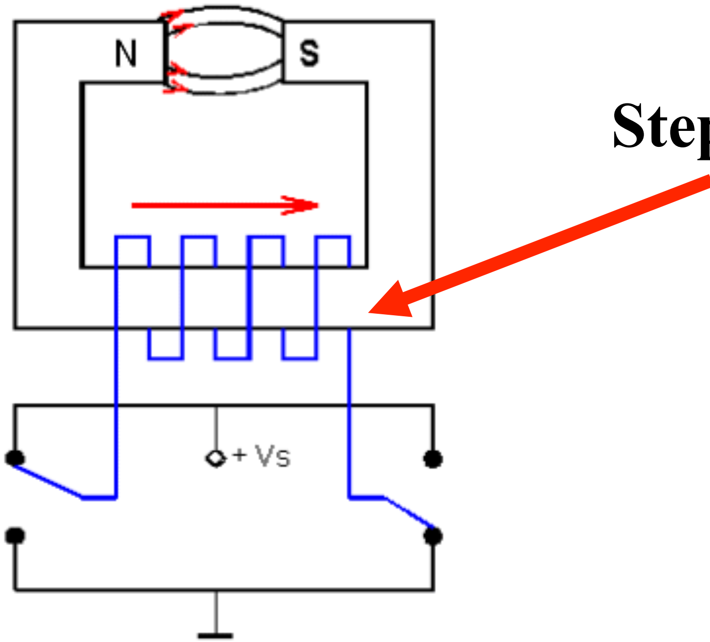
# ROCO222: Intro to sensors and actuators

Lecture 5

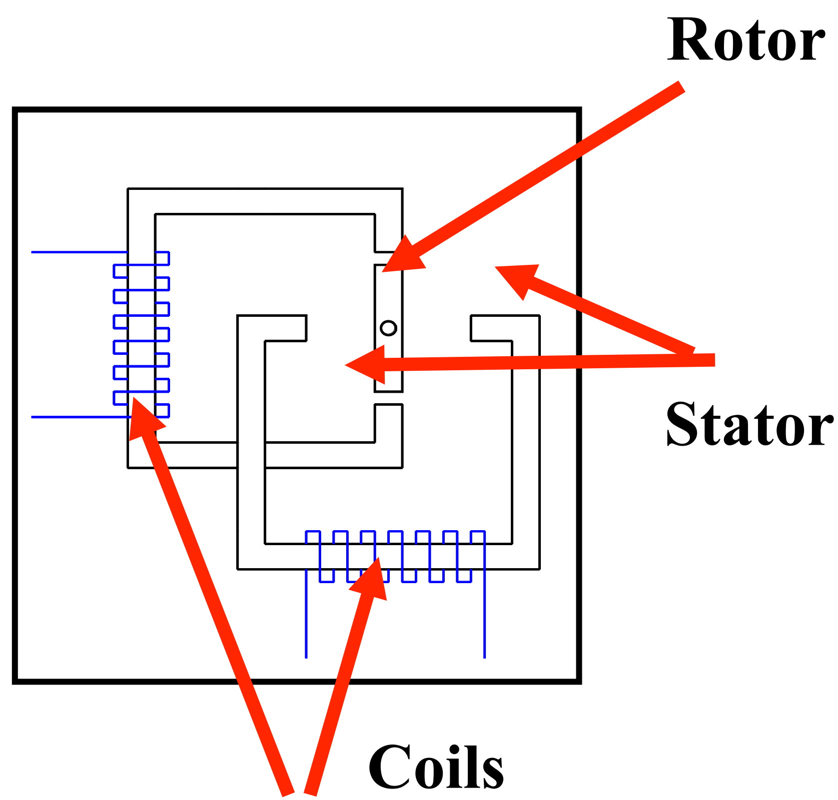
Stepper motors

# Stepper motor basic idea



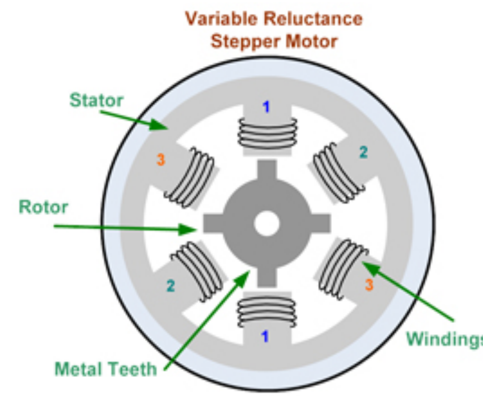

Stepper motors use electro-magnets

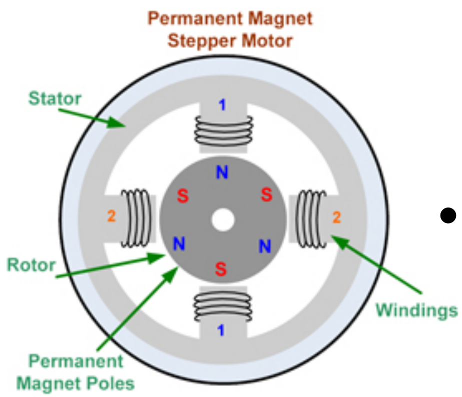
- A step motor is a synchronous electric motor
- Its fixed rotor equilibrium position occurs when aligned with the stator magnetic field
- When stator field changes position, rotor rotates to occupy a new equilibrium position



# Several basic types of stepping motors

- There are different types of stepper motors
  - Variable reluctance stepper motors with metal teeth

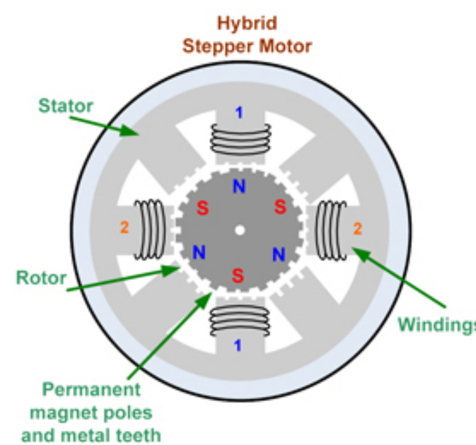



  - Permanent magnet stepper motors

- Hybrid stepper motors with both permanent magnets and metal teeth

- 2 phase hybrid steppers are the main type of motor actually used in practice



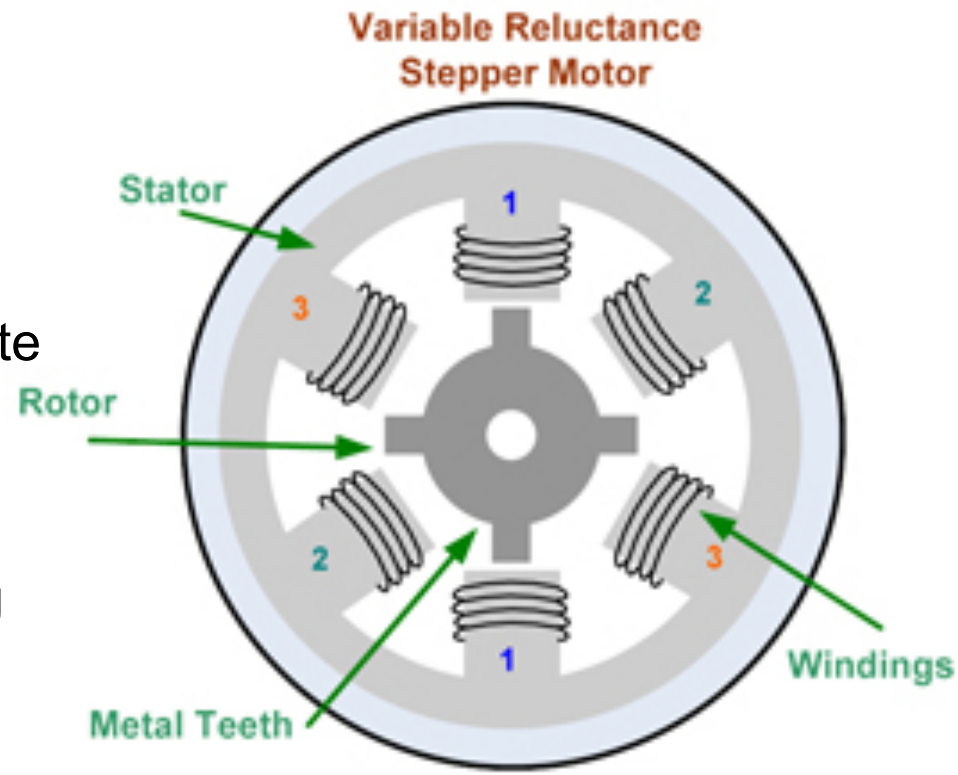
# Variable Reluctance Motor

- In a reluctance stepper motor the rotor consists of a toothed cylinder and it is made of ferromagnetic material

- Rotor is not permanently magnetized

- A stator consists of windings that generate a magnetic field

- The rotation of a variable reluctance stepping motor is produced by energizing individual windings




- When a winding is energized, current flows and magnetic poles are created, which attracts the nearest metal teeth of the rotor

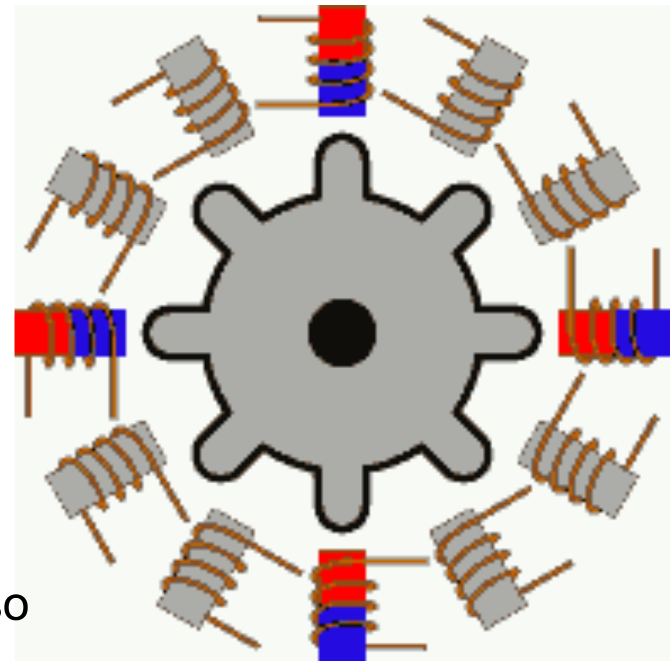
- Thus as current it passed through the stator coils the rotor moves one step to align the offset teeth to the energized winding, thereby minimizing the reluctance of the magnetic path

# Variable reluctance stepper motor operation

- When the rotor is aligned and held at the current position, the next adjacent windings can be energized to continue rotation in another step.

- Alternatively the current winding can remain energized to hold the motor at its current position.

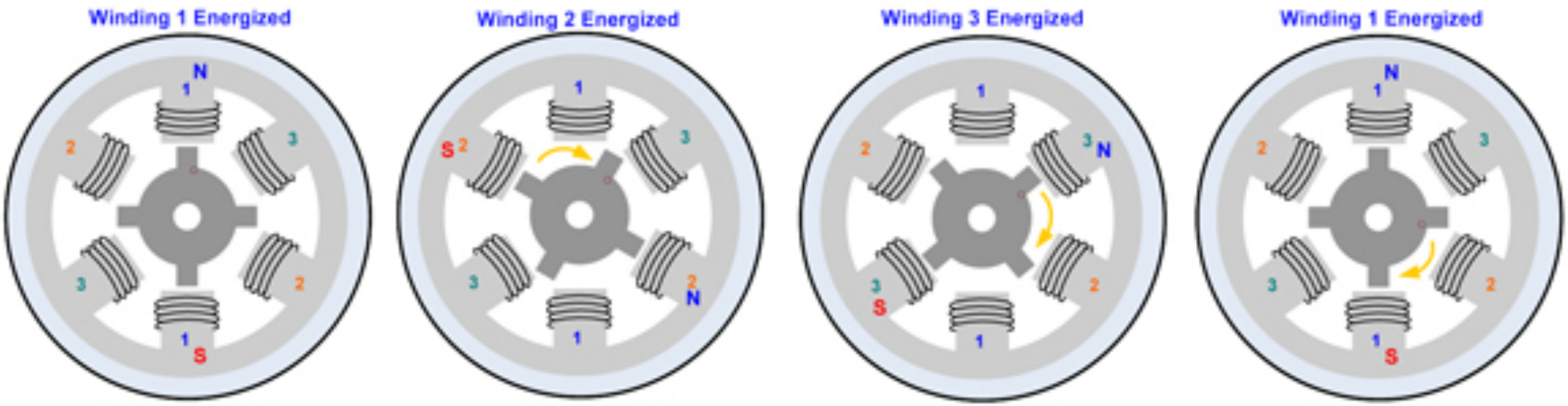
- When the phases are turned on in the appropriate sequence, the rotor rotates continuously



Reluctance stepper motors have the advantages:
- A cheap way to generate high power densities
- Simple to manufacture
- Do not have problems of inducing EMF in the stator coils and so can easily run a high speeds.

