MA2012 INTRODUCTION TO MECHATRONICS SYSTEMS DESIGN

Lecture 6

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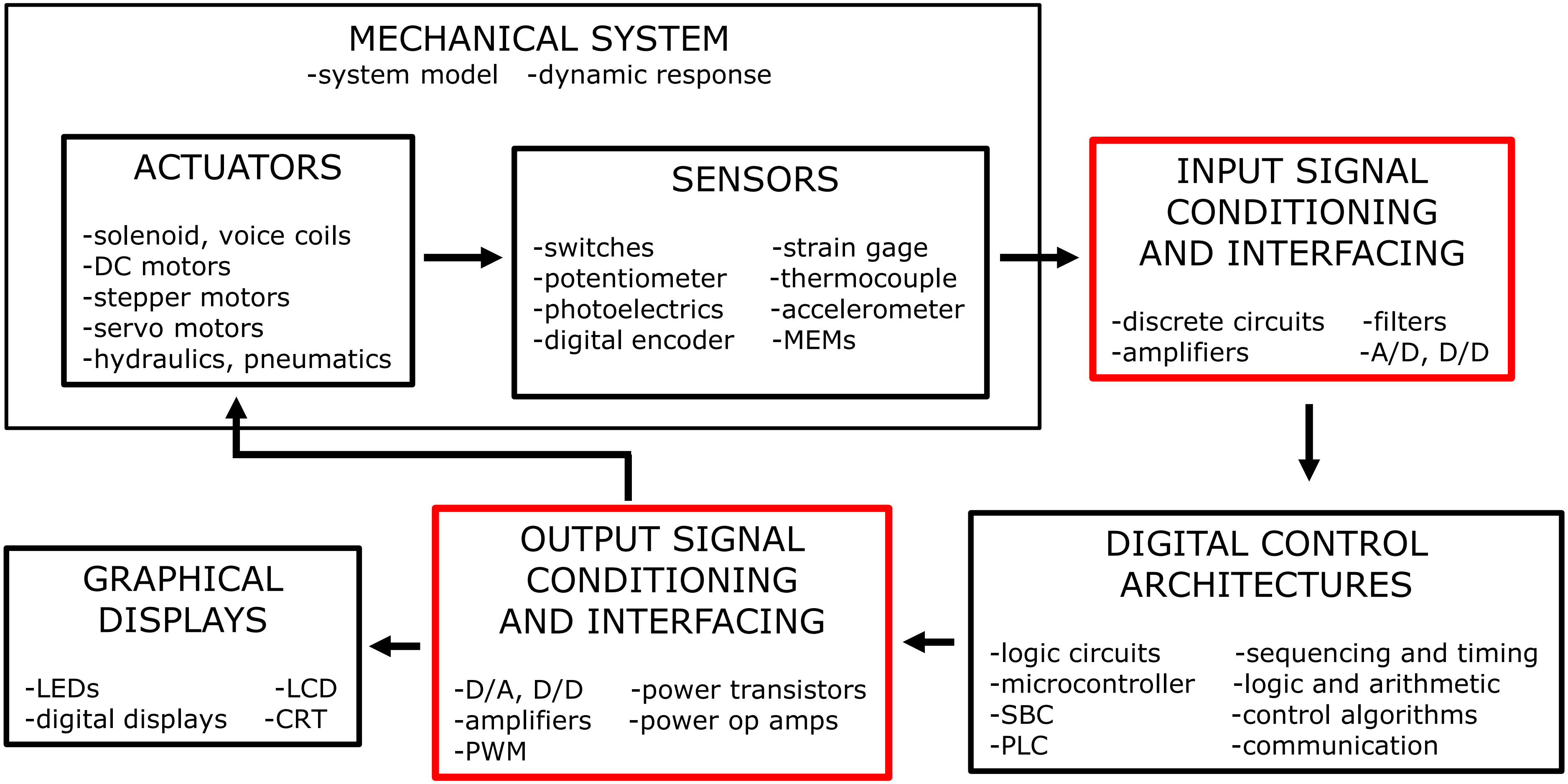
School of Mechanical and Aerospace Engineering

Mechatronic System Components



Signal Conditioning

INPUT SIGNAL CONDITIONING

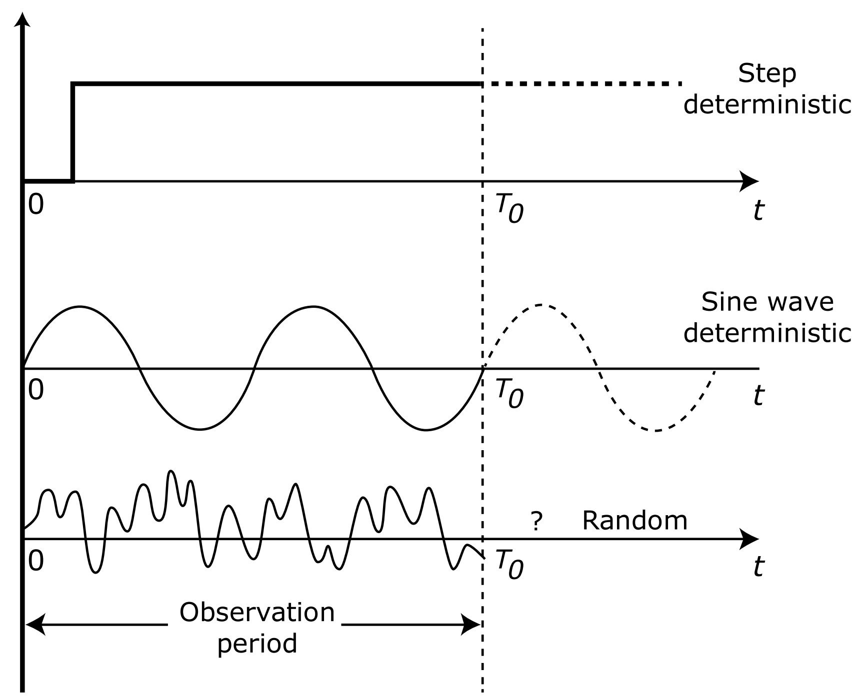
- To convert the output of sensing elements into a form suitable for further processing
- Types
  - Analog-to-Digital conversion
  - To reduce noise level
  - To enhance signal power
  - To improve noise immunisation
  - To eliminate non-linearity

OUTPUT SIGNAL CONDITIONING

- To convert the output of digital control systems (i.e. MCU, PC) into a form suitable for interfacing with output elements
- Types
  - Digital-to-Analog conversion
  - To amplify signal (power, current, voltage, etc.)
  - To improve noise immunisation

Deterministic vs Random Signals

- Deterministic Signals
  - Value can be predicted exactly, after the observation period T_0
- Random Signals
  - Value cannot be predicted exactly, after the observation period T_0
  - The signal cannot be represented by a continuous algebraic equation $y(t)$ for the signal y at time t



Deterministic vs Random Signals

Randomness

- A real process has many parameters that cannot be exactly known, because of the randomness of nature
- Absolutely clean signal does not exist, if resolution is allowed to be infinitesimally small, i.e. Observed randomness is dependent on resolution
- E.g. Leaves falling from a tree

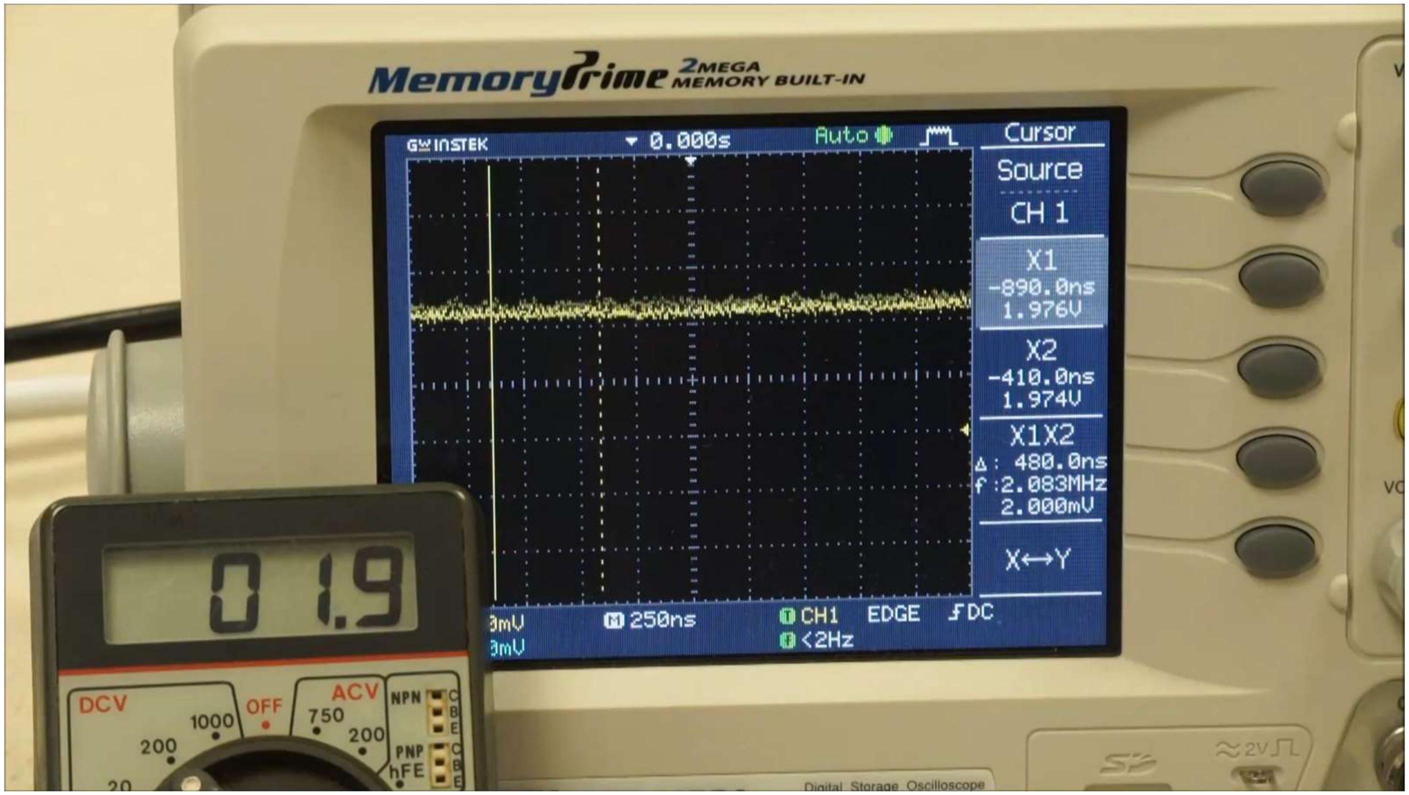
Randomness: leaves falling from a tree

Randomness

- E.g. Leaves falling from a tree:
  - Resolution = 1 $m^2 \rightarrow$ noisy outcome
  - Resolution = 100 $m^2 \rightarrow$ clean outcome

