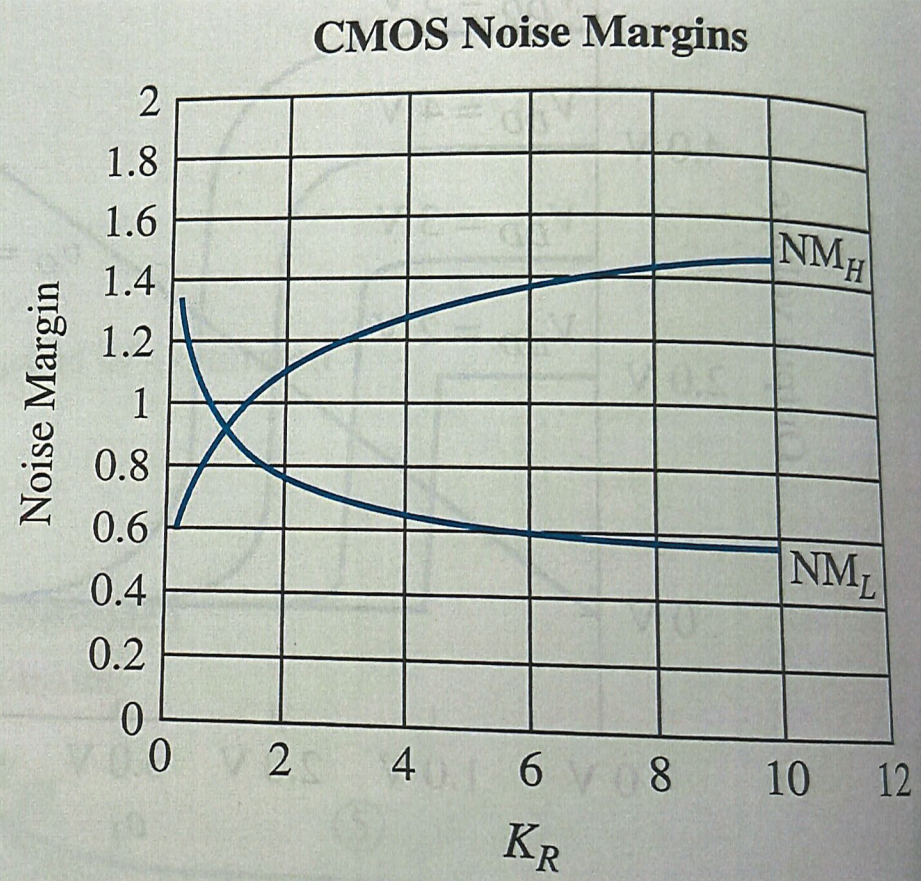


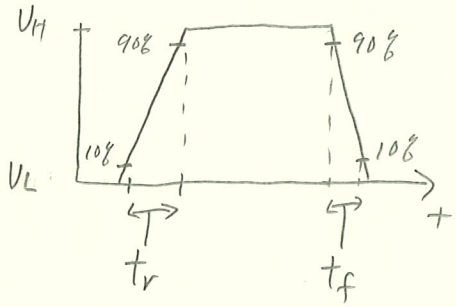
Figure 7.9 Noise margins versus K_R for the CMOS inverter with $V_{DD} = 2.5$ V and $V_{TN} = -V_{TP} = 0.6$ V. $K_R = K_n/K_p$.

2. Rise and Fall Times

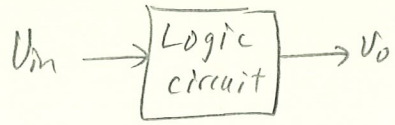
t_r = rise time : time required for signal to transition from 10% to 90% point

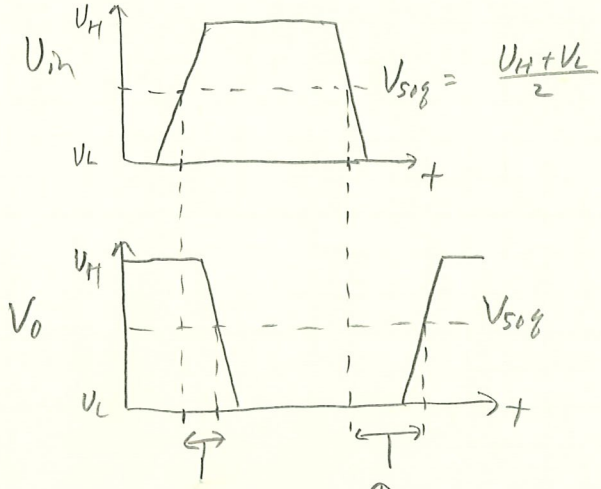
t_f = fall time : time required for 90% to 10% transition

