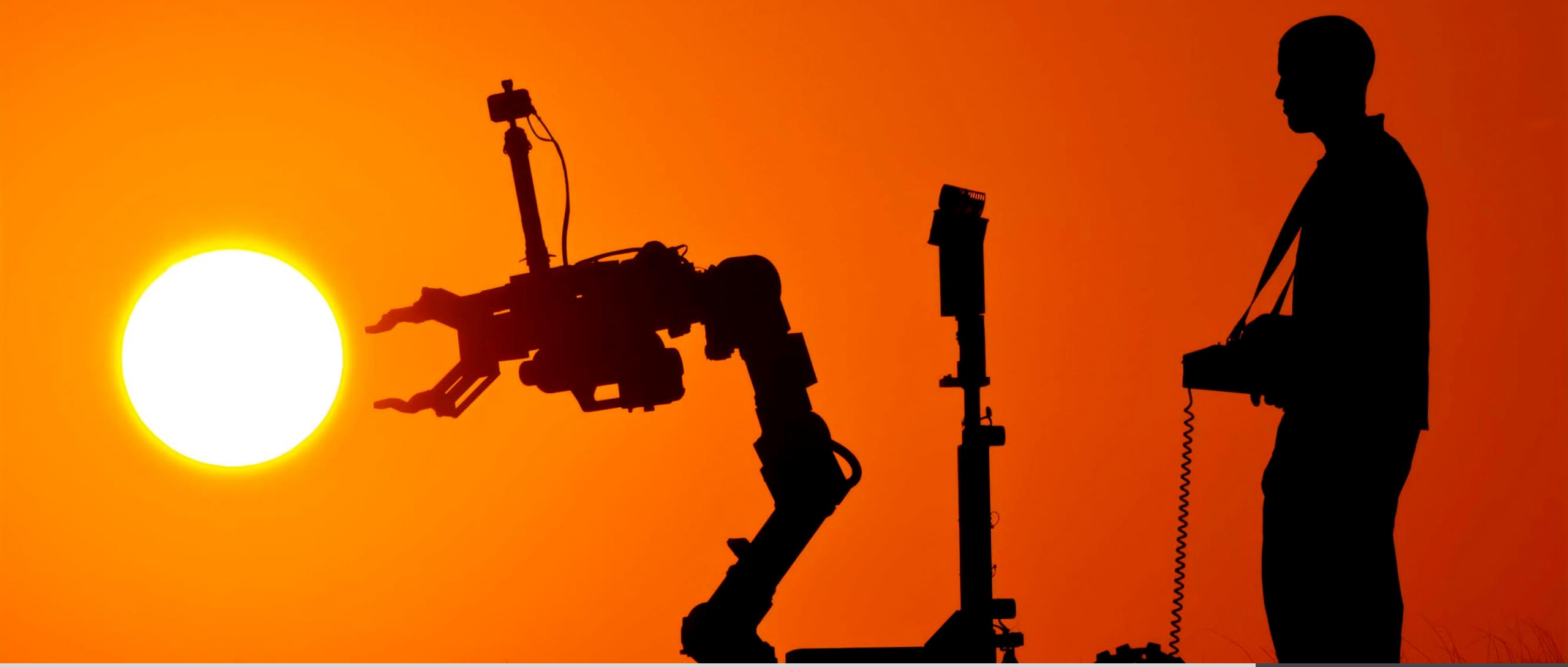


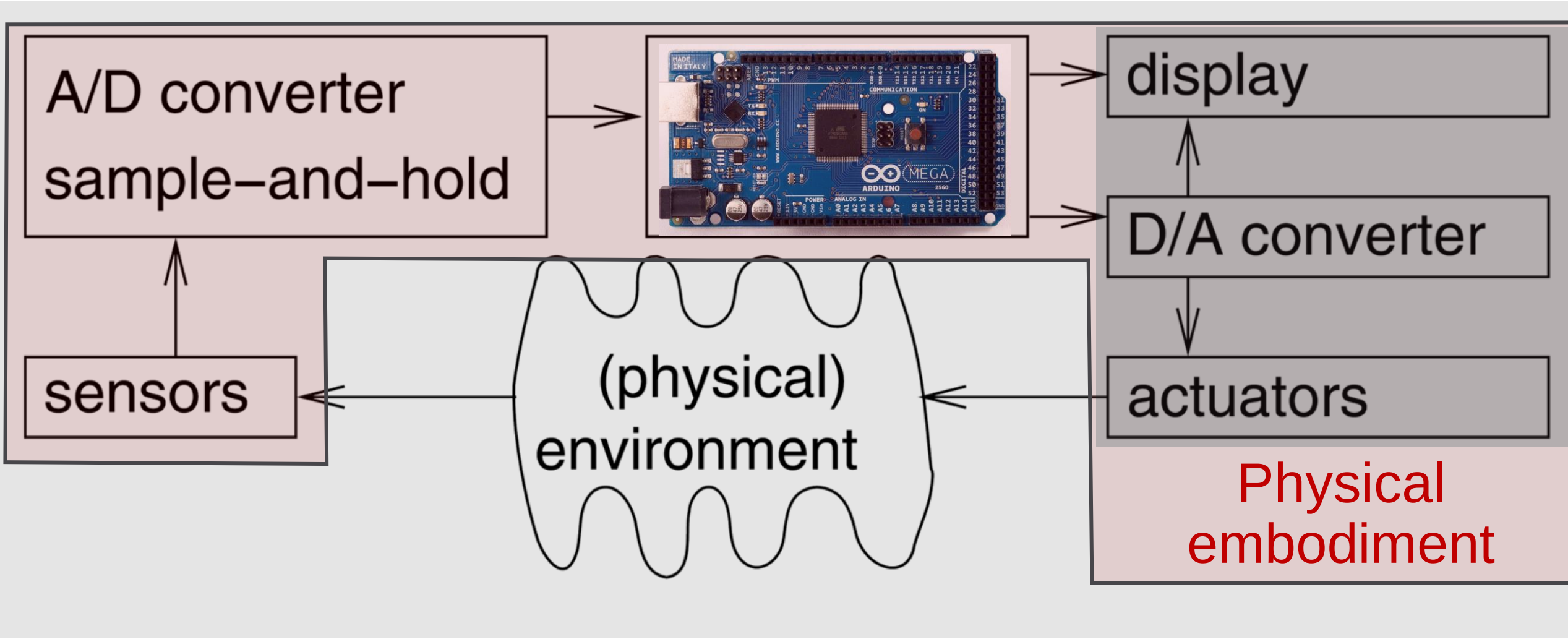
Actuators and electric motors

GIZMO

2021 DE2-Gizmo (Physical Computing)
Lecture 4

v1.0 – N Rojas

Dyson School of Design Engineering



(Extended) Hardware in the Loop

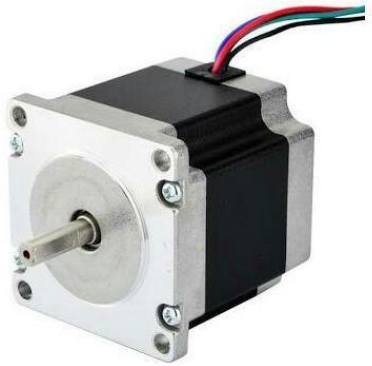
Actuators

An actuator is a device that transforms an electrical signal into a stimulus in a physical system

The variety of available actuators is enormous. Some common examples:

- LEDs
- DC motors
- Stepper motors
- Servos
- Smart servos

Brushed DC Motor



Stepper Motor

Servo Motor

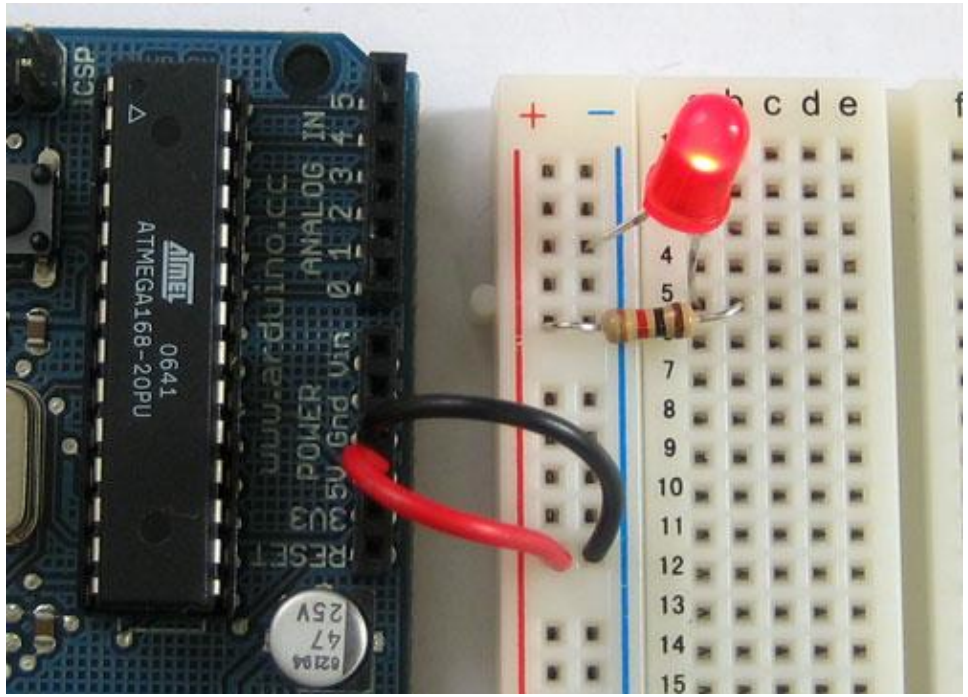
Light-Emitting Diodes (LEDs)

Very few actuators can be driven directly from the digital I/O pins of a microcontroller

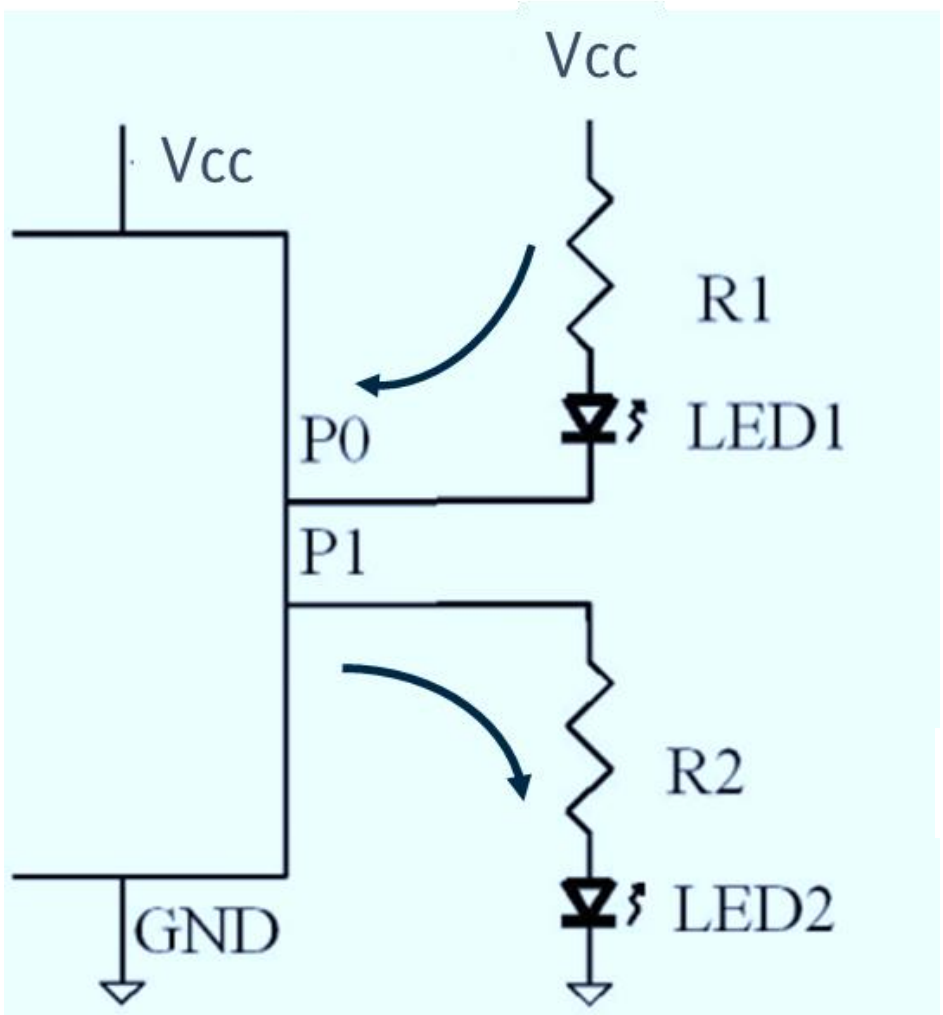
These pins can source or sink a limited amount of current