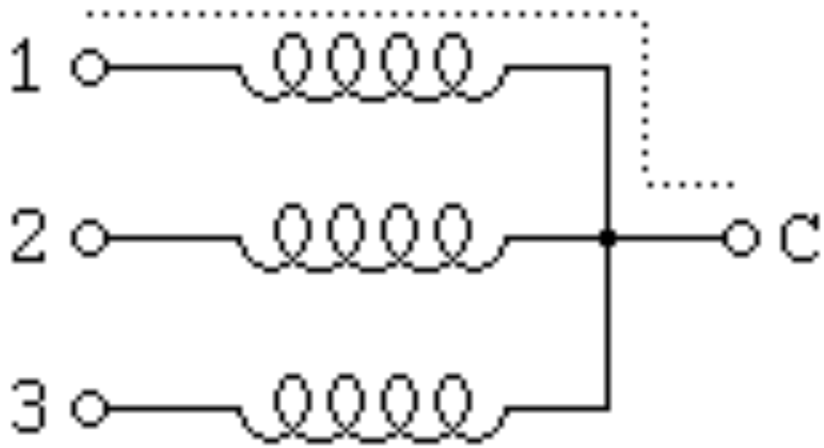
Reluctance stepper motors have the disadvantages:
- Have limited output torque
- Have a lot of torque ripple and are noisy

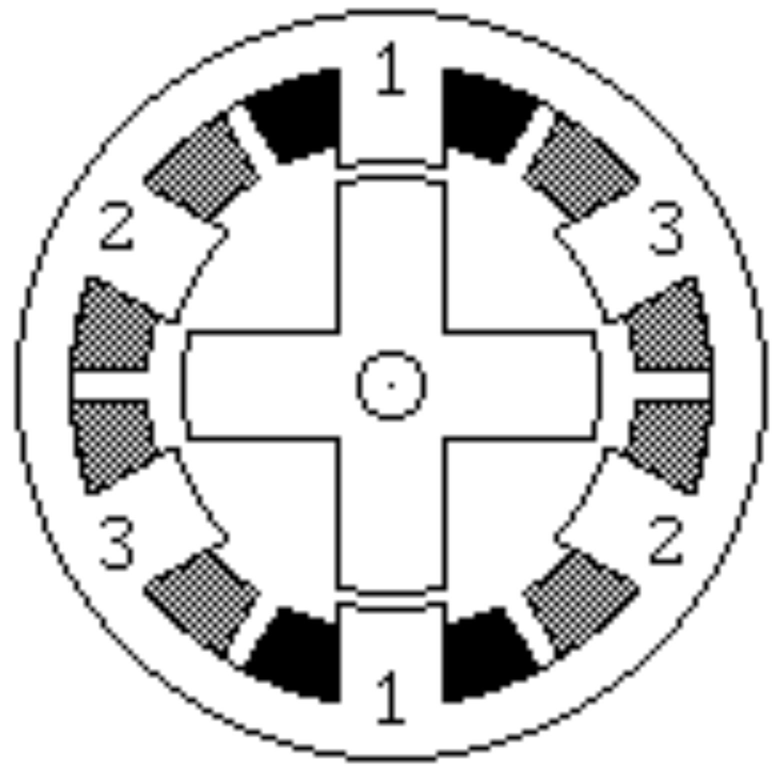
# Variable reluctance stepper motor operation




| | | | | |
|---|---|---|---|---|
| Winding 1 | 0 | + | 0 | 0 |
| Winding 2 | 0 | 0 | + | 0 |
| Winding 3 | + | 0 | 0 | + |

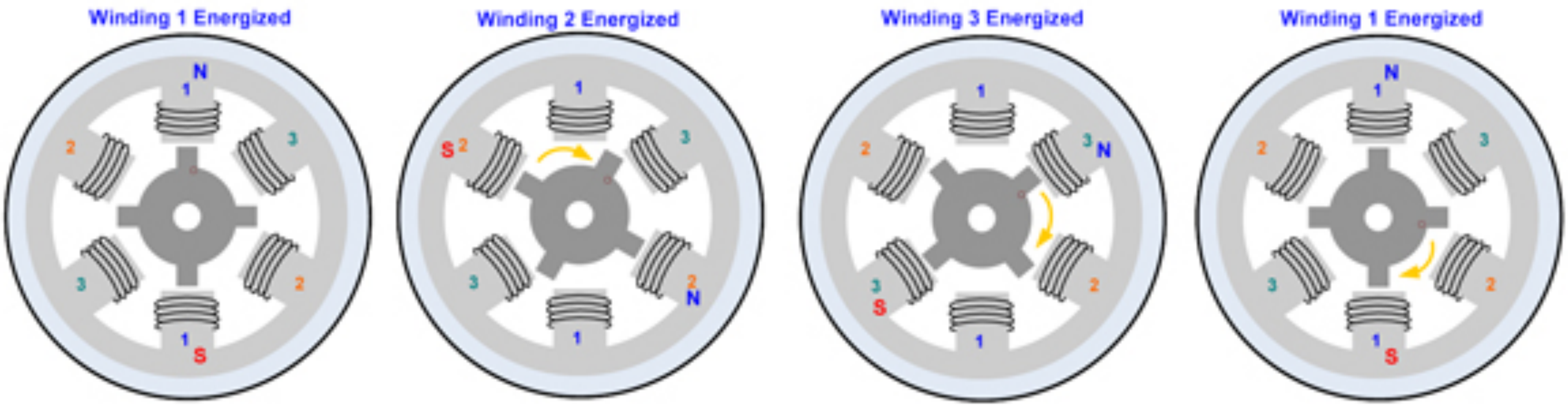
# Variable Reluctance Motor Coils




Example motor with 3 field windings

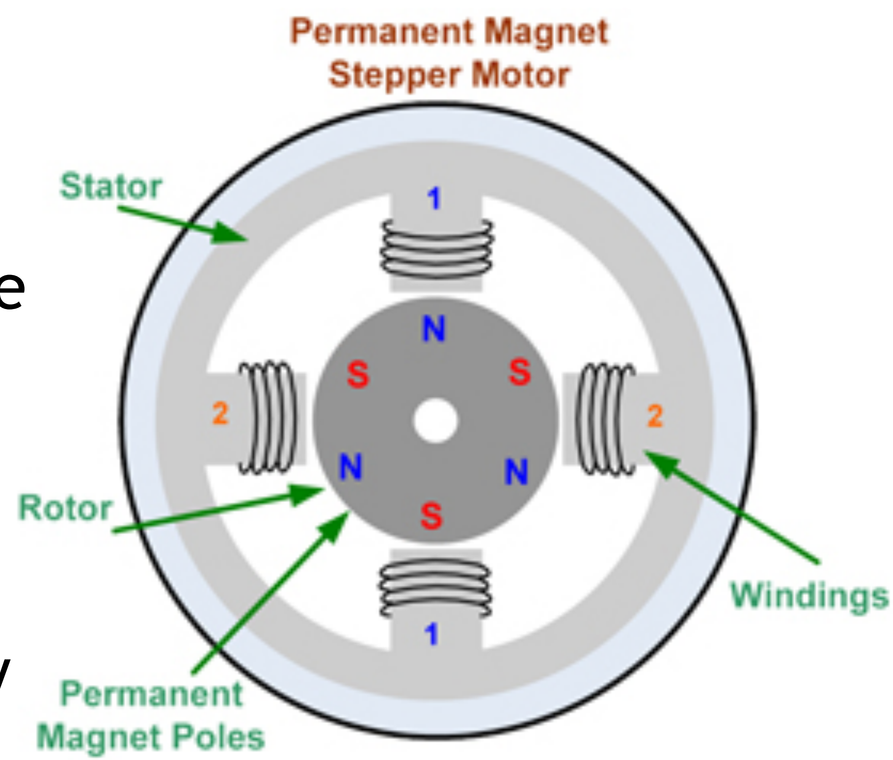
# Variable reluctance stepping motor operation




| | | | | |
|---|---|---|---|---|
| Winding 1 | 0 | + | 0 | 0 |
| Winding 2 | 0 | 0 | + | 0 |
| Winding 3 | + | 0 | 0 | + |

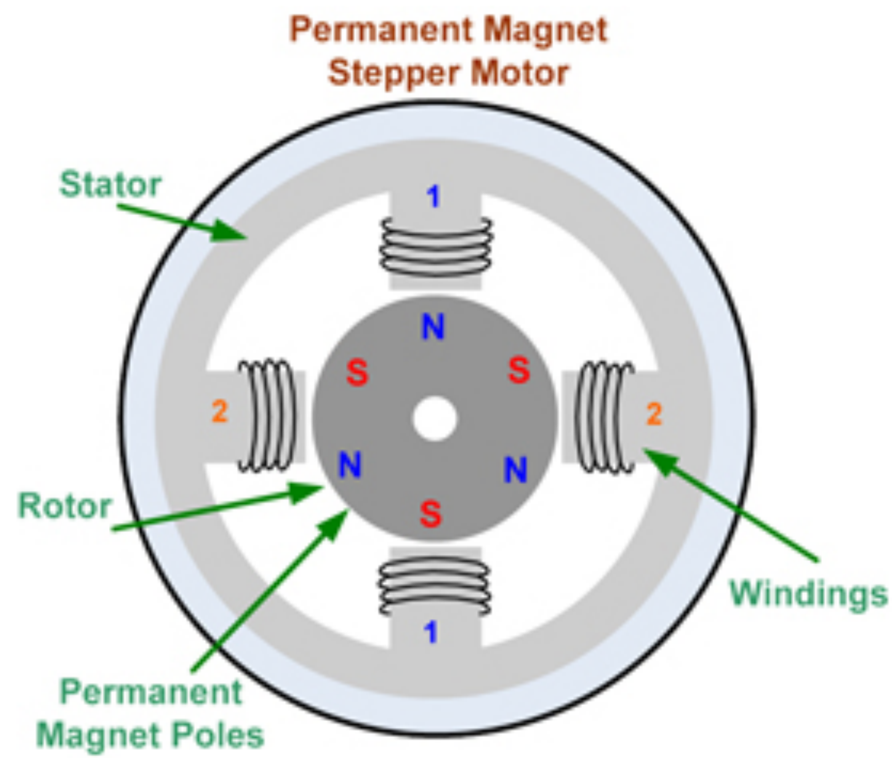
# Permanent magnet stepping motor operation

- A permanent magnet stepping motor consists of a stator with windings and a rotor with permanent magnet poles
- When a winding is energized, a north and south pole are created, depending on the polarity of the current flowing
- These generated poles attract the permanent poles of the rotor
- The rotor moves one step to align the offset permanent poles to the corresponding energized windings
- When the phases are switched on sequentially the rotor is continuously rotated



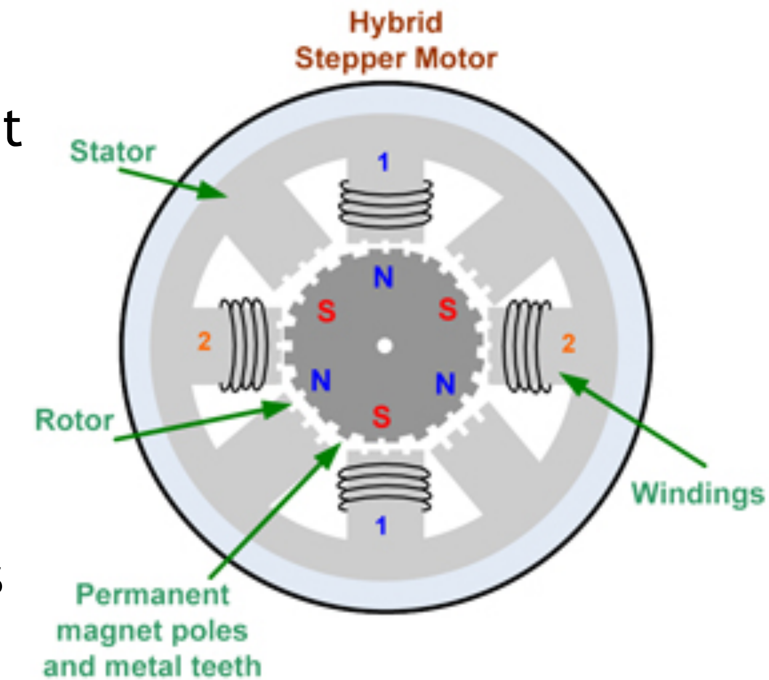
# Permanent magnet stepping motor features

- Stepping motors with magnetized rotors provide greater flux and torque than motors with variable reluctance
- Subjected to influence from the back-EMF of the rotor
- This limits the maximum speed

