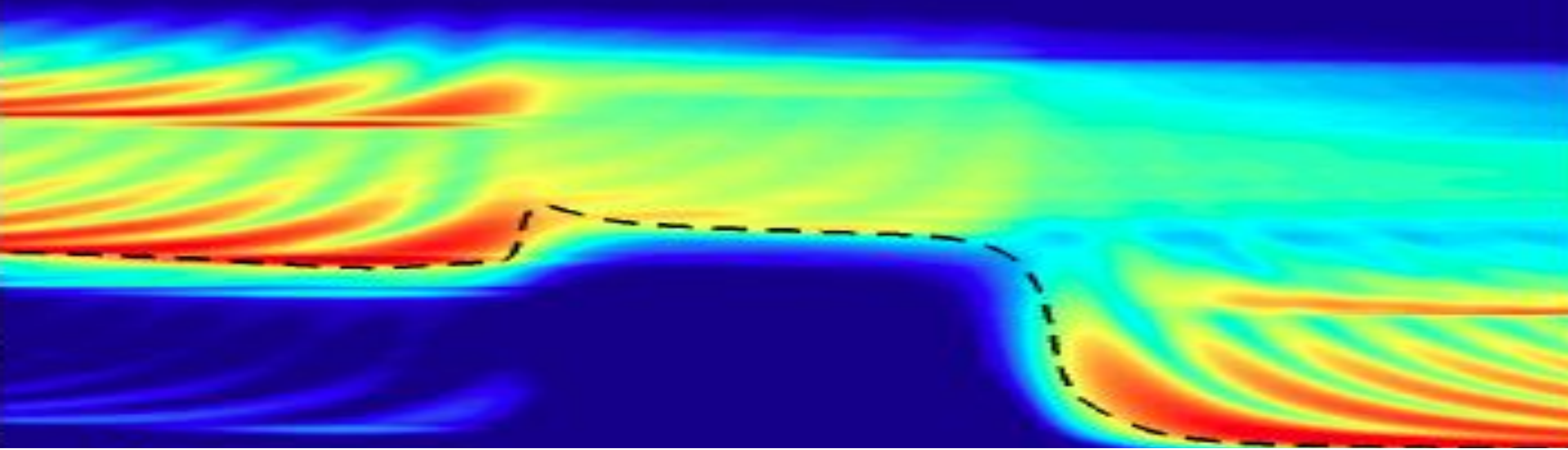


EECS 16B
Designing Information Devices and Systems II
Lecture 2

Prof. Sayeef Salahuddin

Department of Electrical Engineering and Computer Sciences, UC Berkeley, sayeef@eecs.berkeley.edu

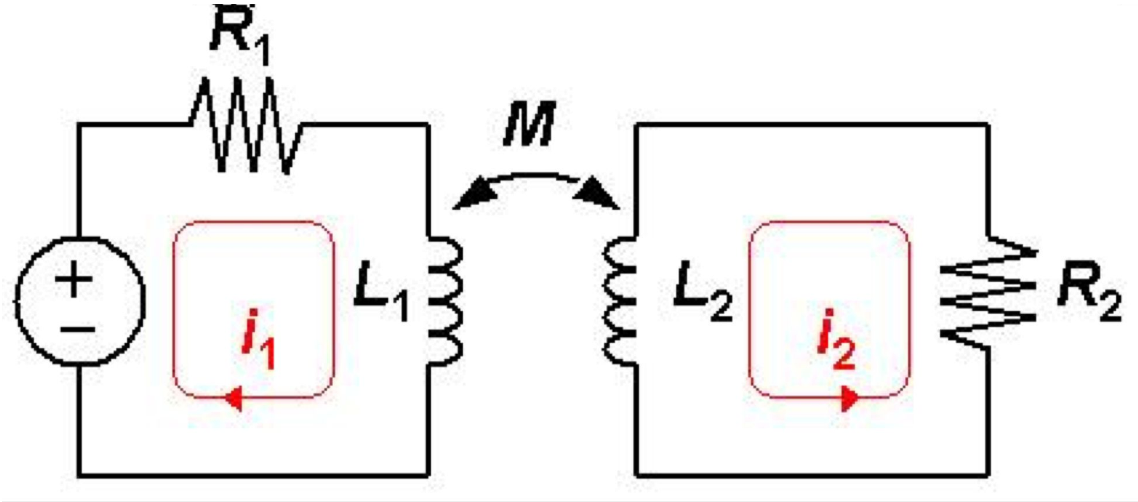
Transient Response

- Outline
  - Mutual Inductance
  - DAC and ADC
  - R-C circuits
  - R-L circuits
  - Steady State

- Reading: Section 3.6, 4.1-4.4, Slides

Mutual Inductance

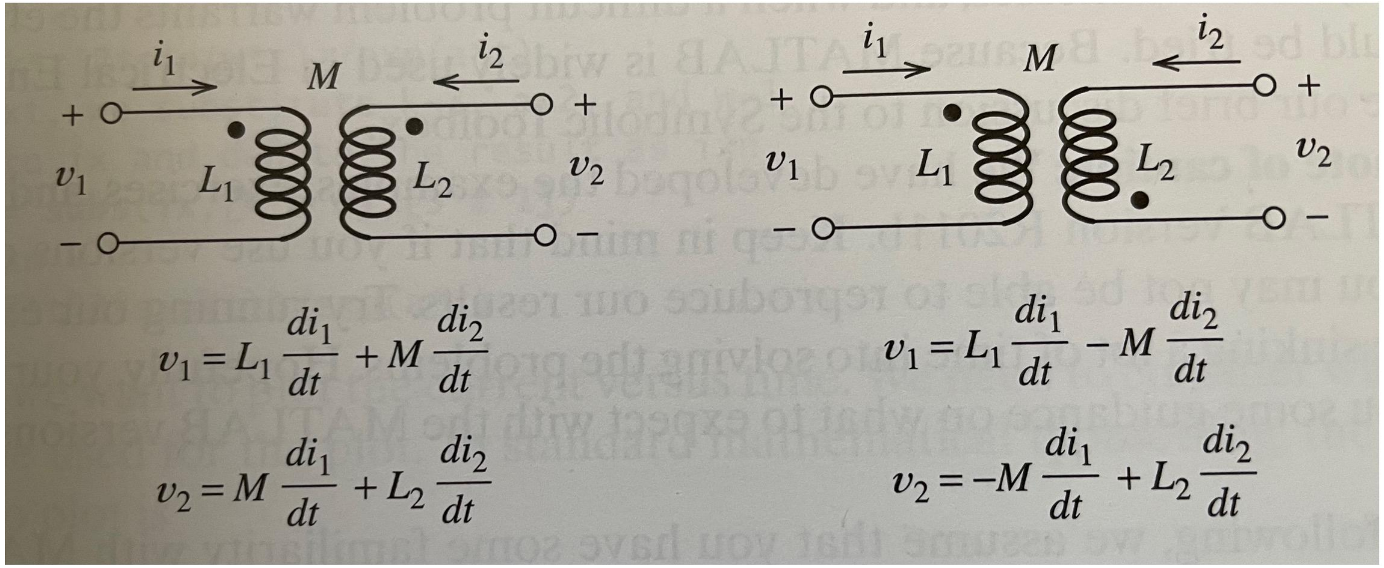
- Mutual inductance occurs when two windings are arranged so that they have a mutual flux linkage
- The change in current in one winding causes a voltage drop to be induced in the other



