Stepper Motors

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Content length : 15 minutes

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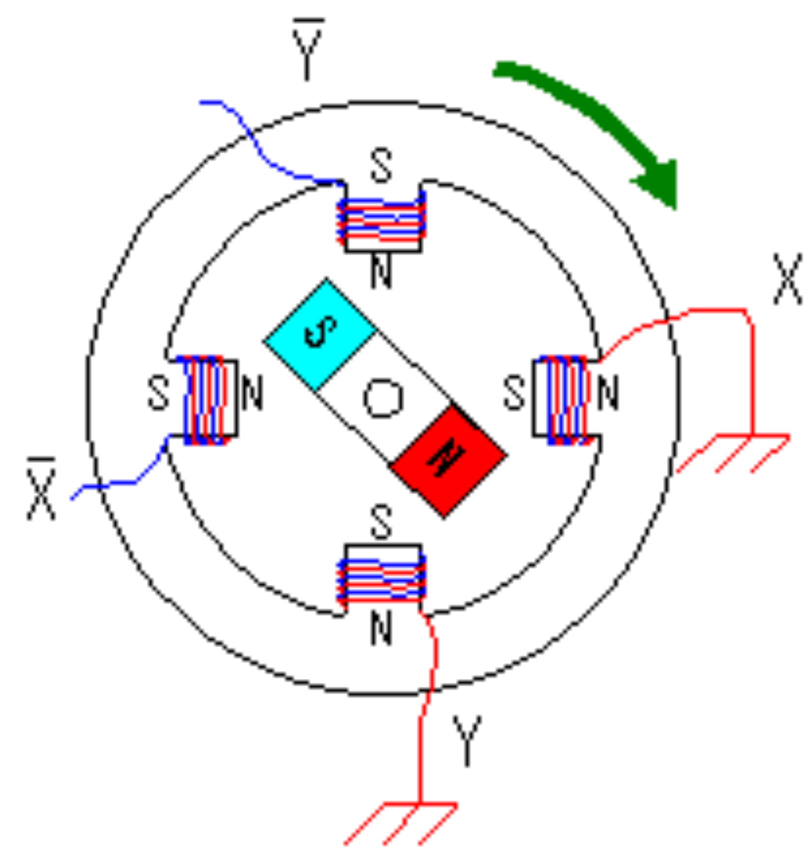
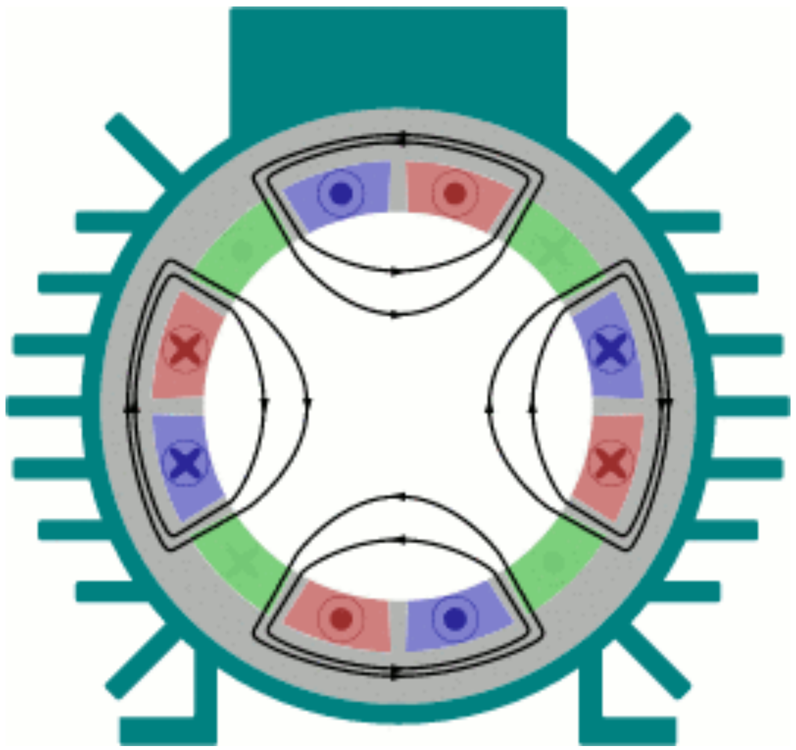
What is a stepper motor

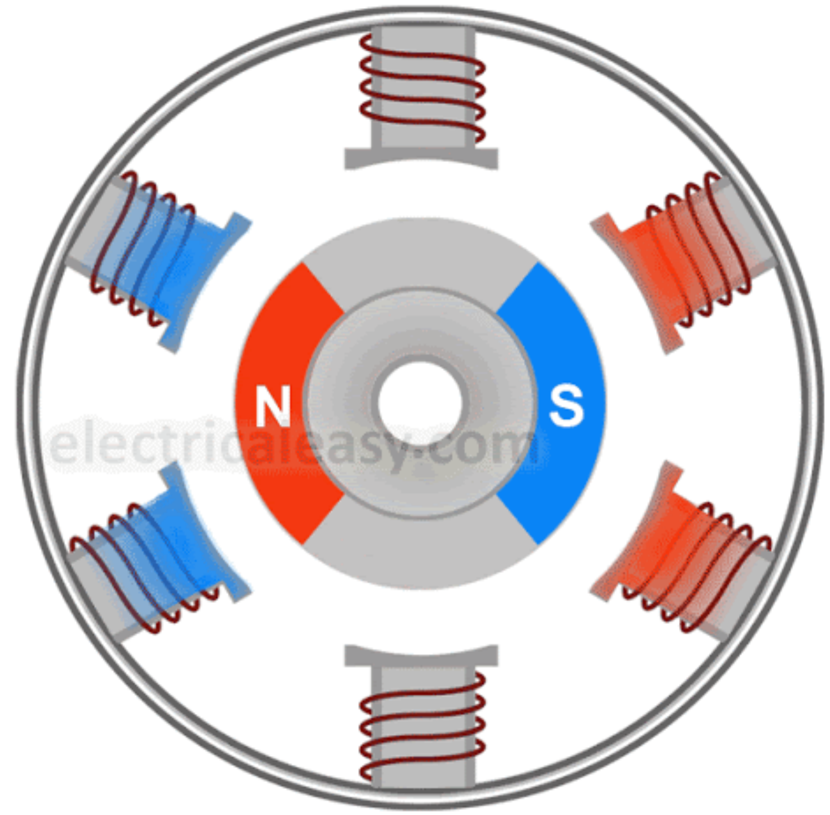
- A motor is a device which converts electrical energy into rotational mechanical movement (in context of ES, a stepper motor is an actuator)
- A stepper motor is an **open loop brushless DC motor** which is supplied with DC signals in a certain control sequence which causes rotation in angular steps for higher precision control.
- The rotation can be stepwise, continuous, forwards, backwards. The motor can even stop at a desired point and hold its position.



X	$\bar{X}$	Y	$\bar{Y}$
0	1	0	1
1	0	0	1
1	0	1	0
0	1	1	0

How DC motor works





The fixed part of the motor is called the “**stator**”. Permanent magnets are used to provide a stationary magnetic field. Normally these magnets are positioned on the outer surface rotor.

In order to create torque, which makes the rotor spin, the **magnetic field of the stator needs to continuously rotate**, so that it’s field attracts and repels the fixed field of the rotor. **To make the field rotate, a sliding electrical switch is used.** The switch consists of the commutator, which is typically a segmented contact mounted to the rotor, and fixed brushes which are mounted to the stator.

Why DC motor not AC?

1. Many motion control applications use permanent magnet DC motors. Since it is **easier to implement control systems using DC motors** compared to AC motors, they are often used when speed, torque, or position needs to be controlled.

2. The power source in many control applications are batteries which produce DC.

3. AC motors are mainly used in industrial environments where very high torque is required, or where the motors are connected to the mains / wall outlet.

Brushed DC motor

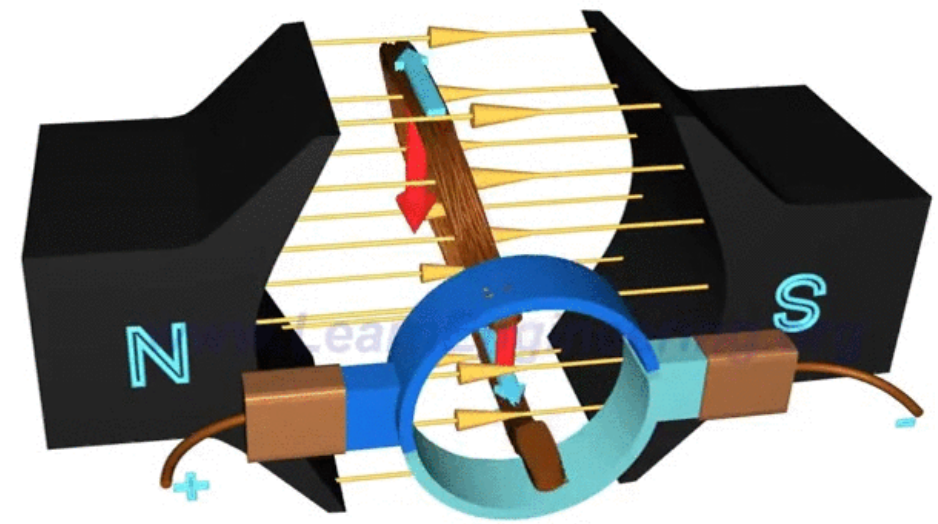
DC brushed motors have brushes, which are used to **mechanically commutate** the motor to cause it to spin.

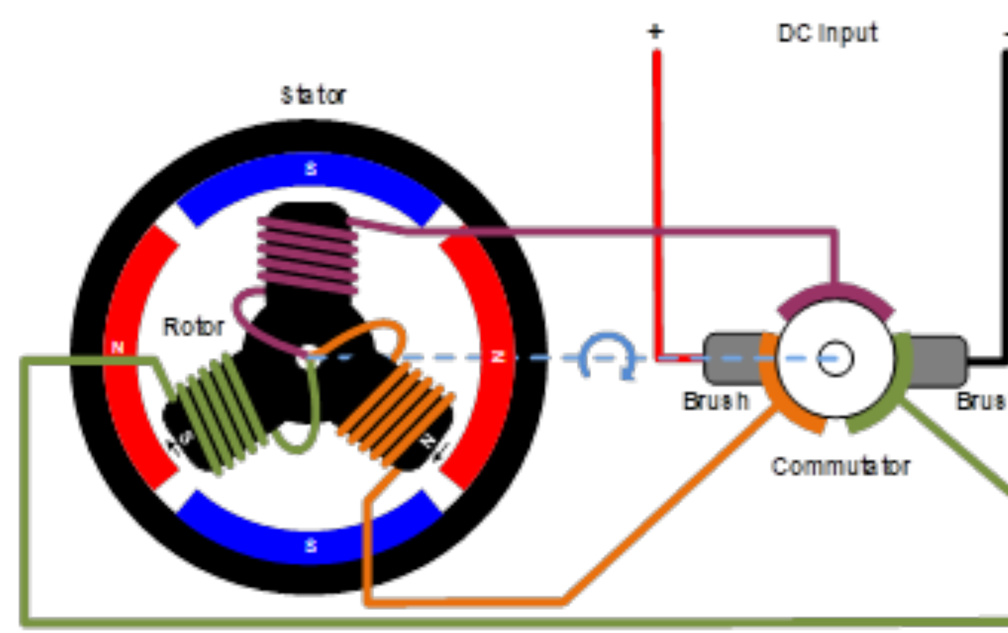
As the rotor turns, different sets of rotor windings are constantly switched on and off by the commutator. This causes the coils of the rotor to be constantly attracted anc repelled from the stator's fixed magnets, which makes the rotor spin.

Since there is some **mechanical friction** between the brushes and commutator, and since it is an electrical contact, it generally **cannot be lubricated** there is **mechanical wear** of the brushes and commutator over the lifetime of the motor.

In cases where **rotation is only needed in one direction, and speed or torque doesn't need to be controlled,** no drive electronics at all are required for a brushed motor. In applications like this, the DC voltage is simply switched on and off to make the motor run or stop.

Inertia.



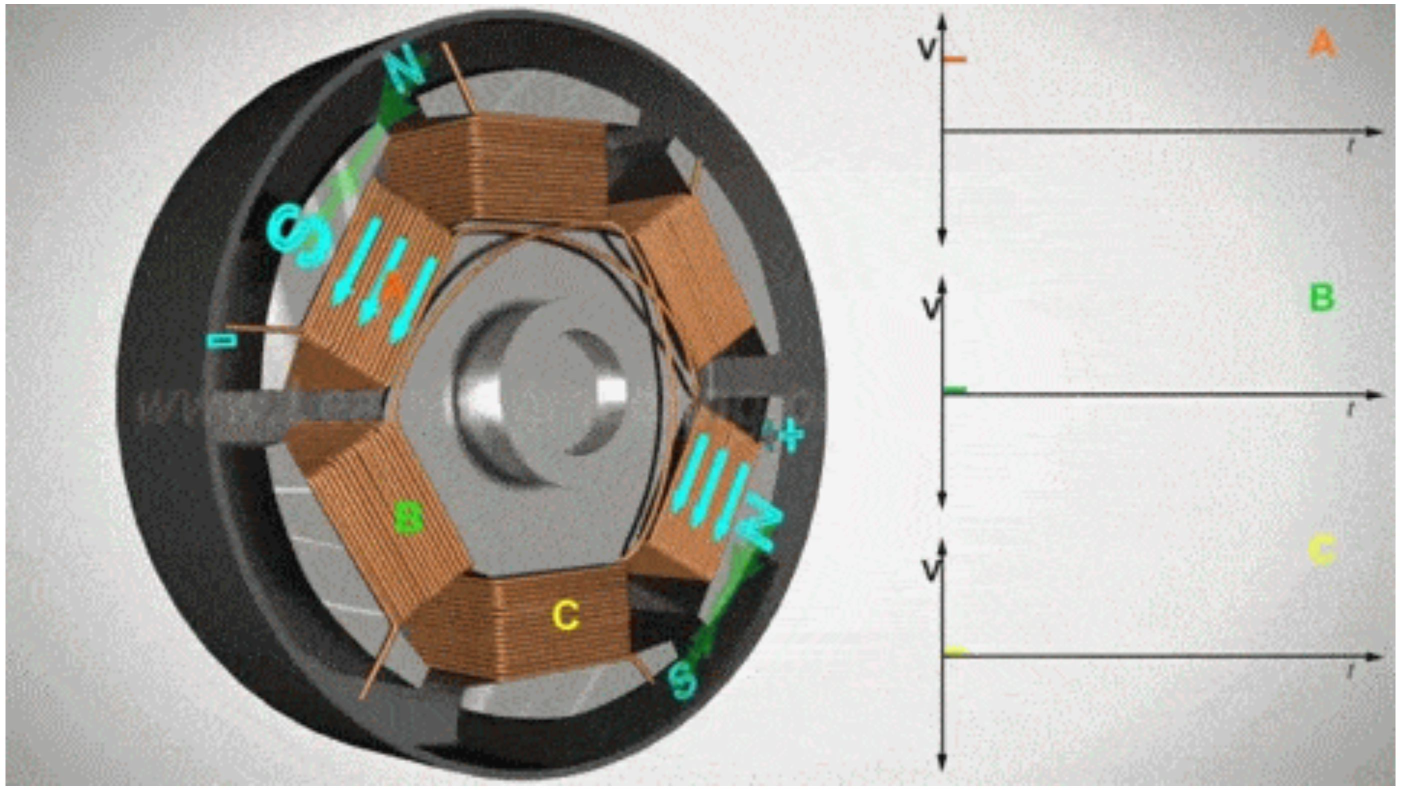


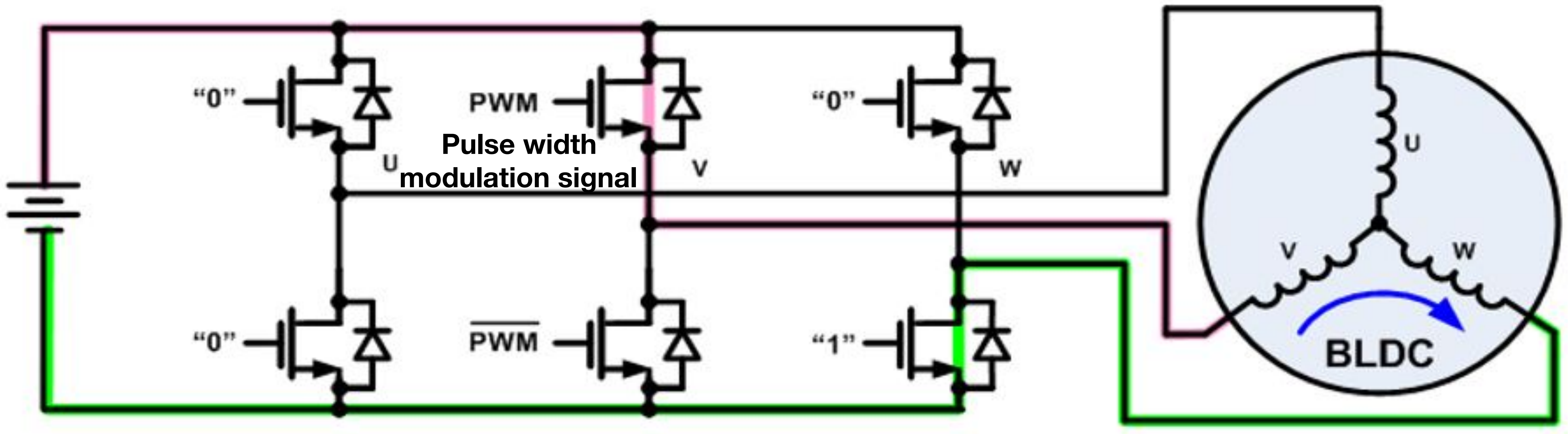
Brushless DC motor

Brushless motors replaces the mechanical commutation function of brushed motors with electronic control.

