- Exam #3 – Wednesday (4/14/04)
- Problem Session – Tuesday 7pm (4/13/04)
- This exam may be taken on Friday at 8-9am or 11-12noon
- ONLY if you contact me today (4/12) by 4pm.
- Please be sure to do the on-line evaluation for this class.

Chapter 10

Elmore Delay –

$$\tau_i \approx \sum_k (C_k R_{ik})$$

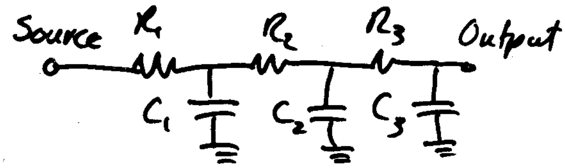
i = node of interest

C_k = capacitance at node k

R_{ik} = sum of all the resistance in common with the path from node i to node k.

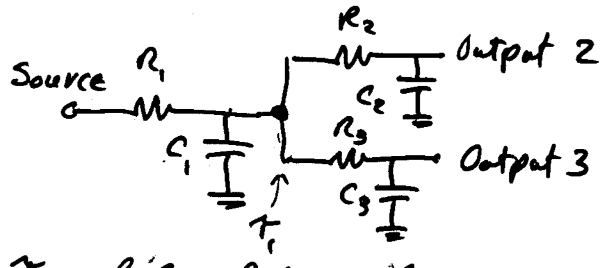
Example

1.)



$$\tau \cong R_1C_1 + C_2(R_1+R_2) + C_3(R_1+R_2+R_3)$$

2.)

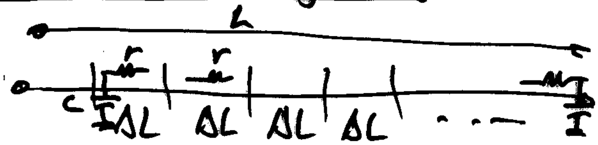


$$\tau_1 = R_1C_1 + R_1C_2 + R_1C_3$$

$$\tau_2 = R_1C_1 + R_1C_3 + (R_1+R_2)C_2$$

$$\tau_3 = R_1C_1 + R_1C_2 + (R_1+R_3)C_3$$

RC Delay in Long Wires



Let $\Delta L = \frac{L}{n} \rightarrow R_{wire} = n R_{int} = nr$

$C_{wire} = n C_{int} = nc$

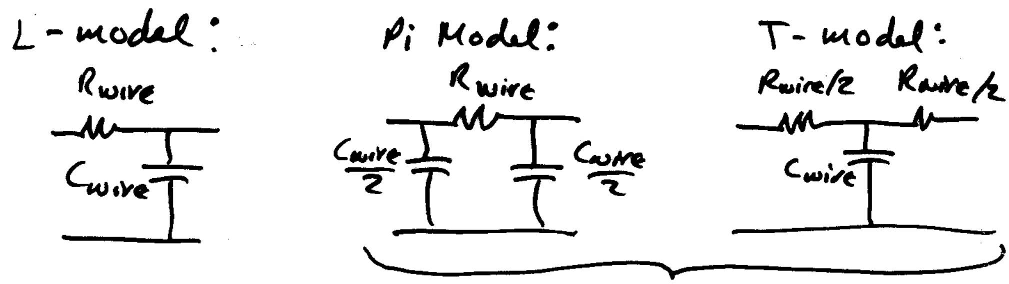
$$\tau_{elmore} = (r\Delta L)(c\Delta L) + 2(r\Delta L)(c\Delta L) + \cdots + n(r\Delta L)(c\Delta L)$$

$$= (\Delta L)^2 rc \frac{n(n+1)}{2} \approx n^2 \Delta L^2 \frac{rc}{2} = L^2 \frac{rc}{2}$$

$$\cong \frac{R_{wire} C_{wire}}{2} \quad (\text{Closer to } 0.38\, R_{wire} C_{wire})$$

Note delay increase with L^2.

