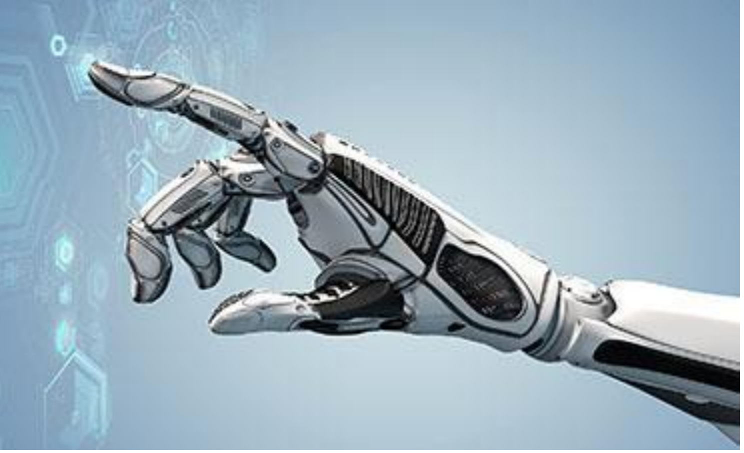
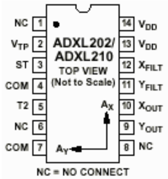


CSE444: Introduction to Robotics
Lesson 4a: Working with Actuators

ALL Follows

Summer 2019



Accelerometer

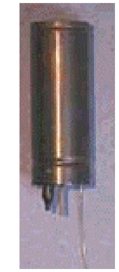

Gyro


Pendulum Resistive
Tilt Sensors

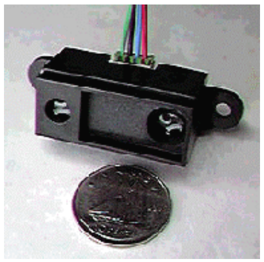

Piezo Bend Sensor


Metal Detector

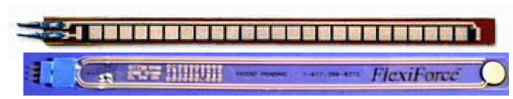
Gas Sensor


Gieger-Muller
Radiation Sensor

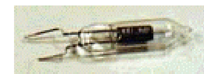

Pyroelectric Detector

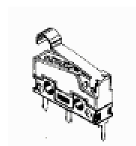

Digital Infrared Ranging


CDS Cell
Resistive Light Sensor



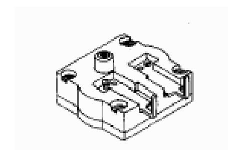
Resistive Bend Sensors

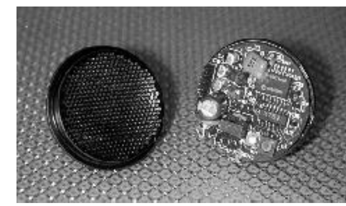

UV Detector

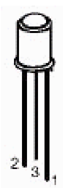

Limit Switch

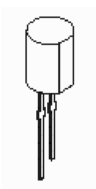

Mechanical Tilt Sensors

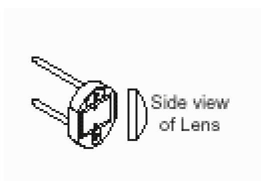

Touch Switch


Pressure Switch

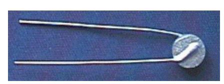

Miniature Polaroid Sensor

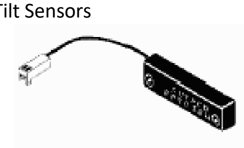


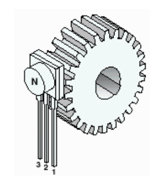

IR Pin
Diode



IR Sensor w/lens


Thyristor

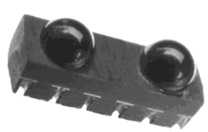

Magnetic Sensor


Hall Effect
Magnetic Field
Sensors

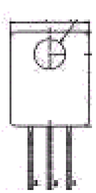

Polaroid Sensor Board

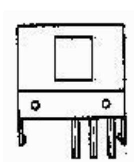

IR Reflection
Sensor


IR Amplifier Sensor


IRDA Transceiver

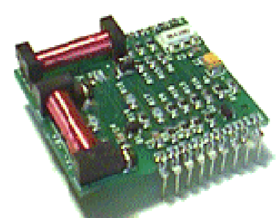

Magnetic Reed Switch

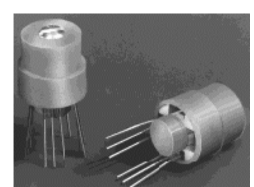

Lite-On IR
Remote Receiver

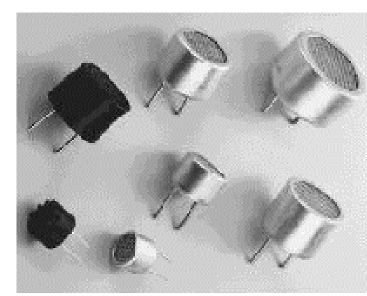

Radio Shack
Remote Receiver


IR Modulator
Receiver


Solar Cell


Compass

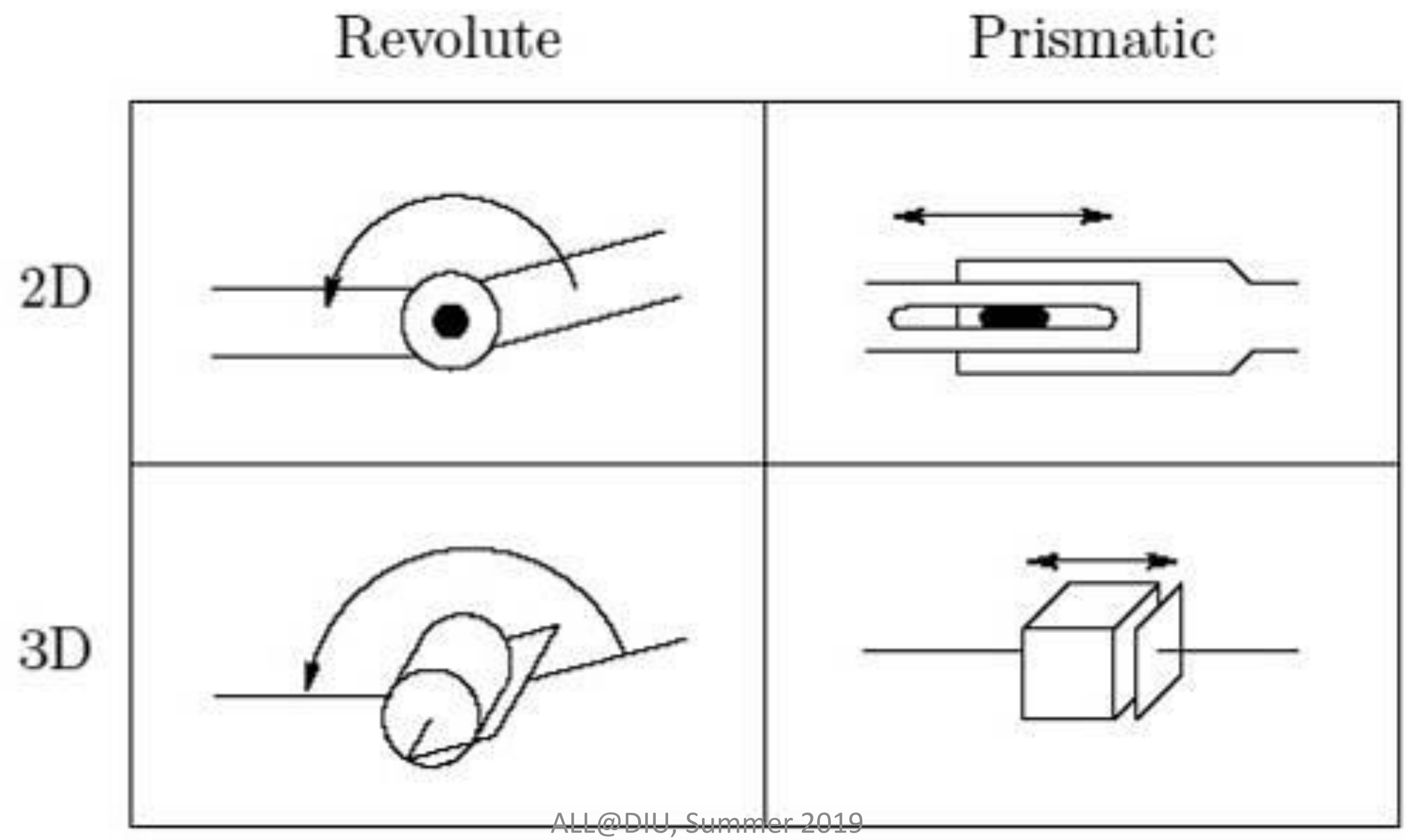

Compass


Piezo Ultrasonic Transducers

Robot Joints

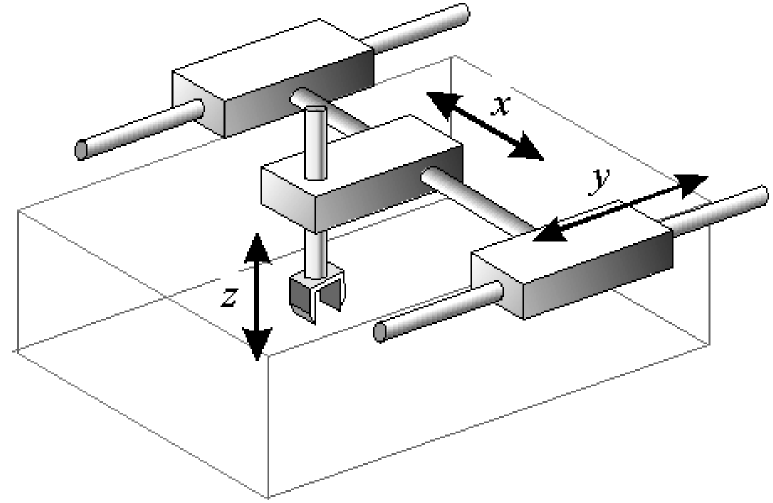
Robot Joints

- Robot joints can be either **rotary** (also known as revolute) or **prismatic** (telescoping)

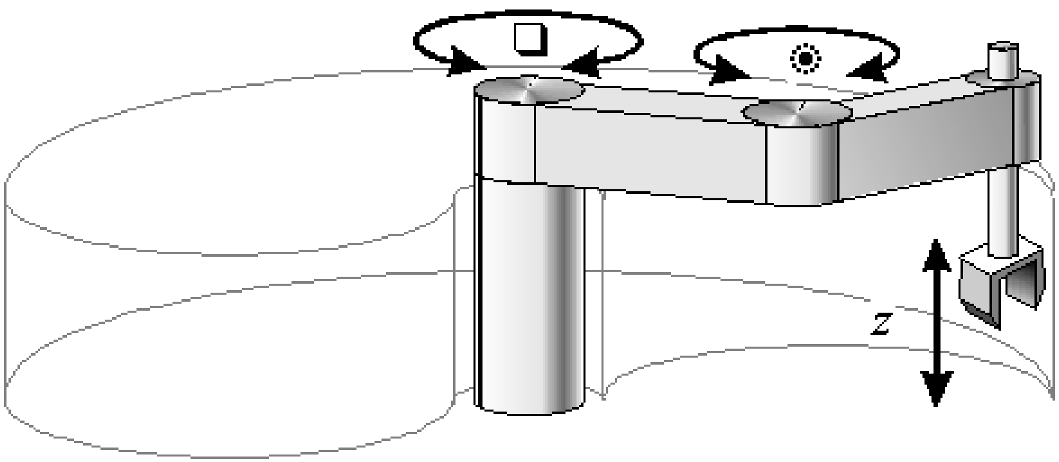


Robot Joints (cont…)

- Prismatic Cartesian robot



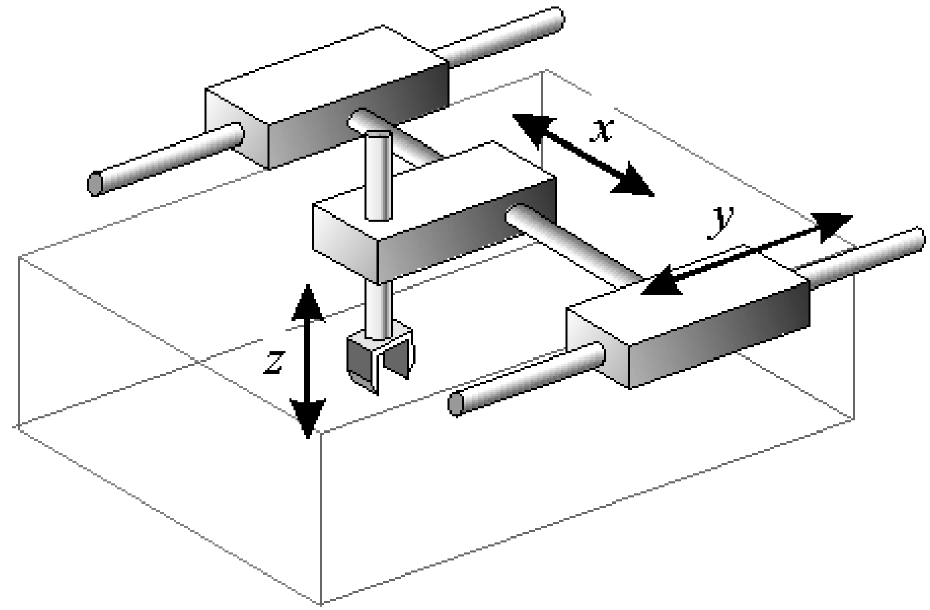
- Actuators are used in order to produce mechanical movement in robots.

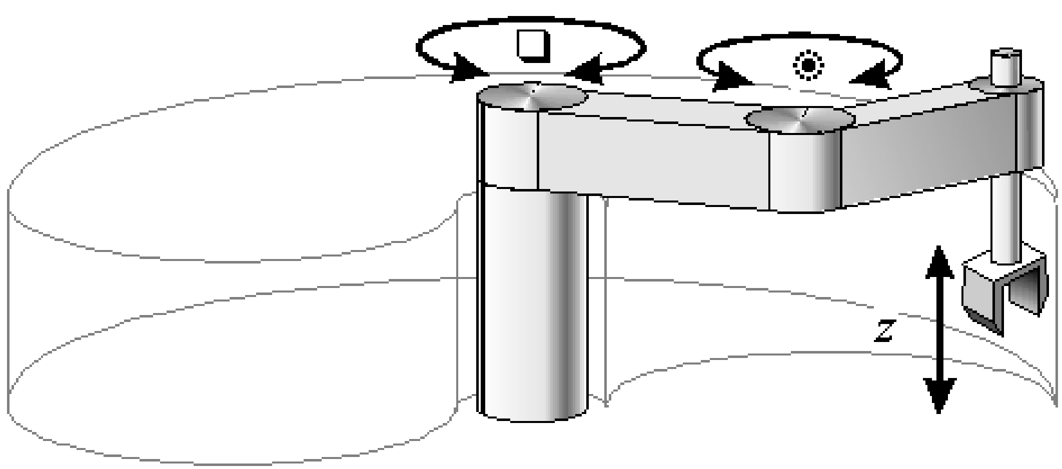


Rotary SCARA robot

Robot Joints (cont…)

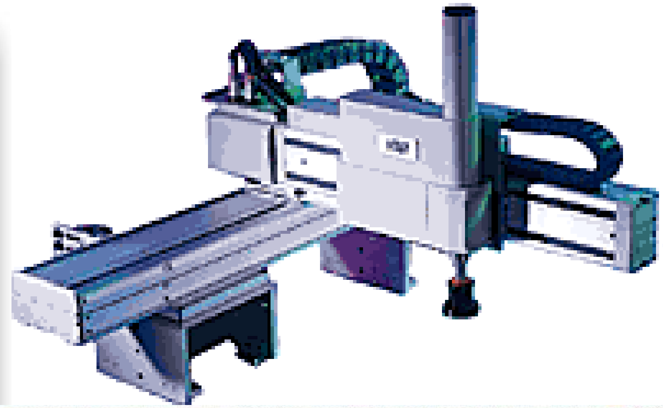
Prismatic Cartesian robot





Rotary SCARA robot

Robot Joints (cont…)



Actuators

- In this course we will only deal with electrical motors
- In past we built pneumatic robots which you can still find in the lab.
  - We will build them again after purchasing air compressor
- My first robot was very strong and it was hydraulic.
  - It pissed hot oil at students in Warsaw.