One exception is LEDs

Put in series with a resistor, can often be connected directly to an I/O pin



Light-Emitting Diodes (LEDs)



Sink

Source

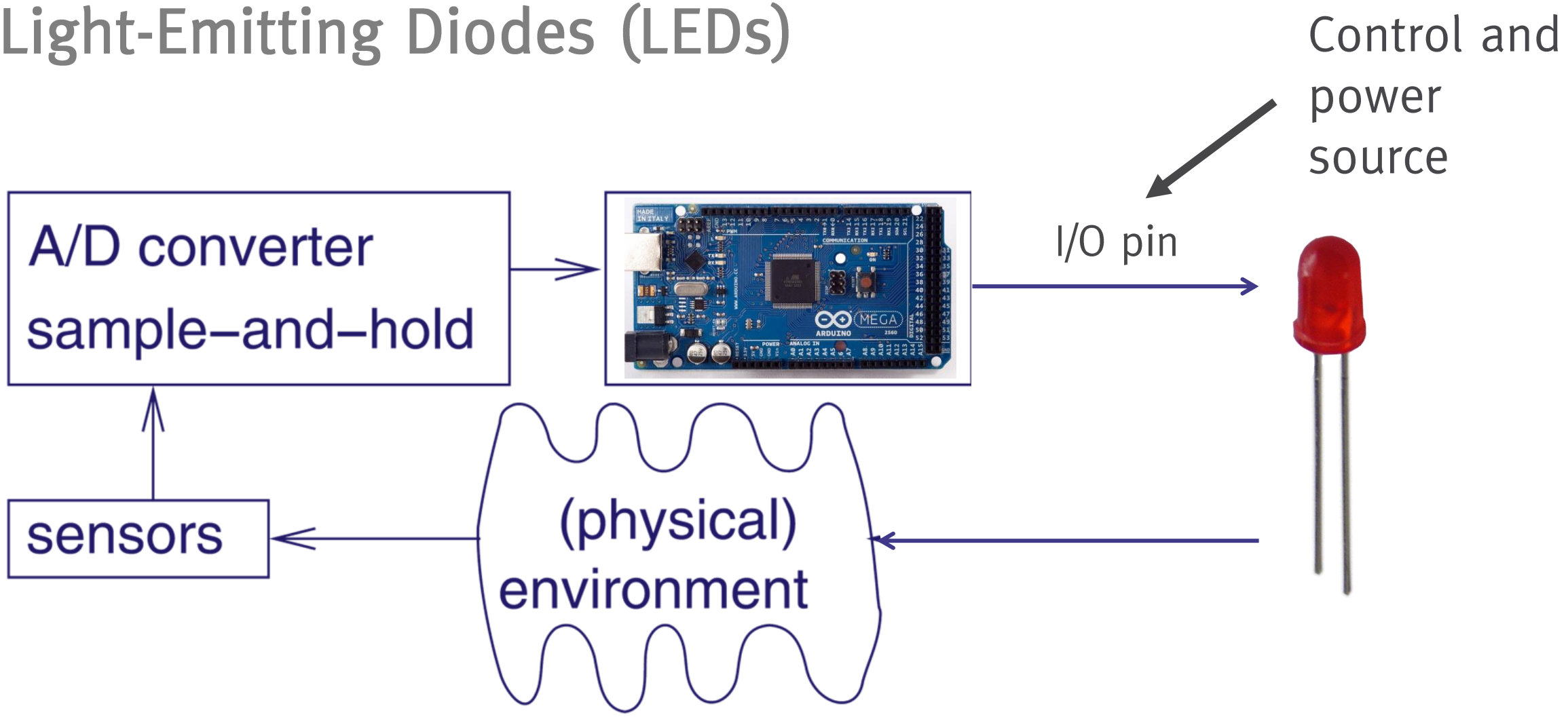
Example: *microcontroller operates at 3V and I/O pins can sink up to 18 mA*

Smallest resistor?

$$R \geq \frac{Vcc - V_{dropLED}}{I_{pin}}$$

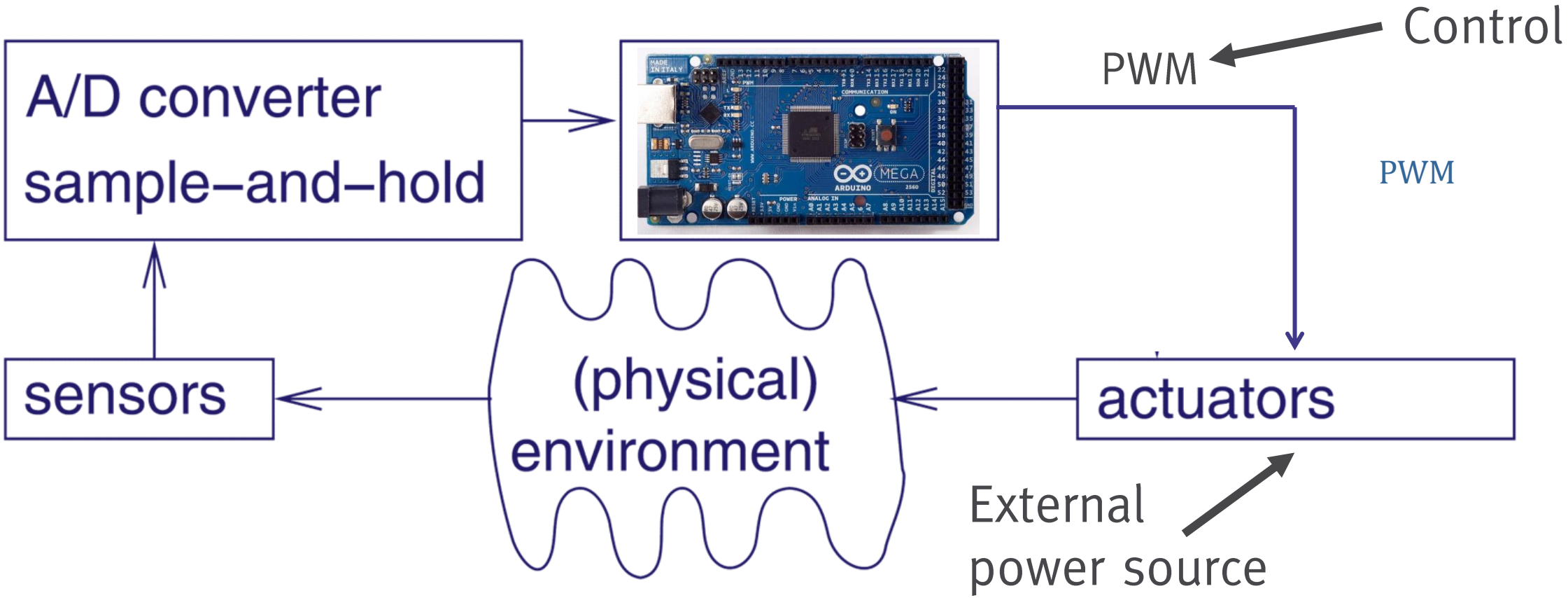
$$R \geq \frac{3 - 2}{0.018} \approx 56\ \Omega$$

Light-Emitting Diodes (LEDs)



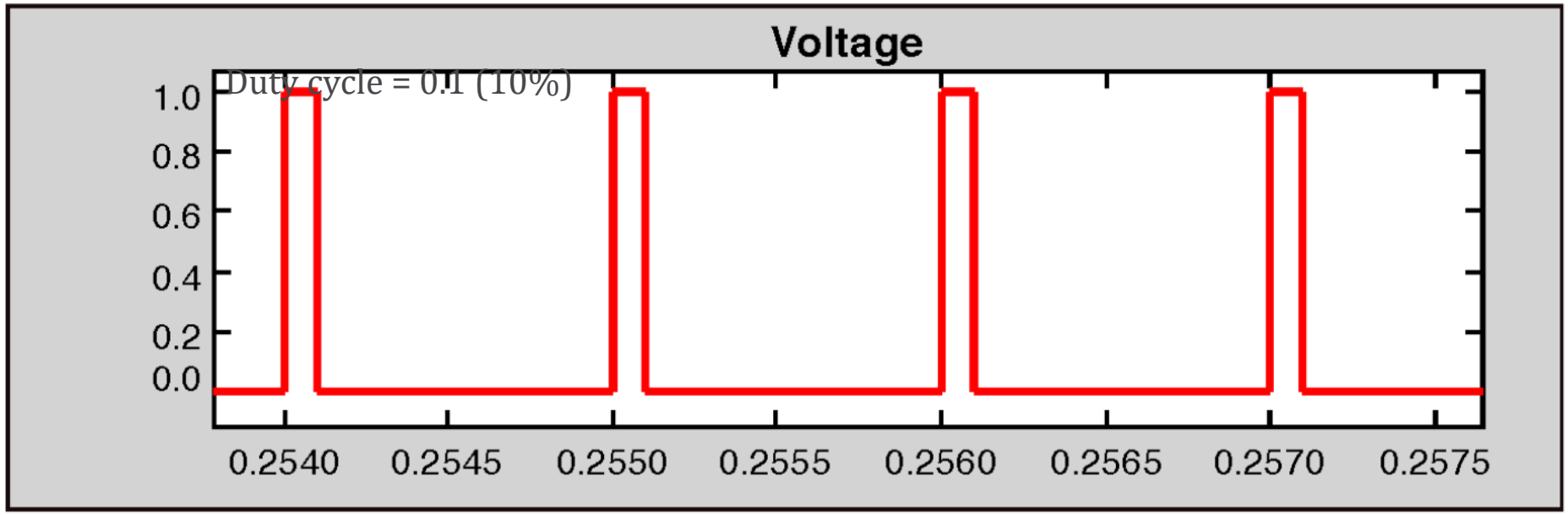
Pulse Width Modulation (PWM)

For some actuators, it is possible to use a switch that we can turn on and off *very fast* with a digital signal from a microcontroller



