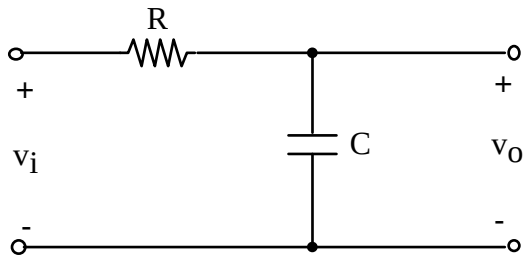
Frequency Dependence of Interconnections

Jose E. Schutt-Aine
Electrical & Computer Engineering
University of Illinois
jesa@illinois.edu

RC Network



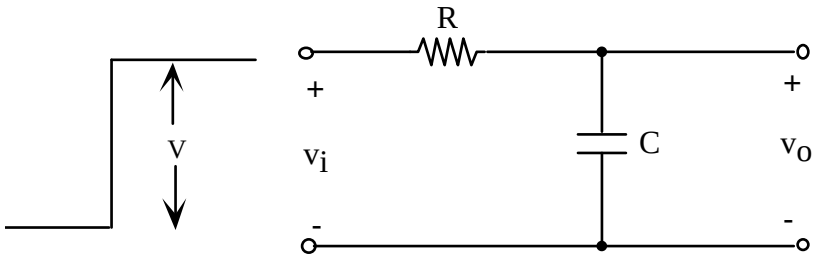
A is the steady-state gain of the network;

$$A = \frac{v_o(f)}{v_i(f)}$$

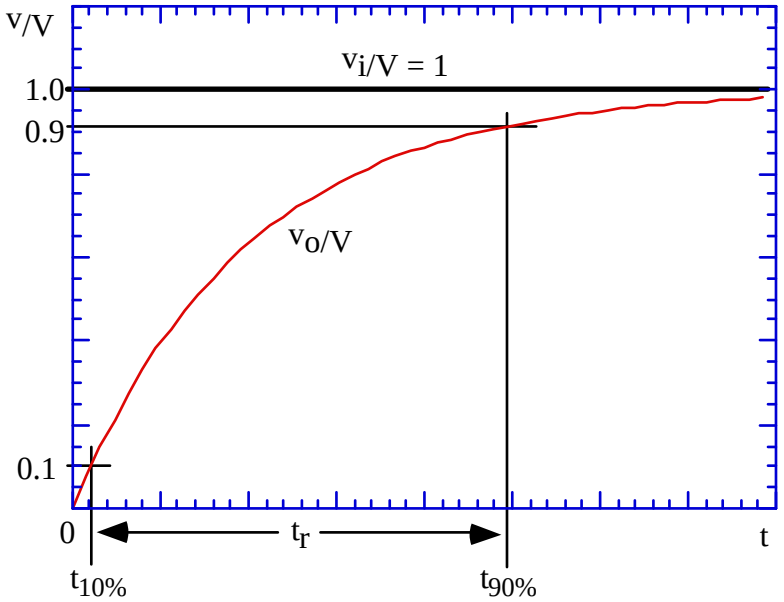
$$|A| = \frac{1}{\sqrt{1+(f/f_2)^2}} \qquad f_2 = \frac{1}{2\pi RC}$$

The gain falls to 0.707 of its low-frequency value at the frequency f_2. f_2 is the *upper 3-dB frequency* or the 3-dB bandwidth of the RC network.

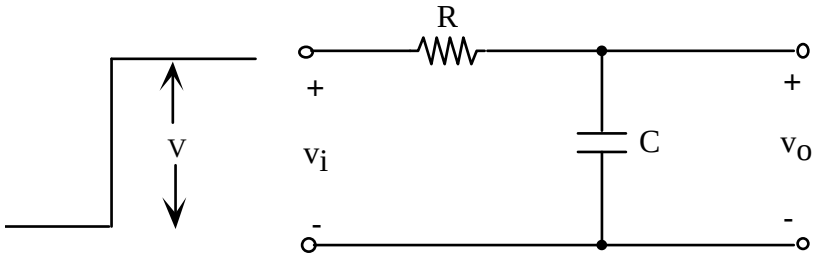
RC Network



$$v_o = V\left(1 - e^{-t/RC}\right)$$



RC Network



Rise time : $t_r = t_{90\%} - t_{10\%}$

$$t_r = 2.2RC = \frac{2.2}{2\pi f_2} = \frac{0.35}{f_2}$$

<u>Rule of thumb</u>: A 1-ns pulse requires a circuit with a 3-dB bandwidth of the order of 2 GHz.

Frequency Dependence of Lumped Circuit Models

- At higher frequencies, a lumped circuit model is no longer accurate for interconnects and one must use a distributed model

- Transition frequency depends on the dimensions and relative magnitude of the interconnect parameters.

$$f \approx \frac{0.3 \times 10^9}{10d\sqrt{\varepsilon_r}} \qquad t_r \approx \frac{0.35}{f}$$

Lumped Circuit or Transmission Line?

- **Determine frequency or bandwidth of signal**
  - RF/Microwave: f= operating frequency
  - Digital: $f=0.35/t_r$
- **Determine the propagation velocity and wavelength**
  - Material medium $v=c/(\varepsilon_r)^{1/2}$
  - Obtain wavelength $\lambda=v/f$
- **Compare wavelenth with feature size**
  - If $\lambda >> d$, use lumped circuit: L_{tot}= L* length, C_{tot}= C* length
  - If $\lambda \approx 10d$ or $\lambda<10d$, use transmission-line model

Frequency Dependence of Lumped Circuit Models

Level	Dimension	Frequency	Edge rate
PCB line	10 in	> 55 MHz	< 7ns
Package	1 in	> 400 MHz	< 0.9 ns
VLSI int*	100 um	> 8 GHz	< 50 ps

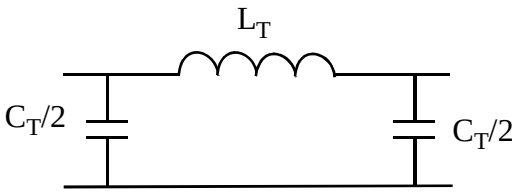
* Using RC criterion for distributed effect

Modeling Interconnections

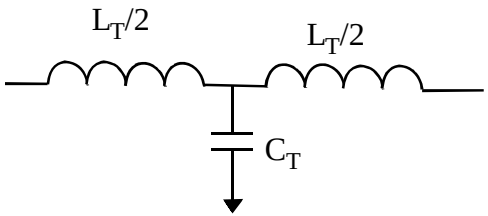
Low Frequency

Short

Mid-range Frequency

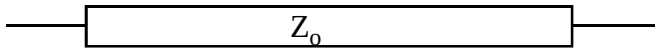


or



Lumped Reactive CKT

High Frequency



Transmission Line