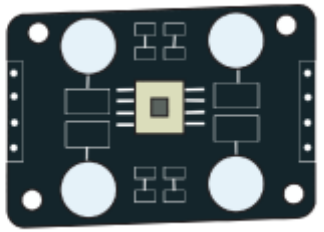
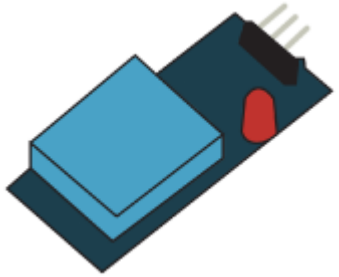
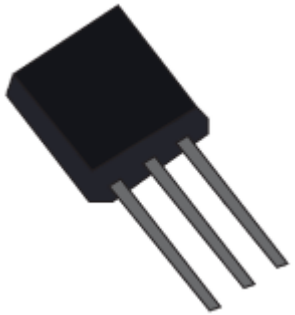
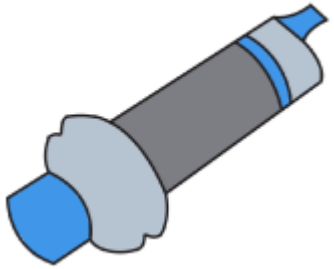
Robust Mechatronics

Sensors and Actuators

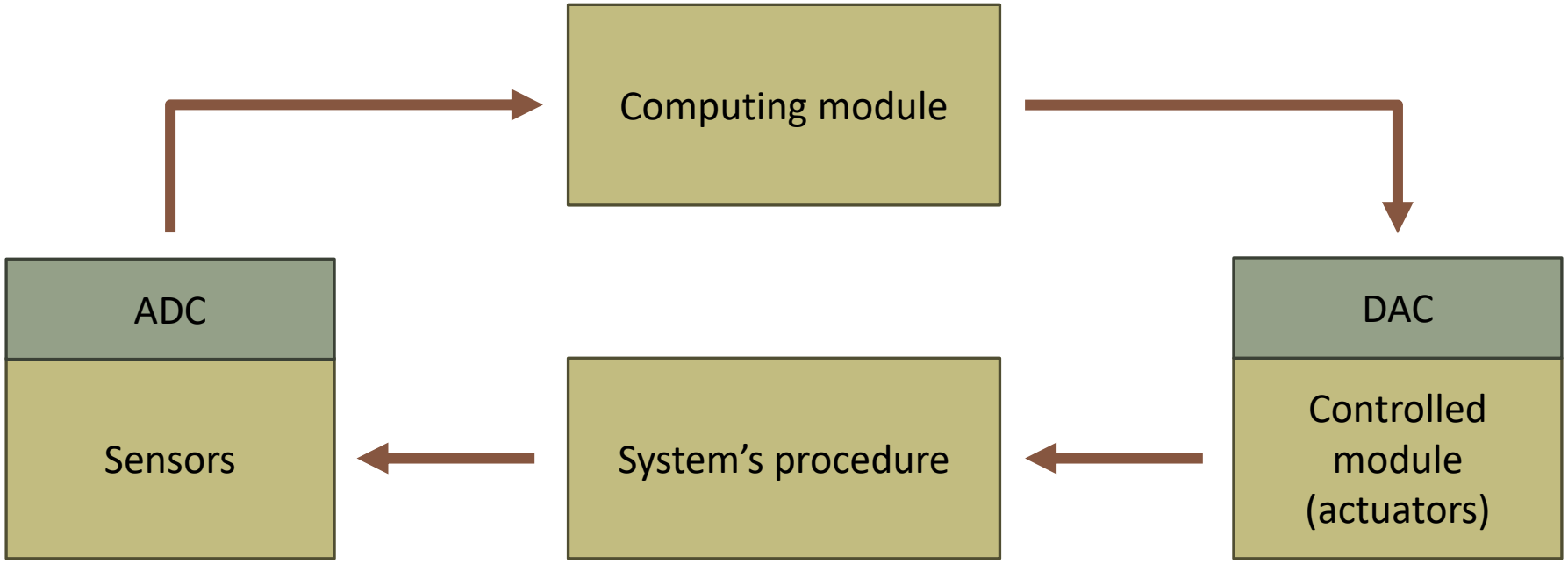



Dr Loukas Bampis, Assistant Professor
Mechatronics & Systems Automation Lab

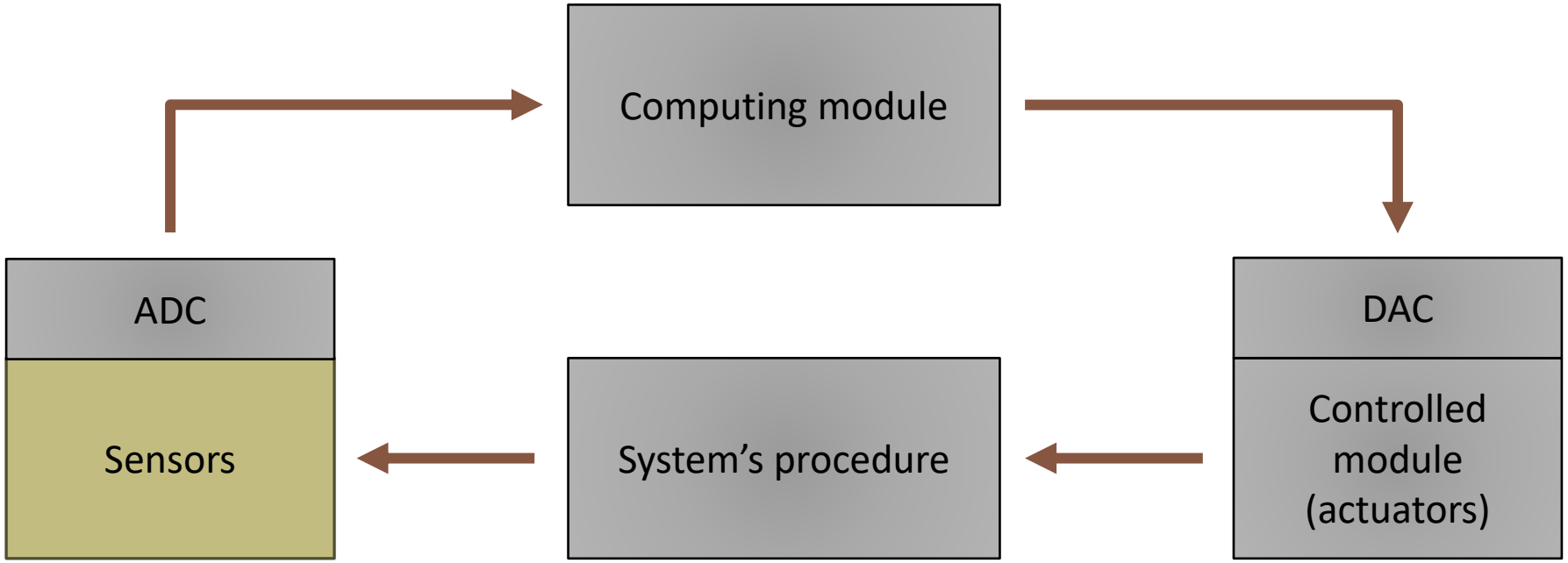
Sensors

Control loop



Sensors

Control loop



Sensors

Sensor

- A device that detects a change in a physical stimulus and responds to it by producing an electrical signal, which can be measured or recorded.

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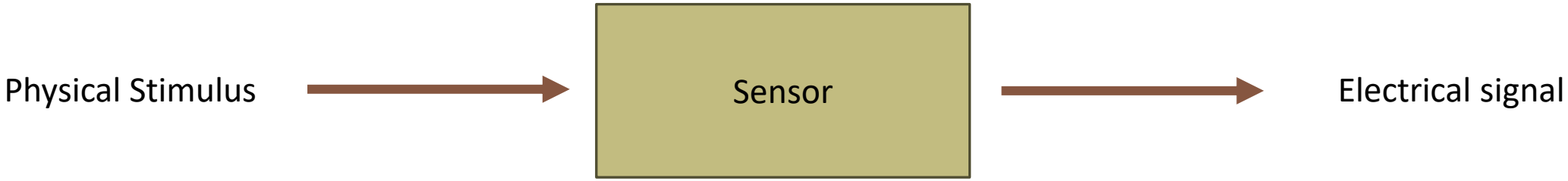


- Temperature
- Radiation
- Sound
- Distance
- Kinetic/inertia state

$F(x)$

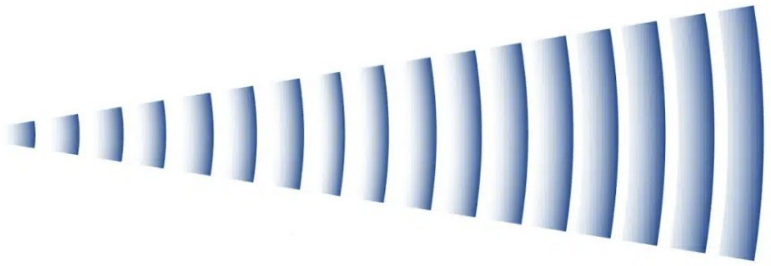
- Voltage (V)
- Current (I)
- Resistance (R)
- Capacitance (C)
- Αυτεπαγωγής (L)
- Frequency (F)

Sensors

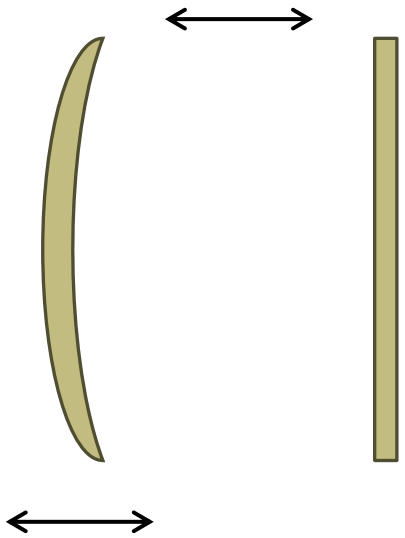
Sensor

- Sound measurement

Sound Wave (H)



Changing distance:
$d(H)$

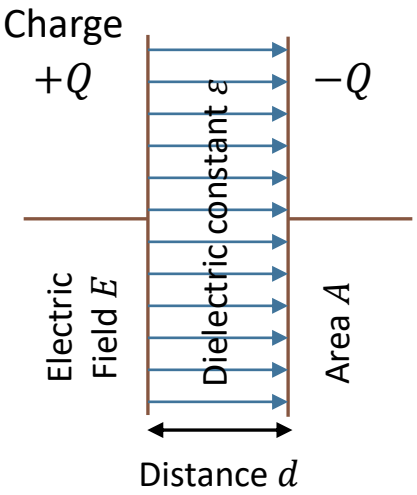


Membrane oscillation

Electric size:

Capacitance $C = \varepsilon \frac{A}{d}$

Electrical magnitude as a function of physical stimulus: $C(d(H))$



ε: dielectric constant of the material

A: Area of overlapping plates

d: Distance between plates

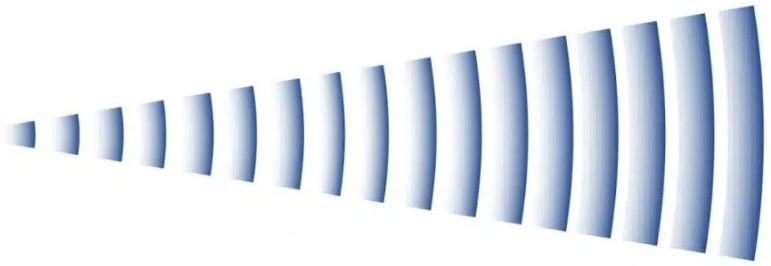
Sensors

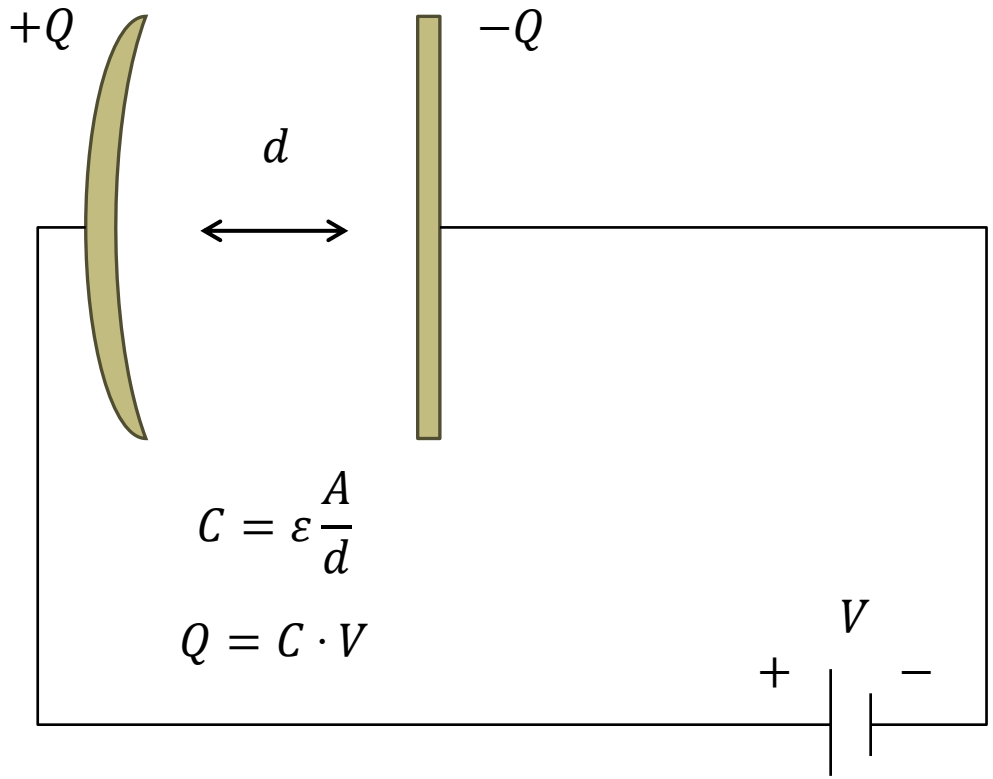
Sensor

- Sound measurement

Capacitance → Voltage

Sound Wave (H)