Transformers (adapters), motors, generators (electric cars)

The Dot Convention

- If a current enters the dotted terminal of a coil, the reference polarity of the voltage induced in the other coil is positive at its dotted terminal.
- If a current leaves the dotted terminal of a coil, the reference polarity of the voltage induced in the other coil is negative at its dotted terminal.
- Total voltage induced in a coil is a summation of its own induced voltage and the mutually induced voltage



Summary

Capacitors:

$$i = C\frac{dv}{dt}$$

$$w = \frac{1}{2}Cv^2$$

- v cannot charge instantaneously
- i **can** charge instantaneously (do not short circuit a charged capacitor)
- *N* capacitors in series $\frac{1}{C_{eq}} = \sum_{i=1}^{N}\frac{1}{C_i}$
- *N* capacitors in parallel $C_{eq} = \sum_{i=1}^{N} C_i$

Inductors:

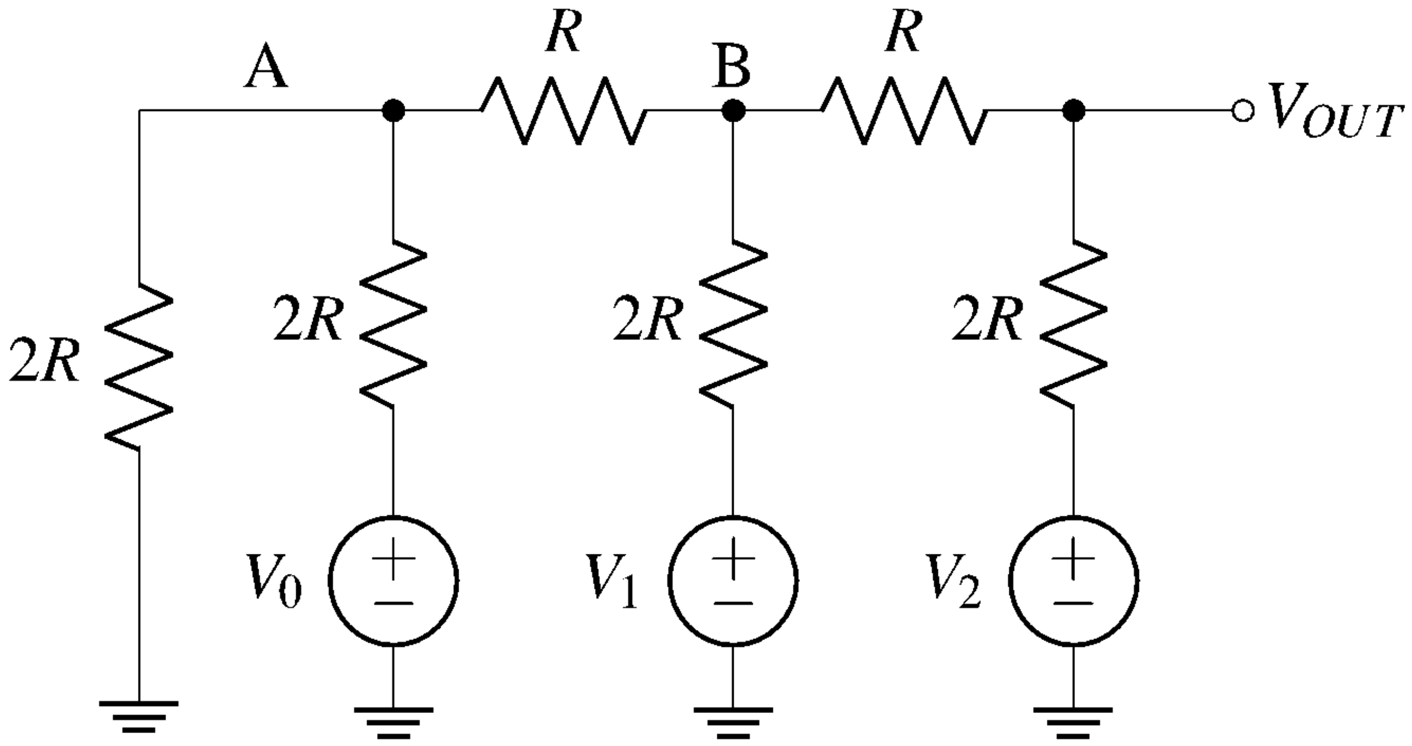
$$v = L\frac{di}{dt}$$

$$w = \frac{1}{2}Li^2$$

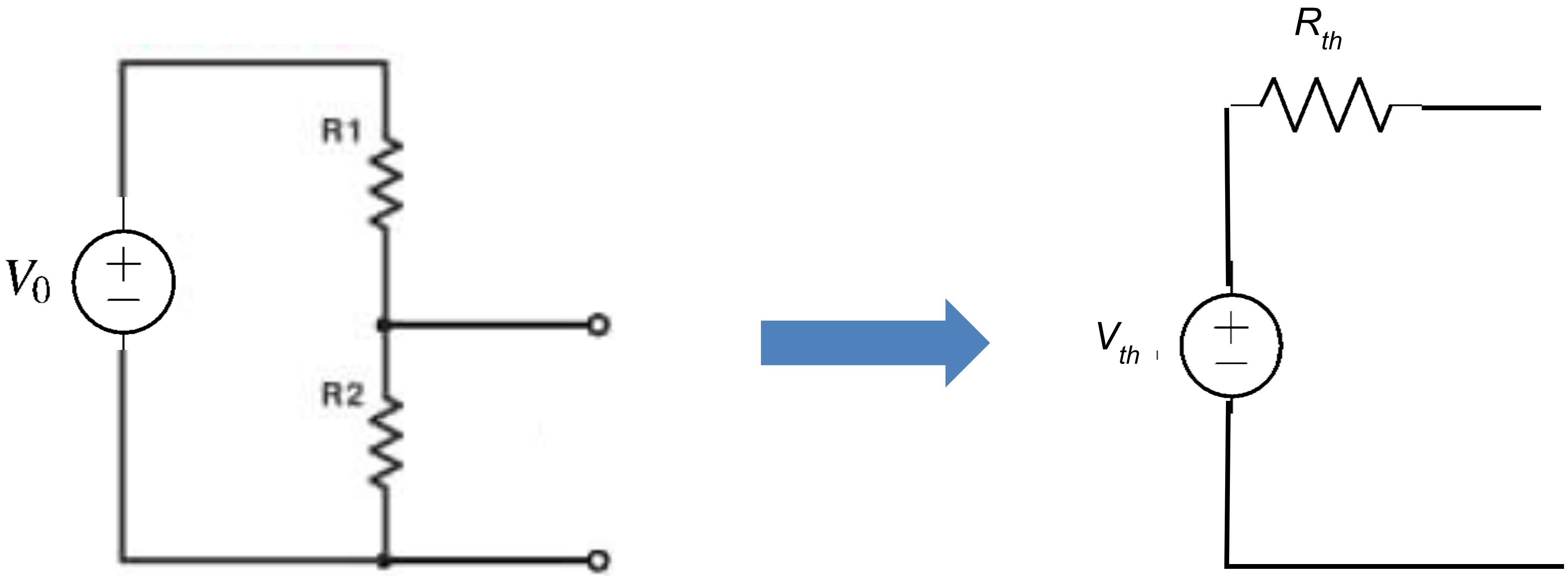
- i cannot charge instantaneously
- v **can** charge instantaneously (do not open an inductor with current)
- *N* inductors in series $L_{eq} = \sum_{i=1}^{N} L_i$
- *N* inductors in parallel $\frac{1}{L_{eq}} = \sum_{i=1}^{N}\frac{1}{L_i}$

Simple Circuits

R-2R Ladder Digital-to-Analog Converter



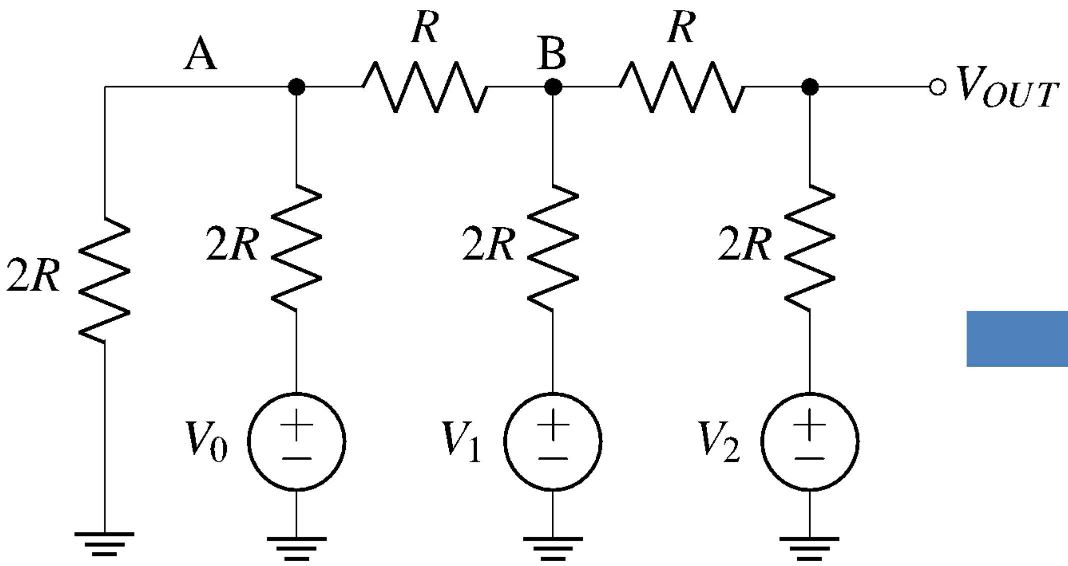
Remember Superposition and Equivalence?