Ex:



a) Propagation Delay



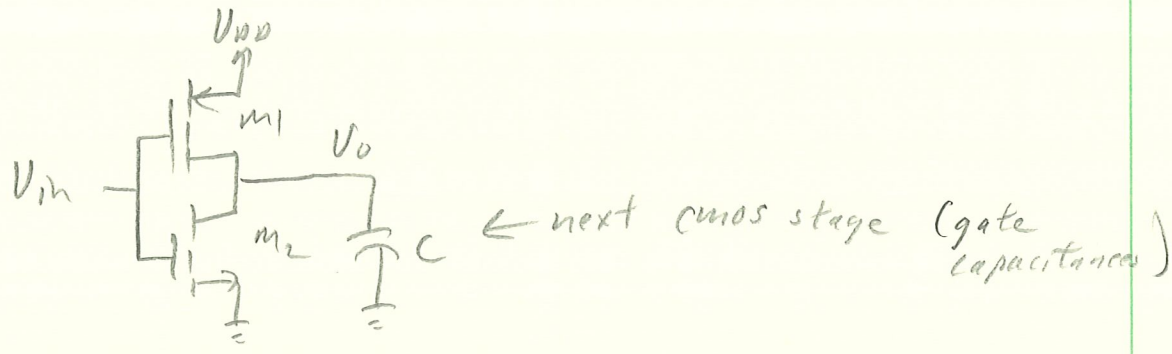


τ_{PLH} τ_{PHL} → propagation delay : high to low

↑ propagation delay : low to high

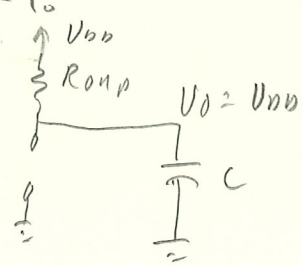
$$\text{Propagation Delay} = \tau_p = \frac{\tau_{PLH} + \tau_{PHL}}{2}$$

inverter

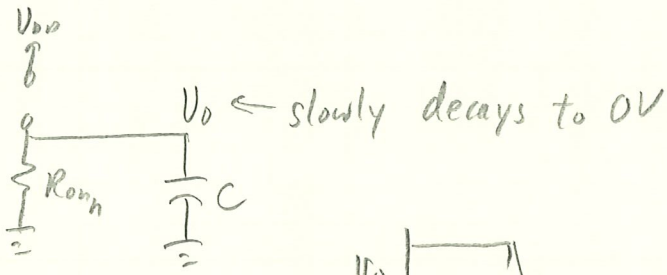


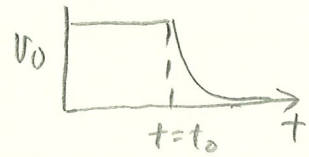
if V_{in} is 0V and switches to +5V at $t = t_0$

$t < t_0$



$t \geq t_0$





$$R_{on} = \frac{1}{K|(V_{GS} - V_T)|}$$

<u>note</u>: Ron approximates R for the RC circuit

for $T \rightarrow K = K'(\frac{W}{L}) \rightarrow (\frac{W}{L})\uparrow$, Ron $\downarrow$, RC time const $\downarrow$

$\therefore$ bigger T's $\rightarrow$ smaller propogation delay

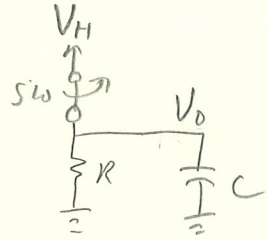
but, bigger $\frac{W}{L} \rightarrow$ gate cap in next stage goes up too

1) More on propagation delay in a CMOS logic gate

$\tau_{PLH} \rightarrow$ propagation delay : low to high

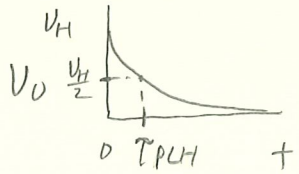
↳ from when $V_{in} = 50\% V_H$ until $V_O = 50\% V_L$

Simple Model :



SW opens at $t = 0$

$t \leq 0 : V_O = V_H$



$$V_O = V_H e^{-t/RC}$$

or $0.5 V_H = V_H (e^{-\tau_{PHL}/RC})$

$$0.5 = e^{-\tau_{PHL}/RC}$$

$$\tau_{PHL} = -RC \ln(0.5) = 0.69 RC$$

If $\tau_{PHL} = \tau_{PLH} \rightarrow \tau_p = 0.69 RC$

a. <u>Rise and Fall Time</u>

t_f = time for $V_O = 0.9 V_H$ until $V_O = 0.1 V_H$

$\therefore 0.9 V_H = V_H (e^{-t_{90\%}/RC})$ (1)

$0.1 V_H = V_H (e^{-t_{10\%}/RC})$ (2)

solve for $t_{90\%}$ and $t_{10\%}$

$\therefore t_f = t_{90\%} - t_{10\%} = 2.2 RC$