DIC L15: Delay (3)

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4.3. RC delay model (1)

- Easily estimate the delay
- RC delay models approximate the nonlinear transistor IV and CV characteristics with an average resistance and capacitance over the switching range of the gate.
  - Total capacitance on output node: C
  - Effective resistance: R
  - Propagation delay ~ RC
- Characterize transistors by finding their effective R values.
  - Not accurate, however good enough to predict RC delay

4.3. RC delay model (2)

- Equivalent R, gate and diffusion capacitance
  - Unit NMOS (for example, $4\lambda/2\lambda$) is defined to have effective resistance R. An NMOS, whose width is k times unit width, has resistance R/k.
  - Let us assume that unit PMOS has effective resistance 2R.
  - Capacitance is linearly scaled.

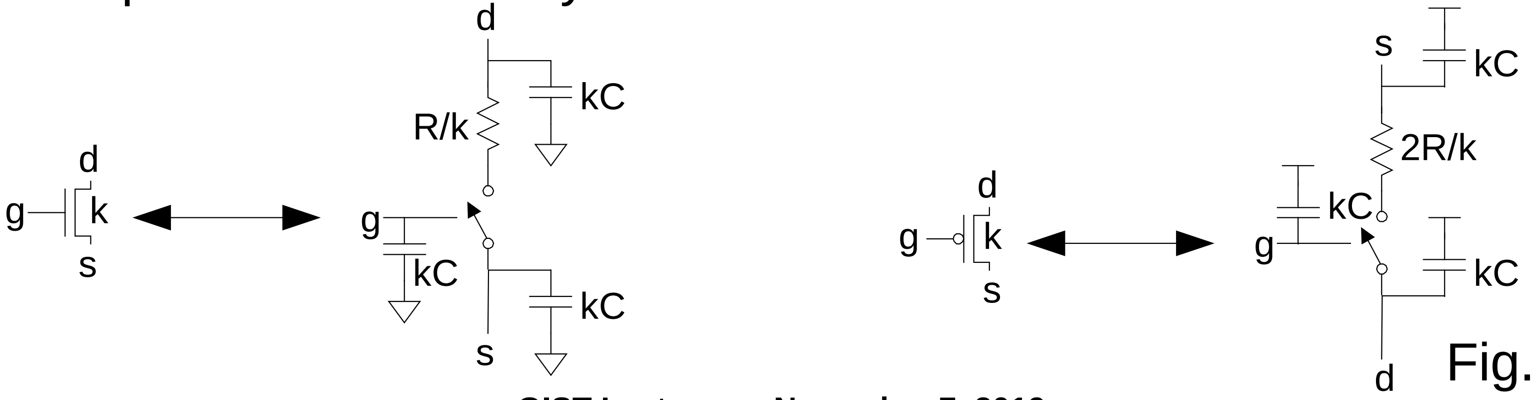


Fig. 4.5

4.3. RC delay model (3)

- A fanout-of-1 inverter
  - Estimate the delay.