Actuator Control

1. Robots are classified by control method into **servo** and **non-servo** robots

2. *Non-servo robots* are essentially open-loop devices whose movements are limited to predetermined mechanical stops

3. Servo robots use closed-loop computer control to determine their motion

Types of Actuators

1. Some of the most common actuators are:

   1. **Electric motors**, the most common actuators in mobile robots, used both to provide location by powering wheels or legs, and for manipulation by actuating robot arms

   2. **Artificial muscles** of various types, none of which are very good approximations of living muscles

   3. **Pneumatic** and **hydraulic** actuators, used in industry for large manipulation tasks but seldom for mobile robots

Actuators

- Motor and Encoder
- H-Bridge
- Pulse-Width-Modulation (PWM)
- Servos
- Other robotic actuators

Actuators and motors

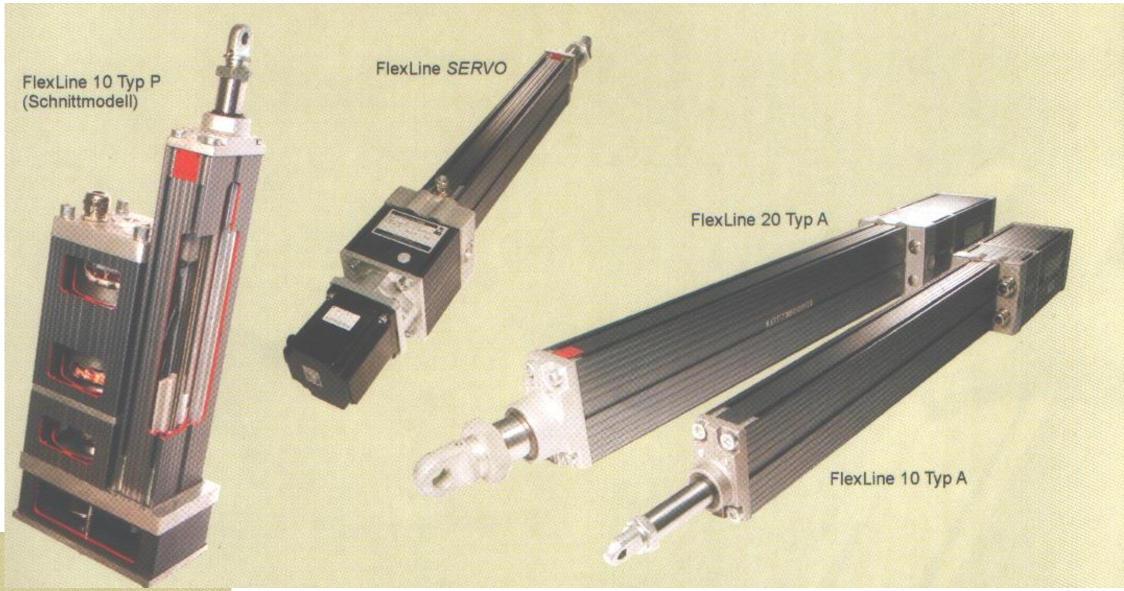
- Most actuators convert electrical energy into mechanical energy through the use of electromagnetic fields and rotating wire coils.
- When a voltage is applied to a motor, it outputs a fixed amount of mechanical power
    - (usually to a shaft, gear, and/or wheel),
    - spinning at some speed
    - with some amount of torque.

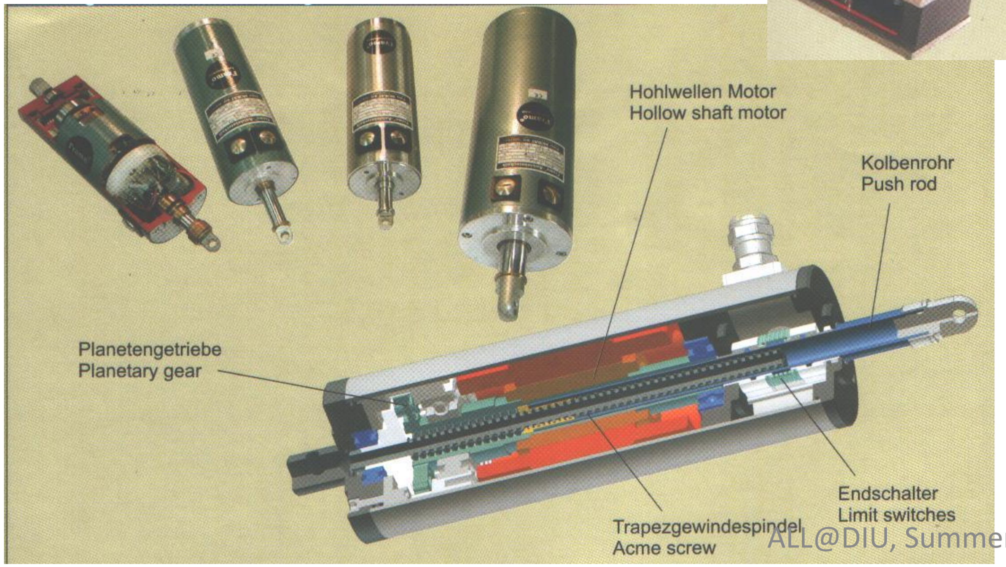
Electric Motors

Electric actuators

•Mainly rotating but also linear ones are available

•linear movement with gear or with real linear motor





Electrical Actuator Types

- DC-motors
- brushless DC-motors
- asynchronous motors
- synchronous motors
- reluctance motors (stepper motors)

Not discussed

Electric Motors

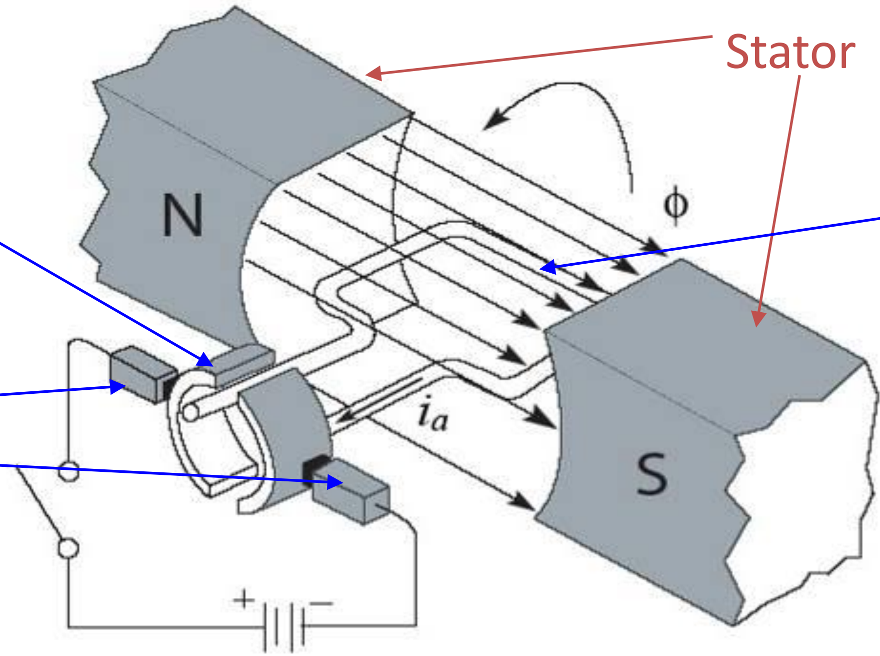
1. Electric motors are the most common source of torque for mobility and/or manipulation in robotics

2. 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

How Do Electric Motors Work?

Components Of An Electric Motor

- The principle components of an electric motor are:
  1. North and south **magnetic poles** to provide a strong magnetic field.
     1. Being made of bulky ferrous material they traditionally form the outer casing of the motor and collectively form the **stator**
  2. 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



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

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

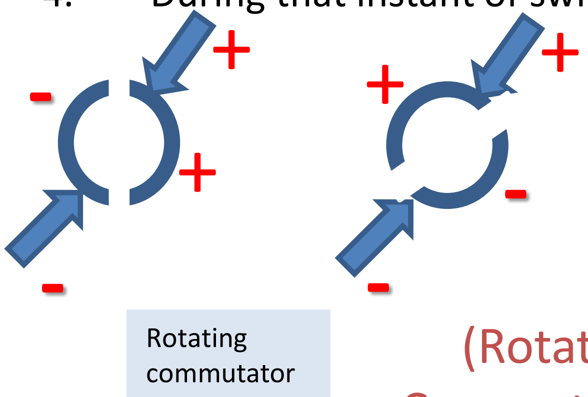
How Do Electric Motors Work?

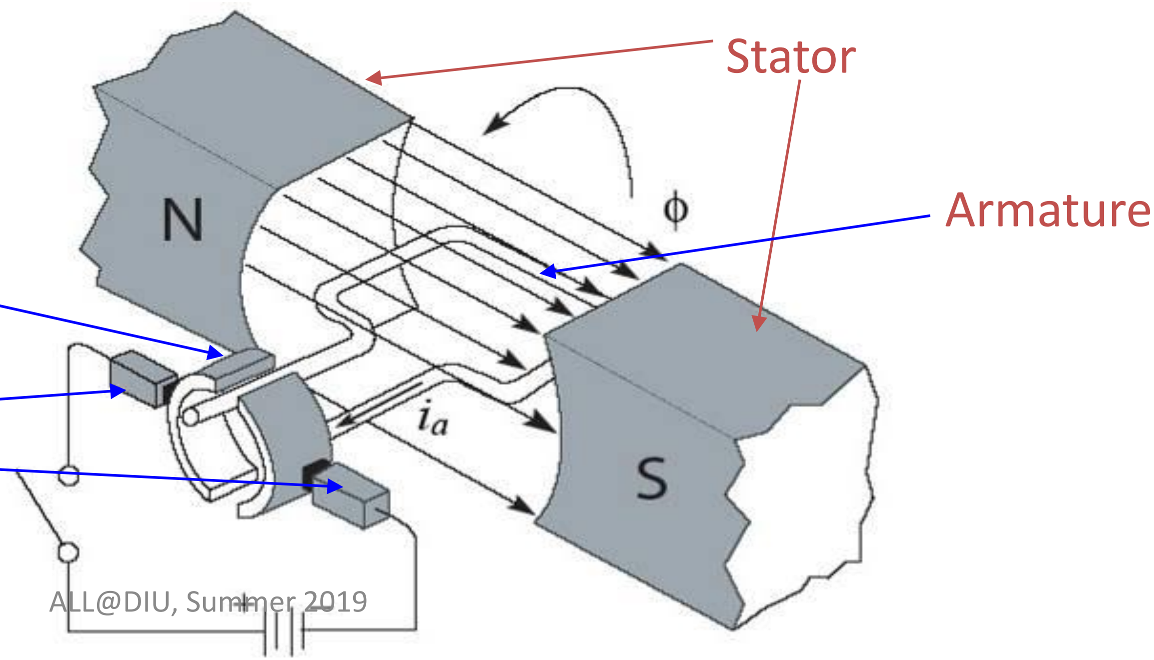
1. The classic DC motor has a rotating armature in the form of an electromagnet

2. **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

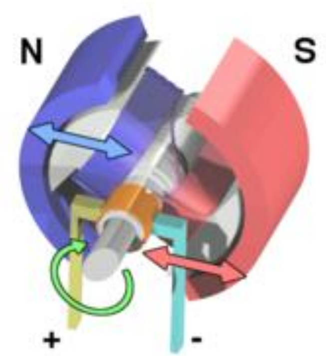
3. As the poles of the armature electromagnet pass the poles of the permanent magnets, the commutator reverses the polarity of the armature electromagnet.

4. During that instant of switching polarity, inertia keeps the motor going in the proper direction

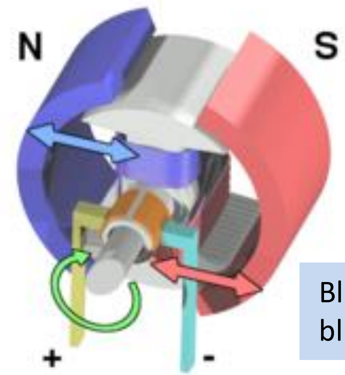




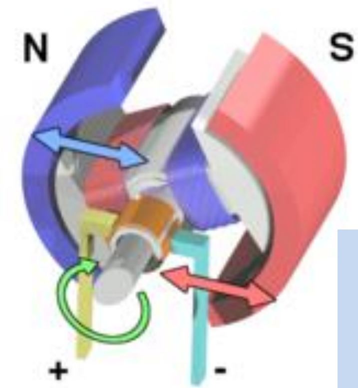
How Do Electric Motors Work? (cont…)



Blue in armature near blue in stator



Blue between blue and red

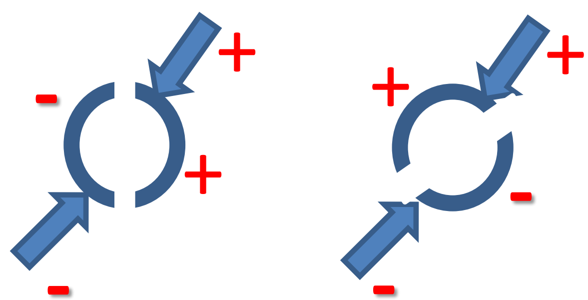


Blue near red, because of commutator rotation

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

The armature continues to rotate

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



Rotating commutator

Application of Electric Motors

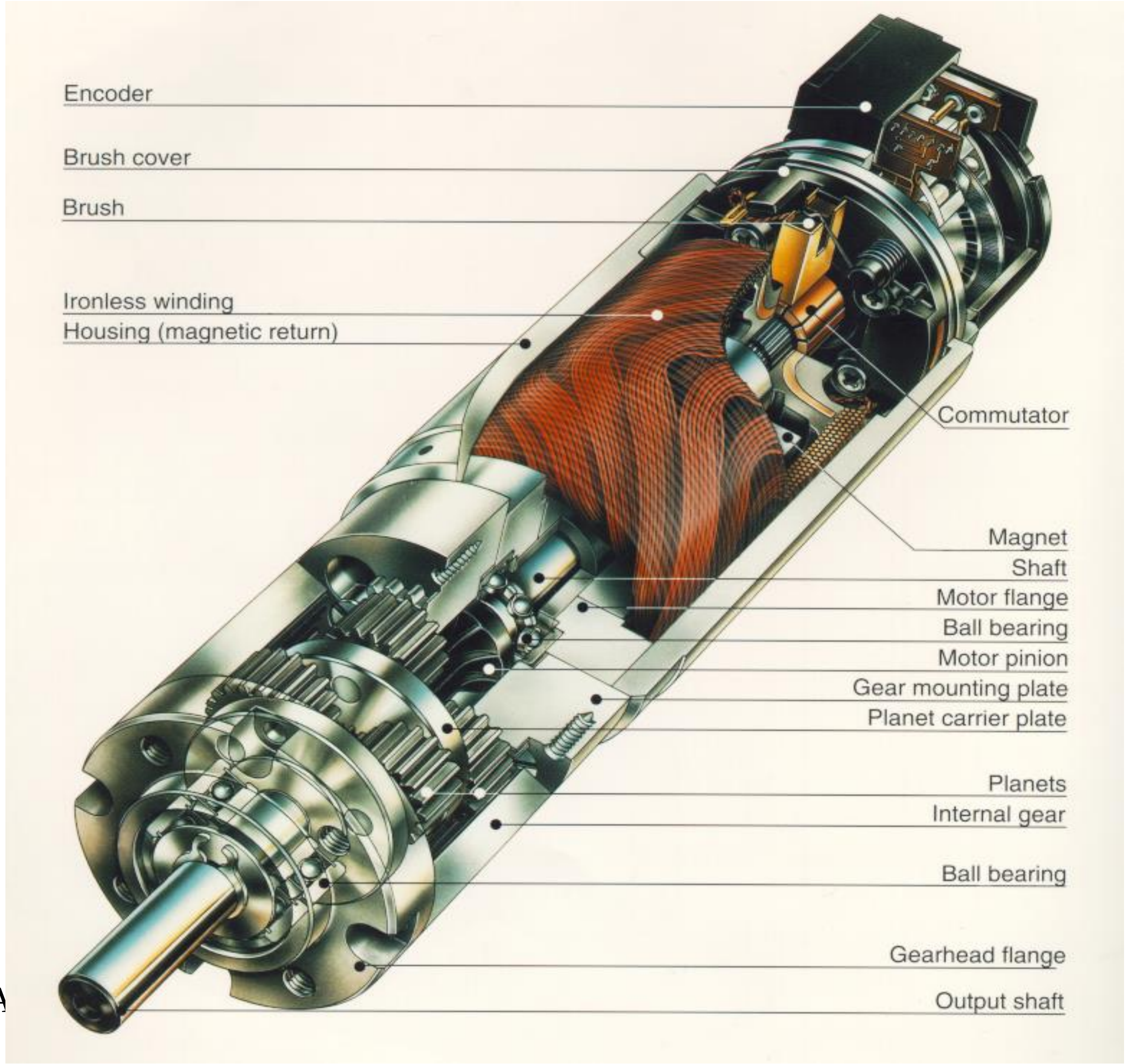
1. Electric motors usually have a small rating, ranging up to a few horsepower

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

3. 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

High quality DC-Motors

- Not cheap
- easy to control
- 1W - 1kW
- can be overloaded
- brushes wear
- limited overloading on high speeds

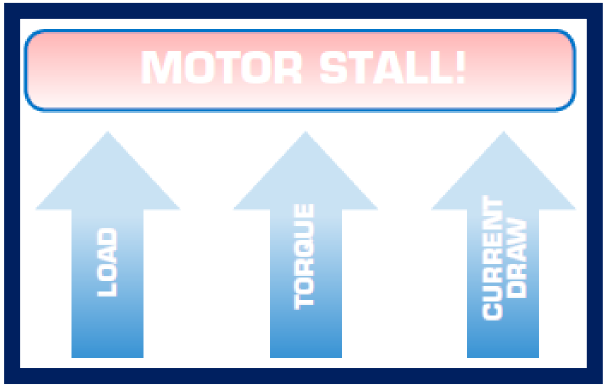


A

▶ Motor Loading

- Motors apply torque in response to loading
- **Motor Loading** happens when there is any opposing force (such as friction or a heavy mass) acting as a load and requiring the motor to ***output torque to overcome it.***
- The higher the load placed on a motor output, the more the motor will "fight back" with an opposing torque.
- However, since the motor outputs a fixed amount of power, the more torque the motor outputs, the slower its rotational speed.