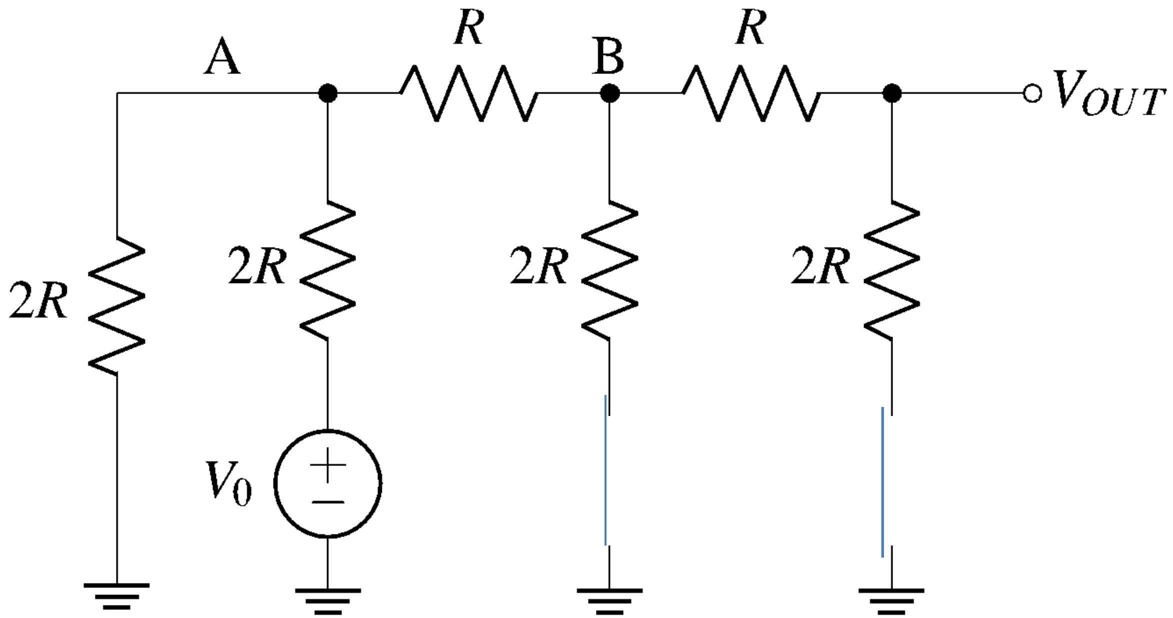


Thevenin Equivalent

R-2R Ladder Digital-to-Analog Converter

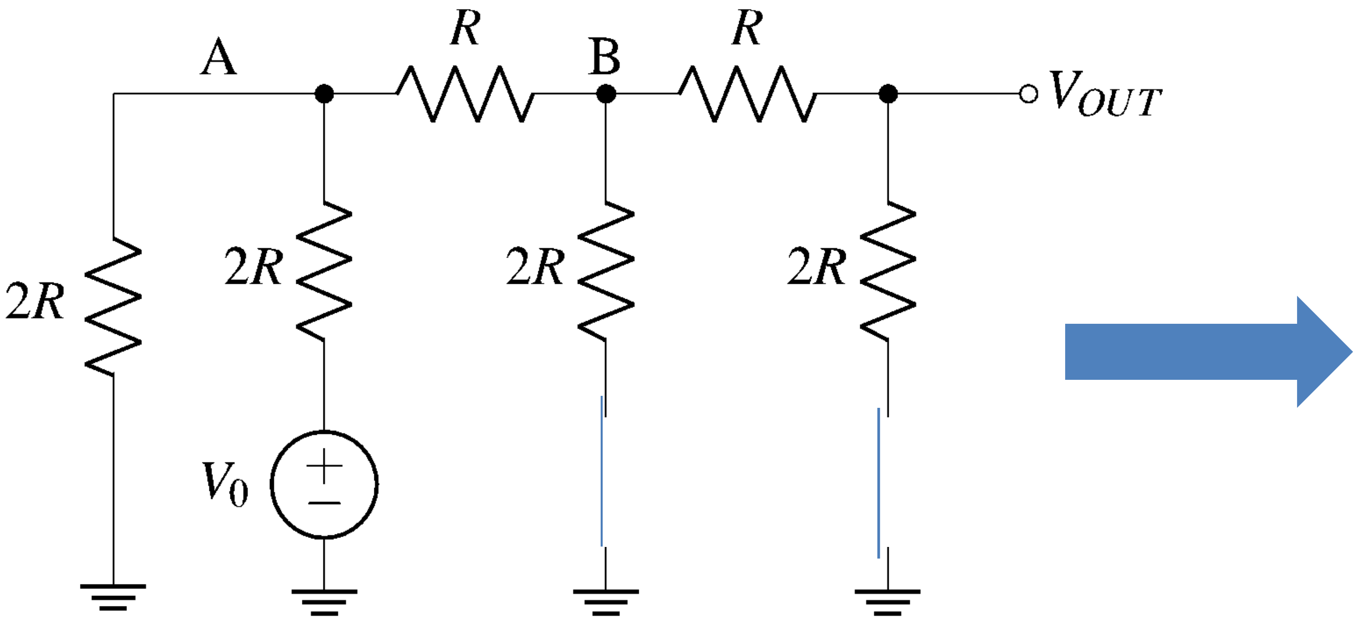
Use superposition: Start with V_0





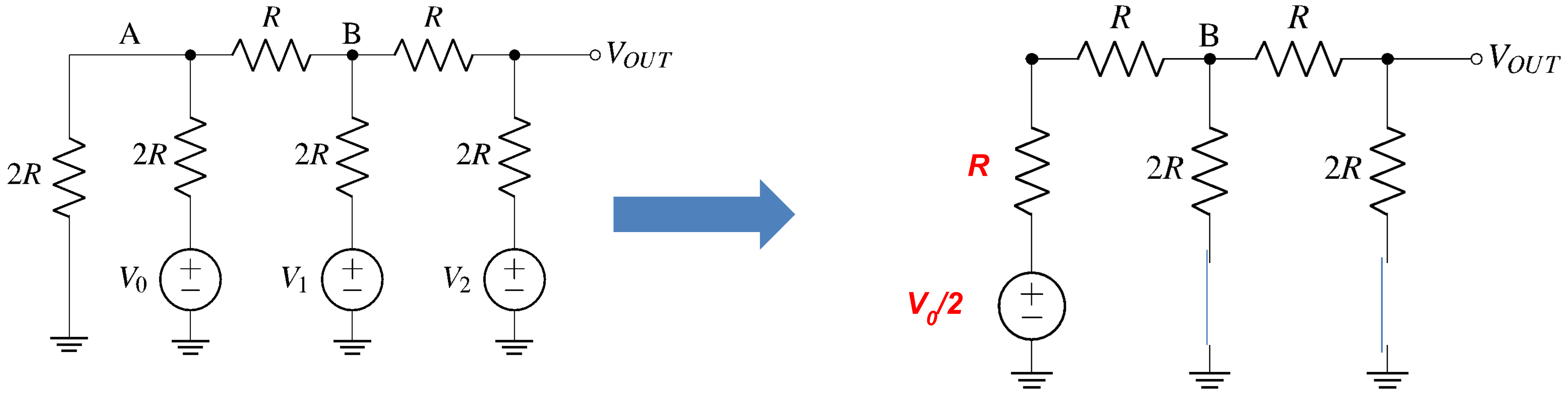
R-2R Ladder Digital-to-Analog Converter

Use superposition: Start with V_0



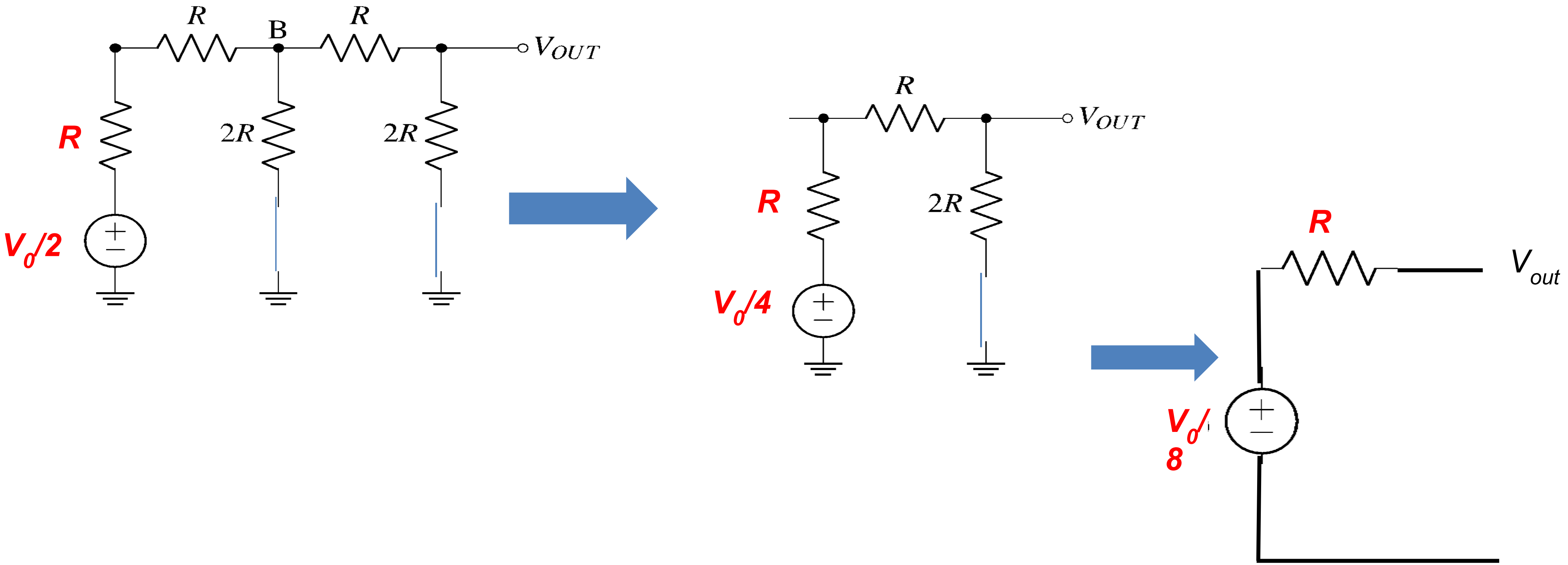
