Embedded System Architecture - CSEN 701

Module 3: *Embedded Hardware*

Lecture 07: *Actuators & PWM*

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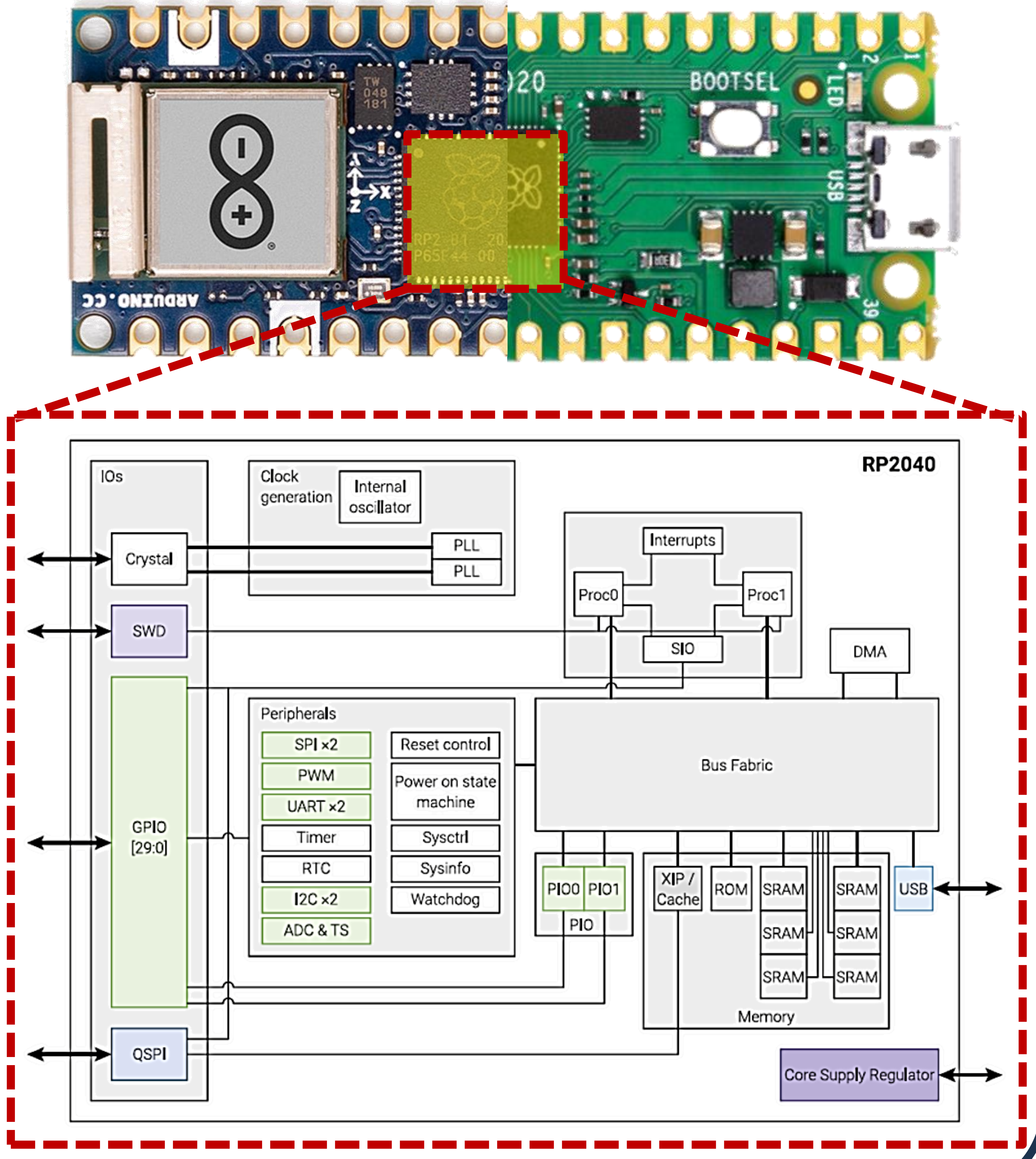
Outline

- Output Devices
- DC Motors
- PWM
- Servo Motors

An Embedded System

Physical System Input "Sensor"

Microcontroller



Physical System Output "Actuator"

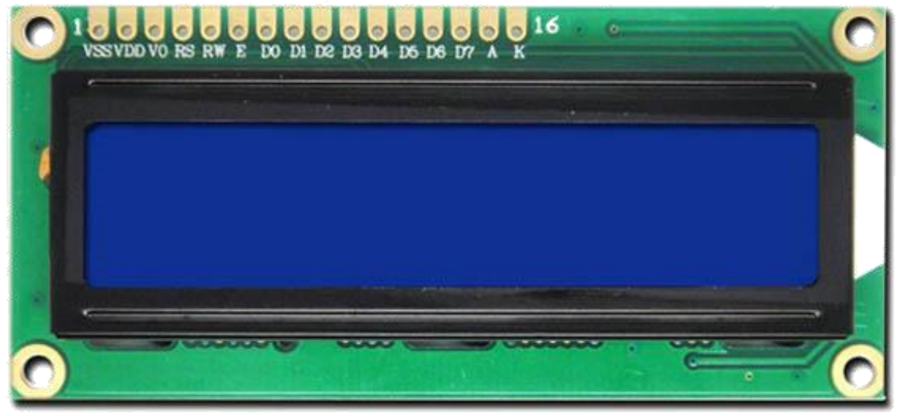
- What is the nature of the I/O Signals?
- How to make sure that the microcontroller understands these signals (Interfacing techniques) ?
- What are the sensors and actuators? Let's go
- How to read the sensor?
- How to control the actuators? Let's go

Output Devices

Definition

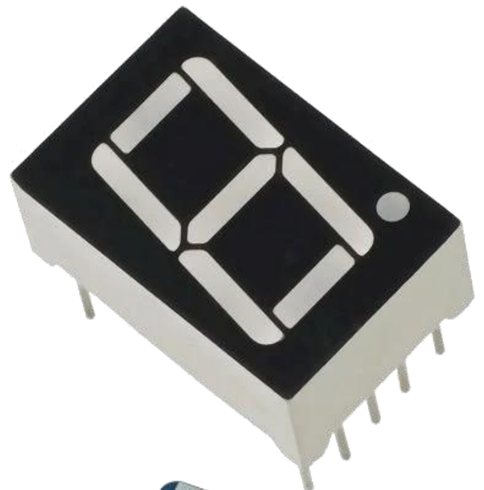
- Output devices in embedded systems are **components** or **peripherals**.
- These devices are responsible for providing information or responding to commands by producing a **physical output**.
- These devices play a crucial role in **communicating with the external environment** or the user.

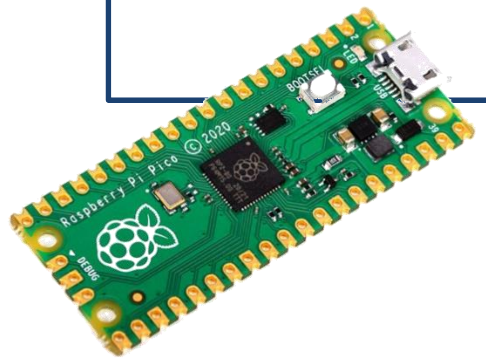
Output Devices

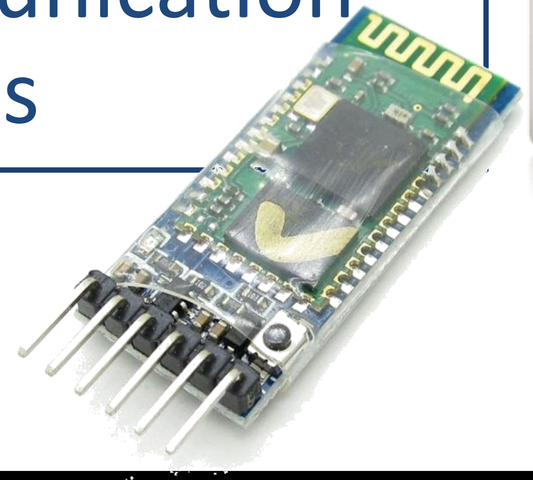


Examples

- LEDs (Light Emitting Diodes)
- LCD Displays (Liquid Crystal Displays)
- 7-Segment Displays
- OLED Displays (Organic Light Emitting Diodes)
- E-ink Displays
- Buzzer or Speaker
- Relays
- Actuators
- Digital Communication Interfaces
- Wireless Communication Modules