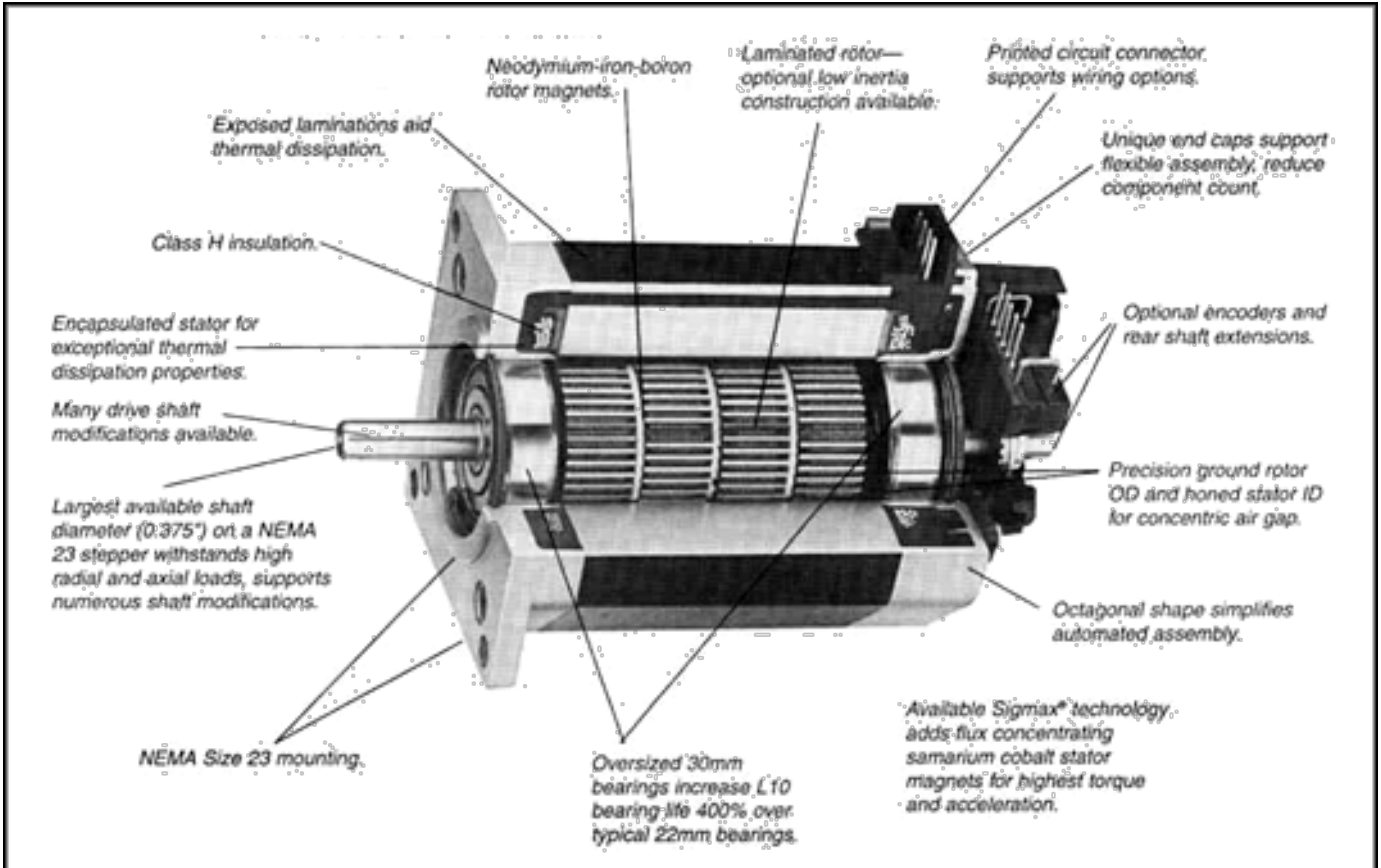


# Hybrid stepping motor

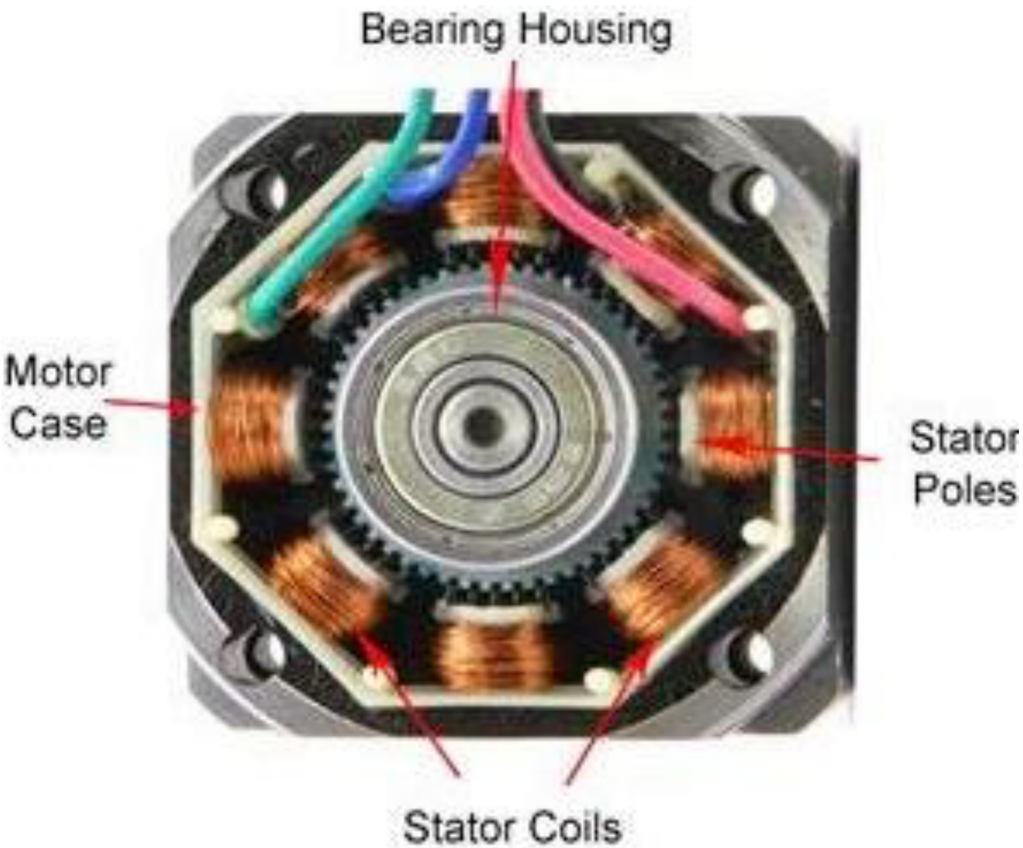
- Hybrid stepping motors combine a permanent magnet and a rotor with metal teeth to provide features of the variable reluctance and permanent magnet motors
- A hybrid motor rotor has teeth placed on the directional axes
- The rotor teeth provide a smaller magnetic circuit resistance in some rotor positions, which improves static and dynamic torque
- Hybrid motors are more expensive than motors with permanent magnets, but they use smaller steps, have greater torque, and have greater maximum speeds

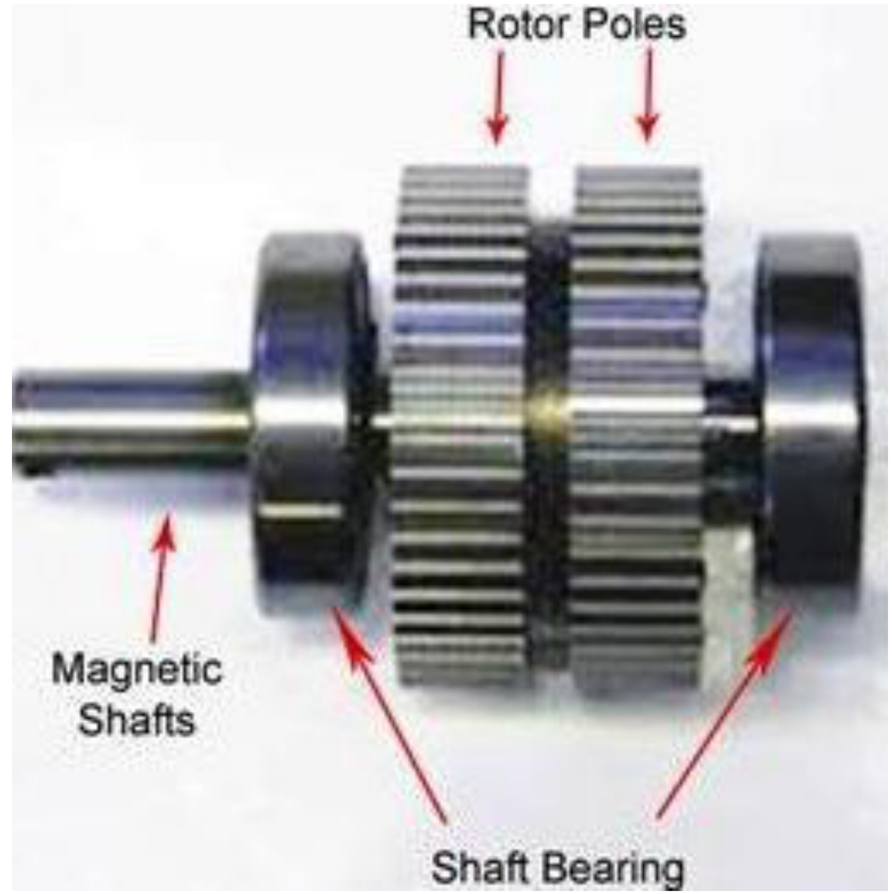


# Parts of a hybrid stepper

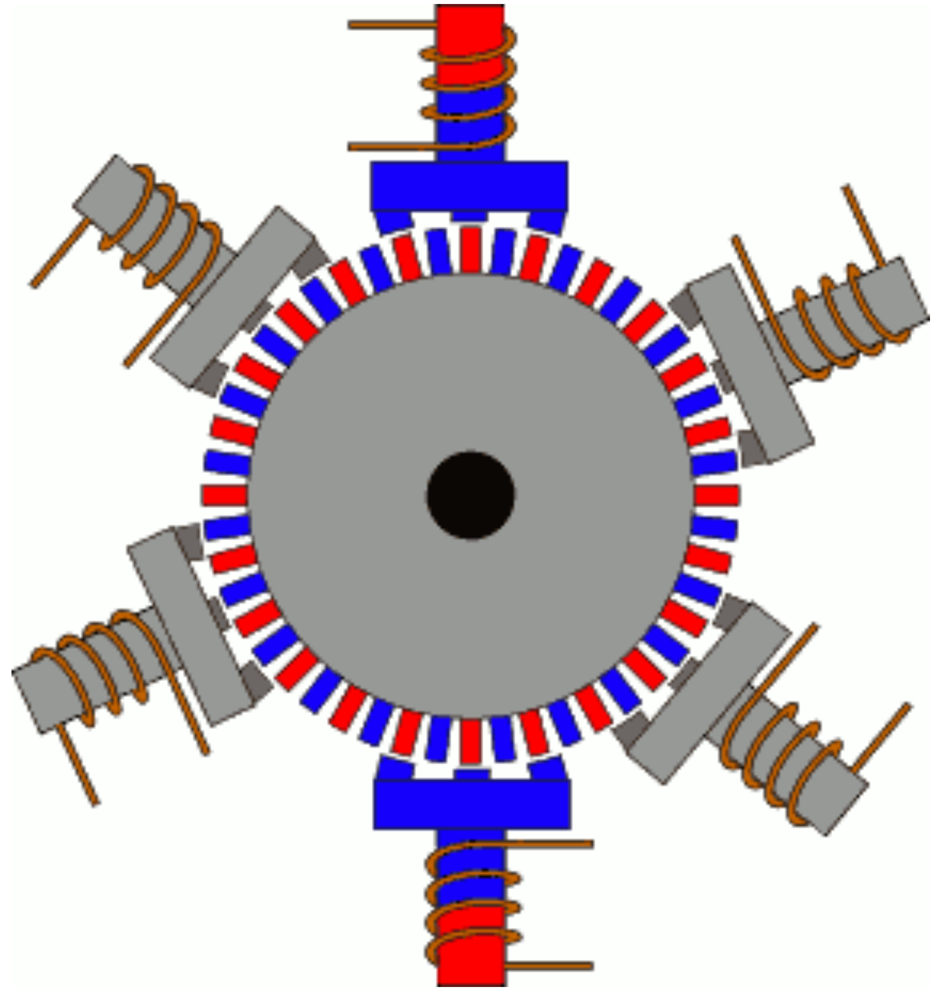


# Inside a hybrid stepper



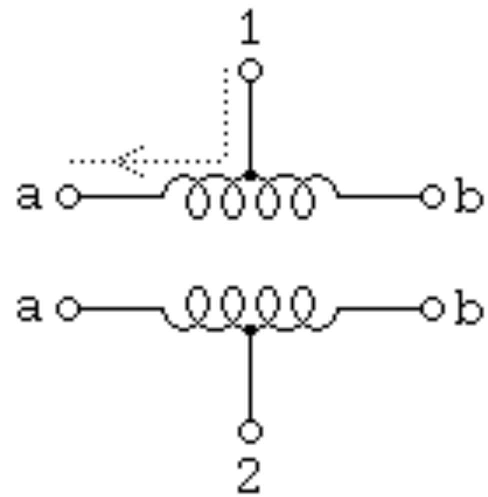



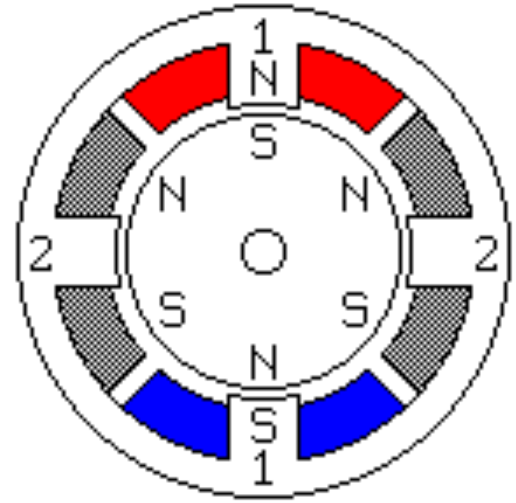
# Hybrid stepping motor operation



# Unipolar motor windings

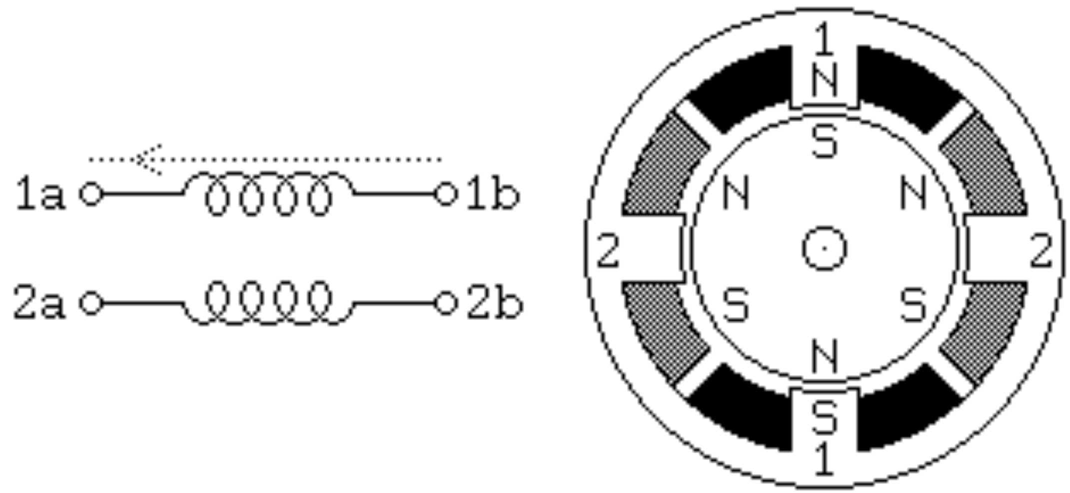
- Unipolar stepping motors are composed of two windings



