Actuators

Actuators

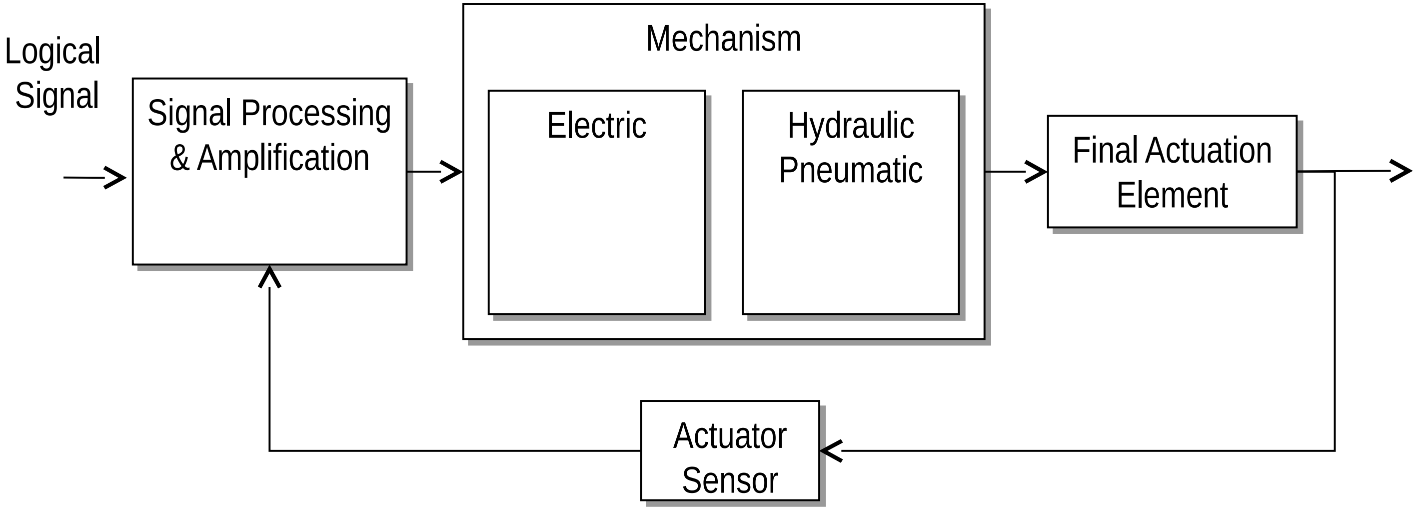
Hardware devices that convert a controller command signal into a change in a physical parameter

- The change is usually mechanical (e.g., position or velocity)

- An actuator is also a transducer because it changes one type of physical quantity into some alternative form

- An actuator is usually activated by a low-level command signal, so an amplifier may be required to provide sufficient power to drive the actuator

Actuators


Logical
Signal
Signal Processing
& Amplification
Mechanism
Electric
Hydraulic
Pneumatic
Final Actuation
Element
Actuator
Sensor

Types of Actuators

1. Electrical actuators
   - Electric motors
     - DC servomotors
     - AC motors
     - Stepper motors
   - Solenoids

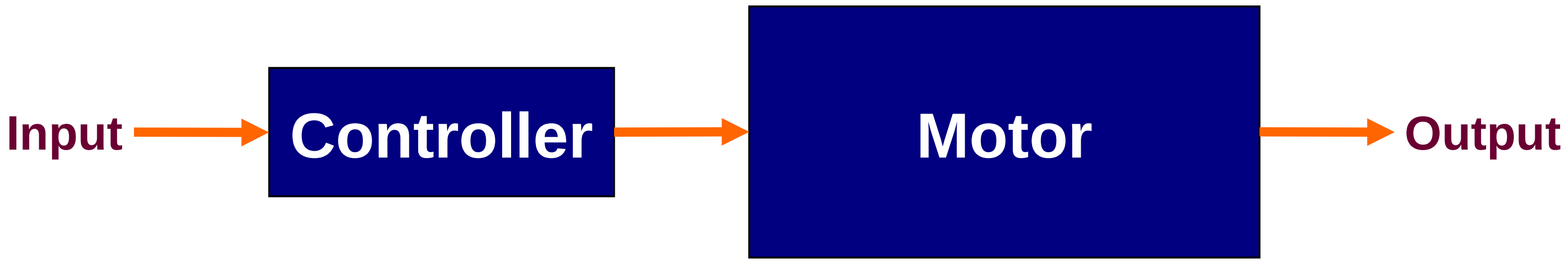


2. Hydraulic actuators
   - Use hydraulic fluid to amplify the controller command

3. Pneumatic actuators
   - Use compressed air as the driving force

Open Loop Controller

- An **open-loop controller** (or non-feedback controller) is a type of controller which computes its input into a system using only the current state and its model of the system
- The system does not observe the output of the processes that it is controlling



Open Loop Controller

- Open-loop control is useful for well-defined systems where the relationship between input and the resultant state can be modeled by a mathematical formula

- Example: Determine voltage to an electric motor that drives a constant load

- Used in simple processes because of its simplicity and low-cost, especially in systems where feedback is not critical

- For a accurate or more adaptive control, it is necessary to feed the output of the system back to the inputs of the controller

Closed Loop Controller

- A **closed-loop controller** uses feedback to control states or outputs of a dynamical system

- Process inputs have an effect on the process outputs, which is measured with sensors and processed by the controller; the result is used as input to the process, closing the loop

Closed Loop Controller

Advantages:

- Disturbance rejection (such as unmeasured friction in a motor)
- Guaranteed performance even with model uncertainties, when the model structure does not match perfectly the real process and the model parameters are not exact
- Unstable processes can be stabilized
- Reduced sensitivity to parameter variations
- Improved reference tracking performance

Electric Motors

- Electric motors are the most common source of torque for mobility and/or manipulation in robotics

- The physical principle of all electric motors is that when an electric current is passed through a conductor (usually a coil of wire) placed within a magnetic field, a force is exerted on the wire causing it to move

Components of an Electric Motor

The principle components of an electric motor are:

- North and south **magnetic poles** to provide a strong magnetic field. Being made of bulky ferrous material they traditionally form the outer casing of the motor and collectively form the **stator**

- An **armature**, which is a cylindrical ferrous core rotating within the stator and carries a large number of windings made from one or more conductors

Components of an Electric Motor (cont…)

- A **commutator**, which rotates with the armature and consists of copper contacts attached to the end of the windings

- **Brushes** in fixed positions and in contact with the rotating commutator contacts. They carry direct current to the coils, resulting in the required motion

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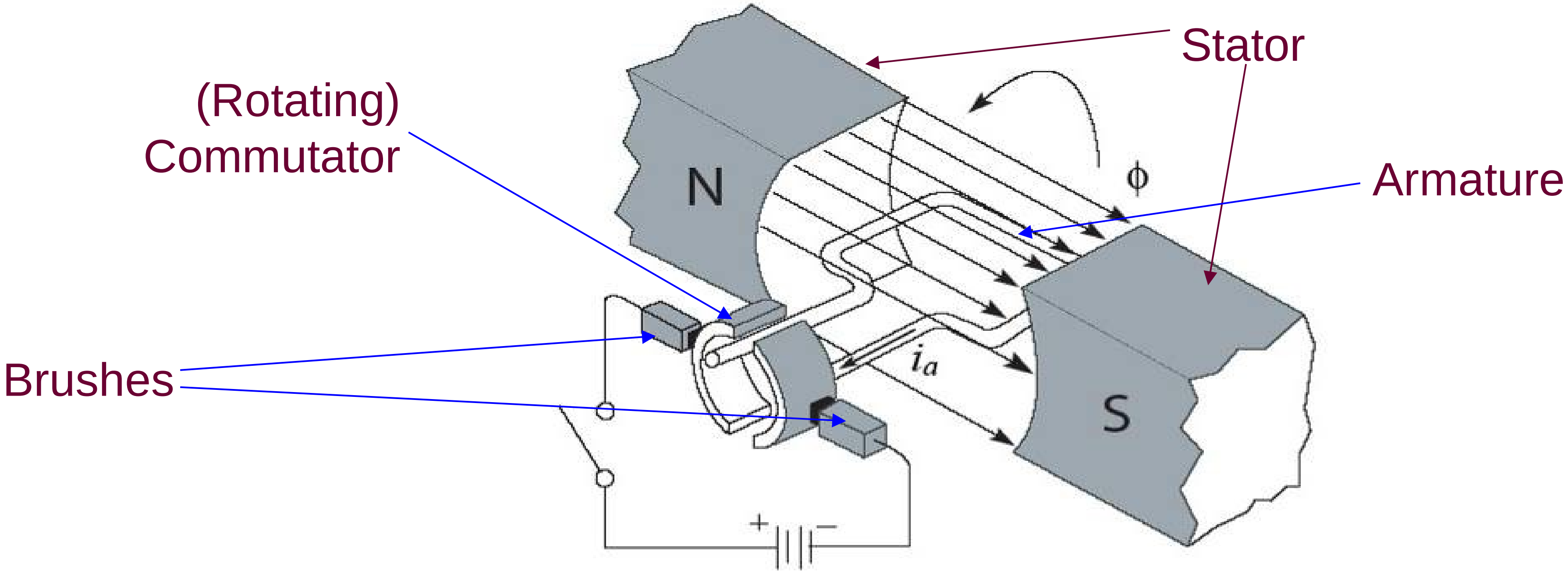
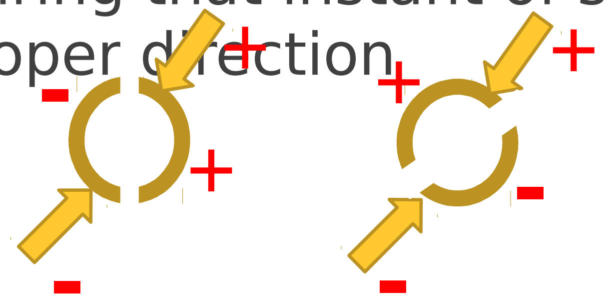
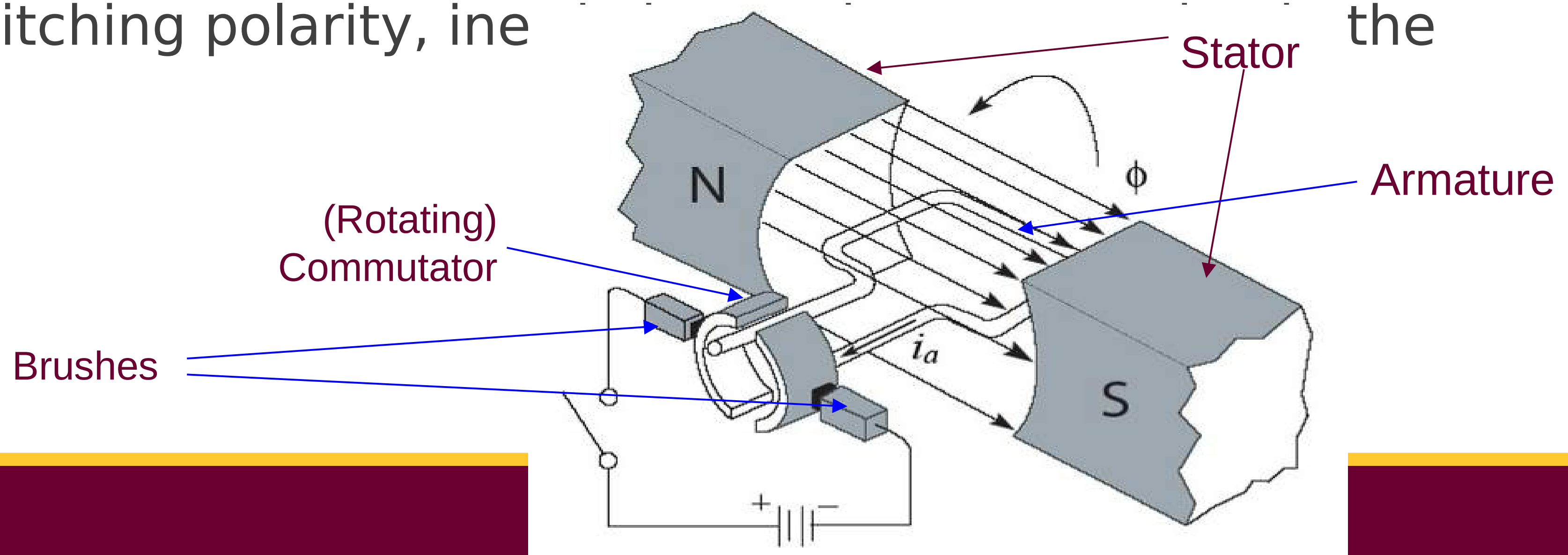