Motor applies torque to overcome the friction of a wheel turning against the ground



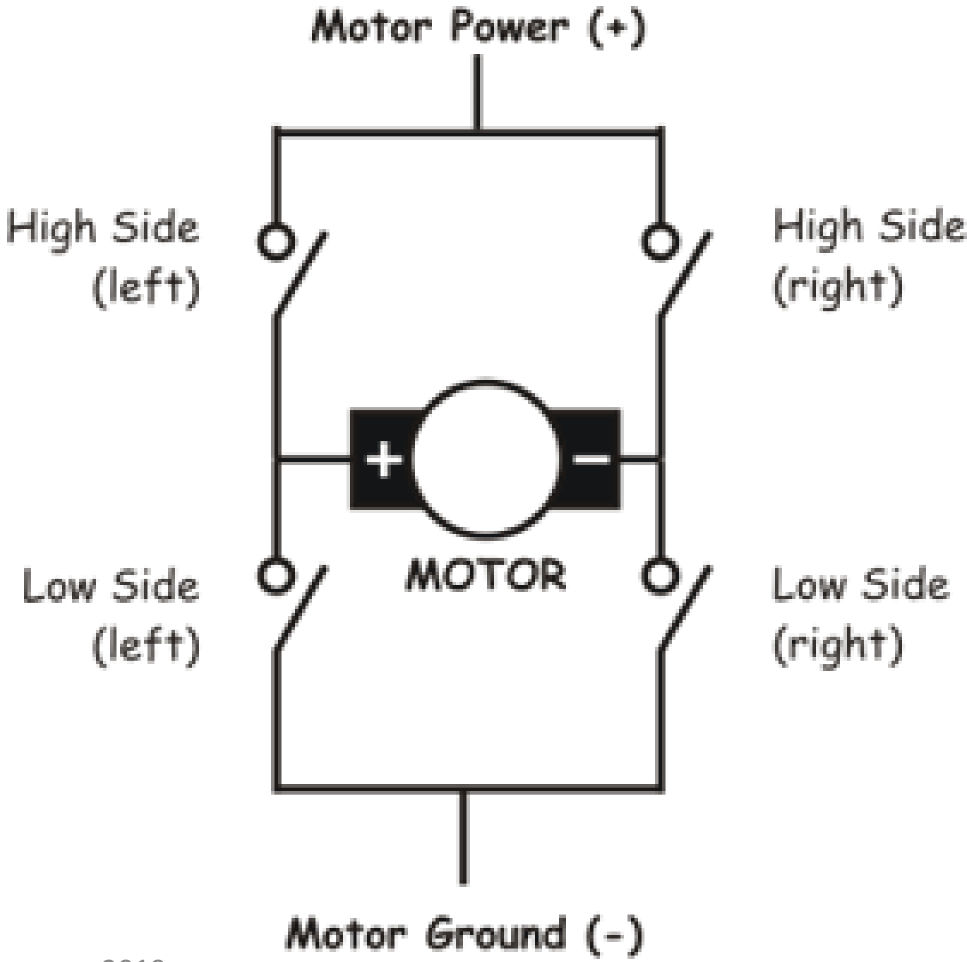
If you keep increasing the load on a motor, the motor eventually stops spinning or **stalls**.

REMEMBER THAT MOTORS STALL.
DO NOT DAMAGE THE SERVOS!!

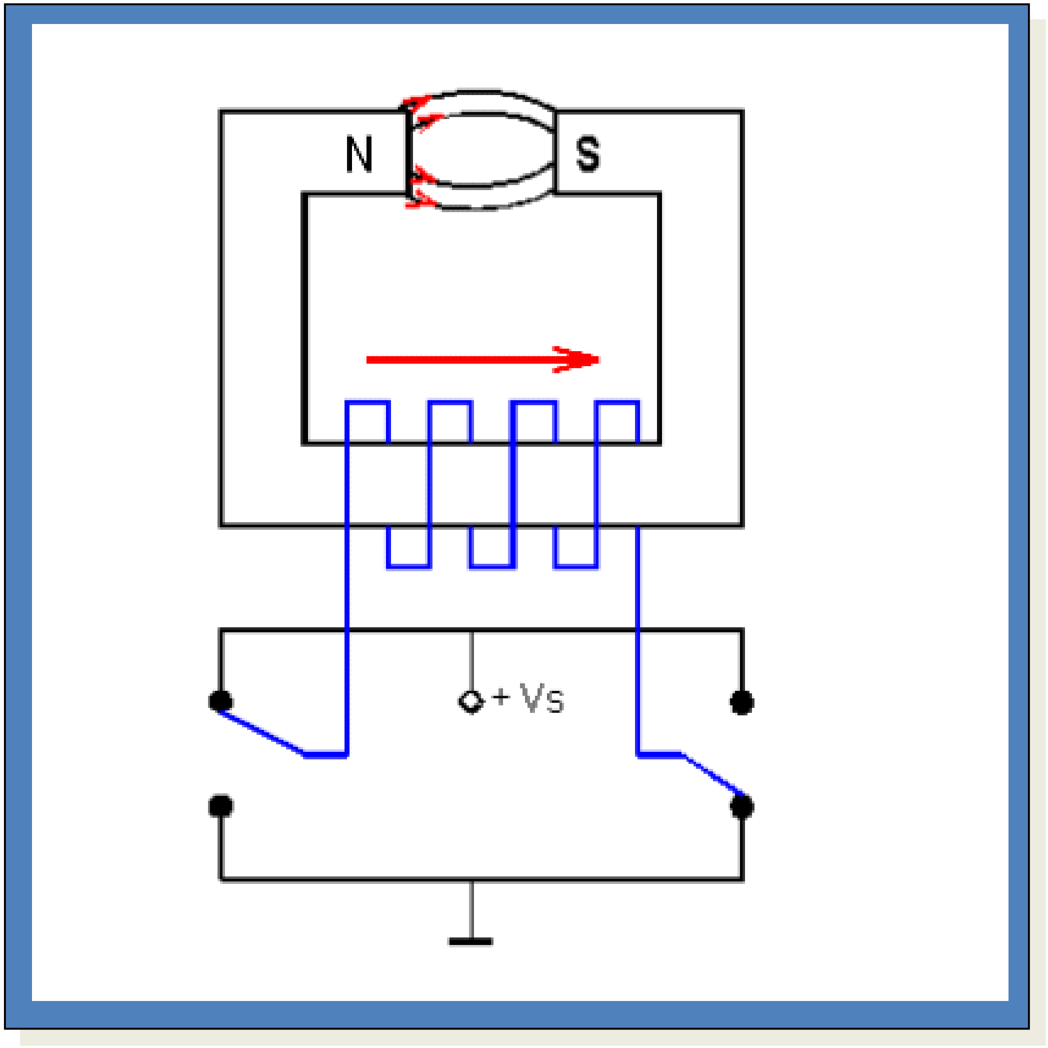
- A DC Motor draws a certain amount of electrical current (measured in amps) depending on how much load is placed on it.
- As the load increases on the motor, the more torque the motor outputs to overcome it and the more current the motor draws.

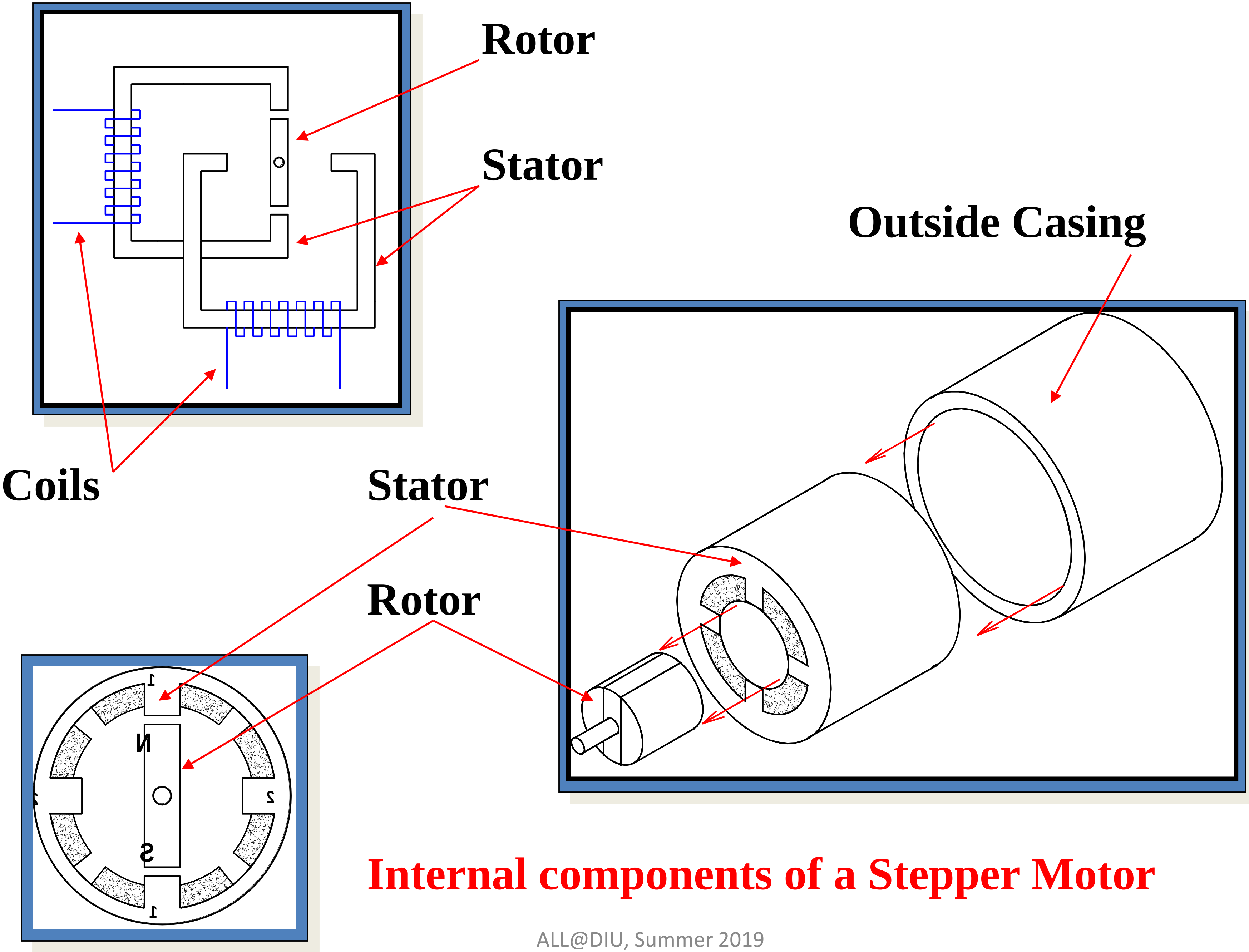
DC-motor control

- Controller + H-bridge
- PWM-control
- Speed control by controlling motor current=torque
- Efficient small components
- PID control