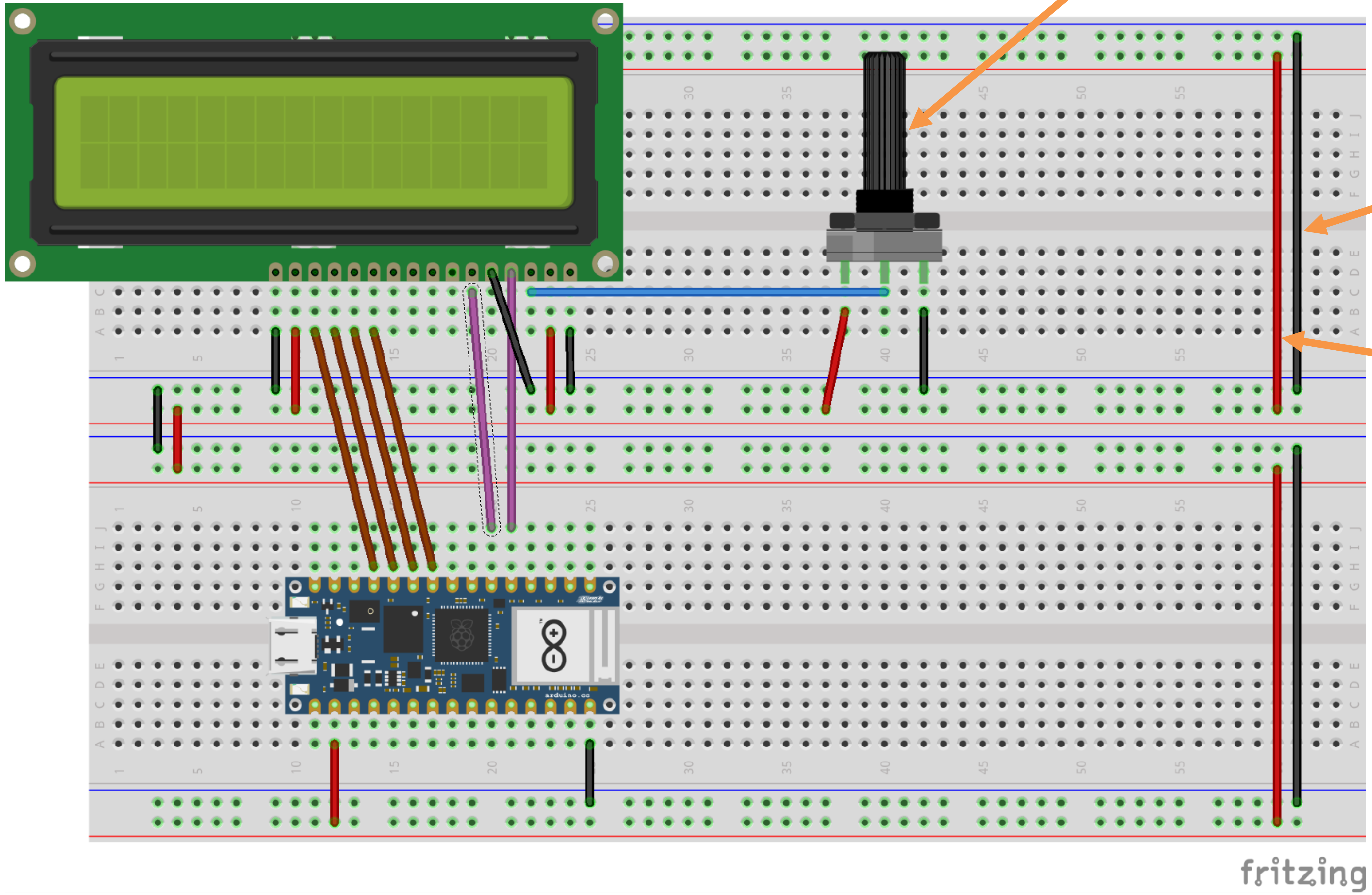




Output Device

LCD Wiring Diagram

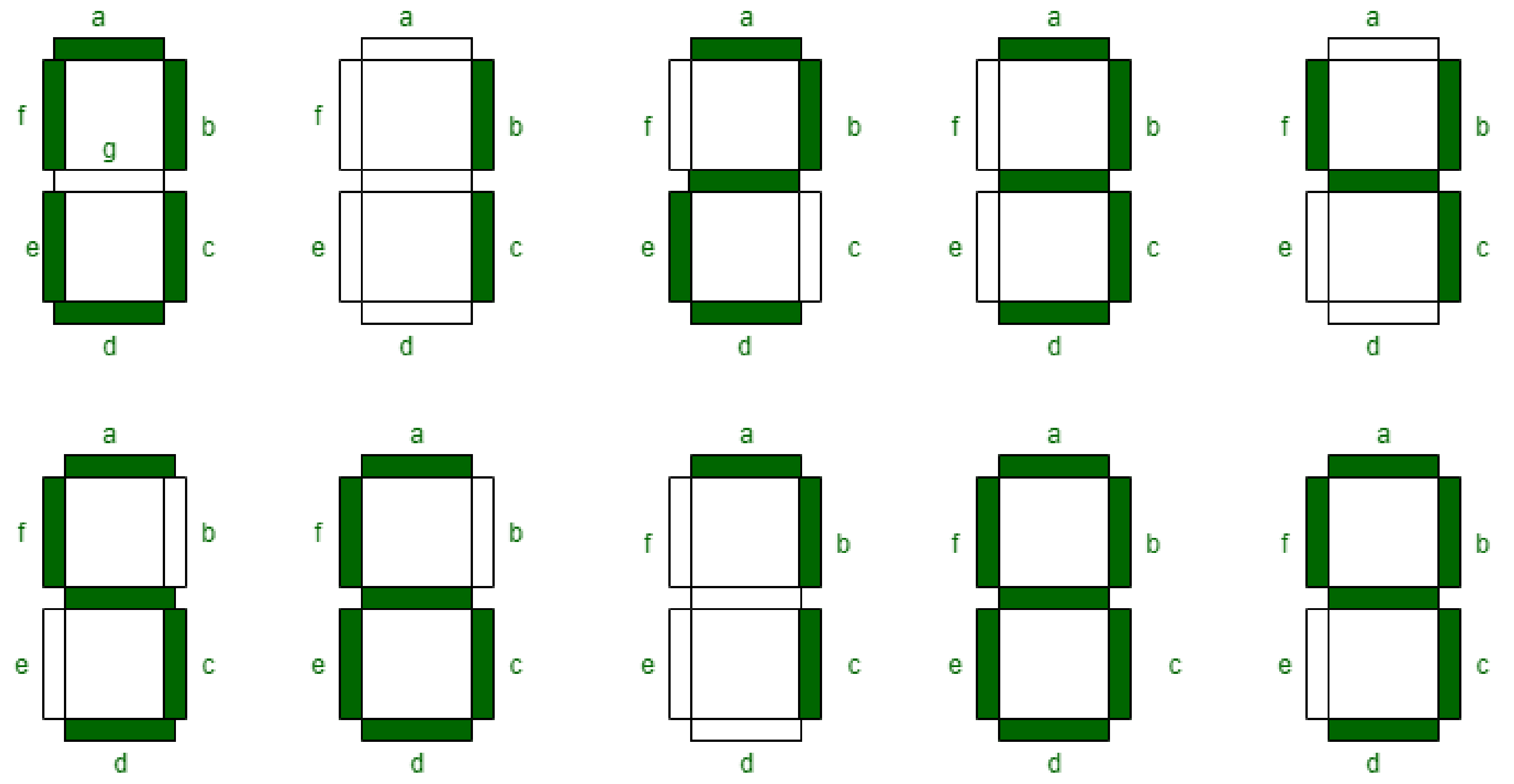
Potentiometer (Variable resistance) that control the brightness of the text on the LCD