How do Electric Motors Work

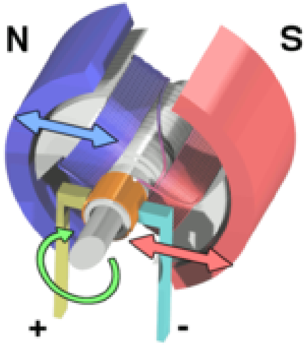
- The classic DC motor has a rotating armature in the form of an electromagnet
- **A rotary switch called a commutator** reverses the direction of the electric current twice every cycle, to flow through the armature so that the poles of the electromagnet push and pull against the permanent magnets on the outside of the motor
- As the poles of the armature electromagnet pass the poles of the permanent magnets, the commutator reverses the polarity of the armature electromagnet.
- During that instant of switching polarity, ine … the proper direction



Rotating commutator

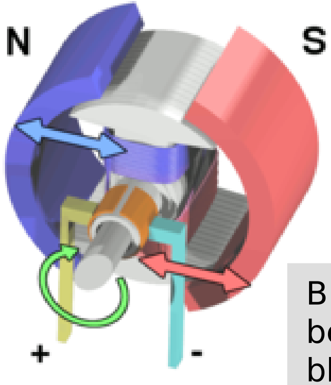


How do Electric Motors Work



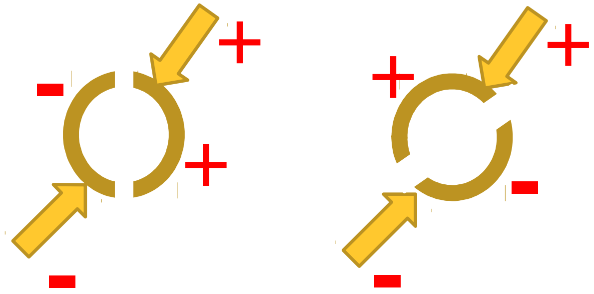
Blue in armature near blue in stator

1. A simple DC electric motor: when the coil is powered, a magnetic field is generated around the armature.
2. The left side of the armature is pushed away from the left magnet and drawn toward the right, causing rotation

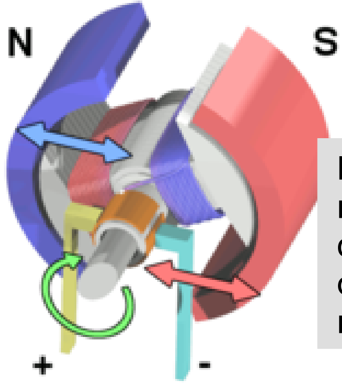


Blue between blue and red

The armature continues to rotate



Rotating commutator



Blue near red, because of commutator rotation

- When the armature becomes *horizontally aligned*, the commutator reverses the direction of current through the coil, ***reversing the magnetic field***.
- The process then repeats.

Electric Motors

- Electric motors usually have a small rating, ranging up to a few horsepower

- They are used in small appliances, battery operated vehicles, for medical purposes and in other medical equipment like x-ray machines

- Electric motors are also used in toys, and in automobiles as auxiliary motors for the purposes of seat adjustment, power windows, sunroof, mirror adjustment, blower motors, engine cooling fans and the like