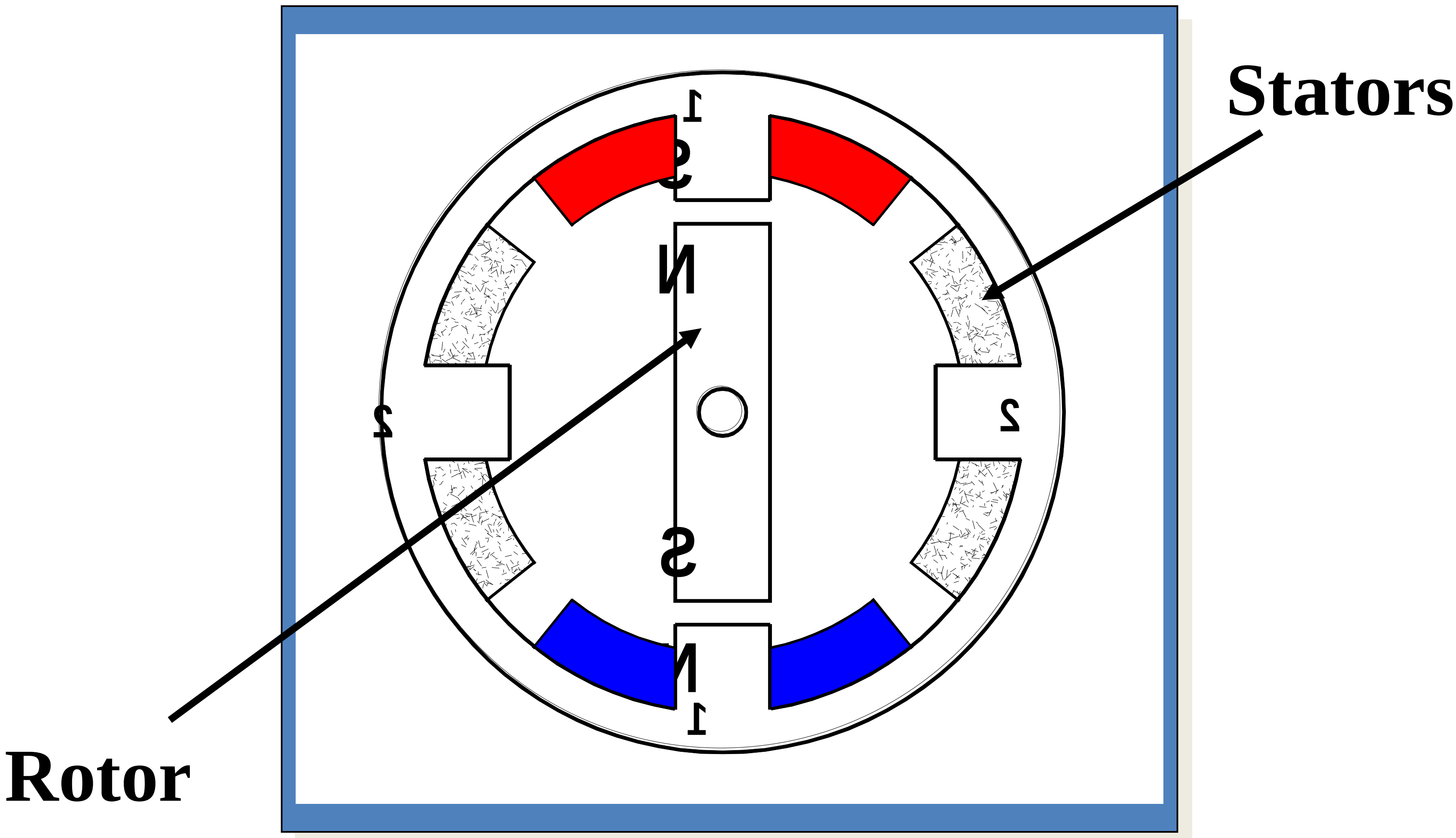
Stepper Motor / Electro magnet



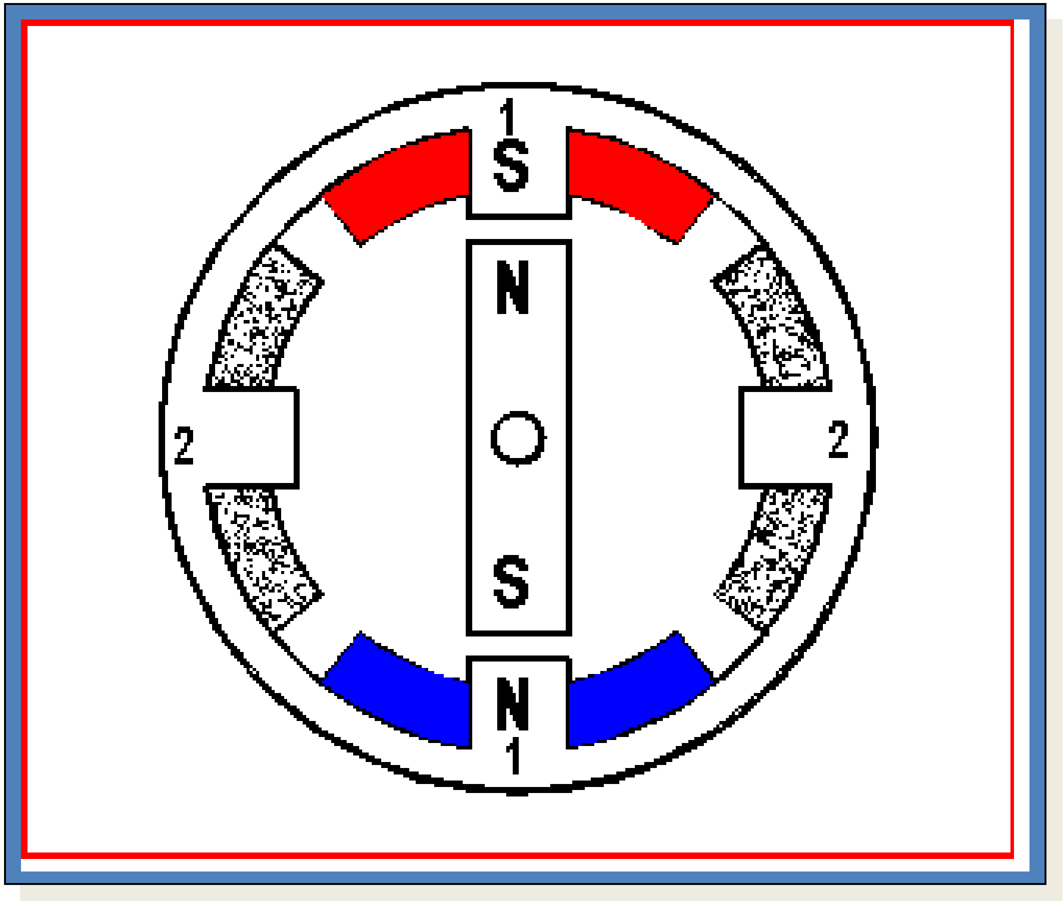


Internal components of a Stepper Motor

Cross Section of a Stepper Motor

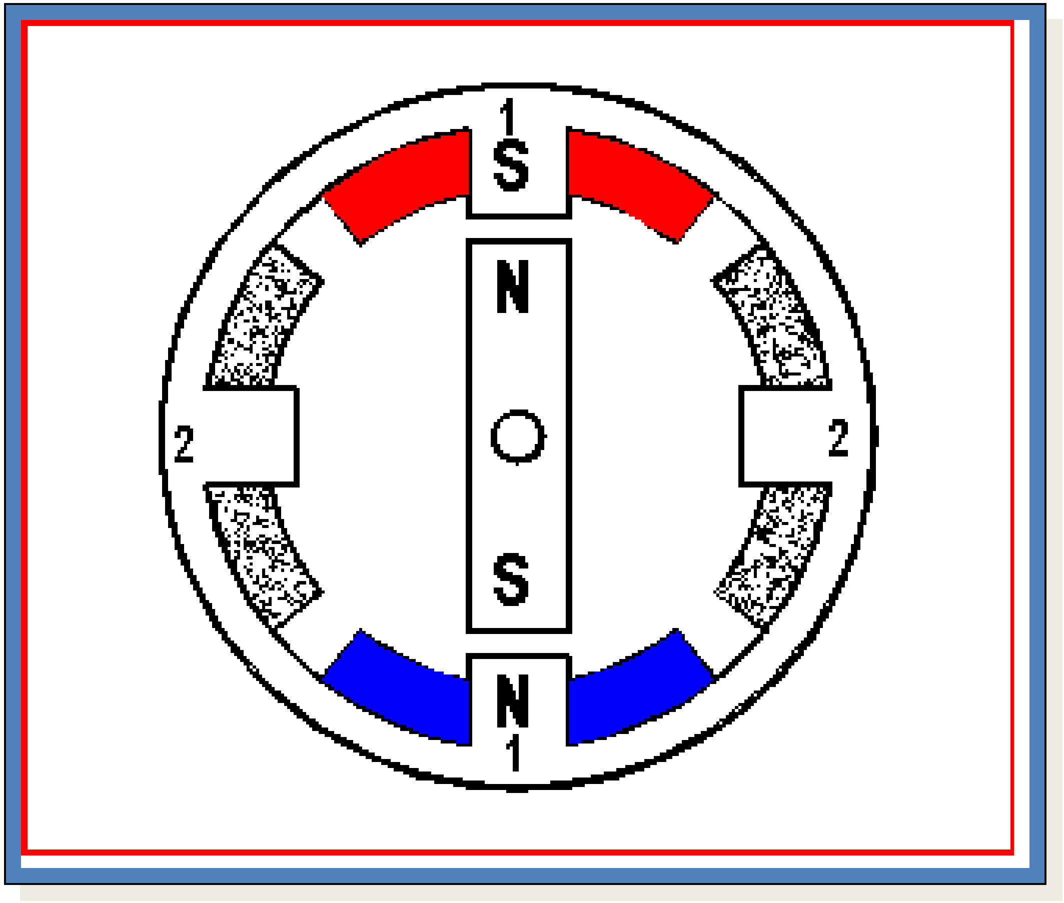


Full Step Operation

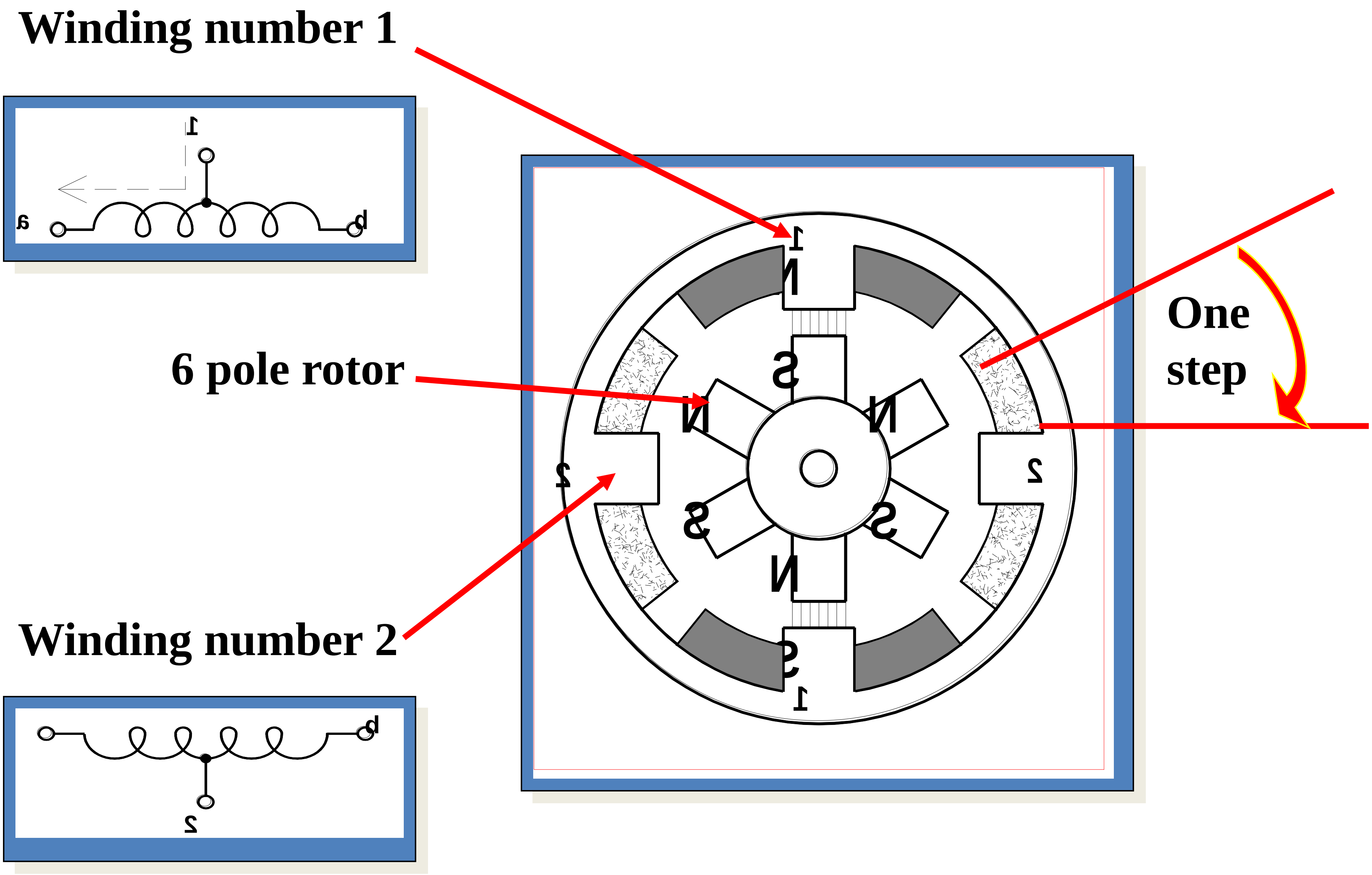


Four Steps per revolution i.e. 90 deg. steps.

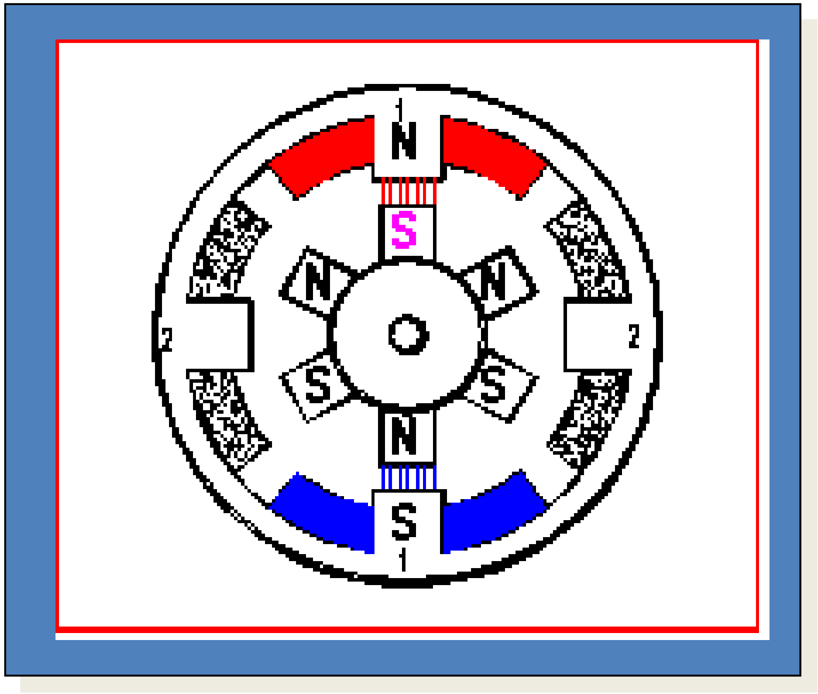
Half Step Operation



Eight steps per. revolution i.e. 45 deg. steps.

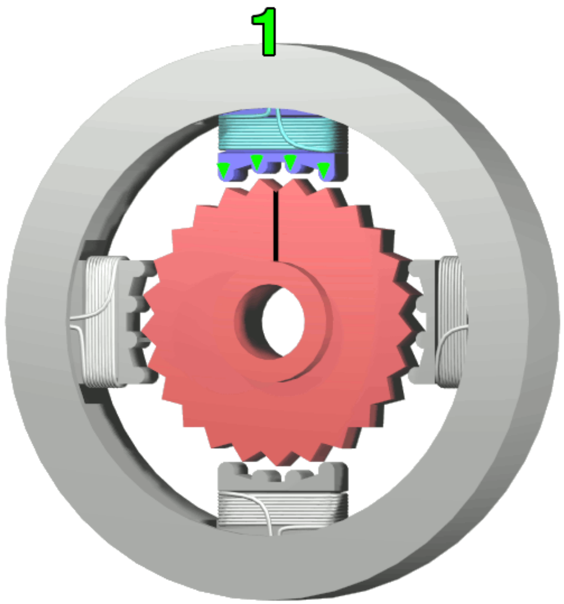

Winding number 1
6 pole rotor
One step
Winding number 2

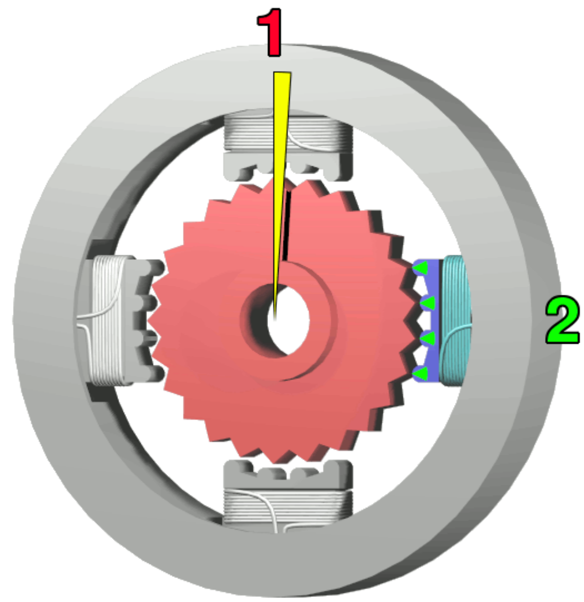
Six pole rotor, two electro magnets.



How many steps are required for one complete revolution?

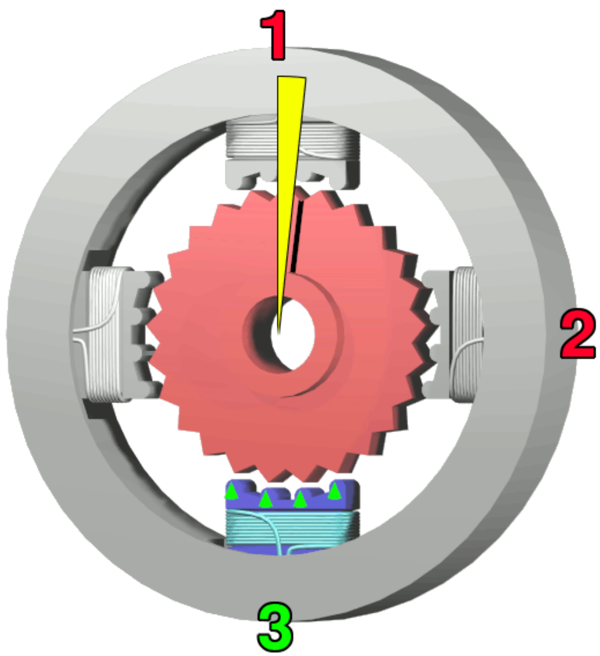
Practical Stepper motor operation



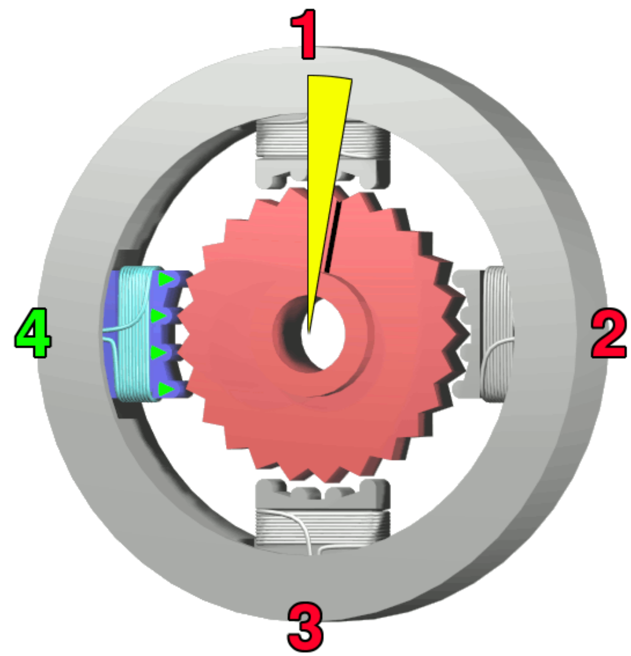


The top electromagnet (1) is turned on, attracting the nearest teeth of a gear-shaped iron rotor. With the teeth aligned to electromagnet 1, they will be slightly offset from electromagnet 2

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

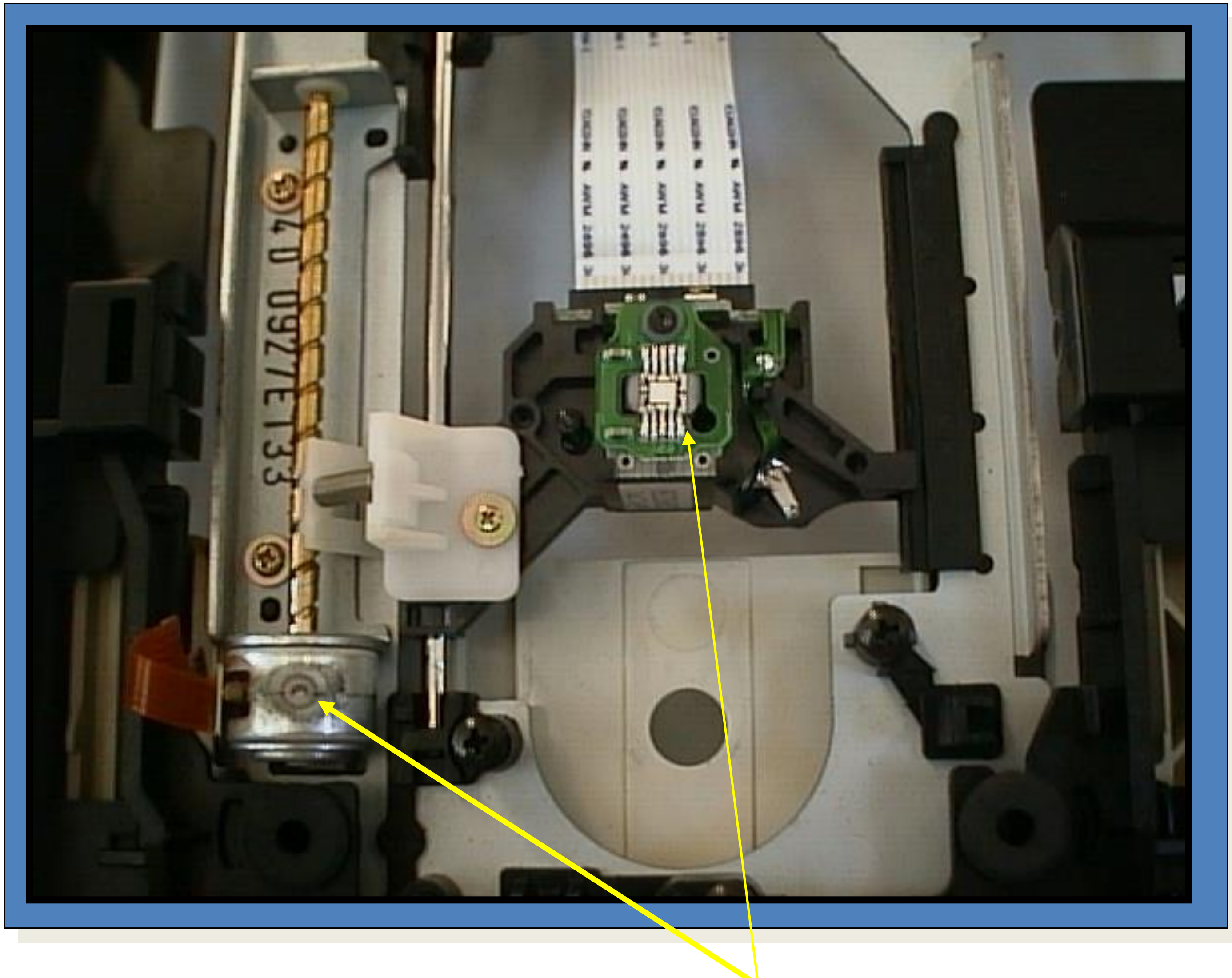


The bottom electromagnet (3) is energized; another 3.6° rotation occurs.