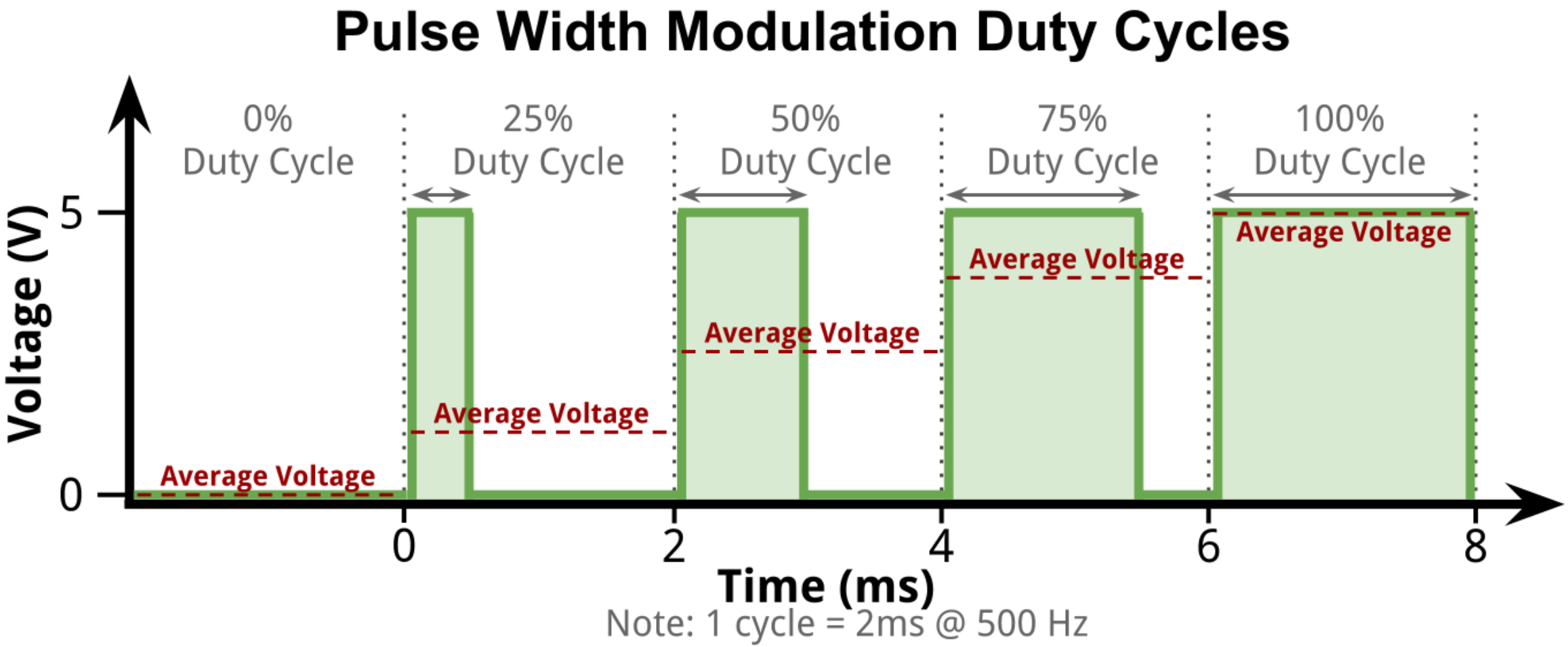
Pulse Width Modulation (PWM)

A PWM signal switches between a high level and a low level at a specified frequency. It holds the signal high for a fraction of the cycle period. This fraction is called the **duty cycle**



Microcontrollers have special modes and output ports to support this operation

Pulse Width Modulation (PWM)



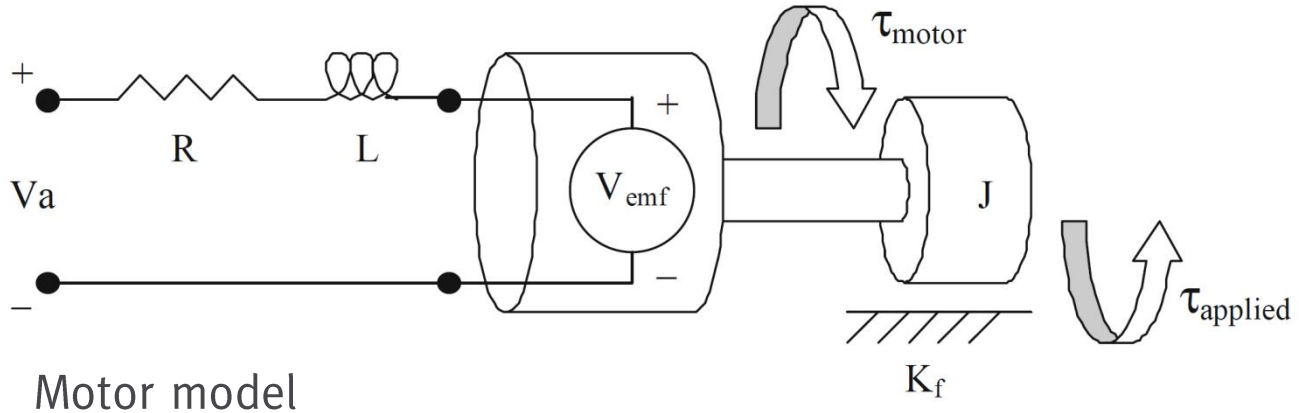
Pulse Width Modulation (PWM)

PWM can efficiently deliver large amounts of power under digital control, **if the device to which the power is being delivered can tolerate rapidly switching on and off its power source.** Devices that tolerate this include:

- LEDs
- Incandescent lamps
- **DC motors**
- **Stepper motors**
- **Servos**

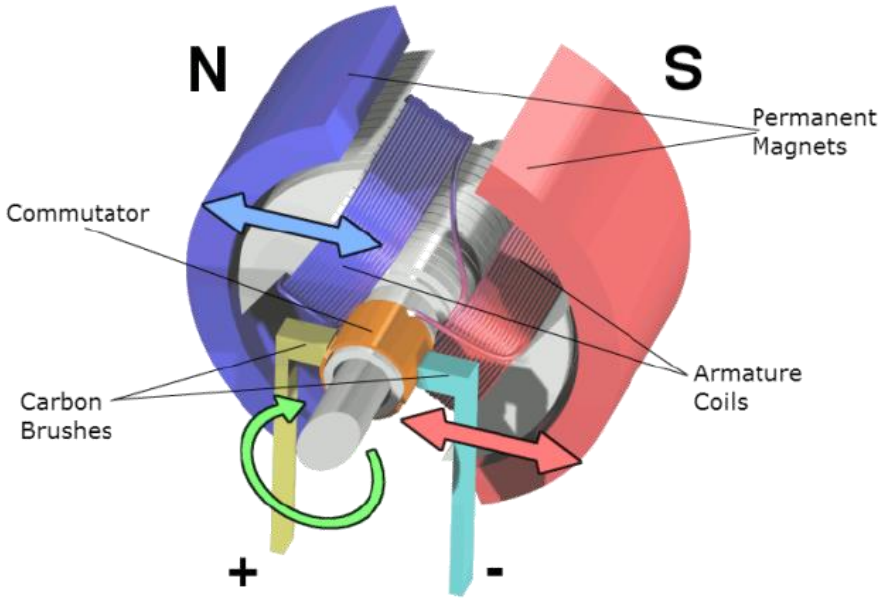
DC Motors

Consist of an electromagnet placed in a magnetic field made with permanent magnets or electromagnets. When current flows through the wires, the core spins. Two types: *brushed* and *brushless*



Motor model

θ	Angular position of shaft, rad	R	Nominal terminal resistance, Ω
ω	Angular shaft velocity, rad/s	L	Rotor inductance, H
α	Angular shaft accel., rad/s^2	J	Rotor inertia, kg·m^2
i	Current through armature, A	K_f	Frictional const., N·m·s / rad
V_a	Applied terminal voltage, V	K_m	Torque constant, N·m / A
V_e	Back *emf* voltage, V	K_e	Back *emf* constant, V·s / rad
τ_m	Motor torque, N·m	K_s	Speed constant, rad / (V·s)
τ_a	Applied torque (load), N·m	K_r	Regulation constant, (V·s) / rad



Inside conventional DC brushed motor

DC Motors

Brushed DC Motor

Advantages:

- Cheapest and simplest motor
- Speed linear to supply voltage
- Simple motor control

Disadvantages:

- High maintenance
- Low life span (due to wear on brushes)

Brushed DC Motor – How it works (video)

DC Motors

Brushless DC Motor

Advantages:

- High efficiency
- Little maintenance & long life
- High power output for size

Disadvantages:

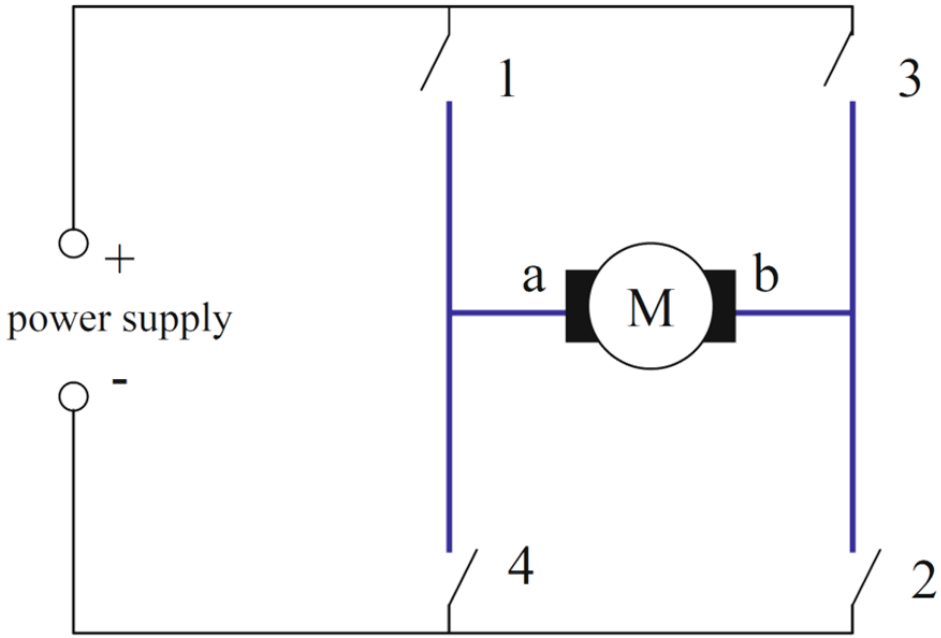
- (Further) extra electronics for control
- Higher initial cost

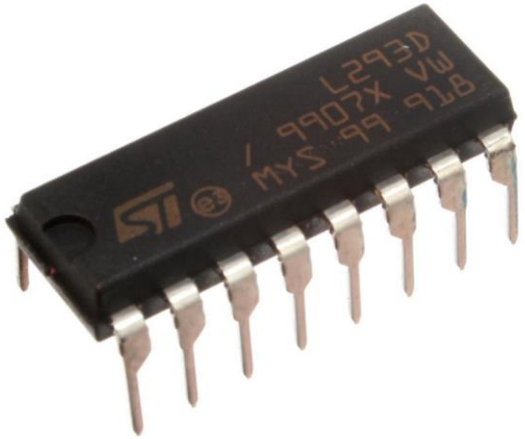
Brushless DC Motor – How it works (video)

Control of DC Motors

H-Bridge

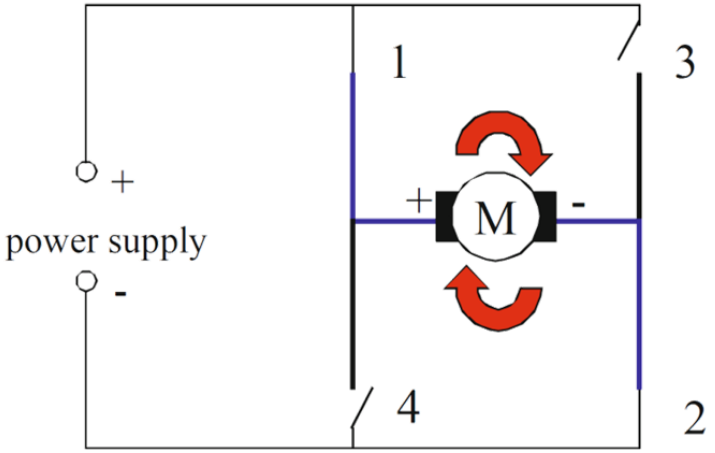
For running the motor in forward and backward directions