DC Motor Control

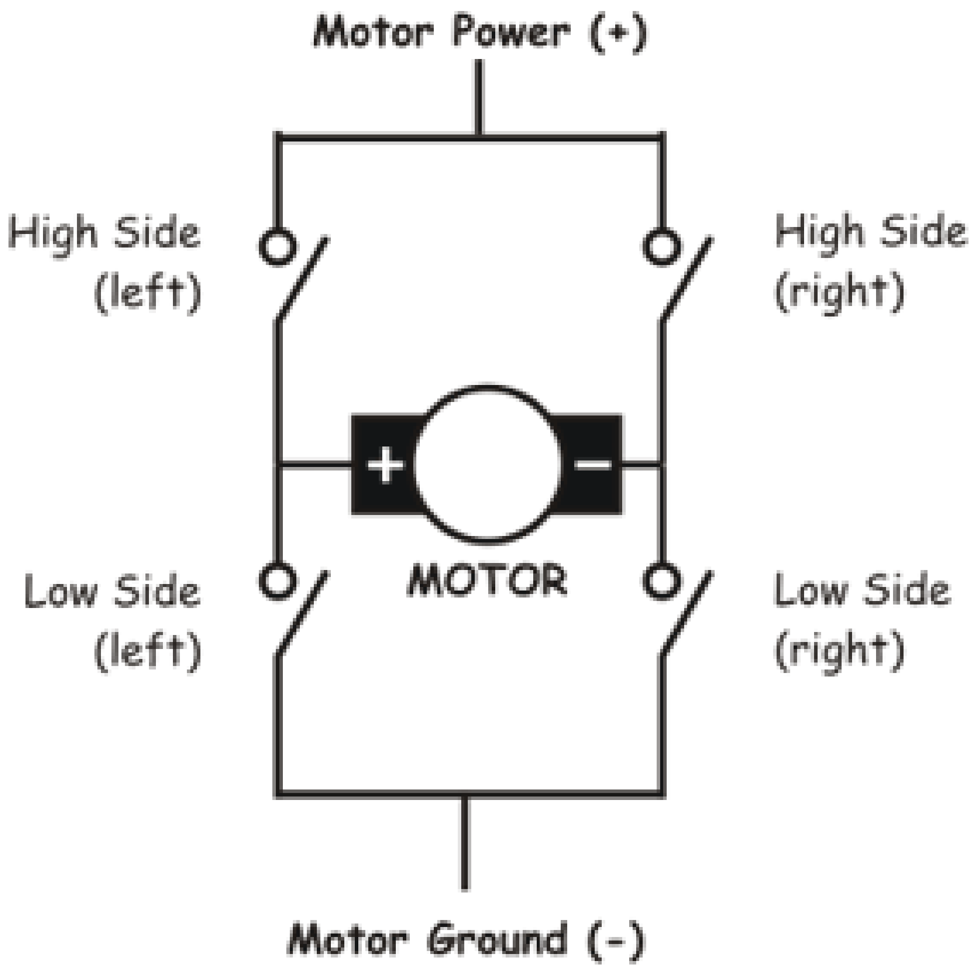
Controller + H-bridge

PWM-control

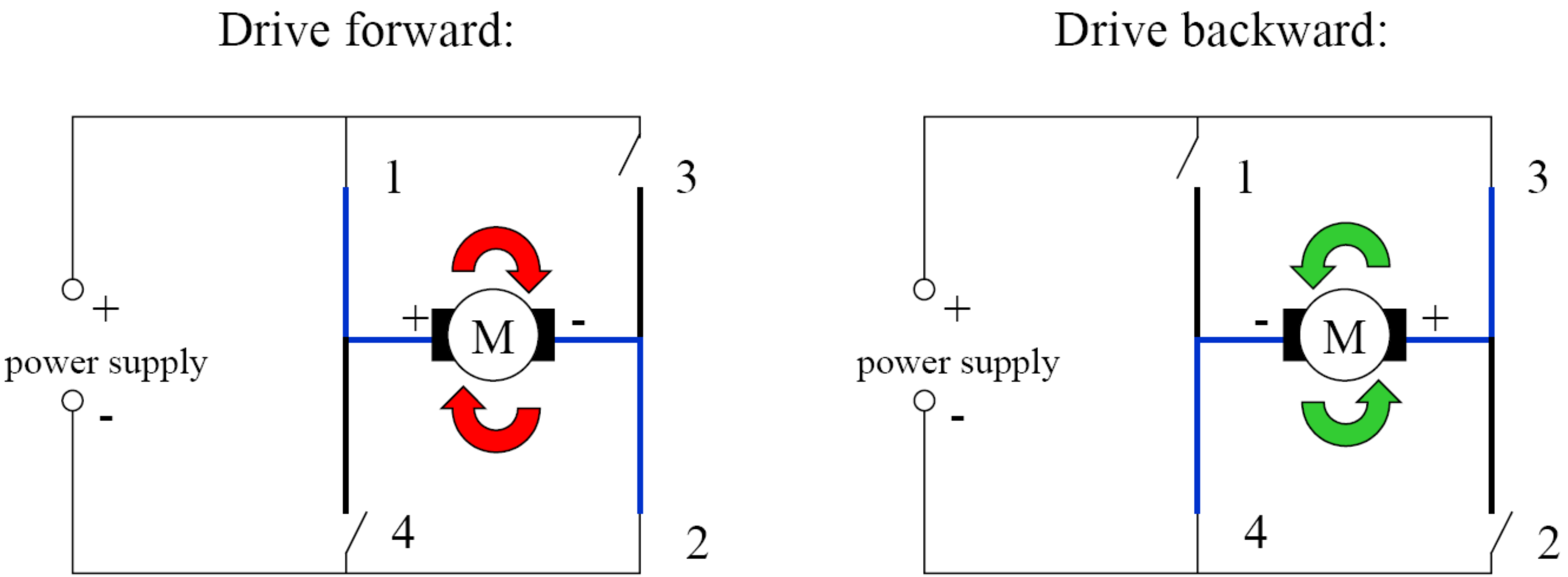
Speed control by controlling motor current=torque

Efficient small components

PID control



H-Bridge



Drive forward:
1
3
+
power supply
-
+
M
-
4
2
Drive backward:
1
3
+
power supply
-
-
M
+
4
2

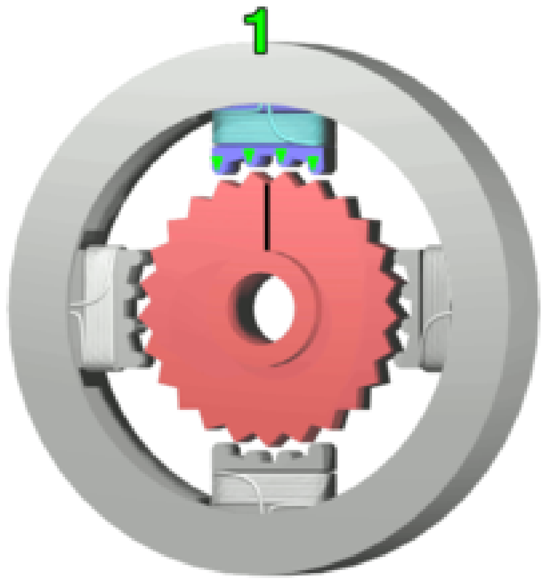
Stepper Motors

- When incremental rotary motion is required in a robot, it is possible to use **stepper motors**
- A stepper motor possesses the ability to move a specified number of revolutions or fraction of a revolution in order to achieve a fixed and consistent angular movement
- This is achieved by increasing the numbers of poles on both rotor and stator
- Additionally, soft magnetic material with many teeth on the rotor and stator cheaply multiplies the number of poles (reluctance motor)

Stepper Motors

- This figure illustrates the design of a stepper motor, arranged with four magnetic poles arranged around a central rotor