The number of windings used in a brushless motor is called the number of phases.

To drive a three phase brushless motor, each of the three phases needs to be able to be driven to either the input supply voltage or ground. To accomplish this, three “half bridge” drive circuits are used, each consisting of two switches.





Brushless motors for precise control

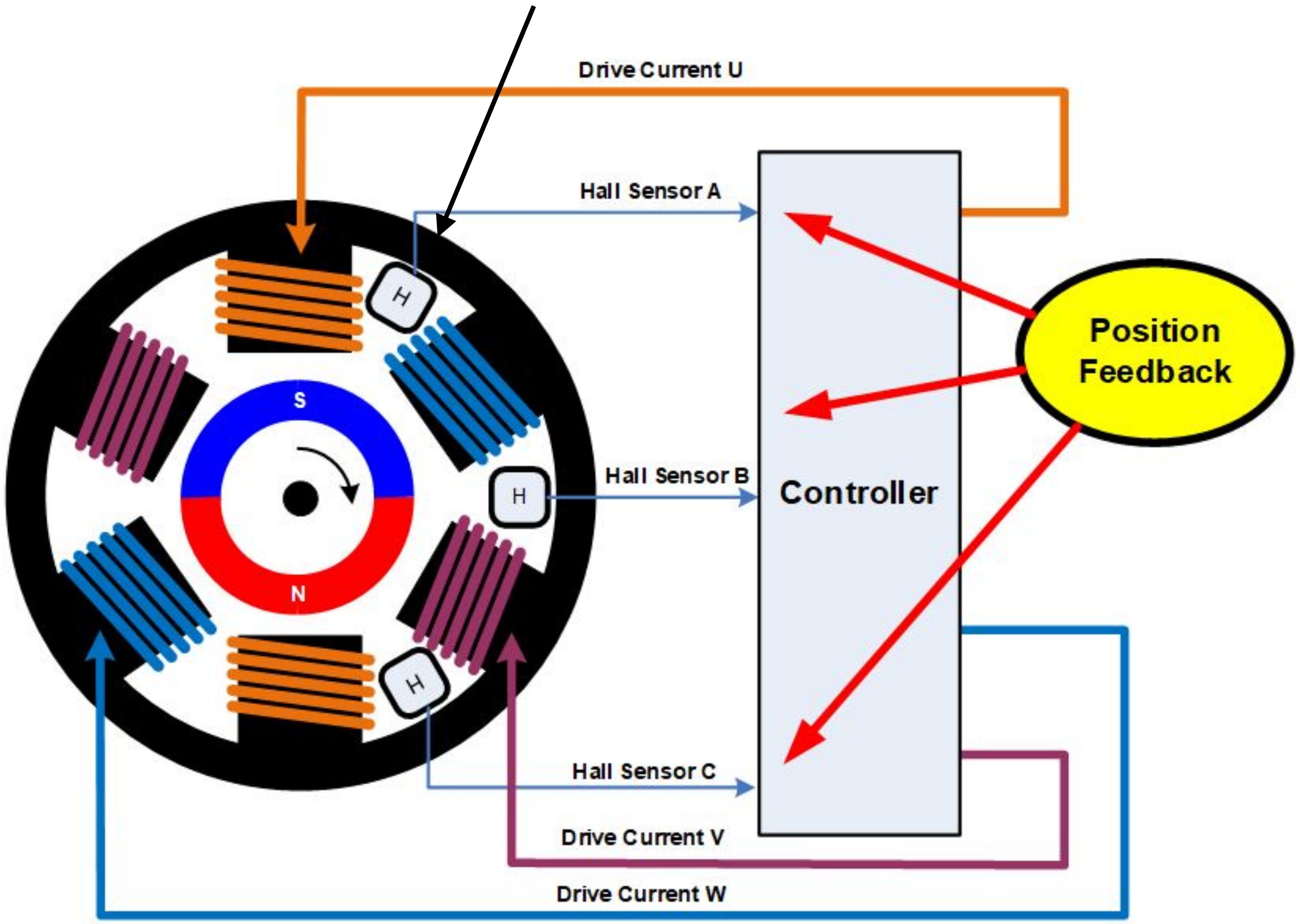
To properly rotate the field, the **control electronics need to know the physical position of the magnets on the rotor relative to the stator**. Often, the position information is obtained using **Hall sensors** that are mounted to the stator. As the magnetic rotor turns, the Hall sensors pick up the magnetic field of the rotor. This information is used by the drive electronics to pass current through the stator windings in a sequence that causes the rotor to spin.

The pattern of magnetic field generated in stator depends in control signals provided.

We can design the control unit to produce different kinds of drive current waveforms to produce a special magnetic field pattern to precisely regulate the motion of rotor.

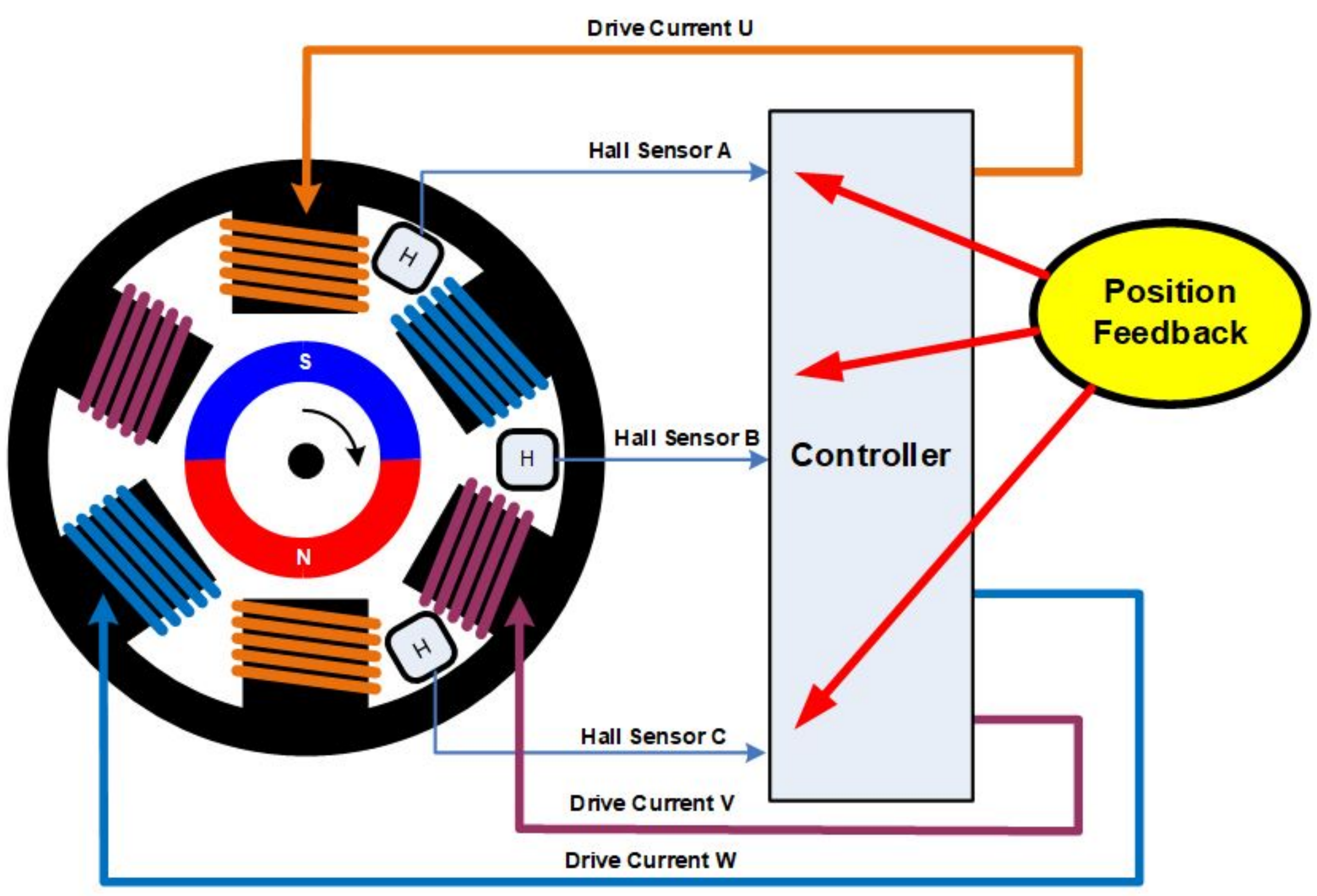
Motors which works on closed control feedback for control are called **servo motors**

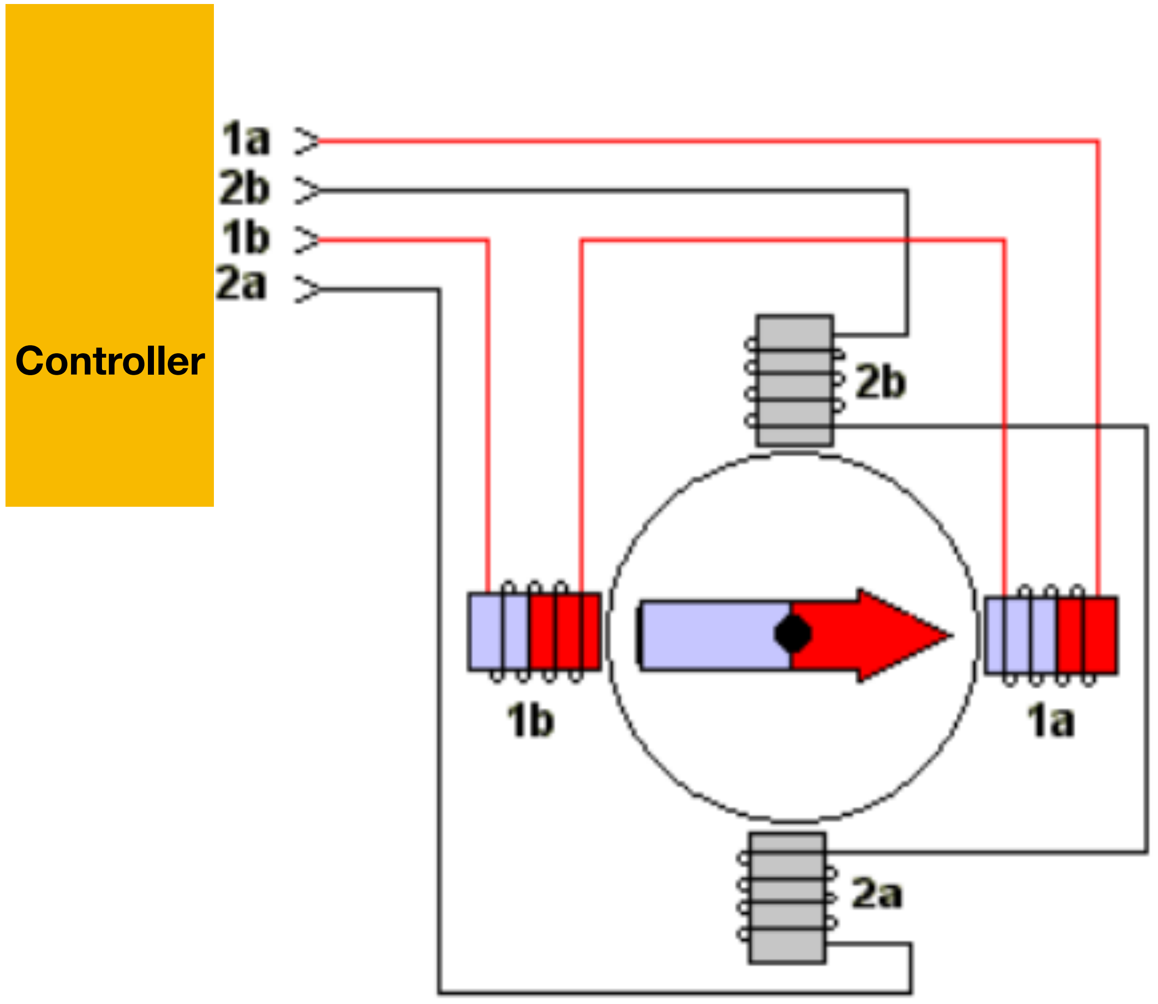
Measures magnitude of magnetic field using the hall effect



Stepper motor

Stepper motor Replaces the closed feedback loop control with an open loop control