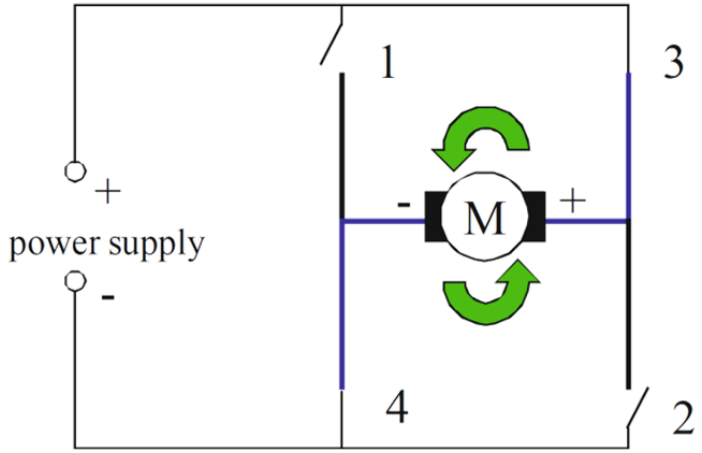


L293D
Quadruple half-H bridges

Drive forward:



Drive backward:

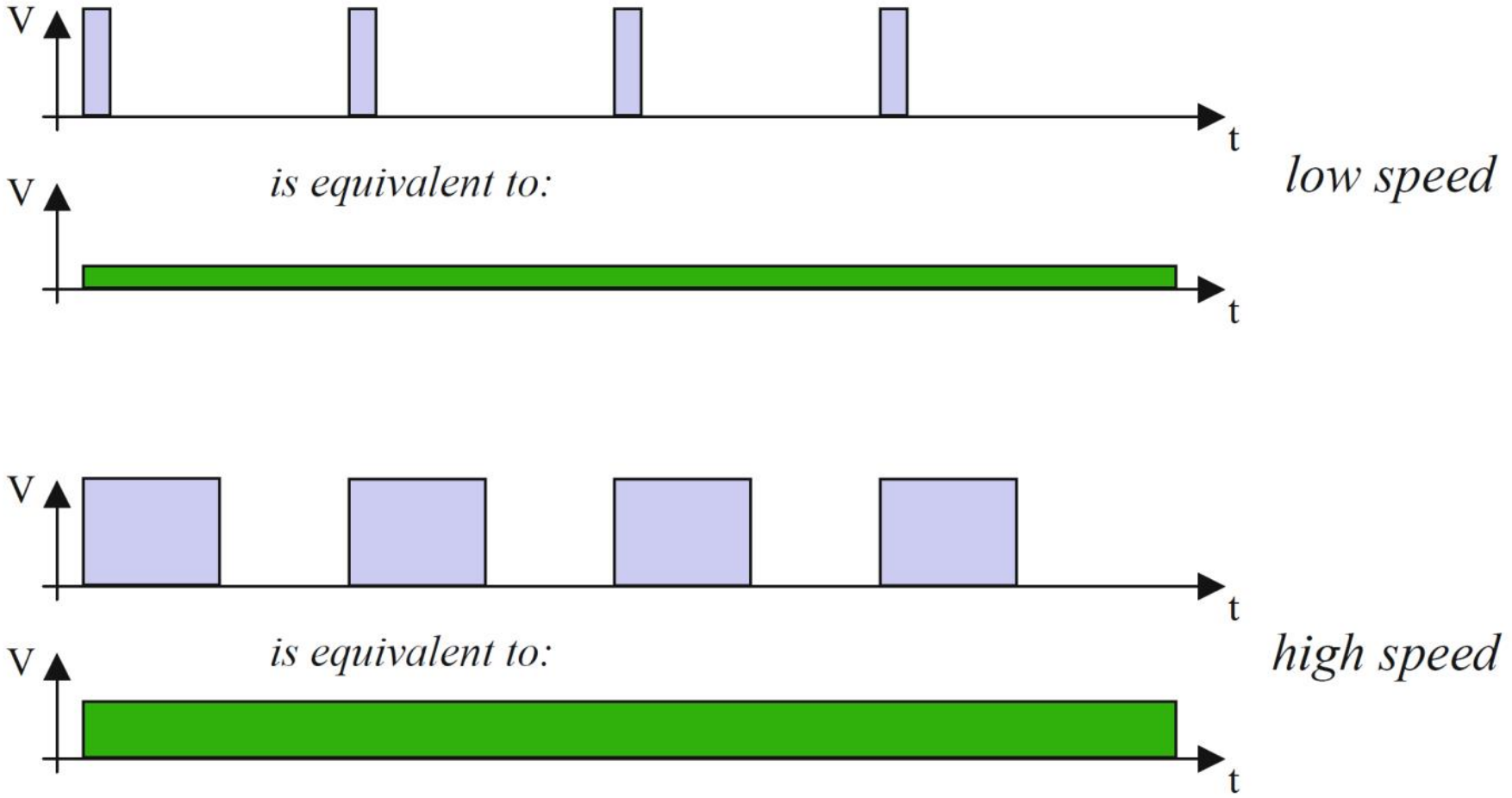


Control of DC Motors

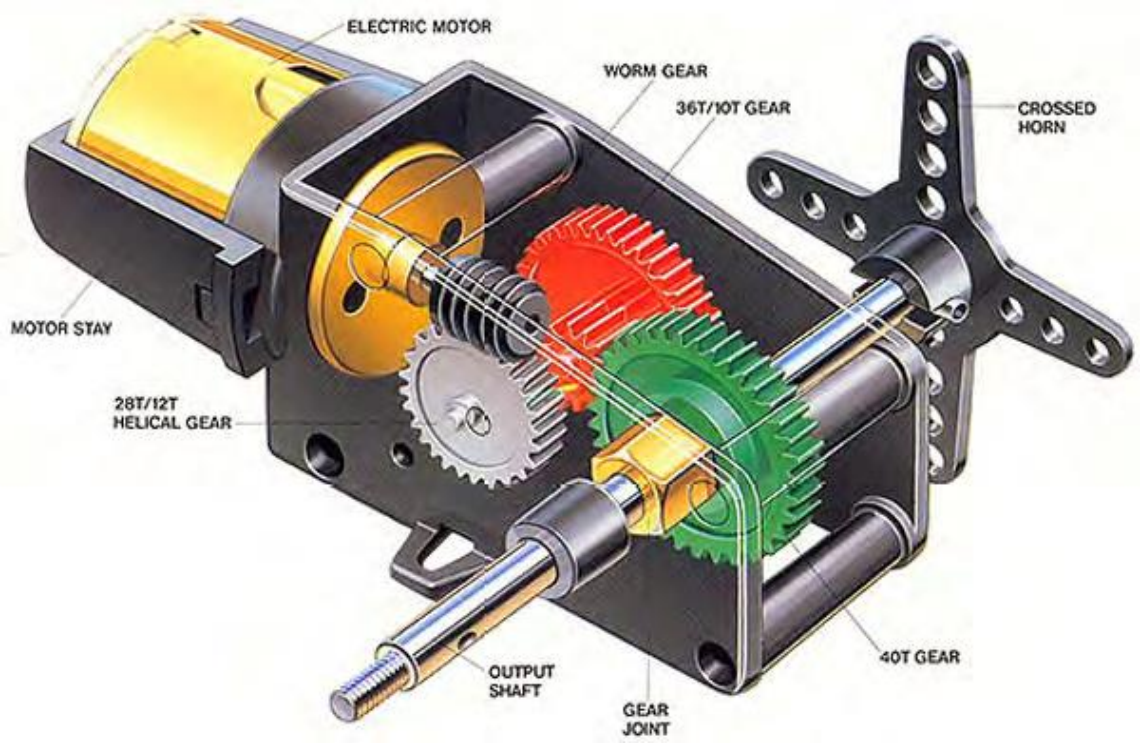
$$\begin{aligned}\bar{y} &= \frac{1}{T}\left(\int_0^{DT} y_{\max}\,dt + \int_{DT}^{T} y_{\min}\,dt\right)\\ &= \frac{1}{T}\left(D\cdot T\cdot y_{\max} + T\,(1-D)\,y_{\min}\right)\\ &= D\cdot y_{\max} + (1-D)\,y_{\min}\end{aligned}$$

PWM

For controlling the motor speed (instead of generating an analog output signal with a voltage proportional to the desired one)



Servos



- Servos != Servo motors: *high-quality DC motors.* Servo motors can handle fast changes in position, speed, and acceleration
- A **servo** is a DC motor with encapsulated electronics for PWM control
- The input pulse signal controls the position of the servo's rotating disk head

Servos

Advantages:

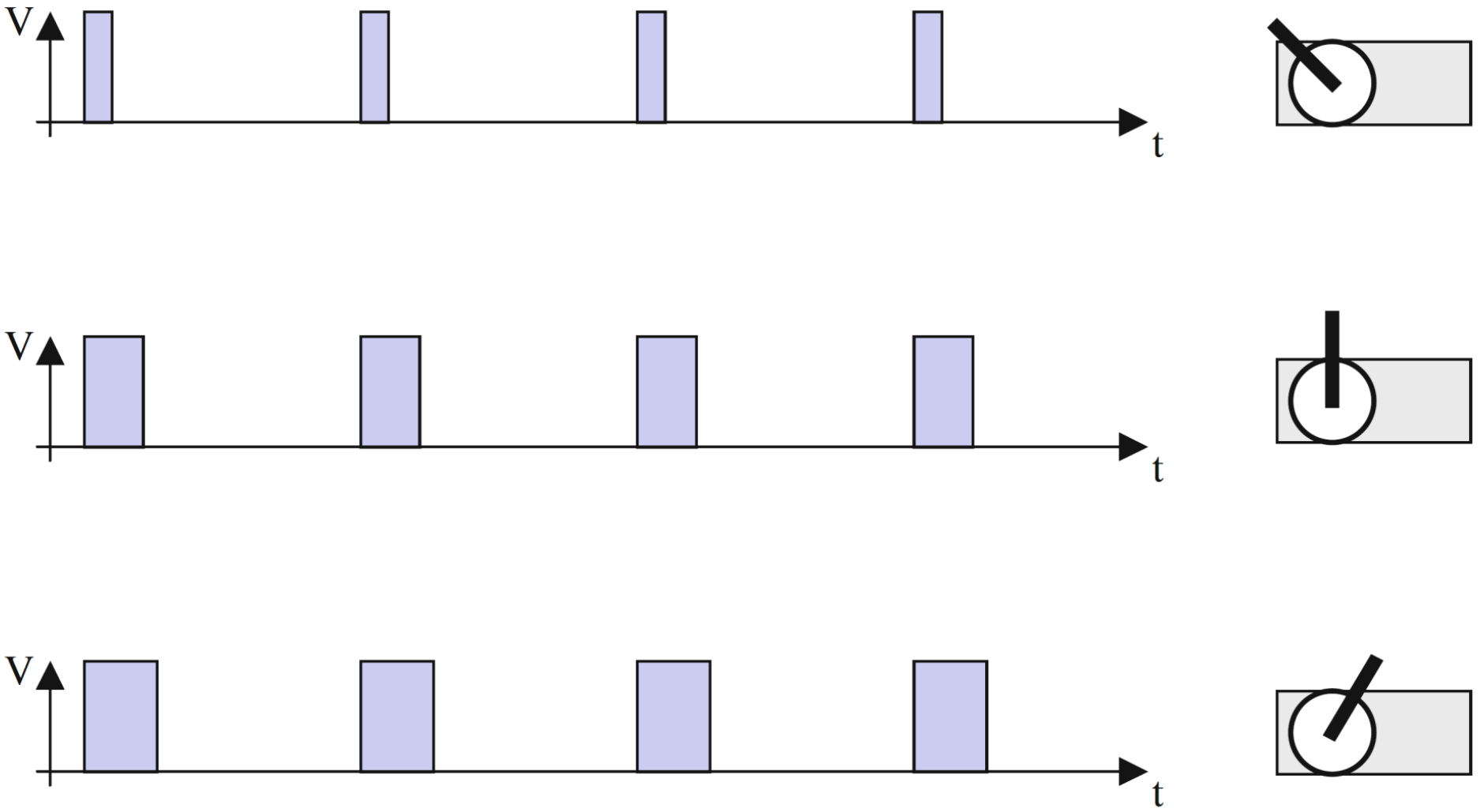
- Rapid speed variation in speed without overheating
- Simple position control