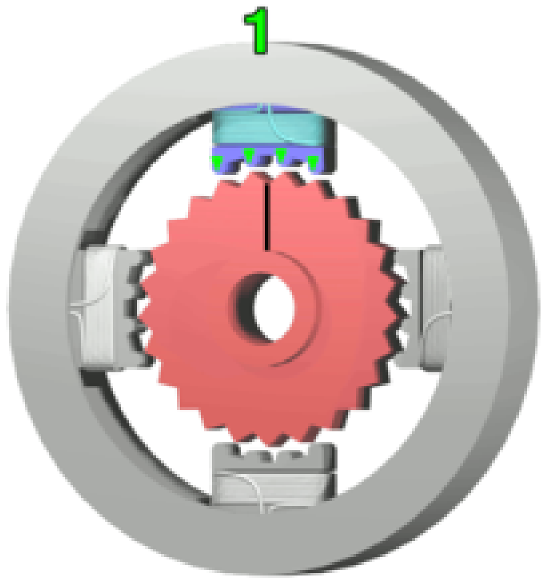
- Note that the teeth on the rotor have a slightly tighter spacing to those on the stator, this ensures that the two sets of teeth are close to each other but not quite aligned throughout



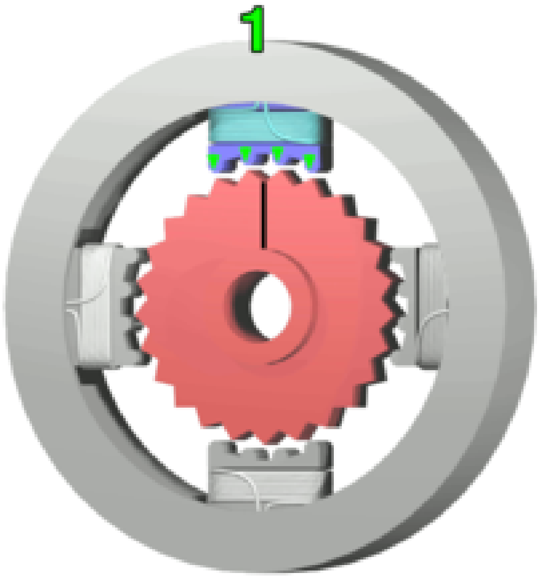
Stepper Motors (cont…)

- Movement is achieved when power is applied for short periods to successive magnets

- Where pairs of teeth are least offset, the electromagnetic pulse causes alignment and a small rotation is achieved, typically 1-2°

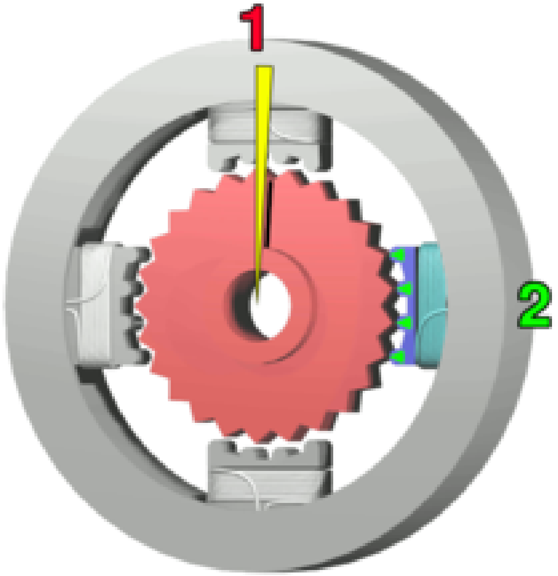


How Does A Stepper Motor Work?



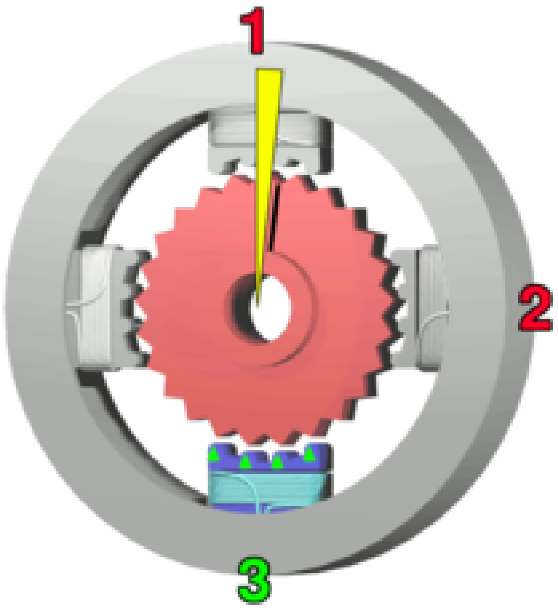
The top electromagnet (1) is charged, attracting the topmost four teeth of a sprocket.

How Does A Stepper Motor Work?



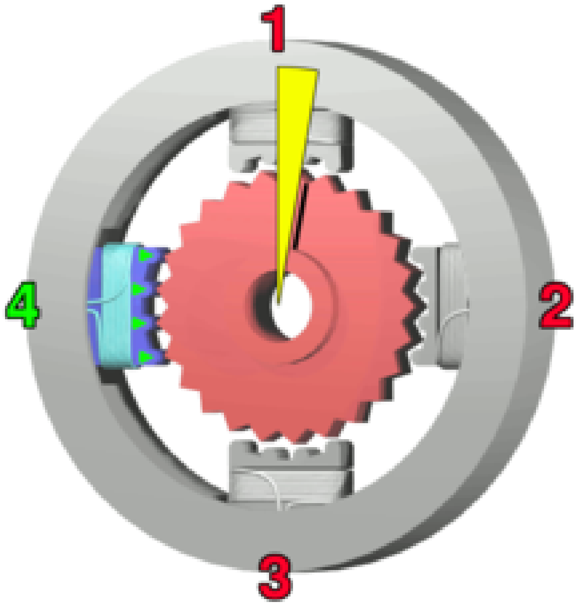
The top electromagnet (1) is turned off, and the right electromagnet (2) is charged, pulling the nearest four teeth to the right. This results in a rotation of 3.6°

How Does A Stepper Motor Work?