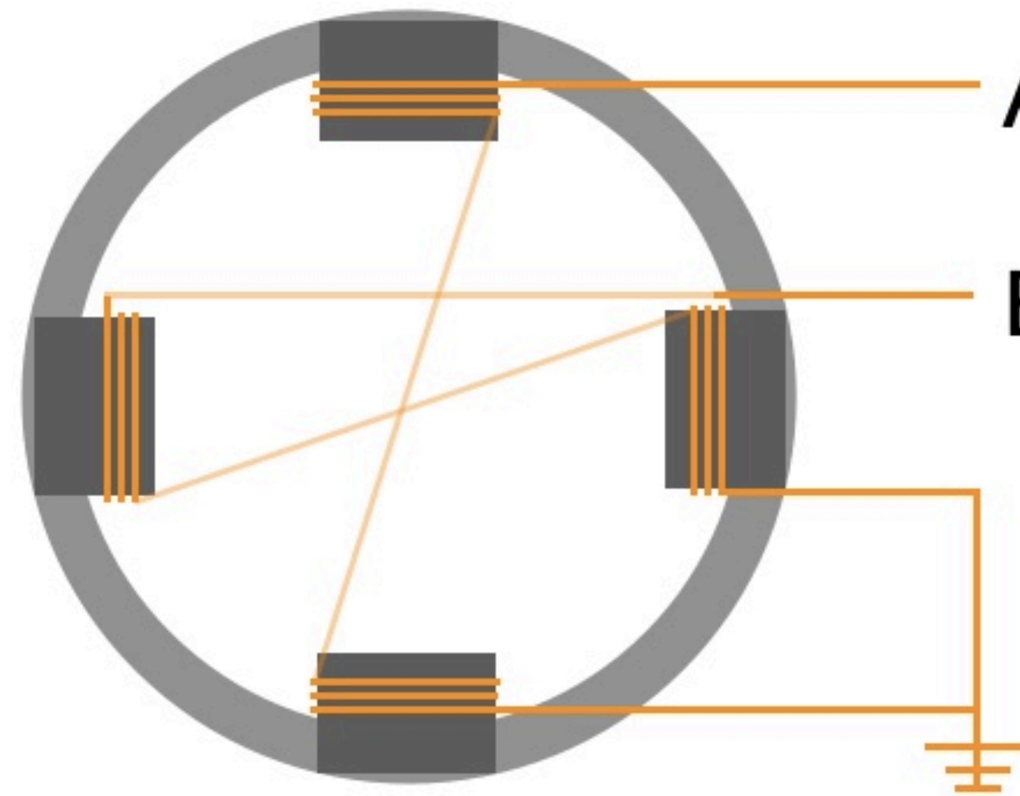


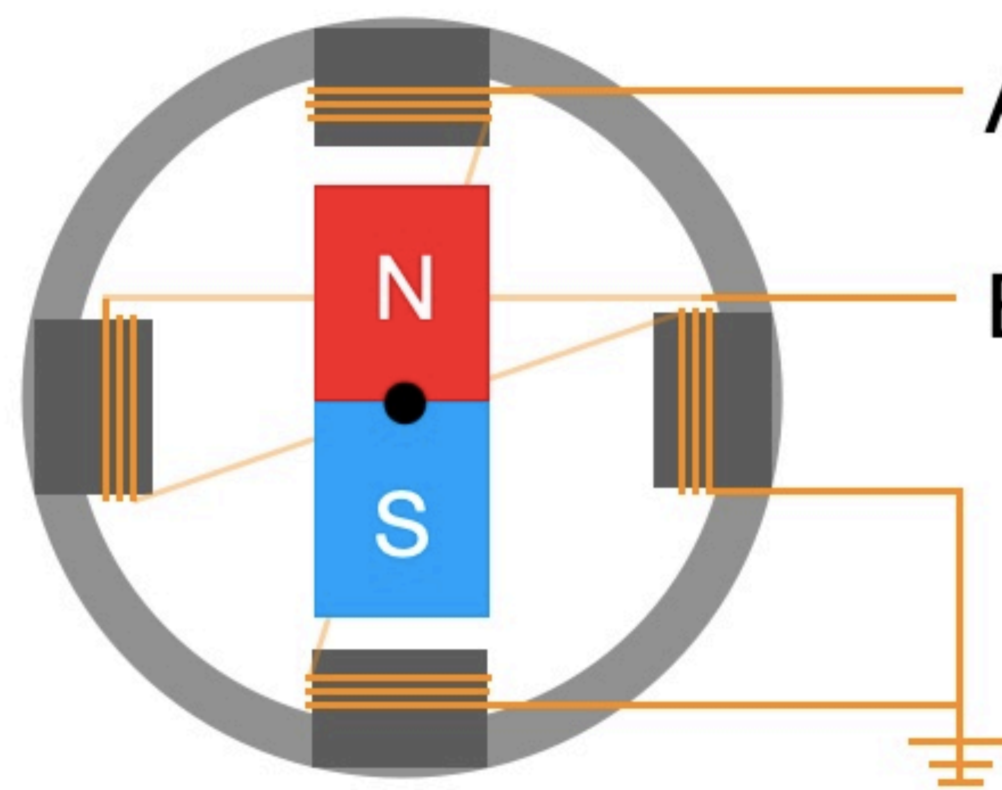
How Stepper motor works

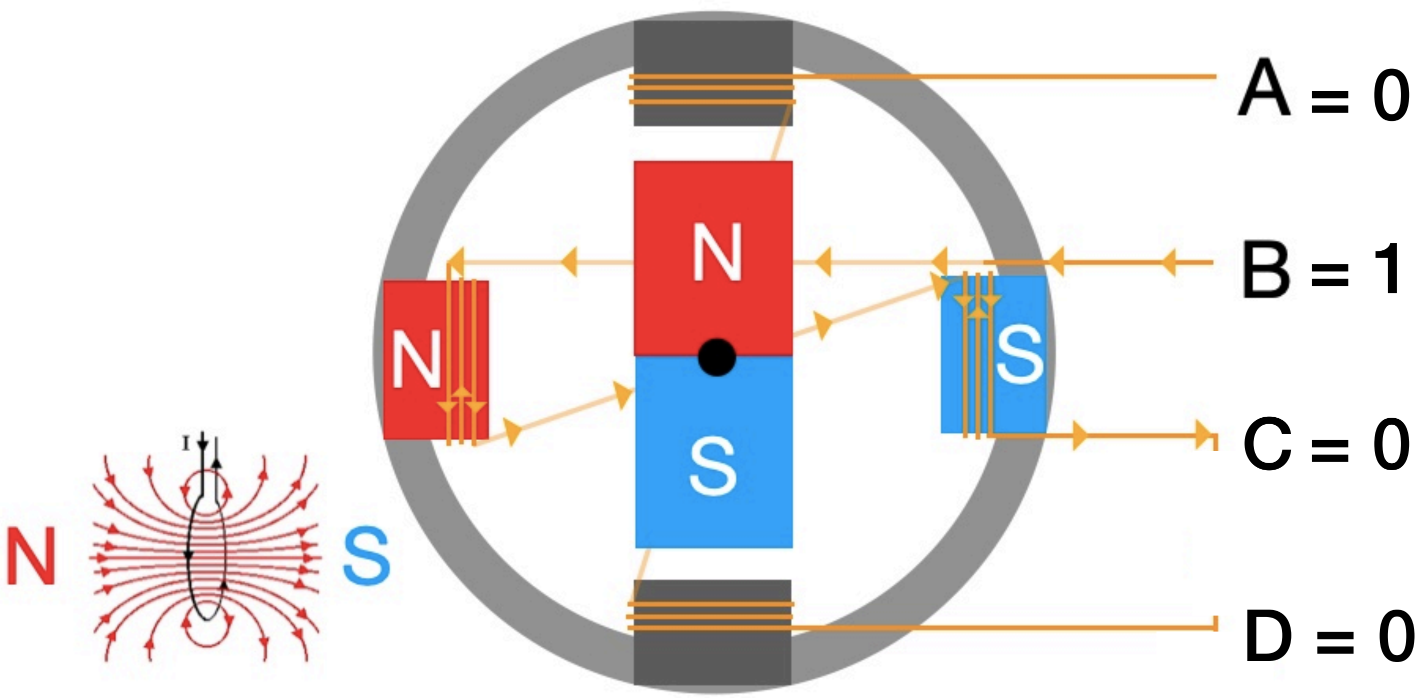
We take the working of variable reluctance type stepper motor which is the simplest one.

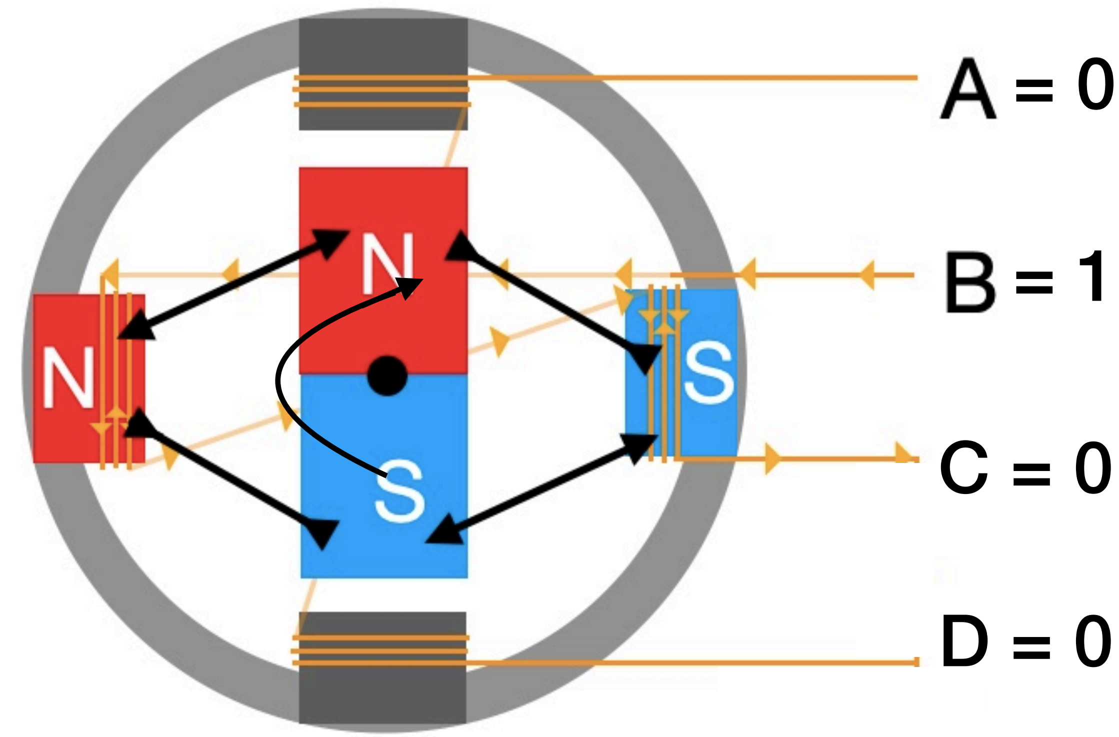
Consider a motor with **four stator teeth** which can be energised using **two separate DC power sources.**

A **rotor has different number of teeth than stator** so that one only one pair of rotor teeth is aligned with the stator at a time.

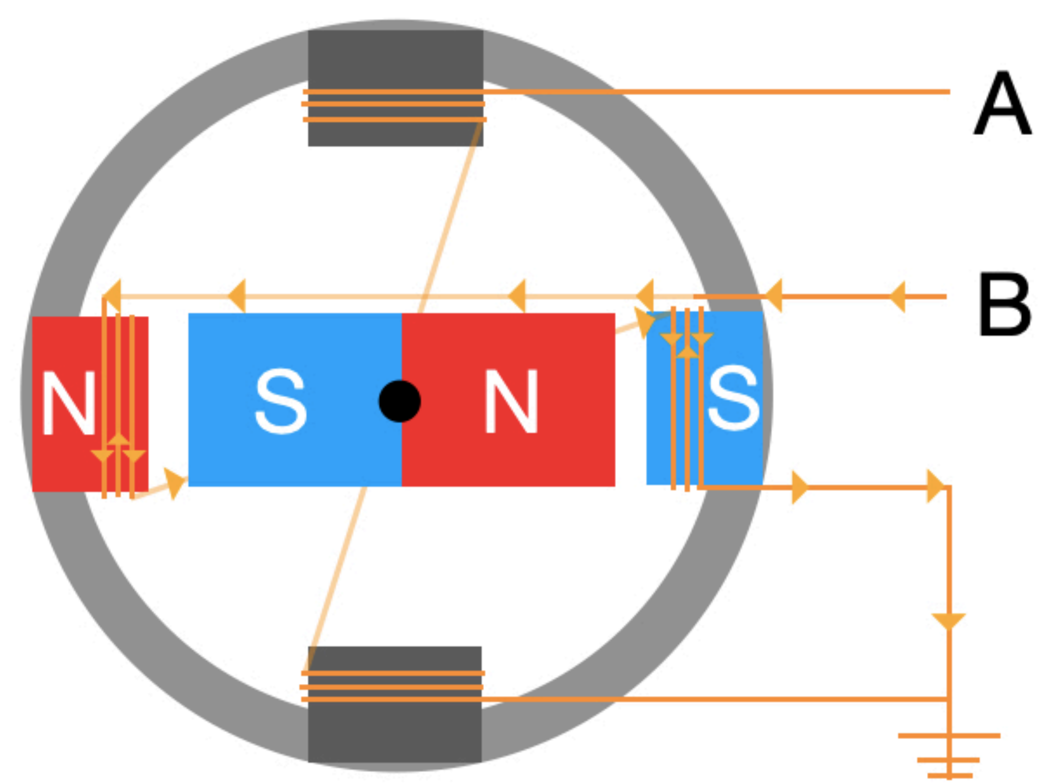


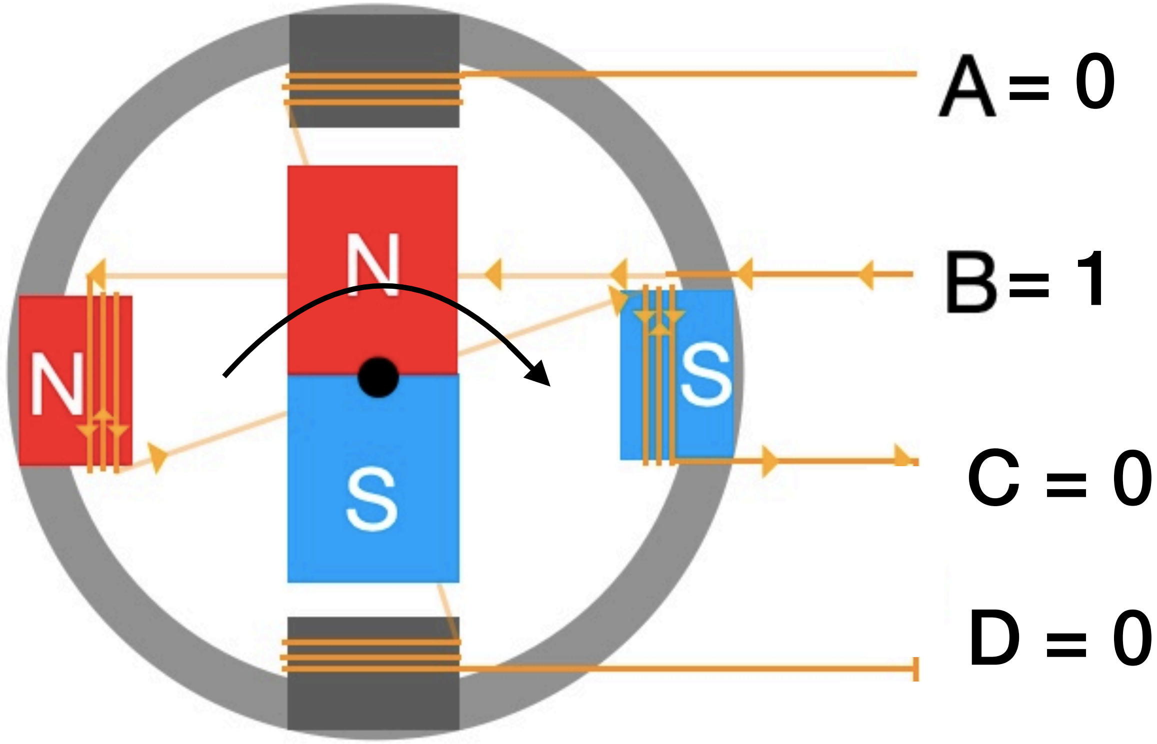




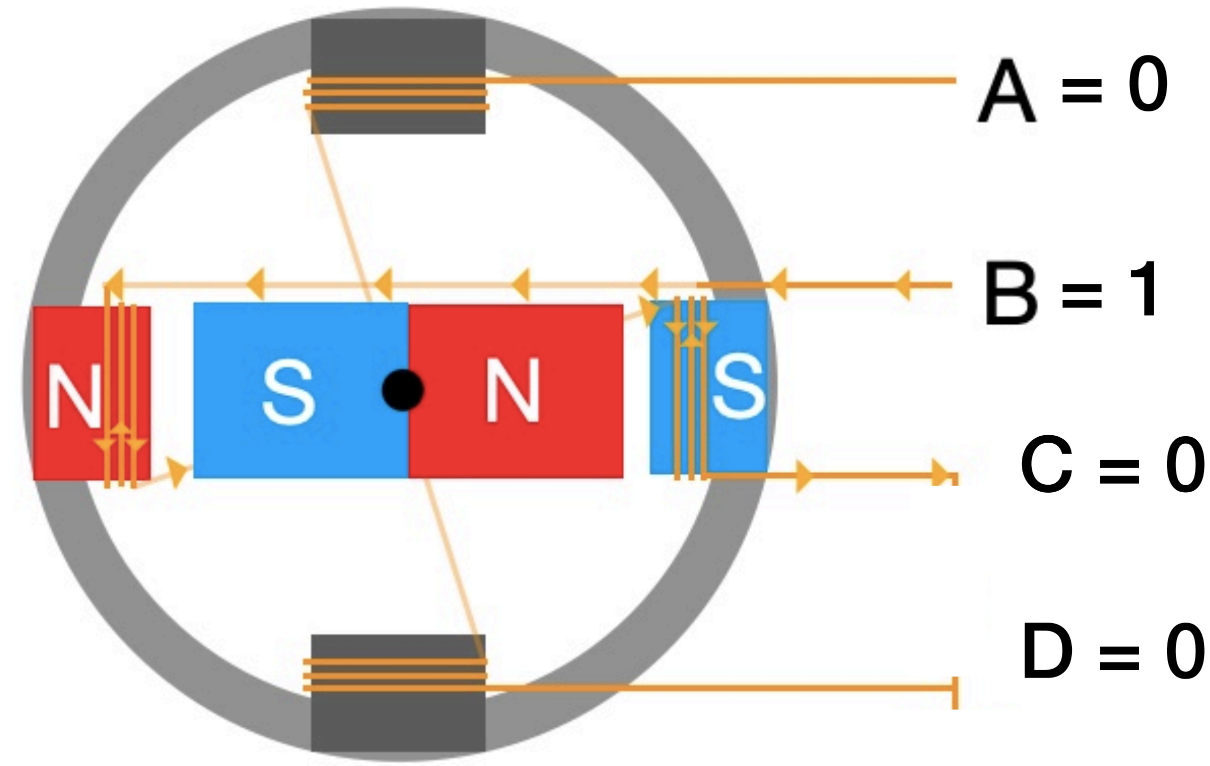


- If we De-energise coil AD and energise coil BC, the rotor is stator with a pair of opposite forces about a fulcrum which creates a torque until rotor moves and aligns with coil B in equilibrium.