Randomness

Click image to play video

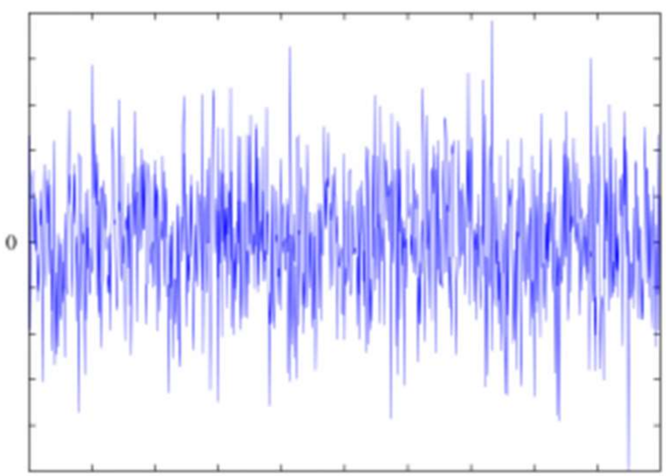


Voltage source

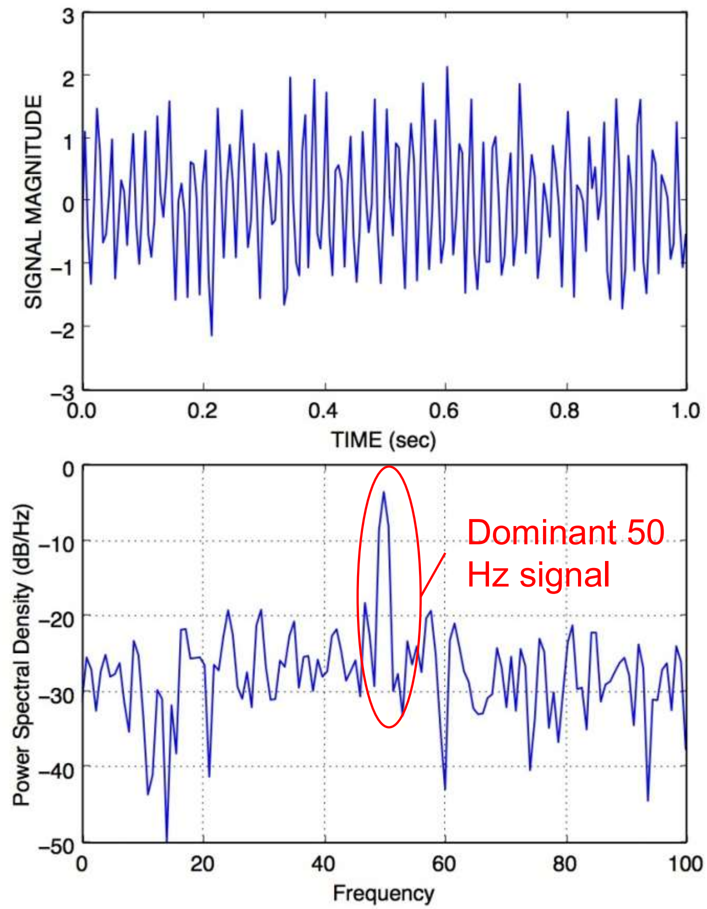
- E.g. A voltage source:
  - Resolution = 0.1 V → clean voltage
  - Resolution = 0.001 V → noisy voltage

Noise

- Noise is unwanted signal
- White noise = signal with equal power in all frequencies and zero mean, i.e. totally random signal
- Coloured noise = unwanted signal with certain bias or distinctive frequency(ies)

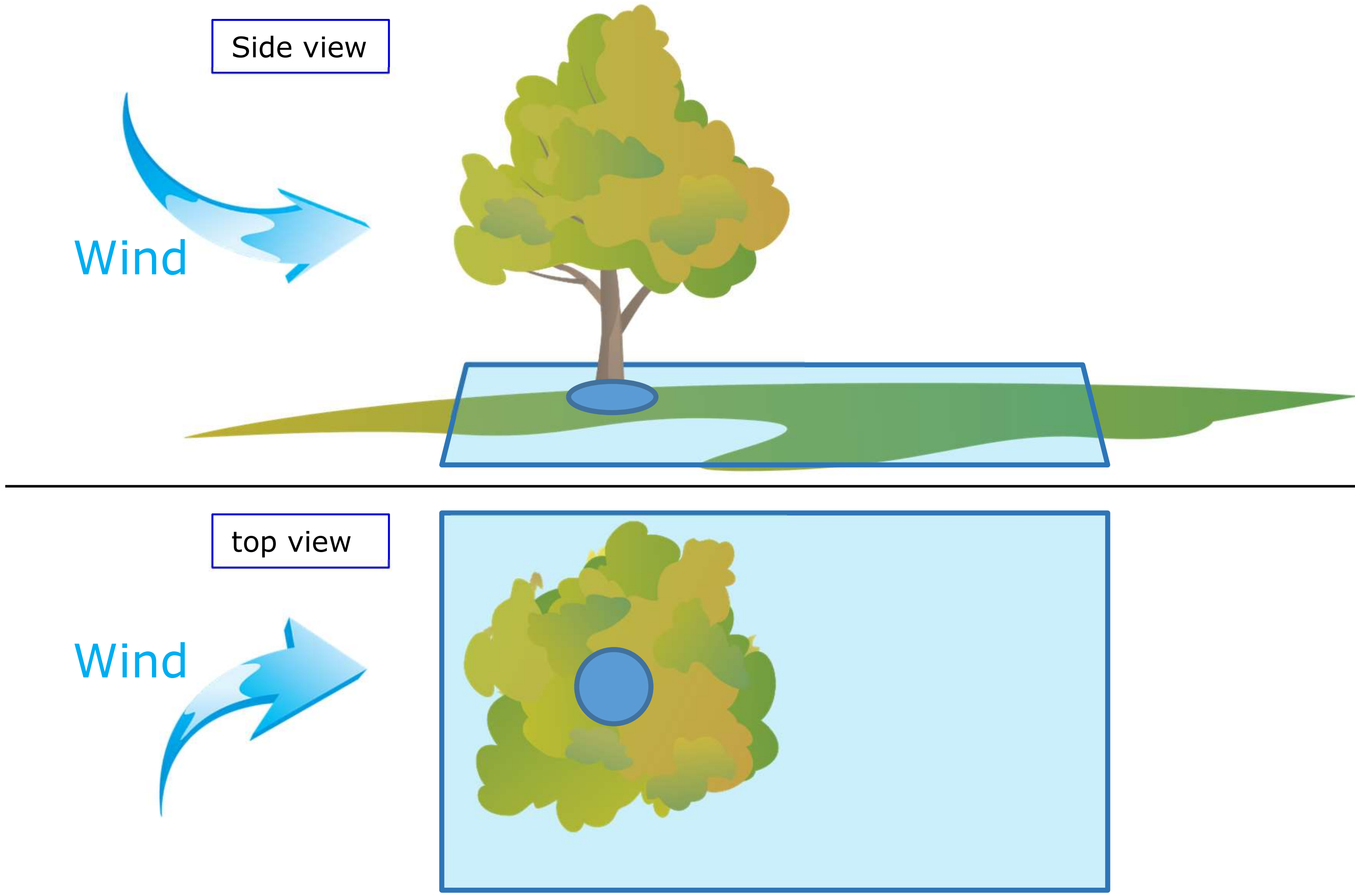


White noise



Coloured noise

Noise



Coloured Noise e.g. Falling leaves with wind blowing

- Mean of the leaves spread is no longer at the foot of the tree, i.e. non-zero mean or bias

Signal-to-Noise Ratio

- Signal-to-noise ratio is defined as the ratio of the power of a signal (meaningful information) and the power of background noise (unwanted signal):

- $$SNR = \frac{Total\ Signal\ Power}{Total\ Noise\ Power} = \frac{W_S}{W_N}$$

- Expressed in decibel:

- $$SNR = 10log_{10}\left(\frac{W_S}{W_N}\right) dB$$

Noise Sources

INTERNAL NOISE SOURCES

- Johnson or thermal noise
  - Random, temperature-induced motion of electrons and other charge carriers in resistors and semiconductors gives rise to a corresponding random voltage
  - White noise proportional to the absolute temperature
- Shot noise
  - Random fluctuations in the rate at which carriers diffuse across a junction of transistor
  - Another source of white noise

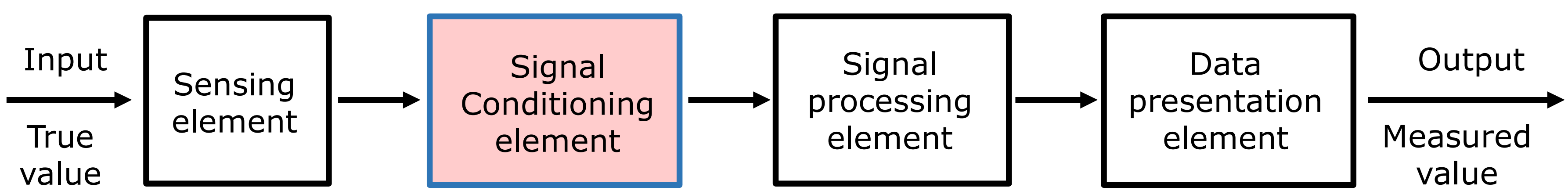
Noise Sources

EXTERNAL NOISE AND INTERFERENCE SOURCES

- AC power circuits operating at 220V, 50Hz (US:110V, 60Hz)
  - Produce “mains pick-up” or “hum” which is a corresponding sinusoidal interference signal in the measurement circuit
- Fluorescent lighting arcing at 2x per cycle of the AC power
  - Arcing is the process of raising the potential to cause electrical current to flow between anode & cathode through the inert gases inside the tube
- Radio frequency (RF) interference
  - Transmitters, welding equipment and electric arc furnaces can produce interference at frequencies of several MHz

Input Signal Conditioning Elements

- Suitable forms
  - DC voltage [MA 2012]
  - DC current; Variable frequency AC voltage
- Examples:
  - Deflection bridges
  - Operational amplifiers (Op-Amp)
  - Filters

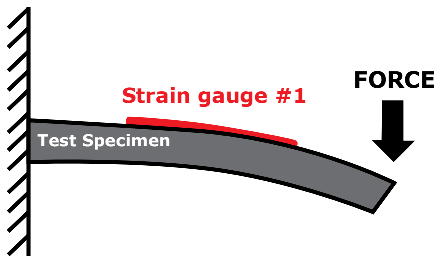


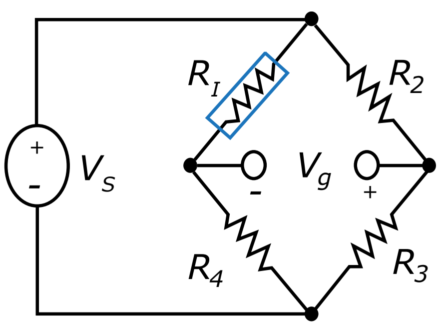
Input signal conditioning elements

Deflection Bridges

- Quarter Bridge
  - Voltage output:

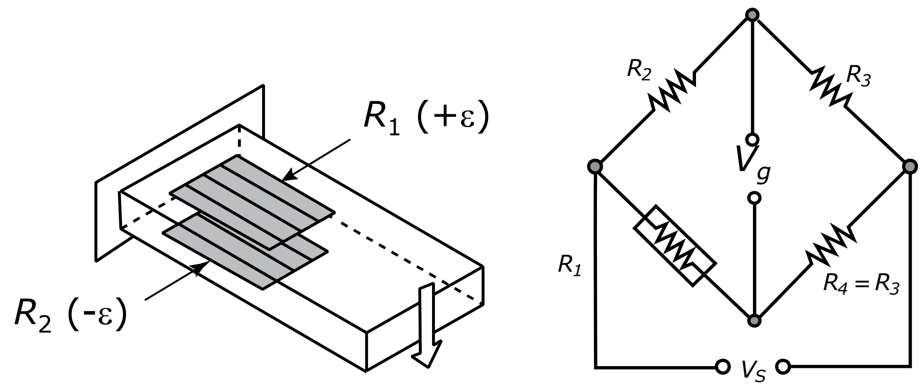
$$V_g = V_S\left(\frac{1}{1+R_4/R_I} - \frac{1}{1+R_3/R_2}\right)$$