Disadvantages:

- Rotational position lags behind signal and ‘rocks’ back and forth when stopped so not suitable for precision control
- Higher cost

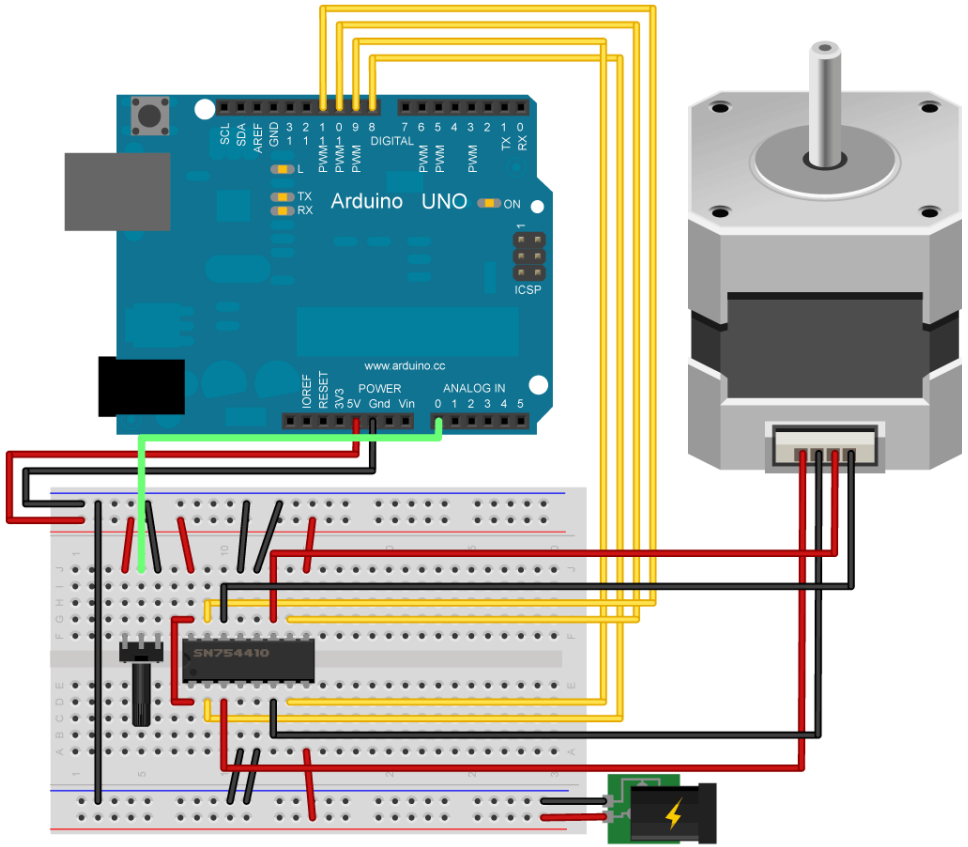
Servo – How it works (video)

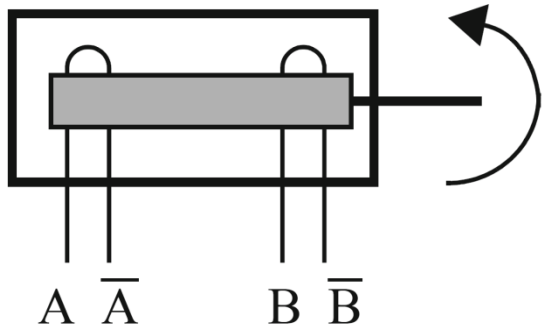
Control of Servos



Stepper Motors

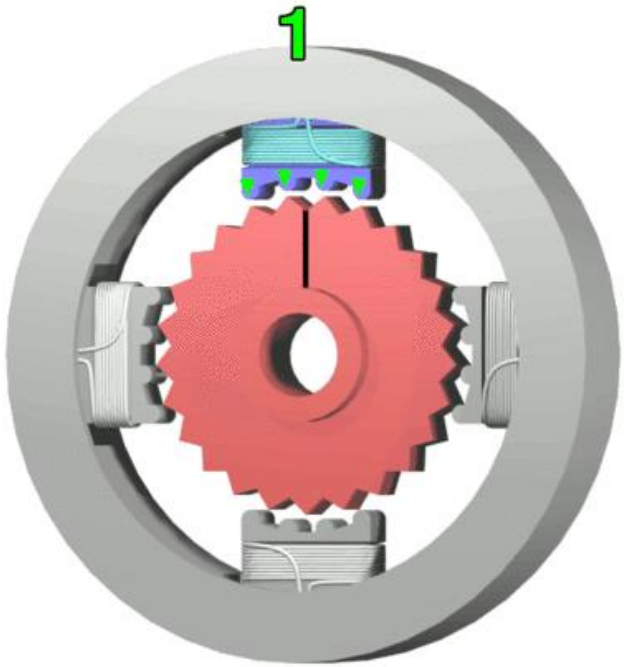
A stepper motor is a brushless DC motor that divides a full rotation into a number of steps





Switching Sequence:

Step	A	B
1	1	1
2	1	0
3	0	0
4	0	1



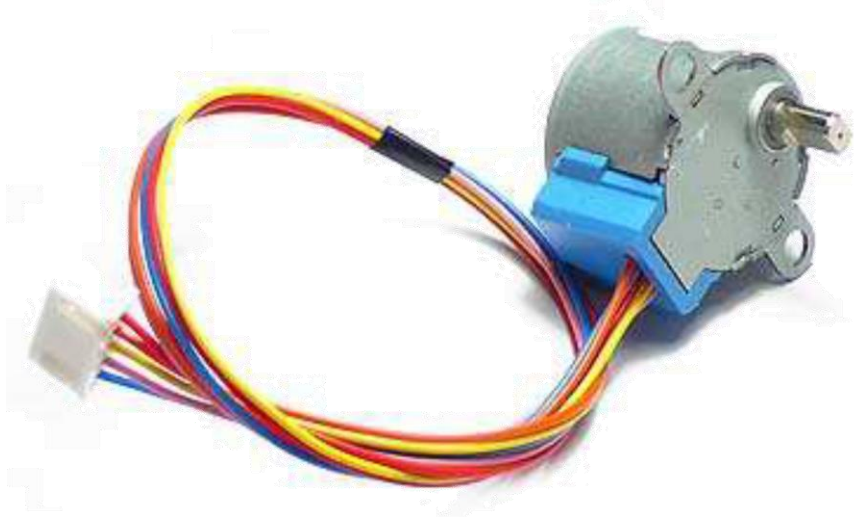
Stepper Motors

Advantages:

- Accurate position control
- Excellent low speed
- Long life

Disadvantages:

- Low efficiency
- Prone to resonances, noise, and torque ripple
- Cannot accelerate loads rapidly



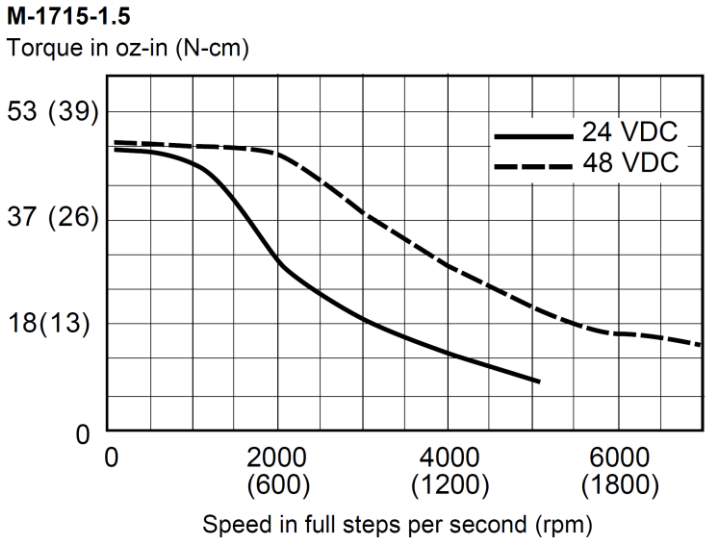
Stepper Motor – How it works
(video)

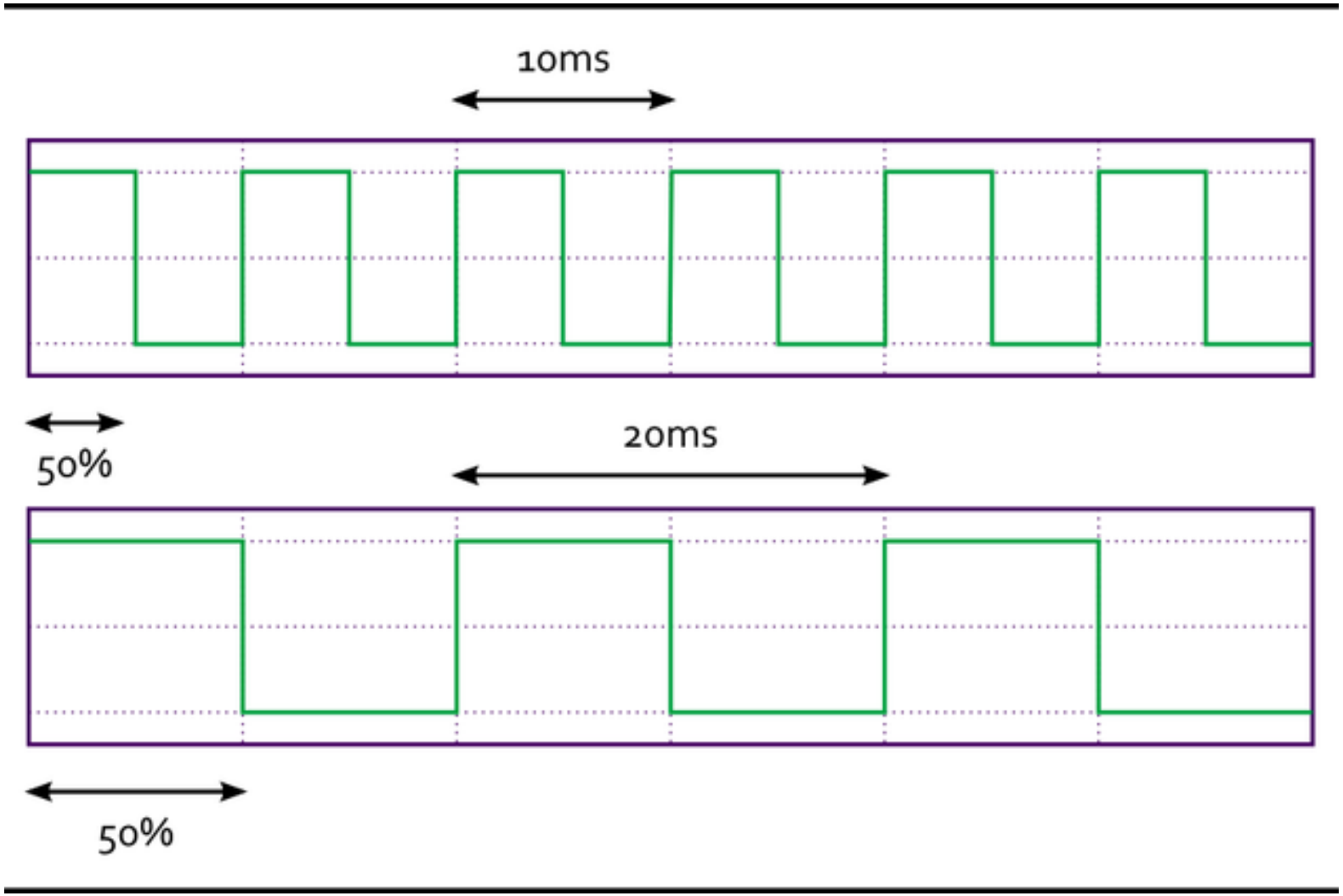
Control of Stepper Motors

PWM duty cycle constant (50%)