The left electromagnet (4) is enabled, rotating again by 3.6°. When the top electromagnet (1) is again enabled, 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 in this example.

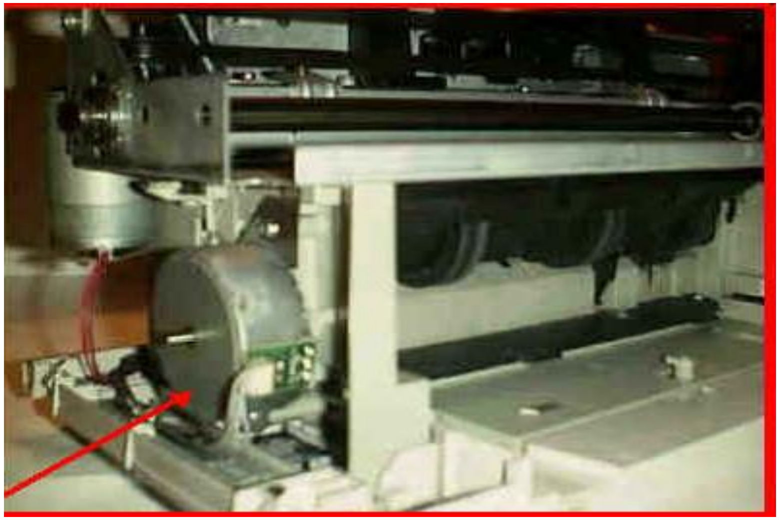
Stepper motor applications



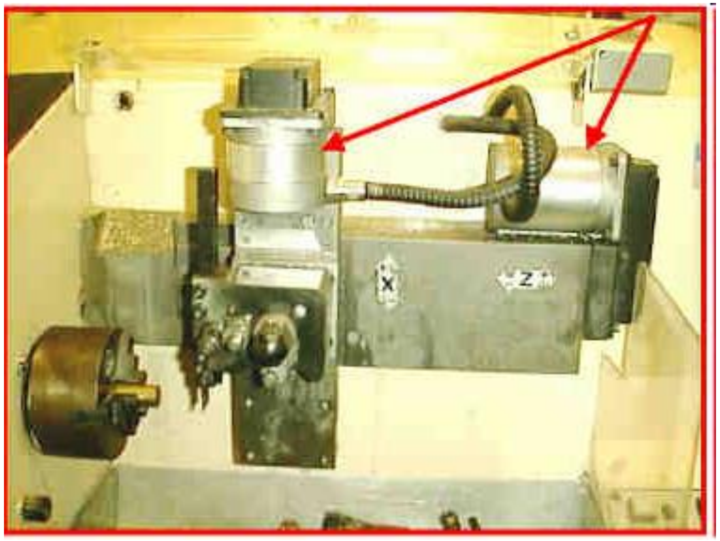
Stepping Motor to move read-write head

Stepper motor applications

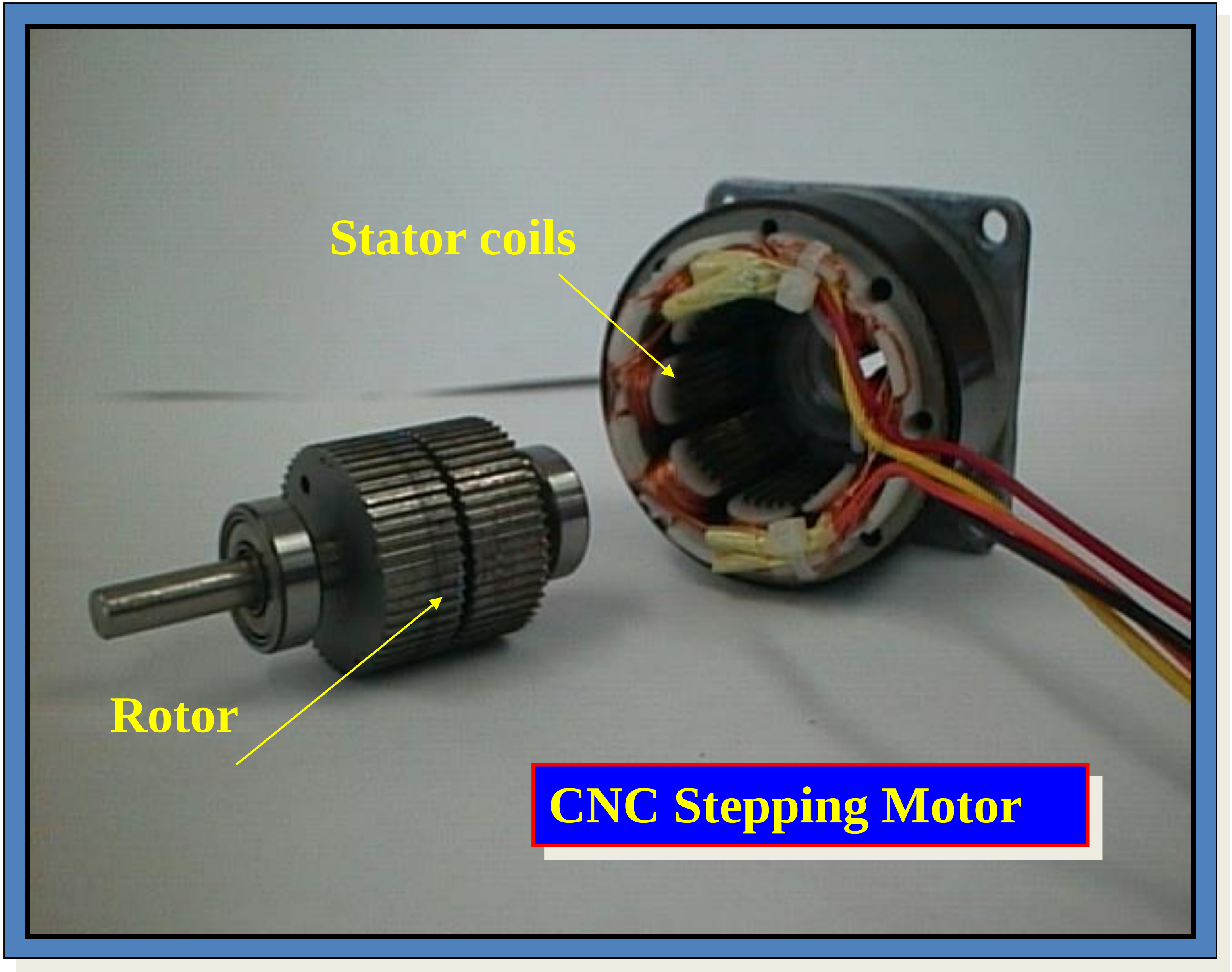
Paper feeder on printers



Stepper motors



CNC lathes


Stator coils
Rotor
CNC Stepping Motor

Advantages / Disadvantages

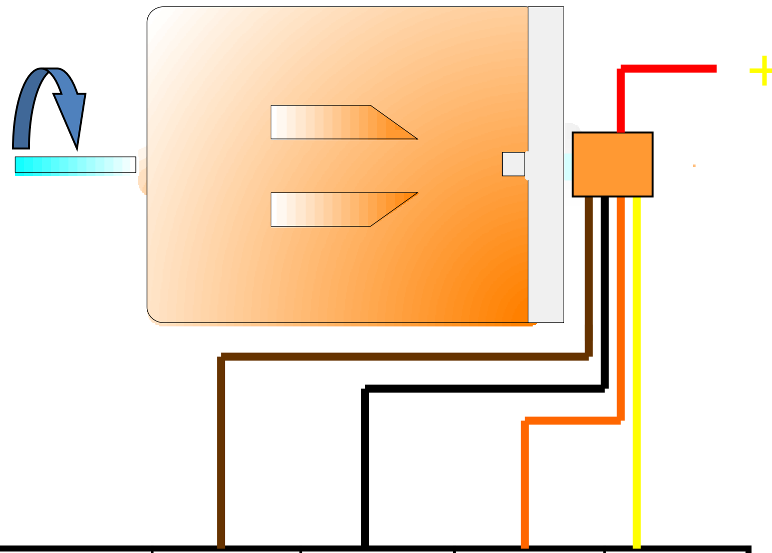
<u>Advantages:-</u>

- **Low cost for control achieved**
- **Ruggedness**
- **Simplicity of construction**
- **Can operate in an open loop control system**
- **Low maintenance**
- **Less likely to stall or slip**
- **Will work in any environment**

<u>Disadvantages:-</u>

- **Require a dedicated control circuit**
- **Use more current than D.C. motors**
- **High torque output achieved at low speeds**

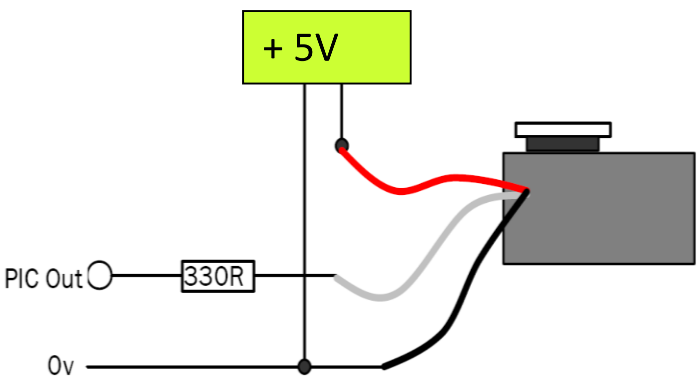
Control sequence to turn a stepper motor



CW ↓ CCW ↑

Step 1	0	0	1	1
Step 2	1	0	1	0
Step 3	1	1	0	0
Step 4	0	1	0	1

Servo Motor Detail



Actuator

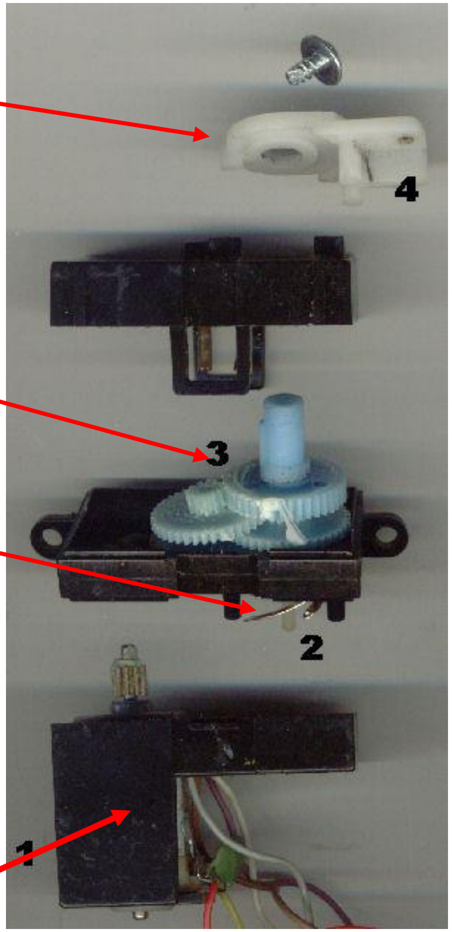
Reduction gear

Position feedback

Potentiometer

(closed loop system)

Small electric DC motor



Stepper Motors

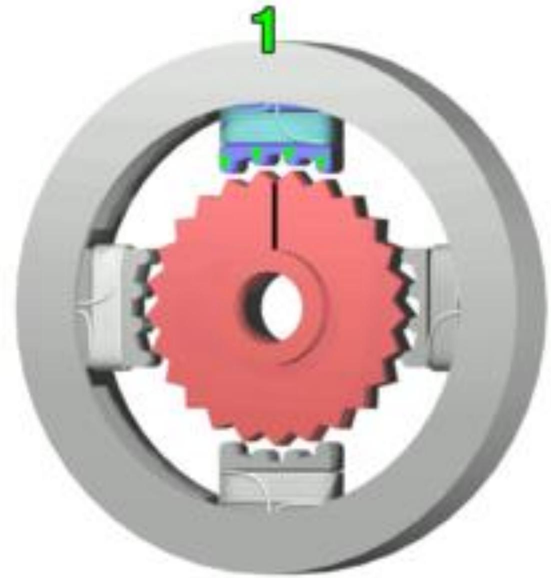
When incremental rotary motion is required in a robot, it is possible to use **stepper motors**

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)

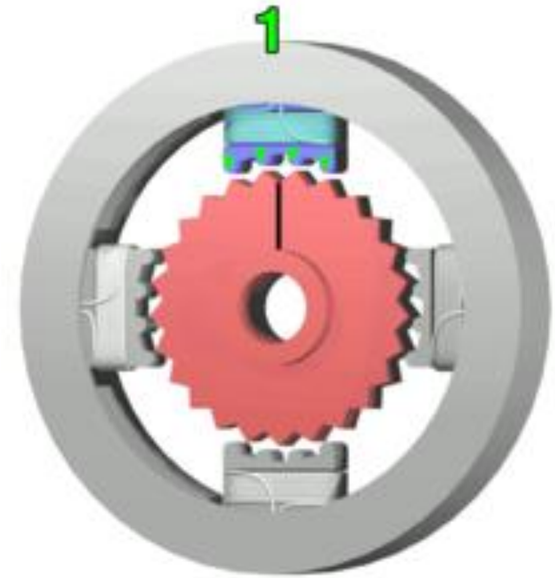
Stepper Motors



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

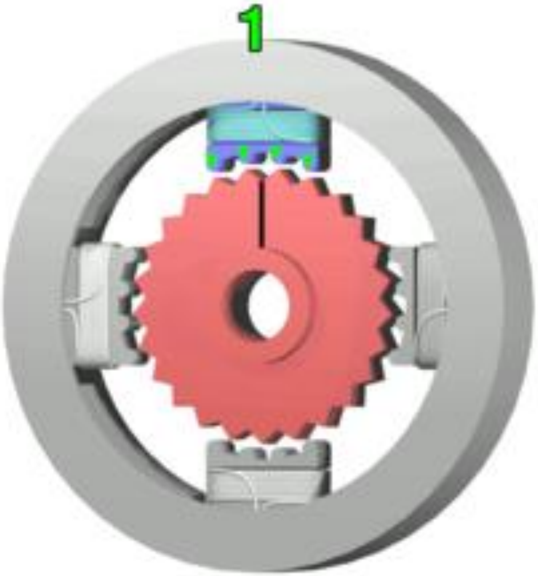
Stepper Motors (cont…)



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

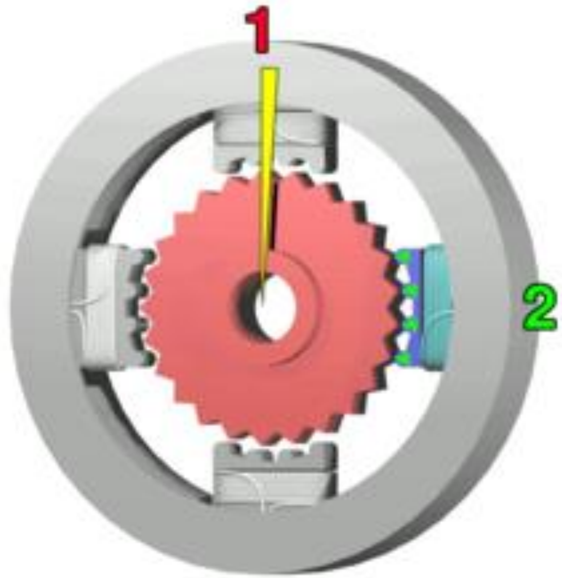
Where pairs of teeth are least offset, the electromagnetic pulse causes alignment and a small rotation is achieved, typically 1-2^{o}

How Does A Stepper Motor Work?



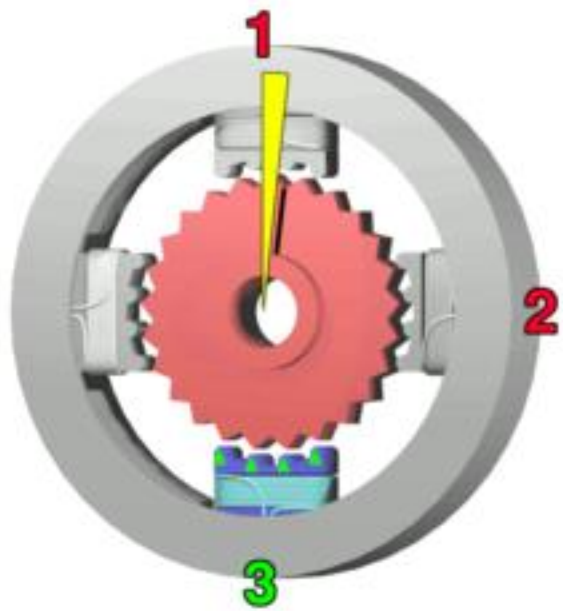
The top electromagnet (1) is charged, attracting the topmost four teeth of a sprocket.

