EHB 322E Digital Electronic Circuits

② _Delays_ considering internal cap.s
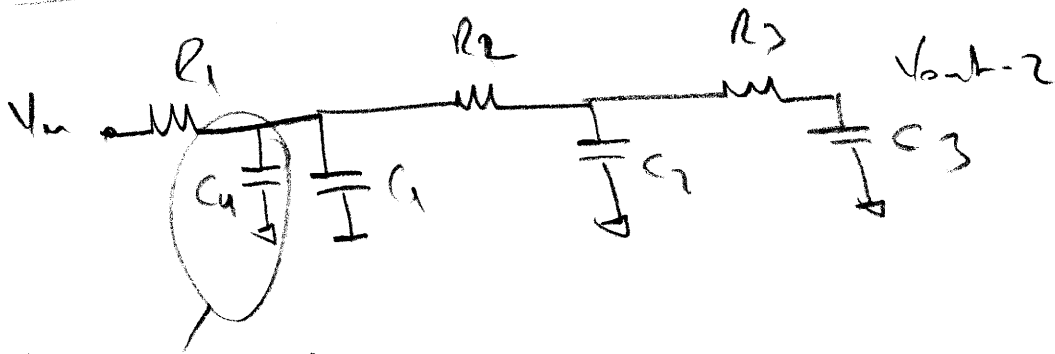
$\underline{\text{Elmore delay model for RC ladder}}$
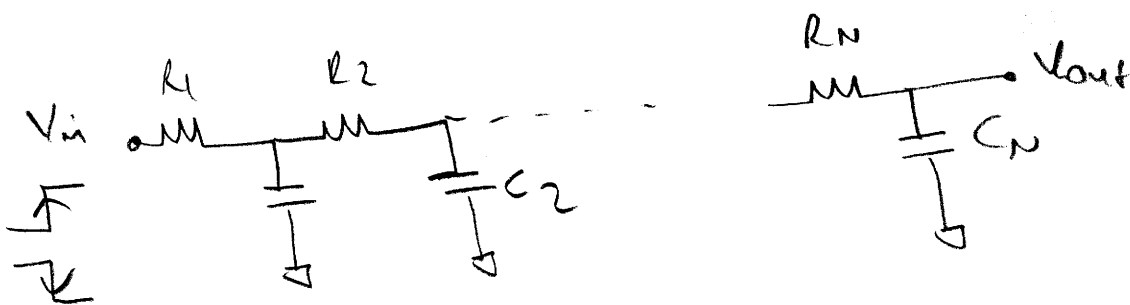


$$t_{PHL, PLH} = 0.69\left\{R_1 C_1 + (R_1 + R_2) C_2 + \cdots + (R_1 + \cdots + R_N) C_N\right]$$

$$t_{PHL, PLH} = 0.69\left\{\sum_{i=1}^{N}\left(C_i \cdot \left(\sum_{j=1}^{i} R_j\right)\right)\right]$$