Speed: *PWM frequency*

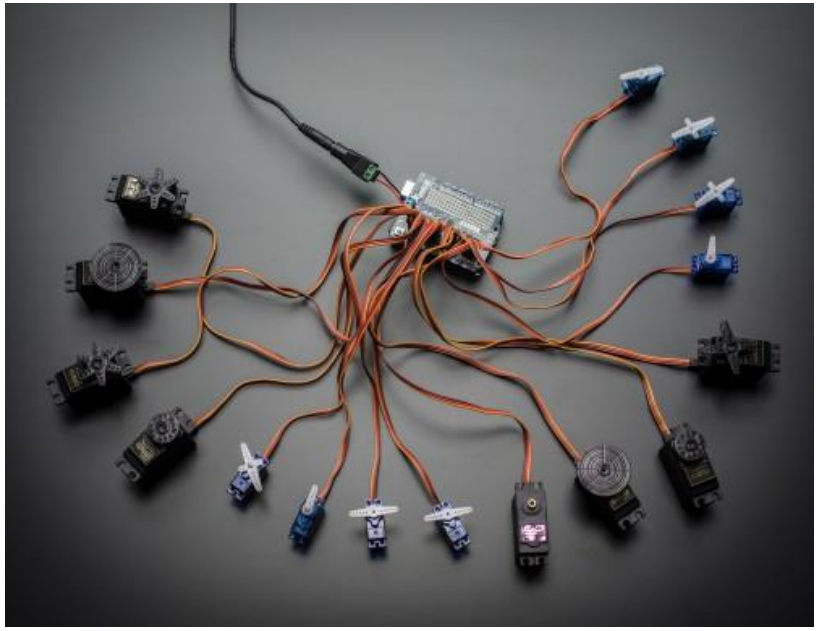
Position: *PWM pulses*

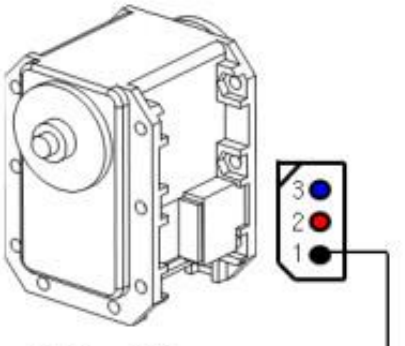




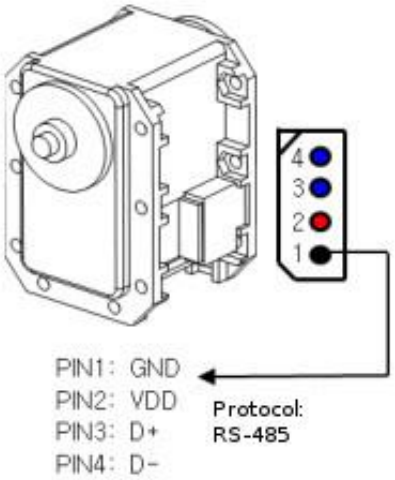
Smart Servos

Smart servos are DC motors with further integrated electronics (controller + driver + sensor + reduction gear + network). Instead of using PWM signals for control, they use serial communication

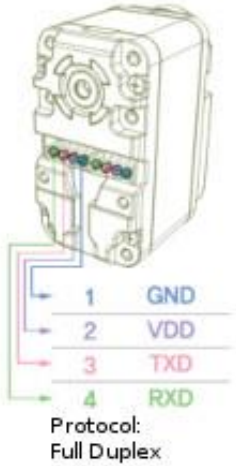




Dynamixel MX-xxT

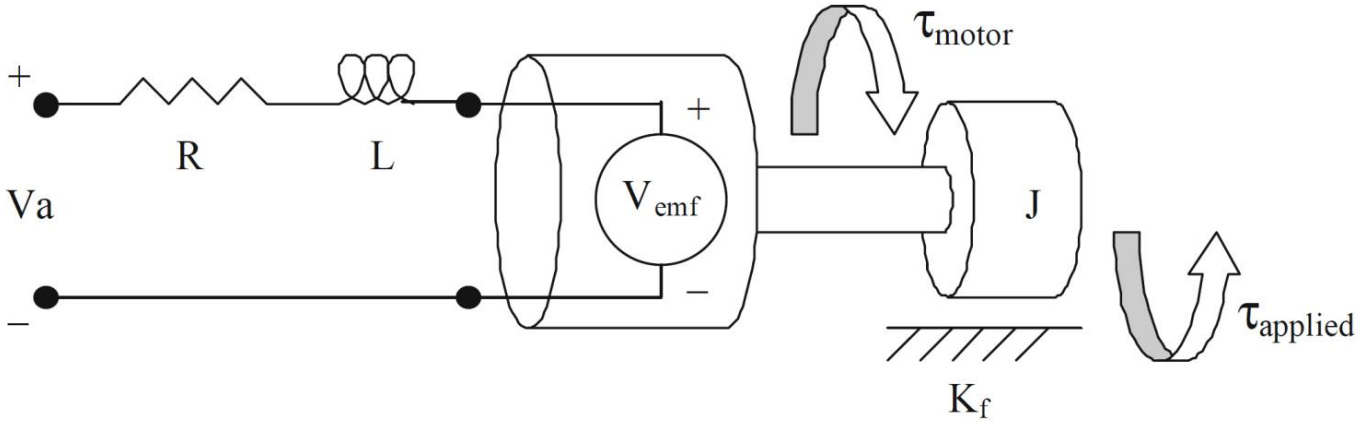


Dynamixel MX-xxR



Herkulex DSR-xxxx

DC Motors - Basic Principles



θ	Angular position of shaft, rad	R	Nominal terminal resistance, Ω
ω	Angular shaft velocity, rad/s	L	Rotor inductance, H
α	Angular shaft accel., rad/s^2	J	Rotor inertia, kg·m^2
i	Current through armature, A	K_f	Frictional const., N·m·s / rad
V_a	Applied terminal voltage, V	K_m	Torque constant, N·m / A
V_e	Back *emf* voltage, V	K_e	Back *emf* constant, V·s / rad
τ_m	Motor torque, N·m	K_s	Speed constant, rad / (V·s)
τ_a	Applied torque (load), N·m	K_r	Regulation constant, (V·s) / rad