R-2R Ladder Digital-to-Analog Converter

Using Thevenin Equivalent



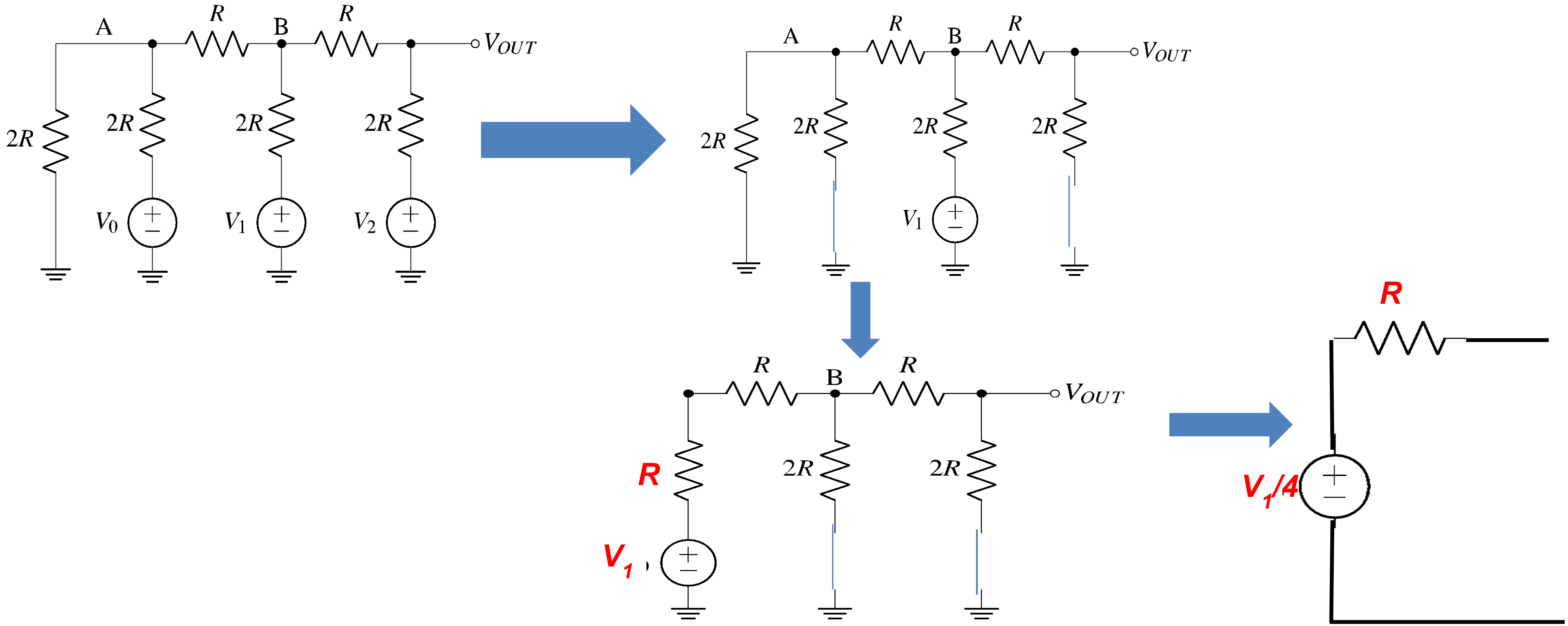
R-2R Ladder Digital-to-Analog Converter

Using Thevenin Equivalent



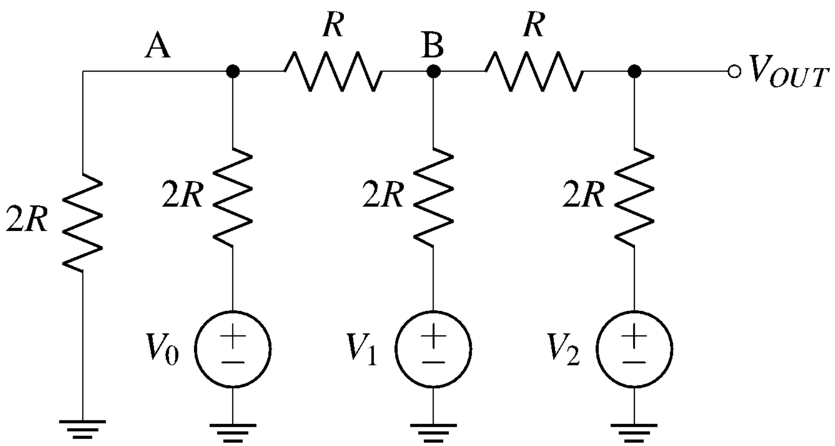
R-2R Ladder Digital-to-Analog Converter

Now lets look at V_1



R-2R Ladder Digital-to-Analog Converter

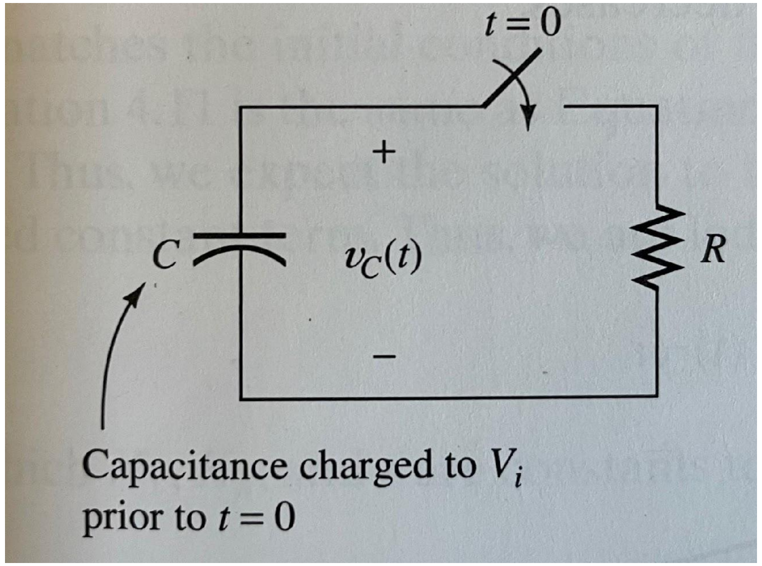