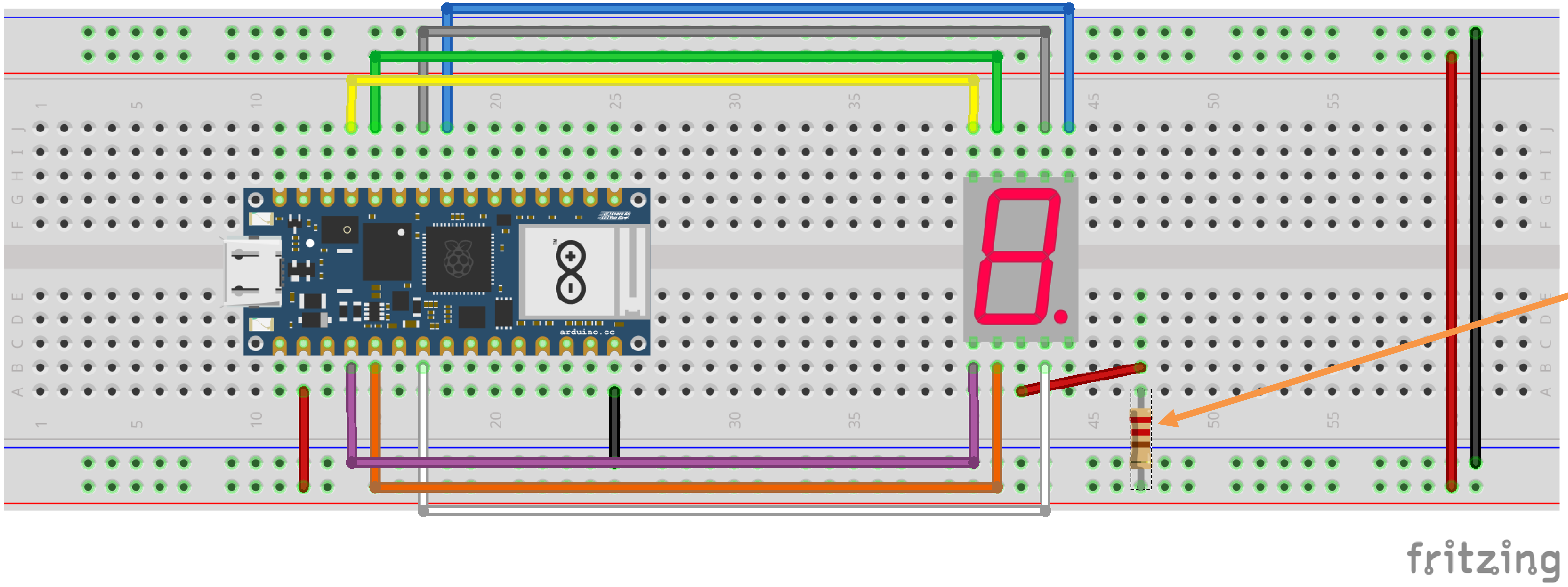


Black Wires is Common Ground

Red Wire is Common VCC connected to the 3.3V pin to the arduino

7-Segment Wiring Diagram





Pull up resistance since it is connected to the Vcc, which means that in order to turn on one of the 7-segments, you need to pull down the resistance which means setting the value to low

Definition

- Actuators are devices or components that are responsible **for converting an input signal or energy into a physical action or motion**.
- They are crucial in various fields, including engineering, automation, and robotics, where they play a pivotal role in **moving, controlling, or manipulating mechanical systems**.

Functionality and Characteristics

- **Movement:** The primary function of actuators is to produce controlled motion. This motion can be linear or rotational.
- **Control:** Actuators are used to control various parameters, such as position, speed, force, or torque.
- **Automation:** They enable the automation of tasks that would be challenging or impractical for humans to perform repeatedly and accurately.
- **Feedback Control:** In many applications, actuators are paired with sensors to create closed-loop control systems. This allows for real-time monitoring and adjustment of the actuator's behavior based on feedback from the system.
- **Energy Conversion:** Actuators often convert one form of energy into another. For example, electrical actuators convert electrical energy into mechanical motion.

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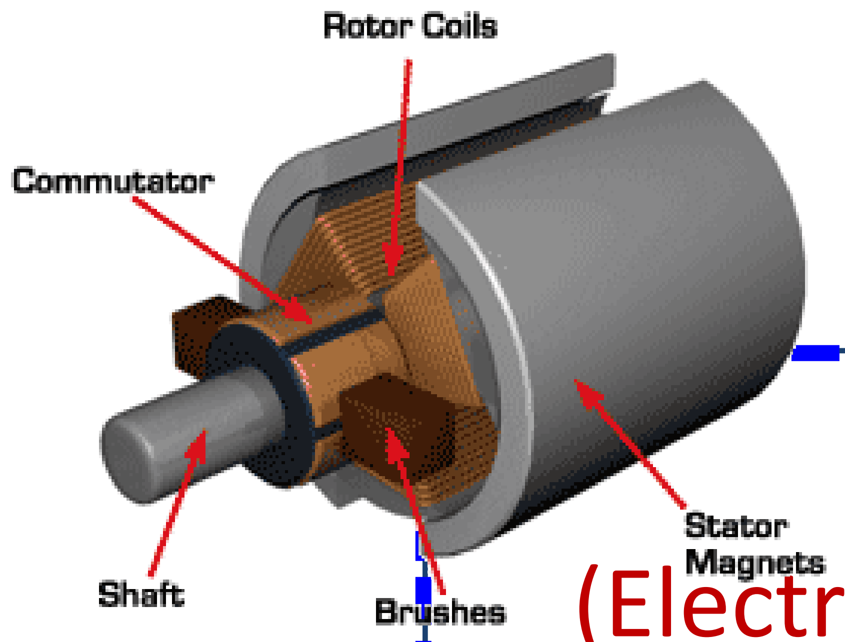
Types



Electrical Actuators
(Electrical to mechanical rotation)

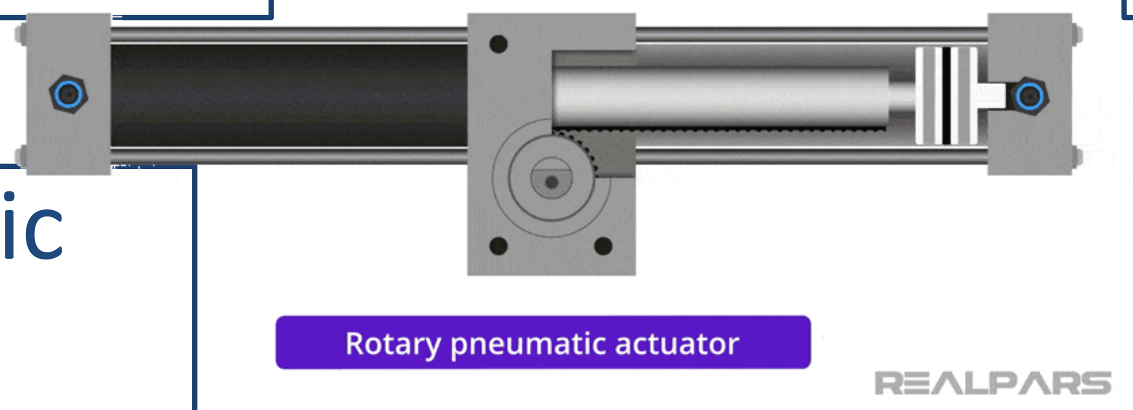
- DC Motors
- Stepper Motors
- Servo Motors

Hydraulic Actuators
(Oil flow to mechanical translation)

- Hydraulic Cylinders
- Hydraulic Motors

Pneumatic Actuators
(Air flow to mechanical translation)