Motor constants $K_s = \frac{\omega}{V_a}$

$K_m = \frac{1}{K_s}$

Current demand $i = \frac{\tau_a}{K_m}$

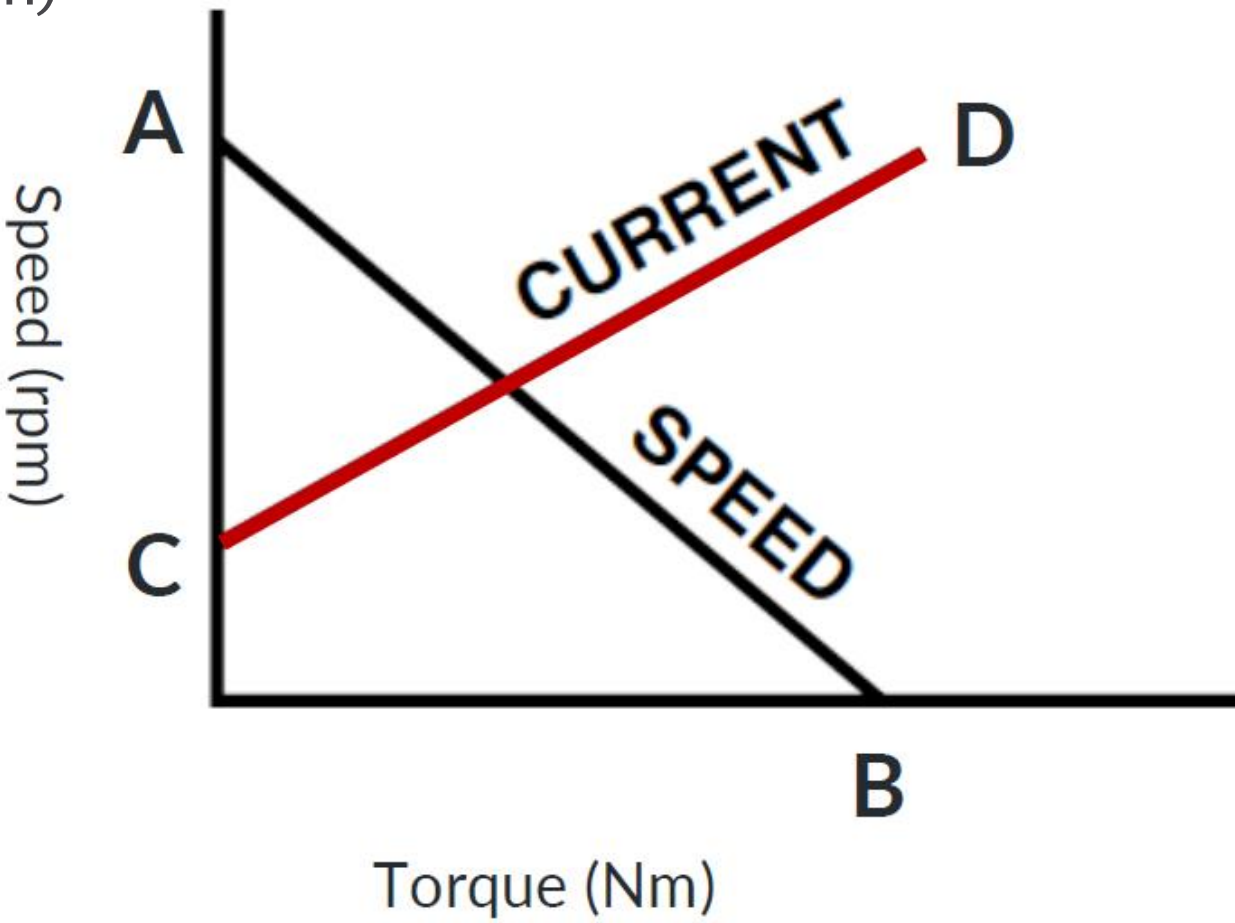
Output power $P_o = \tau_a \omega$

Input power $P_i = V_a i$

Efficiency $\eta = \frac{P_o}{P_i} = \frac{\tau_a \omega}{V_a i}$

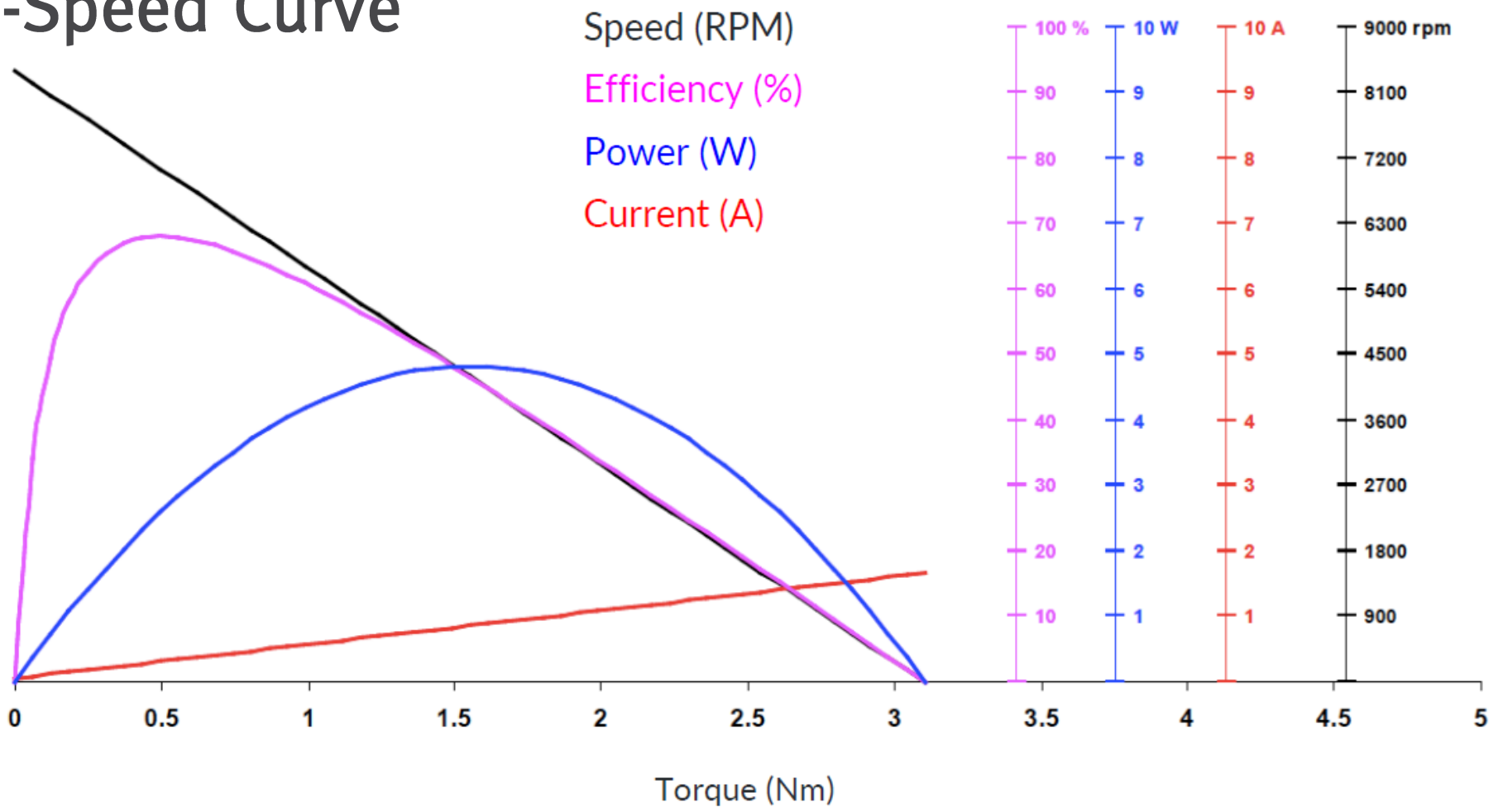
DC Motors - Performance Curves

- A No Load speed, N_o (nominal) (rpm)
- B Stall torque, T_{STALL} (Nm)
- C No Load Current, I_o (A)
- D Stall Current, I_{STALL} (A)