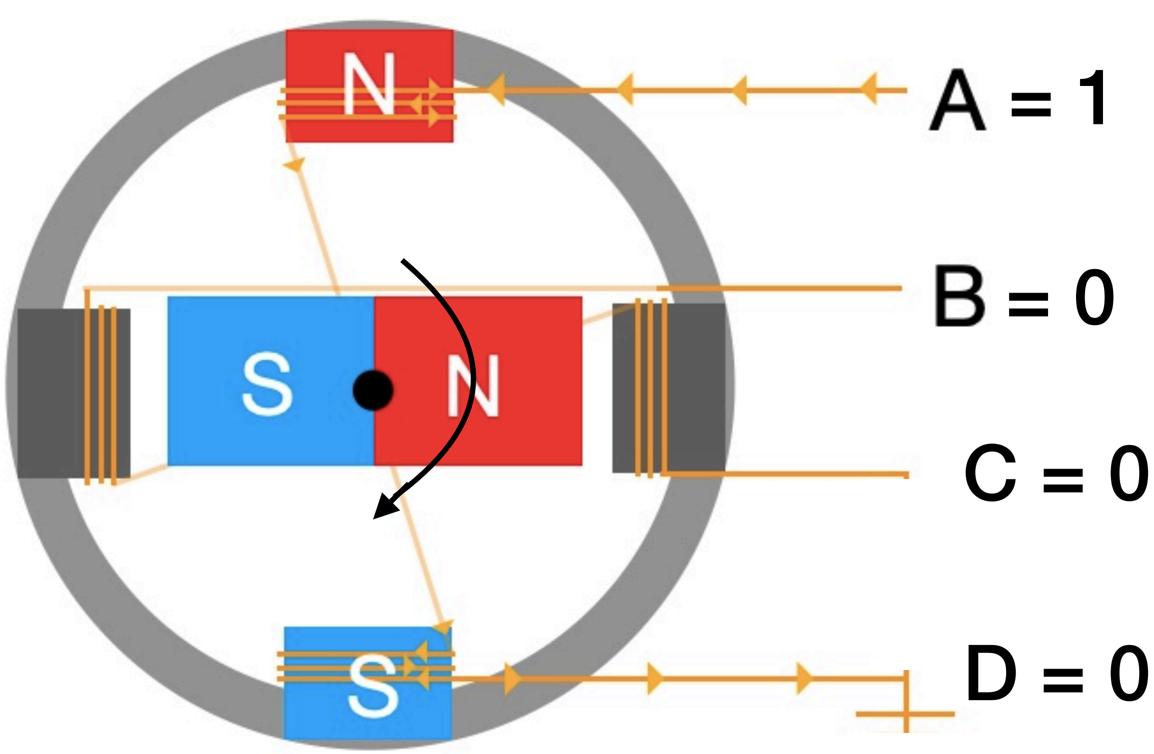




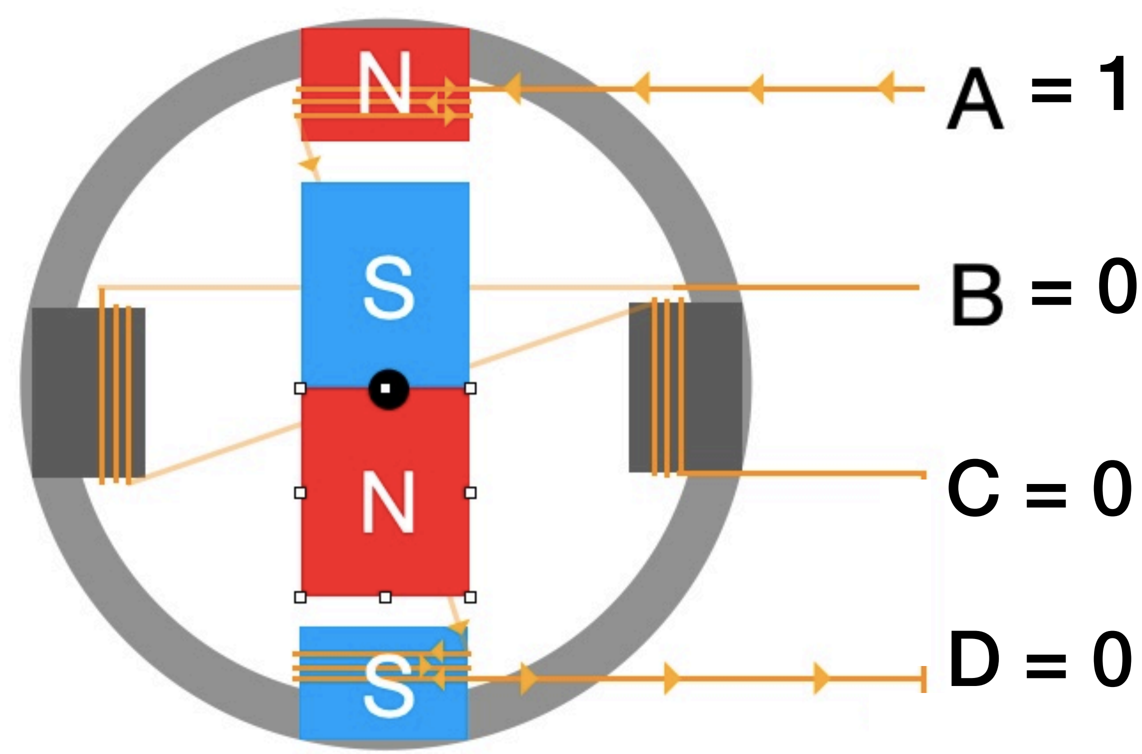
1. Energise BC, De-energise AD



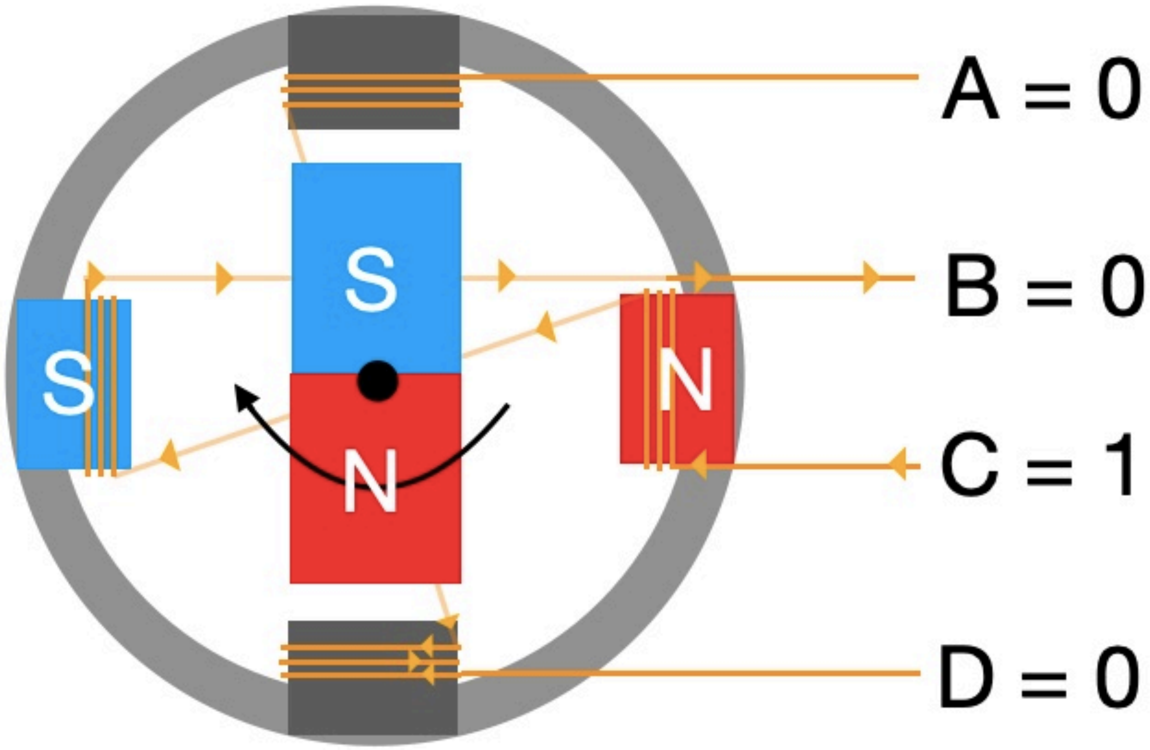
2. Rotor Rotates by step 90° here



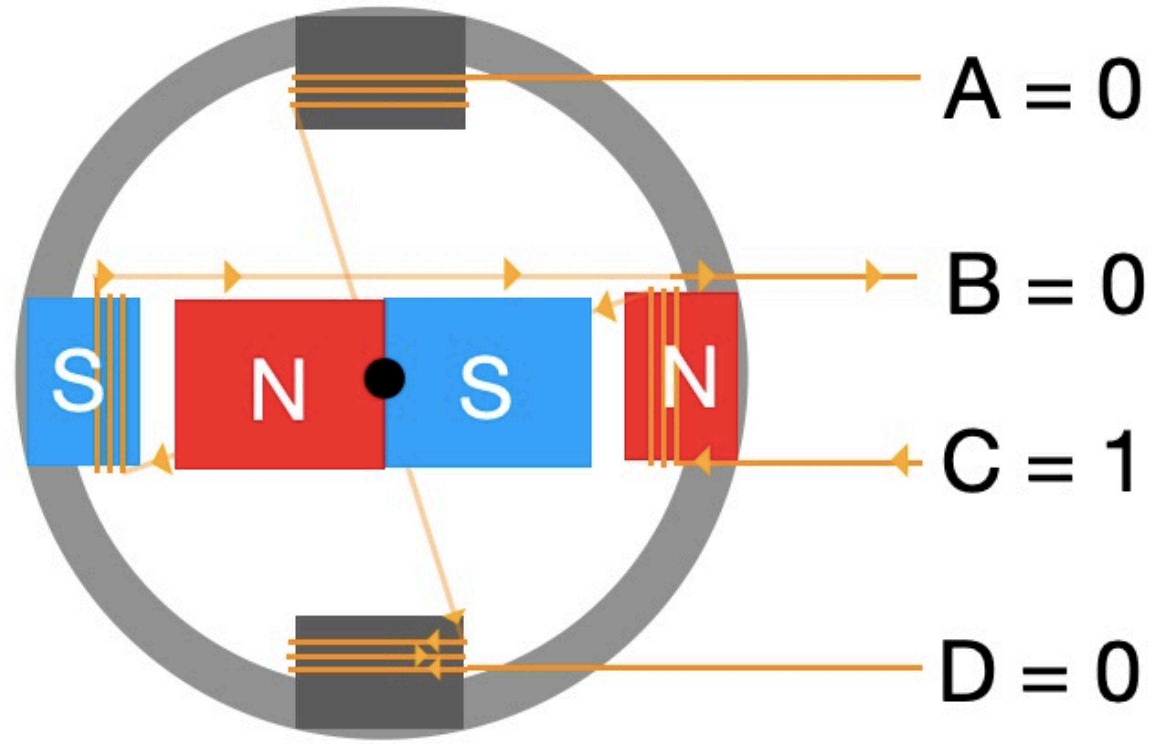
3. Energise AD, De-energise BC



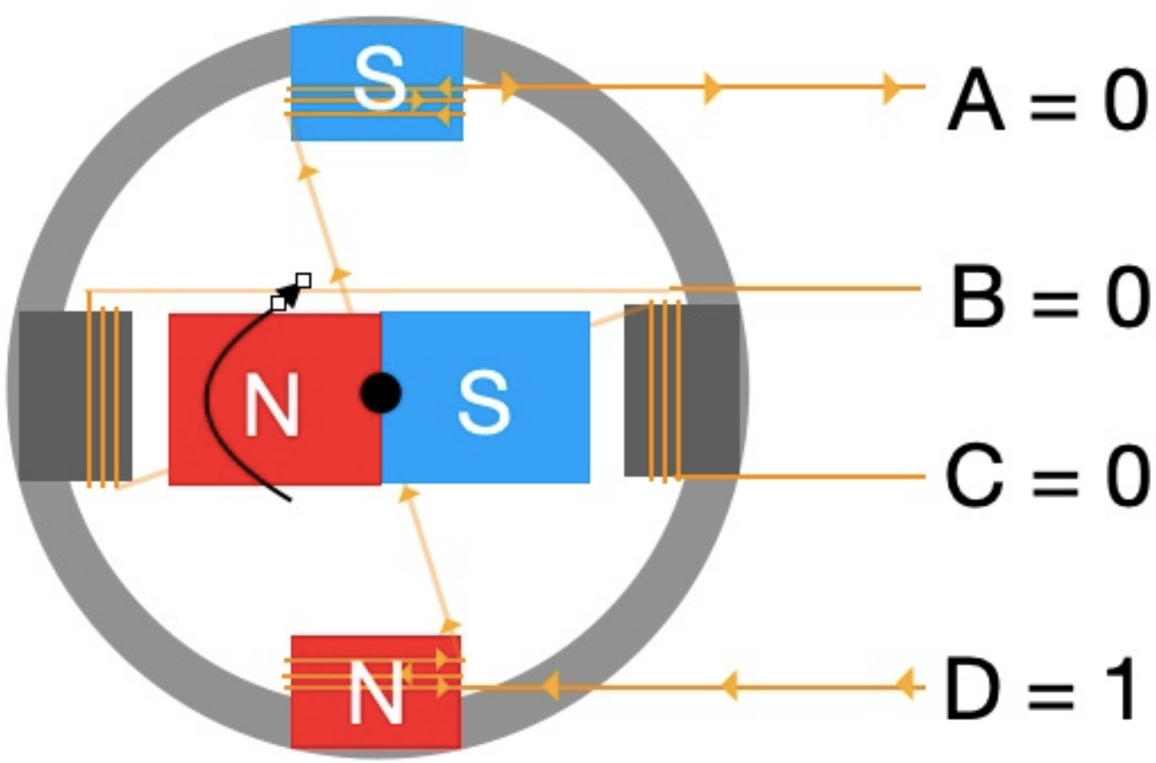
4. Rotor Rotates by step 90° here



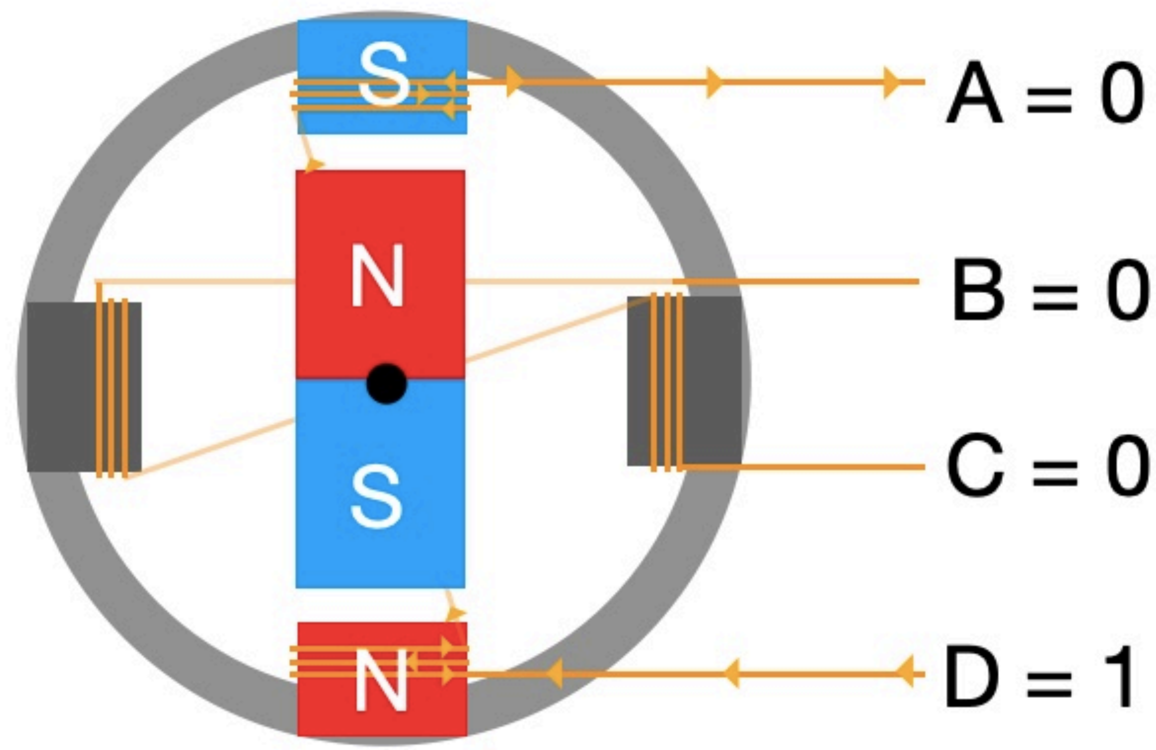
5. Energise CB, De-energise AD



6. Rotor Rotates by step 90° here



7. Energise DA, De-energise BC

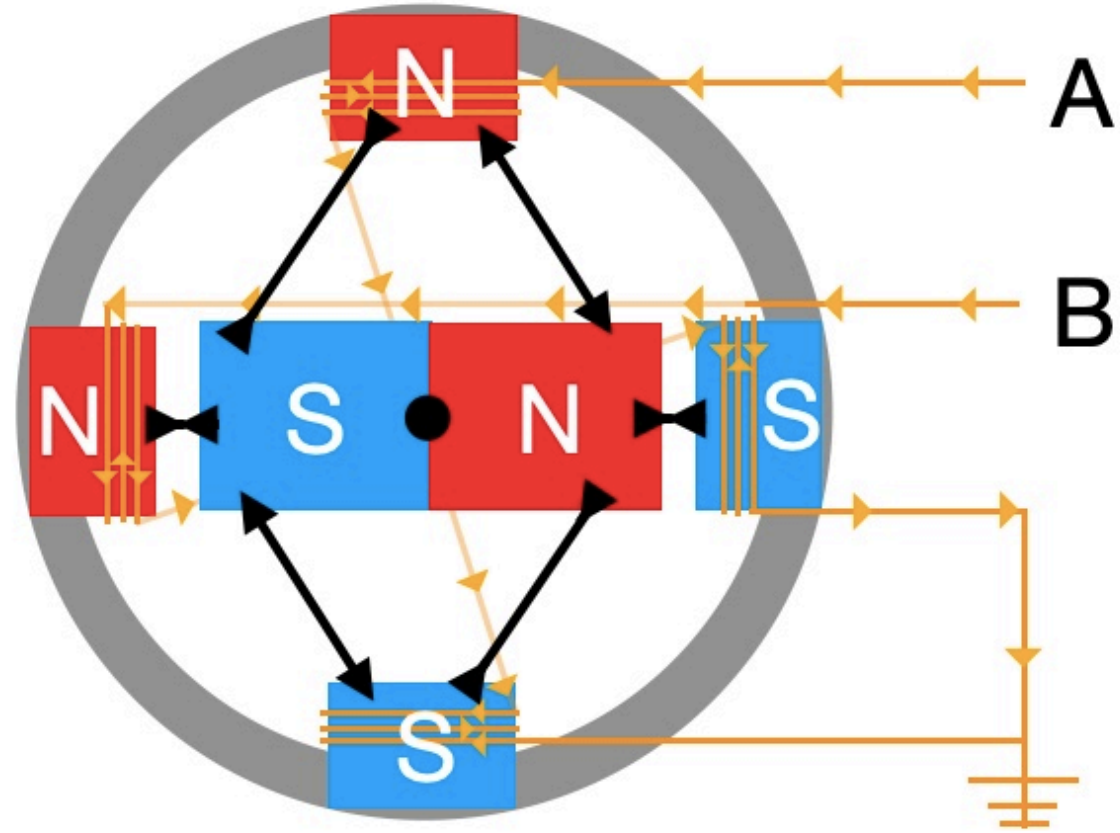


8. Rotor Rotates by step 90° here

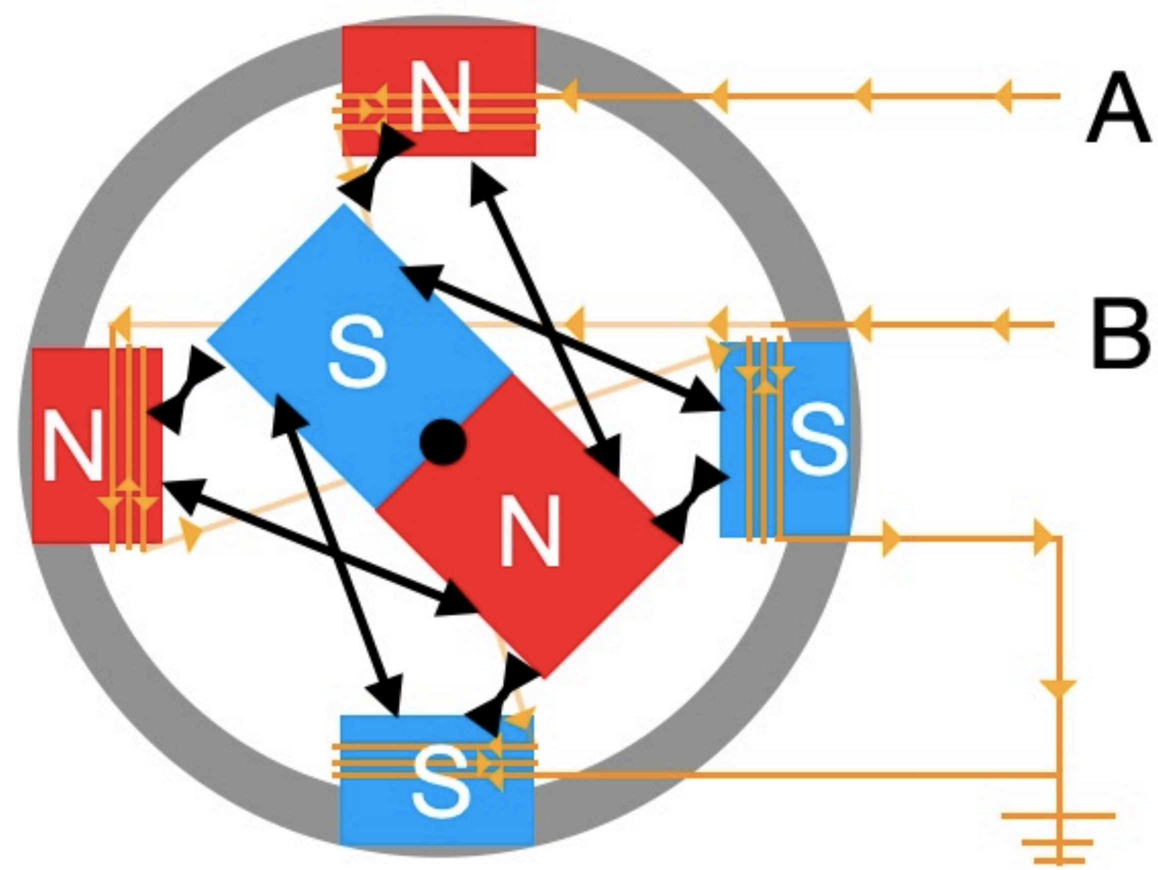
Above example's action table

Coil 1	Coil 2		Coil 1	Action
A	B	C	D	
1	0	0	0	90° turn clockwise
0	1	0	0	90° turn clockwise
0	0	1	0	90° turn clockwise
0	0	0	1	90° turn clockwise

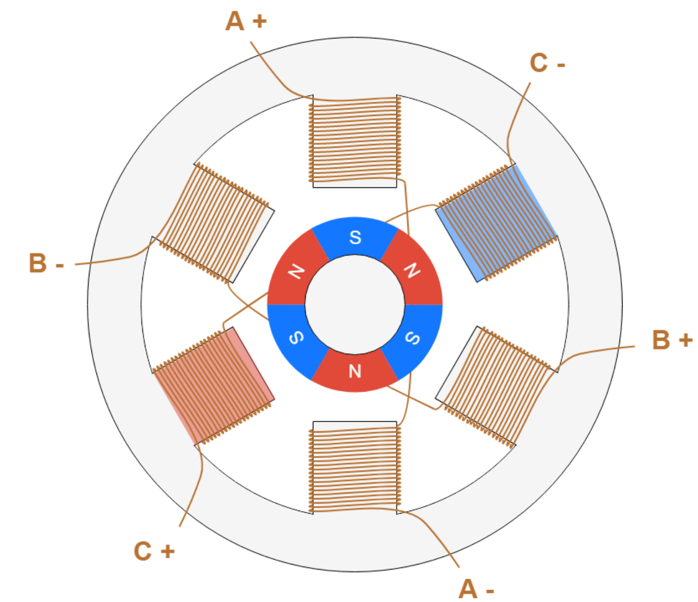
- What happens when coils A and B are energised Simultaneously ?



- The rotor will move between the two coils A & B ie rotate by half step. This type of motion is called half stepping.

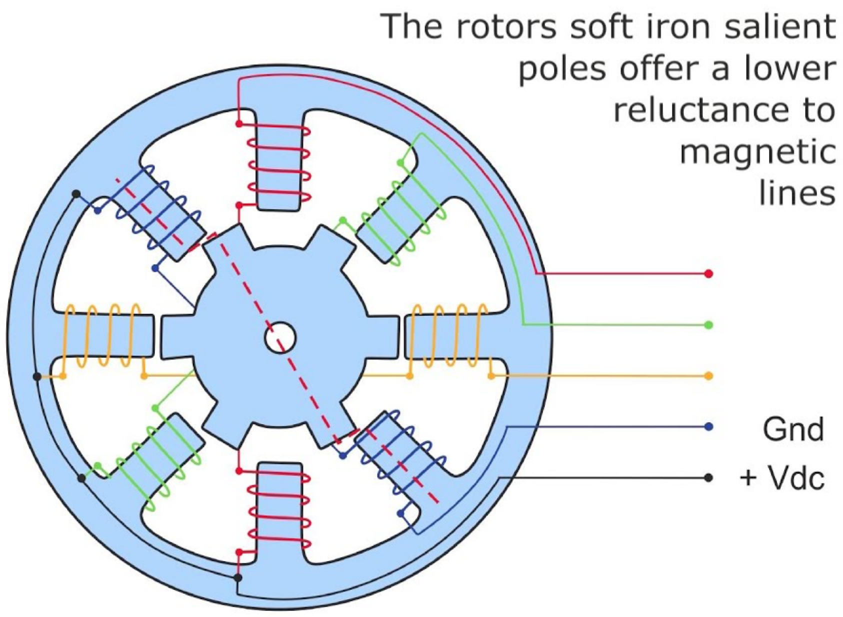


Types of stepper motors



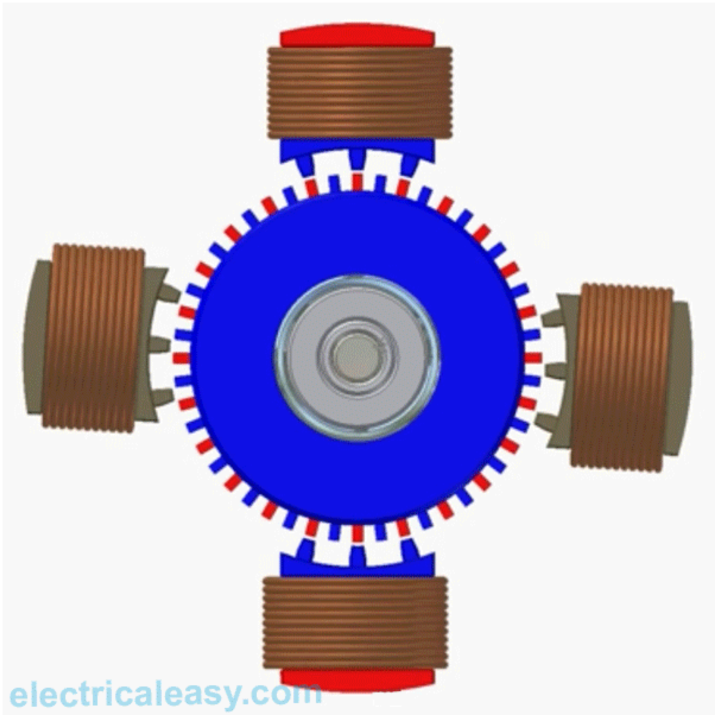