- Pneumatic Cylinders
- Pneumatic Rotary Actuators

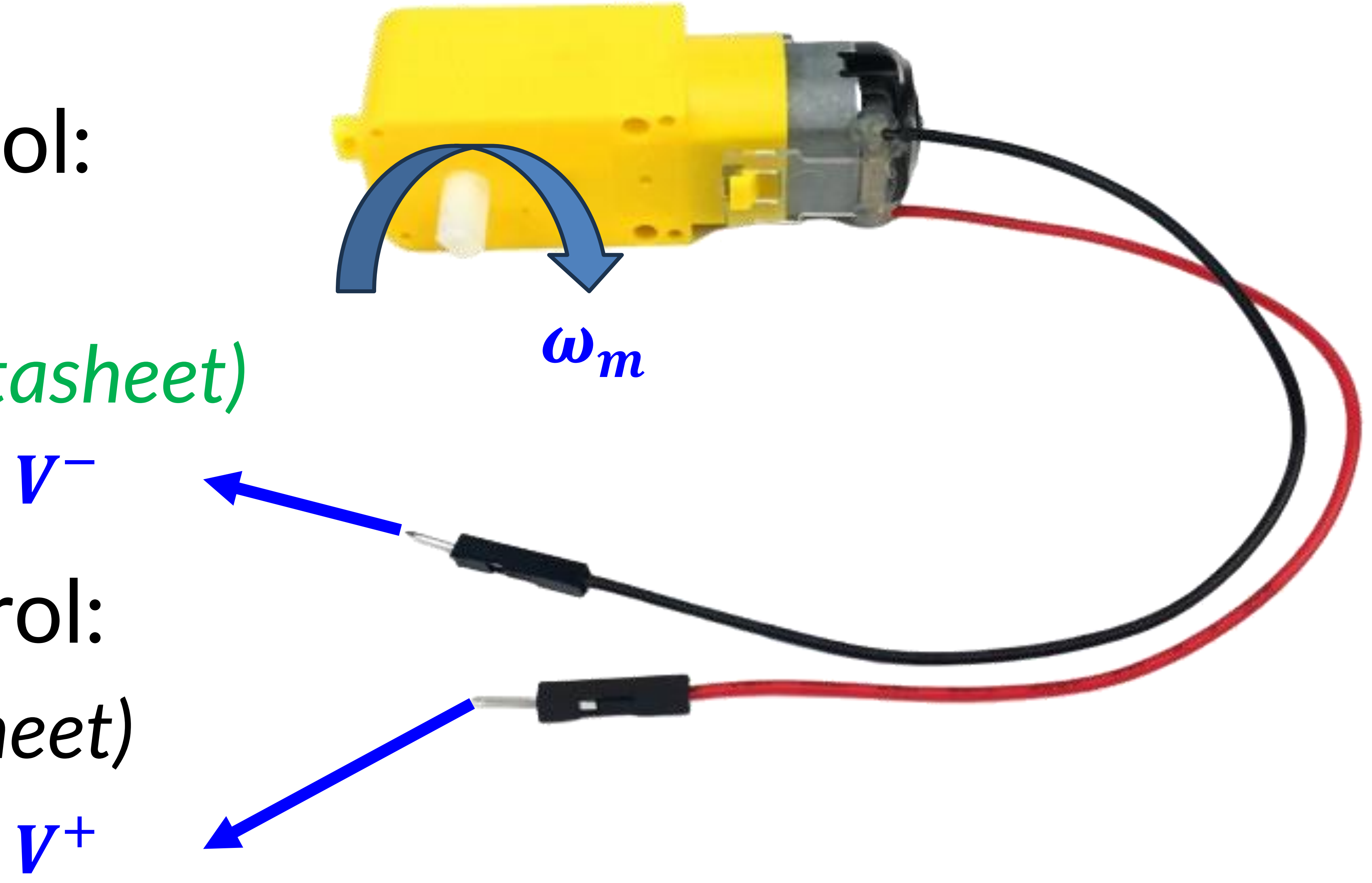


Mechanical Actuators
(mech. Rot. to mechanical translation)

- Levers and Linkages
- Screw Jacks

DC Motor: Connection with µC

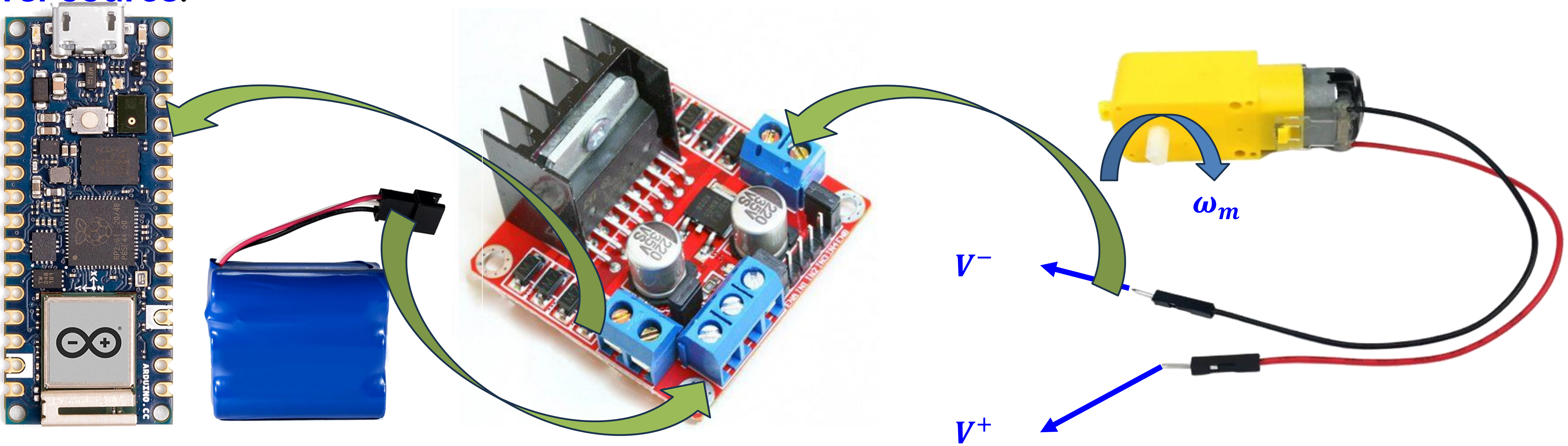
- It is an analog electric actuator that converts electrical energy into mechanical rotary motion.
- It has 2 wires $\boldsymbol{V^{-}}$ and $\boldsymbol{V^{+}}$.
- By changing the **voltage** given to the motor, you can control:
  1. Direction of rotation (CW or CCW)
  2. Speed of rotation $\omega_m = K_v \times V_m$ *(K_v is voltage constant → datasheet)*



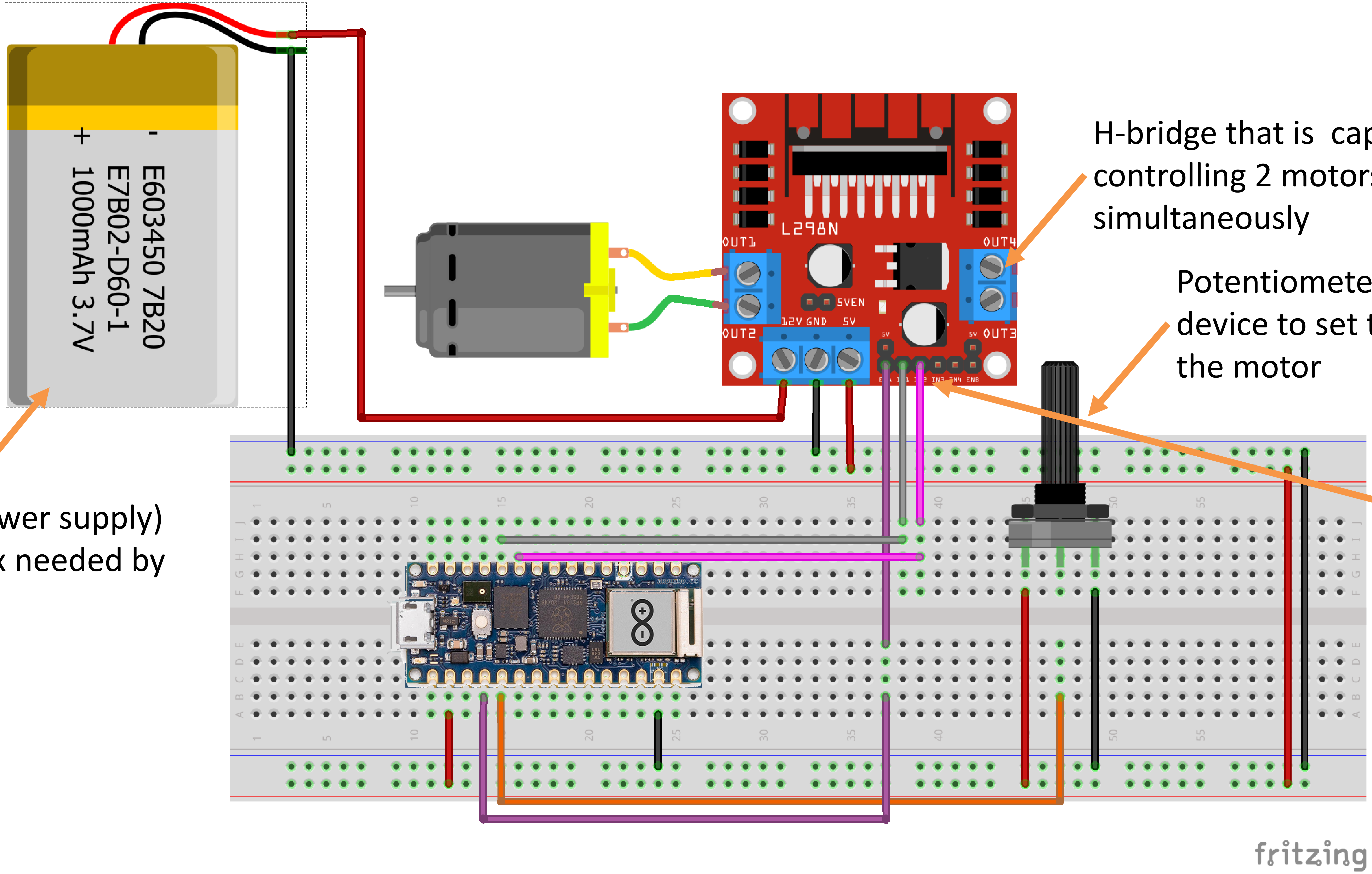
- By changing the **Current** given to the motor, you can control:
  1. Torque produced $\tau_m = K_\tau \times I$ *(K_τ is torque constant → datasheet)*

DC Motor: Connection with µC

- Usually, a DC motor works in **high maximum voltage** and drain **high current**.
- Therefore, we do **NOT** connect our DC motor directly to the microcontroller for its protection.
- Instead, an extra intermediate component is used known as an **H-Bridge** with **an external power source**.