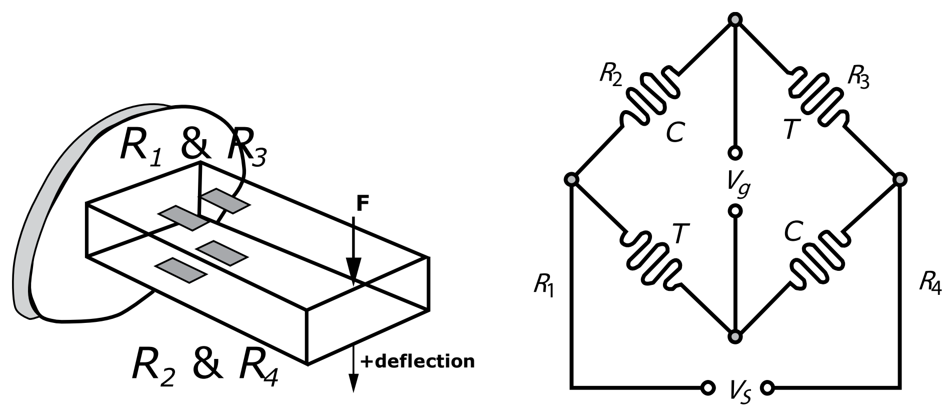
Quarter bridge

- Half Bridge
  - Double sensitivity over ¼B



Half bridge

- Full Bridge
  - Simplicity & linearity over ½B



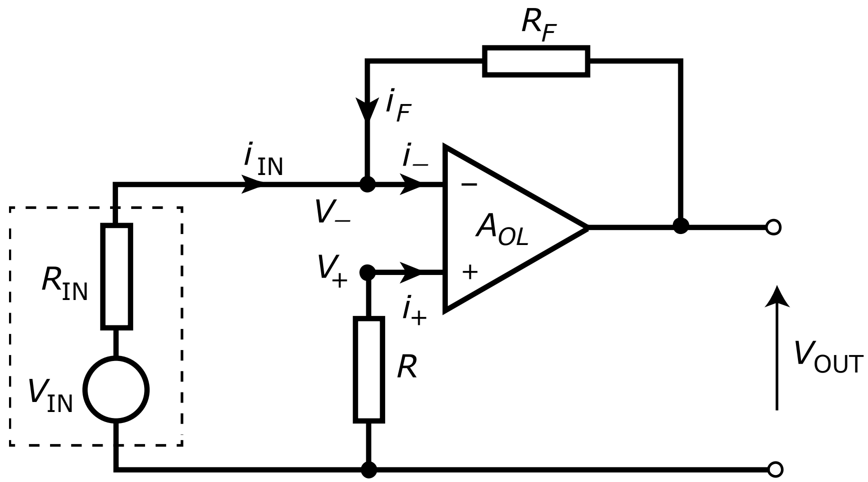
Full bridge

Amplifiers

- The operational amplifiers (op-amps) are used as the basic building blocks for instrumentation and power amplifiers
- Types of op-amp
  - Inverting
  - Non-inverting
  - Voltage follower
  - Voltage adder
  - Differential

- Inverting amplifier

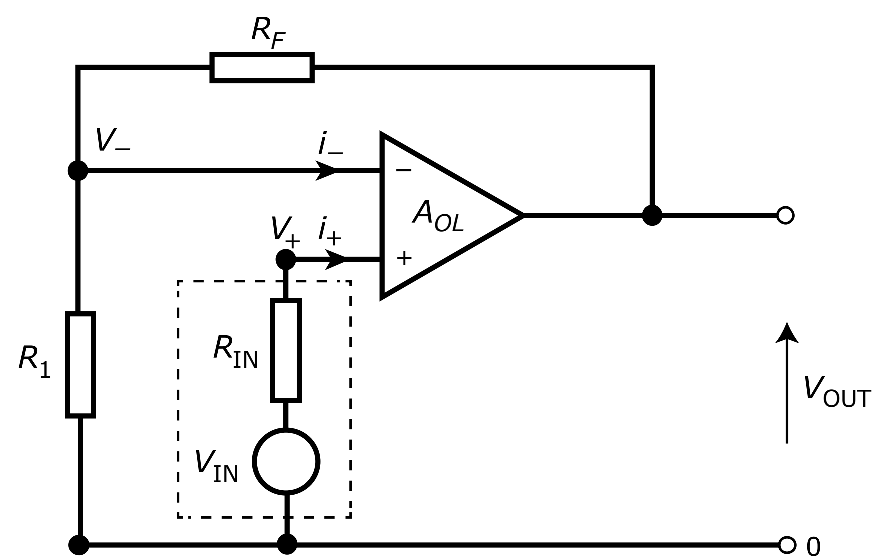
$$V_{out} = \frac{-R_F V_{IN}}{R_{IN}}$$



Inverting amplifier

- Non-inverting amplifier

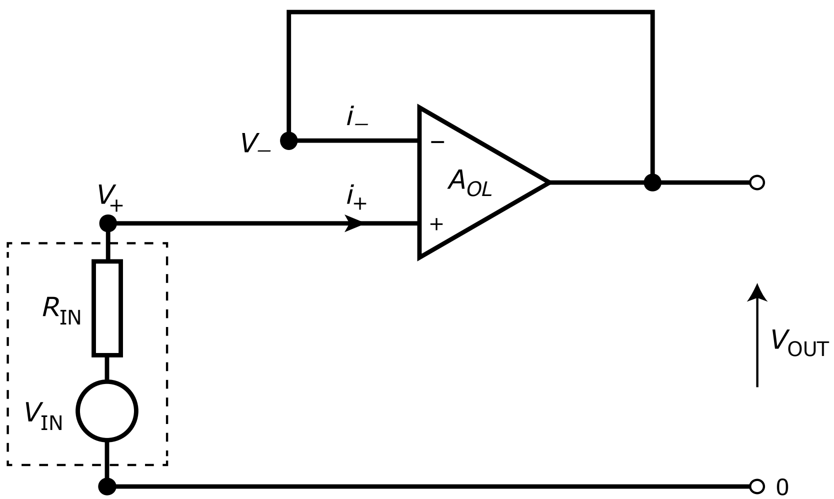
$$V_{out} = \left(1 + \frac{R_F}{R_{IN}}\right) V_{IN}$$



Non-inverting amplifier

- Voltage follower

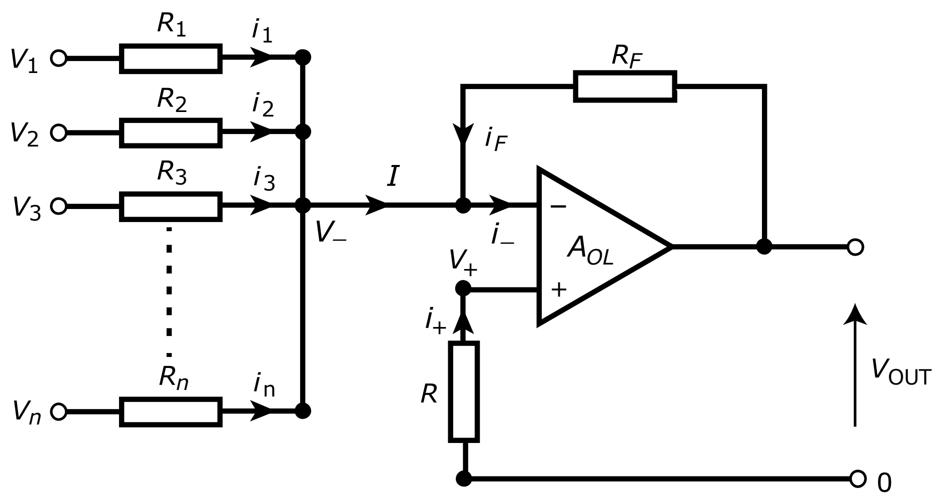
$$V_{out} = V_{IN}$$



Voltage follower

- Voltage adder

$$V_{out} = -R_F\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \cdots + \frac{V_n}{R_n}\right)$$