Changes in distance$d$:

- Change in Capacitance C
- Constant voltage V
- Change in Charge Q

- $d\downarrow \Rightarrow C\uparrow \Rightarrow$ Accumulation of larger charge
- $d\uparrow \Rightarrow C\downarrow \Rightarrow$ Accumulation of lower charge

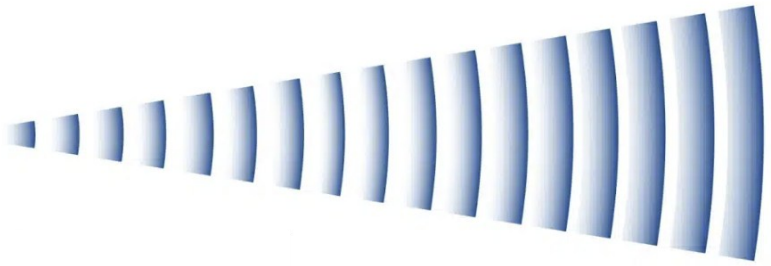
Sensors

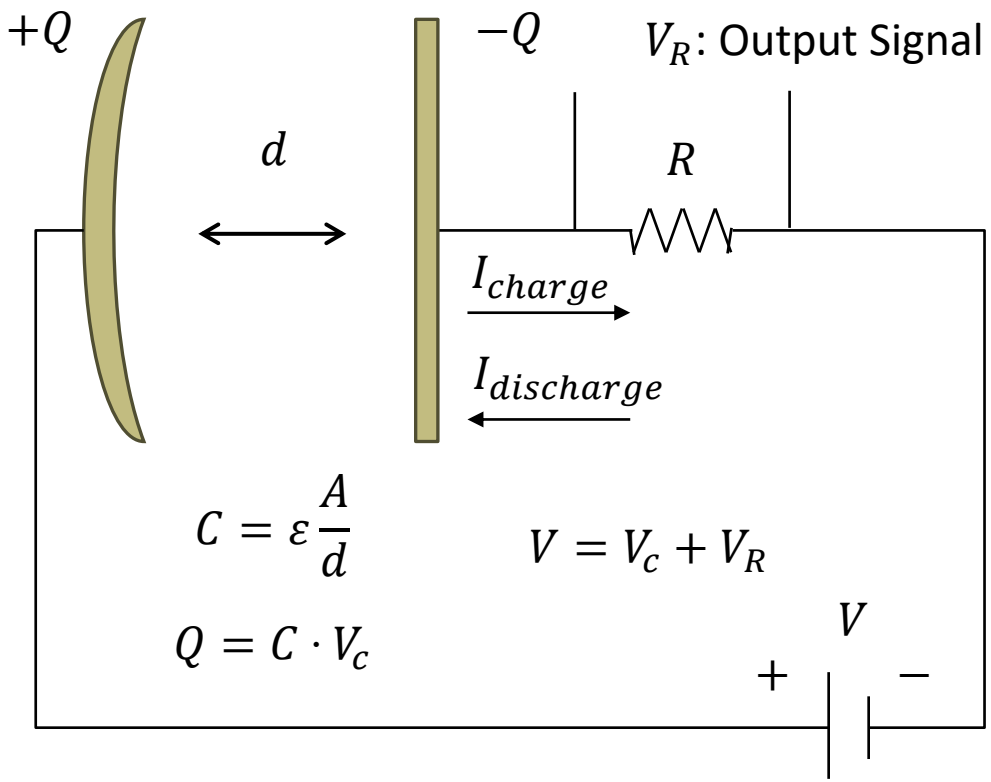
Sensor

- Sound measurement

Capacitance → Voltage

Sound Wave (H)





Changes in distance$d$:

- Change in Capacitance C
- Constant voltage V
- Change in Charge Q

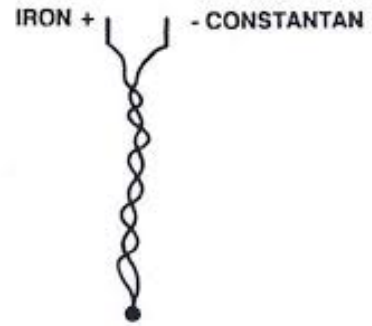
- $d\downarrow \Rightarrow C\uparrow \Rightarrow$ Accumulation of larger charge
  $\Rightarrow$ Current I_{charge}

- $d\uparrow \Rightarrow C\downarrow \Rightarrow$ Accumulation of lower charge
  $\Rightarrow$ Current $I_{discharge}$

Sensors

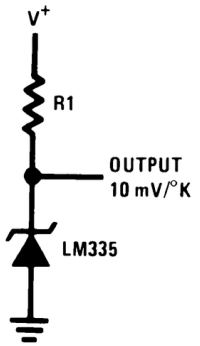
Passive

- They generate an electrical signal in response to a stimulus without requiring additional electrical power, converting the energy of the incoming stimulus into the form of the outgoing electrical signal
  Example:
  - Thermocouple



Active

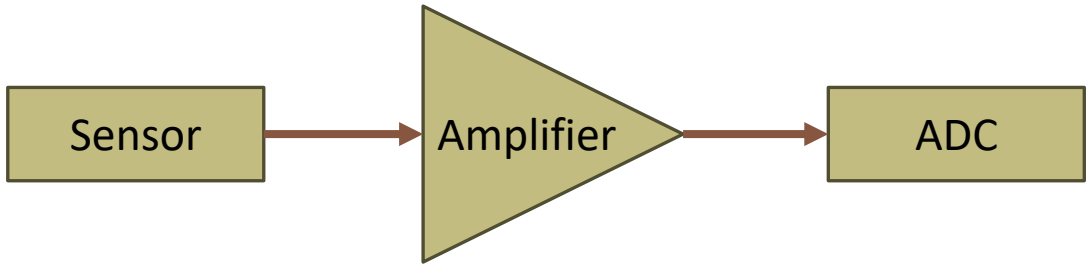
- In order to produce the output signal, they require power consumption that comes from an external source
  Example:
  - LM335



Sensors

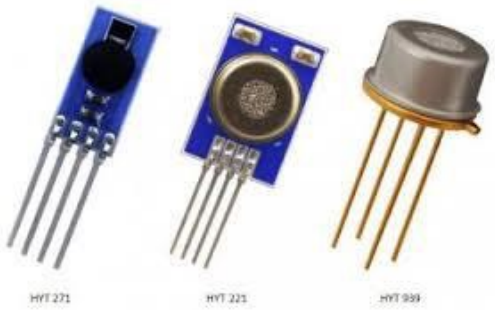
Analog

- Sensors that measure physical quantities and deliver analog output signals
  - Temperature
  - Luminosity
  - Humidity
  - Ph
  - …



Digital

- Sensors whose data is converted and transmitted in digital form
  - Temperature
  - Luminosity
  - Humidity
  - Ph
  - …



01001100

01111000

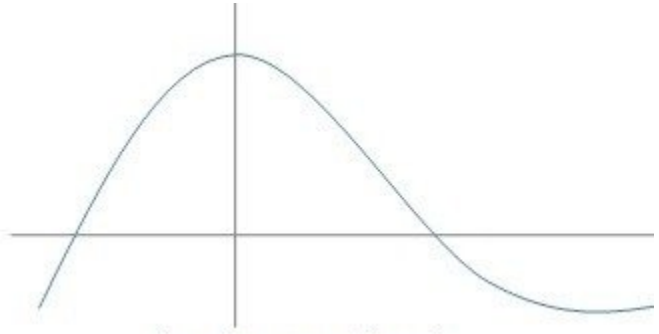
00110010

Sensors

Timely measurements

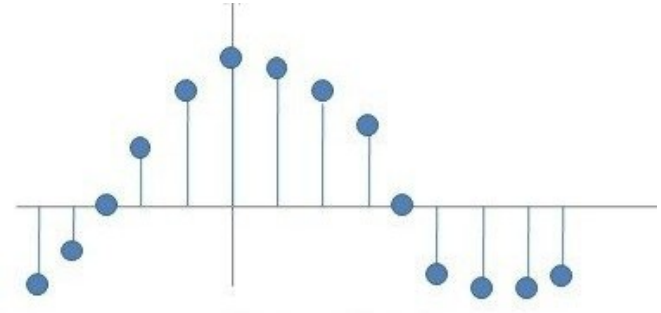
Time Continuous

- A system that determines the value of the measurable quantity in real time by producing a continuous signal.
  Example:
  - Light Dependent Resistor – LDR



Time Discrete

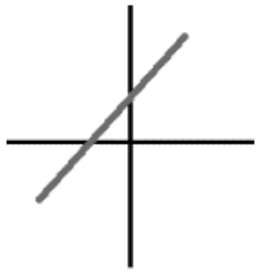
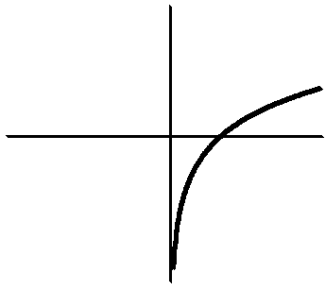
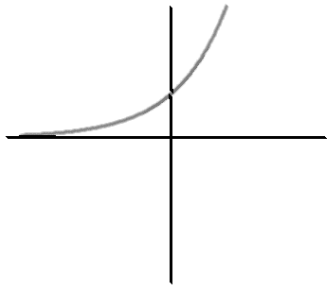
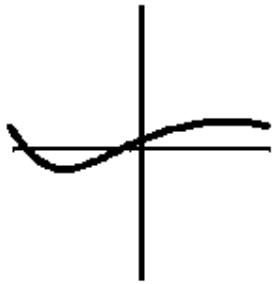
- A system that determines the value of the measurable quantity at regular intervals by producing a discrete signal.
  Example:
  - Measure ambient brightness every five minutes
  - Camera



Sensors

Transfer Function

- Linear $S(x) = \alpha + b\,x$
- Logarithmic $S(x) = \alpha + b\,\ln(x)$
- Exponential $S(x) = \alpha\,e^{k\,x}$
- Polynomial $S(x) = \alpha_0 + \alpha_1 x + \alpha_2 x^2 + \cdots$

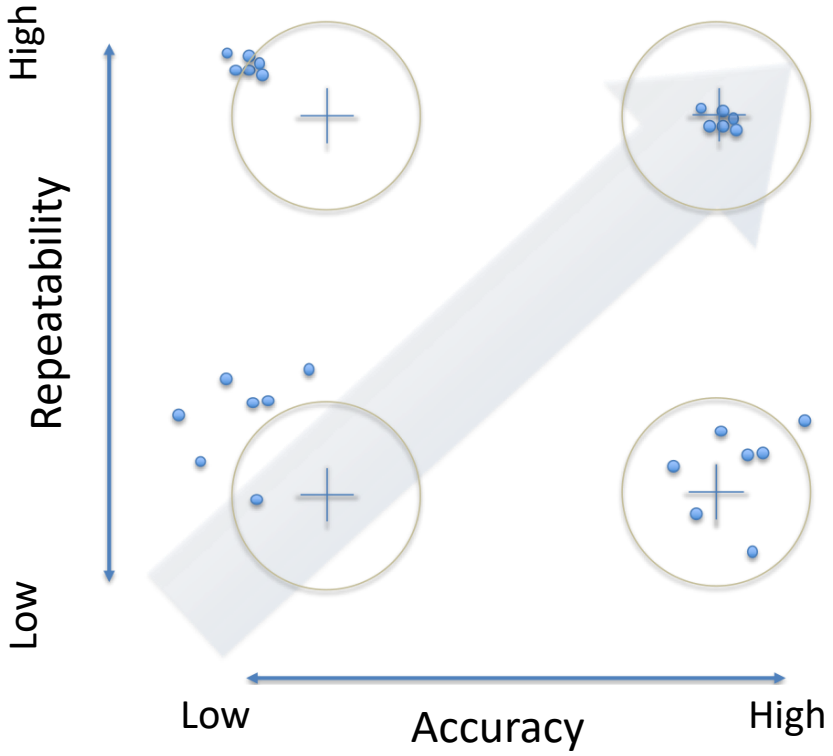
Sensitivity

- Whether the output of the sensor varies per unit of change of its input

Sensors

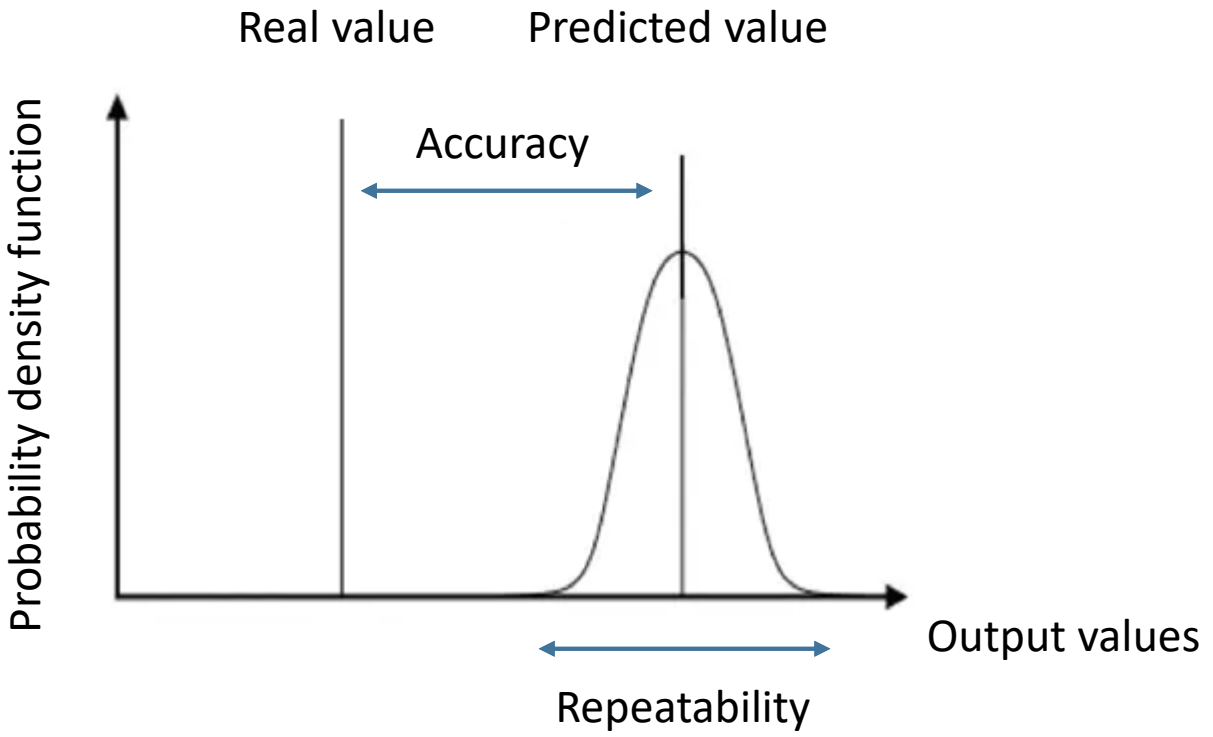
Accuracy

- The deviation of the mean value of a group of sensor measurements from the point where it was intended to be in the same stimulus.