- We discussed **Permanent magnet stepper motor** with large step angle for simplicity.

In a permanent magnet stepper motor, the rotor coils are not excited, instead, we use permanent magnets.



- **Variable reluctance type** stepper motor

It works on the principle of reluctance, according to which magnetic flux always flows through a minimum reluctance path. When the stator phases receive the voltage signal and get excites, there will be the creation of a magnetic field whose axis lines are across the poles. And now, when the rotor attempts to revolve in such a path that it gains low reluctance. This revolution corresponds that a position magnetic field axis created by the stator is the same as the axis that passes across the rotor poles (any two of the poles).



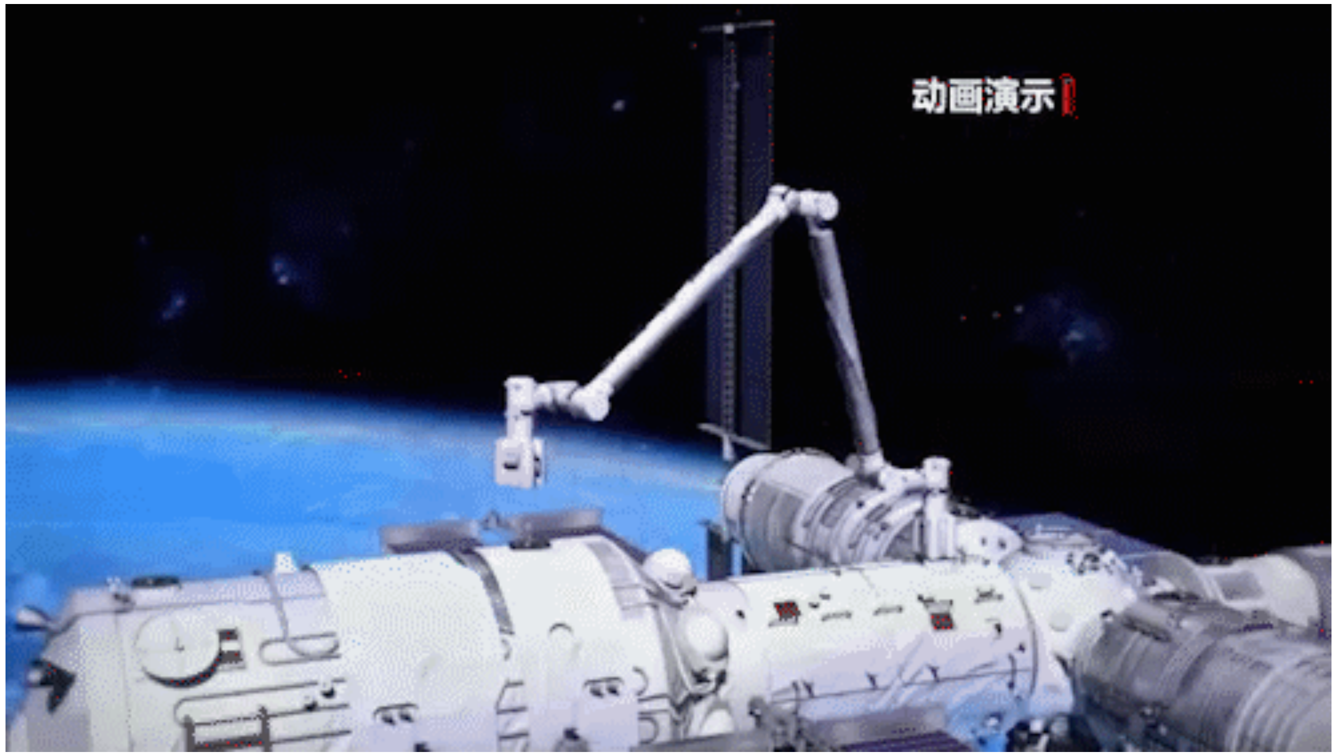
- The most commonly used stepper motor type is **hybrid stepper motor** with very small step sizes, even fraction of a degree,

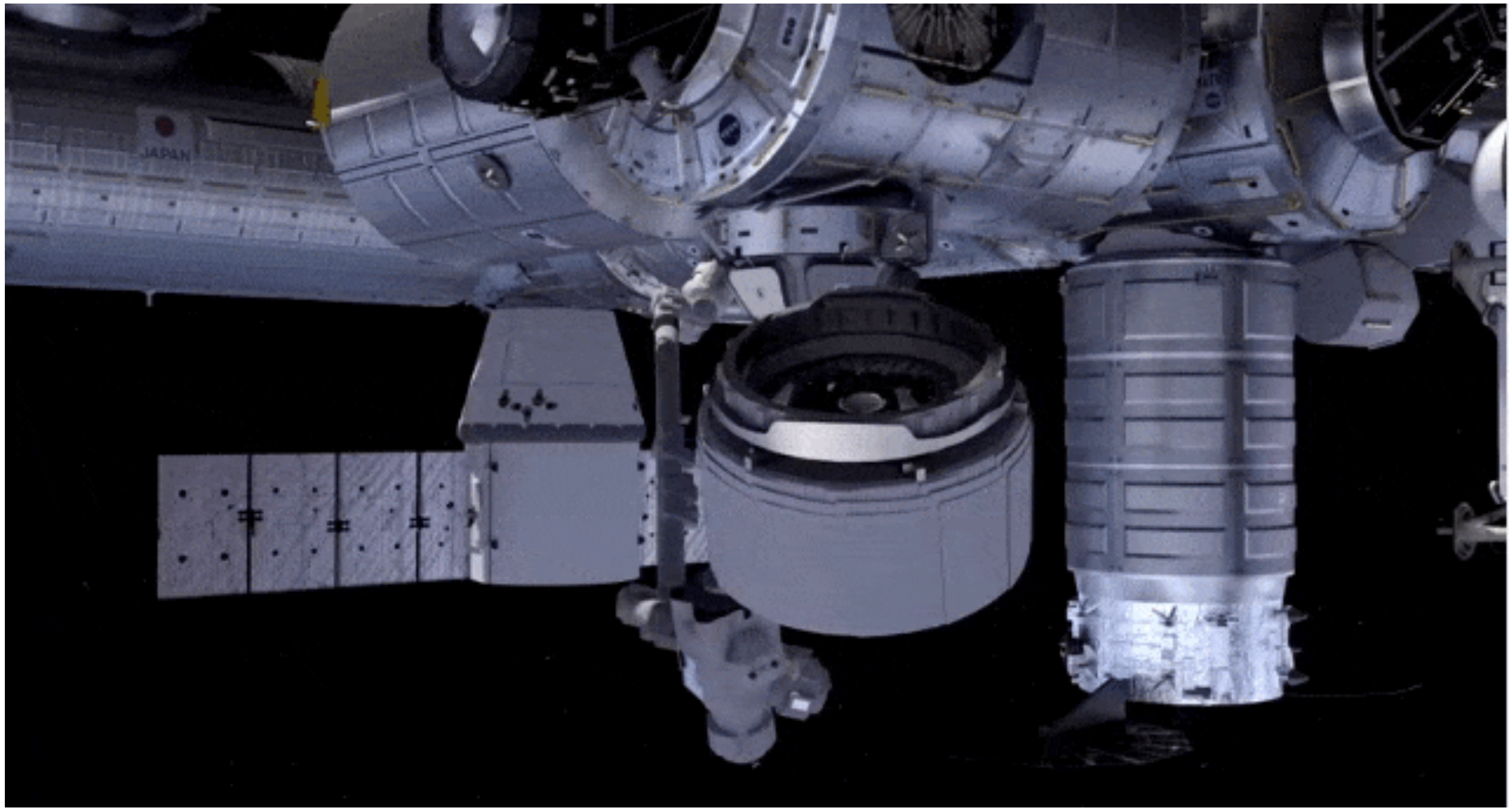
the rotor in this motor is magnetized axially similar to a permanent magnet stepper motor, whereas the stator is energized electromagnetically similar to a variable reluctance stepper motor.