The bottom electromagnet (3) is charged; another 3.6° rotation occurs.

How Does A Stepper Motor Work?



The left electromagnet (4) is enabled, rotating again by 3.6°. When the top electromagnet (1) is again charged, the teeth in the sprocket will have rotated by one tooth position; since there are 25 teeth, it will take 100 steps to make a full rotation.

Stepper Motor

- Stepper motors have several advantages:
  - Their control is directly compatible with digital technology
  - They can be operated open loop by counting steps, with an accuracy of ±1 step.
  - They can be used as holding devices, since they exhibit a high holding torque when the rotor is stationary

Stepper Motors

Step angle is given by: : $$\alpha = \frac{360}{n_s}$$

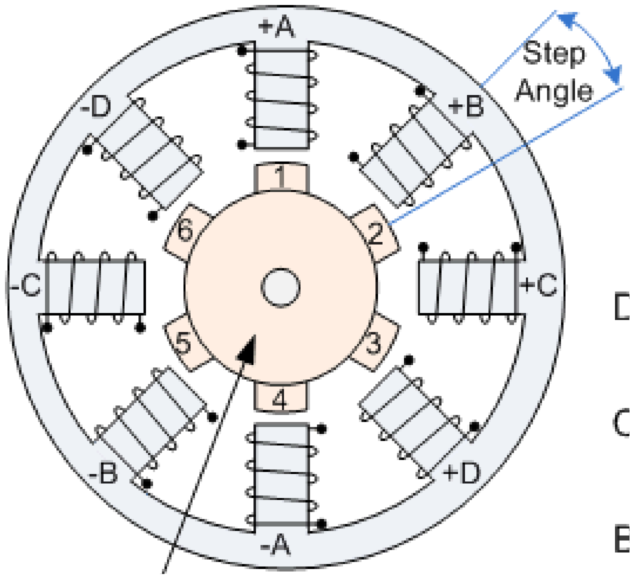
where n_s is the number of steps for the stepper motor (integer)

Total angle through which the motor rotates (A_m) is given by: $$A_m = n_p \alpha$$

where n_p = number of pulses received by the motor.

Angular velocity is given by: $$\omega = \frac{2\pi f_p}{n_s}$$ where f_p = pulse frequency

Speed of rotation is given by: $$N = \frac{60 f_p}{n_s}$$



Example

A stepper motor has a step angle = 3.6°. (1) How many pulses are required for the motor to rotate through ten complete revolutions? (2) What pulse frequency is required for the motor to rotate at a speed of 100 rev/min?

Solution

$$\alpha = \frac{360}{n_s}$$

(1) 3.6° = 360 / n_s; 3.6° (n_s) = 360; n_s = 360 / 3.6 = 100 step angles

$$A_m = n_p \alpha$$

(2) Ten complete revolutions: 10(360°) = 3600° = A_m

Therefore n_p = 3600 / 3.6 = 1000 pulses

$$N = \frac{60 f_p}{n_s}$$

Where N = 100 rev/min:

100 = 60 f_p / 100

10,000 = 60 f_p

f_p = 10,000 / 60 = 166.667 = 167 Hz

Servos

Photos: HiTec

- A servo is a unit combining motor and simple feedback electronics for position control
- A servo is set by supplying a PWM signal of a certain ratio
- Ratio determines servo position, not speed!
- Servos are usually used in model airplanes, etc.

Miniature Servos

Specifications

- Specialized motor for turning to a specific position
- Components:
  - DC motor
  - Gear reduction unit
  - Shaft position sensor
  - Electronic circuit that controls the motor's operation
- "Servo" - capability to self-regulate its behavior, i.e., to measure its own position and compensate for external loads when responding to a control signal
- Widely used in hobby radio control applications:
  - RC cars: position the front wheel rack-and-pinion steering
  - RC airplanes: control the orientation of the wing flaps and rudders

Futaba S148 Servo Motor with Mounting Horns ($17.00)

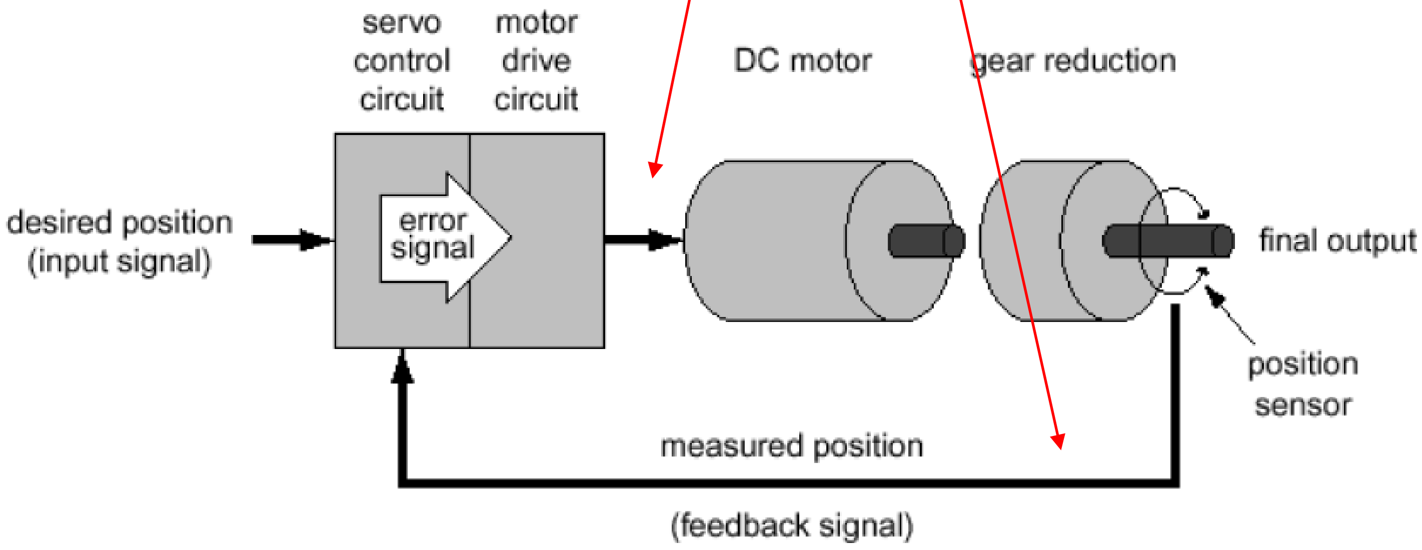
- Positioning applications:
  - Shaft travel is restricted to 180 degrees
  - Input waveform specifies desired angular position of output shaft
  - Electronics measure current position
  - If different from desired position, servo is turned on to drive the shaft to the desired position