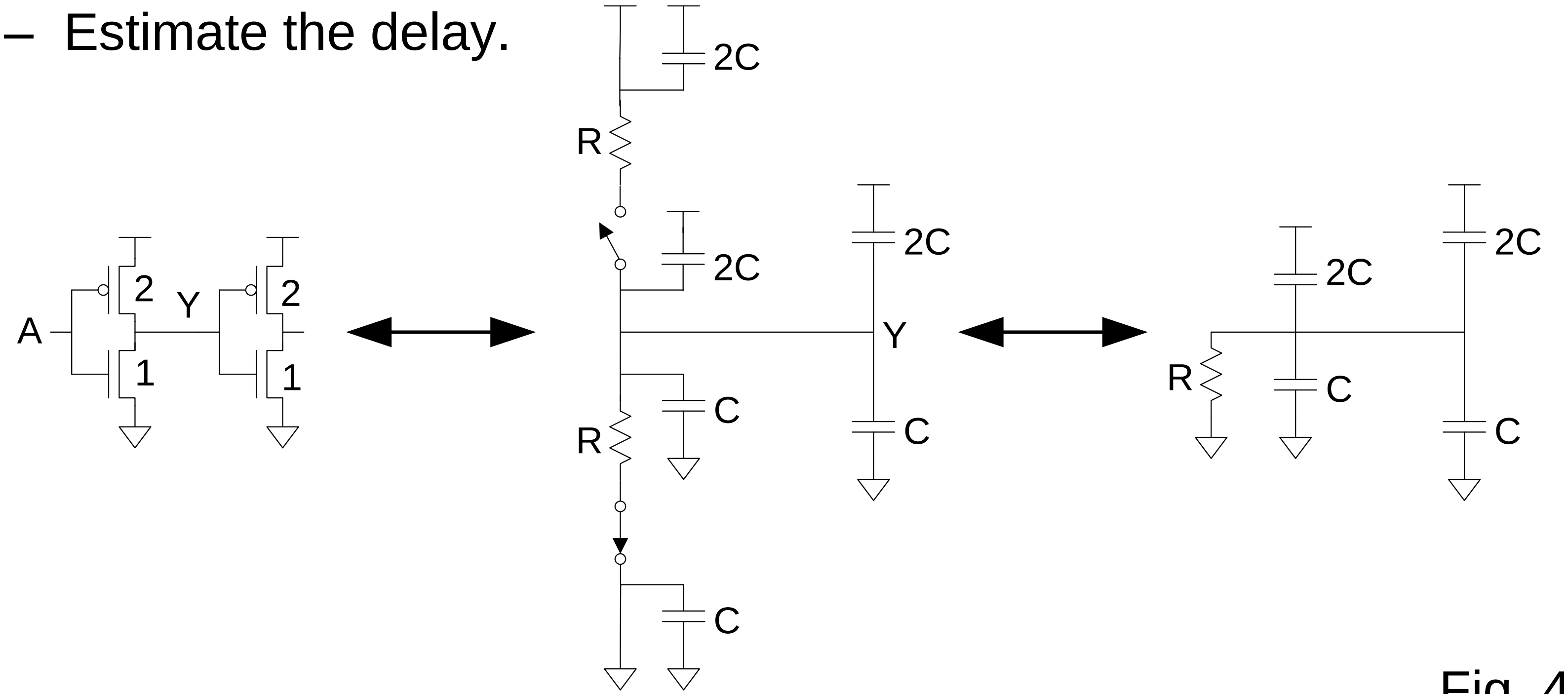


Fig. 4.6

4.3. RC delay model (4)

- Example 4.2

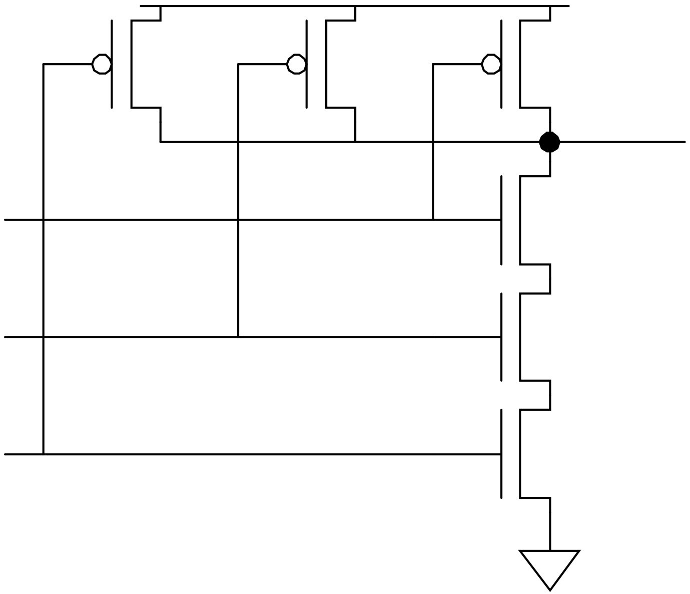


Fig. 4.7(b)

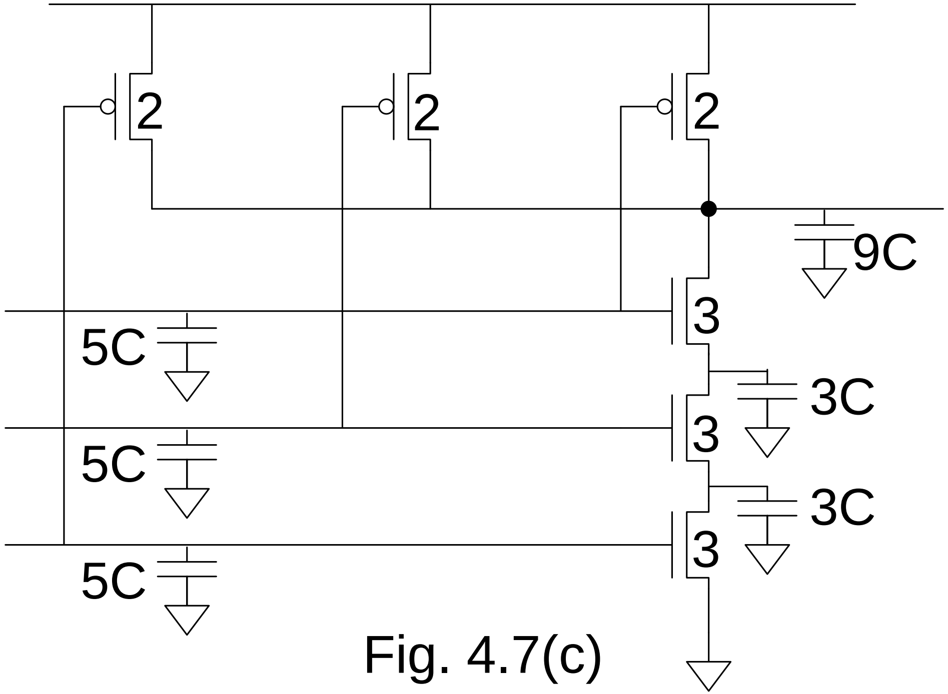


Fig. 4.7(c)