Applications of stepper motors

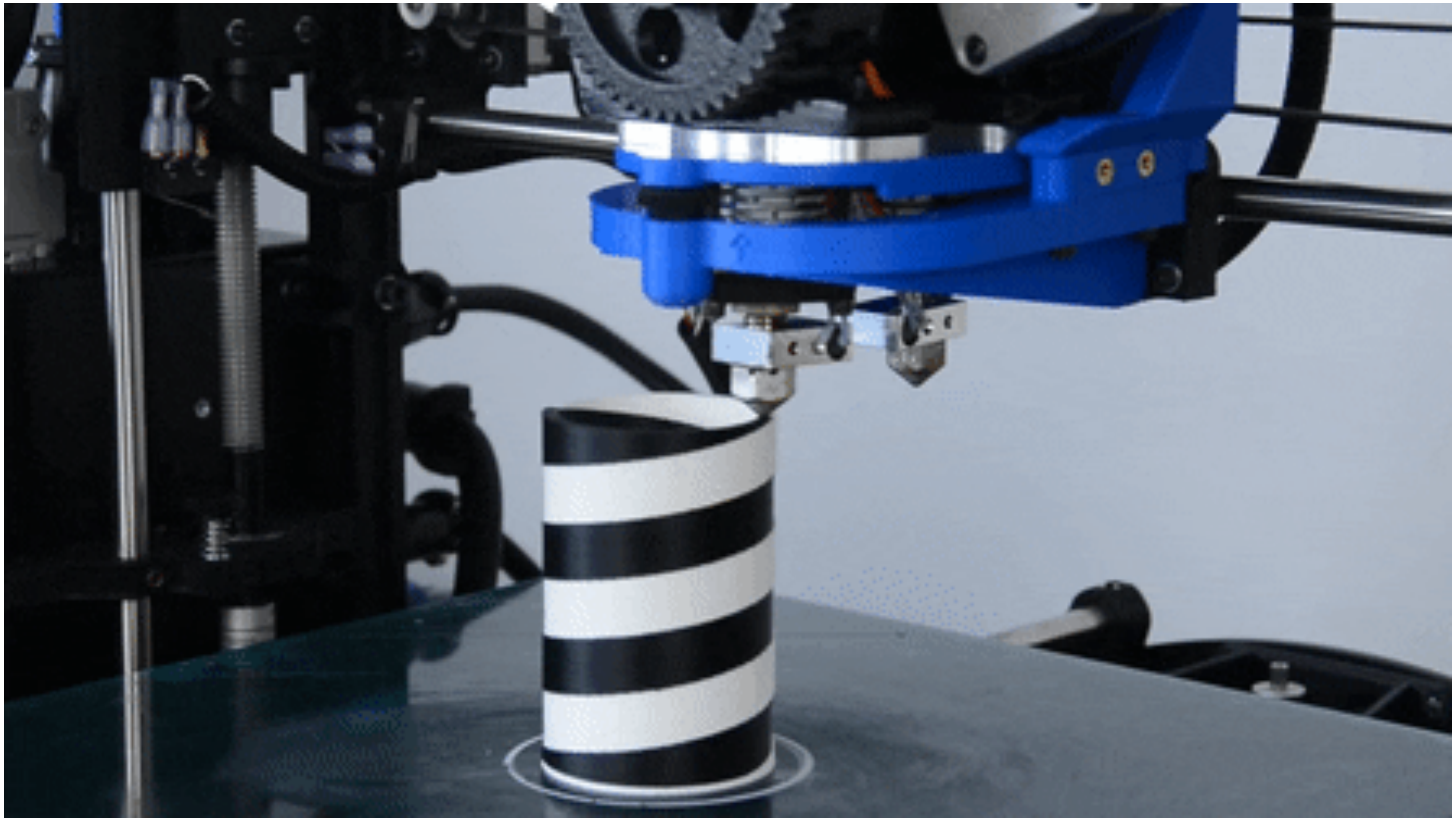
Automated manufacturing

Assembling and Repairing arms on space stations

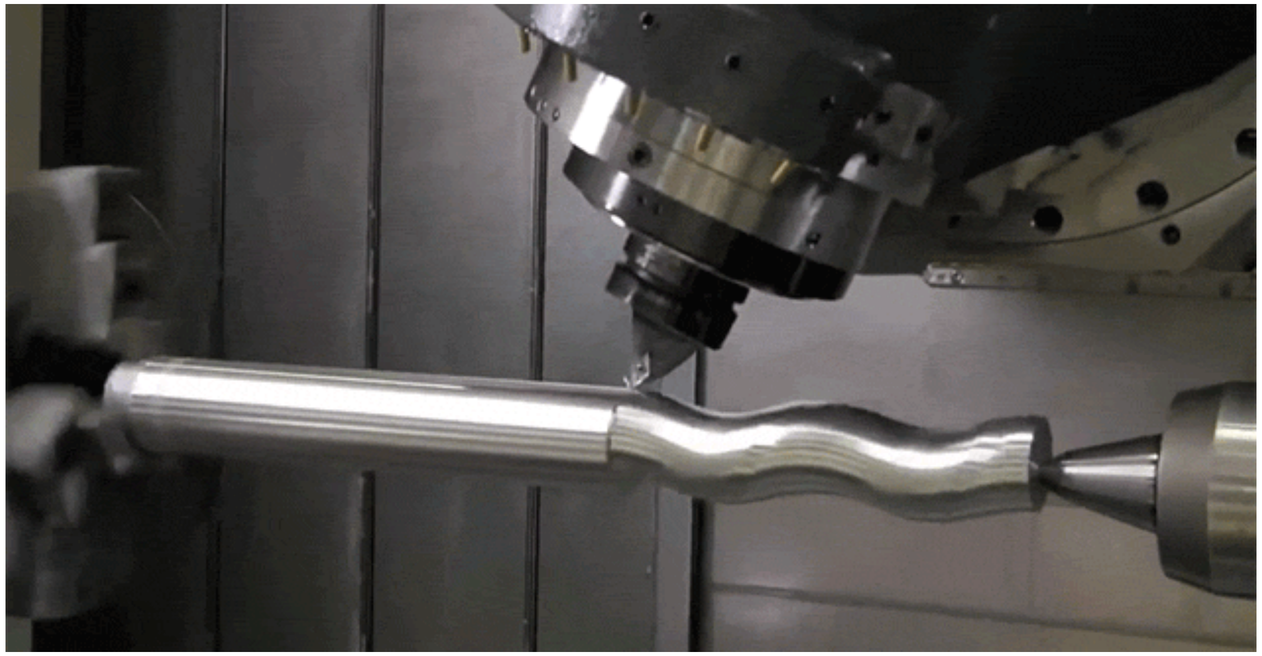


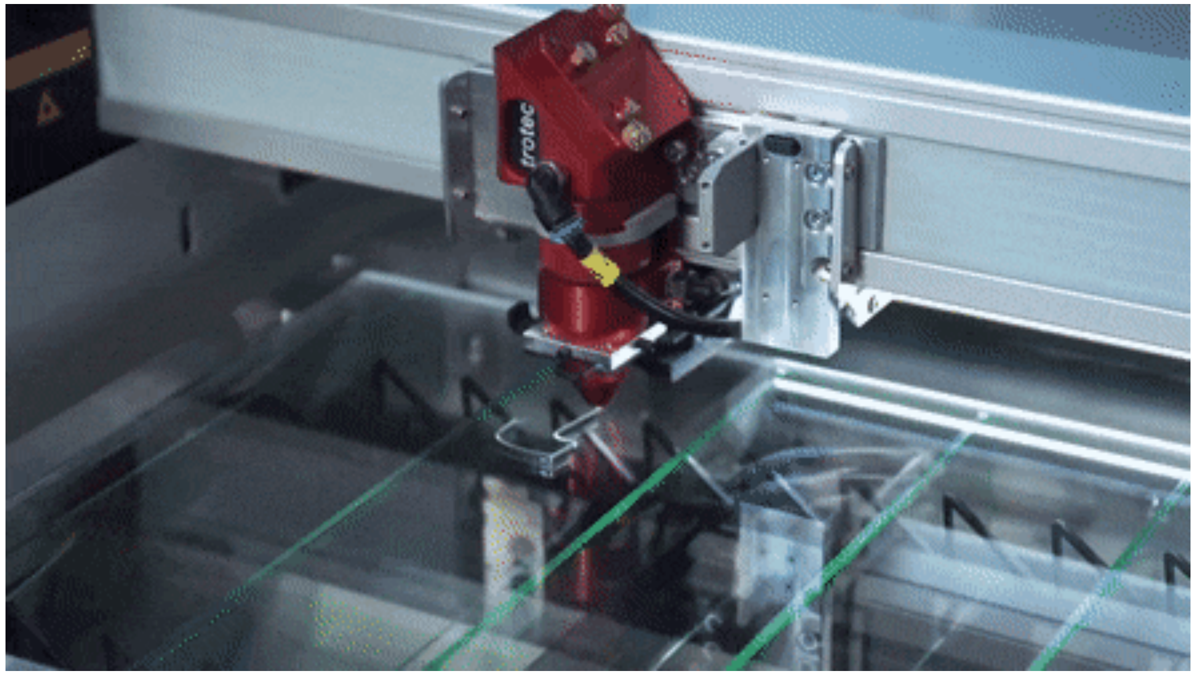


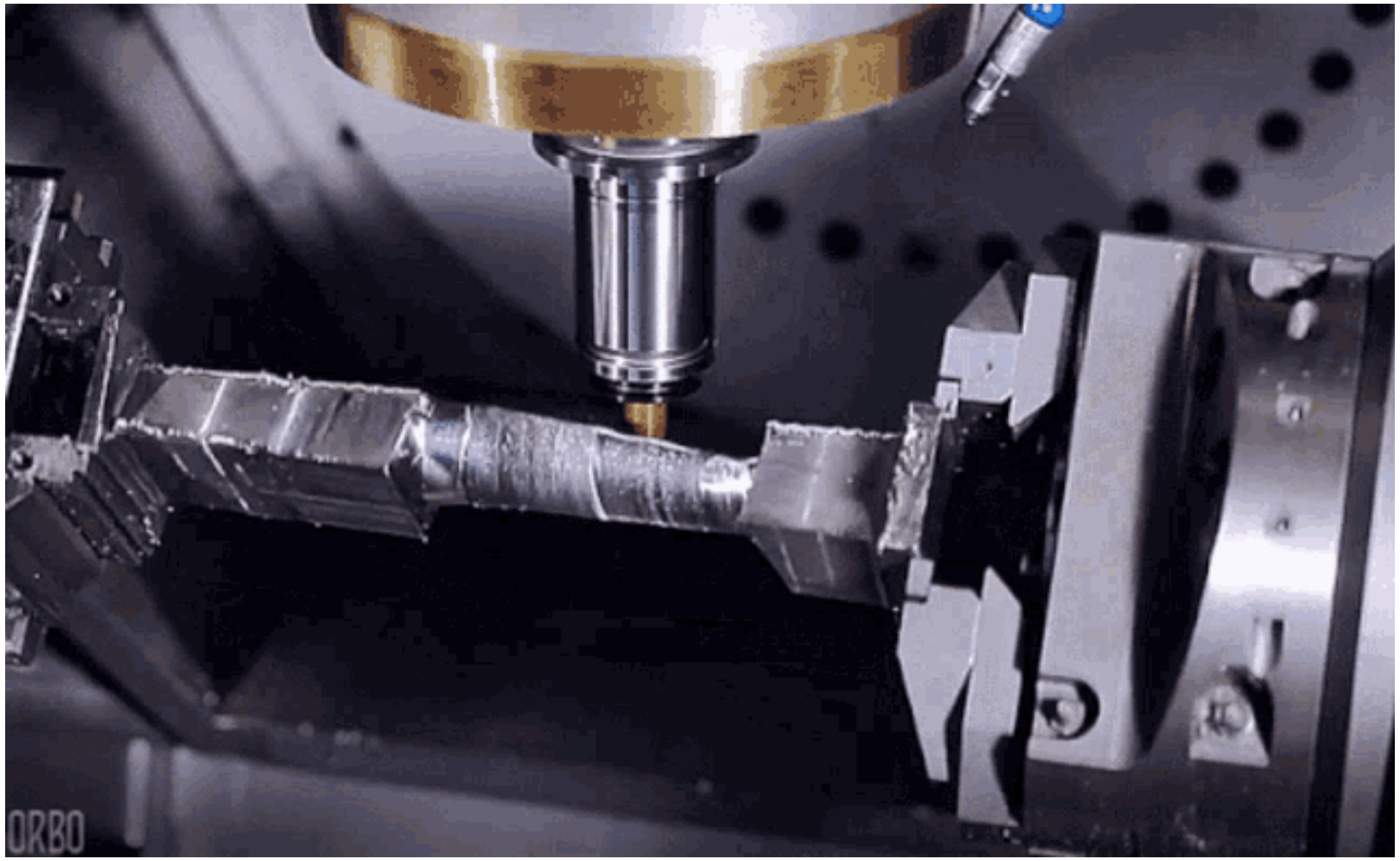
3D printing



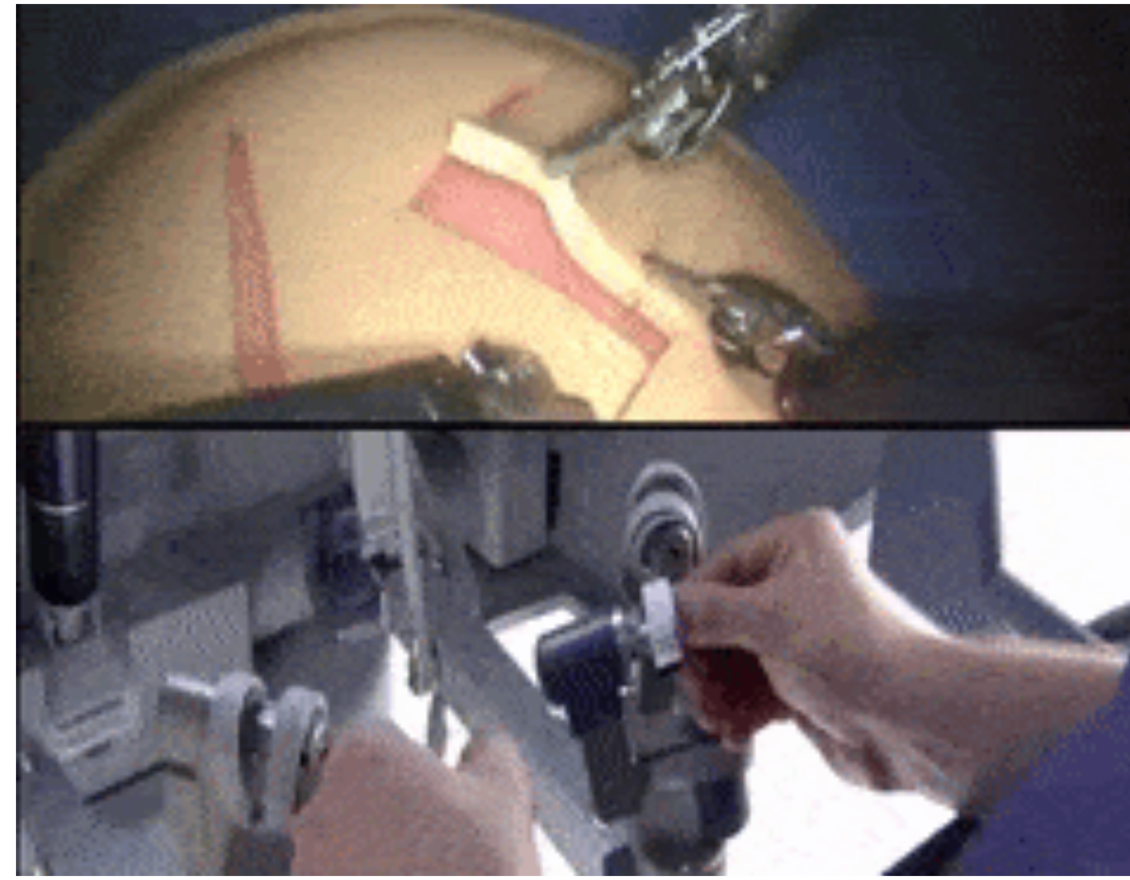
Precision machining and cutting

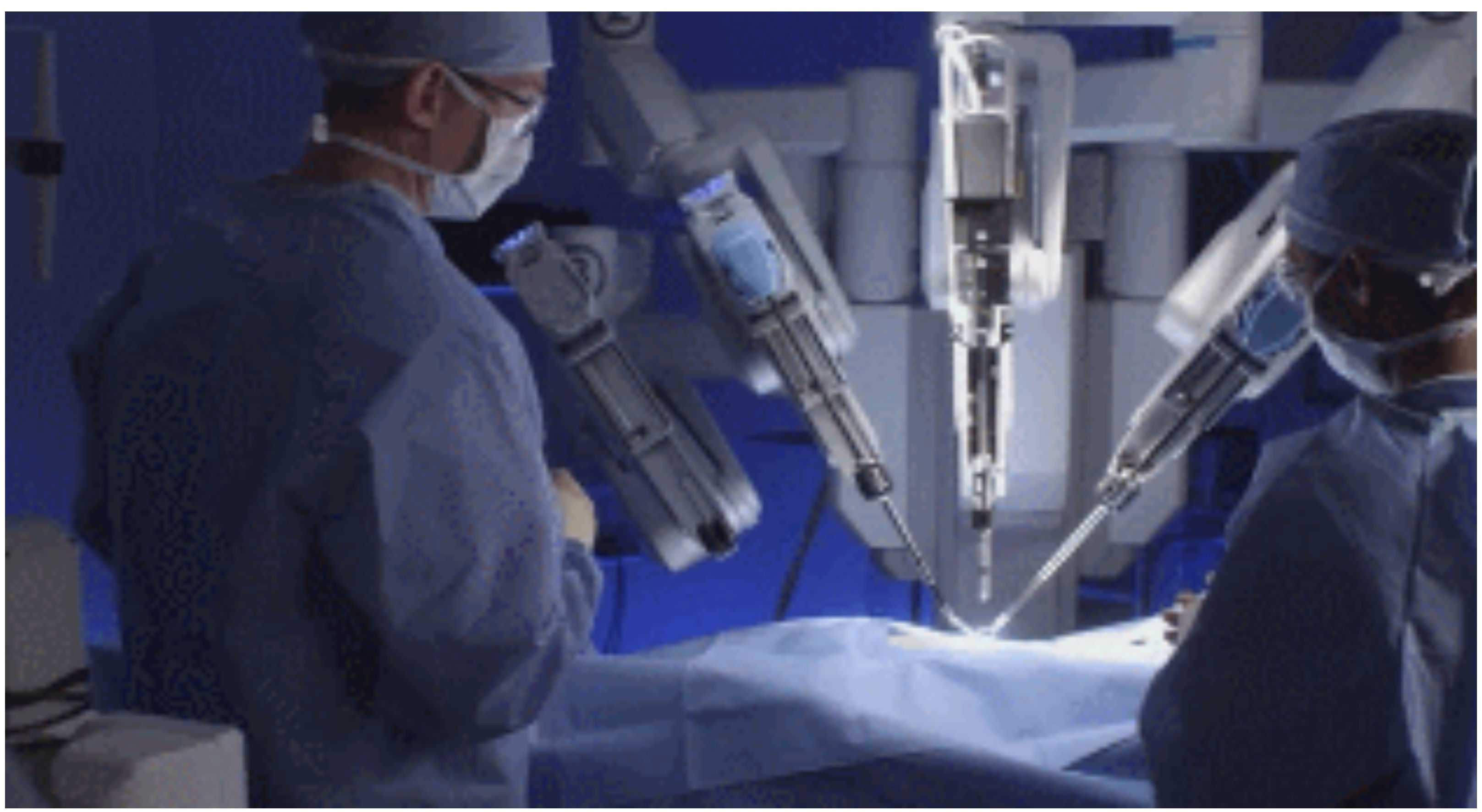






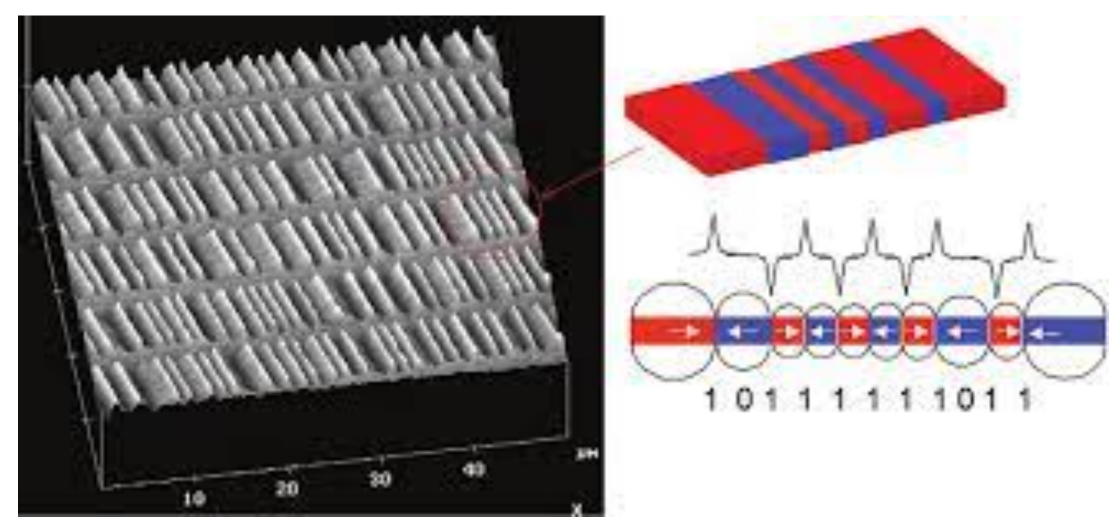
Automated Surgery



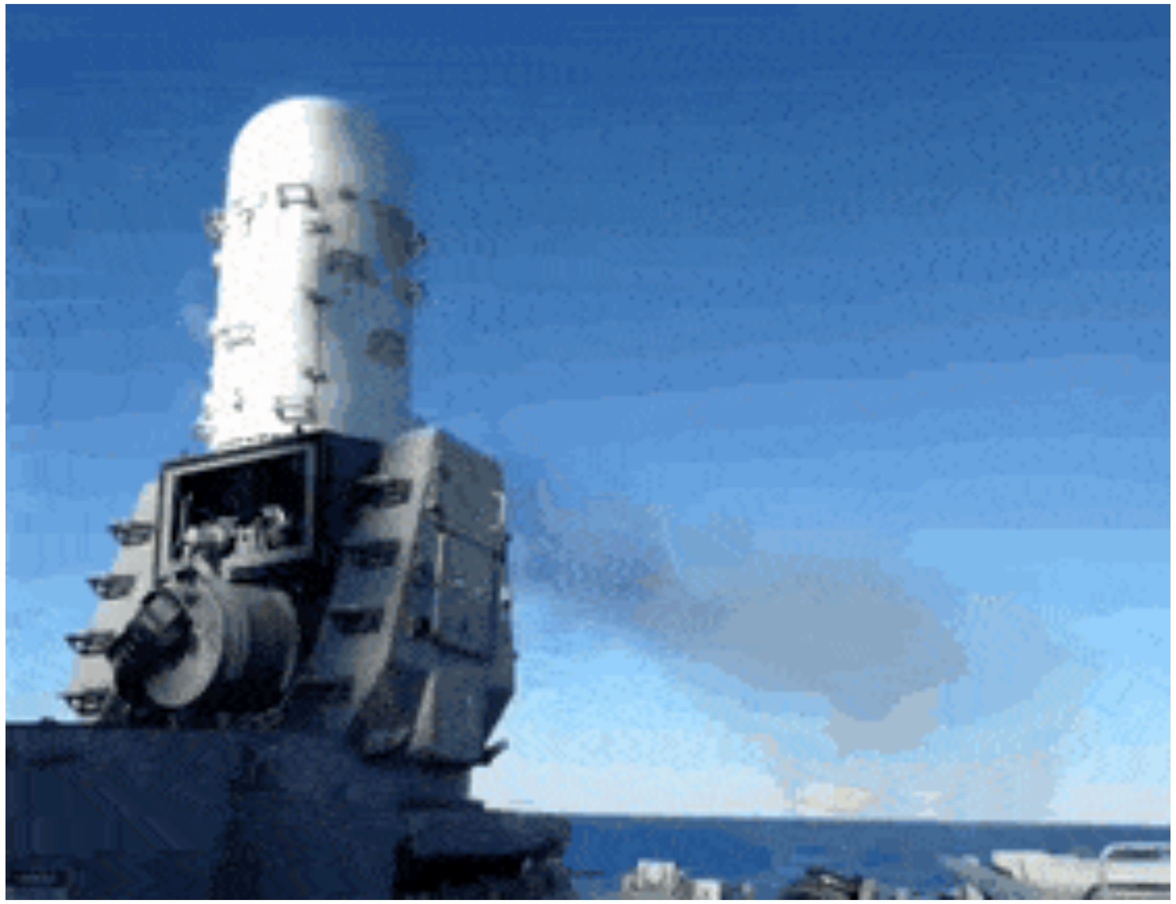


Computer components

Probing tools



Hard Disk Drives :
tracks are order of 100 um apart



Close in weapon system CIWS

Parameters of stepper motor

