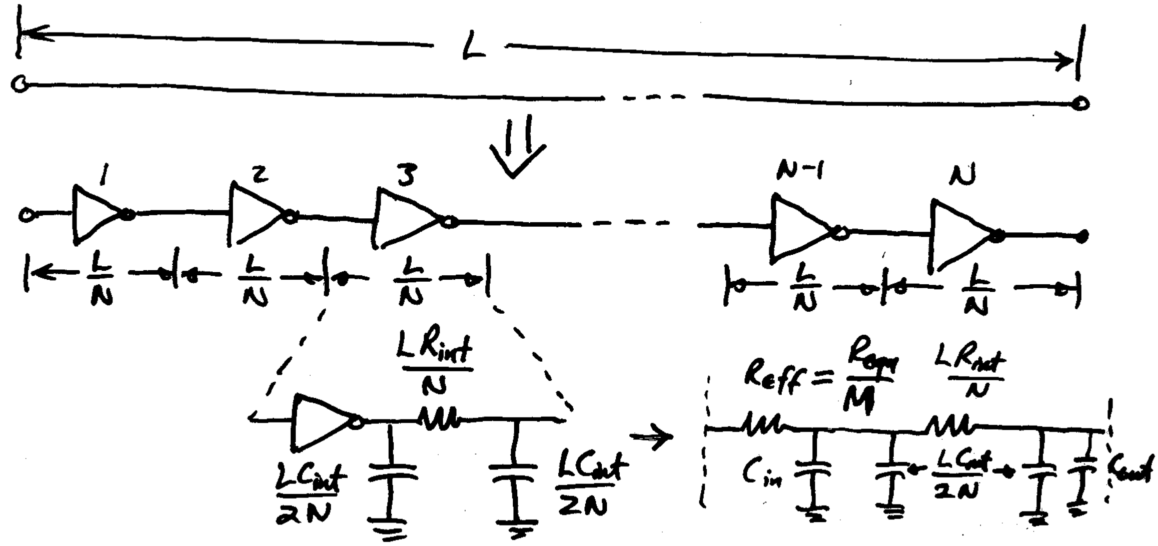
How do you reduce the delay of long wires?

Use the concept of buffer insertion.



$$C_{in} = C_{eff}(W_n + W_p) = C_{eff} W_n\left(1 + \frac{W_p}{W_n}\right) = C_J(1+B)$$

where $C_J = C_{eff} W_n$ and $B = \frac{W_p}{W_n}$

$$C_{out} = C_g(W_n + W_p) = C_g W_n(1+B) = C_G(1+B)$$

$R_{eff} = \frac{R_{eqn}}{M}$ where M = optimal buffer size for the insertion problem.

Elmore delay for a segment,

$$t_{seg.} = \frac{R_{eqn}}{M}\left[C_J(1+B)M + \frac{C_{int}L}{2N}\right] + \left[\frac{R_{eqn}}{M} + \frac{R_{int}L}{N}\right]\left[\frac{C_{int}L}{2N} + C_G(1+B)M\right]$$

$$= R_{eqn}(C_J + C_G)(1+B) + \left[\frac{R_{eqn}}{M}\frac{C_{int}L}{2N} + \frac{R_{eqn}}{M}\frac{C_{int}L}{2N}\right] + \frac{R_{int}L}{N}\left[\frac{C_{int}L}{2N} + C_G M(1+B)\right]$$

Total delay -

$$t_{total} = N \times t_{seg.} = \underbrace{N(C_J + C_G)R_{eqn}(1+B)}_{\text{Buffer only}} + \underbrace{\left[C_G(1+B)R_{int}M + \frac{C_{int}R_{eqn}}{M}\right]L} + \left(\frac{C_{int}R_{int}}{2N^2}\right)L^2$$

1.) Wire resistance × buffer cap

2.) Buffer driving the wire cap

Interconnect only term

Error in book

To optimize the wire delay with buffer insertion, find N and M.

$$N = \sqrt{\frac{R_{int} C_{int} L^2}{2 R_{eqn} (C_J + C_G)(1+B)}} = \sqrt{\frac{t_{wire}}{FO1}} \quad \& \quad M = \sqrt{\frac{R_{eqn} C_{int}}{C_G (1+B) R_{int}}}$$

where FO1 is the delay of an inverter driving an identical inverter and all buffers are sized identically.

<u>Ex. 10.4</u>

Do Ex. 10.3 but use buffer insertion approach.

$R_{int} = 54\ m\Omega/\mu m$, $C_{int} = 0.1\ fF/\mu m$, $L = 20{,}000\ \mu m$

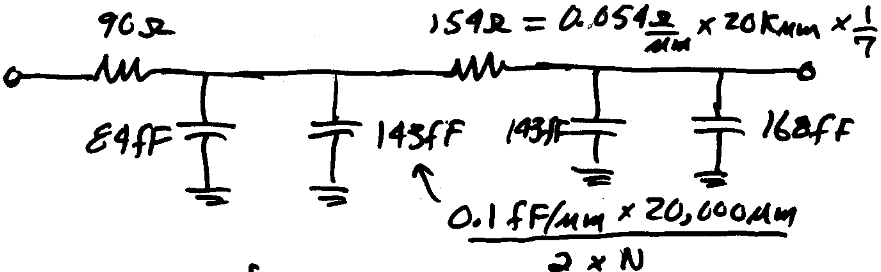
$R_{eqn} = 12.5\ k\Omega/\square$, $C_g = 2\ fF/\mu m$, $C_{eff} = 1\ fF/\mu m$