How Does A Stepper Motor Work? (cont…)



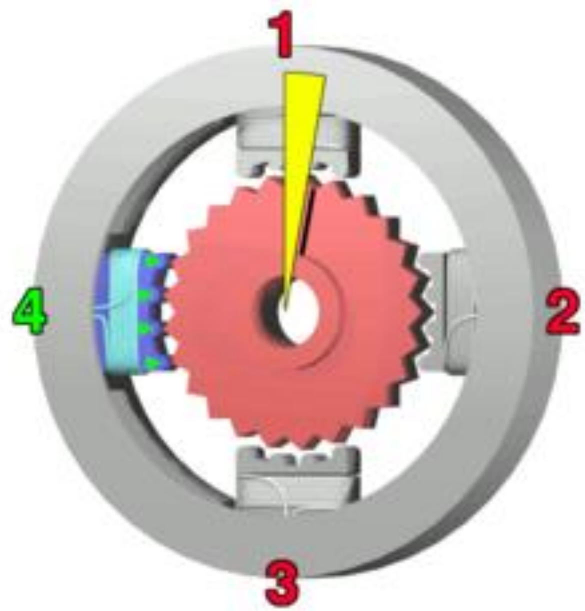
The top electromagnet (1) is turned off, and the right electromagnet (2) is charged, pulling the nearest four teeth to the right. This results in a rotation of 3.6°

How Does A Stepper Motor Work? (cont…)



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

How Does A Stepper Motor Work? (cont…)



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:

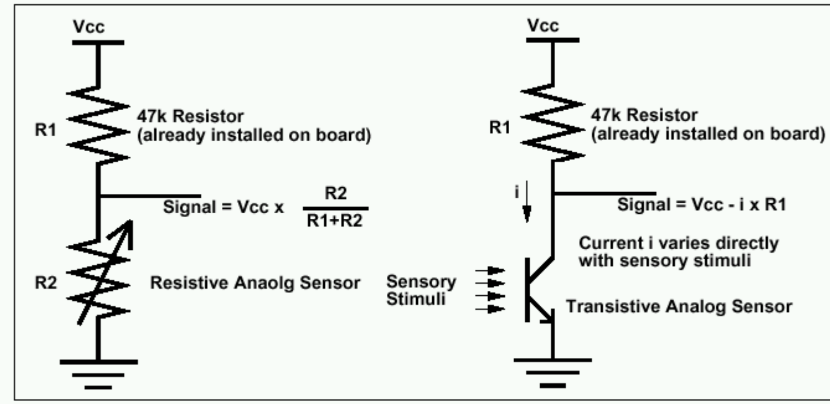
- Their control is directly compatible with digital technology
- They can be operated open loop by counting steps, with an accuracy of ± 1 step.
- They can be used as holding devices, since they exhibit a high holding torque when the rotor is stationary

Analog Sensors

Analog Sensors

- A number of sensors have analog output signal rather than digital signals
- A/D converter is required to connect to CPU
- Examples:
  - Microphone
  - analog infrared distance sensor
  - analog compass
  - barometer sensor

Resistive Sensors



- The resistance of resistive analog sensors, like the bend sensors or potentiometers, change with changes in the environment:
  - an increase in light,
  - or a physical deformation.
- The change in resistance causes a change in the voltage at the signal input by the voltage divider relation.

$$V_{sig} = \frac{R_{sensor}}{47\Omega + R_{sensor}} * 5V$$

Transitive Analog Sensor

- Transitive analog sensors, like the photo transistors and reflectance sensors, work like a water faucet.

- Providing more of what the sensor is looking for opens the setting of the valve, allowing more current to flow.

- This makes the voltage at the signal decrease.
- A photo transistor reads around 10 in bright light and 240 in the dark.
- One problem that may occur with transitive sensors is that the voltage drop across the resistor may not be large enough when the transistor is open.
  - Some transitive devices only allow a small amount of current to flow through the transistor.

Transitive Analog Sensor (cont)

- A larger range for the sensor can be accomplished by putting a larger pull-up resistor.
  - By having a larger resistor, the voltage drop across the pull-up resistor will be proportional to the resistance.
- Martin’s book gives examples of use and mountings for each type of sensor.
- Keep in mind that these are only simple examples and are not the only possible uses for them.
- It's up to you to make creative use of the sensors you have.

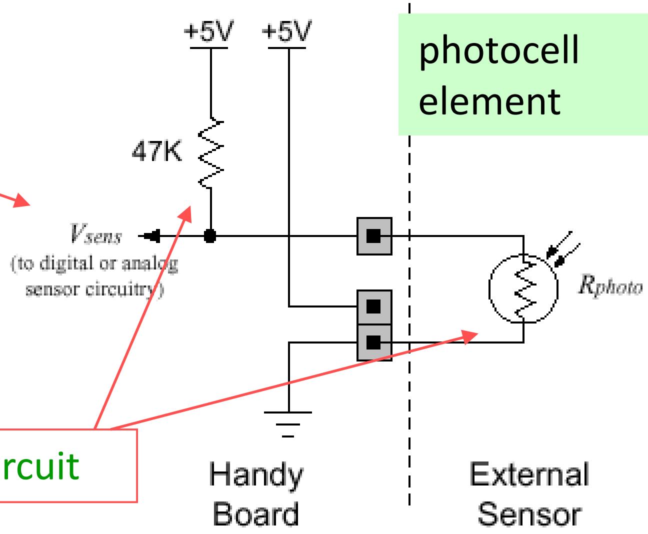
Sensor Interfacing to Analog Inputs

•V_{sens} voltage at the center tap of the two resistors is proportional to the ratio of the two resistances.

R_{photo} = 47KΩ, V_{sens} = 2.5 v (exactly)

R_{photo} << 47KΩ, V_{sens} ~= gnd

R_{photo} >> 47KΩ, V_{sens} ~= +5 v



photocell element

Two resistors form voltage divider circuit

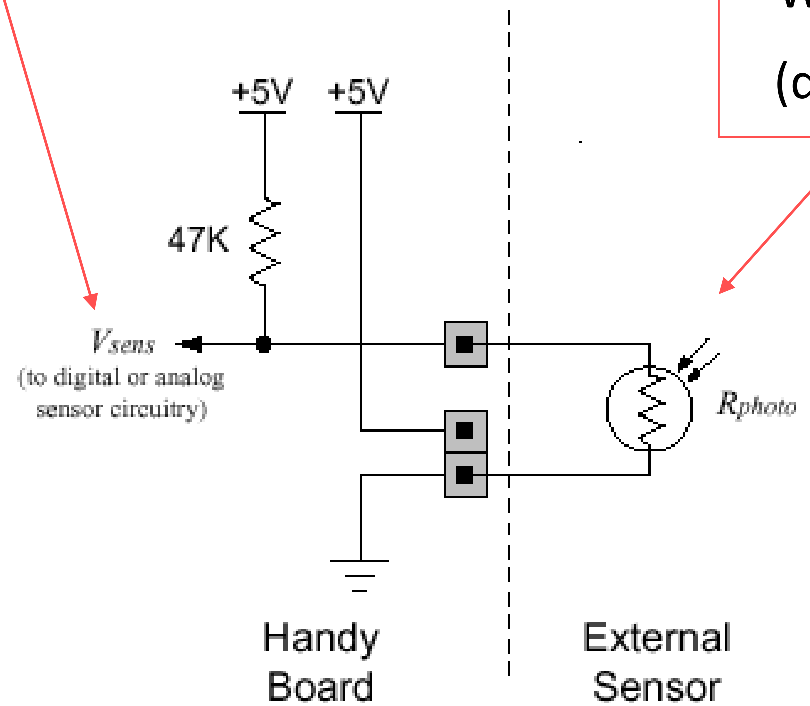
Also possible to connect circuits that generate a voltage

Sensor Interfacing to Analog Inputs

0 to 5 volts are converted into 8–bit numbers 0 to 255 (decimal) (A/D conversion)

–When the photocell resistance is small (brightly illuminated), the V_{sens} ~= 0v

– When the photocell resistance is large (dark), V_{sens} ~= +5 v

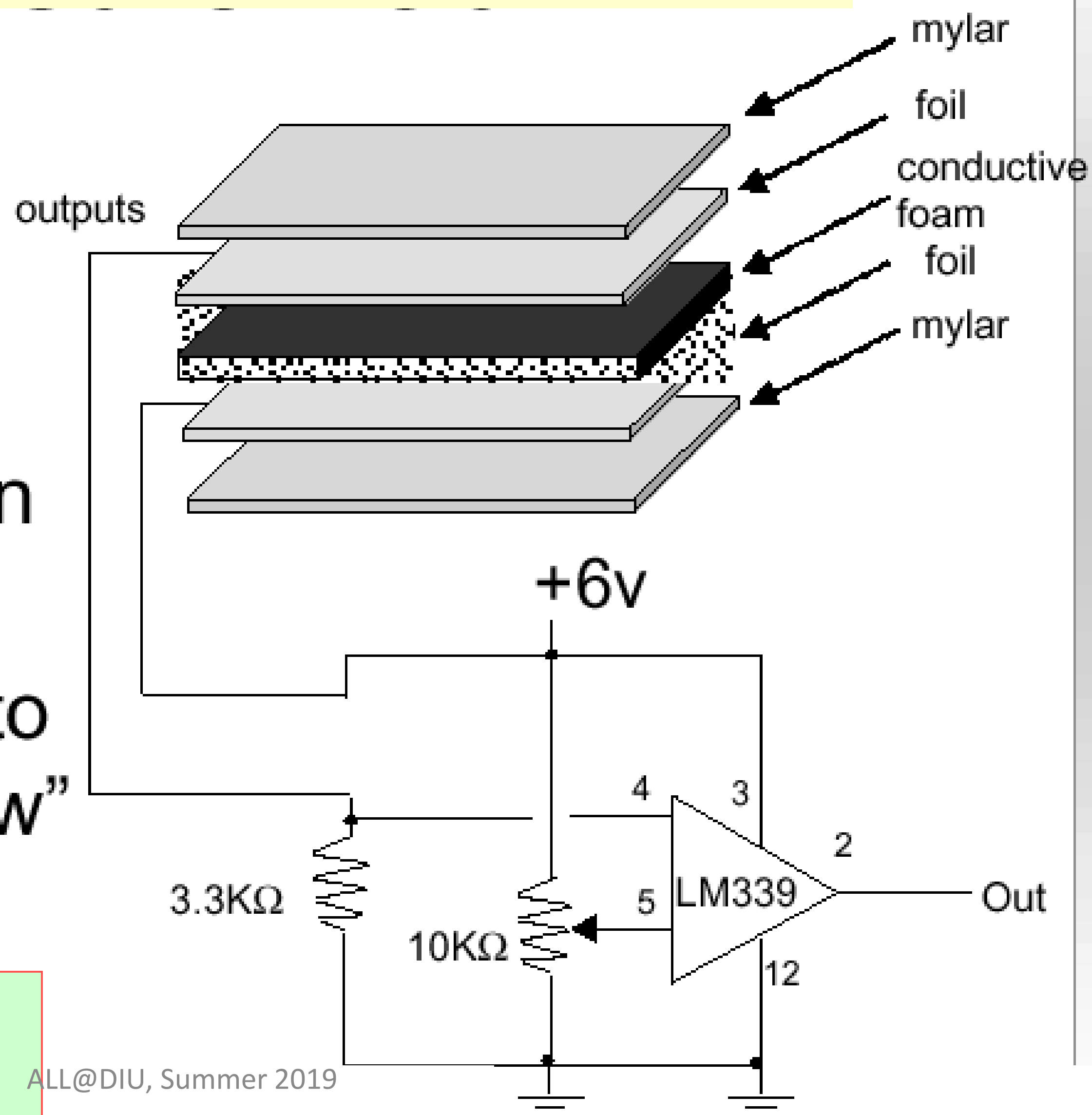


Resistive Position Sensors

Potentiometers. Glowes. Pads. Bend Sensors. Other….?

Pressure Pad

- Often used in grippers to detect the amount of pressure applied in picking up objects
- Relatively simple to build a “home-brew” version

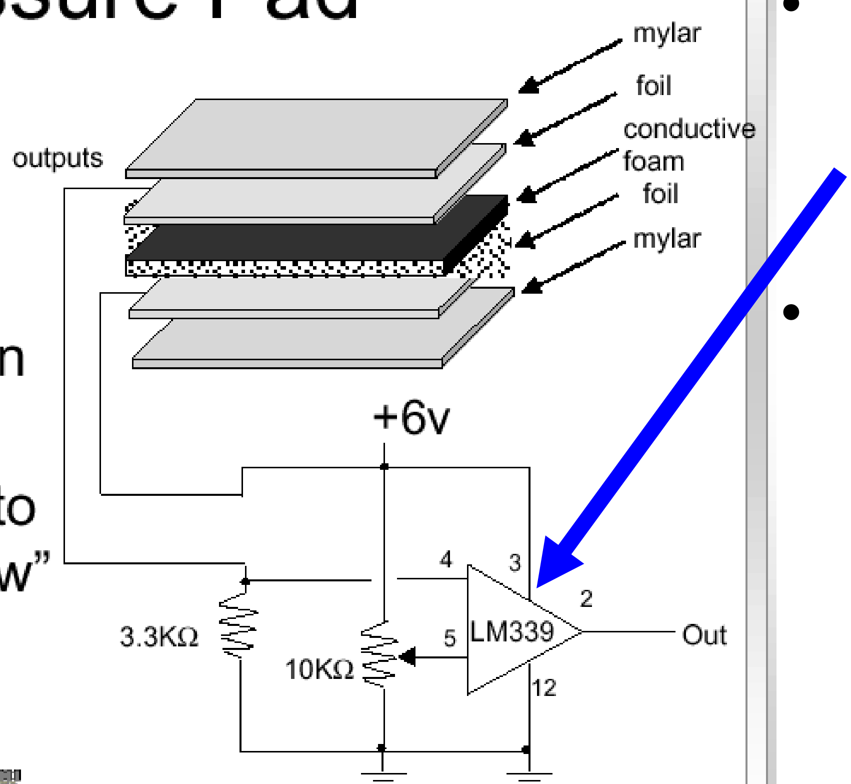


You can purchase such pad for Nintendo games

Pressure Pad

Pressure Pad

- Often used in grippers to detect the amount of pressure applied in picking up objects
- Relatively simple to build a "home-brew" version



- LM339 is a quad comparator circuit:
  - Output will be +6V
- Another approach is to use ohm meter to detect the resistance change which would be proportional to amount of pressure applied.

Potentiometer: the main ideas

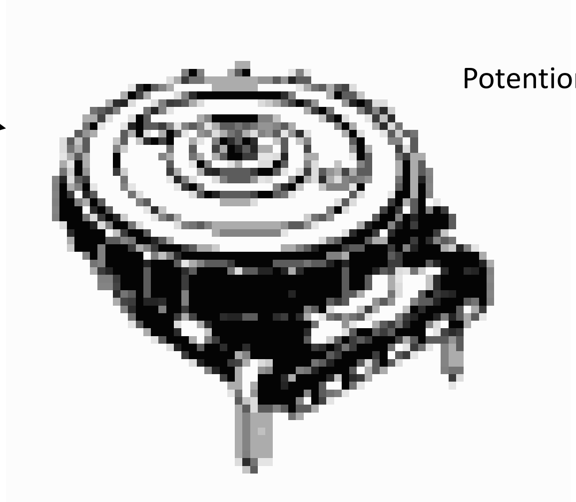
- **Potentiometers** are very common for manual tuning; you know them from some controls (such as volume and tone on stereos).
- Typically called ***pots,*** they allow the user to manually adjust the resistance.

- The general idea is that the device consists of a movable tap along two fixed ends.
- As the tap is moved, the resistance changes.

- As you can imagine, the resistance between the two ends is fixed, but the resistance between the movable part and either end varies as the part is moved.
- In robotics, pots are commonly used to ***sense*** and **tune position** for sliding and rotating mechanisms.

Potentiometers versus resistance sensors

- Fixed Rotation Sensors
- Easy to find, easy to mount



Potentiometer

Light Sensor

- Good for detecting direction/presence of light
- *Non-linear* resistance
- Slow response

Look to catalogs:

Cadmium Sulfide Cell

HANDYBOARD: Gleason Research. http://www.gleasonresearch.com/

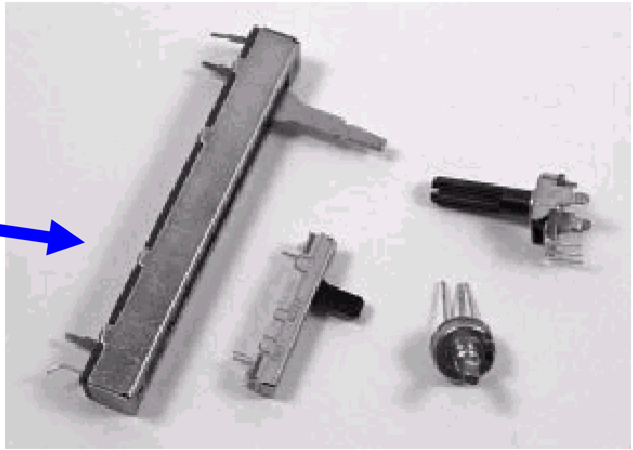
http://handyboard.com

DISTRIBUTOR OF AGE BEND SENSOR: Images Company: http://www.imagesco.com

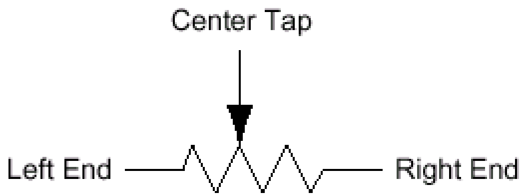
PITSCO LEGO DACTA, JAMECO, ETC - see the book and my webpage.