- **Step Angle** − The step angle is the angle in which the rotor moves when one pulse is applied as an input of the stator. This parameter is used to determine the positioning of a stepper motor. In example we saw, step angle was 90°

- **Steps per Revolution** − This is the number of step angles required for a complete revolution. So the formula is 360° /Step Angle. In example we saw, steps per revolution were 360° / 90° = 4

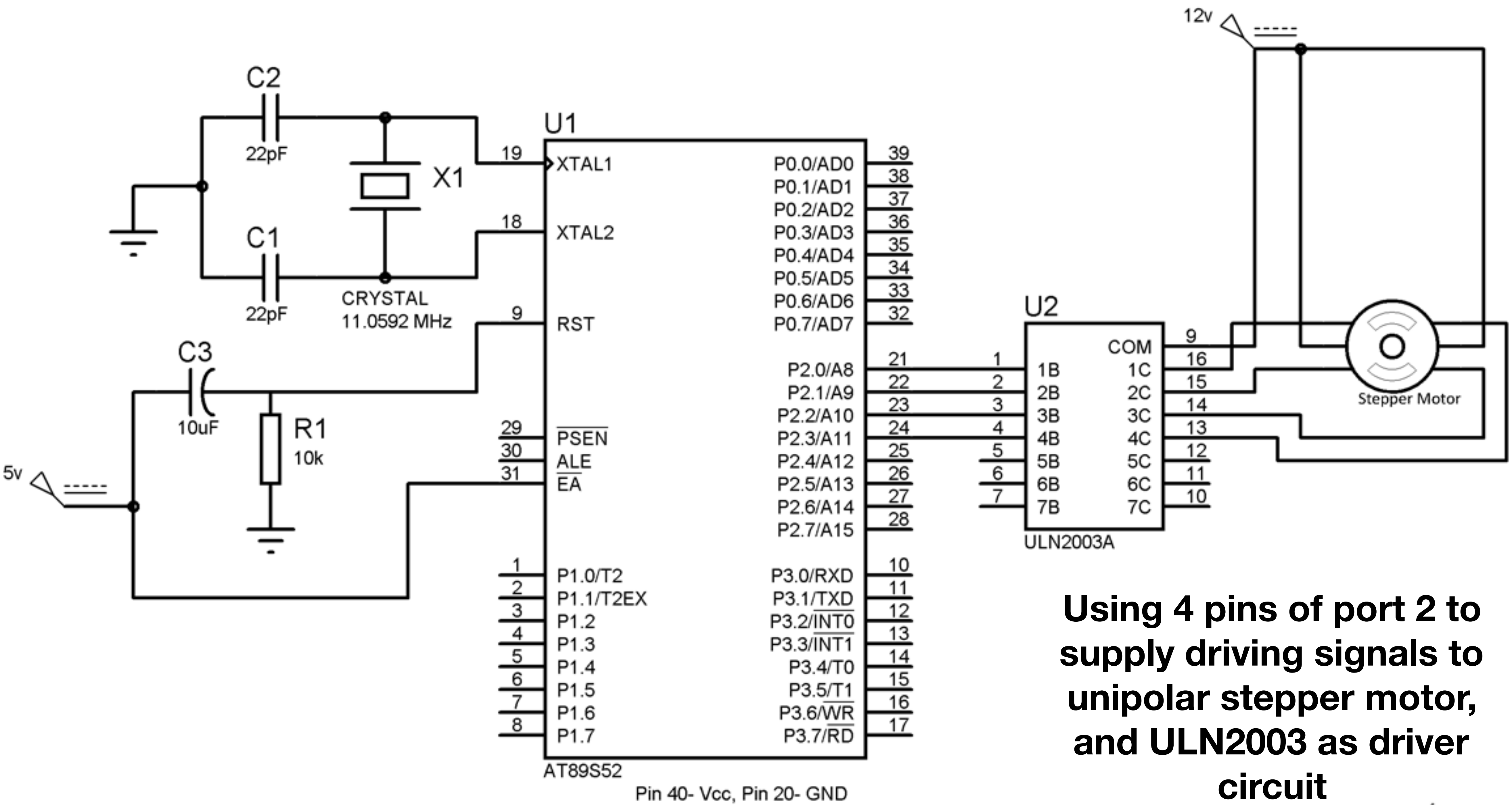
- **Steps per Second** − This parameter is used to measure a number of steps covered in each second.

- **RPM** − The RPM is the Revolution Per Minute. It measures the frequency of rotation. By this parameter, we can measure the number of rotations in one minute.