Three Wire Interface in Servos

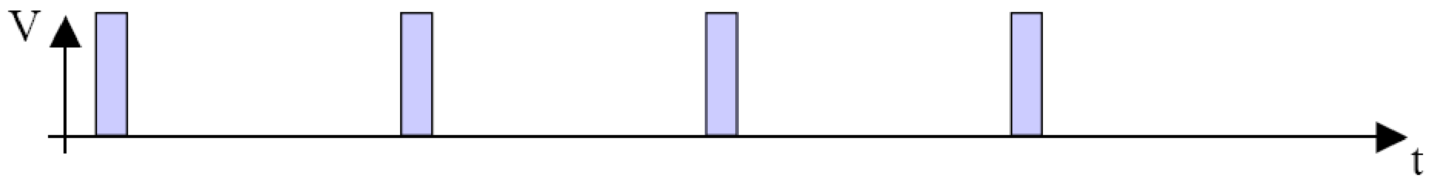
Servo Control

- Most hobby servo motors use a standard three wire interface:
  - Power
  - Ground
  - Control Line
- Power supply is typically 5 to 6 v

The **input** to the **servo motor** is desired position of the output shaft. This signal is compared with a **feedback signal** indicating the actual position of the shaft (as measured by position sensor). An **"error signal"** is generated that directs the motor drive circuit to power the motor. The servo's gear reduction drives the final output.



PWM Control of Servos

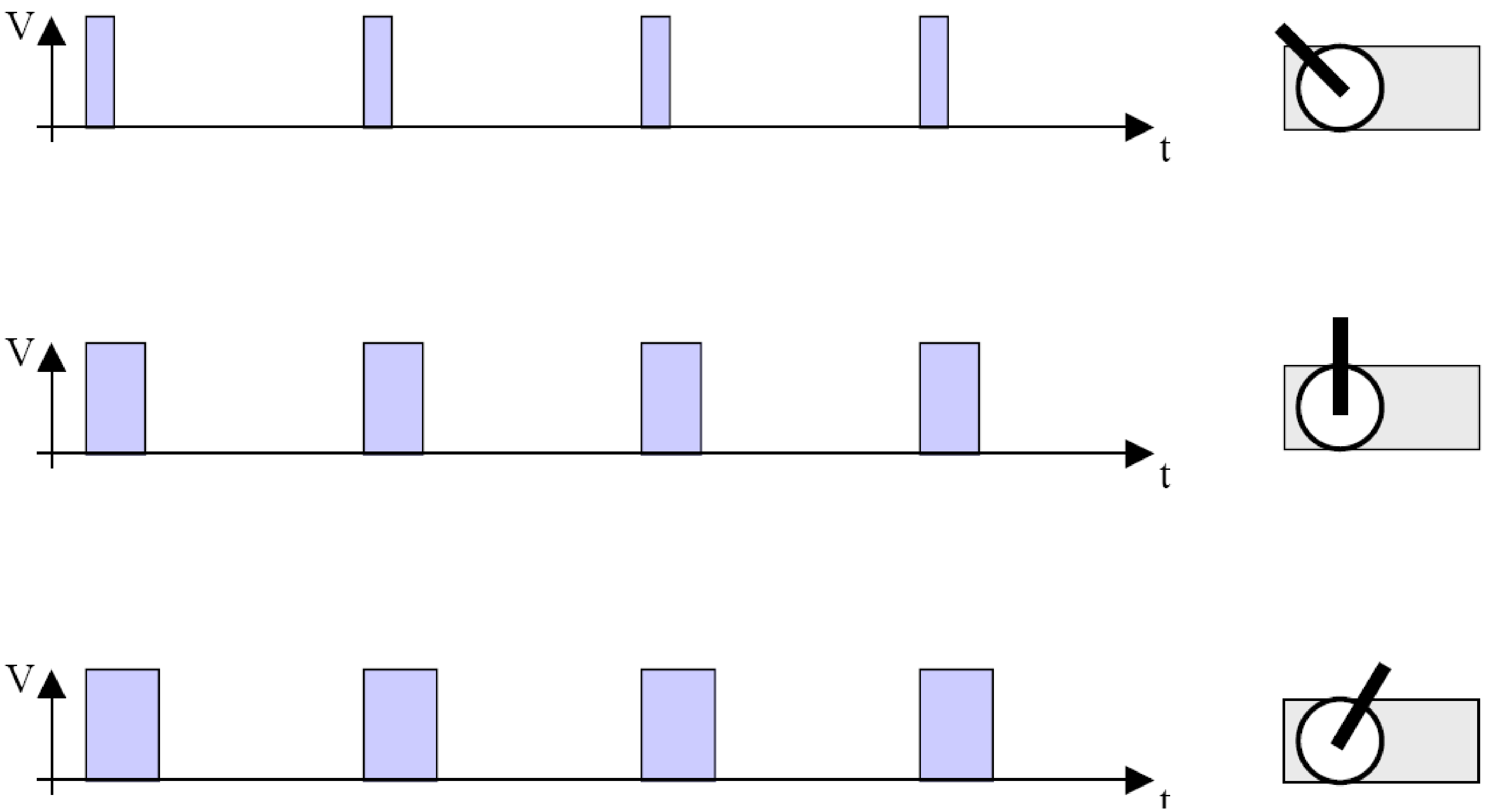


- Servos usually have three cables: power, ground and PWM-signal
- Servos require a PWM signal with 50Hz frequency (20ms)
- The pulse should be between 0.5 ms and 2.0 ms long
  this sets the servo to its extreme left or right position