Repeatability

- The size of the dispersion of a group of measurements of the sensor at the same stimulus.



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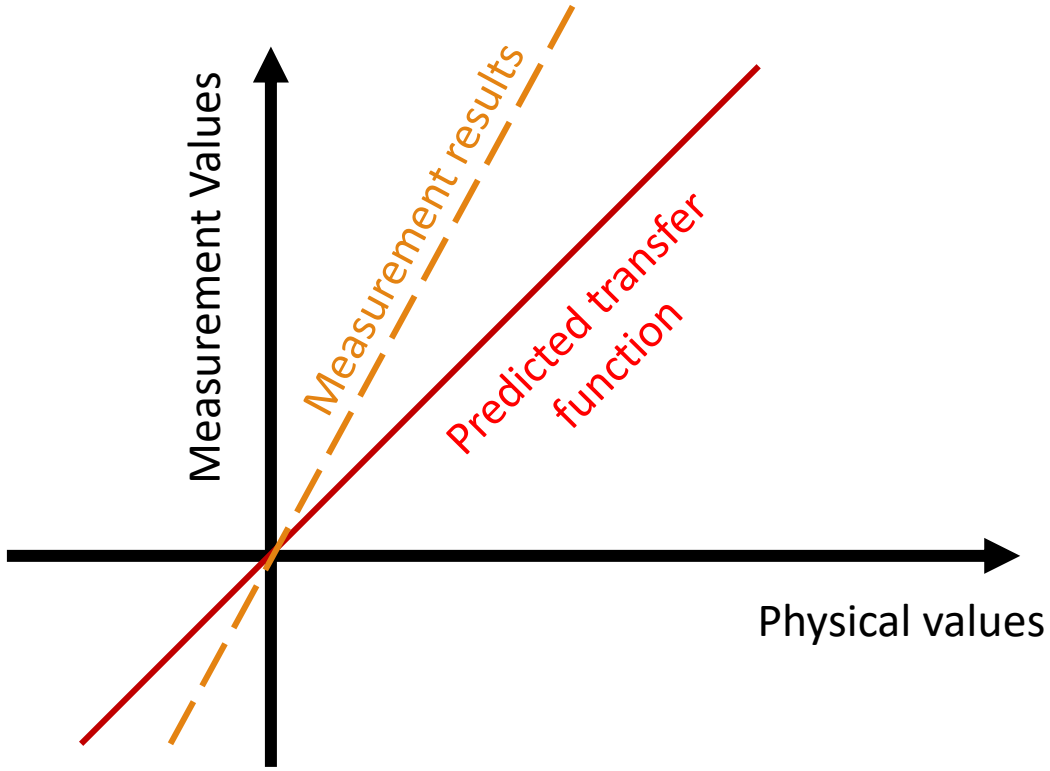

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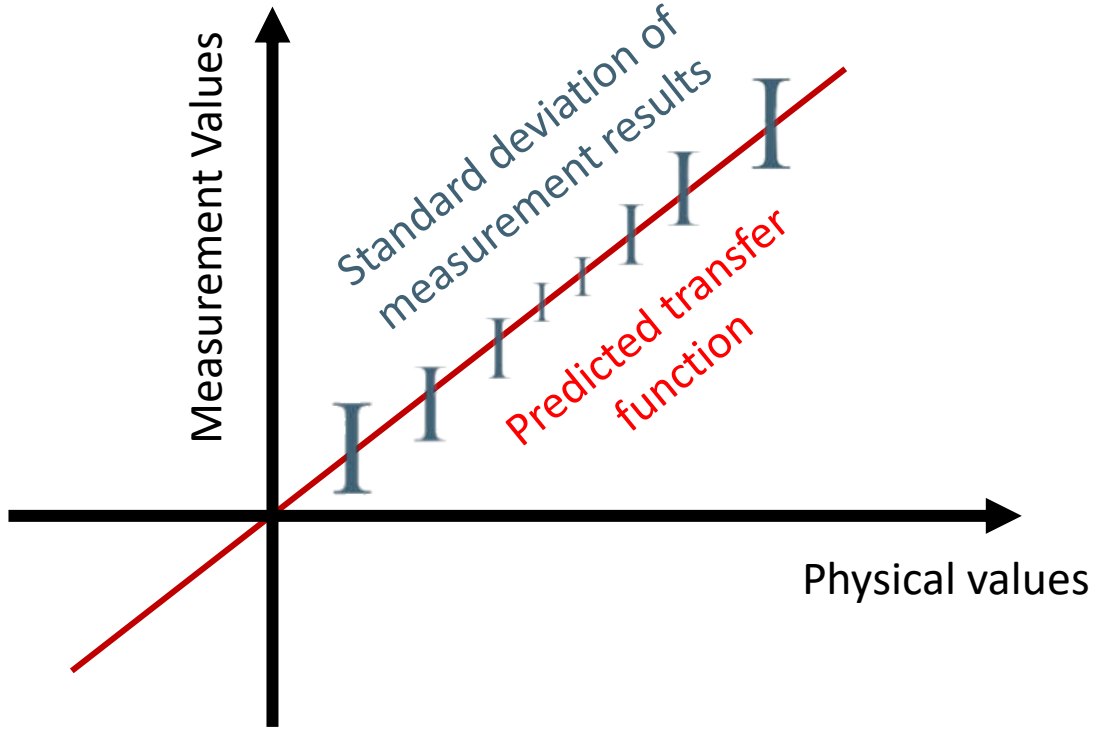


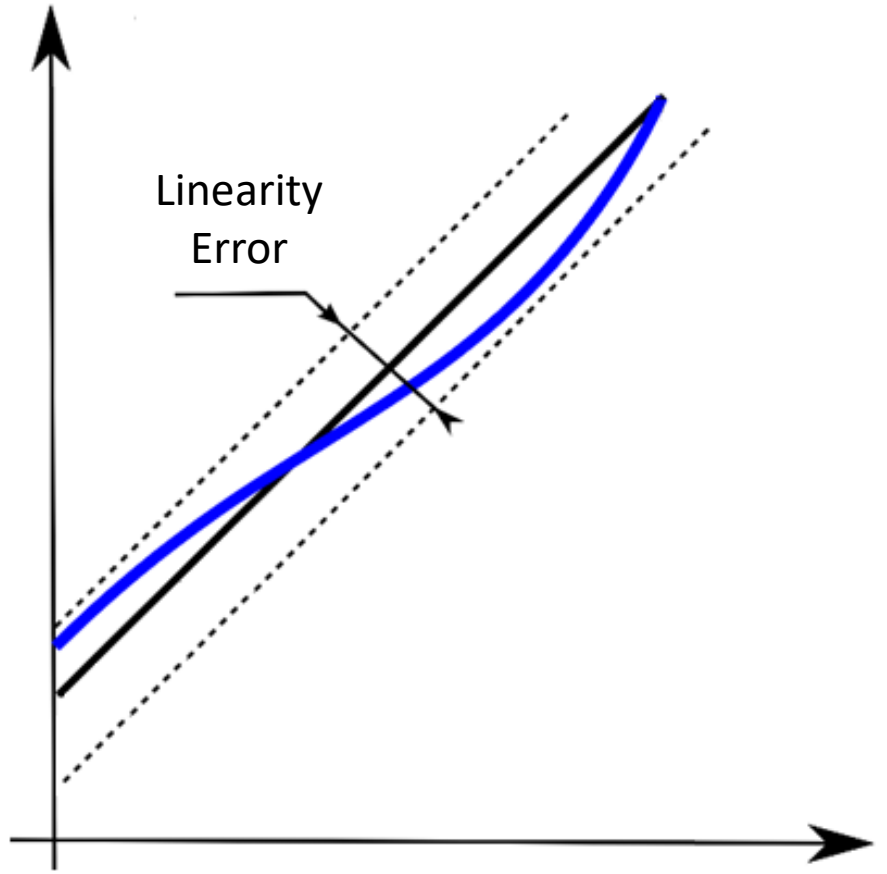
Sensors

Linearity

- The ability of a sensor to assign values in a linear region.

The correction can be carried out through:

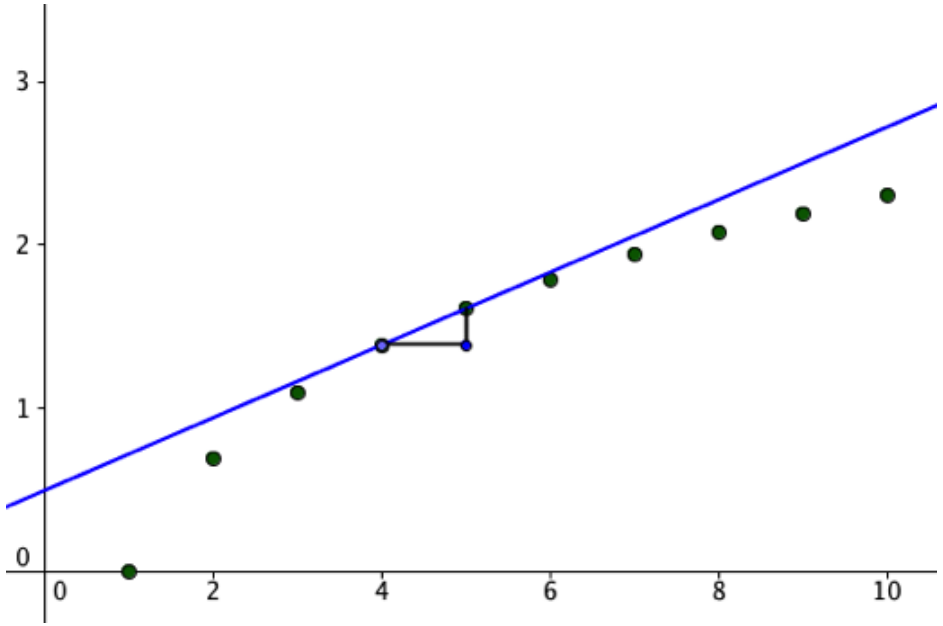
- Drawing a straight line to connect the two ends of the nonlinear curve
- Drawing a nonlinear line by the least squares method



Sensors

Local linearity

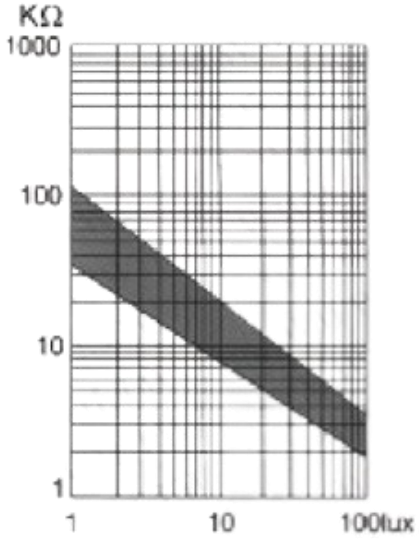
- In many cases, a nonlinear function can be considered linear within a limited range of values



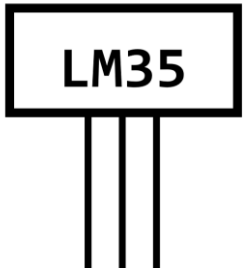
Sensors

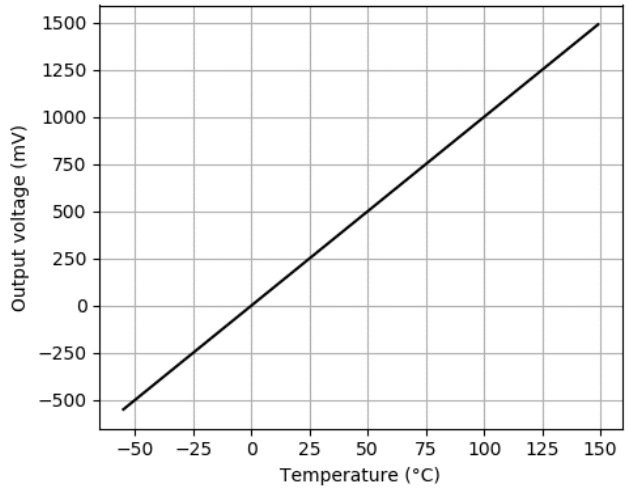
Examples of sensors

Luminosity
Light-Dependent Resistor (LDR)

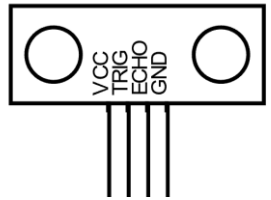


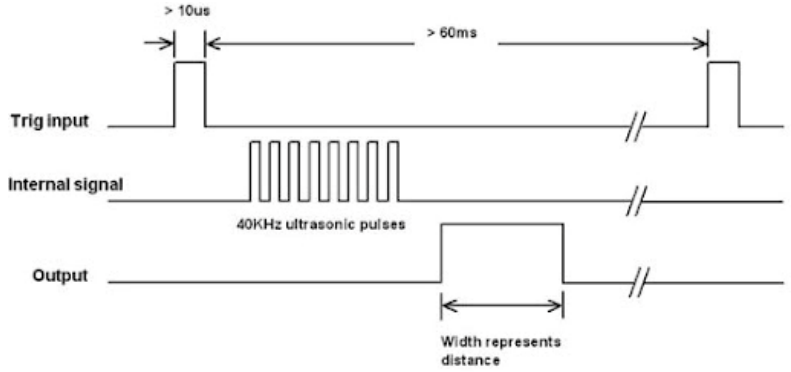
Temperature
LM35





Distance
Ultrasonic HC-SR04

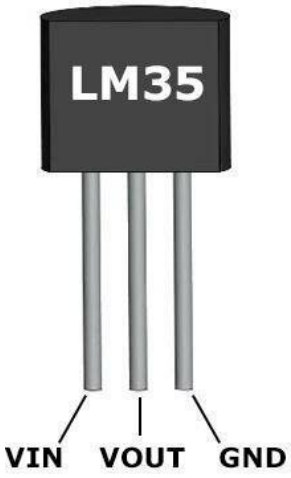




Sensors

Example

The temperature sensor LM35 exhibits linear behavior. Design an experiment to find its transfer function.