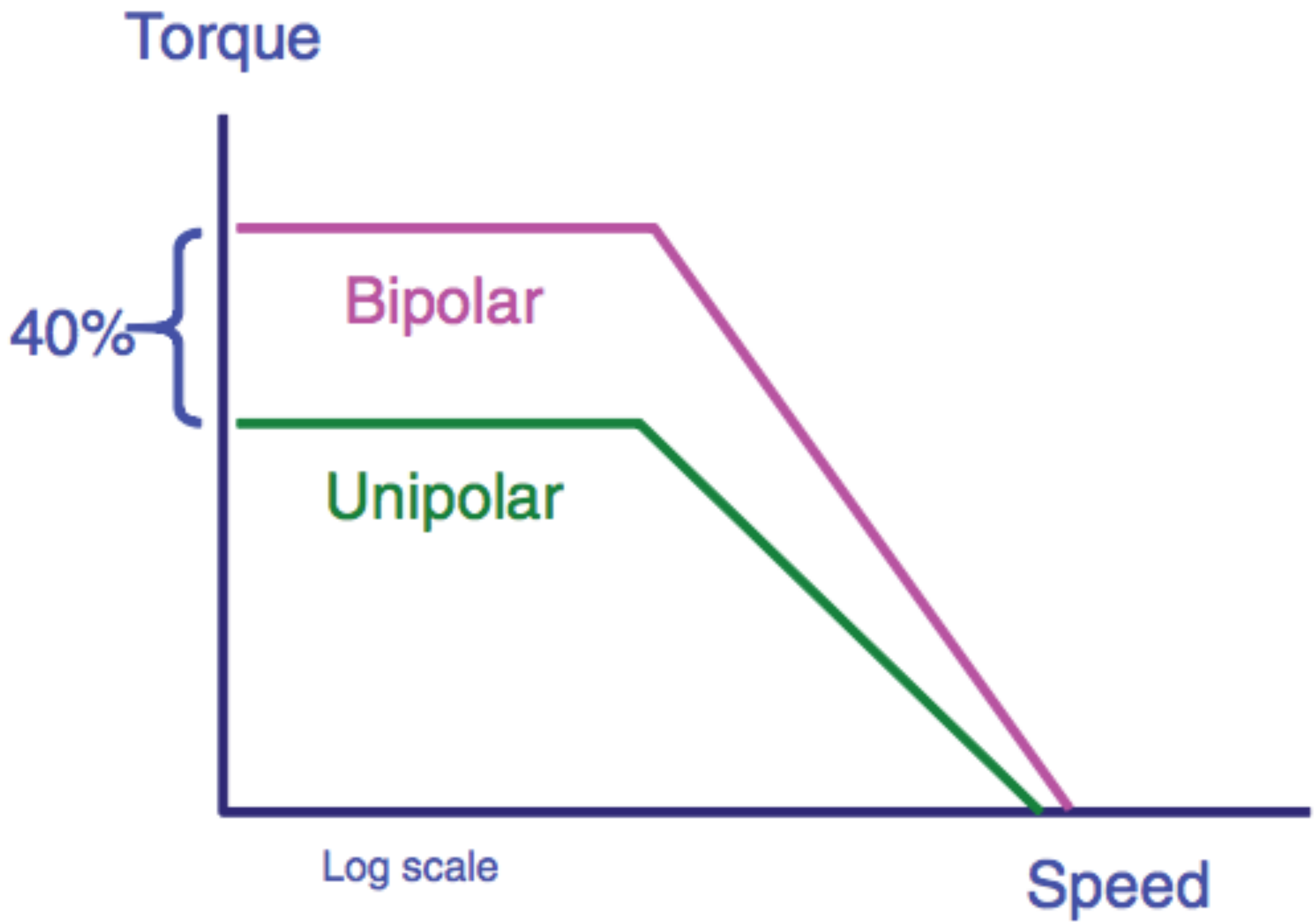

- Each windings has a center tap either brought outside motor separately or  connected together and brought outside as one wire
- Therefore unipolar motors have 5 or 6 wires
- Center taps normally tied to GND, ends of the coils alternately V+
- Unipolar drivers always energize the coils in the same direction.
- Current flow is never reversed, hence the name unipolar
- Less available torque because only half of the coils energized at a time

# Bipolar motor windings



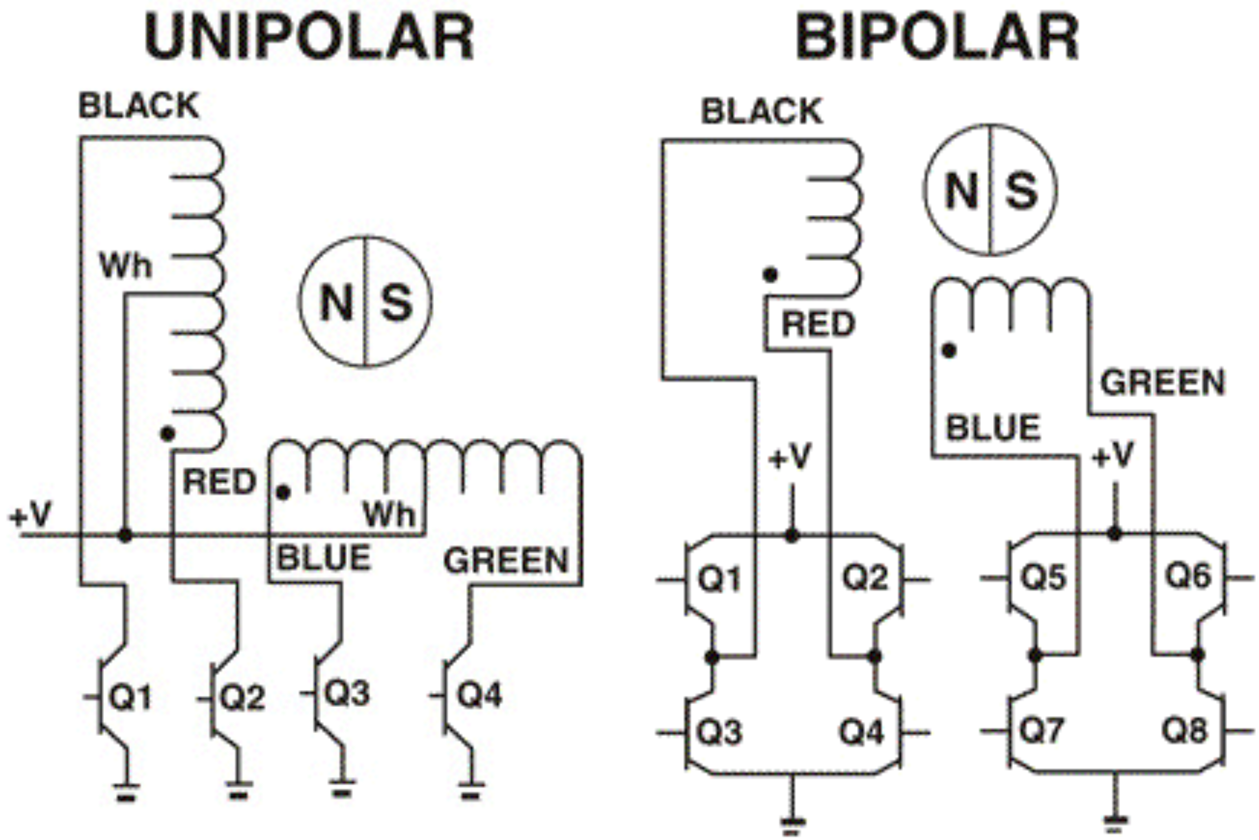

- In a bipolar winding the current flow on the coils is reversed, which reverses electromagnetic polarity
- All the windings can be used to drive the motor
- Four wires
- No common center connection.
- Two independent sets of coils
- Need H-bridge to reverse direction of current in coils

# Bipolar delivers more torque than unipolar




- All of bipolar windings used each time
- Only half of unipolar winding used at once

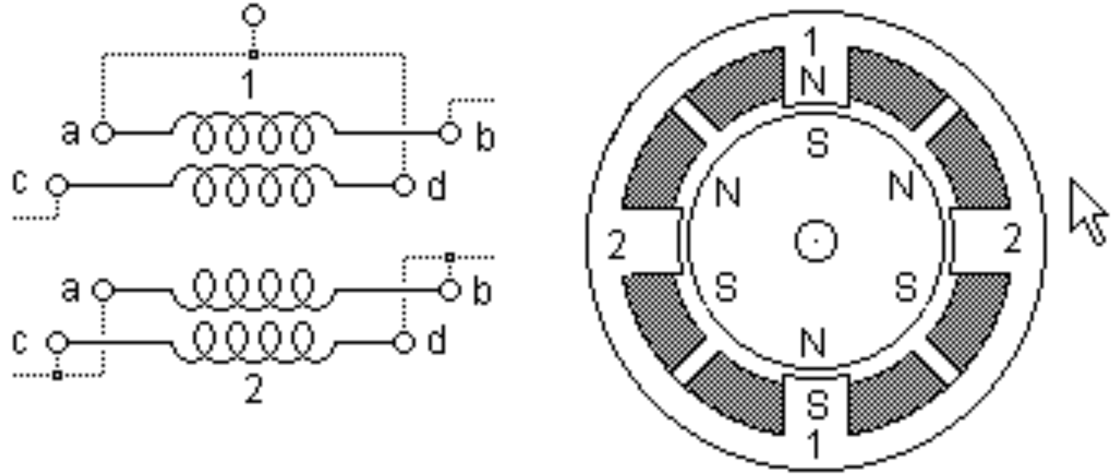
# Unipolar versus bipolar circuitry




- Only need simple switching units to operate
- Don't need H-bridge
- Unipolar drivers can be implemented with simple transistor circuitry

- Bipolar drivers need H-bridge circuitry to reverse the current flow though the coil
- Not really a problem there days!

# Bifilar stepper motor




- Almost identical to bipolar stepper motors
- But have two windings per phase in parallel
- Can be used as unipolar or bipolar motors
- In addition both parallel coils can be used in bipolar mode with half the normal drive supply voltage
- Thus this is a flexible design but at the cost of having extra wires

# ROCO222: Intro to sensors and actuators

Lecture 5

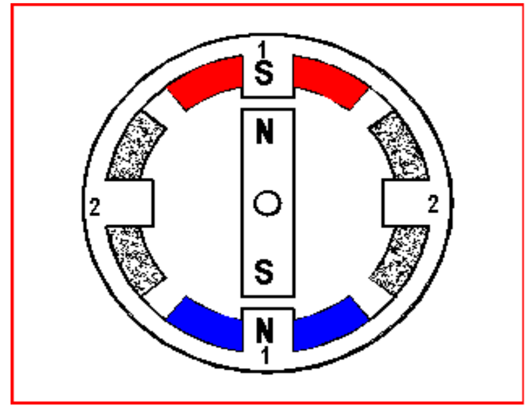
Stepper motor modes

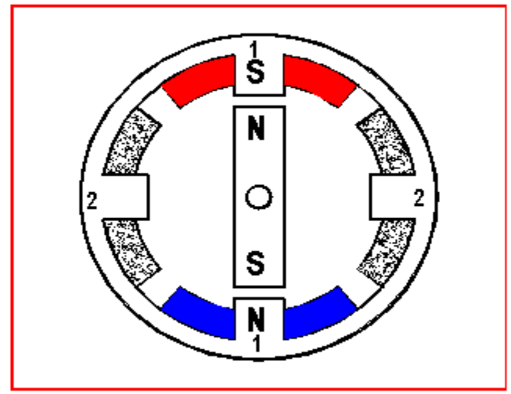
# Stepping motor control modes

There are several stepper motor drive modes:

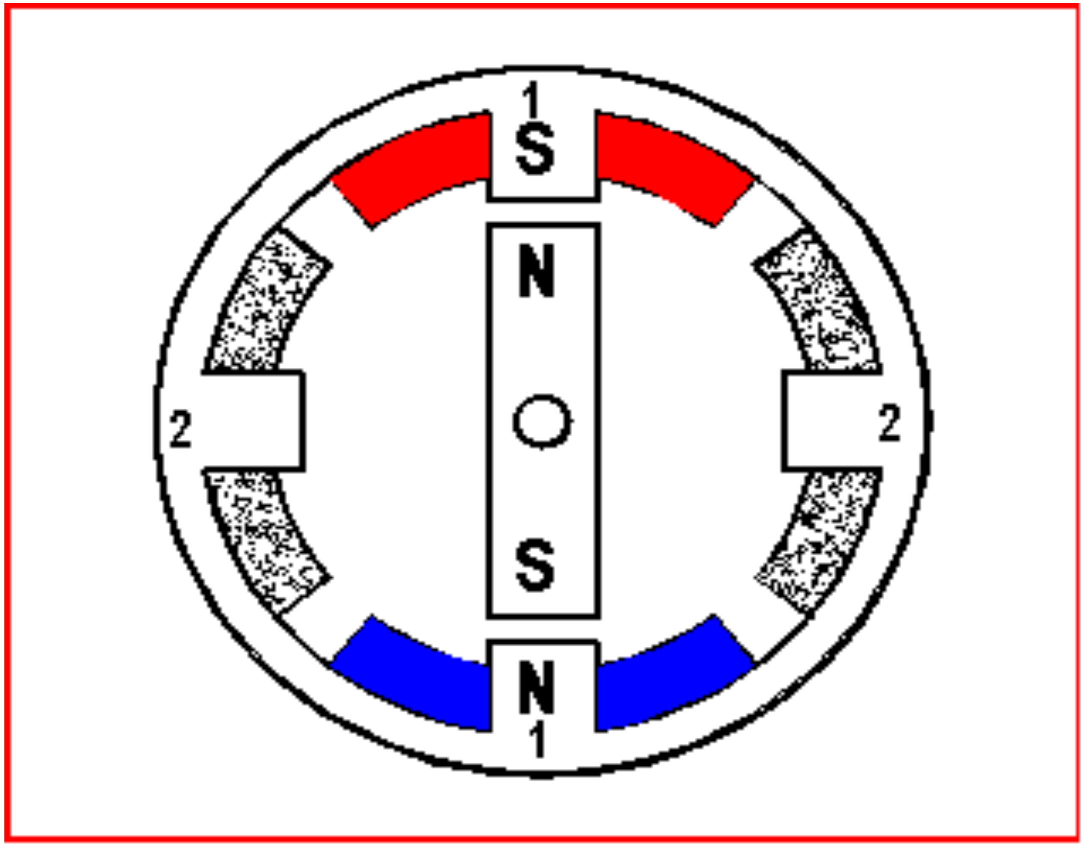
- Full-step mode
- Double-step mode
- Half-step mode
- Micro step Mode

Each of these modes controls stepping motor phases in different ways



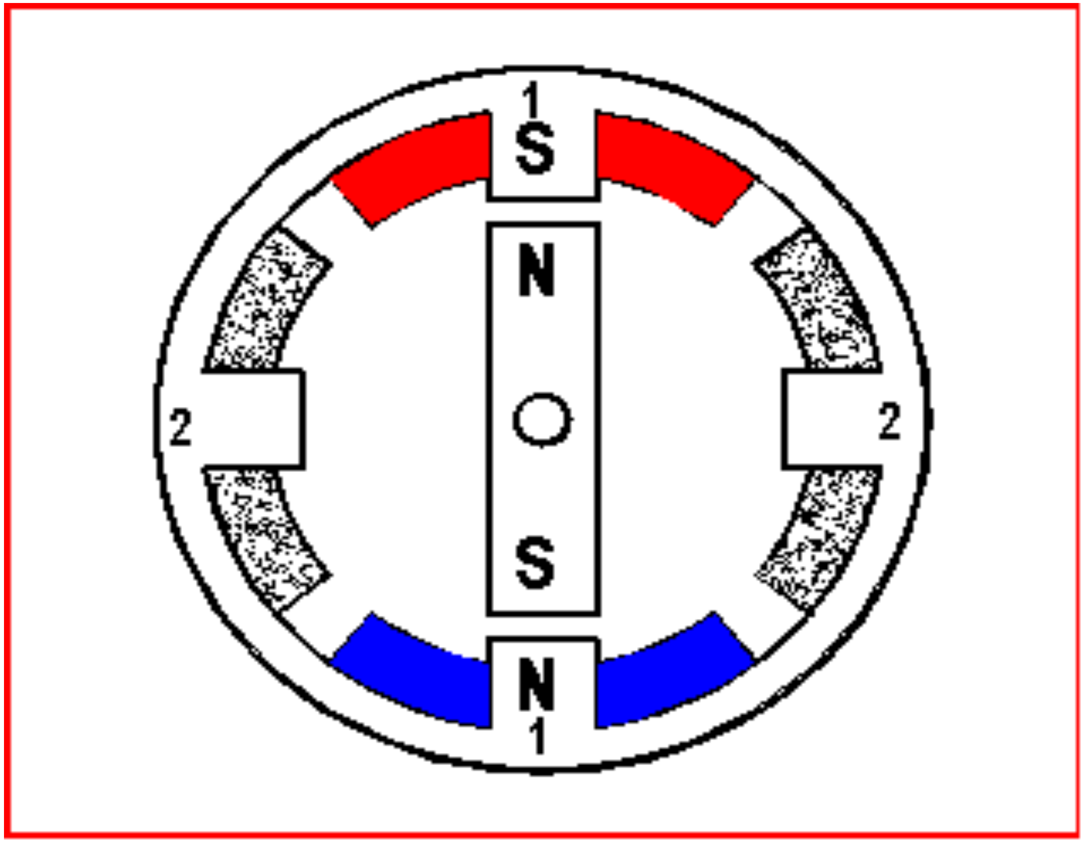
# Full step operation




For this motor:

- 1 phase on at a time
- Four steps per revolution
- 360°/4 = 90° rotation per step

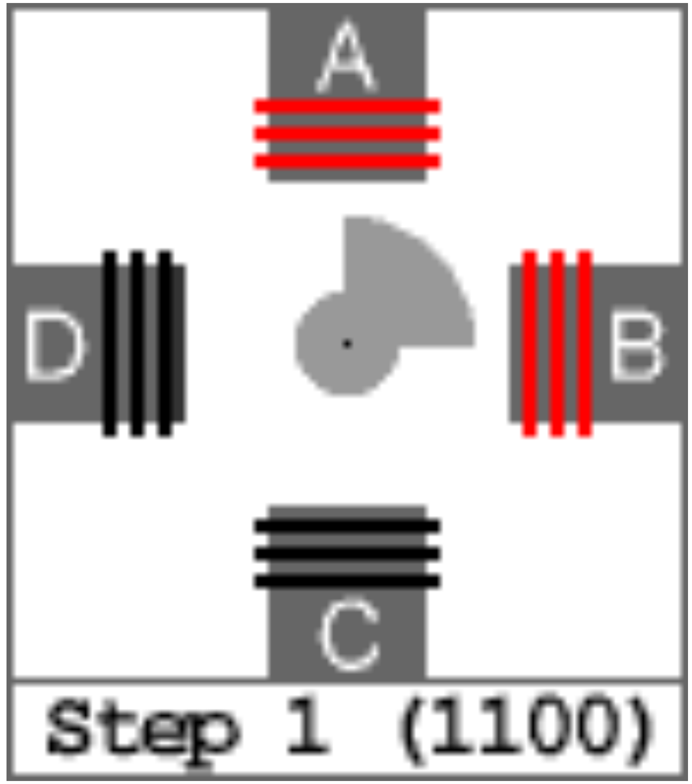
# Half step operation




For this motor:

- 1 or 2 phases on at a time
- Eight steps per revolution
- $360^\circ/8 = 45^\circ$ rotation per step

# 2 phase full step operation

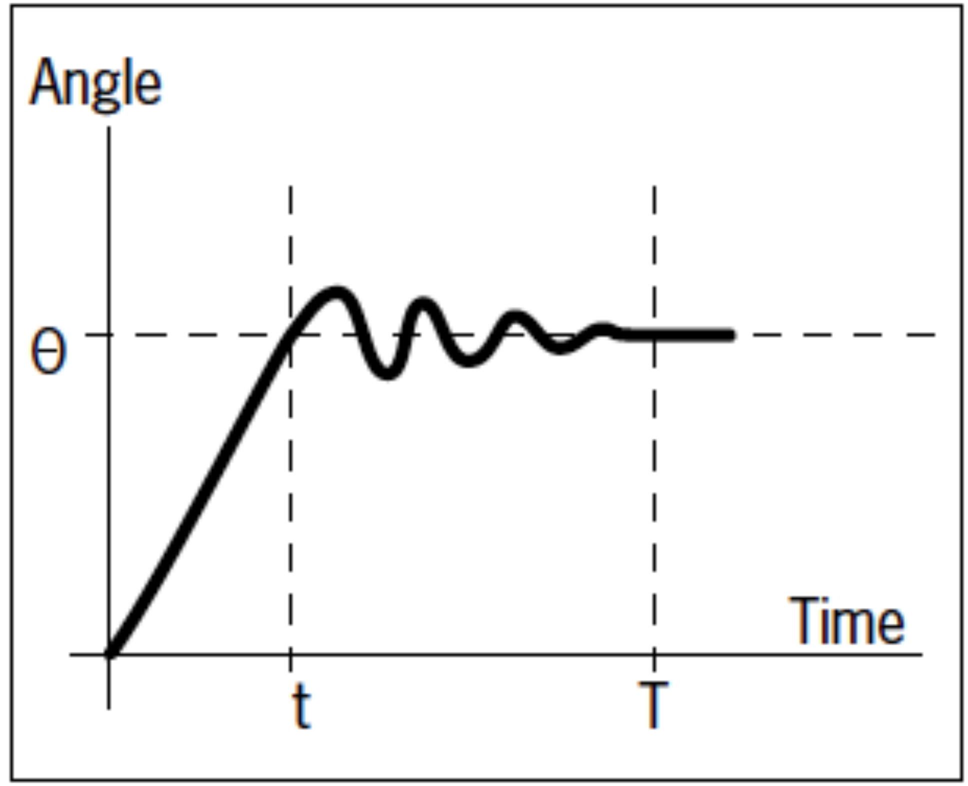



For this motor:

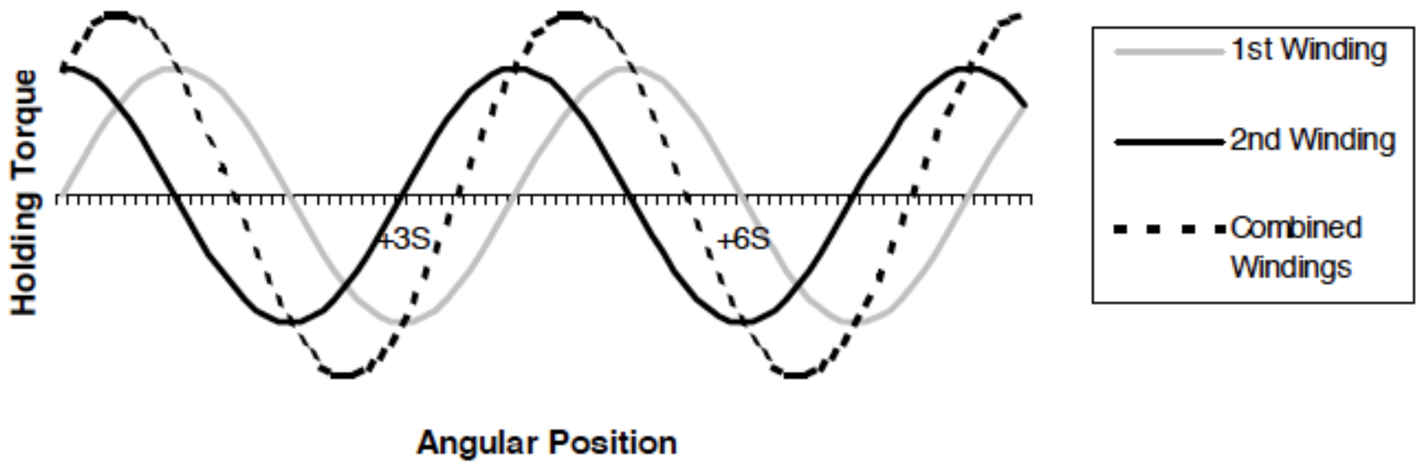
- 2 phases on at a time
- Four steps per revolution
- $360^\circ/4 = 90^\circ$ rotation per step
- More output torque than 1 phase operation

# Single step response and resonances

- Single step operation may result in resonances
- Depends on moment of inertia of motor and also resorting force to step alignment equilibrium position
- Also load dependent
- It will be damped by frictional and viscous loads
- Half step and micro stepping helps to reduce these unwanted effects
- In any case pulsing at resonant frequency is inadvisable



# Microstepping




- Single stepping a motor results in jerky movements of the motor, especially at lower speeds
- Sine-cosine micro stepping adjusts the current in each winding so the net torque is constant
- Gradually transfers current from one winding to another
- Normally achieved by pulse-width modulating the voltage across the windings of a motor
- The duty cycle of the signal of one winding is decreased as the duty cycle of the signal of other winding is increased

# Sine-cosine micro stepping

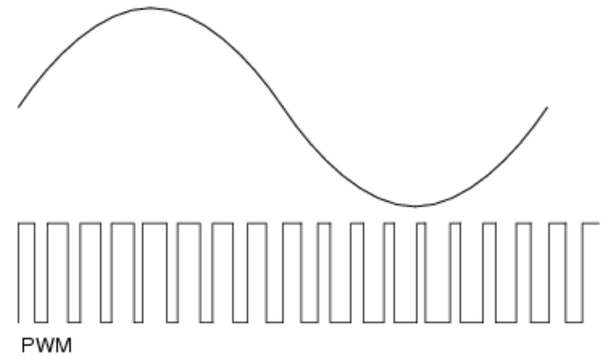
$T_1 = H sin(((\pi/2)/S)\theta)$

$T_2 = H cos(((\pi/2)/S)\theta)$

$I_1 = I_{MAX} cos(((\pi/2)/S)/\theta)$

$I_2 = I_{MAX} sin(((\pi/2)/S)/\theta)$

where $T_1$ = torque of the first winding
$H$ = holding torque
$S$ = step angle, in radians
$\theta$ = shaft angle, in radians