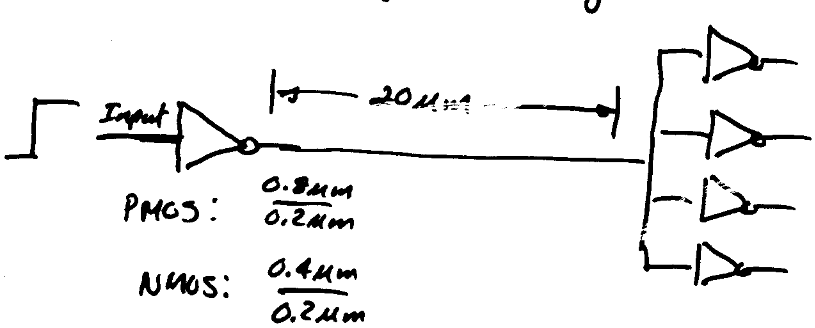
Lumped Models for Interconnect



Best since the delay $\approx \frac{1}{2} R_{wire} C_{wire}$

Example of Delay with Short Wires (Ex. 10.2)

Find the propagation delay thru the 1st inverter. Assume 0.18 μm Technology

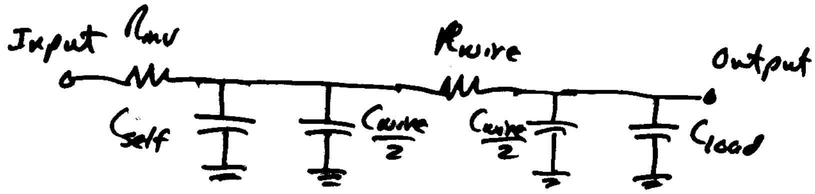


$C_g = 2fF/\mu m$

$C_{eff} = 1fF/\mu m$

$C_{int} = 0.2fF/\mu m$

Model –



$C_{self} = C_{eff}(W_p + W_n) = 1\,fF/\mu m\,(0.8 + 0.4)\mu m = 1.2\,fF$

$C_{wire} = 0.2\,fF/\mu m \times 20\,\mu m = 4\,fF$

$C_{load} = 4\,C_g\,(W_n + W_p) = 9.6\,fF$ Wire width $= 0.2\,\mu m$

$R_{inv} = 12.5\,k\Omega\left(\frac{0.2}{0.4}\right) = 6.25k$

$R_{wire} = (54\,m\Omega/\square)\left(\frac{20\,\mu m}{0.2\,\mu m}\right) = 5.4\,\Omega$

$\tau_{delay} = R_{inv}\left(C_{self} + \frac{C_{wire}}{2}\right) + (R_{inv} + R_{wire})\left(C_{load} + \frac{C_{wire}}{2}\right)$

$= 6.25\,k\Omega\,(1.2\,fF + 2\,fF) + (6.25k + 5.4\,\Omega)(2\,fF + 9.6\,fF)$

$= 20\,ps + 72.6\,ps = 92.6\,ps$

Repeat this example if the wire is 20 mm long. ($W = 0.5\,\mu m$)

$R_{wire} = R_{mt}\left(\frac{L}{W}\right)$

Assume metal 5 (Al) $\rightarrow$ $R_{mt} = 27\,m\Omega/\square$

$\therefore R_{wire} = 27\,m\Omega/\square\left(\frac{20{,}000}{0.5}\right) = 1080\,\Omega$

Inverter is now ×100

$R_{inv.} = \frac{6.25\,k\Omega}{100} = 62.5\,\Omega$

$C_{self} = C_{eff}(3W) \times 100 = 1\frac{fF}{\mu m}(3 \times 0.2\,\mu m) \times 100 = 60\,fF$

$C_{wire} = C_{int}L = \left(0.1\frac{fF}{\mu m}\right)(20{,}000\,\mu m) = 2\,pF$

Metal 5 is further away from the substrate.

$\tau_{delay}(long) \cong \underbrace{(62.5\,\Omega)(1\,pF)}_{125} + \underbrace{(62.5 + 1080)(1\,pF)}_{135} \cong \overset{1.205}{1.2\,ns}$

How do you reduce the delay of long wires?
Buffer insertion.