Vin: 4 to 30Volt

Sensors

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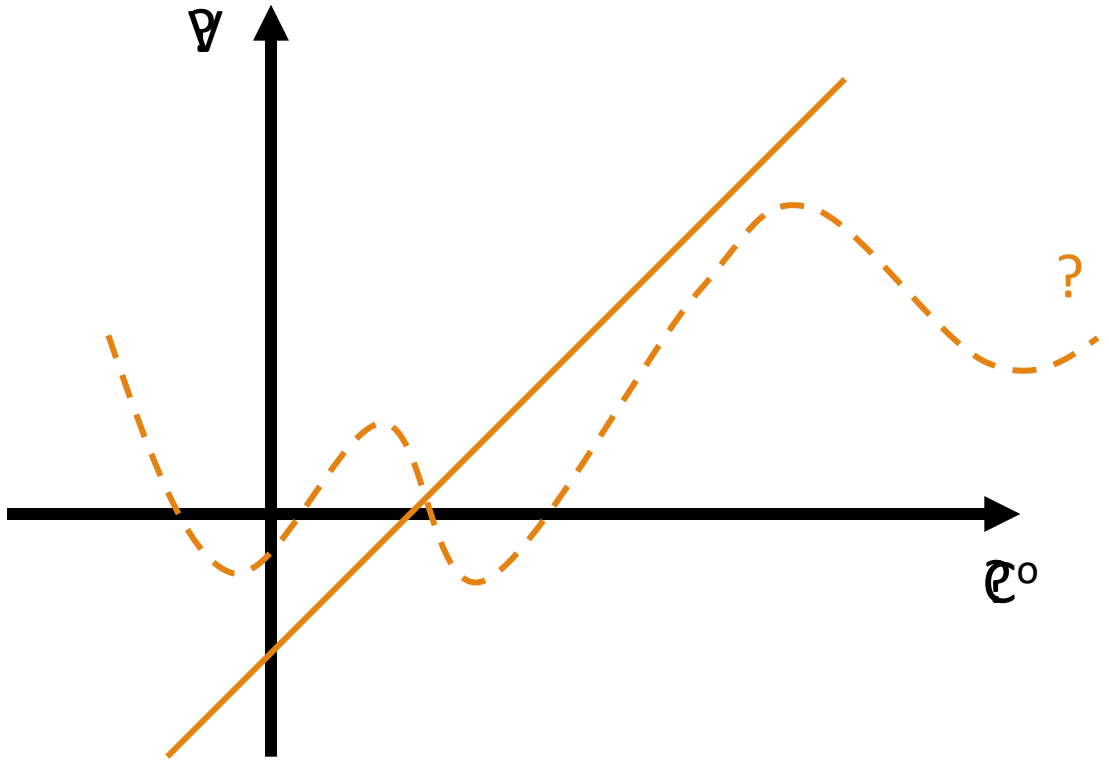

$$? = ?(?) = ?? + ?$$

Vin: 4 to 30Volt

Sensors

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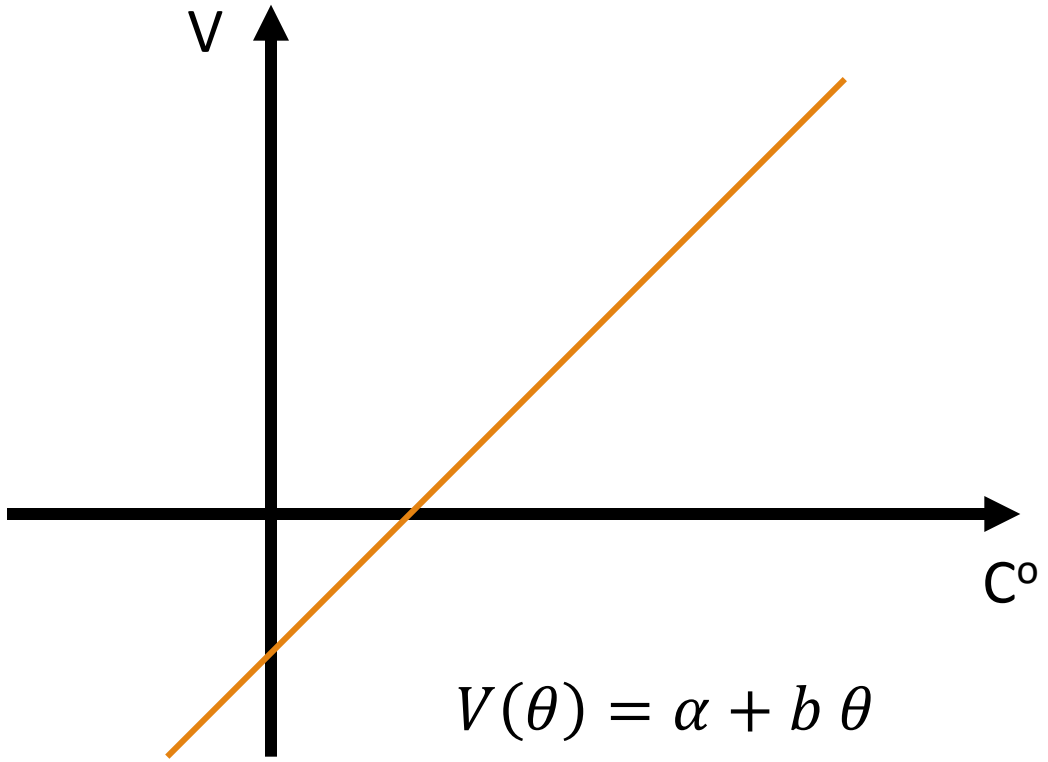
Example experimental protocol ?



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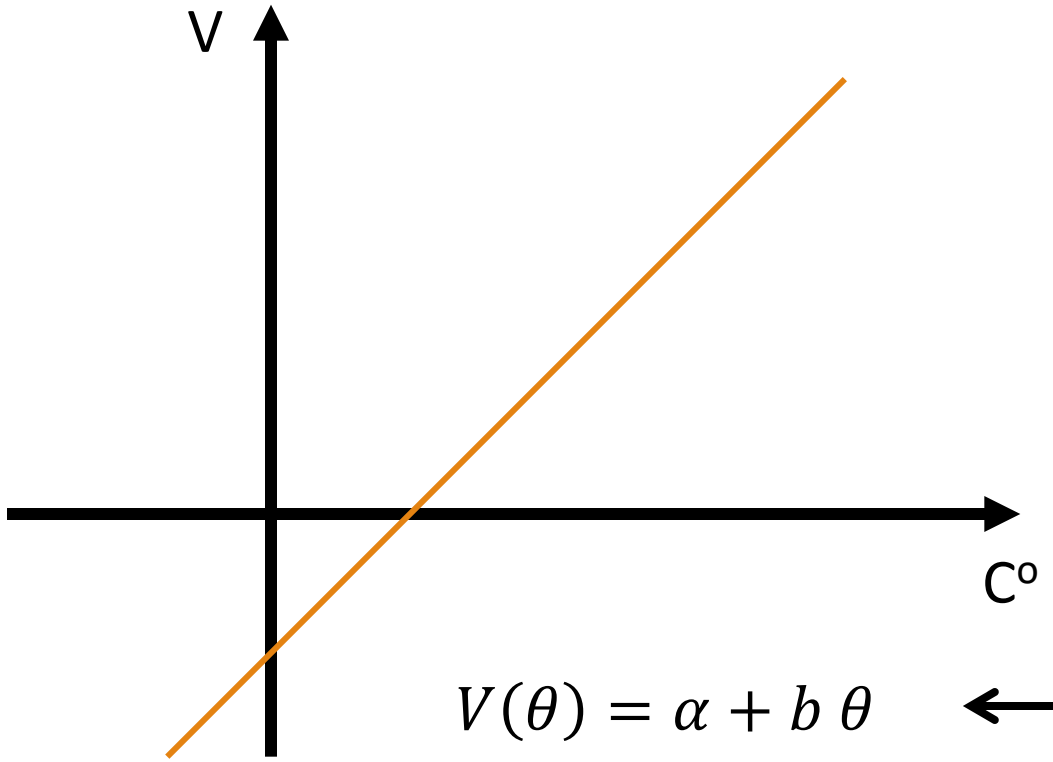
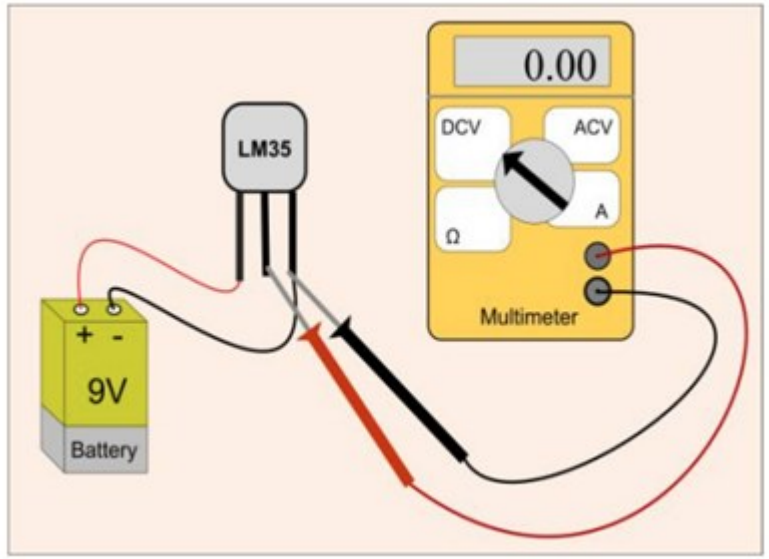


$V(\theta) = \alpha + b\,\theta$ ⟵ 2 Unknowns

Measurements?

Example experimental protocol



Sensors

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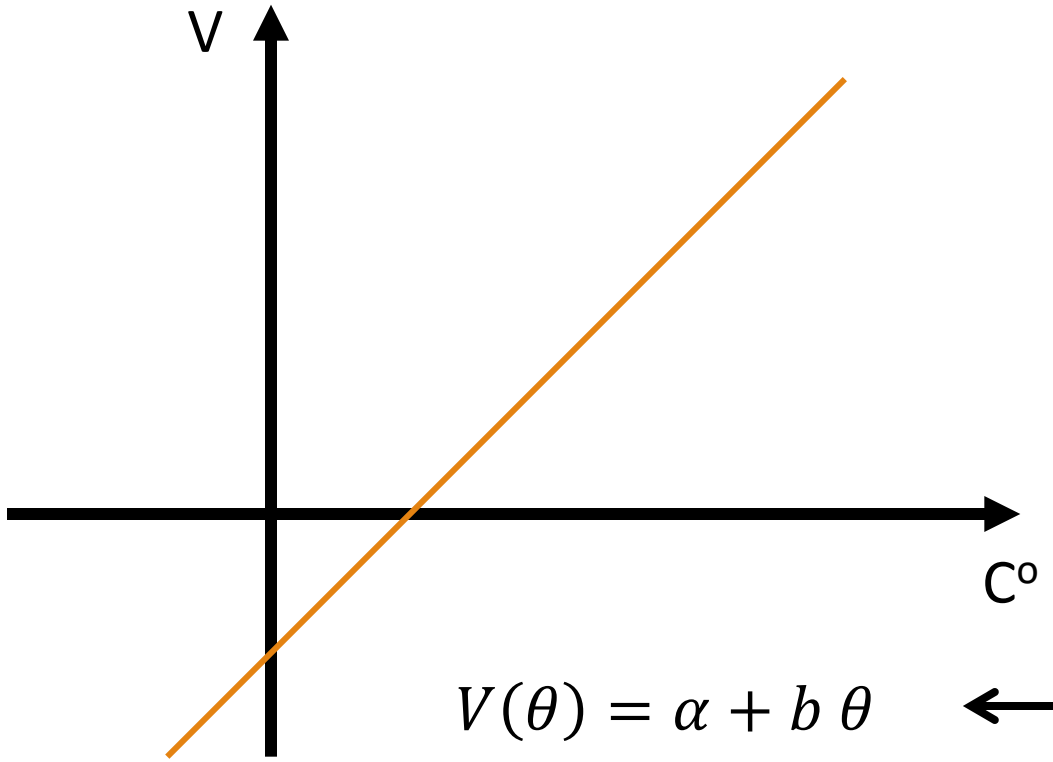