4.3. RC delay model (5)

- First-order RC circuit
  - Its output voltage follows

$$V_{out}(t) = V_{DD} \exp\left(-\frac{t}{RC}\right) \qquad \text{Eq. (4.7)}$$

  - Then, the propagation delay becomes

$$t_{pd} = RC \ln 2 \qquad \text{Eq. (4.8)}$$

- Second-order RC circuit

$$V_{out}(t) = V_{DD} \frac{\tau_1 e^{-t/\tau_1} - \tau_2 e^{-t/\tau_2}}{\tau_1 - \tau_2} \qquad \text{Eq. (4.11)}$$

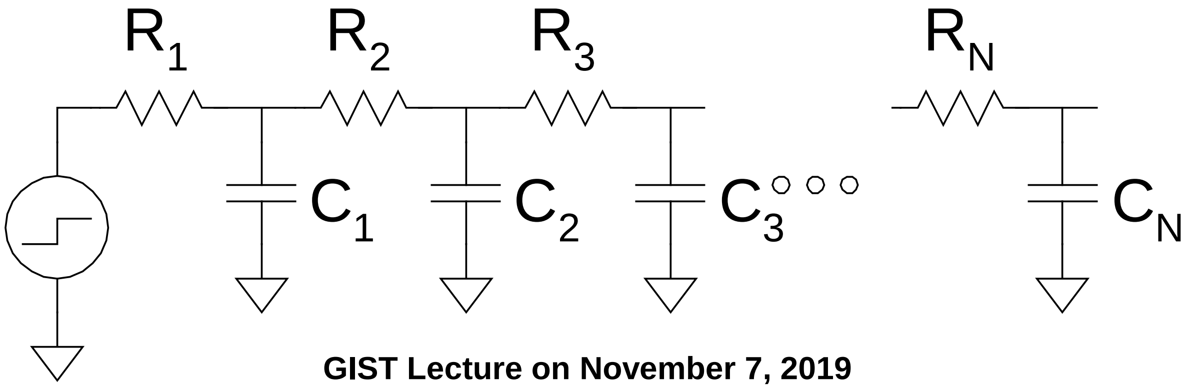
- How about general RC tree circuits?

4.3. RC delay model (6)

- Elmore delay
  - A simple single time constant approximation

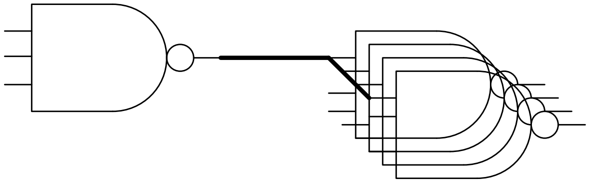
$$t_{pd} \approx \sum_{\text{nodes } i} R_{i-to-source} C_i \qquad \text{Eq. (4.14)}$$

$$= R_1 C_1 + (R_1 + R_2) C_2 + \ldots + (R_1 + R_2 + \ldots + R_N) C_N$$



4.3. RC delay model (7)

- Example 4.7



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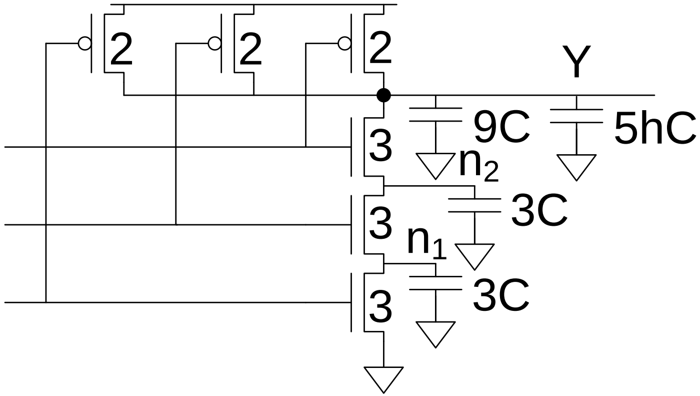
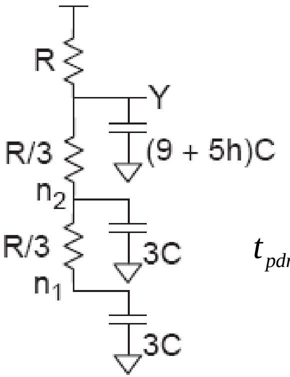
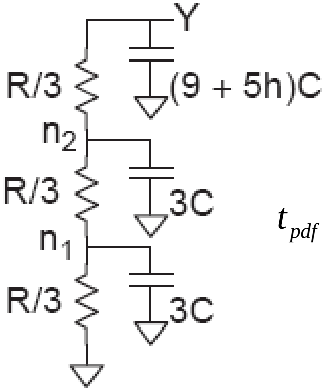




$$t_{pdr} = (9+5h)RC$$



$$\begin{aligned} t_{pdf} &= (3C)\left(\tfrac{R}{3}\right) + (3C)\left(\tfrac{R}{3} + \tfrac{R}{3}\right) + \left[(9+5h)C\right]\left(\tfrac{R}{3} + \tfrac{R}{3} + \tfrac{R}{3}\right) \\ &= (12+5h)RC \end{aligned}$$