Adding all contributions from the sources



$$V_{out} = \frac{V_0}{8} + \frac{V_1}{4} + \frac{V_2}{2}$$

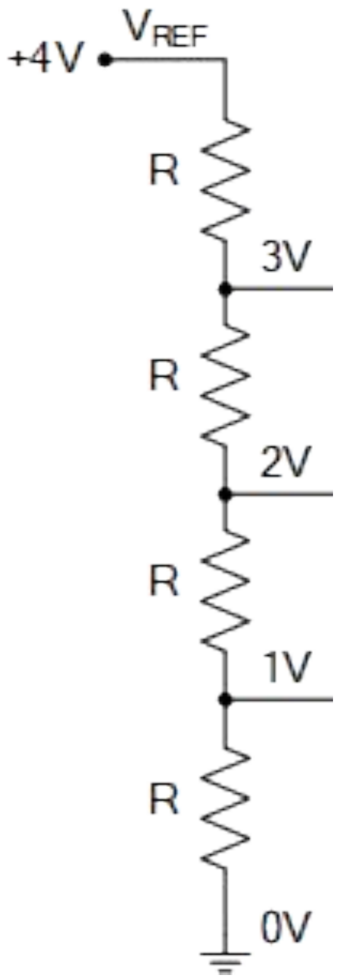
R-C circuits: Response in time

Say a capacitor C had a stored charge of Q so that it held a voltage of V_i across it. At t=0 a switch connects it to a resistor completing the circuit.