DC Motor: Connection with µC



H-bridge that is capable of controlling 2 motors simultaneously

Potentiometer that is used as input device to set the desired speed of the motor

External battery (power supply) that provides V_max needed by the motor

The three pins are used to control the rotation directions (2 digital) and speed (1 analog)

D1	D2	OUT
0	0	Brake
0	1	CW
1	0	CCW
1	1	Brake

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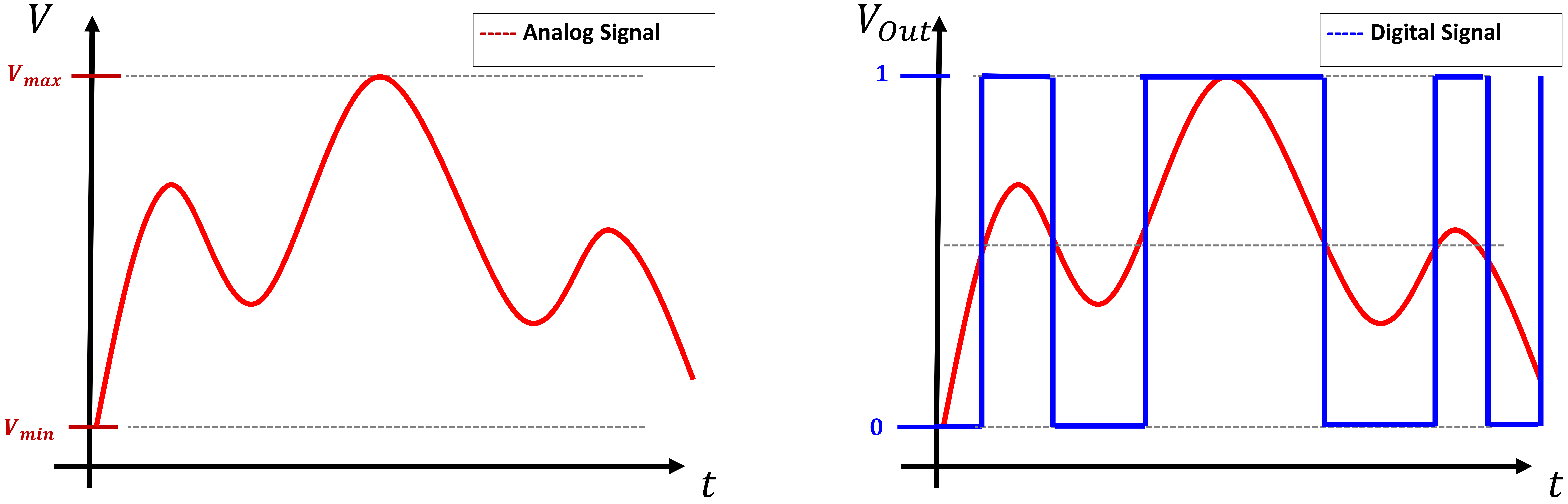
DC Motor: Speed Control

Note that: 0 means V_{min} and 1 means V_{max} as per the quantization concept.
Note that: the signal is also sampled in the time domain

- As previously mentioned, in order to change the speed of the motor ω_m, we should change the motor voltage V_m.
- But before we do that, let's again remember the signals concept:

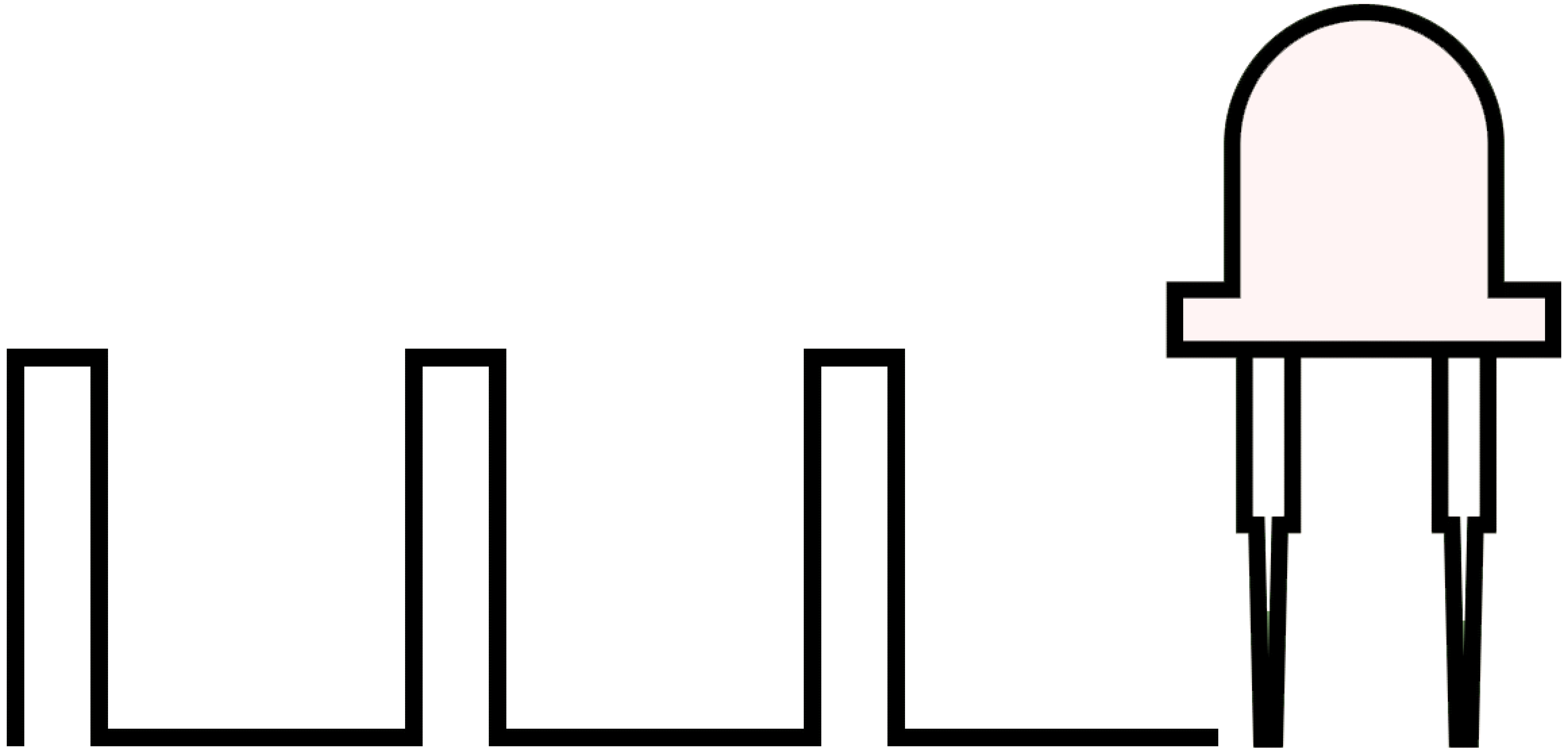


DC Motor: Speed Control

- In order to control the motor, a third type of signals has been introduced as a **hybrid** between the analog and digital signals.
- This signal type is known as the ***Pulse Width Modulation (PWM)***