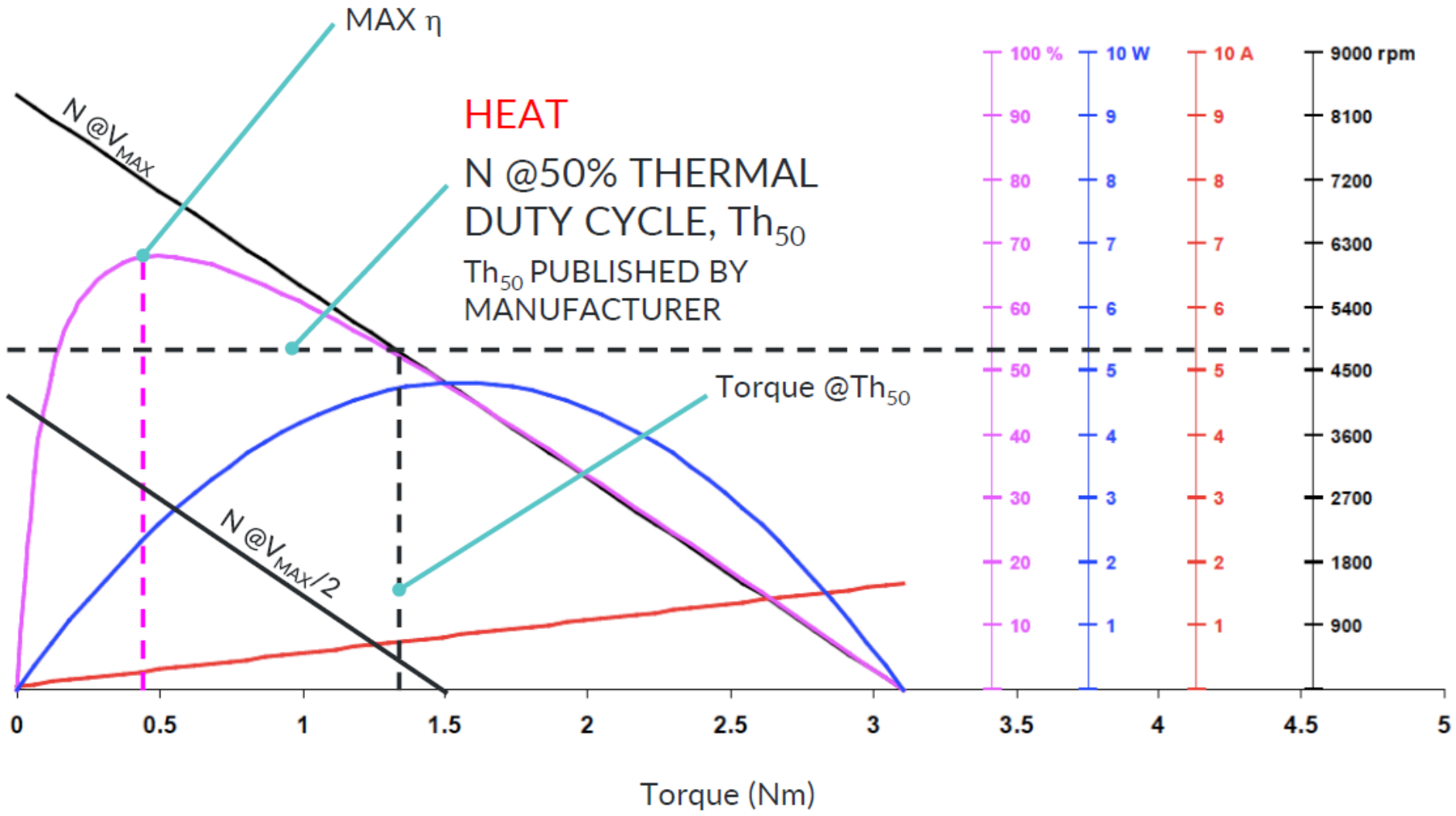


DC Motors – Performance Curves

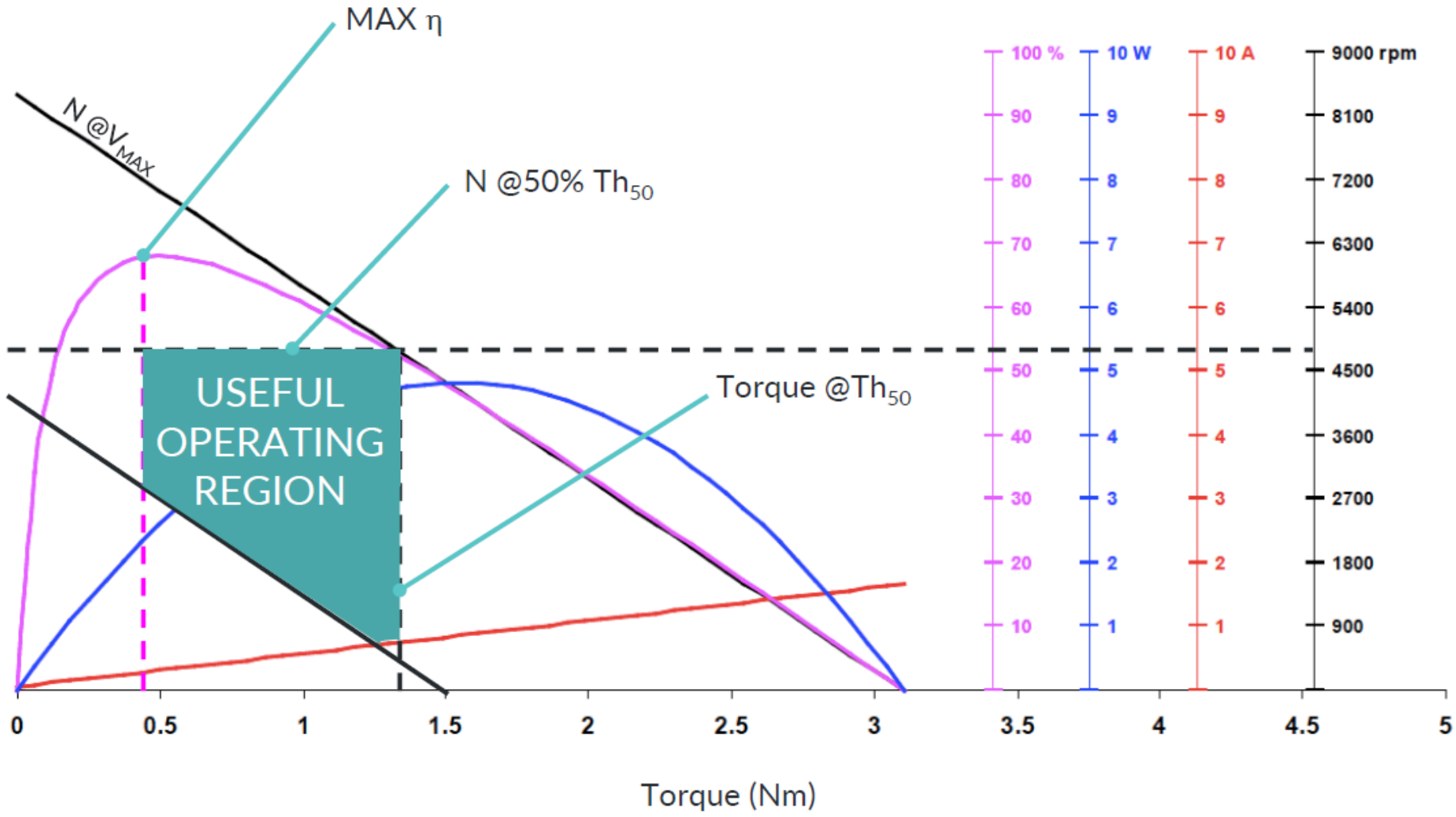
Torque-Speed Curve



DC Motors – Performance Curves

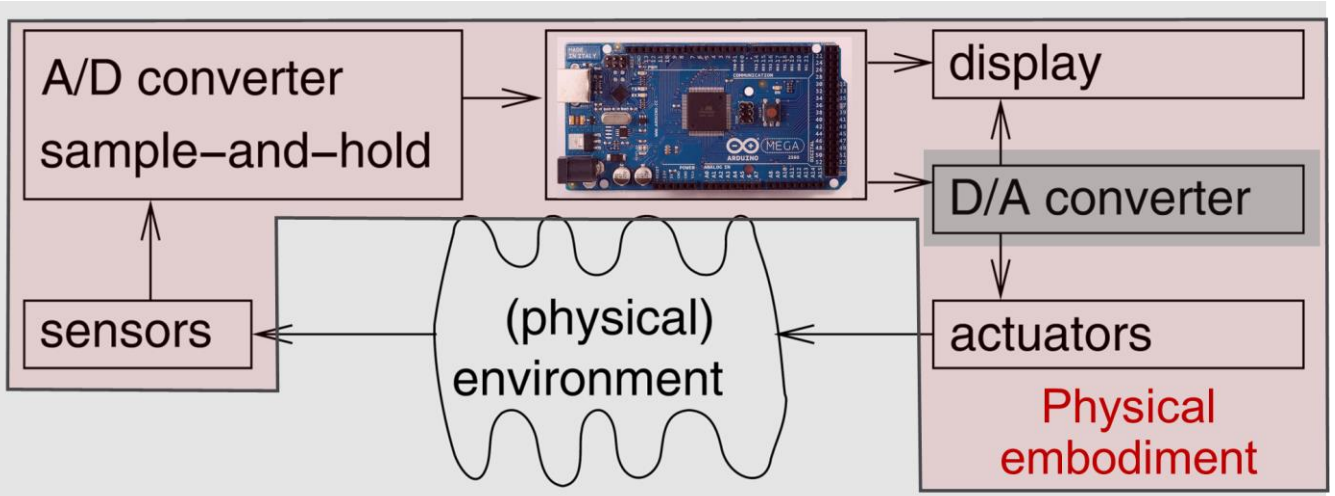


DC Motors – Performance Curves

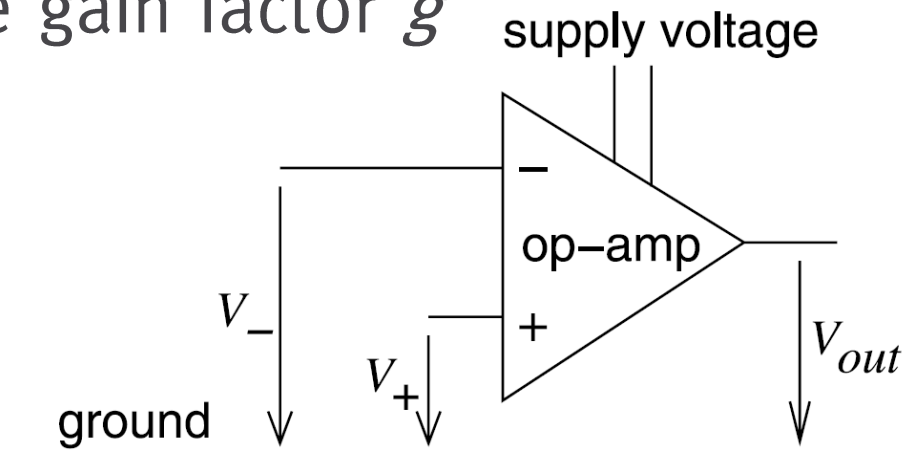


Digital-to-Analogue Converter

Conversion between digital signal and analogue signal. Particularly useful for audio and video

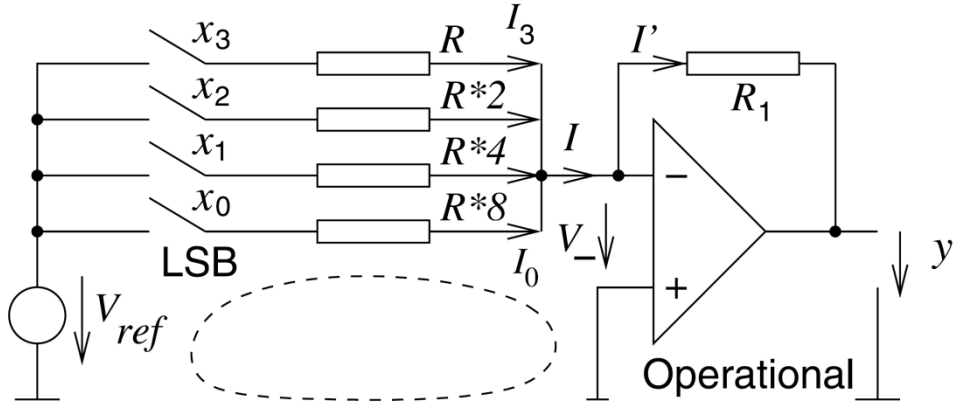


Operational amplifiers (op-amps) amplify the voltage difference between two input terminals by a large gain factor g



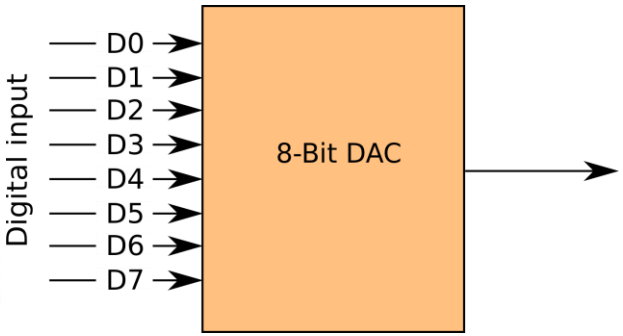
$$V_{out} = g \cdot (V_+ - V_-)$$

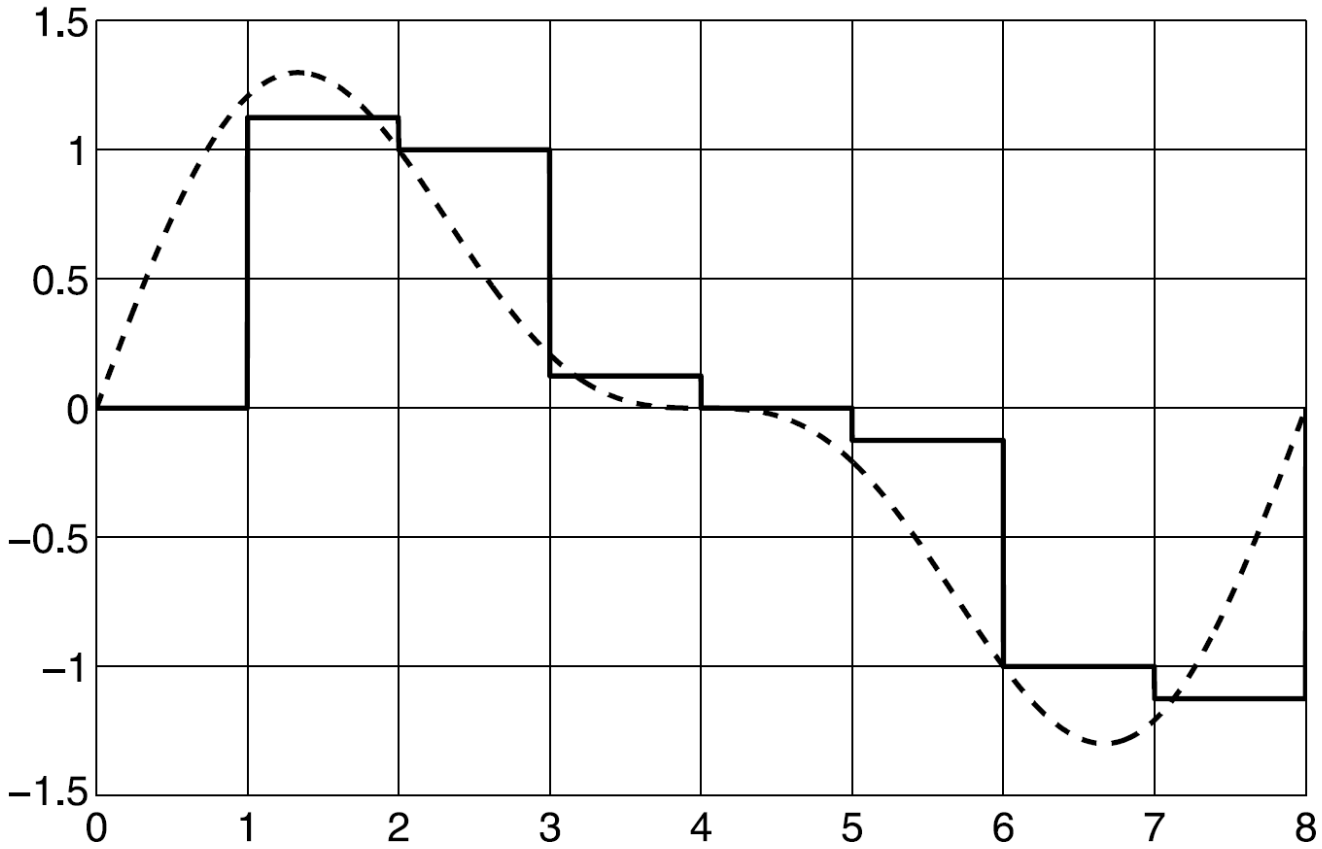
Digital-to-Analogue Converter

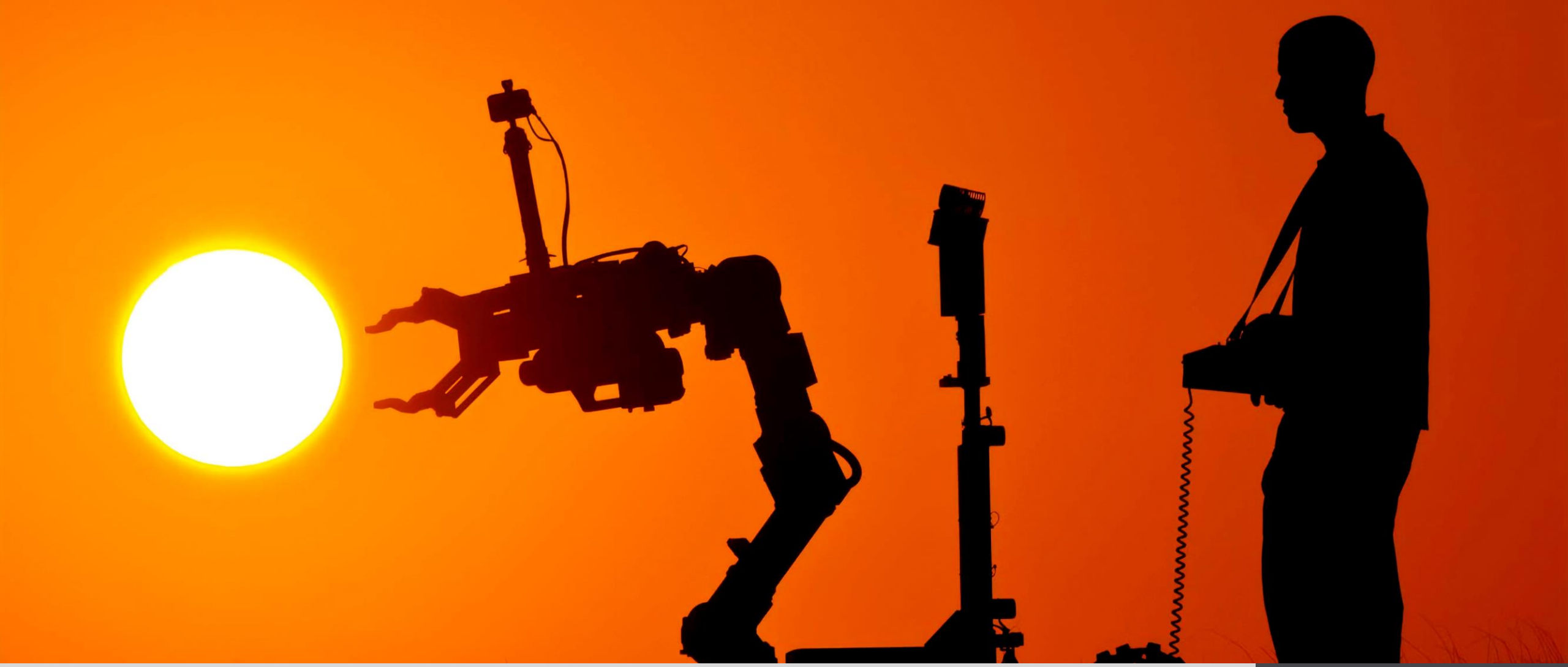


$$y = -V_{ref} * \frac{R_1}{R} * \sum_{i=0}^{3} x_i * 2^{i-3}$$

TLC7524CN
8-bit DAC







Actuators and electric motors

GIZMO

2021 DE2-Gizmo (Physical Computing)
Lecture 4

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Dyson School of Design Engineering