The relation between RPM, steps per revolution, and steps per second is like below:

```
Steps per Second = rpm x steps per revolution / 60
```

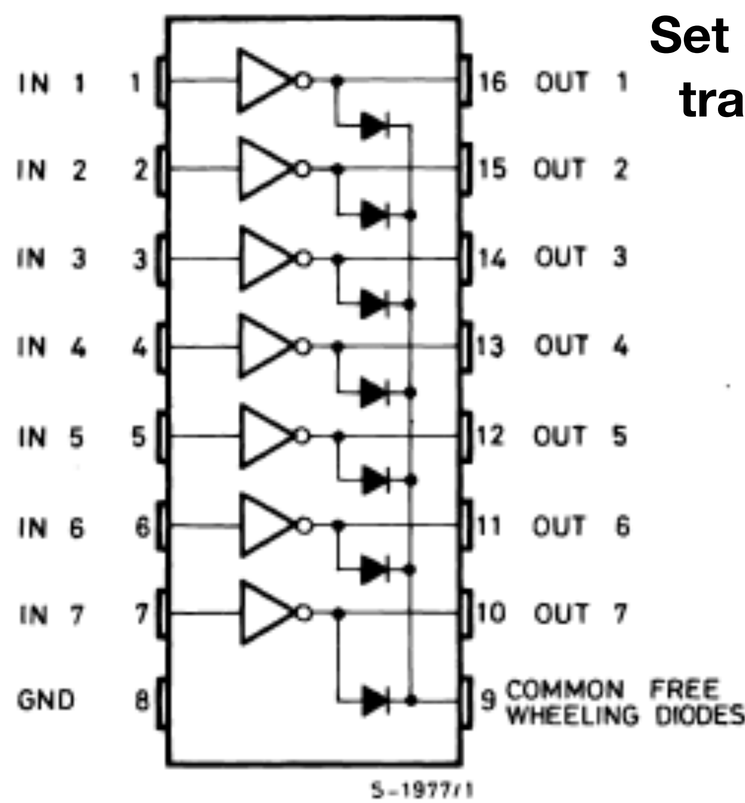
Interfacing stepper motor with 8051

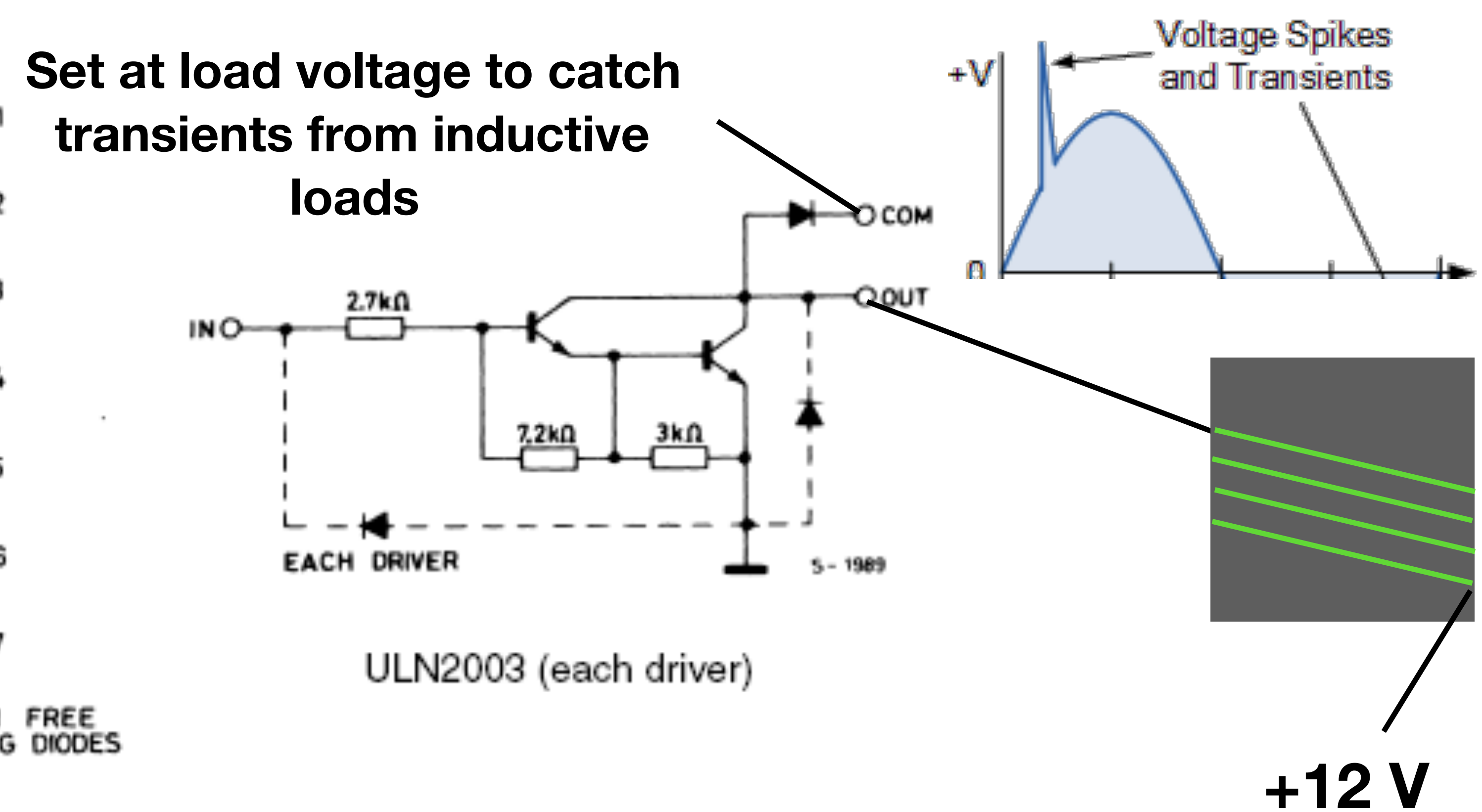


Using 4 pins of port 2 to supply driving signals to unipolar stepper motor, and ULN2003 as driver circuit

ULN2003 as driver IC

Here ULN2003 is used as signal amplifier. This is basically a high voltage, high current Darlington transistor array. Each ULN2003 has seven NPN Darlington pairs. It can provide high voltage output with common cathode clamp diodes for to catch transients while switching inductive loads on and off.





A Darlington transistor (also known as Darlington pair) achieves very high current amplification by connecting two bipolar transistors in direct DC coupling so the current amplified by the first transistor is amplified further by the second one. The resultant current gain is the product of those of the two component transistors is

$$\beta_{\text{total}} \approx \beta_1 \cdot \beta_2$$

The seven Darlington pairs in ULN2003 can operate independently except the common cathode diodes that connect to their respective collectors.

Driving modes of stepper motor

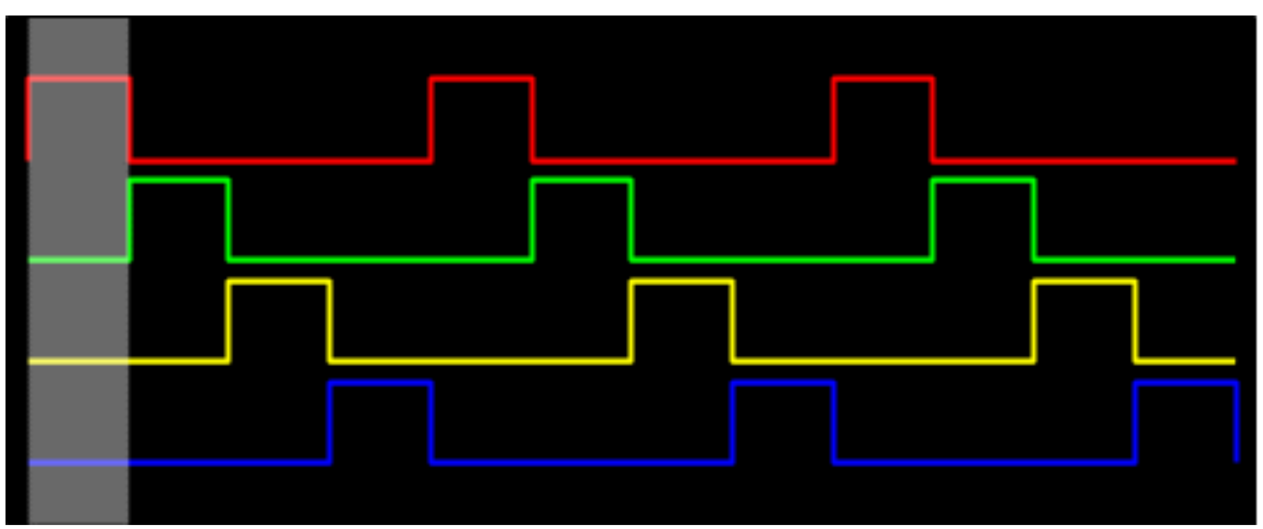
The Unipolar (two teeth on rotor) stepper motor works in three modes.

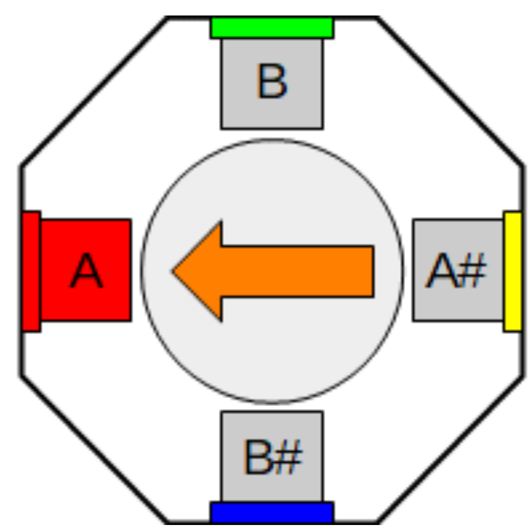
1. Wave drive mode
2. Full drive mode
3. Half drive mode

Wave drive mode

In this mode, one coil is energized at a time. So all four coils are energized one after another. This mode produces less torque than full step drive mode.

Steps	Winding A	Winding B	Winding C	Winding D
1	1	0	0	0
2	0	1	0	0
3	0	0	1	0
4	0	0	0	1

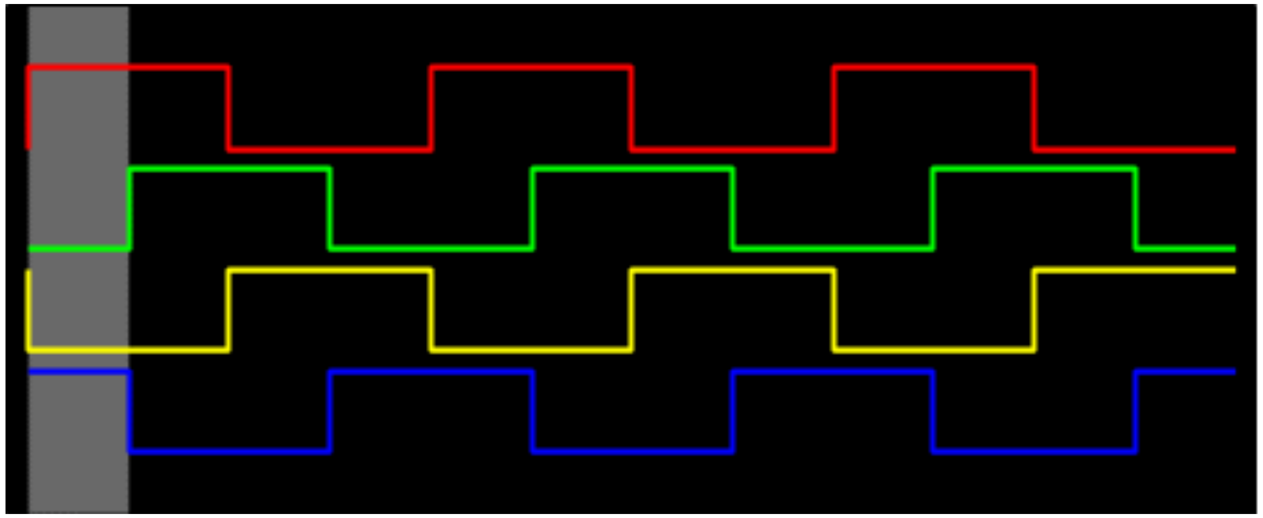


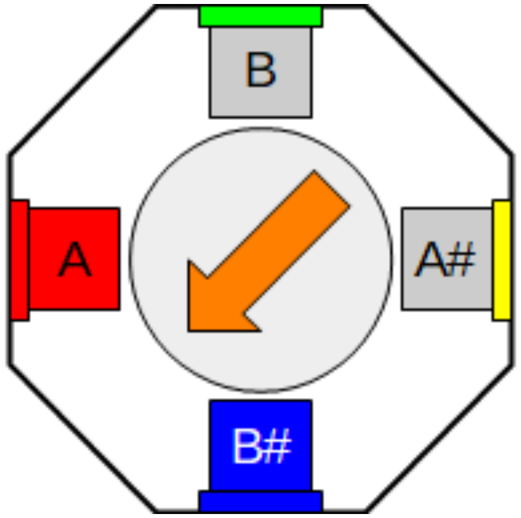


Full drive mode

In this mode, two coils are energized at the same time. This mode produces more torque. Here the power consumption is also high

Steps	Winding A	Winding B	Winding C	Winding D
1	1	1	0	0
2	0	1	1	0
3	0	0	1	1
4	1	0	0	1

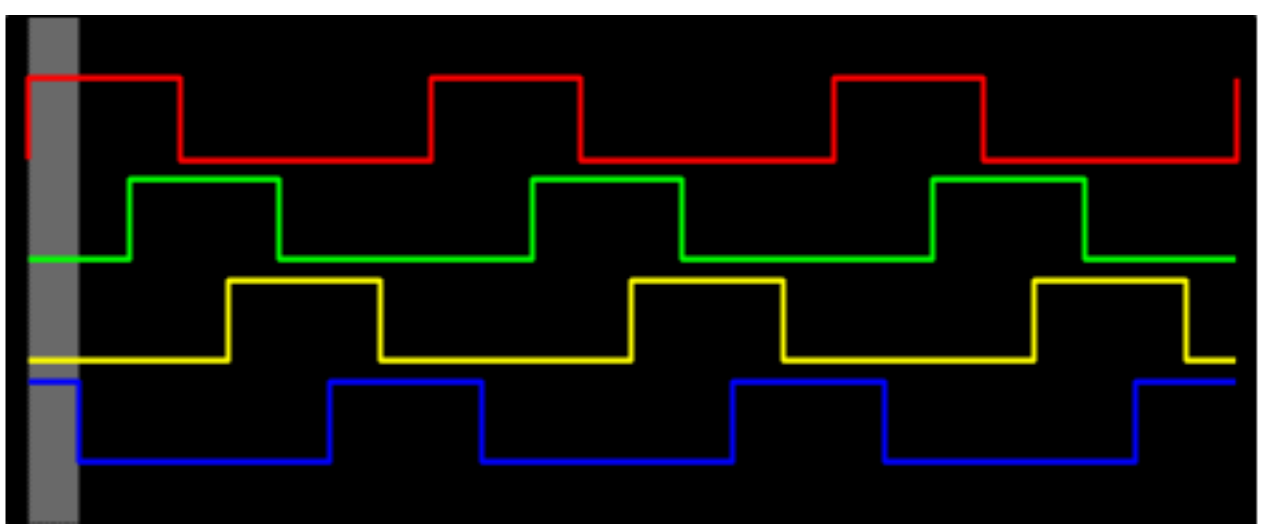


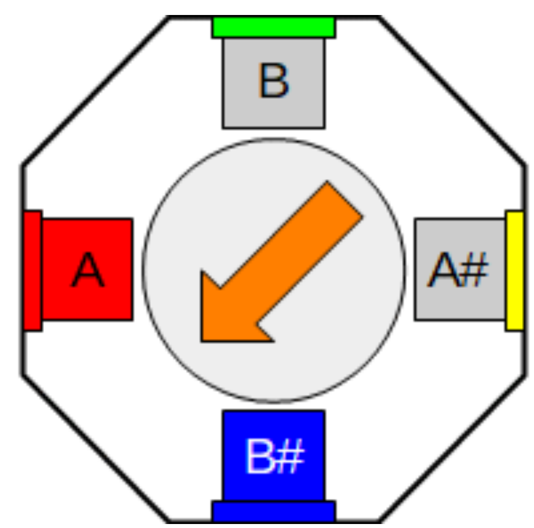


Half drive mode

In this mode, one and two coils are energized alternately. At first, one coil is energized then two coils are energized. This is basically a combination of wave and full drive mode. It increases the angular rotation of the motor.

Steps	Winding A	Winding B	Winding C	Winding D
1	1	0	0	0
2	1	1	0	0
3	0	1	0	0
4	0	1	1	0
5	0	0	1	0
6	0	0	1	1
7	0	0	0	1
8	1	0	0	1





C program for full drive mode

```
#include<P89V51RD2.h>
void delay(int ms){
   unsigned int i, j;
   for(i = 0; i<ms; i++){ // Outer for loop for given milliseconds value
      for(j = 0; j < 1085; j++){
         //1MC = 1.085 us
         //1ms = 1085 machine cycles
       }
   }
}
void main(){
   int rot_angle[] = {0x0C,0x06,0x03,0x09};
   /*
    Full drive mode
    A B C D
    1 1 0 0 0x0C
    0 1 1 0 0x06
    0 0 1 1 0x03
    1 0 0 1 0x09
   */
   int i;
   while(1){
      //infinite loop for rotating motor
      for(i = 0; i<4; i++){
         P2 = rot_angle[i];
         delay(100);
         //Assuming speed of 10 steps / second
      }
   }
}
```

References

- https://www.onetransistor.eu/2017/12/arduino-code-stepper-motors.html
- https://forum.fritzing.org/t/28byj-48-stepper-motor-and-uln2003-driver-module/12883
- Illustrations on slides 7-9 by yash vinayvanshi
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