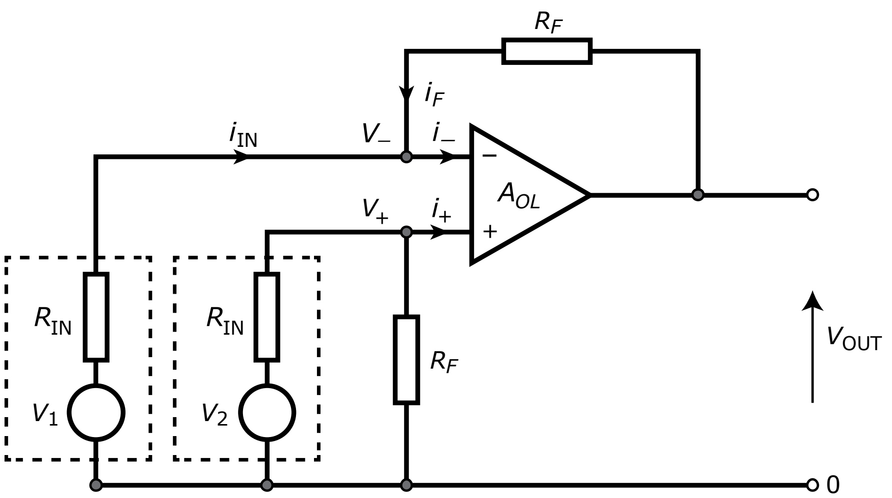


Voltage adder

Op-Amp

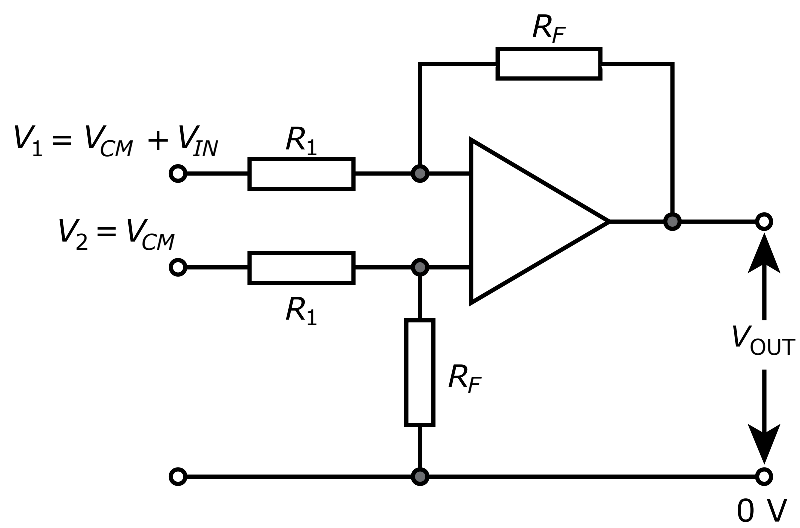
- Differential amplifier

$$V_{out} = \frac{R_F}{R_{IN}}(V_2 - V_1)$$



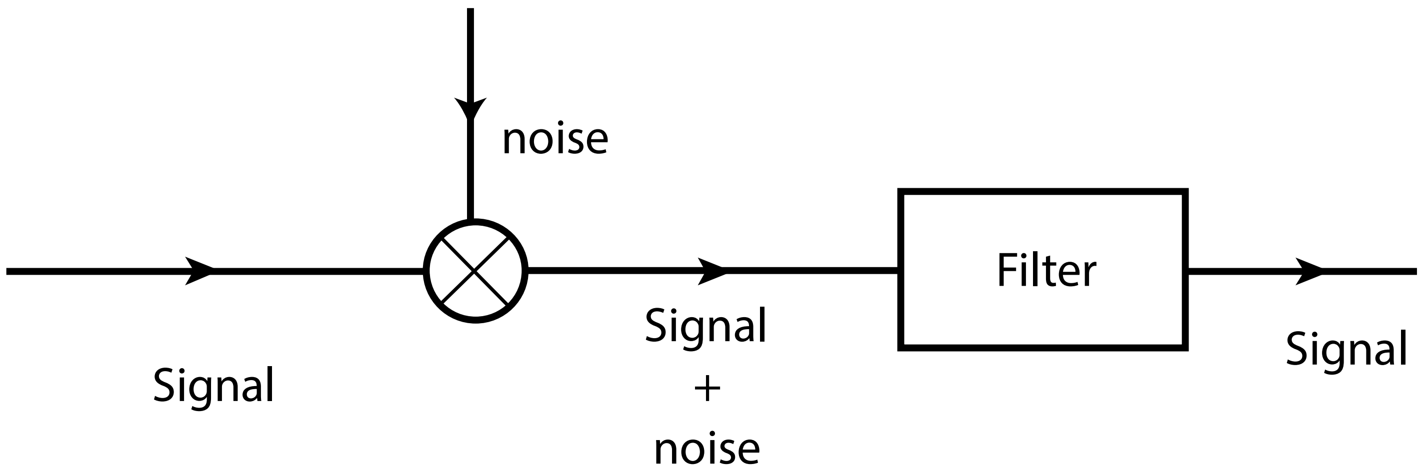
Differential amplifier

- Common mode interference voltages can be successfully rejected



Filtering

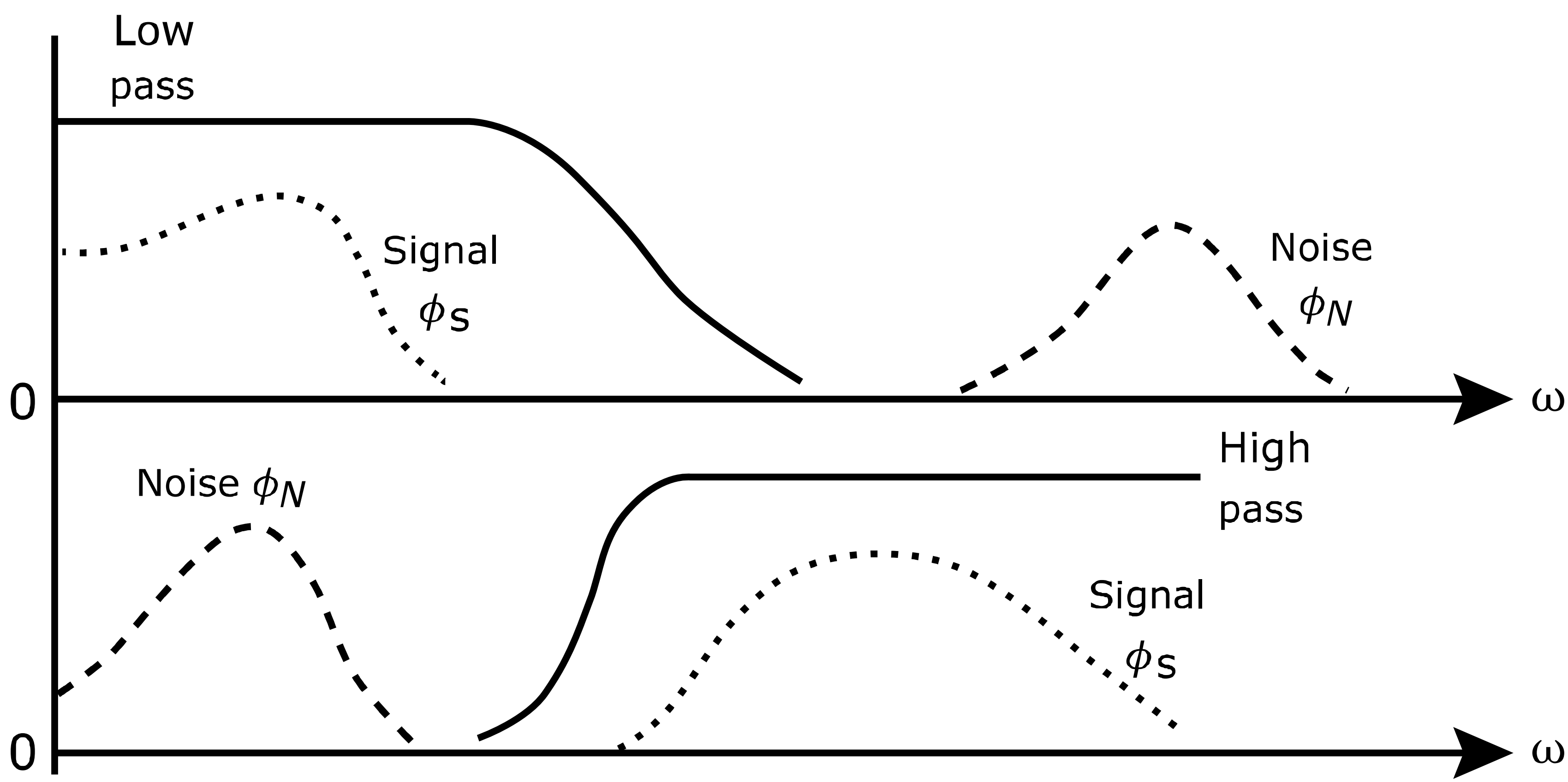
- A frequency selective filter is an element which transmits a certain selected range(s) of frequencies and rejects all others
- Analog filter is a network of resistors, capacitors and op amps to process continuous signals
- Digital filter is a computer programmed to process sampled values of a signal