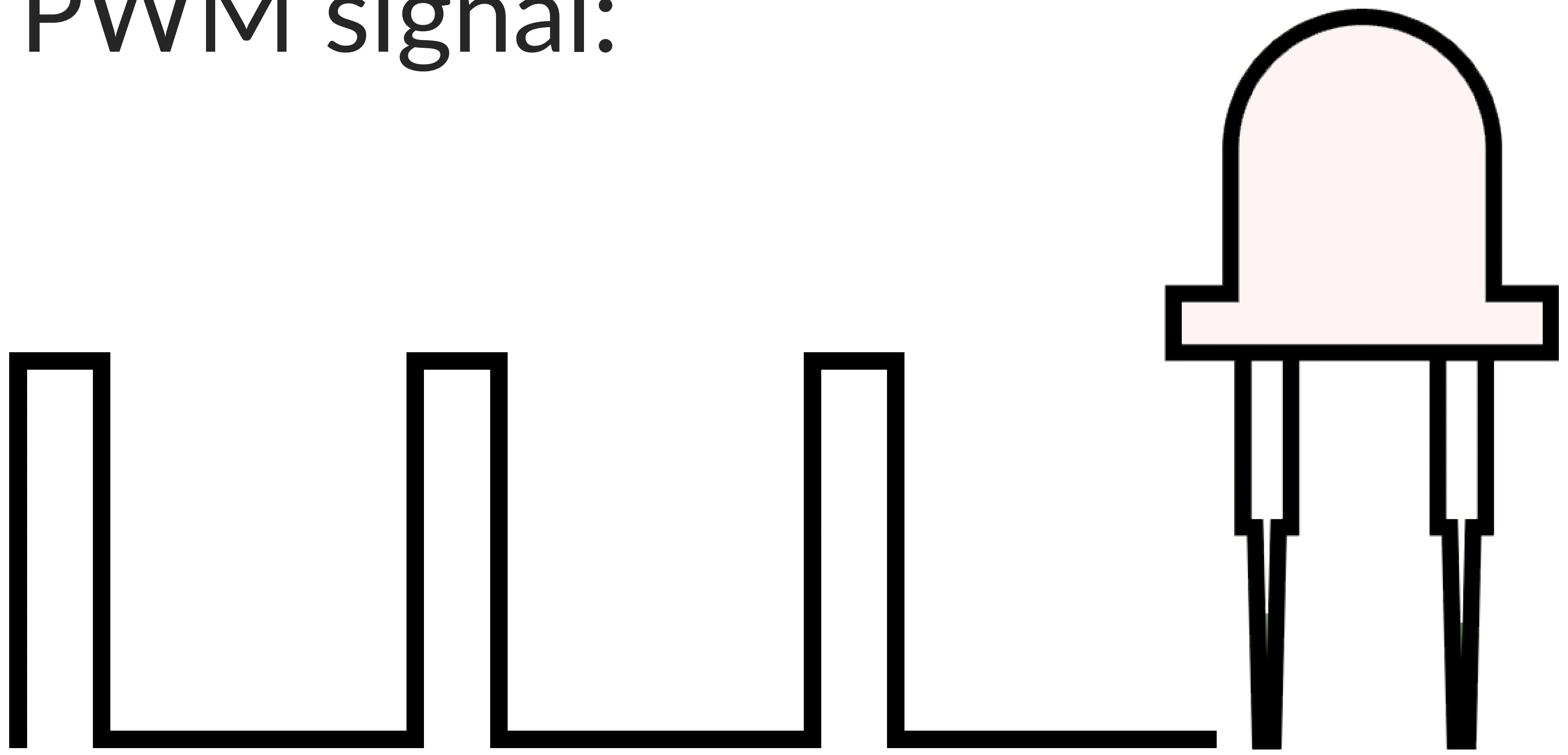
Pulse Width Modulation (PWM)

- The PWM is a digital signal that has a response of a digital one.
- That means we are generating a sequence of ones and zeros pulses yet we can get the effect of ranging the voltage from V_{min} to V_{max}.
- These pulses are generated for different time intervals and that what gives us the analog effect.



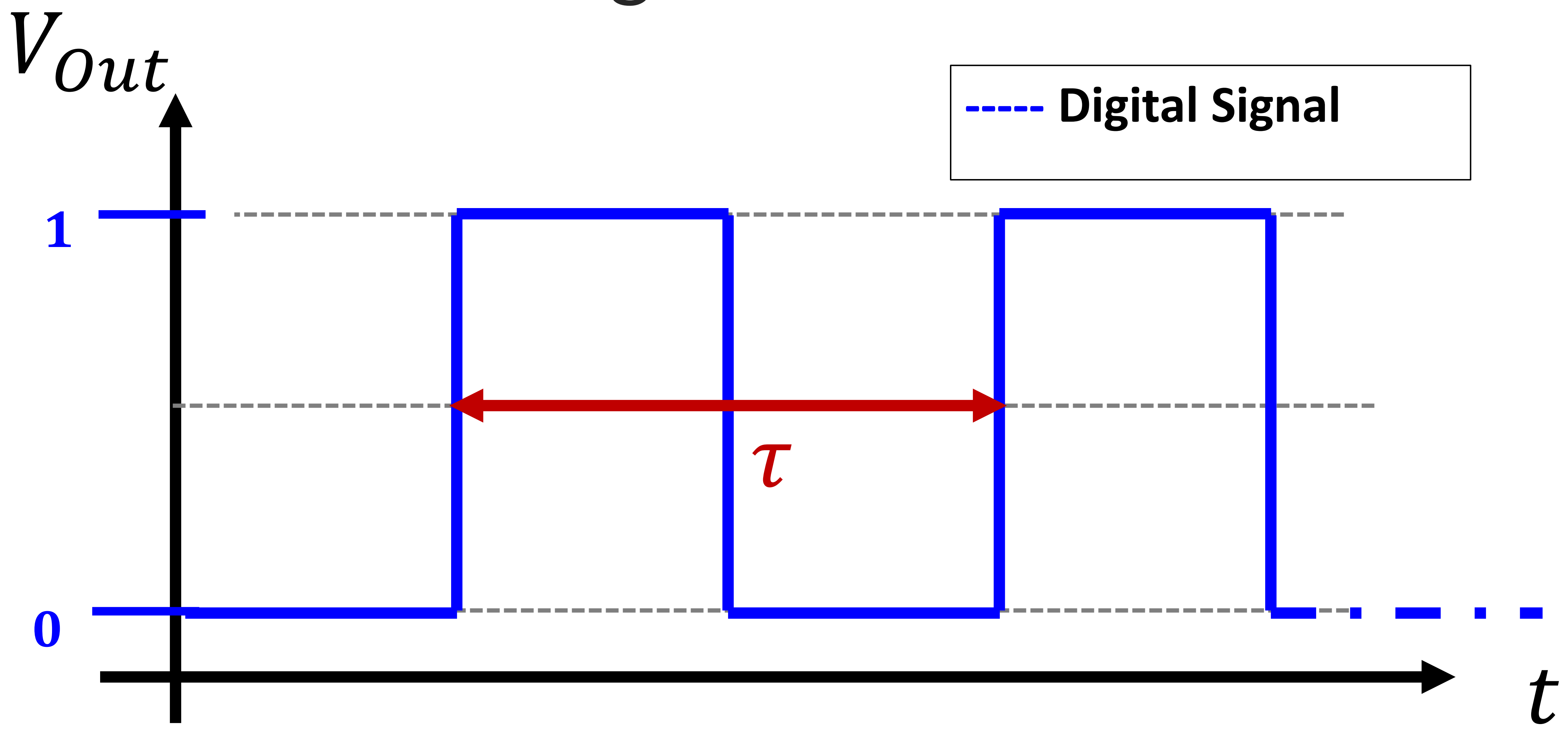
Pulse Width Modulation (PWM): Parameters

- There are three important parameters associated with PWM signal:
  - ➢ Duty Cycle of PWM
  - ➢ Frequency of PWM
  - ➢ Output Voltage of PWM signal



Pulse Width Modulation (PWM): Frequency

- The frequency of PWM determines how fast a PWM completes a period.
- The frequency of a pulse is shown in the figure above.



- The frequency of PWM can be calculated as follows:

$$Time\ Period\ (\tau) = Time\_ON + Time\_OFF$$

$$Frequency = \frac{1}{Time\ Period\ (\tau)}$$

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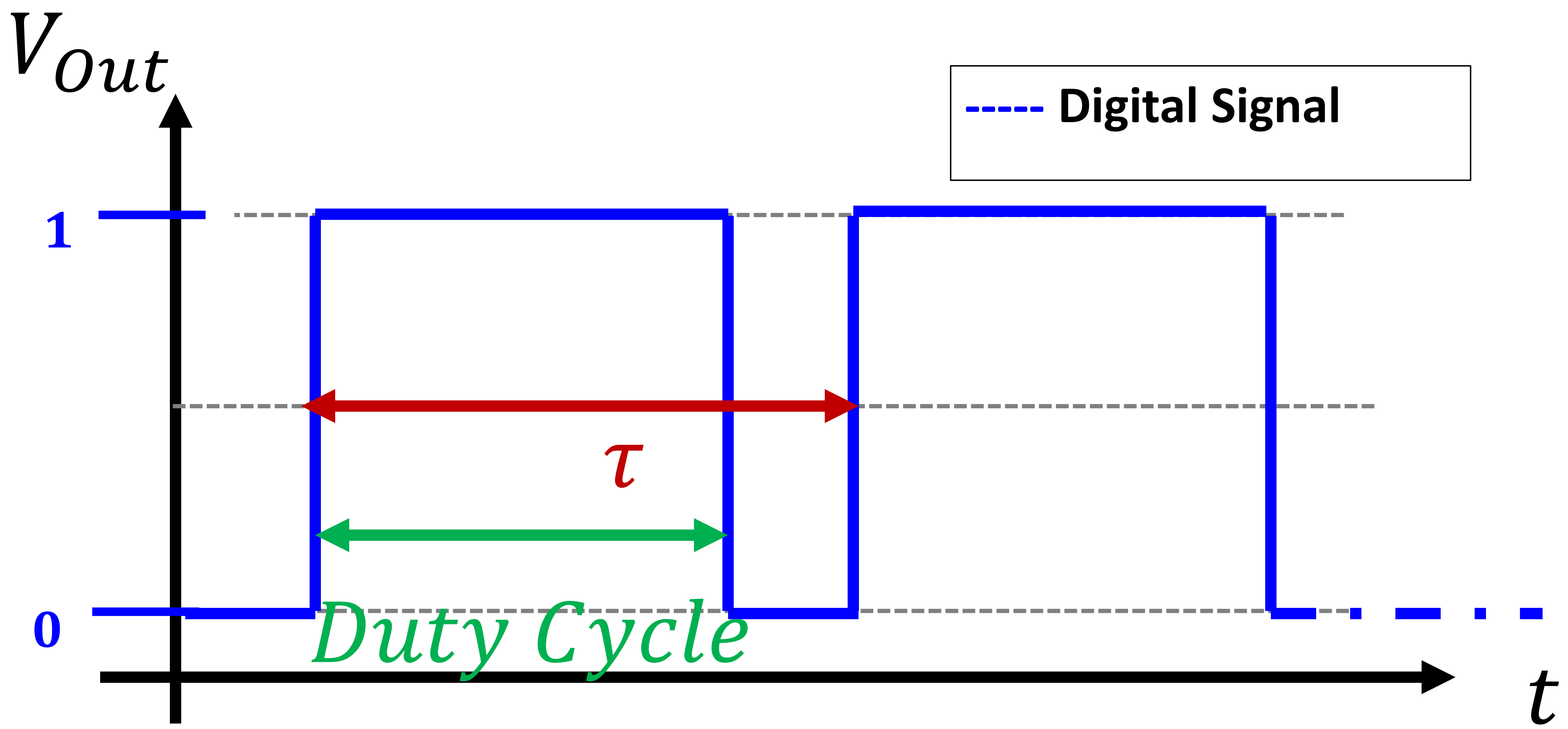
Pulse Width Modulation (PWM): Duty Cycle