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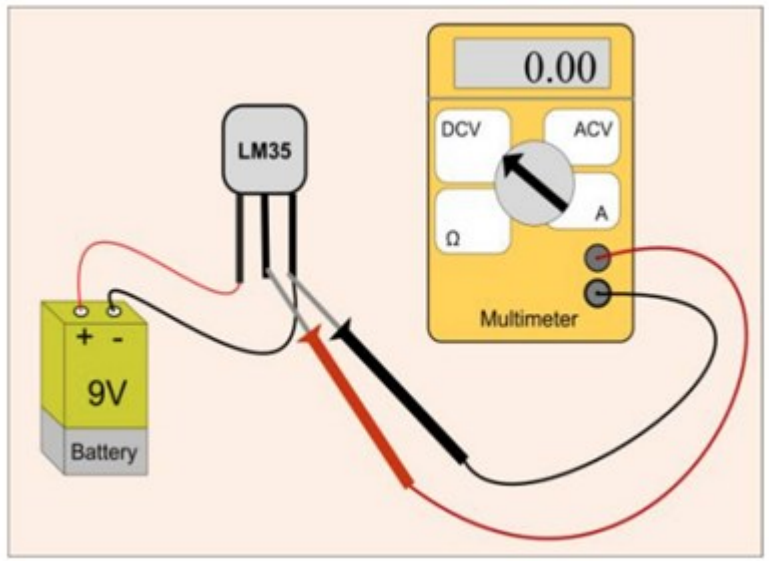
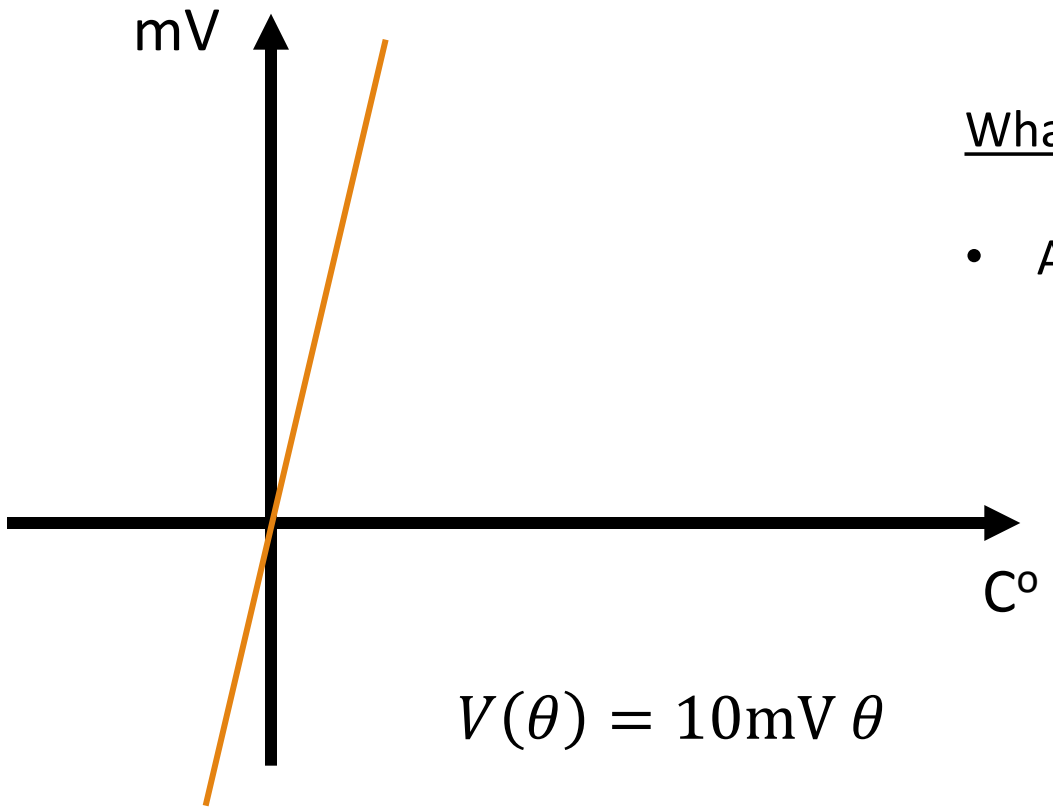


- 0 Cº → 0 mV
- 100 Cº → 10mV

Sensors

Example

The temperature sensor LM35 exhibits linear behavior. Design an experiment to find its transfer function.



$$V(\theta) = 10\text{mV}\,\theta$$

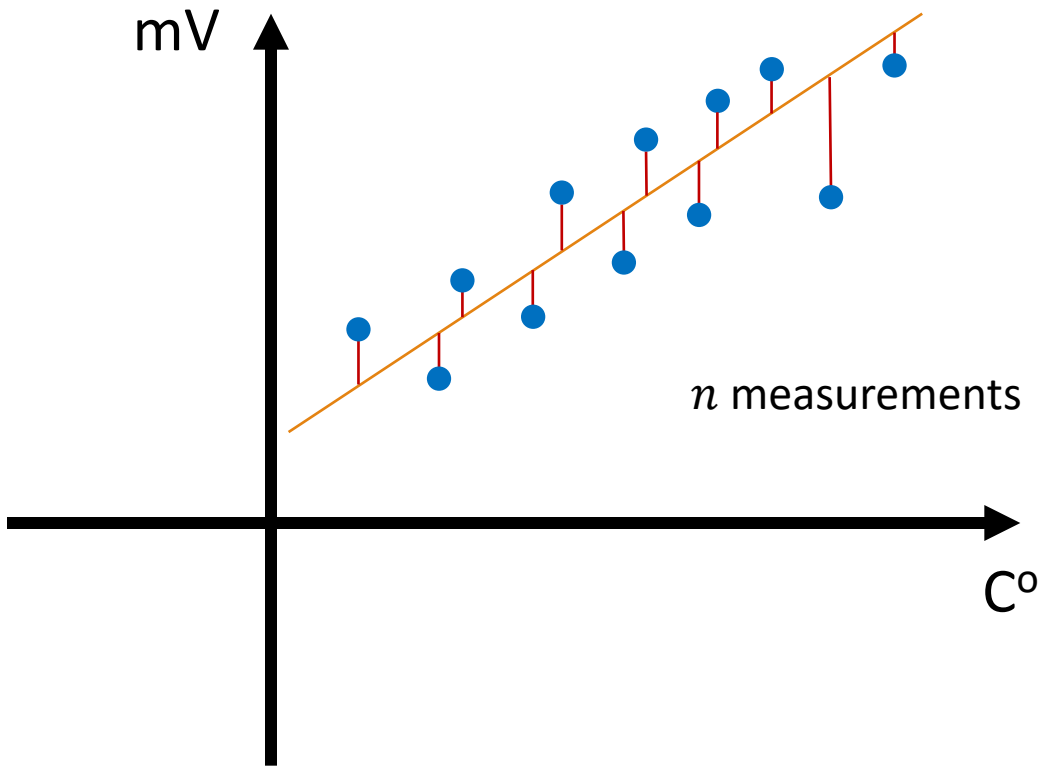
What is the sensitivity of the LM35 sensor?

- Answer: 10mV/Cº

Sensors

Example

Design an experiment to find the transfer function of the LM35 temperature sensor.



Least Squares

Model: $S(x) = a_0 + a_1\, x$

Residual: $r_i = y_i - S(x_i, \boldsymbol{a})$

Cost function: $C = \sum_{i=1}^{n} r_i^2$

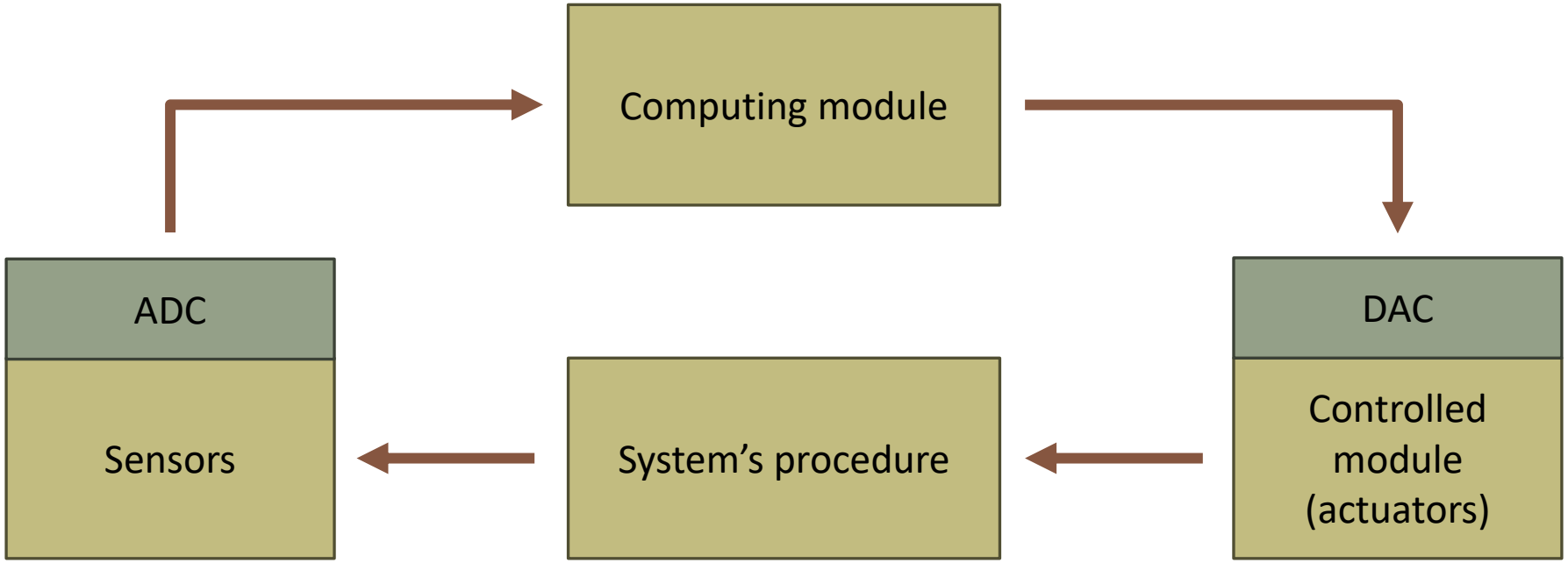
Minimization:

$$\boldsymbol{a} = \underset{\boldsymbol{a}}{\operatorname{argmin}}\, C$$

$$\frac{dC}{da_j} = 0, \qquad j = 0,1$$

Actuators

Control loop



Actuators

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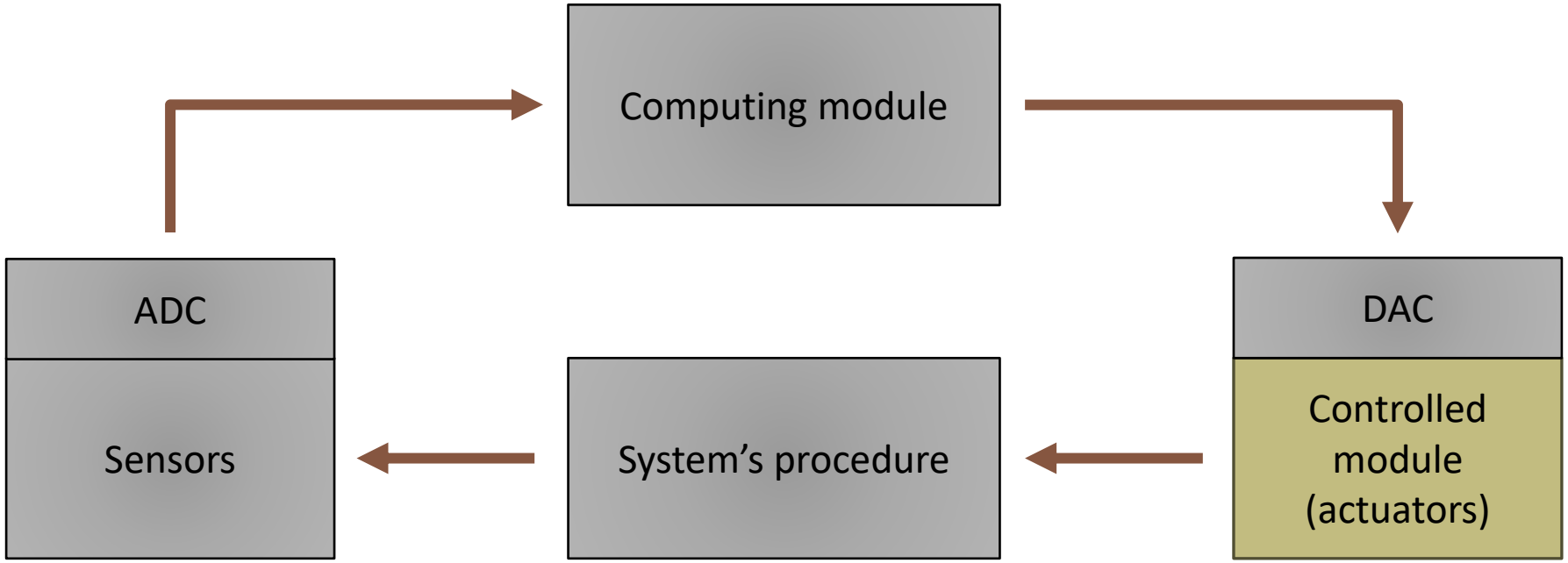


Actuators

There are two main approaches to control an Actuator:

- Digital to Analog Converter (DAC)

- Pulse Width Modulation (PWM)