$R_x$

$\underline{\text{Delay at } V_{out}1}$
$$t_{PLH-1} = ?$$

$\underline{\text{Delay at } V_{out}2}$
$$t_{PLH-2} = ?$$

ladder form $V_{in}$



$$t_{PLH-1} = 0.69\left[R_1 (C_1 + C_2 + C_3) + (R_1 + R_4) C_4\right]$$
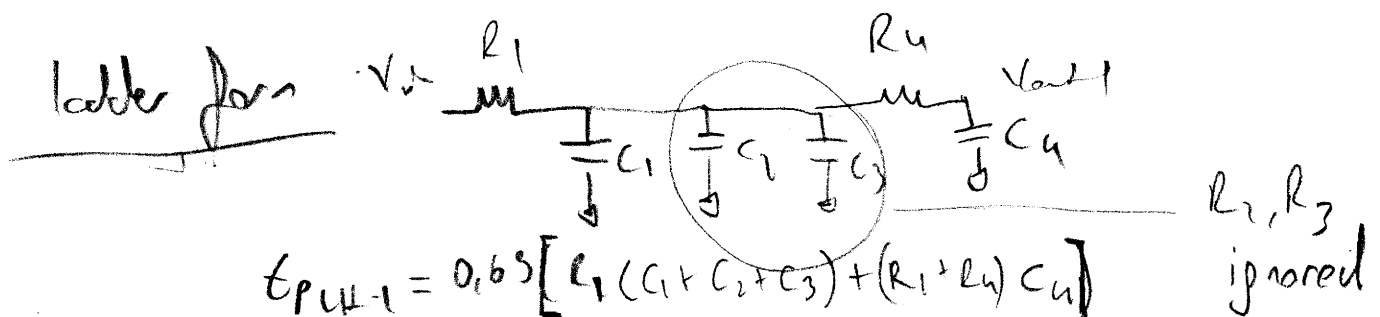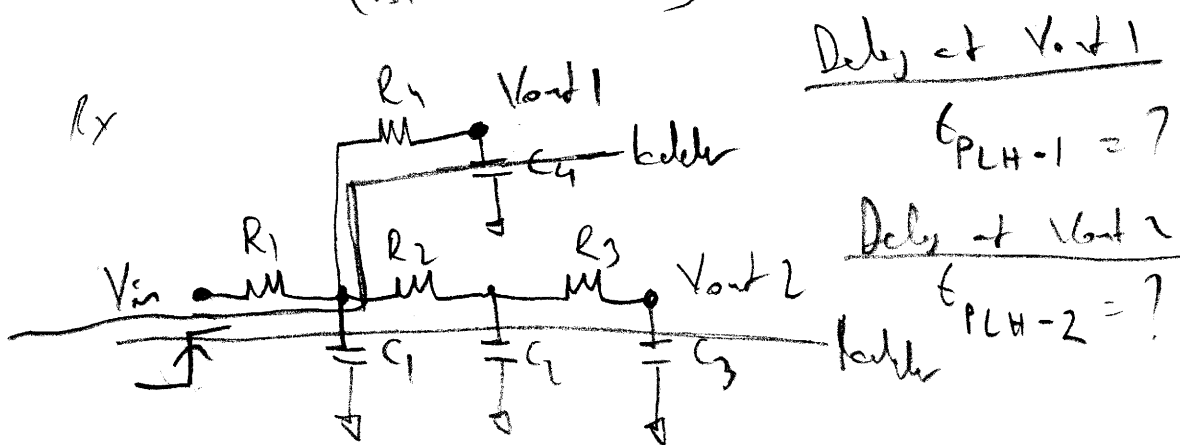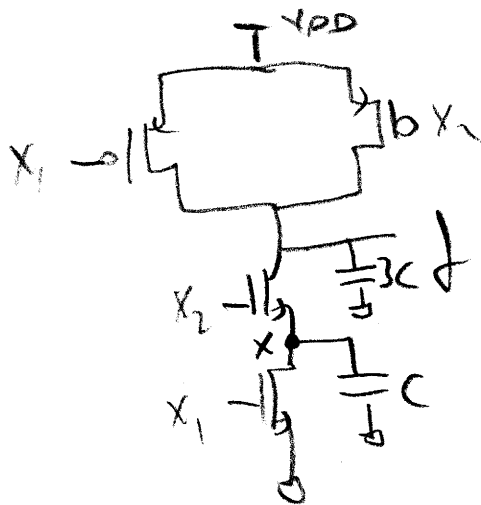
$R_2, R_3$ ignored

# ladder form



$R_4$ ignored

$$t_{PLH} = 0.69 \left\{ R_1 (C_1 + C_4) + (R_1 + R_2) C_2 + (R_1 + R_2 + R_3) C_3 \right\}$$

## Elmore model for CMOS circuits

Ex 2-input NAND gate

$$f = \overline{(x_1 \cdot x_2)}$$



Suppose that each tran. has an internal capacitor of $C$ at its DRAIN node. Each ON tran. is modeled with a resistor of $R$.