Filtering

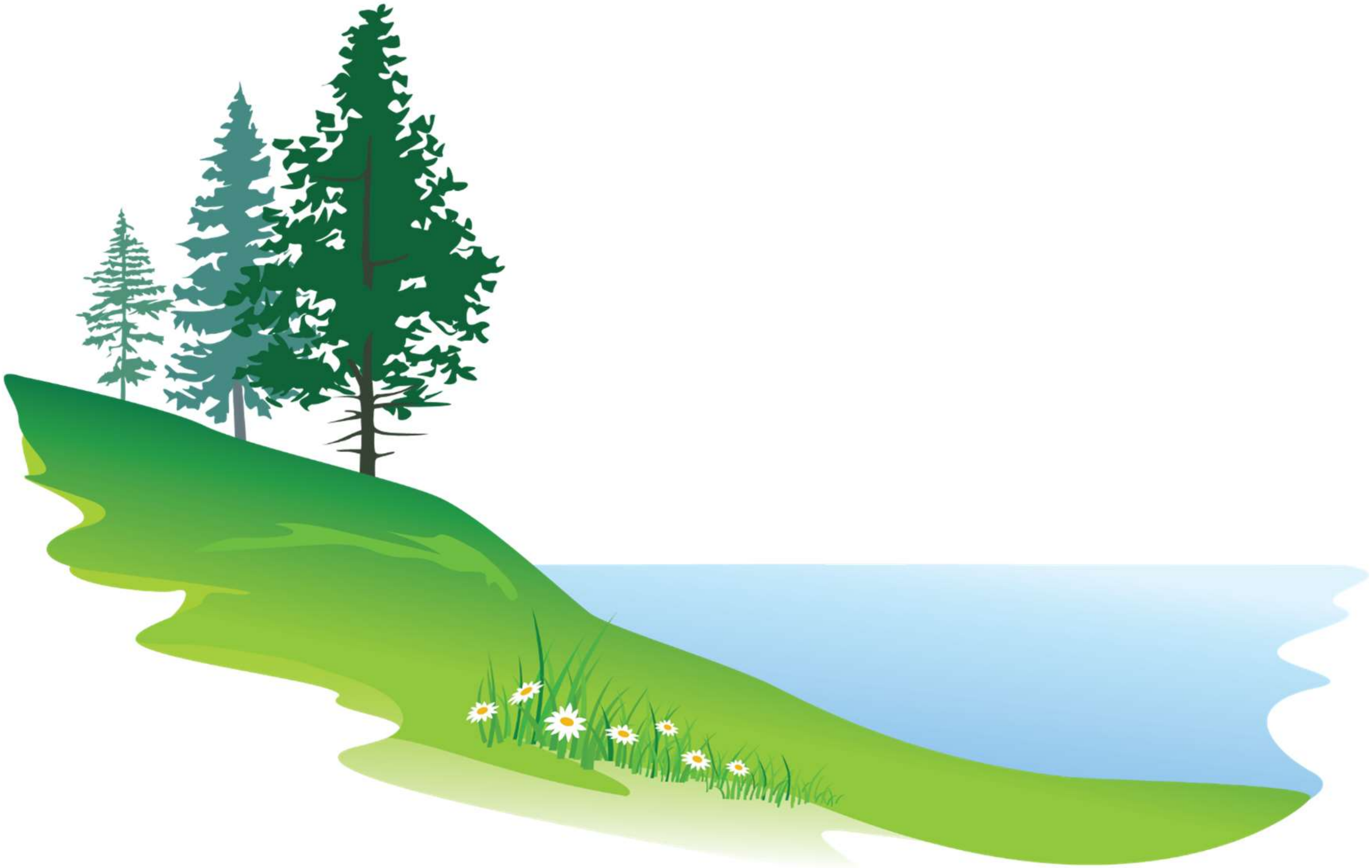
Filtering

- Low & High Pass Filters



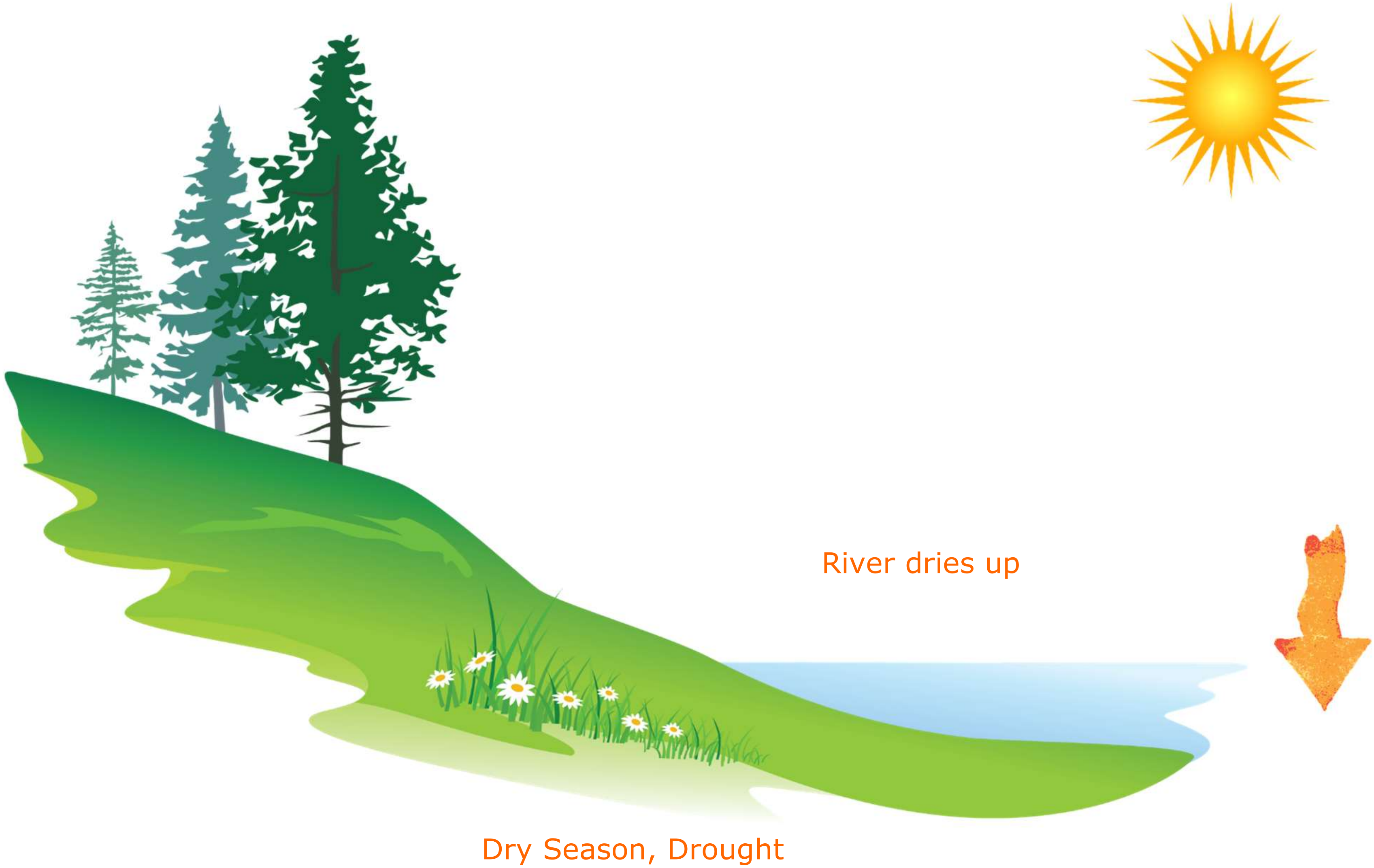
Low and high pass filters

Filtering



River Stream

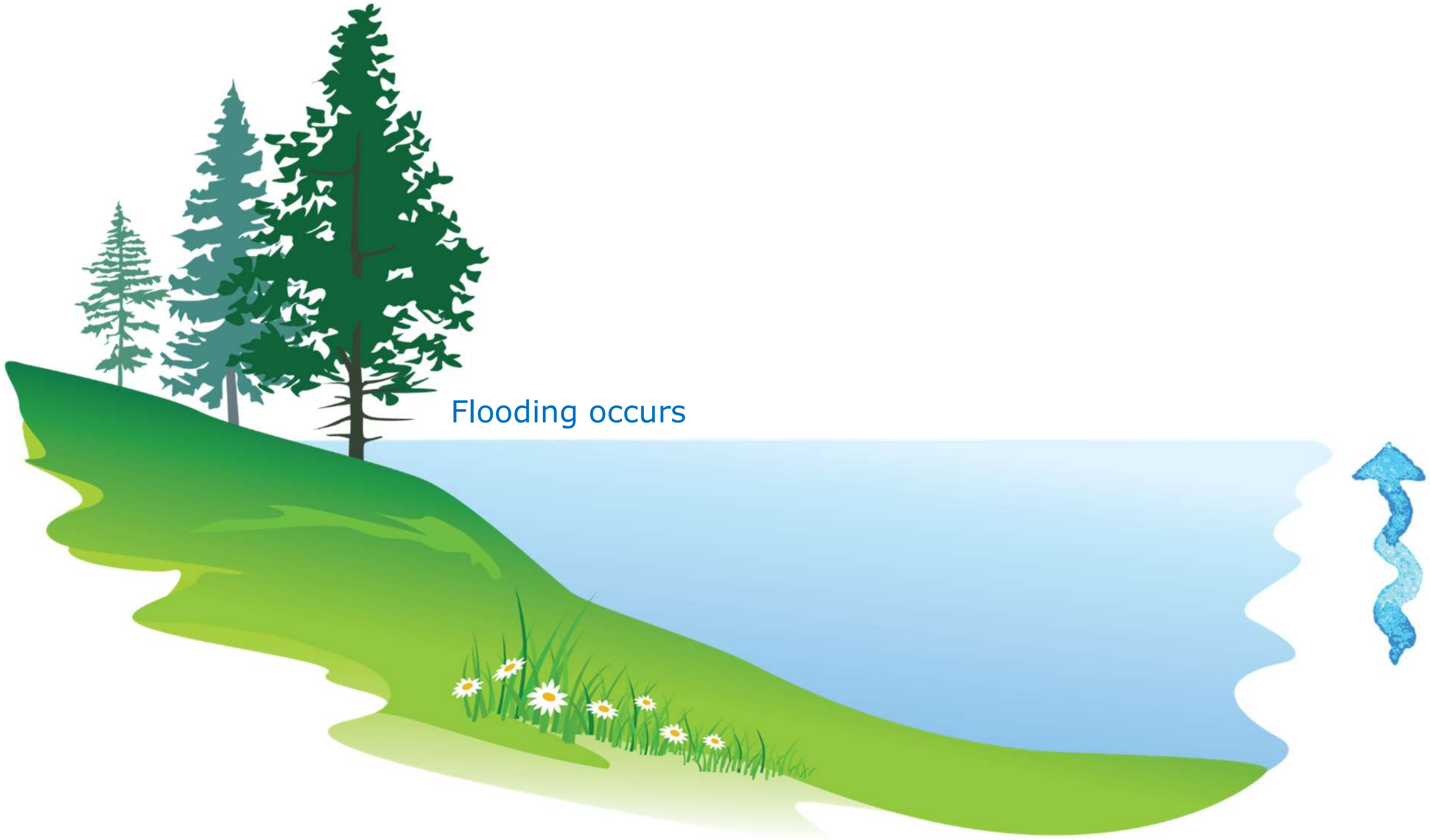
Filtering



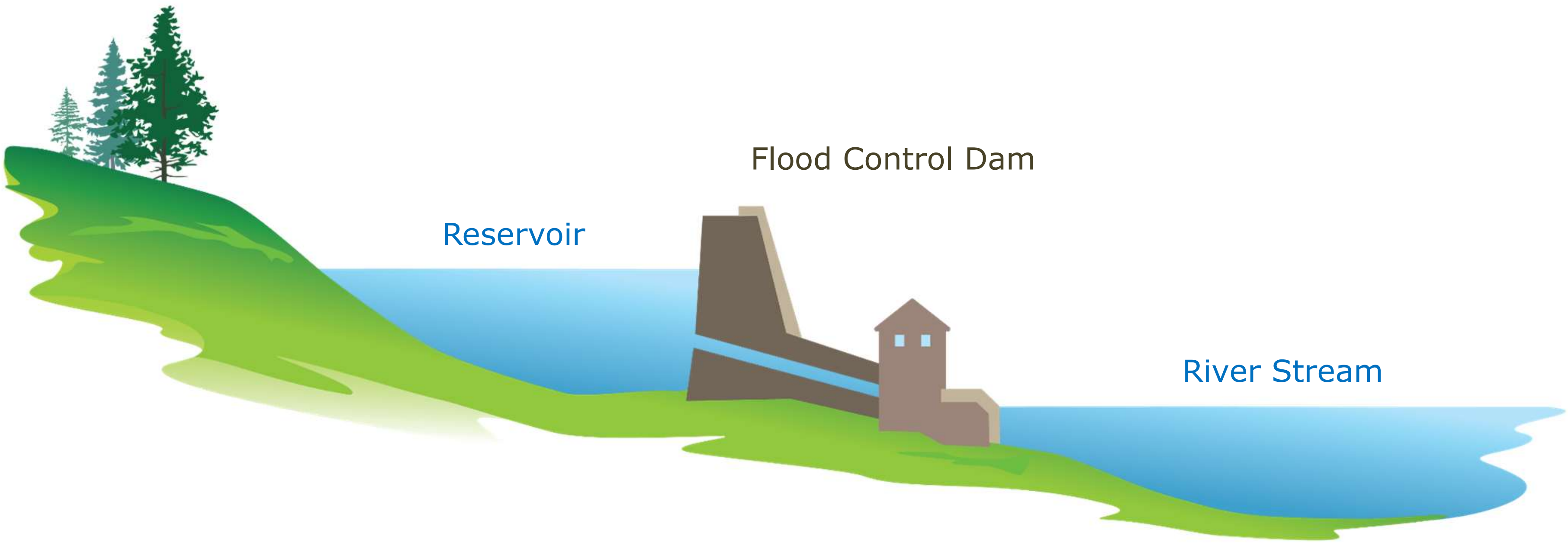
Filtering

Rainy Season/Accelerated Snow melt

Filtering

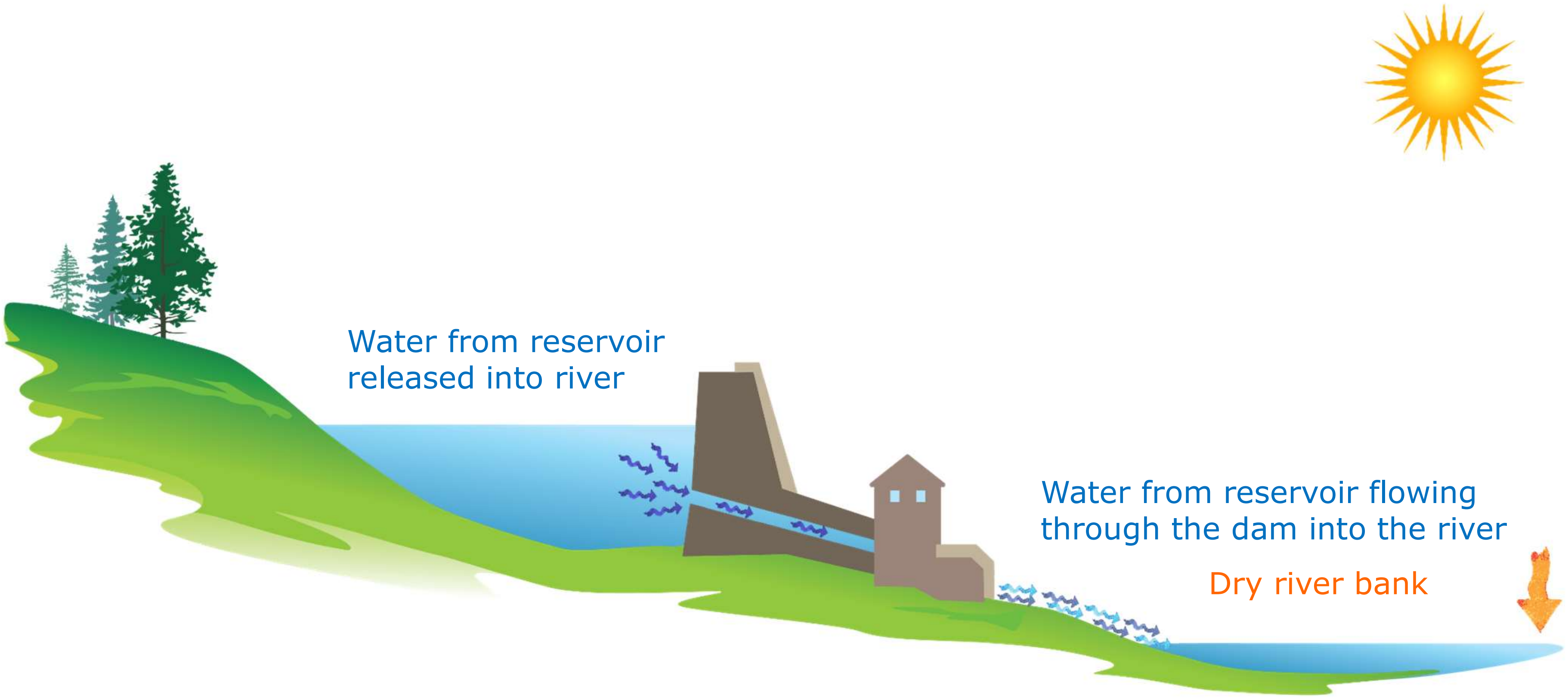


WITH A DAM



Filtering

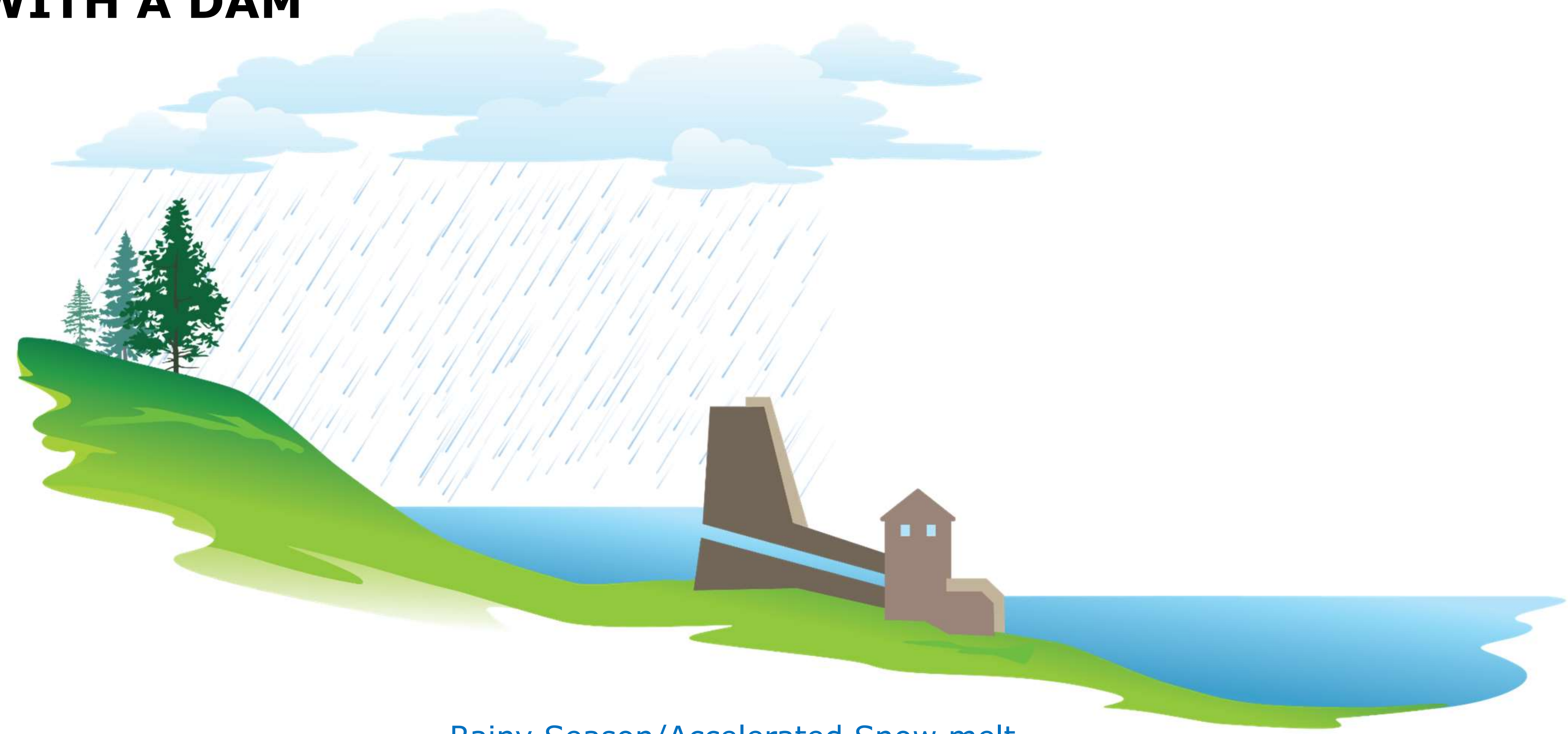
WITH A DAM



Dry Season, Drought

WITH A DAM

WITH A DAM



Rainy Season/Accelerated Snow melt

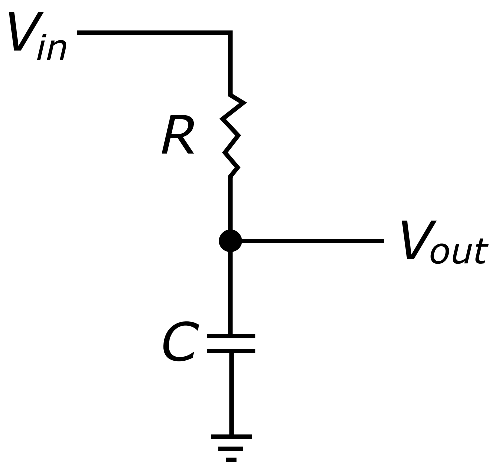
Filtering

WITH A DAM

RC Filters

- Low Pass Filters

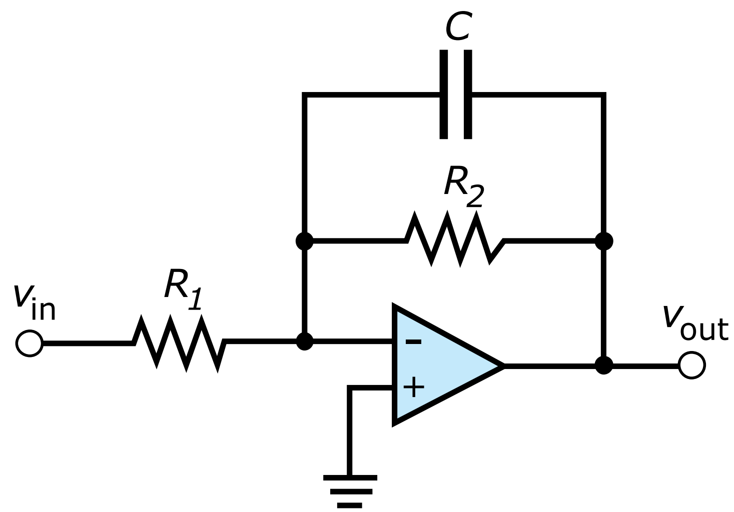
Passive