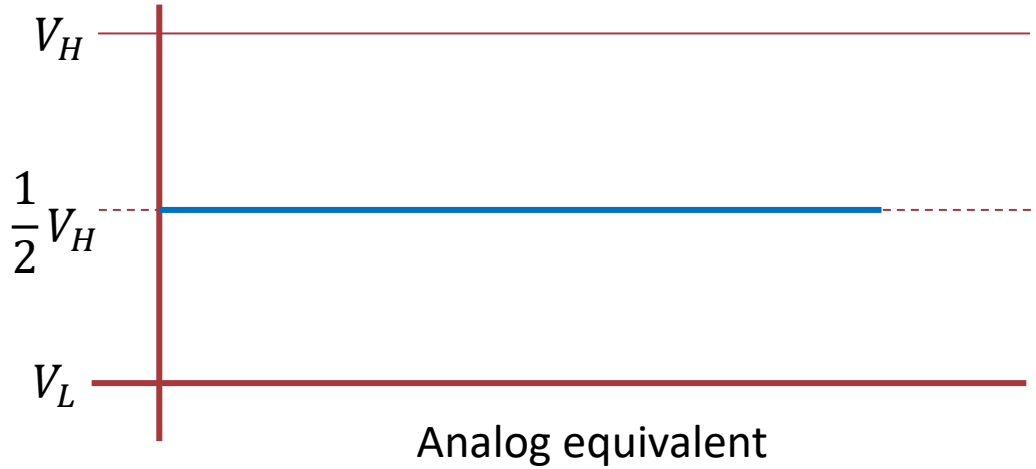
Actuators

Digital to Analog Converters (DAC)

00001111 → Digital to Analog Converter → Analogue signal

0	0	0	0	1	1	1	1

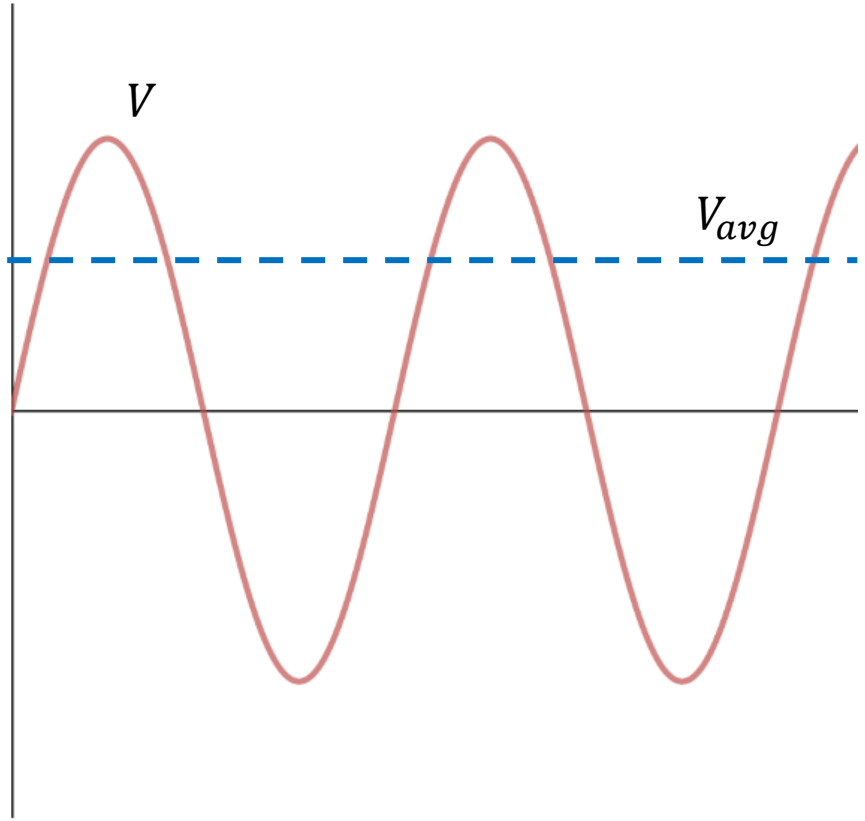
Register



Analog equivalent

Actuators

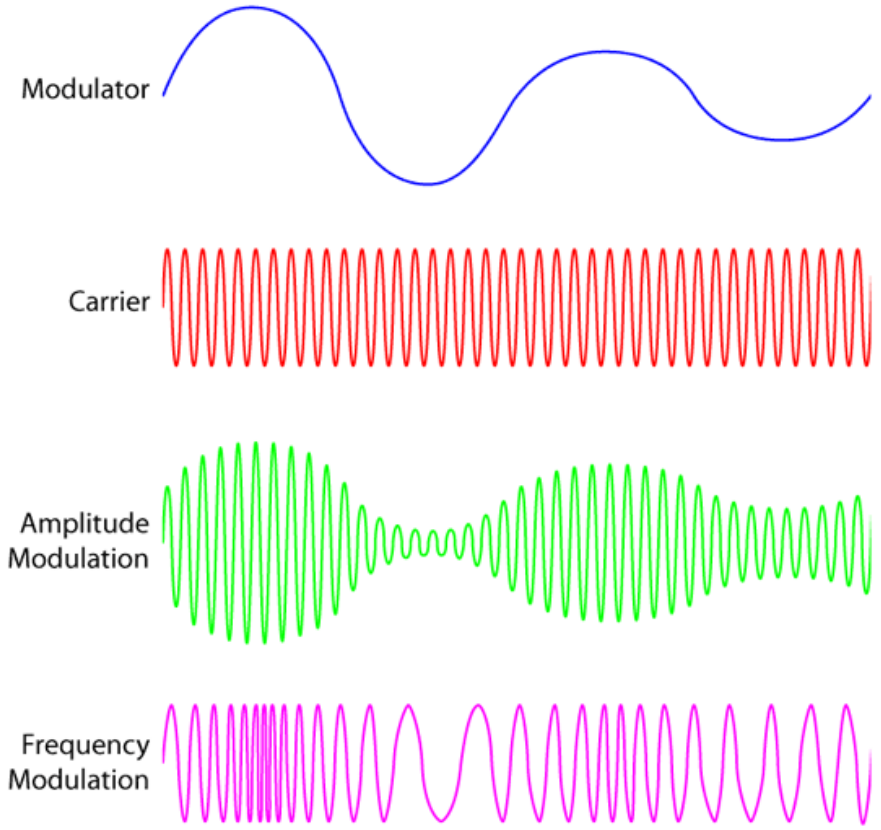
PWM:: Using average voltage as analog equivalent



Actuators

Signal Modulation

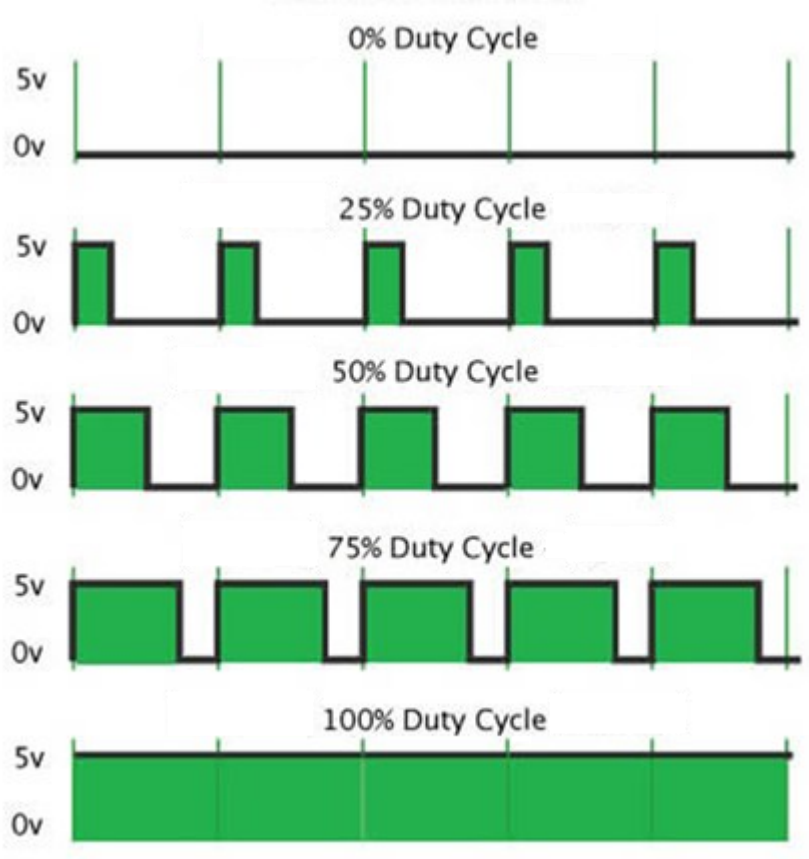
- Process by which one or more characteristics of a periodic waveform (Carrier Signal) are changed according to another fluctuating signal (Modulation Signal)



- Examples:
  - Amplitude Modulation – AM
  - Frequency Modulation – FM

Actuators

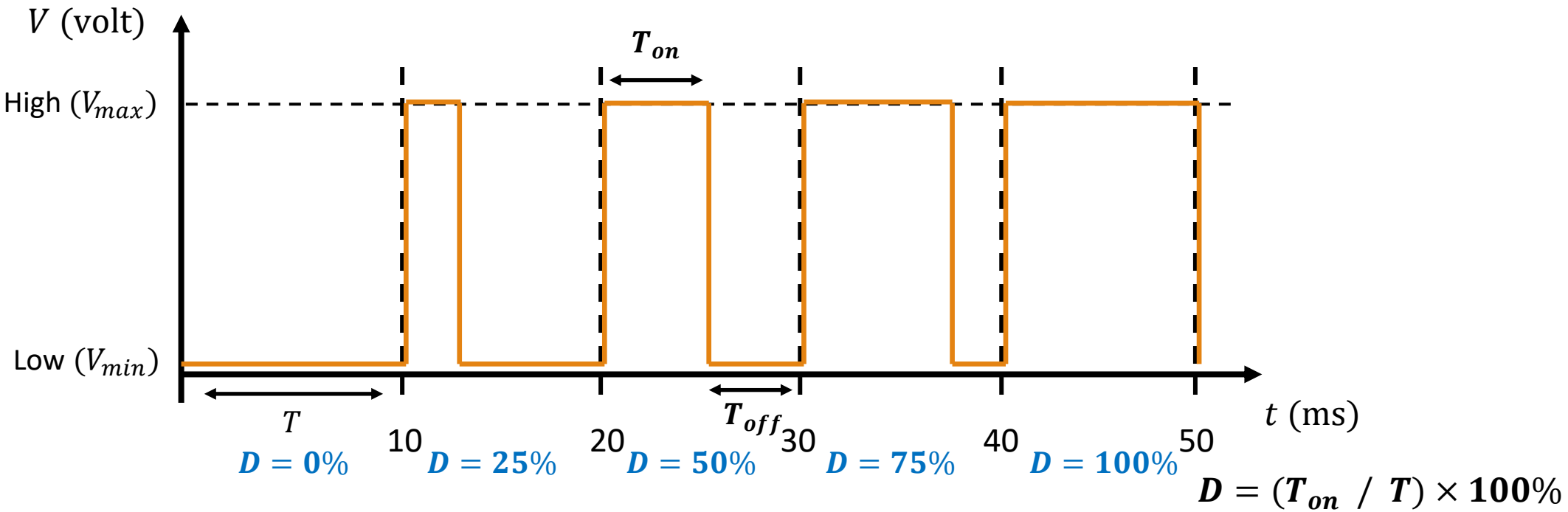
Pulse Width Modulation



- It is a method for controlling the average power provided by a digital signal.
- The average voltage (and amperage) is controlled by turning the power supply on and off at a specific rate.
- It is used
  - for producing approximate analog voltage values
  - Load control through digital outputs

Actuators

Pulse Width Modulation

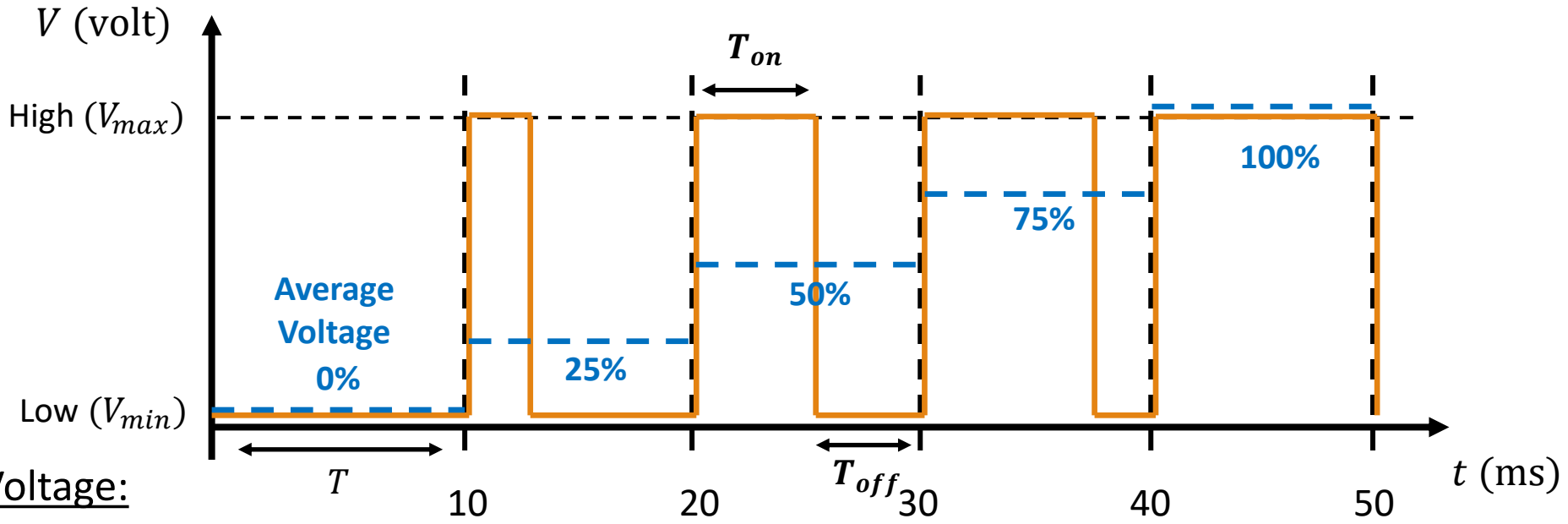


$$D = (T_{on} \ / \ T) \times 100\%$$

- **Period T**: The time required for a full cycle. It is the inverse of frequency $T = \frac{1}{f}$
- **T_{on} (on time)** : The time the signal remains in a **high** state within a period
- **T_{off} (off time)** : The time the signal remains in a **low** state within a period
- **Duty Cycle D** : The percentage of time the signal is in a **high** state within a period