Potentiometers

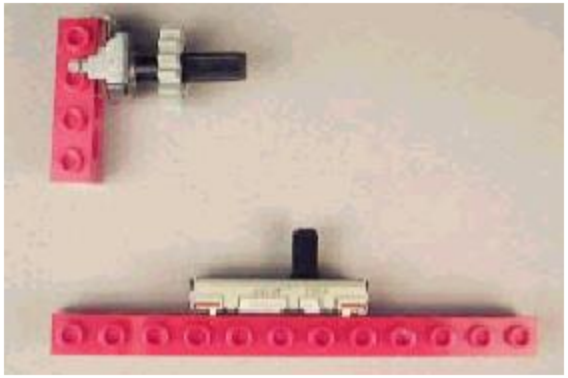
- Manually-controlled variable resistor, commonly used as volume/tone controls of stereos



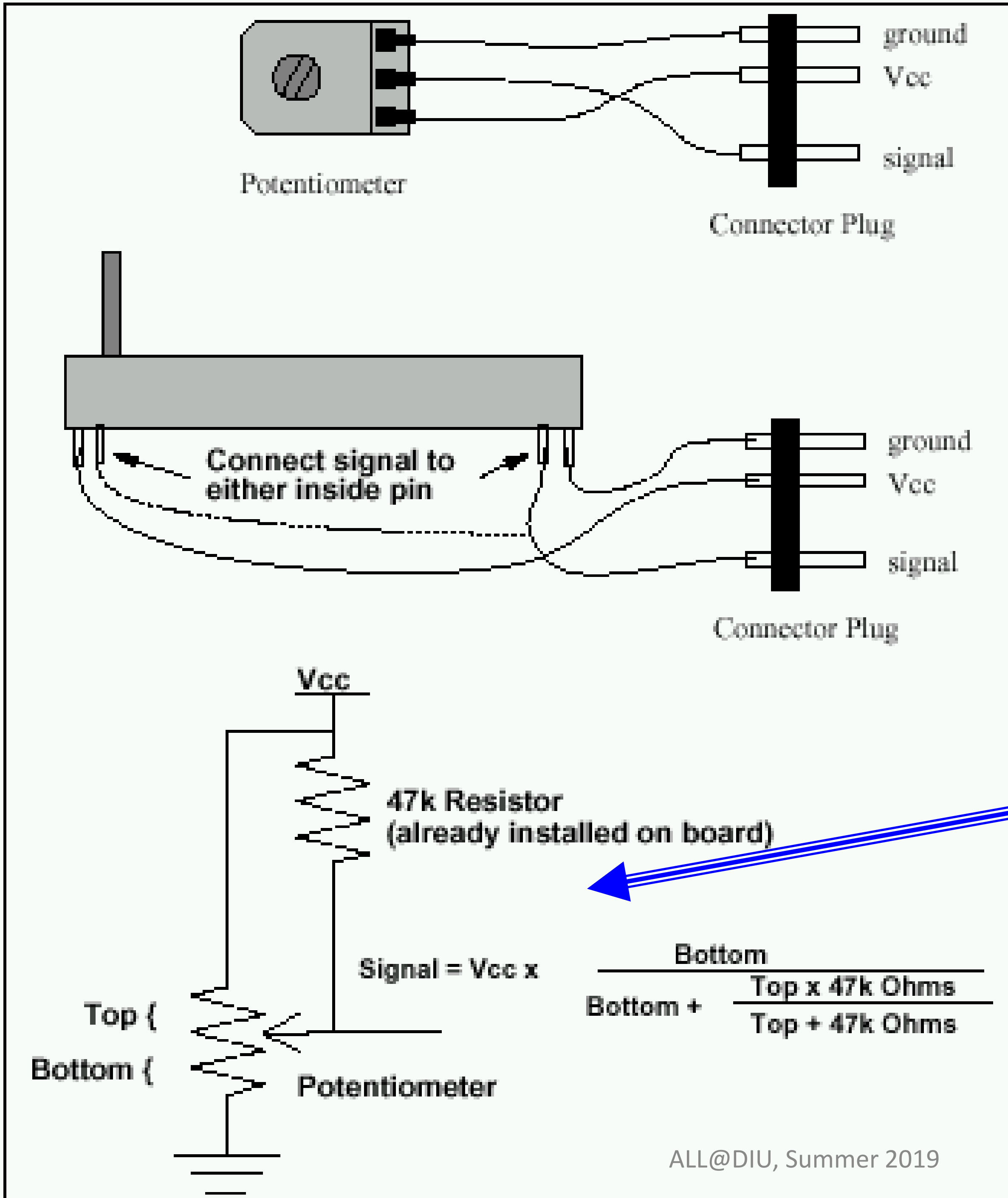
- Mechanical varieties:
  - – Linear and rotational styles - make position sensors for both sliding mechanisms and rotating shafts
  - – Resistance between the end taps is fixed, but the resistance between either end tap and the center swipe varies based on the position of the swipe



- Electrical varieties:
  - – Linear taper - linear relationship between position and resistance. Turn the pot 1/4 way, the resistance between the nearer end and the center is 1/4 of end-to-end resistance
  - – Audio taper - *logarithmic* relationship between position and resistance. At one end, 1/4 turn would swipe over a small bit of total resistance range, while at the other end, 1/4 turn would be most of the range



Potentiometer Assemblies

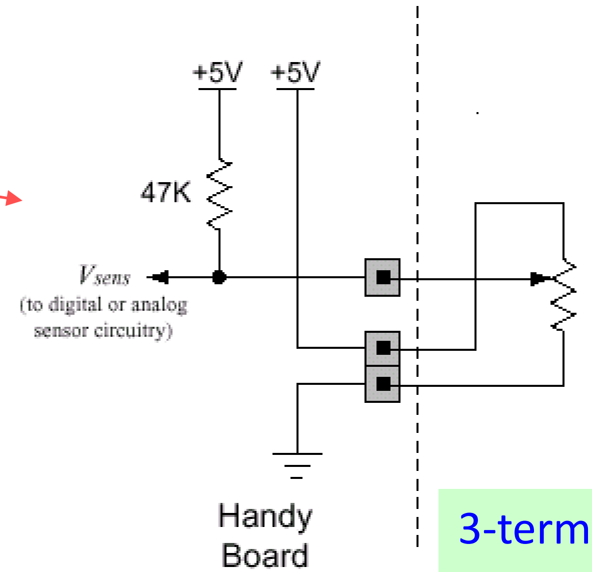


- Kits contain several sizes of potentiometers, also known as variable resistors.
- Potentiometers should be wired with Vcc and ground on the two outside pins, and the signal wire on the center tap.
  - This will, in effect, place the resistance of the potentiometer in parallel with the 47K pull-up on the expansion board and is more stable than just using one side and the center tab to make a plain variable resistor

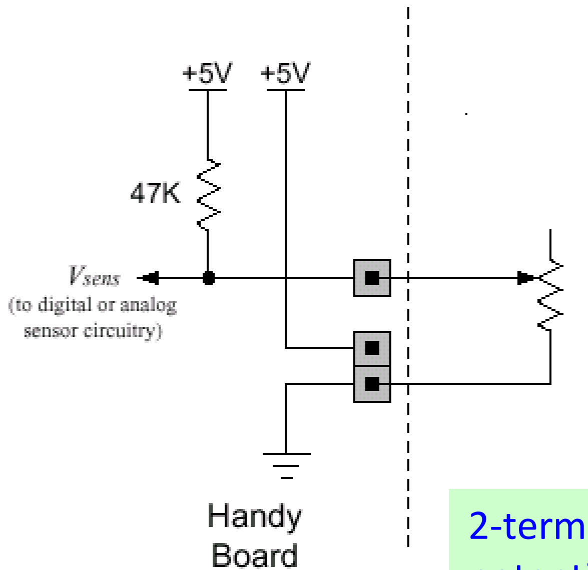
Two ways of using Potentiometers as

Resistive Posit

works best when the potentiometer resistance is small enough such that a 47K resistance in parallel with the pot's resistance has only a small effect



3-terminal potentiometer



2–terminal potentiometer works best when the pot's value is large

2-terminal potentiometer

Various uses of Potentiometers

- Potentiometers have a variety of uses:
  - In the past, they have been used for menuing programs
  - For angle measurement for various rotating limbs
  - For scanning beacons.

- They can be used with a motor to mimic servos, but that's a difficult task.
  - It is important to notice that the pots are ***not designed to turn more than about 270 degrees.***
  - Forcing them farther is likely to break them.

Tell about our previous project of animation inverse kinematics
robot with many pots and A/D board. (the one that was stolen)

Various uses of Potentiometers

- A potentiometer can be attached to a LEGO beam
  - such that it can be used in place of a bend sensor.
  - The rotation of the beam will produce a rotation in the potentiometer.

- See if you can come up with an assembly that can be used in place of a bend sensor.
  - The advantage to such a sensor is that it is much sturdier than the bend sensor.
  - The disadvantage is that it is bulkier.

Linear Potentiometers and their use in HandyBoard

- A linear potentiometer can be used to measure precise linear motion,
  - such as a gate closing,
  - or a cocking mechanism for ring balls or blocks.

- **Frob-knob**
  - The frob knob is the small white dial on the lower left corner of the Expansion Board.

- *It returns values between 0 and 255* and provides a handy user input for adjusting parameters on the y or for menuing routines to select different programs.

- You may find it useful to glue a small LEGO piece to the frob knob to make turning it easier.

Resistive (Analog) Position Sensors

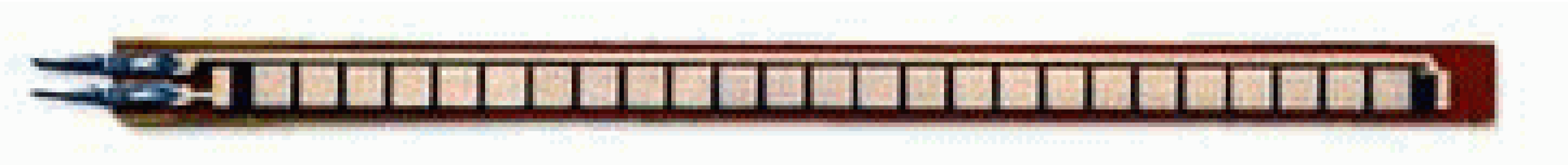
Resistive Position Sensors: bending

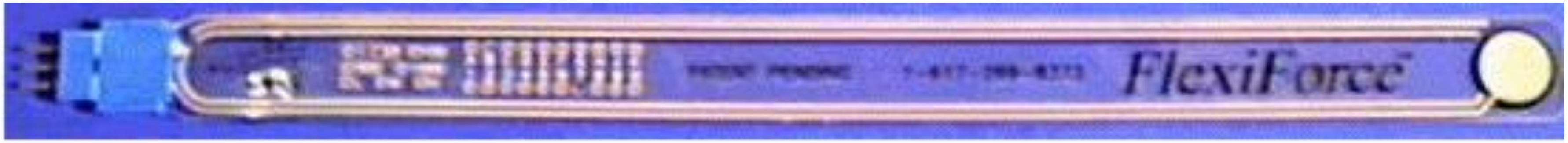
- We said earlier that a photocell is a resistive device, i.e., it senses resistance in response to the light.

- We can also sense resistance in response to other physical properties, such as ***bending***.
  - **The resistance of the device increases with the amount it is bent.**

- These bend sensors were originally developed for video game control
- They are generally quite useful:
  - Nintendo Powerglove
  - Video game accessories are in general useful for robotics and virtual reality and very cheap.

Resistive Bend Sensors

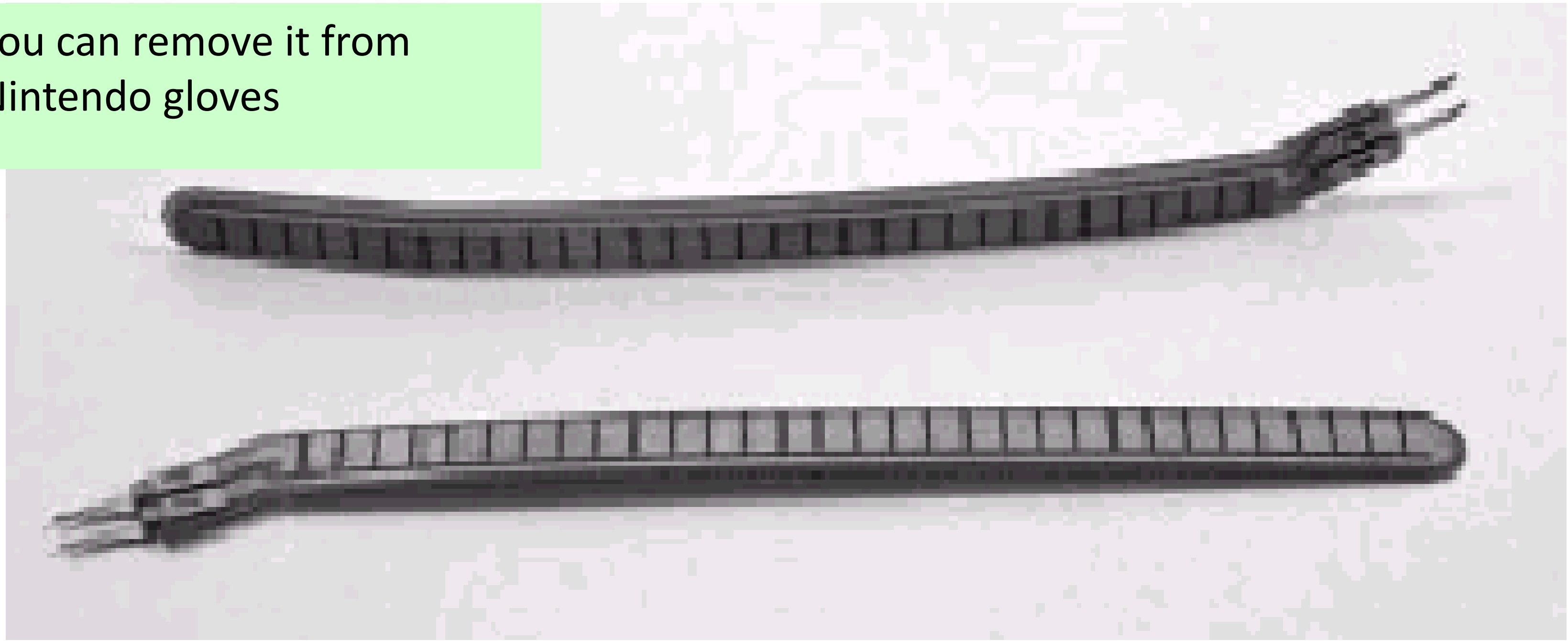




- Resistance = 10k to 35k
- Force to produce 90deg = 5 grams
- www.jameco.com = 10$

Bend Sensors

You can remove it from Nintendo gloves



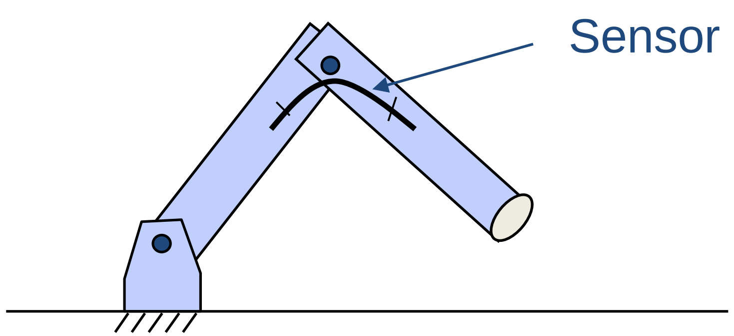
- Useful for contact sensing and wall-tracking
- The bend sensor is a simple resistance
  - As the plastic strip is bent (with the silver rectangles facing outward), the resistance increases

Resistive Position Sensors

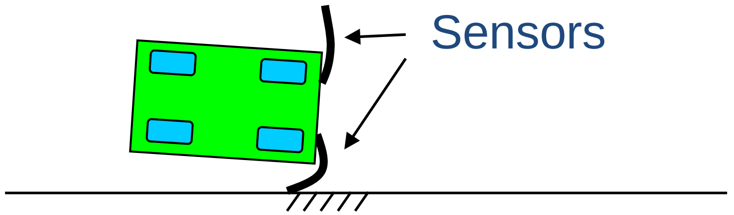
- Mechanically, the bend sensor is not terribly robust, and requires strong protection at its base, near the electrical contacts.
  - Unless the sensor is well-protected from direct forces, it will fail over time.
- Notice that even in a good arrangement, repeated bending will **wear out** the sensor.
- **Remember:** a bend sensor is much *less robust* than light sensors,
  - although they use the same underlying resistive principle.