Passive low pass filter

$$f_c = \frac{1}{2\pi\tau} = \frac{1}{2\pi RC}$$

Active



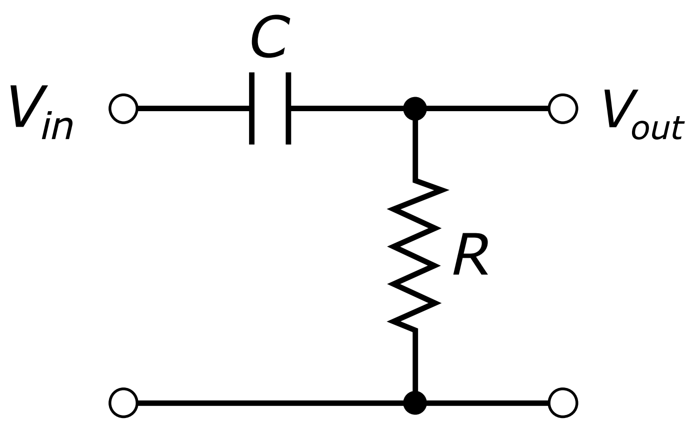
Active low pass filter

$$f_c = \frac{1}{2\pi R_2 C}$$

RC Filters

- High Pass Filters

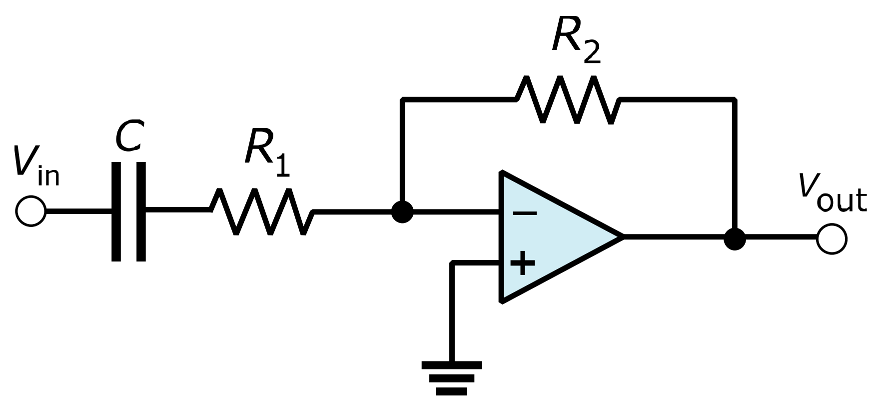
Passive



Passive high pass filter

$$f_c = \frac{1}{2\pi\tau} = \frac{1}{2\pi RC}$$

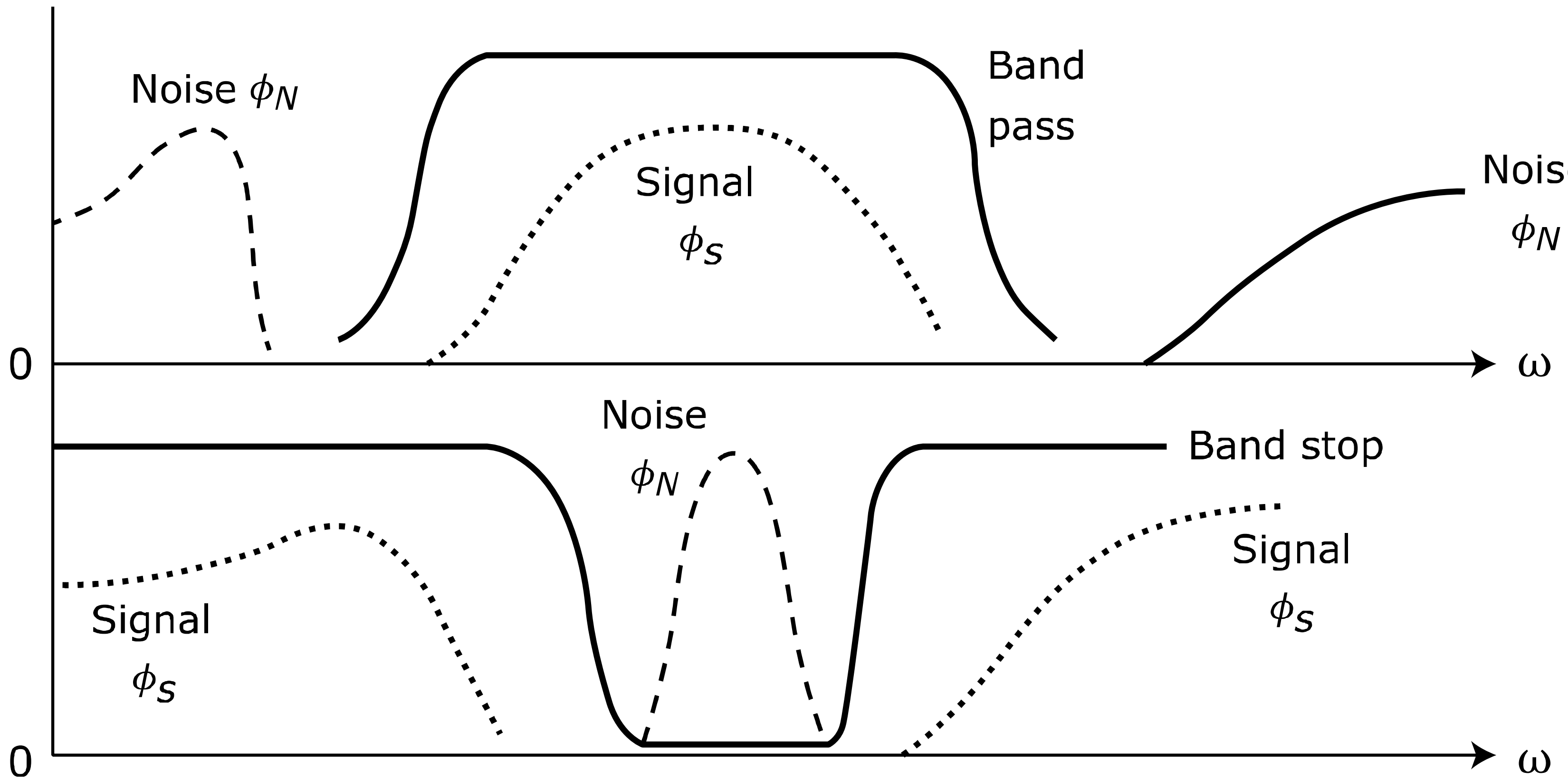
Active



Active high pass filter

$$f_c = \frac{1}{2\pi\tau} = \frac{1}{2\pi R_1 C},$$

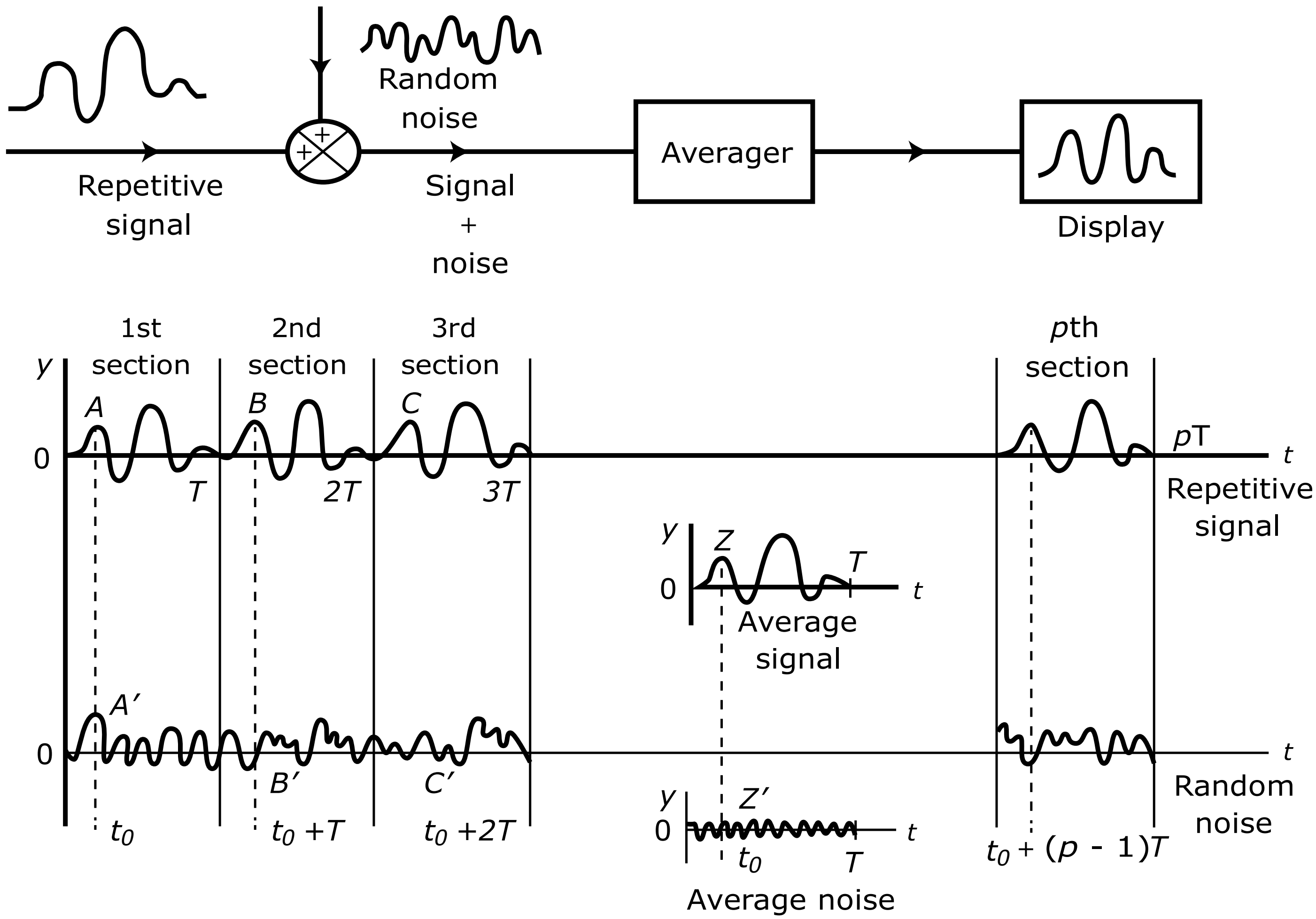
- Band Pass & Band Stop Filters



Band pass and band stop filters

Reducing Effects of Noise & Interference

- Averaging



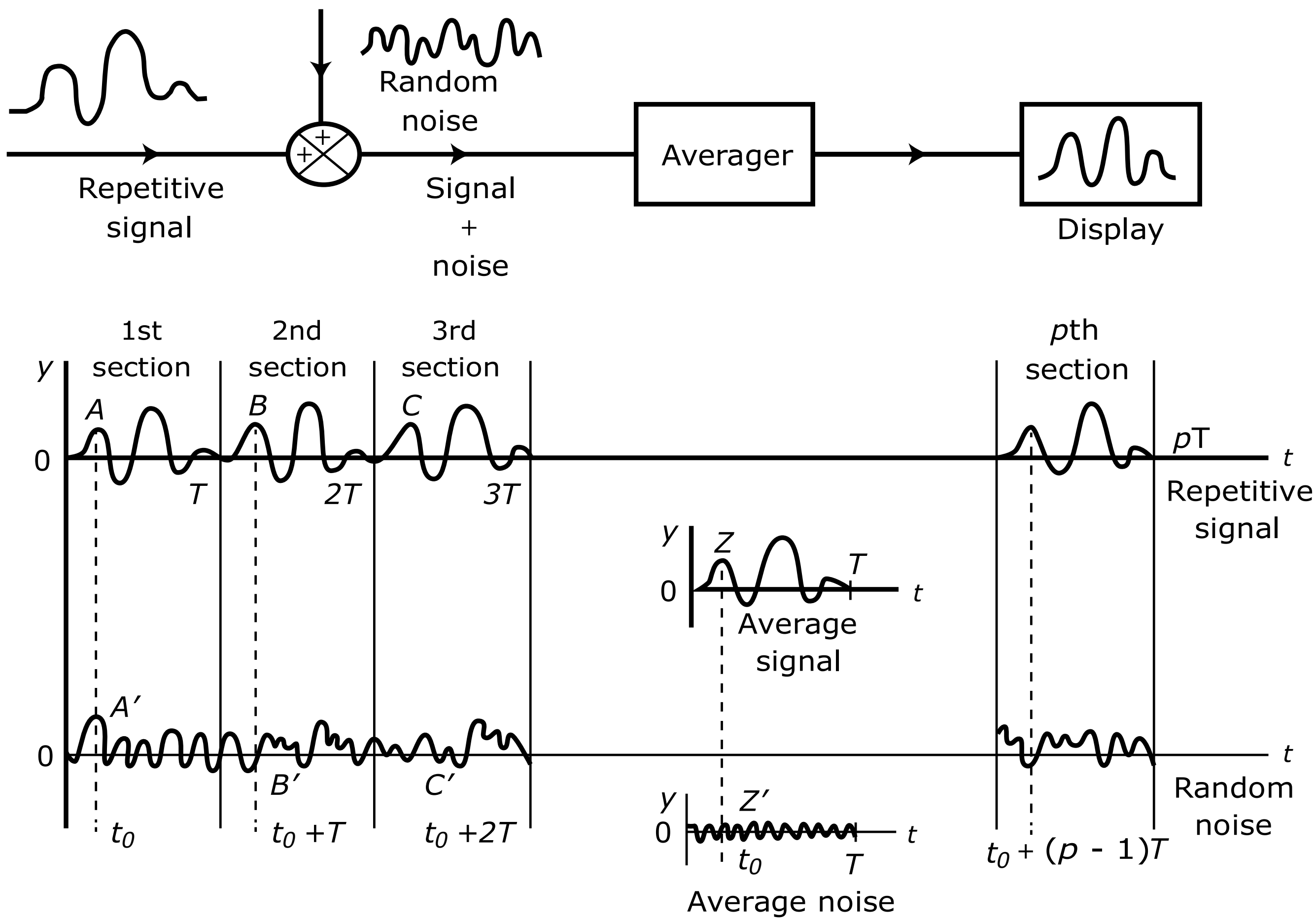