$W_n = 0.2\ \mu m$ and $B = 2$ $(W_p = 0.4\ \mu m)$

$N = 6.9 \rightarrow N = 7$ and $M = 139 \rightarrow 140$

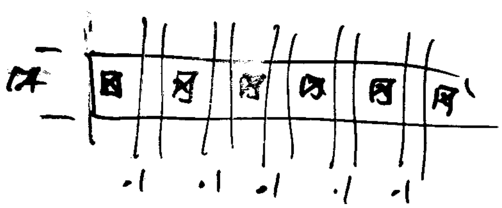
$R_{eff} = \frac{12.5k\Omega}{140} = 90\Omega$ $C_{self} = C_{eff}(2w + w)140 = 84fF$

Buffer cap. $= C_{in} = C_g(2W+W)140 = 168fF$

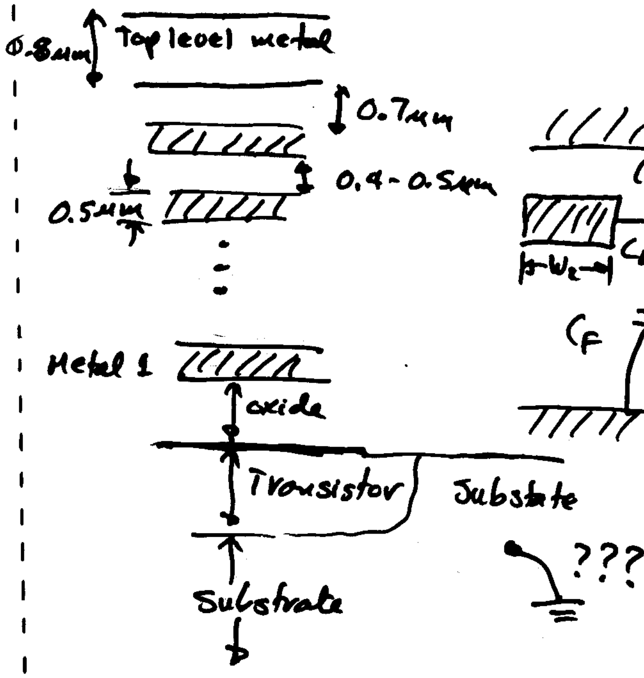


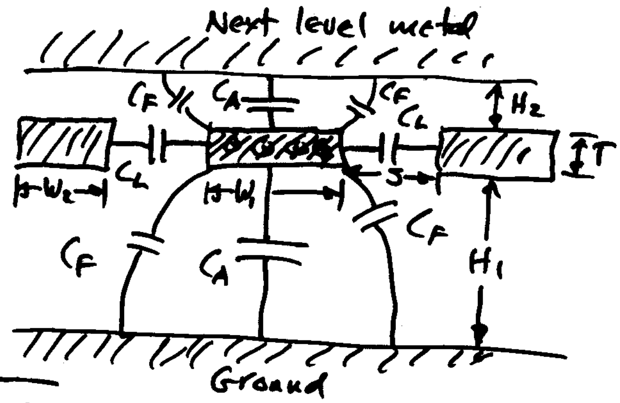
Total delay $\cong 7 \times \left[90(84fF + 143fF) + (90 + 154)(143fF + 168fF) \right]$

$= 0.67\ ns$ (with no buffers, delay 1.3ns)



INTERCONNECT COUPLING CAPACITANCE





1.) Vertical-area (C_A)

2.) Lateral (C_L)

3.) Fringing (C_F)

Approximate formulas-

$$C_A = \epsilon_{ox} \frac{W}{H} = 4\epsilon_0 \frac{W}{H} \doteq 0.035 \frac{W}{H} \ fF/\mu m$$

$$C_L = \epsilon_{ox} \cdot \frac{T}{S} = 0.035 \frac{T}{S} \ fF/\mu m$$

$$C_F = \epsilon_{ox} \ln\left(1 + \frac{T}{H}\right) \ fF/\mu m$$

For 0.18um Upper level metal: $T = 0.8\mu m$ & $S = 0.4\mu m$

$W = 0.4$ Lower level metals: $T = H = 0.5\mu m$

	Closely Spaced ($S=0.4\mu m$)	Widely Spaced ($S = 4\mu m$)
Lower Metal $T=0.5\mu m$ $H=0.8\mu m$	$C_{int} = 2(C_A + C_L + C_F)$ $= 2(0.015) + 2(0.035) + 0$ $= 0.1 fF/\mu m$	$C_{int} = 2(C_A + C_F + C_L)$ $\cong 2(0.015) + 2(0.025) + 0$ $\approx 0.1 fF/\mu m$
Upper metal $T=0.8\mu m$ $H=0.5\mu m$	$C_{int} = 2C_A + 2C_L + 2C_F$ $= 2(0.03) + 2(0.07) + 0$ $= 0.2 fF/\mu m$	$C_{int} = 2C_A + 2C_F + 2C_L$ $= 2(0.03) + 2(0.025) + 0$ $\approx 0.1 fF/\mu m$