- In ideal motor torque produced by each winding proportional to the current and torques add linearly
- Saturation and fringe-field effects make real motors non-ideal
- In practice, close enough so can ignore nonlinearities

# Arduino micro stepping example code

```
// demonstrate principle of microstepping
int microsteps = 200;      // microsteps for step
float amp = 255;           // scaling for output
int pulseDelay = 10;       // microseconds between write
int a[200];                // declare arrays
int b[200];
int idxG;

void setup() {
  int idx;

  Serial.begin(9600);    // initialize the serial port:
  idxG=0;                 // init output index

  // build sin and cos array
  for (idx = 0 ; idx < microsteps; idx++) {
    a[idx] = amp * sin(idx * 2 * PI / microsteps);
    b[idx] = amp * cos(idx * 2 * PI / microsteps);
  }

  // set pin function
  pinMode(12, OUTPUT);
  pinMode(13, OUTPUT);
  pinMode(9, OUTPUT);
  pinMode(8, OUTPUT);

  // take breaks off
  digitalWrite(8, LOW);
  digitalWrite(9, LOW);
}
```

Define and initialize variables

Setup output index

Build sin and cos tables

Set digital pins use with motor shield to outputs

Take off the breaks

# Arduino micro stepping example code

```
// write to specified stepper channel
void WriteValue(int value, int chanAnalog, int chanDigit)
{
  int vaueAbs = abs(value);         // get absolute value
  analogWrite(chanAnalog, value); // write absolute value as PWM
  if (value > 0) {                  // set direction +ve
    digitalWrite(chanDigit, HIGH);
  }
  else {                            // set direction -ve
    digitalWrite(chanDigit, LOW);
  }
}
```

Can only write 0-255 to PWM output
So take absolute value

Use sign of value to set output direction

```
void loop() {
  // debugging
  //     Serial.print(a);
         // seperator for plot
  //     Serial.print(",");
  //     Serial.println(b);
```

For debugging

```
  WriteValue(a[idxG], 3, 12);   // write out chan A sin value
  WriteValue(b[idxG], 11, 13);   // write out chan B cos value
```

Write out sin and cos
values to stepper

```
  idxG++; // update index
  if (idxG == microsteps) {
    idxG = 0;
  }
```

Update index

```
  delayMicroseconds(pulseDelay); // wait delay
}
```

Delay

# Stepper motor step parameters

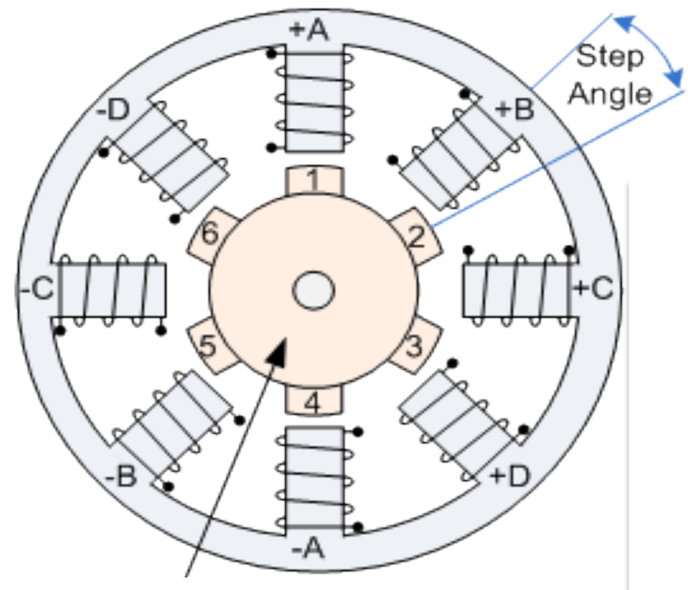
Step angle is given by: $$\alpha = \frac{360}{n_s}$$ where $n_s$ is the number of steps for the stepper motor (integer)

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: Step parameters

A stepper motor has a step angle = 3.6°.

How many steps are there per revolution?

$3.6° = 360° / n_s$;

$n_s = 360° / 3.6° = 100$ steps per rev

How many pulses are required for the motor to rotate through 10 complete revolutions?

For 10 complete revolutions:

$10 * (360°) = 3600° = A_m$

Therefore $n_p = 3600 / 3.6 = 1000$ pulses

What pulse frequency is required for the motor to rotate at a speed of 100 rev/min?

$N = 100$ rev/min: requires 100x100 pulses in 60s

$10000 = 60\ f_p$

$f_p = 10{,}000 / 60 = 166.667 = 167$ Hz

# Current flow in stepper motors

Summing voltages around circuit

$$v_s = v_R + v_L$$

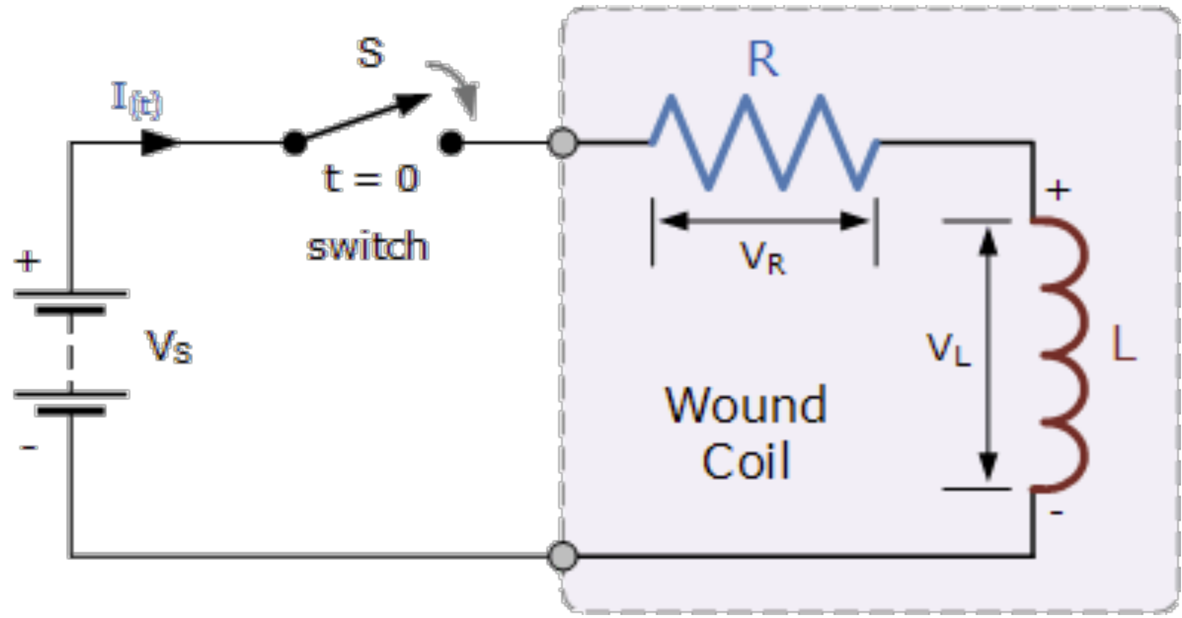
Voltage across resistor

$$v_R = IR$$

Voltage across induction

$$v_L = L\frac{dI}{dt}$$

$$\Rightarrow v_s = IR + L\frac{dI}{dt}$$

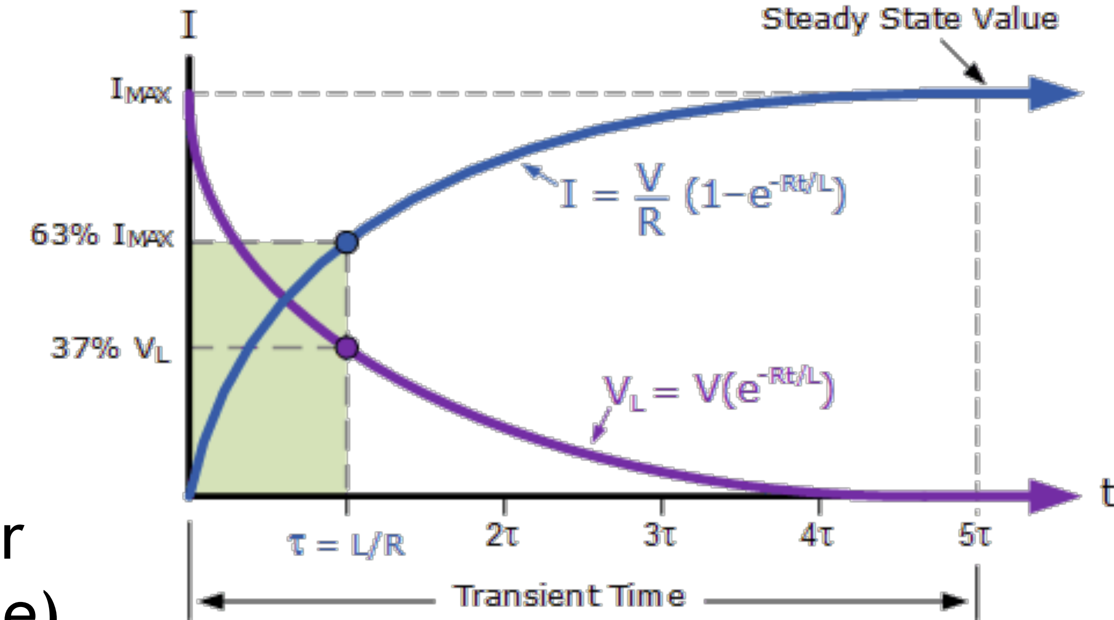



Current response to switch on given by

$$I = \frac{V_s}{R}\left(1 - e^{\frac{-Rt}{L}}\right)$$

# Current flow in stepper motors

$$I = \frac{V_s}{R}\left(1 - e^{\frac{-Rt}{L}}\right)$$




- τ=L/R is the time constant for the LR circuit in seconds

- When time t = τ=L/R (i.e. after a time constant's worth of time) the L and the R terms cancel

$$I = \frac{V_s}{R}\left(1 - e^{-1}\right) = \frac{V_s}{R}\left(1 - 0.3679\right) = 0.6321\frac{V_s}{R}$$

- After switch on current reaches 63% of maximum value after τ seconds
- Maximum current value given by $\mathrm{I}_{MAX} = \frac{V_s}{R}$

# Current flow in stepper motors

- So like DC motors current flowing through coils depends on inductance
- Differentiating the expression for current I

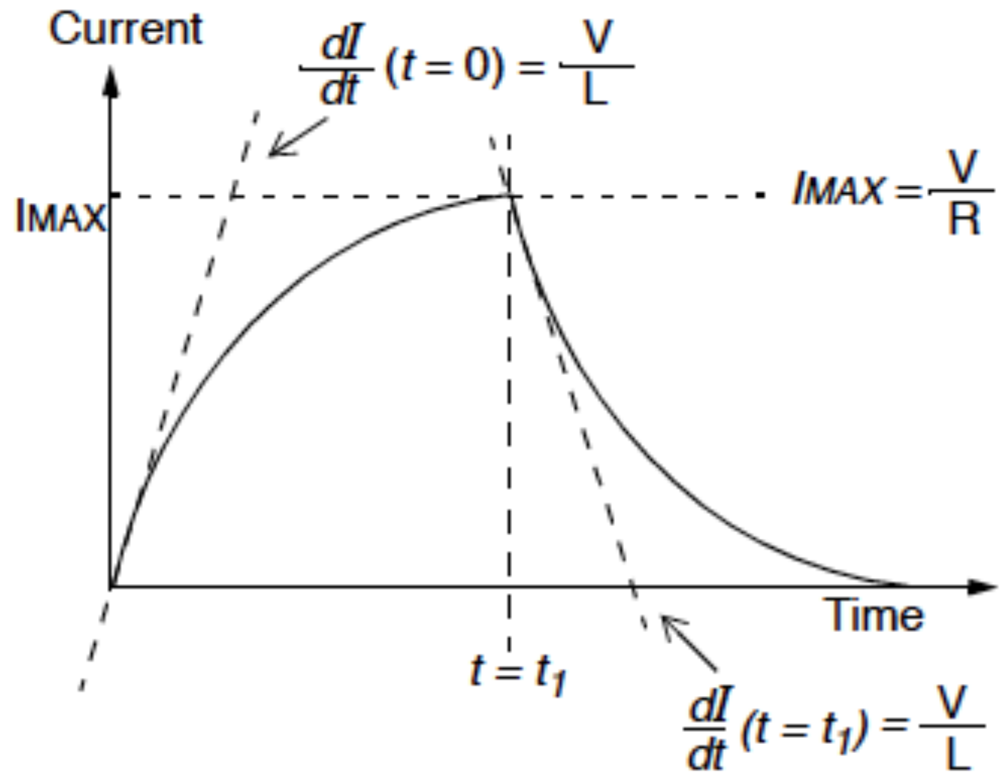
$$\Rightarrow \frac{dI}{dt} = \frac{dI}{dt}\left[\frac{V_s}{R}\left(1 - e^{\frac{-Rt}{L}}\right)\right]$$

Now since $\dfrac{d}{dt}(e^u) = \dfrac{du}{dt}e^u$

$$\frac{dI}{dt} = \frac{V_s}{R}\frac{-R}{L} - e^{\frac{-Rt}{L}} \quad = \frac{V_s}{L}e^{\frac{-Rt}{L}}$$