Remember:

- Servo speed cannot be set
  servo tries to get to new position as fast as possible
- Servos do not provide feedback to the outside

Servo – Pulse



Pulse between 0.6 ms and 2.0 ms

Pulse length controls the angle of the shaft

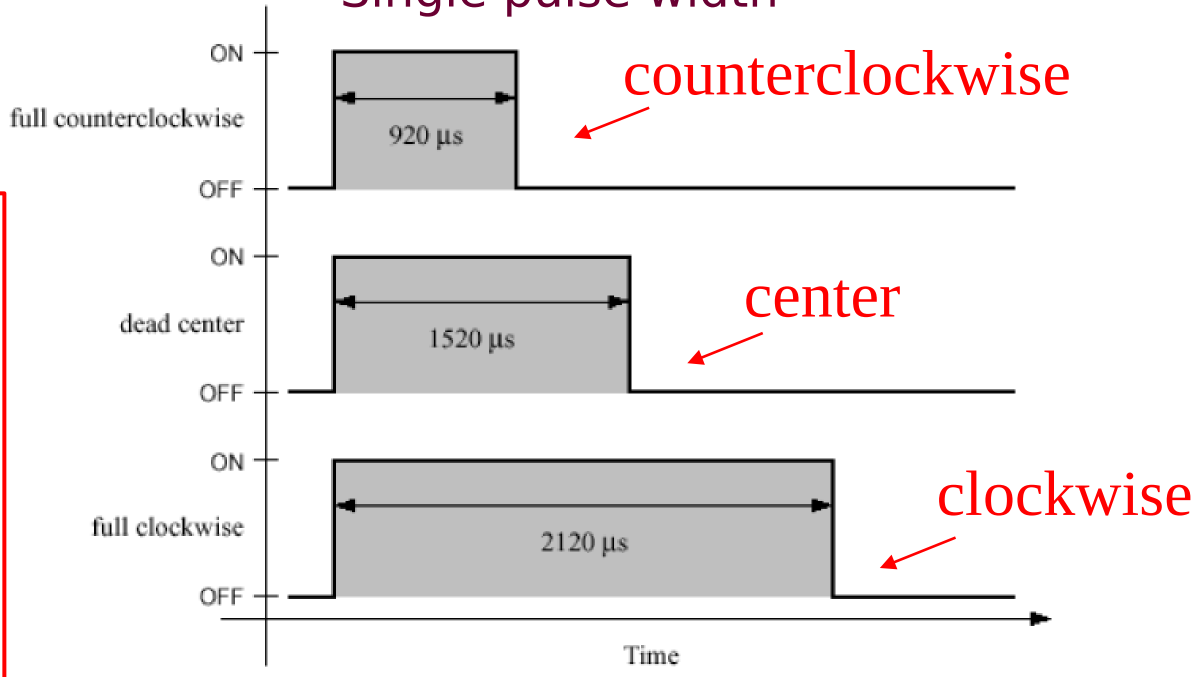
Servo – Control Signal

- Control line uses a **PWM scheme** for encoding the position signal

- Servo PWM method is different from the speed control PWM
  - Speed control PWM: **overall duty cycle** (i.e, percentage of on-time) determines the speed of the motor
  - Servo PWM: **length of the pulse** is interpreted to signify control value

- Waveforms' length:
  - **920 µs** - full counterclockwise
  - **1520 µs** - center position
  - **2120 µs** - full clockwise

Single pulse width

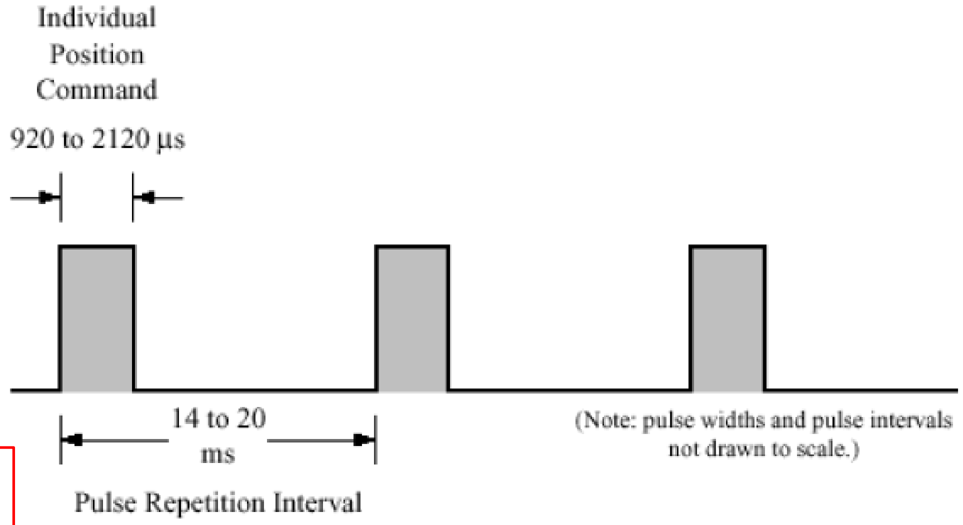


Three sample waveforms for controlling a servo motor

Speed Control PWM is not the same as the Servo PWM

Servo – Control Signal

- To complete the servo control, all that one must do is periodically repeat the individual control pulses
- Servo turns off when pulses stop
- For **Futaba servo motors**, the recommended interval between control pulses is 14 to 20 ms
- Servo Timing Signal
  - Pulse width must be accurate in µs; otherwise servo exhibits **jitter**
  - Interval between pulses may vary 14 - 20 ms; successive pulses need not be exactly same distance apart
- Limits mechanical first, then electrical
  - Electronics will try to drive output shaft to a point beyond mechanical limits



To get the servo motor to continually attempt to reach the desired position, the timing pulse must be repeated at a regular interval

Experiment: find range of motion of different servo motors