- The percentage of time for which the signal remains “ON” is known as the **duty cycle**.



- If the signal is always “ON,” then the signal must have a 100 % duty cycle.
- The formula to calculate the duty cycle is given as follows:

$$Duty\ Cycle(\%) = \frac{Time\_ON}{Time\_ON + Time\_OFF}$$

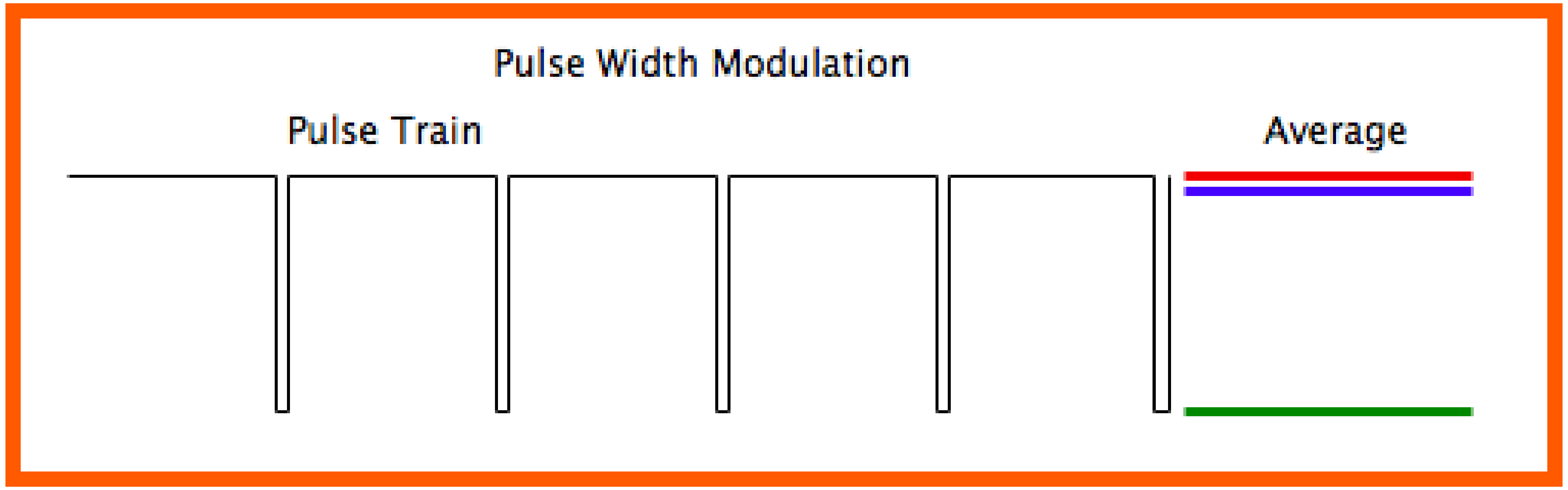
- The average value of the voltage depends on the duty cycle.

Pulse Width Modulation (PWM): Output Voltage

- The output voltage of the PWM signal will be **the percentage of the duty cycle.**

$$V_{Out} = V_{max} \times Duty\ Cycle(\%)$$

- For example
  - ➢For a 100% duty cycle, if the operating voltage is 5 V then the output voltage will also be 5 V.
  - ➢If the duty cycle is 50%, then the output voltage will be 2.5 V.
  - ➢If the duty cycle is 25%, then the output voltage will be 1.25 V.



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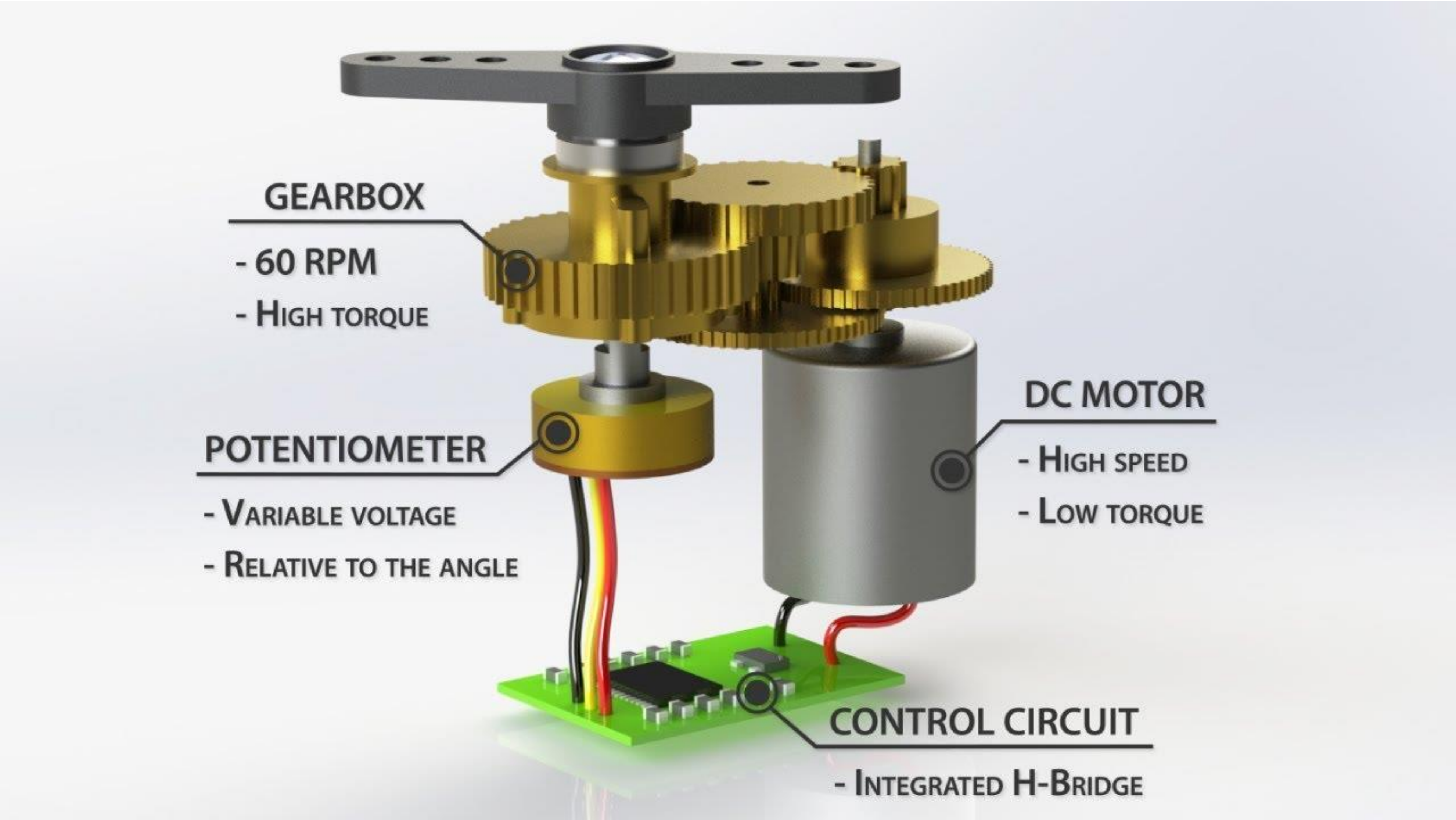
Servo Motor