- When time t is zero

$$\frac{dI}{dt} = \frac{V_s}{L}e^{\frac{-R.0}{L}} \qquad = \frac{V_s}{L}$$



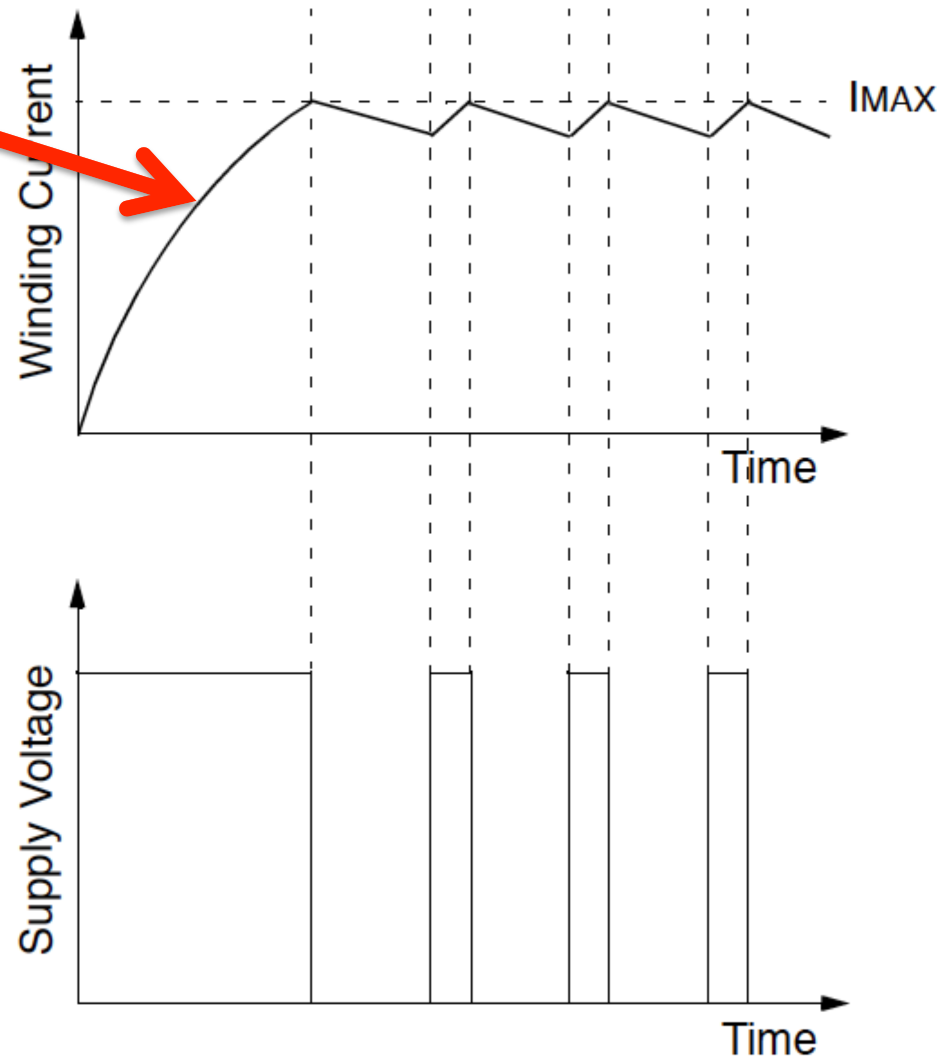

- Which just depends on voltage $V_s$, inductance L and NOT resistance R

# Chopper control of current

- To achieve good high rotational speed performance we want current applied to rise very fast!
- This requires high supply voltage
- But then

$$I_{MAX} = \frac{V_s}{R}$$

- may then exceed the motor spec
- Also R low for high performance units
- Solution is to measure current and use PWM to regulate it by modulate supply to coils to prevent current exceeding stepper ratings
- This is now implemented in commercially available stepper motor drivers like the A4988



# Rough calculation of max pulse rate

- When time t is zero $$\frac{dI}{dt} = \frac{V_s}{L}$$
- Therefore if we drive with a high voltage using a current limiting controller, current will initially rise linearly and

$$\frac{dI}{dt} \approx \frac{\Delta I}{\Delta T} \qquad \Rightarrow \frac{\Delta I}{\Delta T} \approx \frac{V_s}{L} \quad \Rightarrow \Delta I \approx \frac{V_s}{L} \Delta T$$

- Therefore starting from I=0 and going to maximum rating current for stepper $I_{smax}$ will take $T_{rise}$ seconds, where

$$\mathrm{I}_{smax} \approx \frac{V_s}{L} T_{rise} \qquad \Rightarrow T_{rise} = \mathrm{I}_{smax} \frac{L}{V_s}$$

- For a pulse current must go up by then down again

$$\Rightarrow T_{pulse} = 2\,\mathrm{I}_{smax} \frac{L}{V_s}$$

# Rough calculation of max pulse rate

From

$$T_{pulse} = 2\mathrm{I}_{smax} \frac{L}{V_s}$$

since

$$f_{pulse} = \frac{1}{T_{pulse}}$$

$$\Rightarrow f_{pulse} = \frac{V_s}{2\mathrm{I}_{smax} L}$$

$$\Rightarrow RPM_{\max} = \frac{V_s}{2\mathrm{I}_{smax} L} \cdot \frac{60}{N_s}$$

- Where $N_s$ is pulses per revolution for the stepper

Typical stepper motor example:

- L=3mH and Vs= 12v
- $N_s$ =200 pulses per rev, $I_{smax}$=1A

$$\Rightarrow RPM_{\max} = \frac{12}{2 \times 1 \times 3/1000} \cdot \frac{60}{200} = 600$$

NB: this assumes current rises linearly
Only true if $V_s$ large and $I_{smax} << V_s/R$

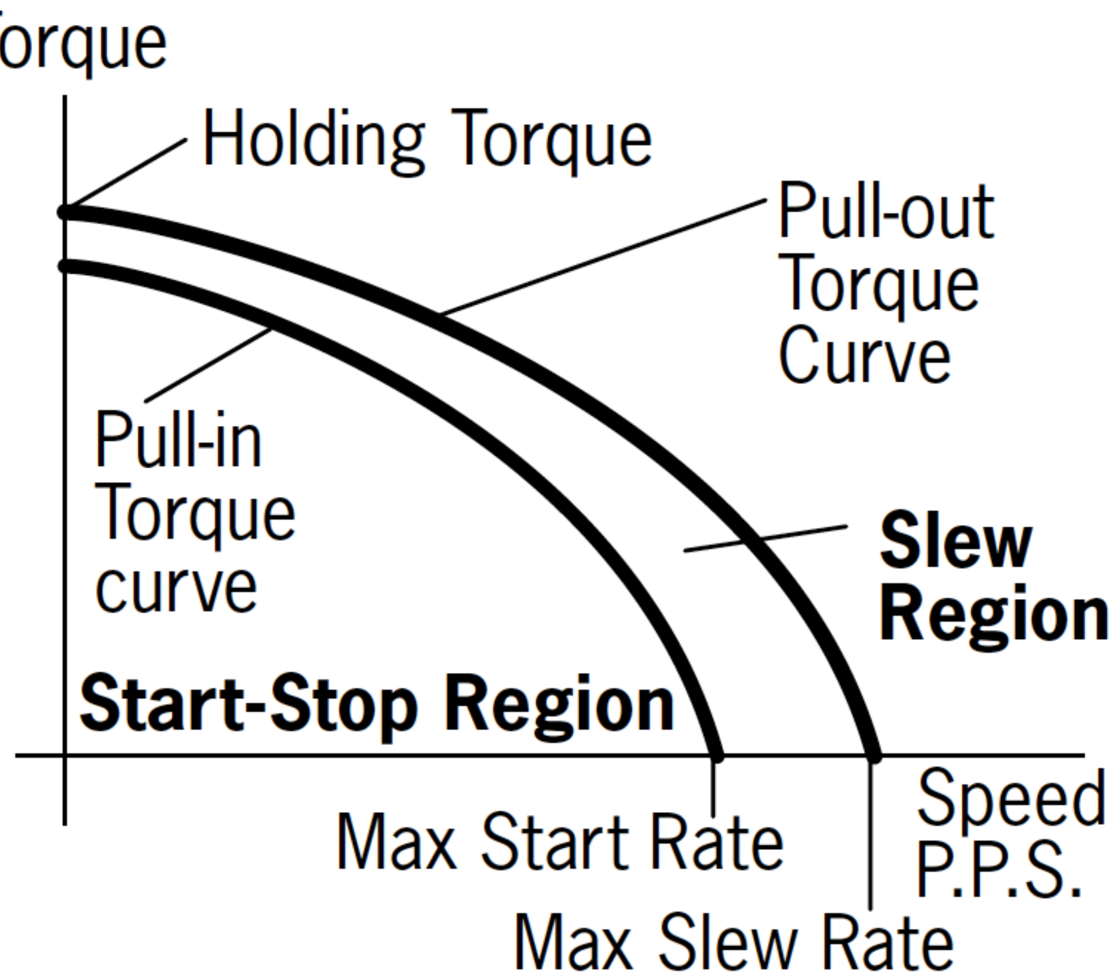
# Stepper motor torque-speed characteristic

**Detent torque**

- Amount of torque the motor produces when the windings are not energized
- This resists the shaft turning

**Holding torque**

- Amount of torque needed in order to move the motor one full step when the windings are energized but the rotor is stationary



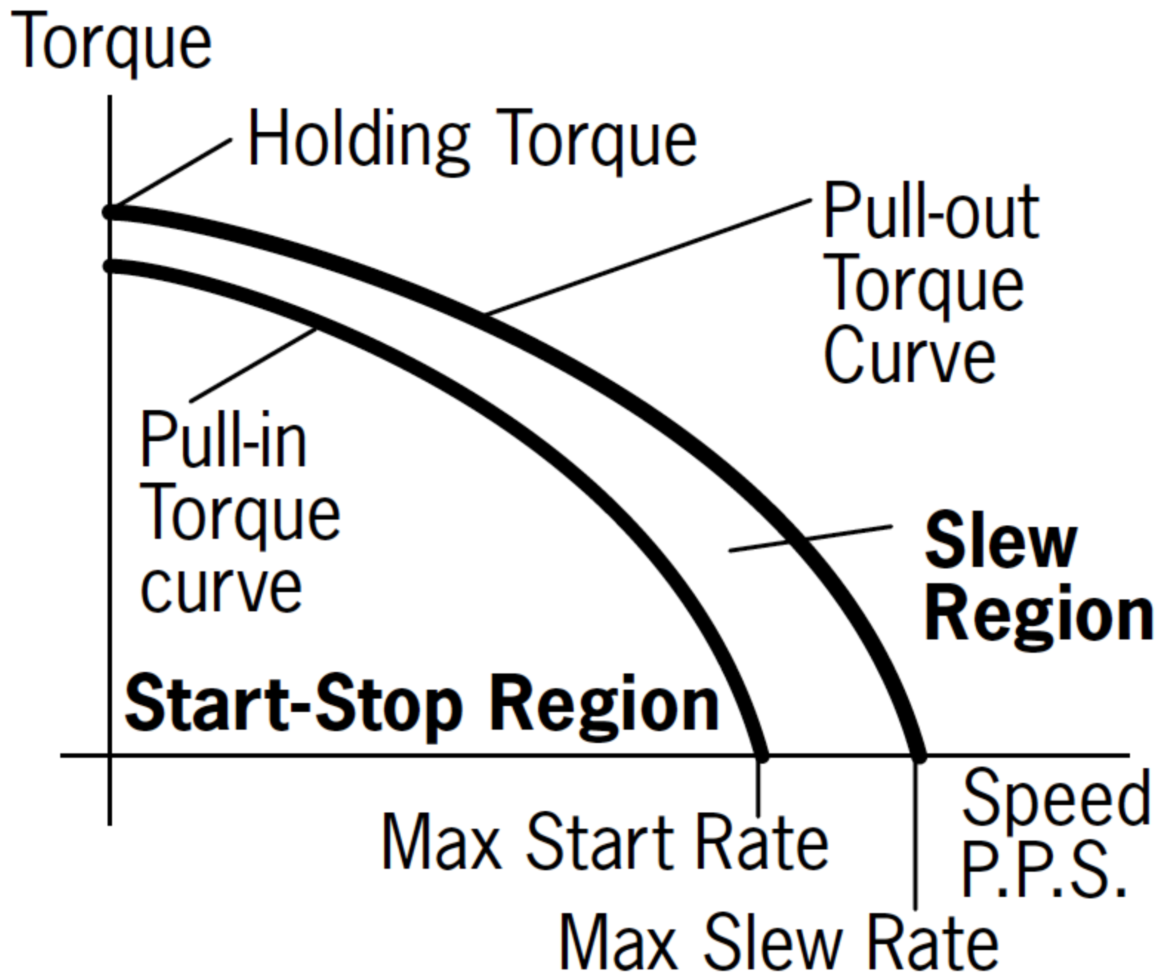
# Stepper motor torque-speed characteristic

**Pull-in Torque Curve**

- Maximum torque at given speeds that the motor can start, stop or reverse in synchrony with input pulses.
- Motor cannot start at a speed beyond this curve
- Motor cannot instantly reverse or stop with any accuracy at a point beyond this curve

**Stop / Start Region**

- Area underneath pull-in curve.
- Within this region motor can start, stop, or reverse "instantly"