Reducing effects of noise and interference - averaging

Reducing Effects of Noise & Interference

- Averaging
  - For a repetitive measurement signal affected by random noise, suppose
    - It has a period *T*, a total of *p* cycles & *N* samples in each cycle, giving *pN* samples in total
    - For each sample, there are *p* number of corresponding samples from each cycle
    - The average value of the *i*th sample is

$$y_i^{AV} = \frac{1}{p}(y_{i1} + y_{i2} + \ldots + y_{ip}), \qquad i = 1, \ldots, N$$

- Averaging

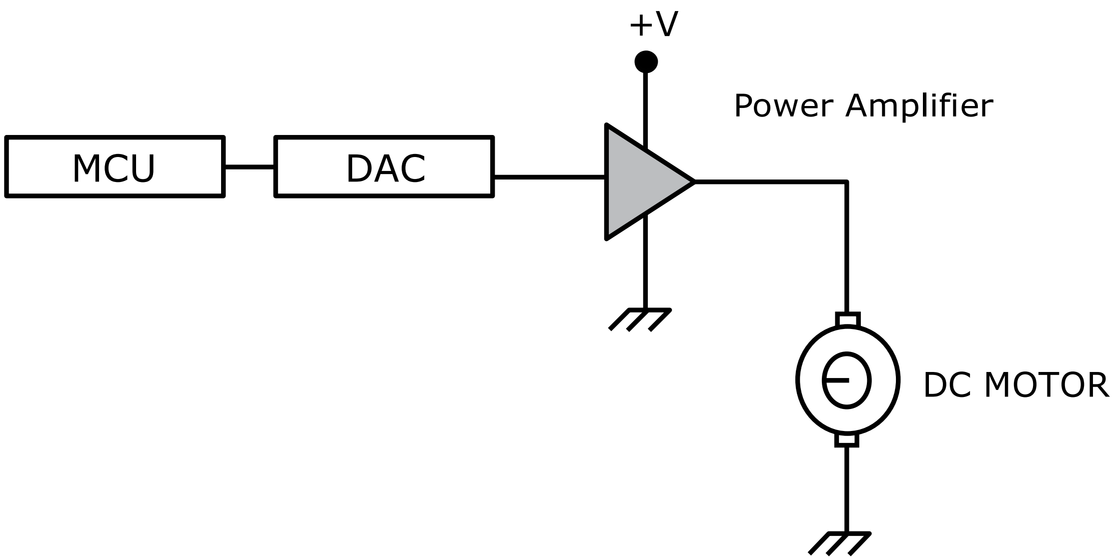


Reducing effects of noise and interference - averaging

$$y_i^{AV} = \frac{1}{p}(y_{i1} + y_{i2} + \ldots + y_{ip}), \qquad i = 1, \ldots, N$$