Applications of Resistive Analog Sensors

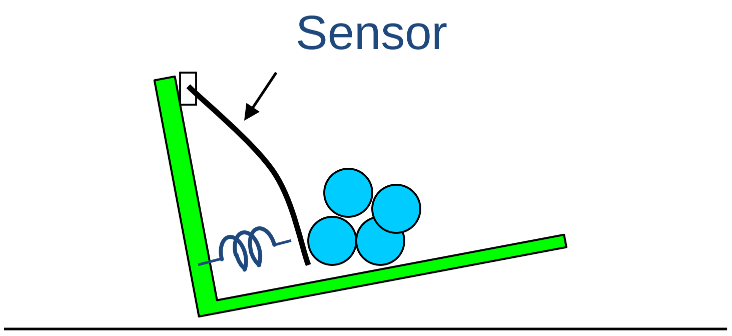
- Measure bend of a joint



- Wall Following/Collision Detection



- Weight Sensor

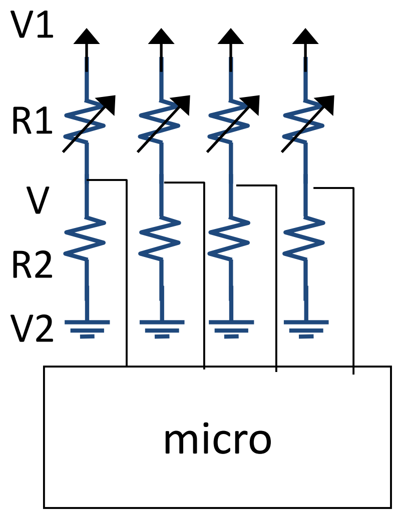


Inputs for Resistive Sensors

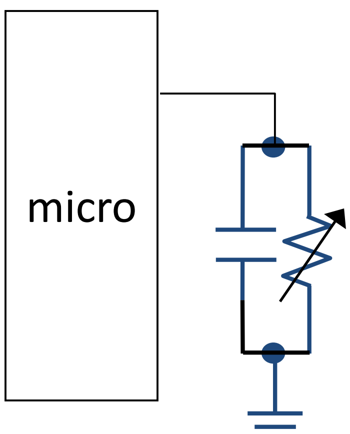
Voltage divider:
You have two resisters, one is fixed and the other varies, as well as a constant voltage

V1 – V2 * (R2/R1+R2) = V

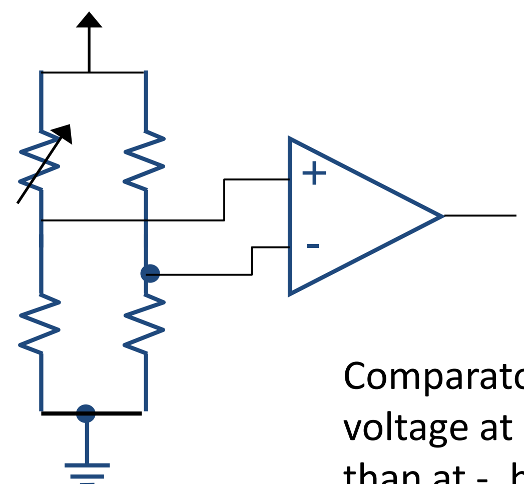
Known unknown measure



Analog to Digital
(pull down)



Single Pin
Resistance
Measurement



Binary
Threshold

Comparator: if voltage at + is greater than at -, high value out

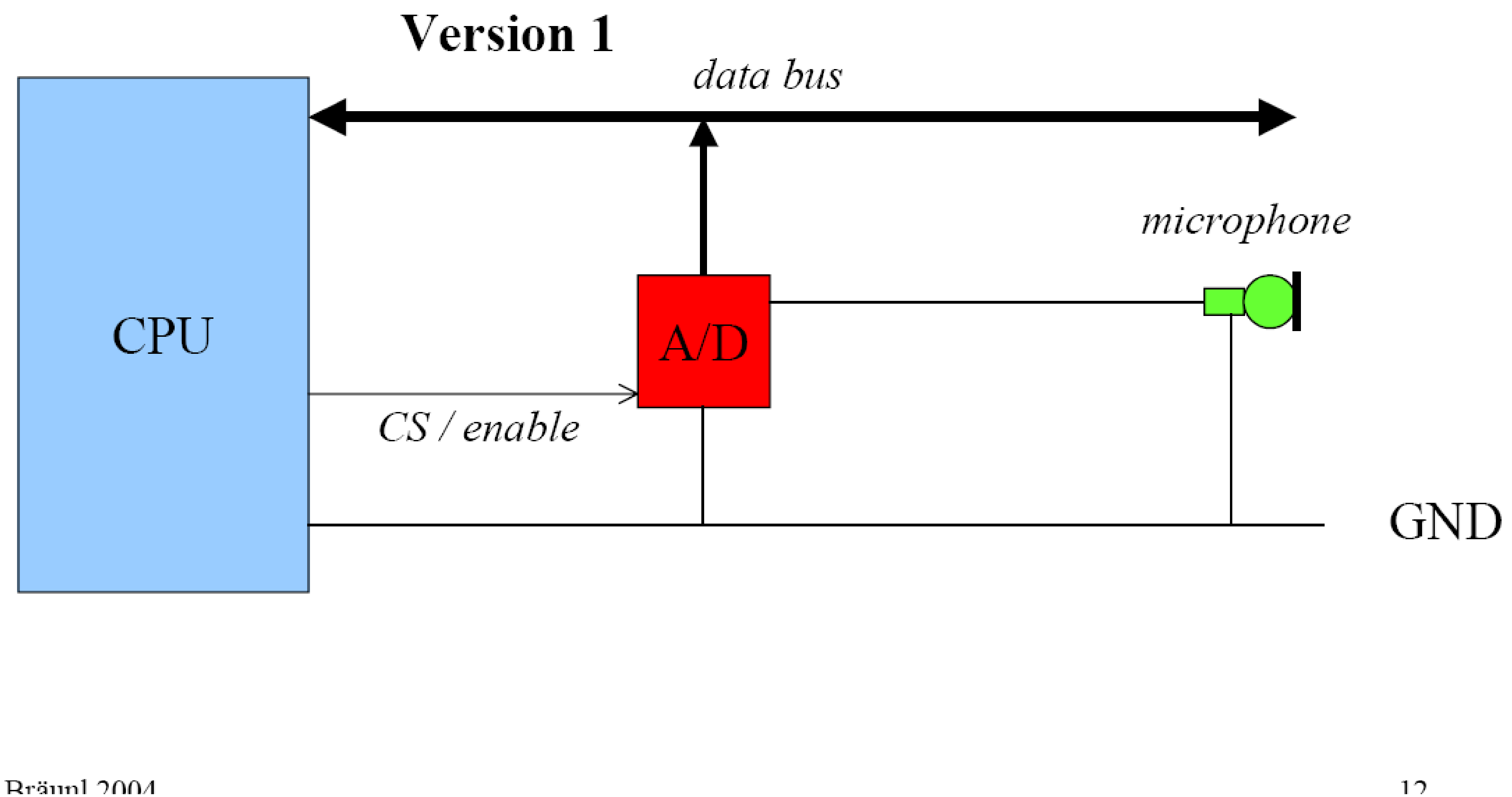
A/D Converter

- Signal has to be provided at correct level, e.g. between 0 .. 5V
- If multiple channels are read: low internal resistance of signal line is important
- A/D converter translates analog voltage level into digital value
- Digital output from A/D converter can be
  - parallel

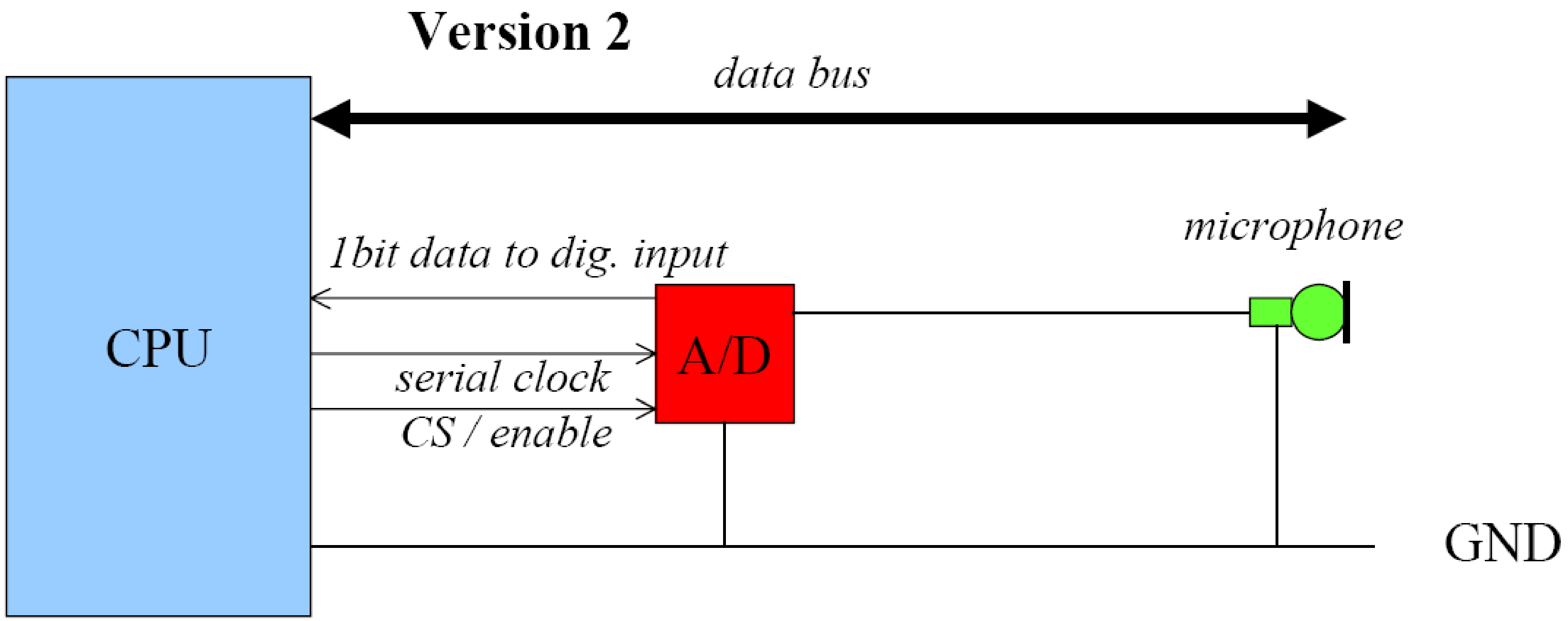
  (e.g. 8 bit, direct connection to data bus)
  - serially digital

  (provide programmed clock signal to converter to read data bit by bit)

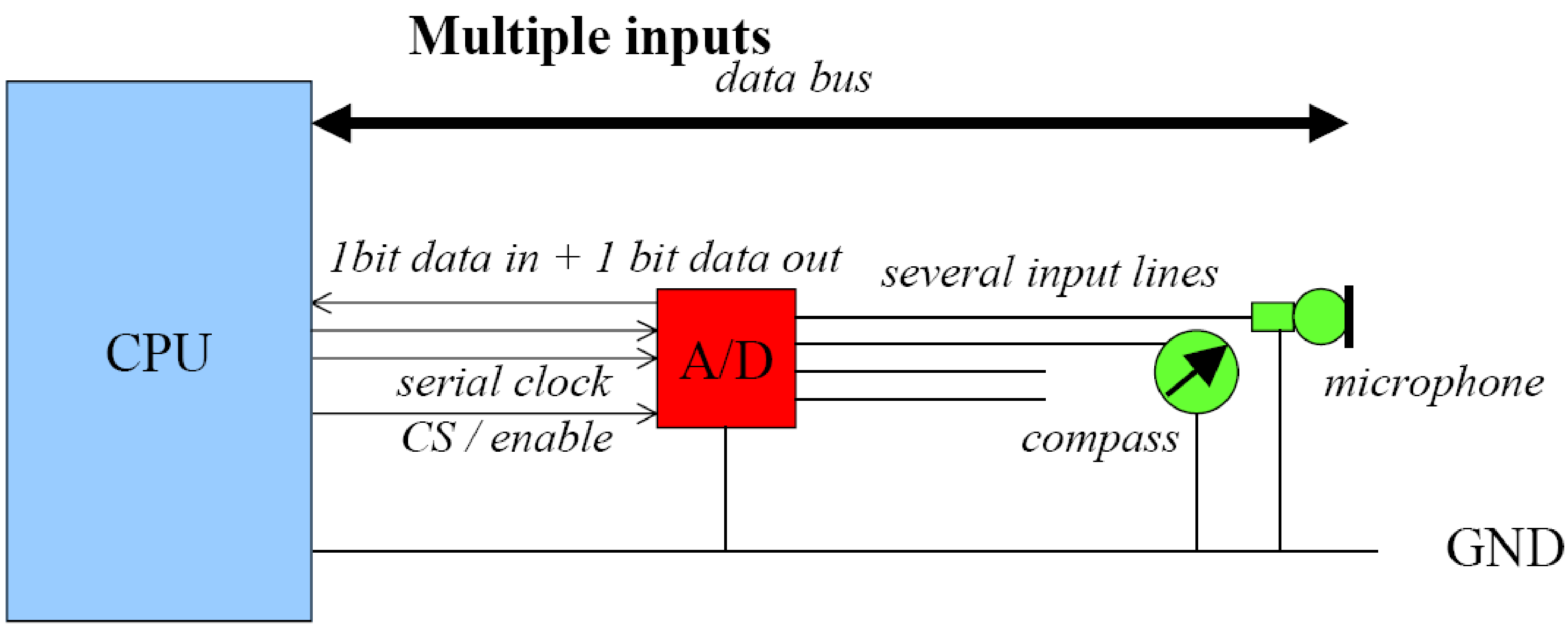
A/D Converter



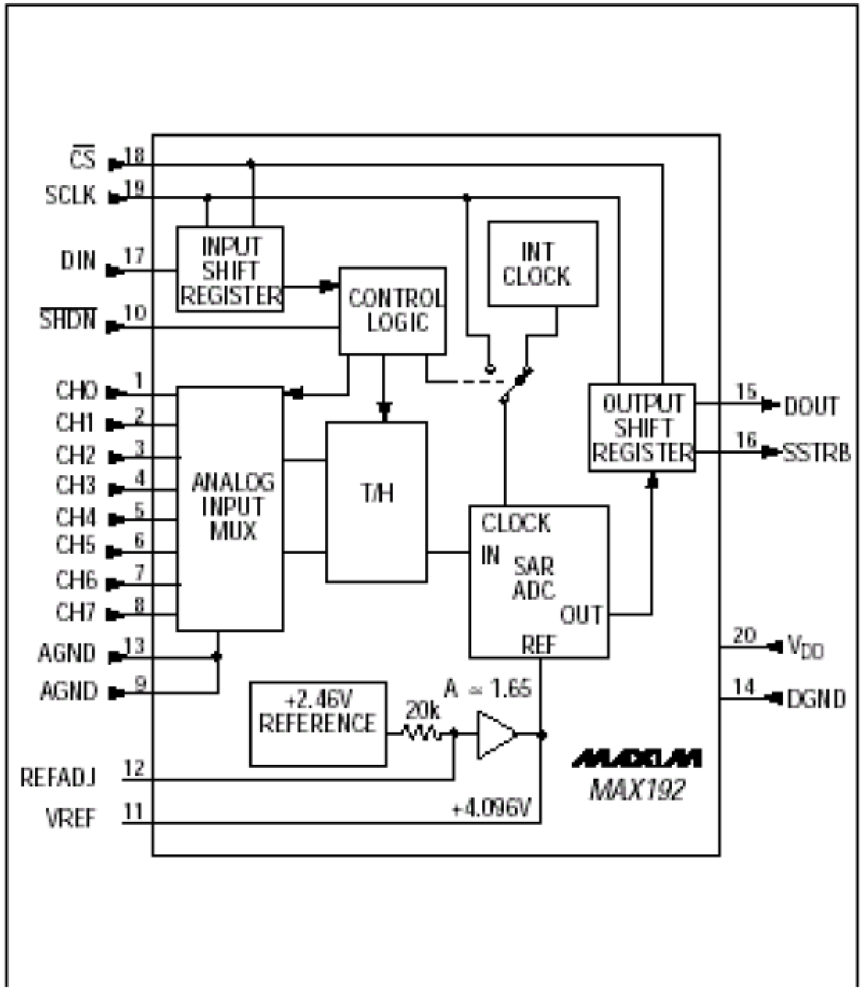
A/D Converter

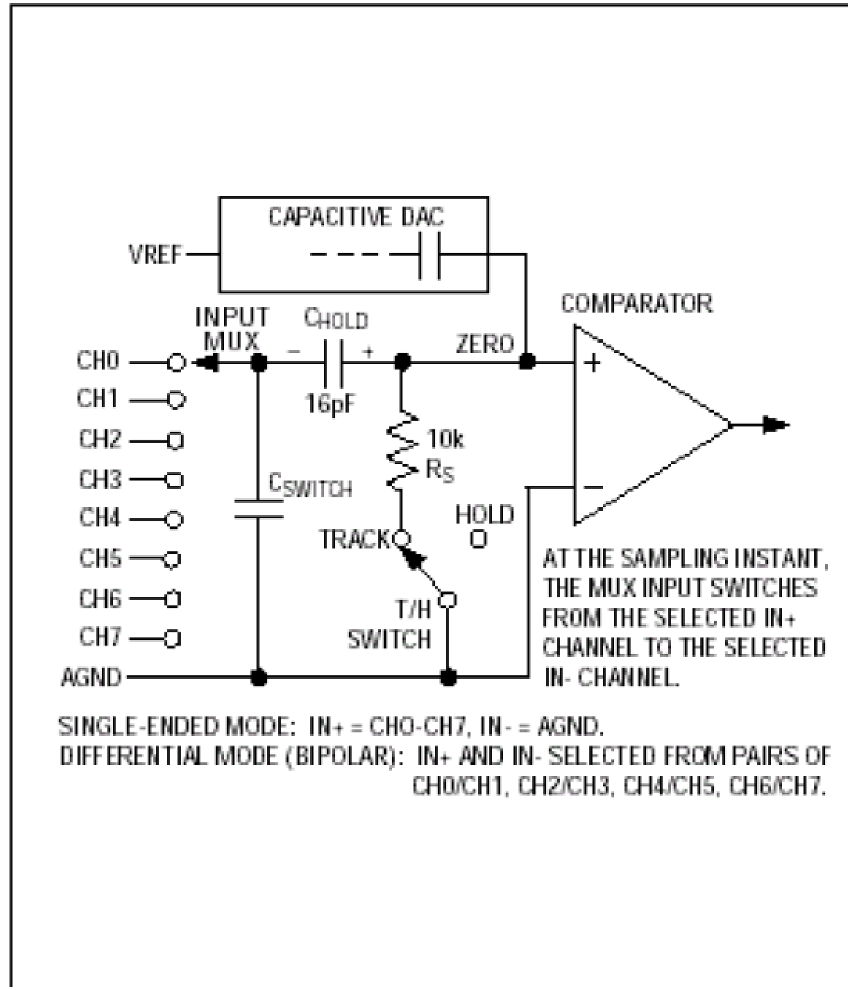


A/D Converter



A/D Converter





MAX192

A/D Converter