Calculate the delay

a) $x_1 = 0 \to 1$ ↗
$x_2 = 0 \to 1$ ↗
$\forall x - initial = V_{DD}$

b) $x_1 = 1$ •
← $x_2 = 0 \to 1$ ↗

c) $x_1 = 1 \to 0$ ↗
$x_2 = 1 \to 0$ ↗

a) $t_{PHL}$
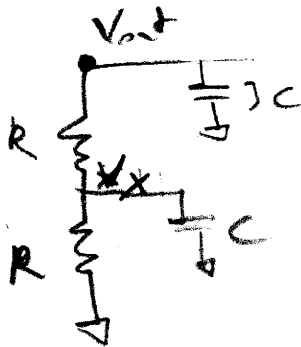
$V_{out}$
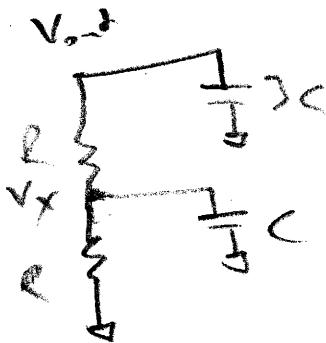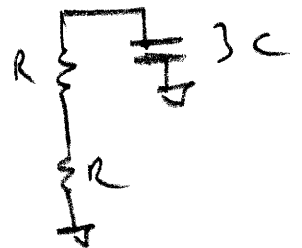
$V_{out-initial} = V_{DD}$

$t_{PHL} = 0.69 \{RC + 2R \cdot 3C\}$

b) $t_{PHL}$

$V_{out}$
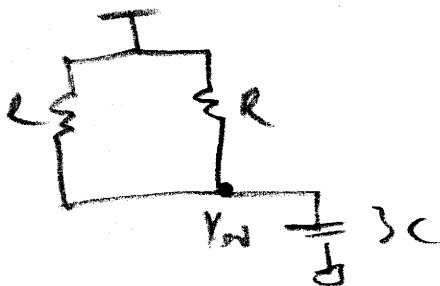
$V_{out-initial} = V_{DD}$

$V_{x-initial} = 0 \Rightarrow$

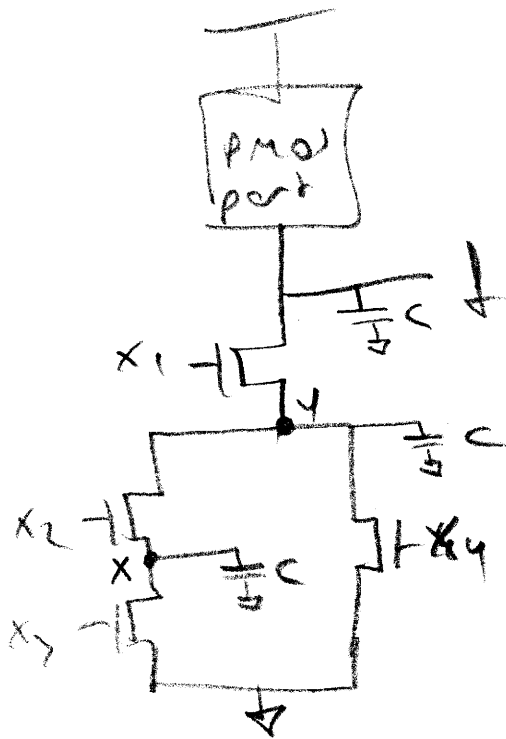$t_{PHL} = 0.69 \{2R \cdot 3C\}$

c) $t_{PLH}$

$V_{out-initial} = 0$

$t_{PLH} = 0.69 \{\frac{R}{2} \cdot 3C\}$

$V_{out}$ $3C$

$\underline{By}$ / Consider a CMOS circuit shown below. Each NMOS transistor has an equivalent resistor $R_N$. Suppose that $V_{TN}$ is very small compared to $V_{DD}$.



Calculate the delays

a) $X_1 = 1$  ○
$X_2 = 1$  ○
$X_3 = 0 \rightarrow 1$  ↗
$X_4 = 0 \rightarrow 1$  ↗

b) $X_1 = 0 \rightarrow 1$  ↗
$X_2 = 1$
$X_3 = 1$
$X_4 = 1$

a) $V_{out-initial} = V_{DD}$

$(V_{DD} - V_{TN}) < V_{Y-initial} \leq V_{DD} \approx V_{DD}$

$V_{DD} - V_{TN} \leq V_{X-initial} \leq V_{DD} \approx V_{DD}$

$t_{PHL} \approx 0.69 \left\{ (R + (R//2R)) C + (R//2R) C \right\}$

            ignored



b) $V_{out-init} = V_{DD}$
$V_{X-in} = 0$    $t_{PHL} = 0.69 \left( R + R//2R \right) C$   ignored
$V_{Y-in} = 0$