Output Signal Conditioning Elements

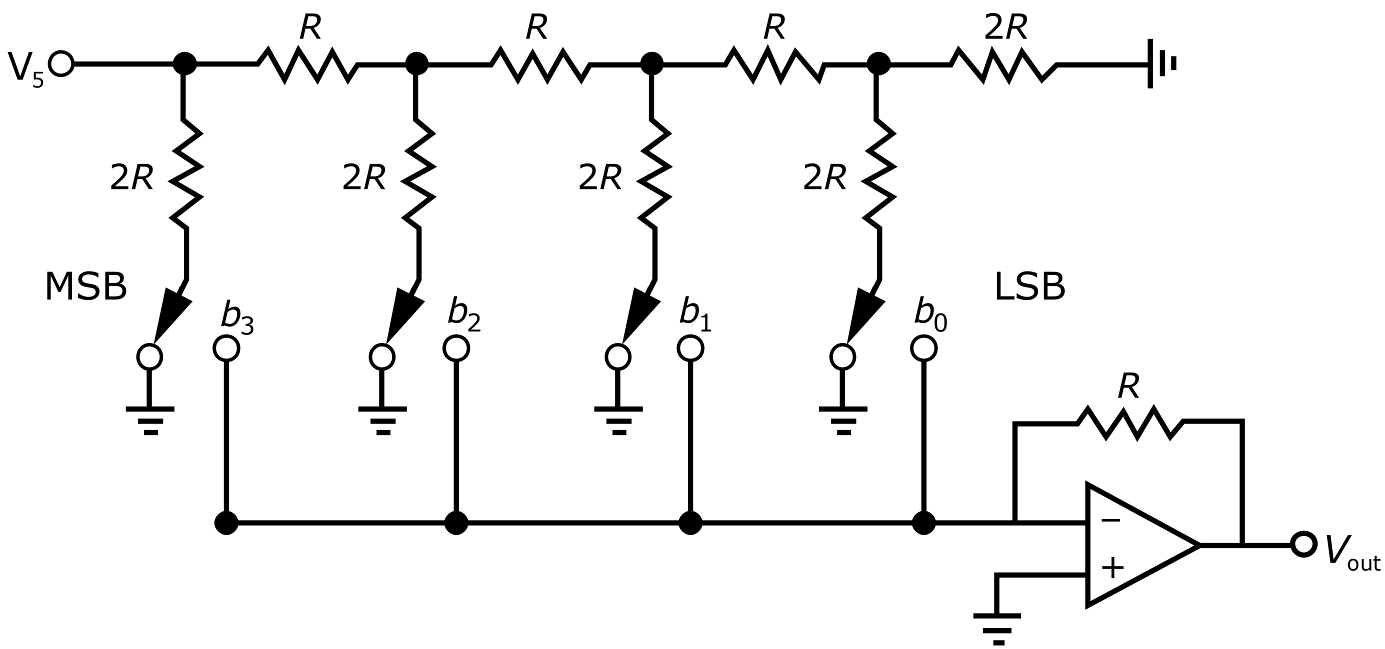
- Purpose
  - To convert the output of MCU into a form suitable for interfacing with the output devices
- Suitable forms
  - Analog signal: voltage or current
  - Higher voltage
  - Higher current
  - Alternating current



Output signal conditioning elements

Digital-to-Analog Converter

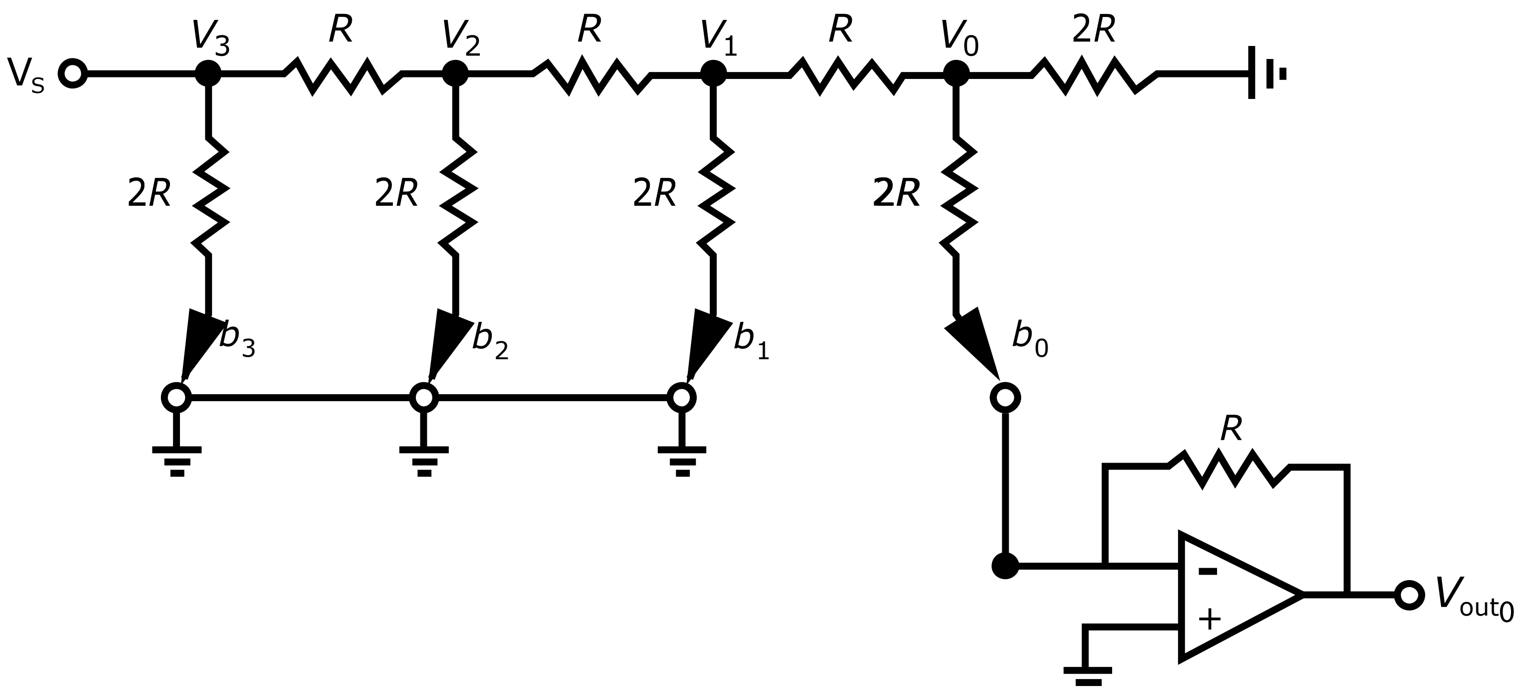
- Simplest type of DAC is a resistor ladder network connected to an inverting op amp circuit



Resistor ladder network connected to an inverting op amp circuit

Digital-to-Analog Converter

- Consider a 4-bit output 0001
- Analog circuit equivalent:



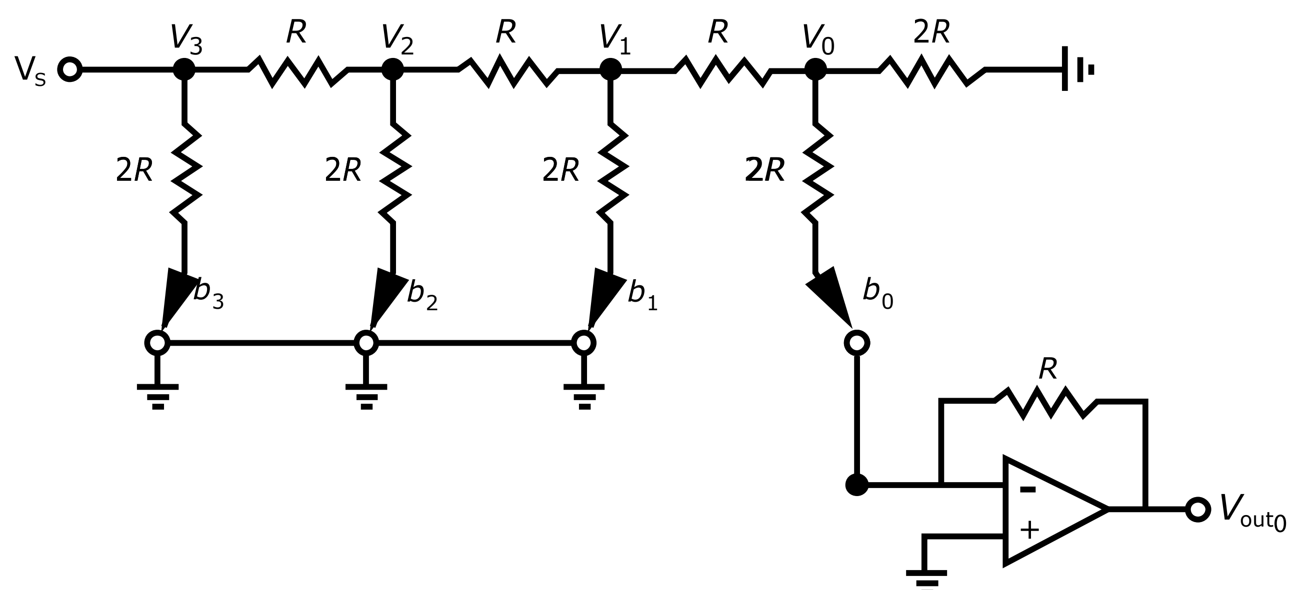
4-bit output: analog circuit equivalent

Digital-to-Analog Converter

- Using voltage division,

$$V_0 = 0.5V_1;\ V_1 = 0.5V_2 \text{ and } V_2 = 0.5V_3$$

- Therefore, $V_0 = 0.125V_3 = 0.125V_s$
- V_0 is the input to the inverting op amp, which has a gain of -R/2R = -0.5
- Therefore, the analog output voltage of input 0001 is V_{out0} = -0.0625V_s

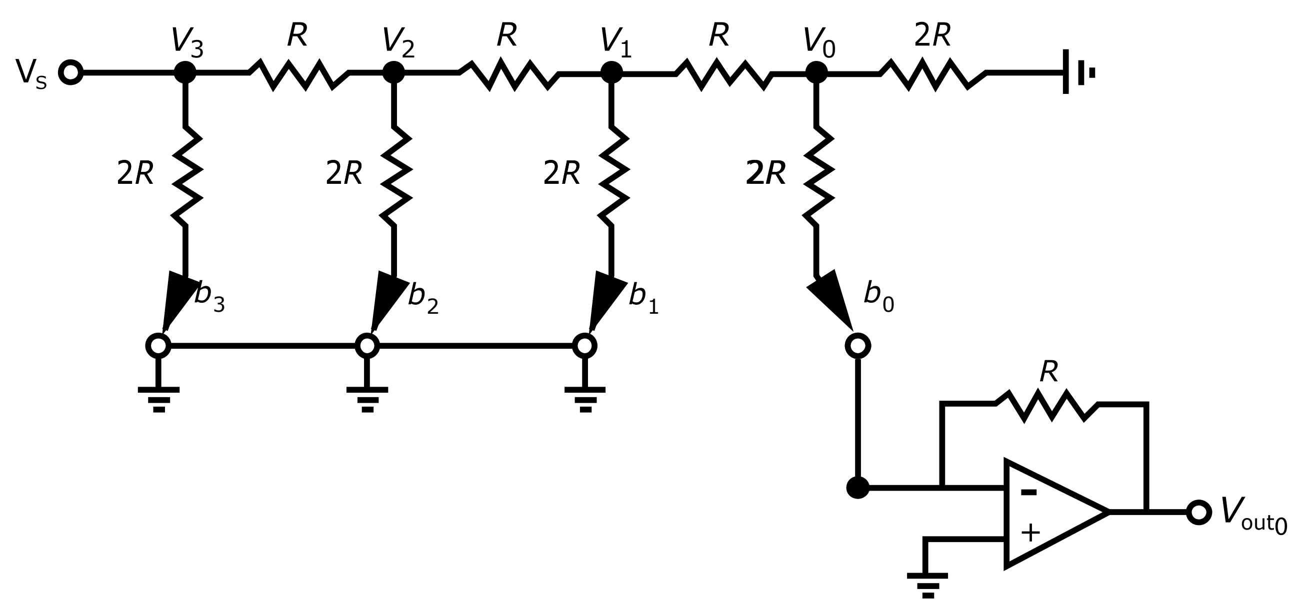


4-bit output: analog circuit equivalent

Digital-to-Analog Converter

- Analog output voltage of input
  - 0010 is $Vout_1$ = - 0.125 Vs
  - 0100 is $Vout_2$ = - 0.25 Vs
  - 1000 is $Vout_3$ = - 0.5 Vs
- The output for any combination of the four bits is

$$Vout = b_3 Vout_3 + b_2 Vout_2 + b_1 Vout_1 + b_0 Vout_0$$



4-bit output: analog circuit equivalent

Summary

- Signals & Noise
  - Deterministic vs random signals
  - Noise characteristics & sources
  - Signal-to-Noise Ratio
- Input Signal Conditioning
  - Deflection Bridge: Quarter, Half, Full
  - Op-amps: Inverting, non-inverting, differential, voltage follower, voltage adder
  - Filters: Low Pass, High Pass, Band Pass, Band Stop
  - Averaging
- Output Signal Conditioning
  - Digital-to-Analog Converter