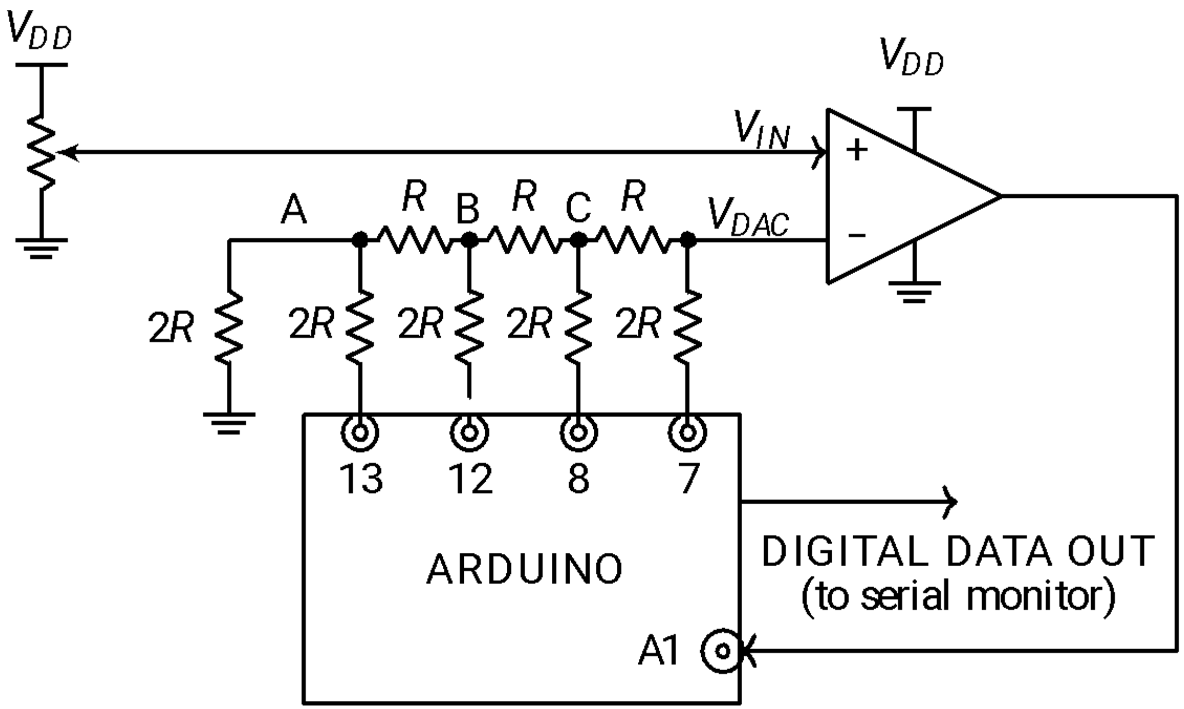


Analog to Digital Conversion

Say we want to convert an analog signal to a 2 bit digital signal 4 levels

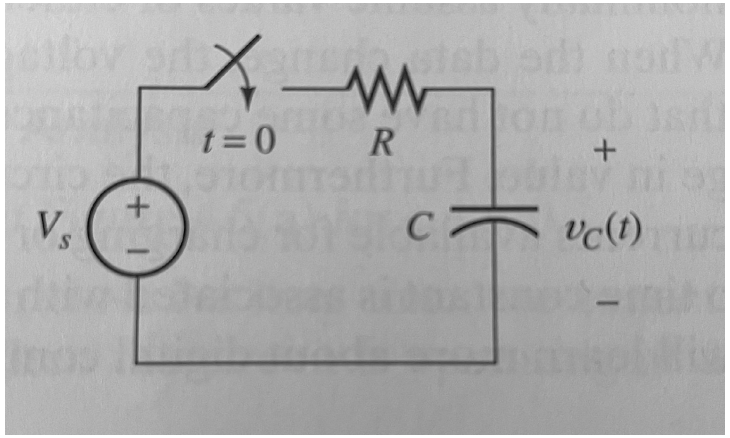


Lab 2: SAR (Successive Approximation Resistor) ADC



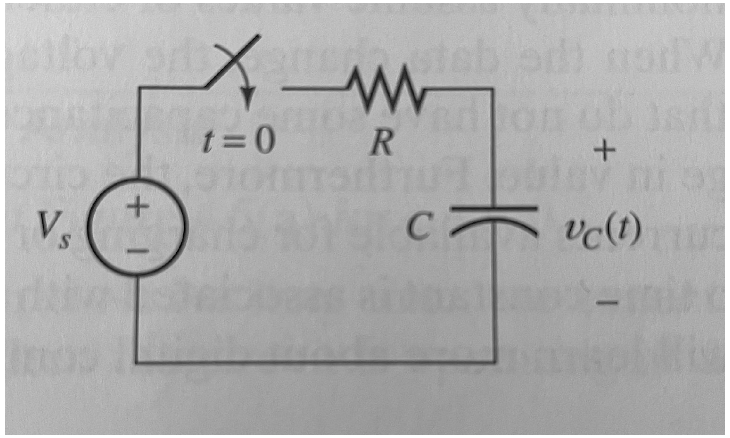
R-C circuits: Response in time

We now ask a slightly different question. What happens if a capacitor that had initially no charge is connected to a constant voltage at t=0



R-C circuits: Response in time

We now ask a slightly different question. What happens if a capacitor that had initially no charge is connected to a constant voltage at *t*=0



General Solution of the Differential Equation

General Solution of the Differential Equation

For a first order, linear differential equation of the form

$$\frac{dy}{dt} + ay(t) = b(t)$$ where we assume a to be a constant