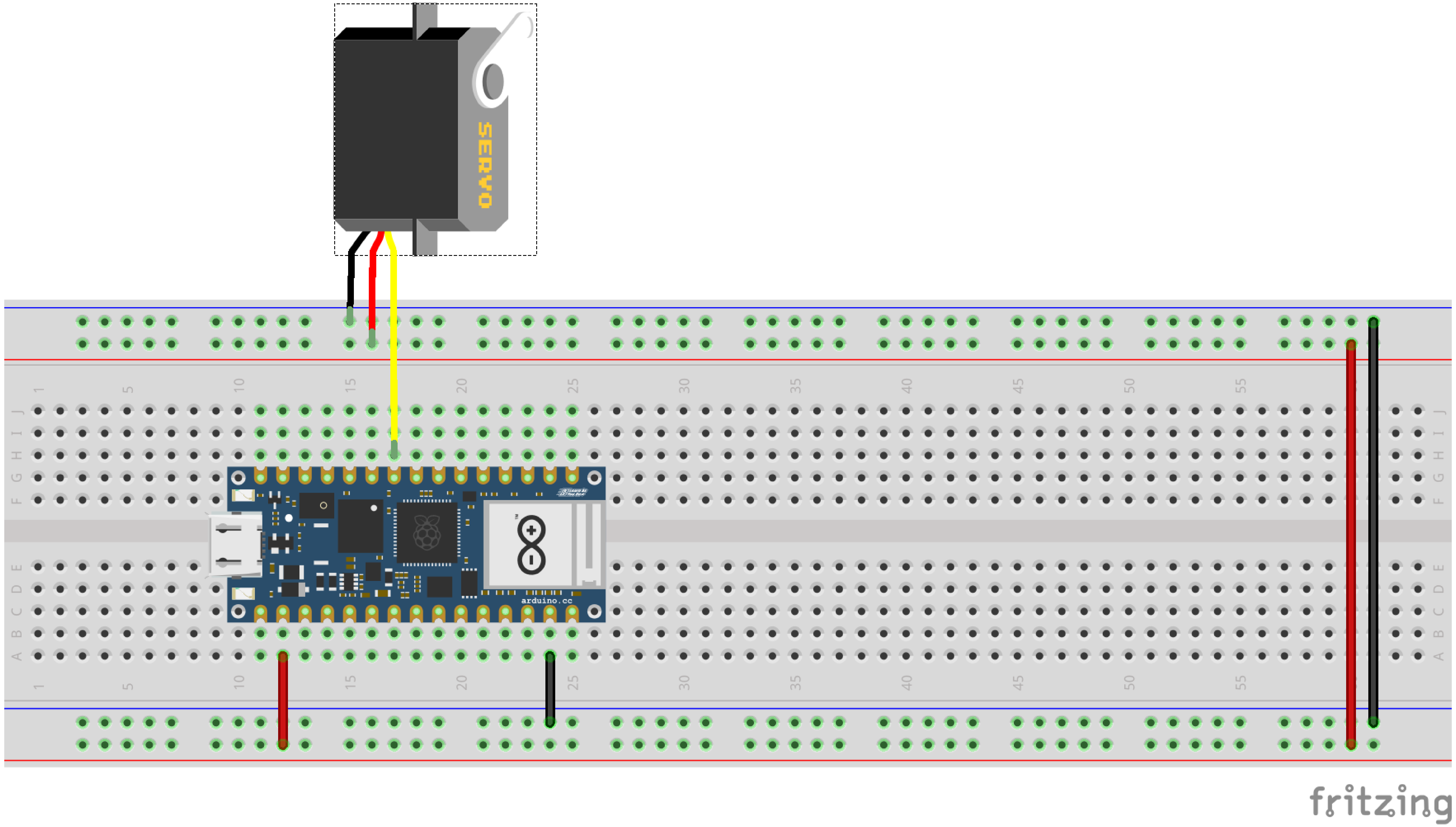
- A servo motor is a type of electric motor that is designed for precise control of position, speed, and acceleration.
- It is composed of a regular DC motor + a potentiometer for feedback on the current angle + a control circuit with integrated H-bridge that can ensure that the motor is at a precise angle position.
- Servo motors are commonly used in various applications, especially those that require high precision and accuracy, such as robotics, automation, CNC machinery, and remote-controlled systems.



Servo Motor

- Some of the key features and characteristics of servo motors are:
  - **Closed-Loop Control:** Servo motors are typically used in closed-loop control systems, which means they are equipped with feedback devices like encoders or resolvers.
    These feedback devices continuously monitor the motor's actual position and provide feedback to the control system.
    This allows the control system to make real-time adjustments to ensure the motor reaches and maintains the desired position or speed.
  - **Precise Position Control:** Servo motors are known for their exceptional precision when it comes to positioning.
    They can move to a specific angle or position with great accuracy, often down to fractions of a degree.

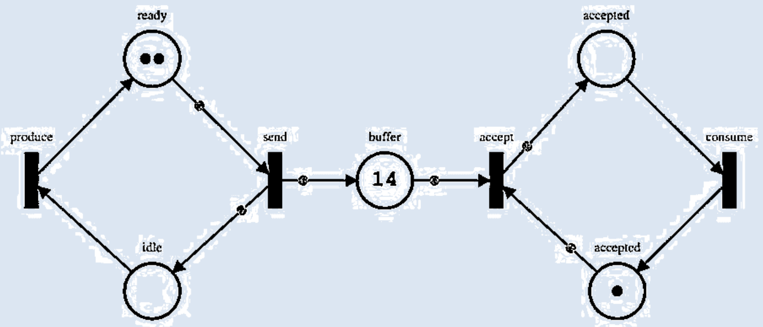
Servo Motor: Connection with µC



The big Picture

ES Modeling & Design
(*2 Modules*)

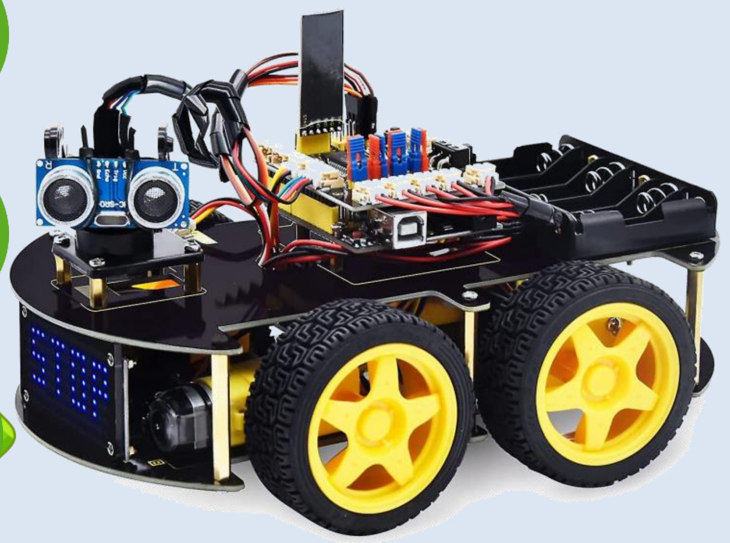
- System Modeling — Let's go
- Design Considerations
- Power management and optimization
- Reliability and fault tolerance



The Real-time Embedded System

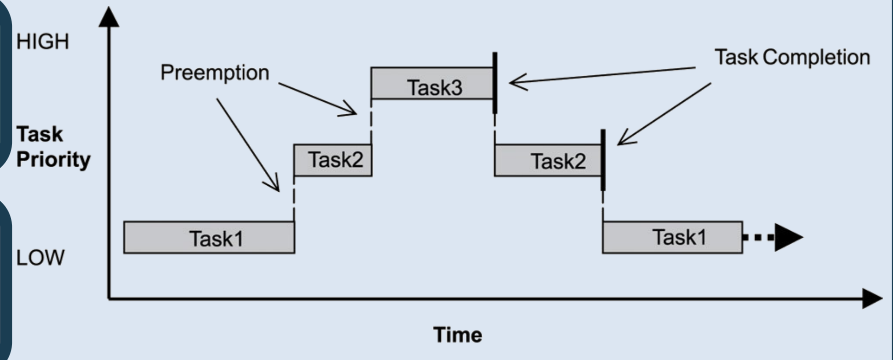
ES Hardware Components
(*4 Modules*)

- Microcontroller Fundamentals
- Embedded programming languages
- Embedded Hardware
- Communication and Networking



ES Software Components
(*1 Module*)

- Real-Time Systems
- Multi-tasking
- Scheduling
- Resource Management



Embedded System Tools & Software Development
(*2 Modules*)

- Debugging techniques
- Interrupts and exception handling
- Memory management

For Further Inquiries, Please send an email

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Thank you for your attention!

See you next time ☺