Actuators

Pulse Width Modulation



Average Voltage:

$$V_{avg} = \frac{1}{T}\int_0^T V(t)\,dt = \frac{1}{T}\left(\int_0^{DT} V_{max}\,dt + \int_{DT}^T V_{min}\,dt\right) =$$

$$= \frac{1}{T}(D \cdot T \cdot V_{max} + T(1-D) \cdot V_{min}) =$$

$$= D \cdot V_{max} + (1-D) \cdot V_{min}$$

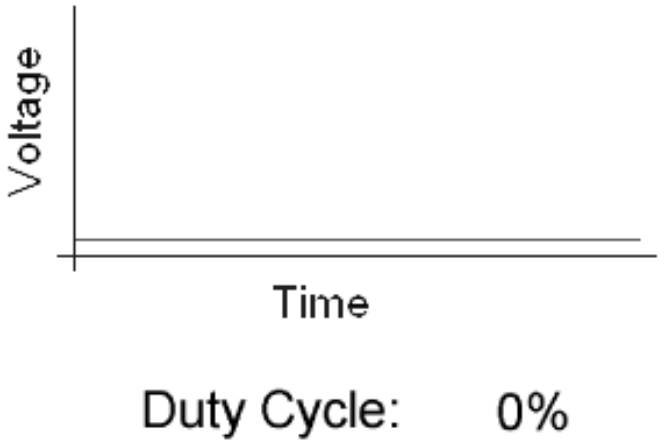
$$\boldsymbol{D = (T_{on}\ /\ T) \times 100\%}$$

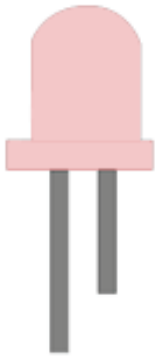
For $V_{min} = 0$:

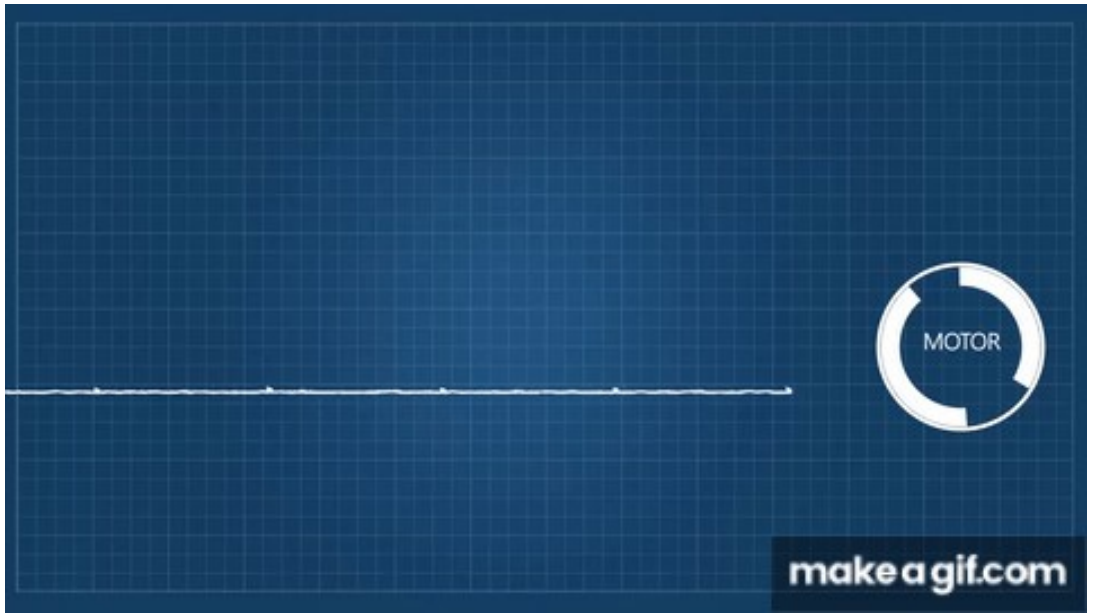
$$V_{avg} = D \cdot V_{max}$$

Actuators

Pulse Width Modulation:: Applications

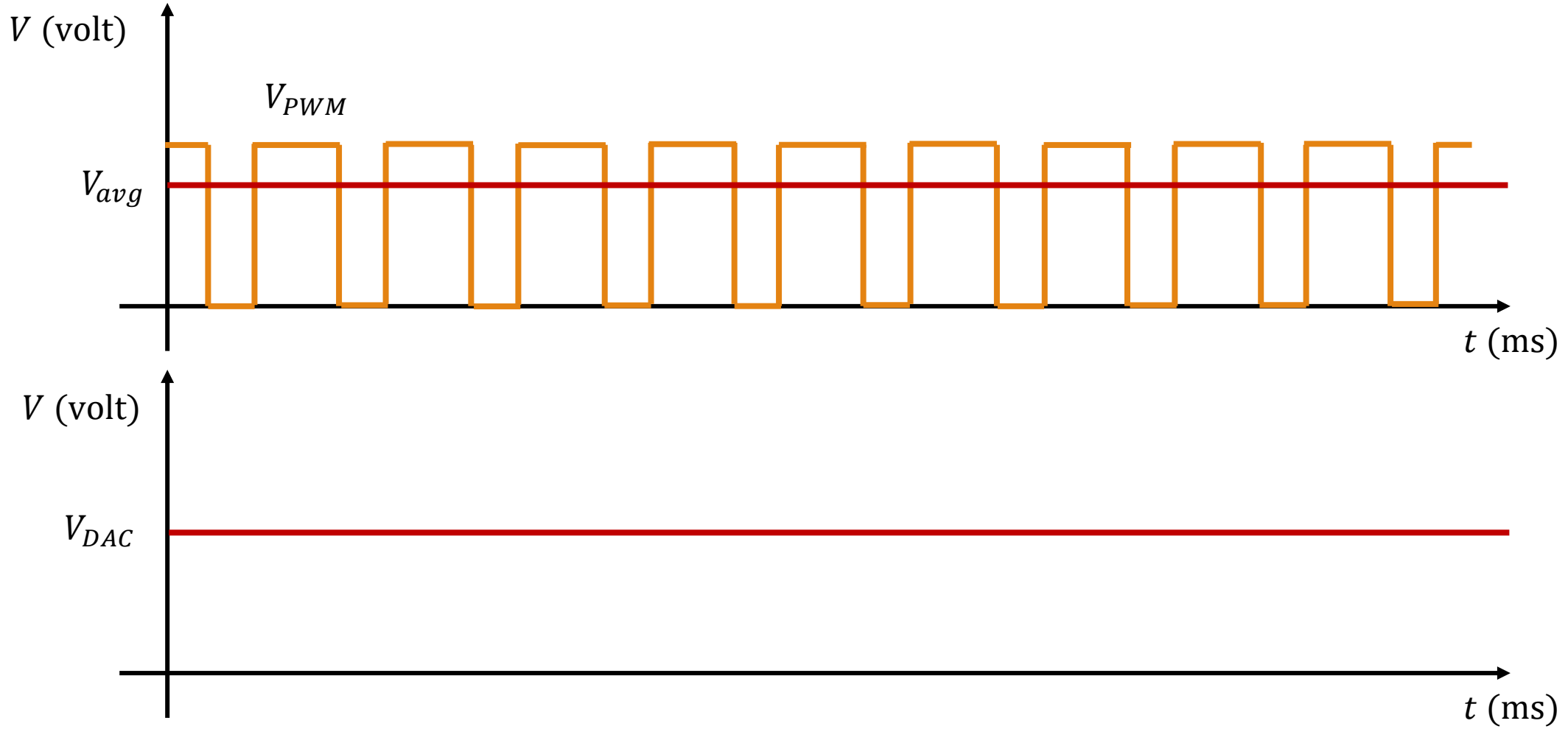




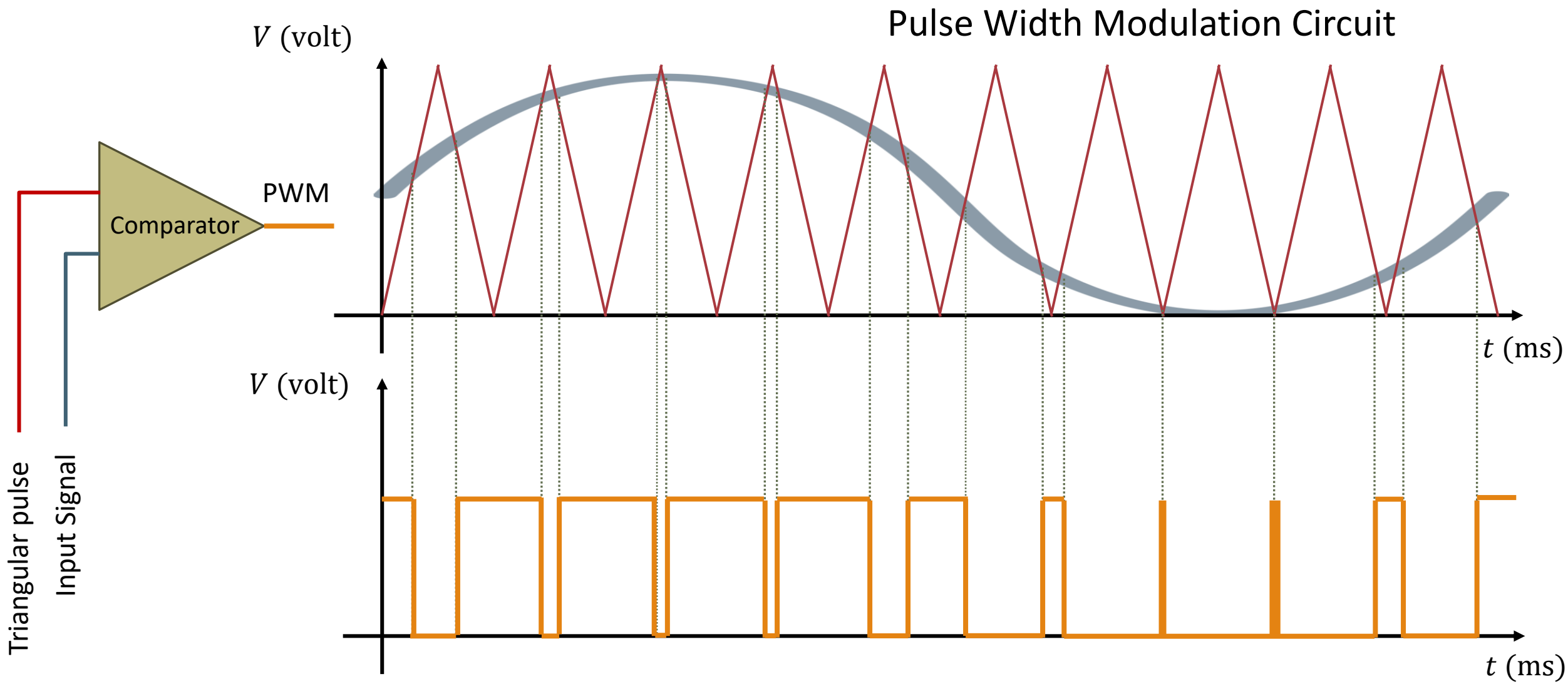


Actuators

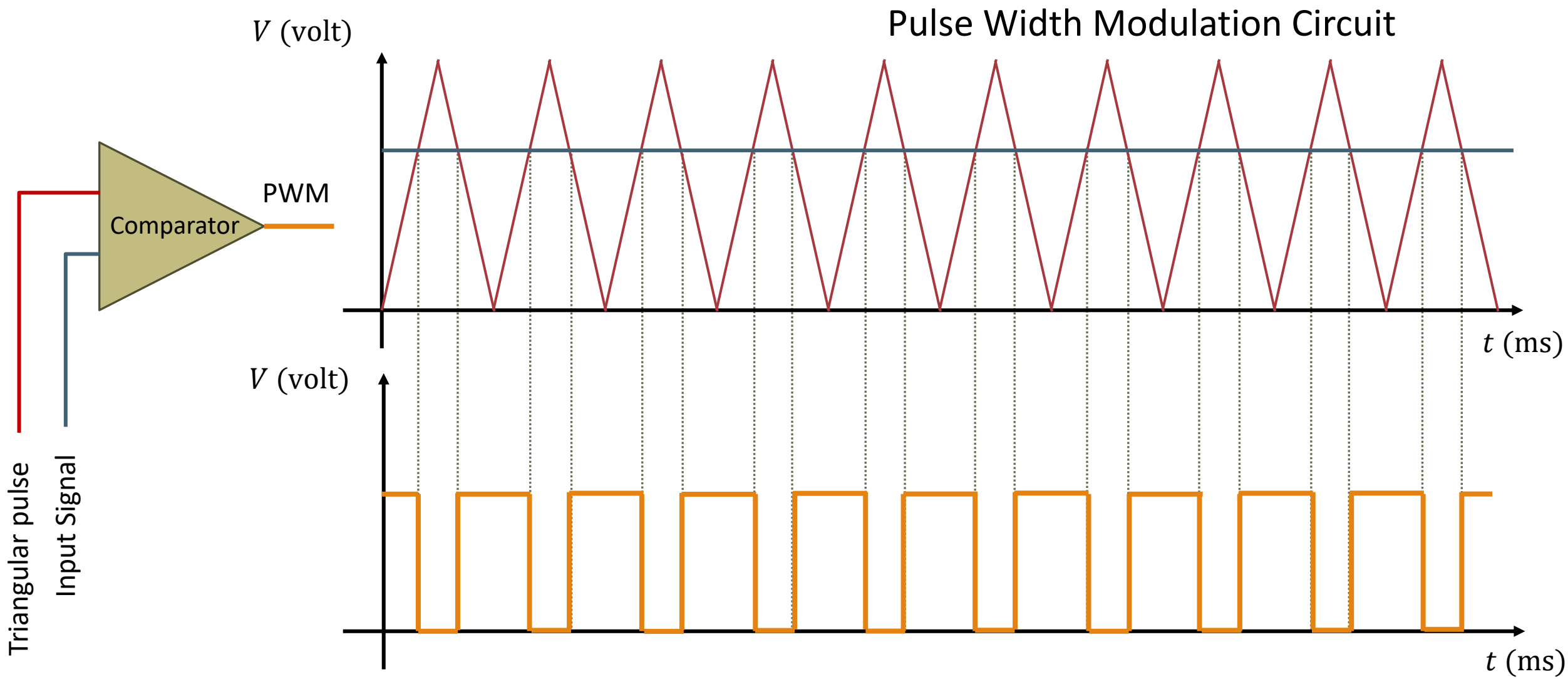
PWM vs DAC



Actuators

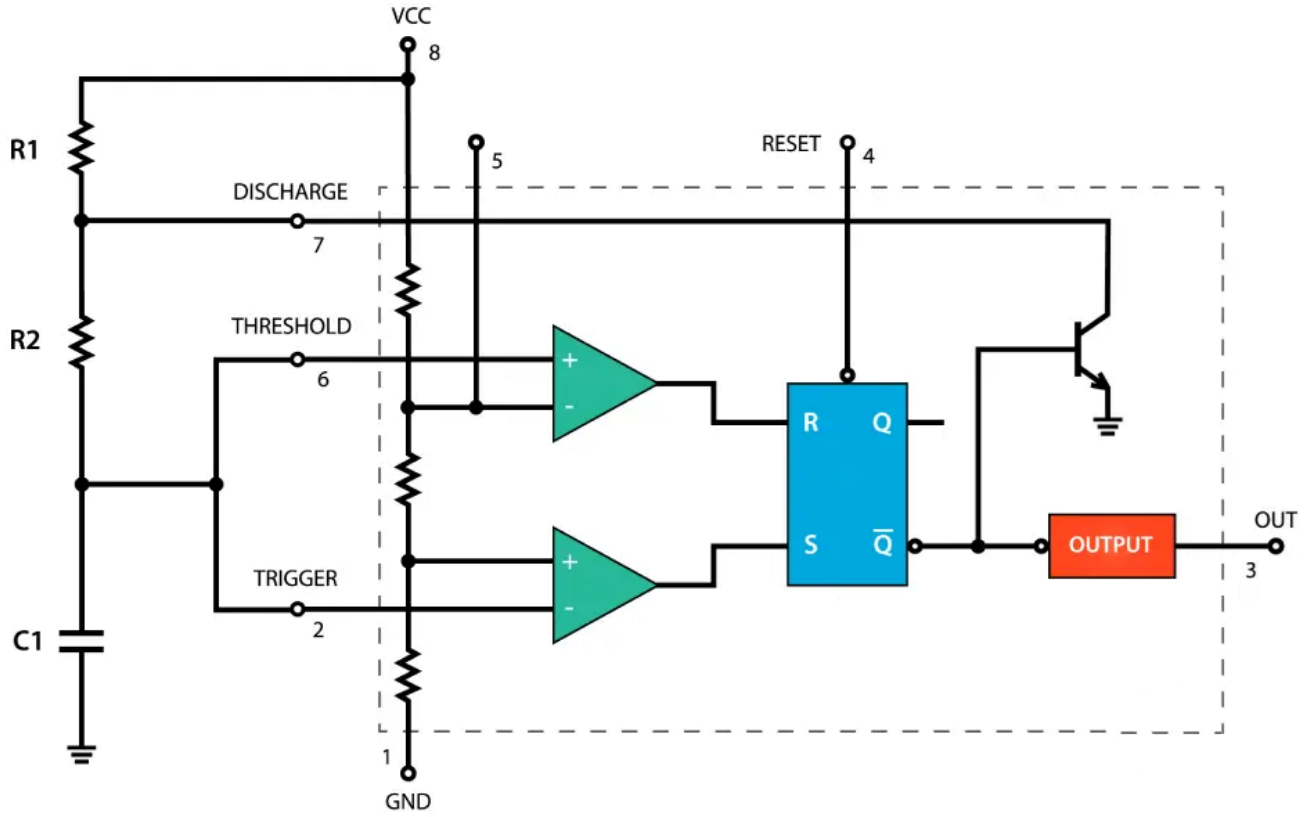

Pulse Width Modulation Circuit
V (volt)
Comparator
PWM
Triangular pulse
Input Signal
t (ms)
V (volt)
t (ms)

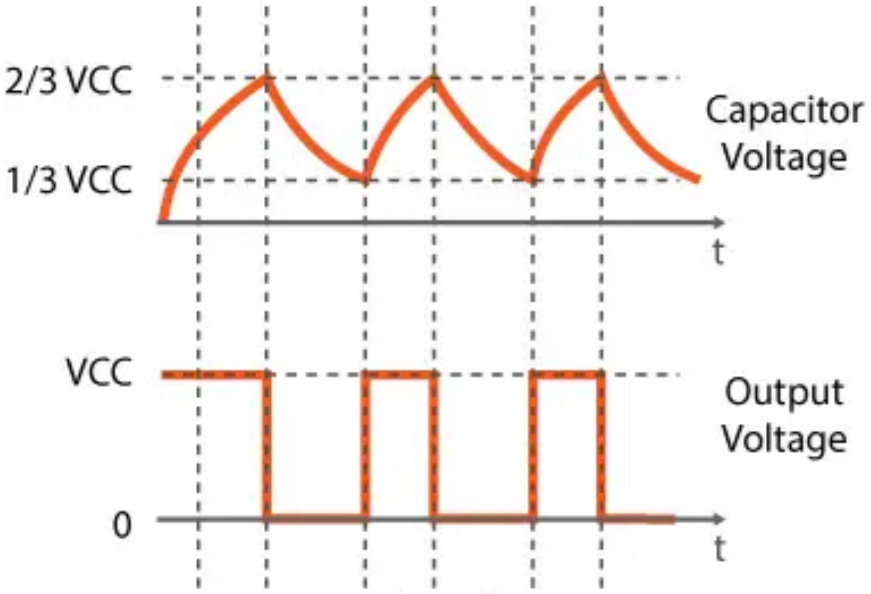
Actuators


Pulse Width Modulation Circuit
V (volt)
PWM
Comparator
Triangular pulse
Input Signal
t (ms)
V (volt)
t (ms)

Actuators

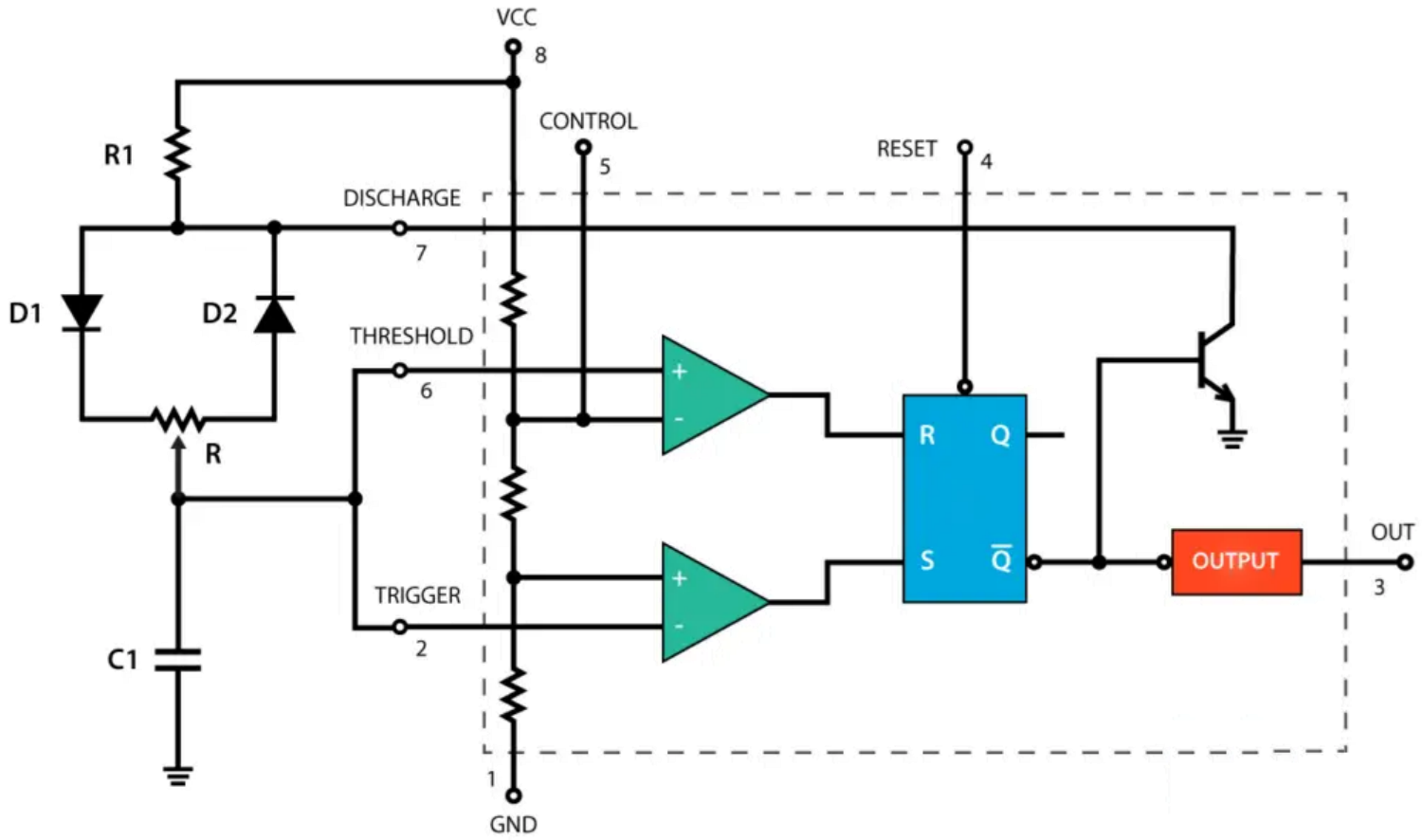
Pulse Width Modulation through 555 Circuit





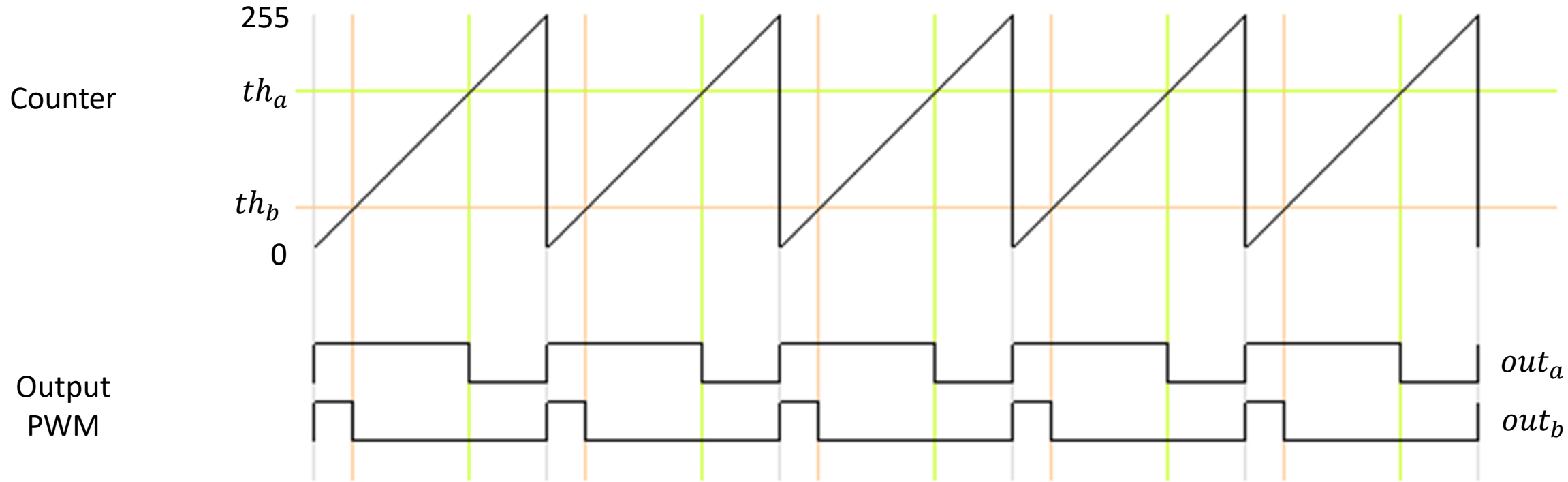
Actuators

Pulse Width Modulation through 555 Circuit



Actuators

Pulse Width Modulation algorithmic production



- The Counter constantly counts from 0 to 255
- The Counter value is compared to a digital value (th) that we have defined
- The output value (out) is defined by logical control

- If the value of th is greater than the Counter, then
  - Output out = High
- Otherwise
  - Output out = Low