Homogeneous/Complementary solution

$$\frac{dy}{dt} + ay(t) = 0$$

$$\Rightarrow \frac{dy}{y} = -a$$

$$\Rightarrow \ln(y) = -at + C$$

$$\Rightarrow y(t) = Ke^{-at}$$

Particular Solution (Integrating Factor Method):

$$\frac{dy}{dt} + ay(t) = b(t)$$

We want to find a multiplier function *f(t)* such that

$$f(t)\frac{dy}{dt} + af(t)y(t) = b(t)f(t)$$

can be written as

$$\frac{d}{dt}[y(t)f(t)] = b(t)f(t) \quad \text{--(A)}$$

For equation (A) to hold

$$\frac{df(t)}{dt} = af(t)$$

$$\Rightarrow f(t) = e^{at}$$

Then from (A)

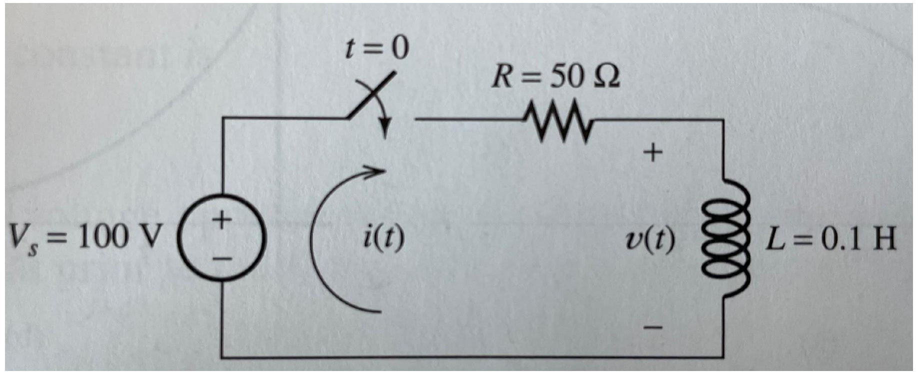
$$y(t) = \frac{1}{f(t)}\int b(t)f(t)dt$$

$$\Rightarrow y_p(t) = e^{-at}\int e^{at}b(t)dt$$

$$\boxed{y(t) = Ke^{-at} + e^{-at}\int e^{at}b(t)dt}$$

K is determined using initial condition

R-L Circuits



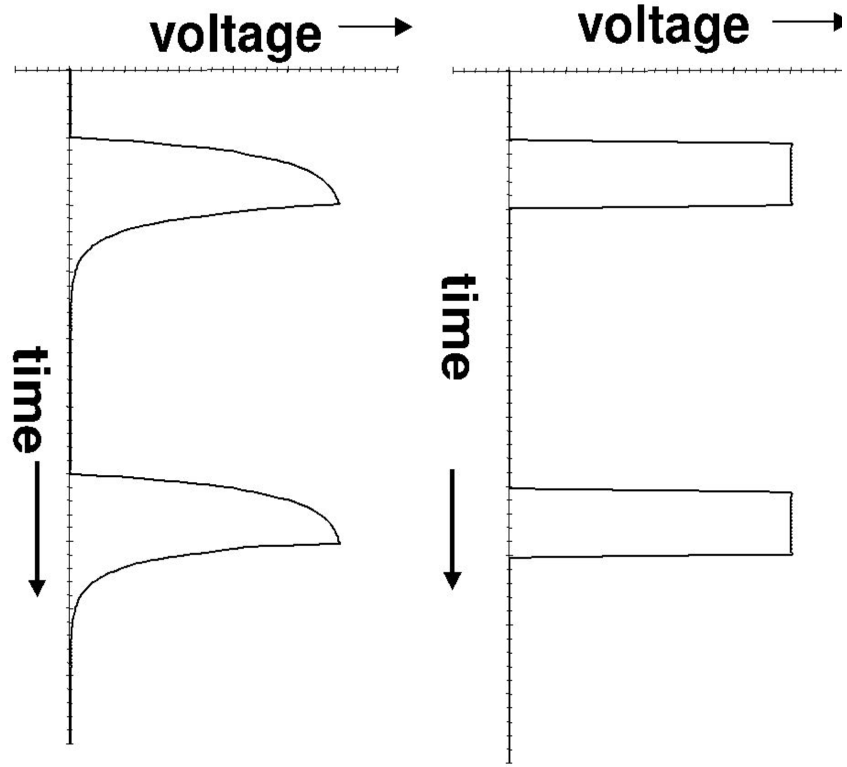
Steady State

Capacitors:

Inductors:

Digital Signals to a RC circuit

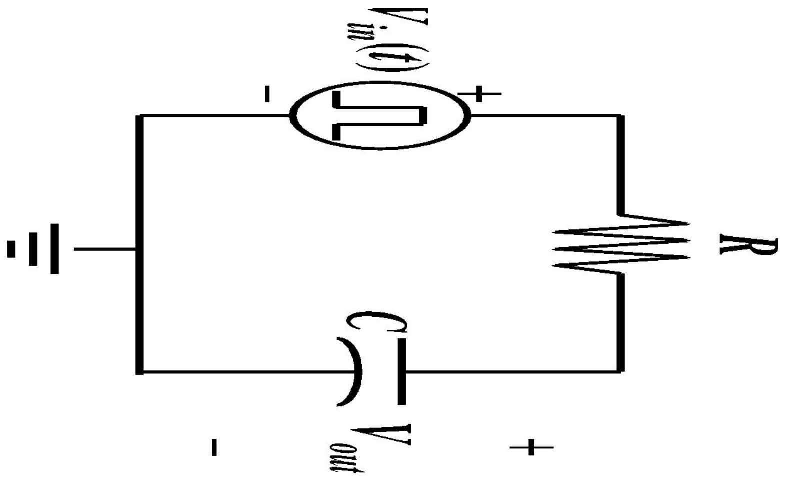
- Every node in a real circuit has capacitances

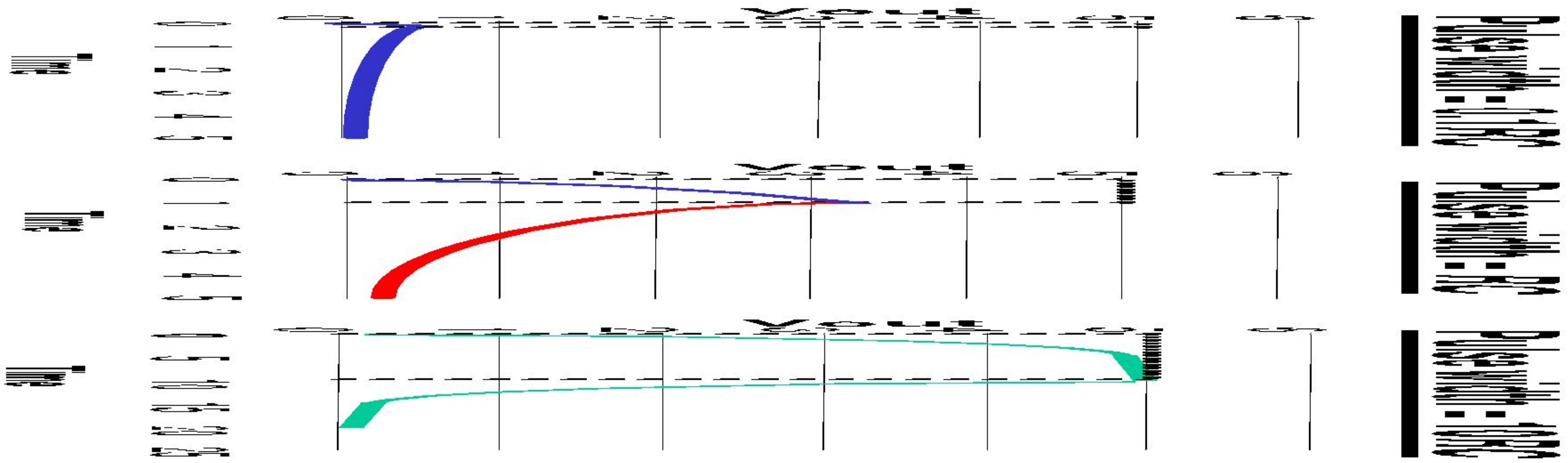


- Even if we send in very ‘pure’ square looking pulses what we actually get is how it looks in the right due to capacitor charging and discharging unless we go very very slow

Pulse Distortion

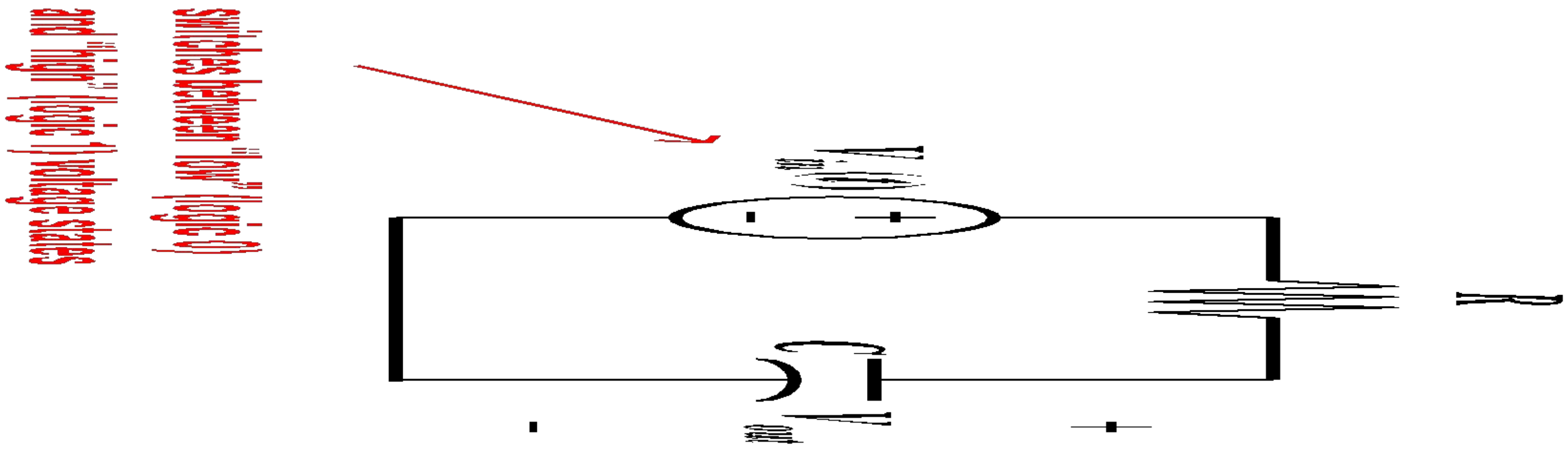
The input voltage pulse width must be large enough; otherwise the pulse is distorted





Computers are RC circuits (almost)

- Digital circuits are predominantly RC circuits (other than the communication part)
- Simplistically a logic gate can be model as a RC circuit
- The speed of the computer is limited by the RC time constant



Complex Numbers

- $e^{i\theta} = \cos(\theta) + isin(\theta)$

- Read the note j