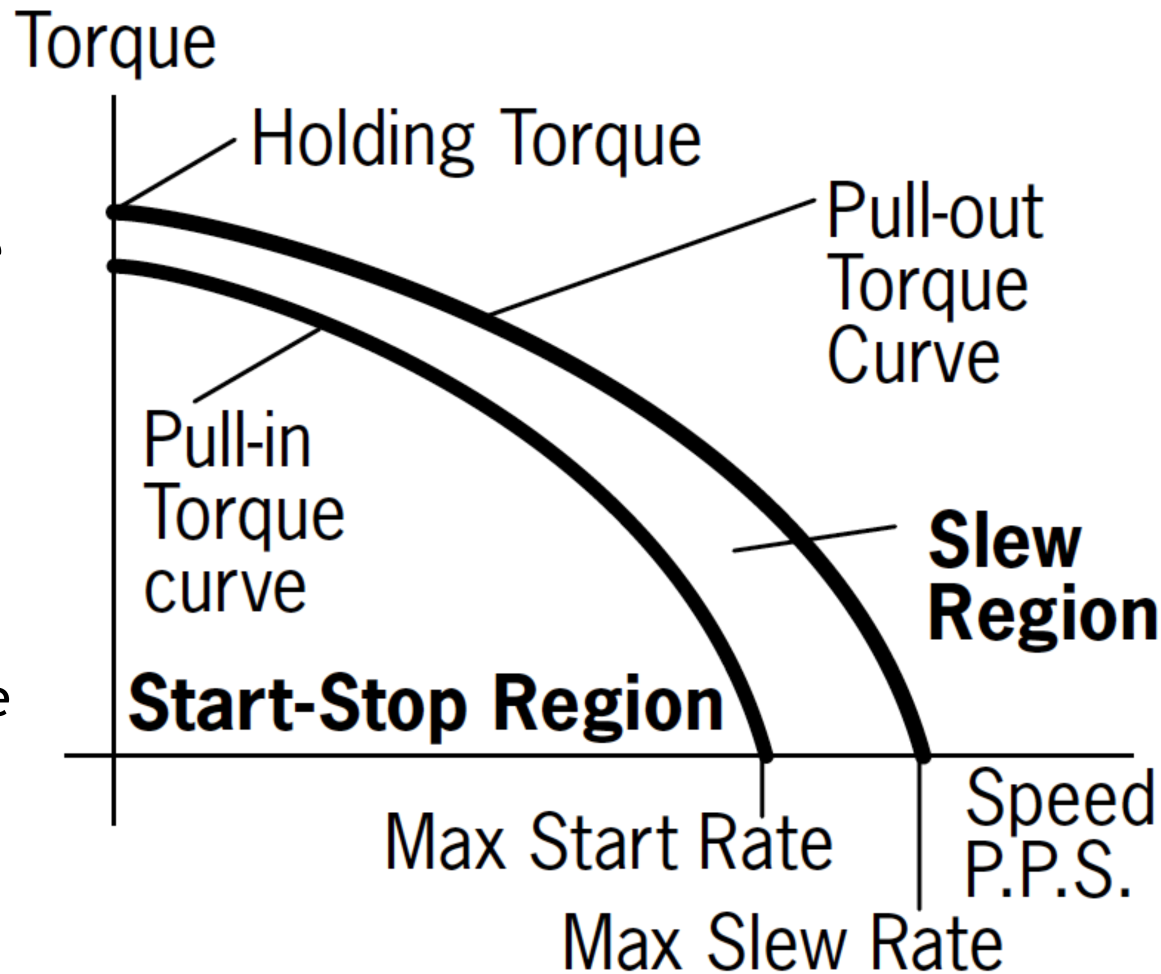
# Stepper motor torque-speed characteristic

**Pull-out Torque Curve**

- Maximum torque at given speeds that the motor can generate while running synchronously
- Above this curve motor will stall

**Slew Range**

- Area between the pull-in and the pull-out curves
- In this region motor speed must be adjusted gradually  to maintain synchronism

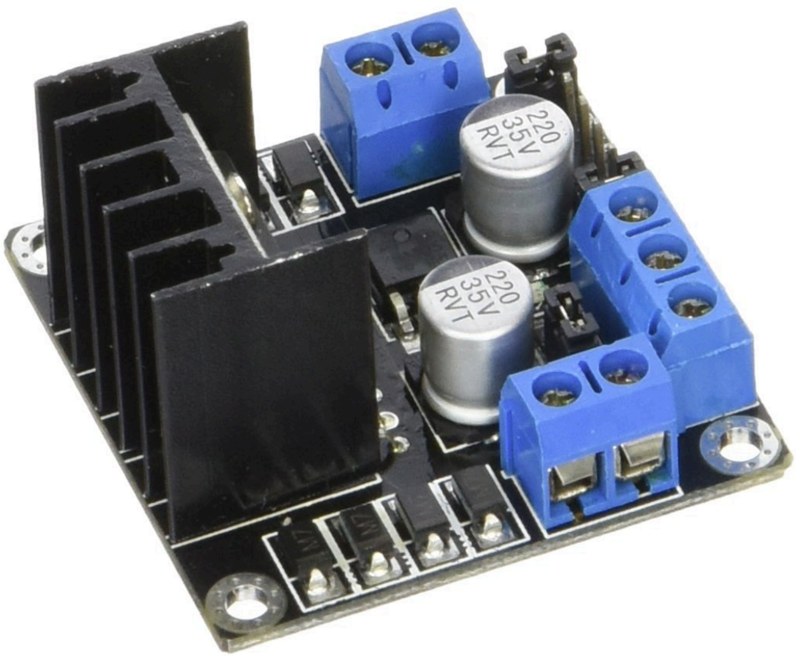


# ROCO222: Intro to sensors and actuators

Lecture 5

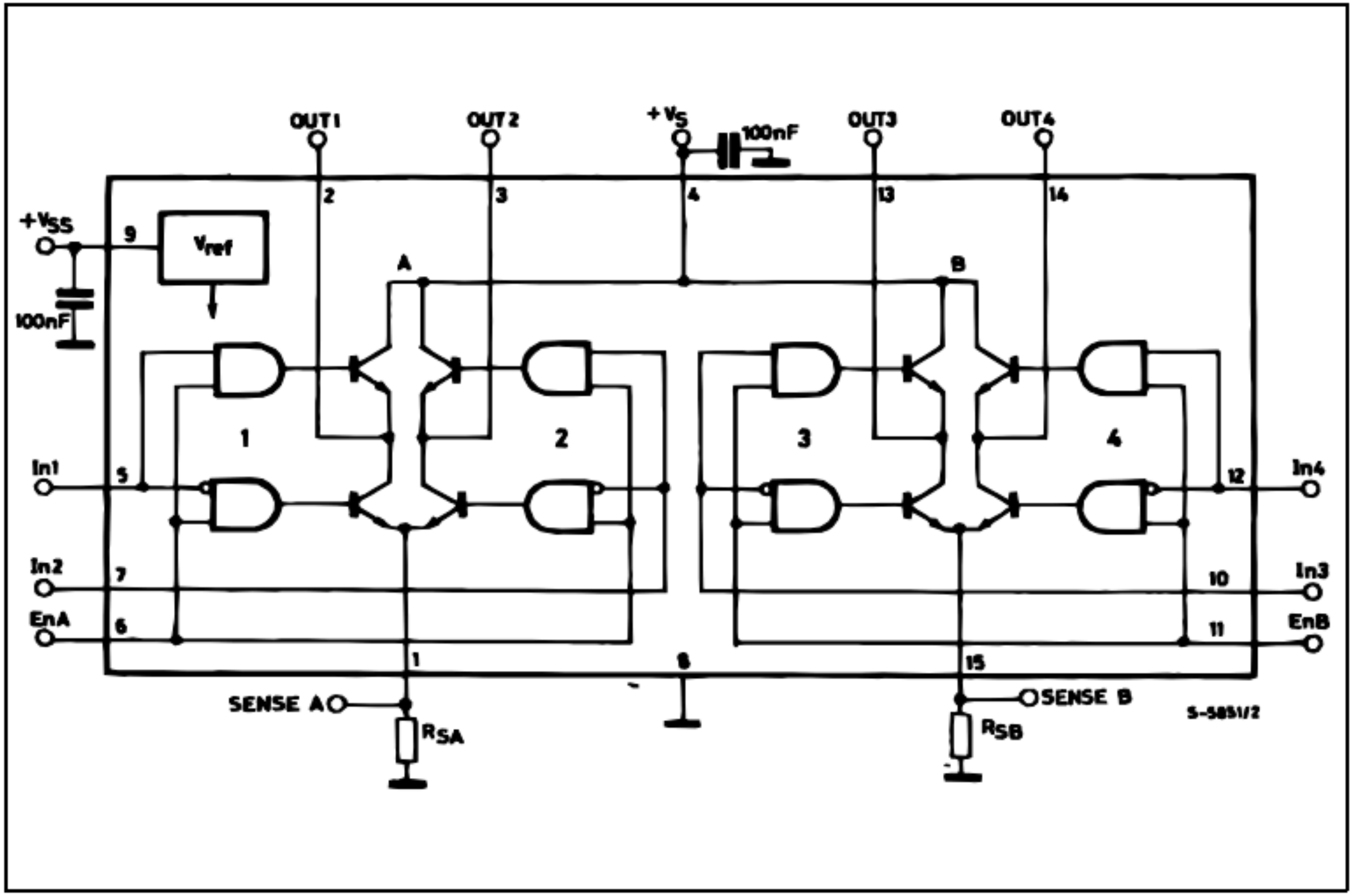
Stepper motor drivers

# L298N DC Stepper Motor Controller

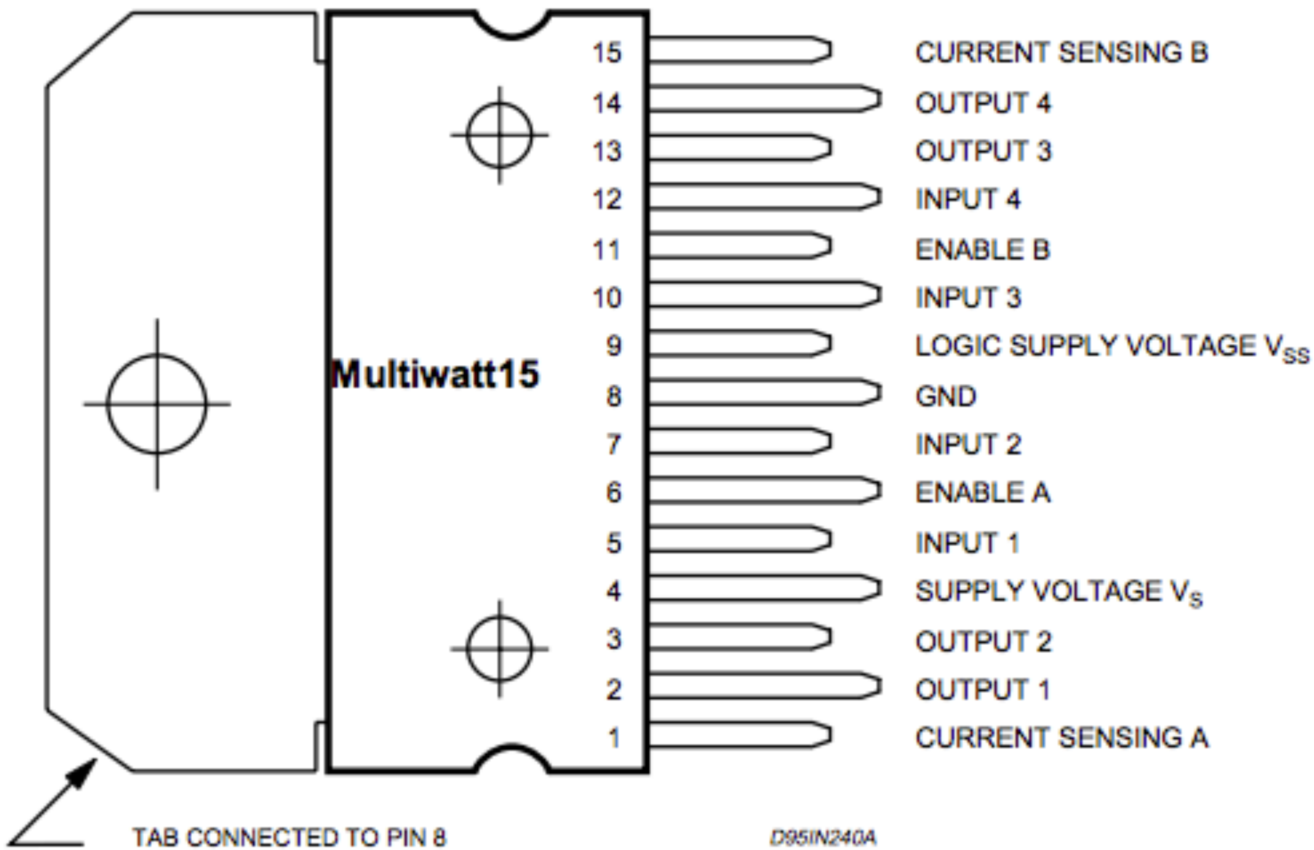



- L298N as main driver chip makes strong driving ability/small heating/strong anti-interference/low calorific value
- Use large-capacity filter capacitors and diode with freewheeling protection function, increasing reliability
- Dual-channel H-bridge driver working mode creates higher working efficiency
- To avoid damage the voltage stabilizing chip, please use an external 5V logic supply when using more than 12V driving voltage
- With large capacitance filter capacitor and after flow protection diode, more stable and reliable

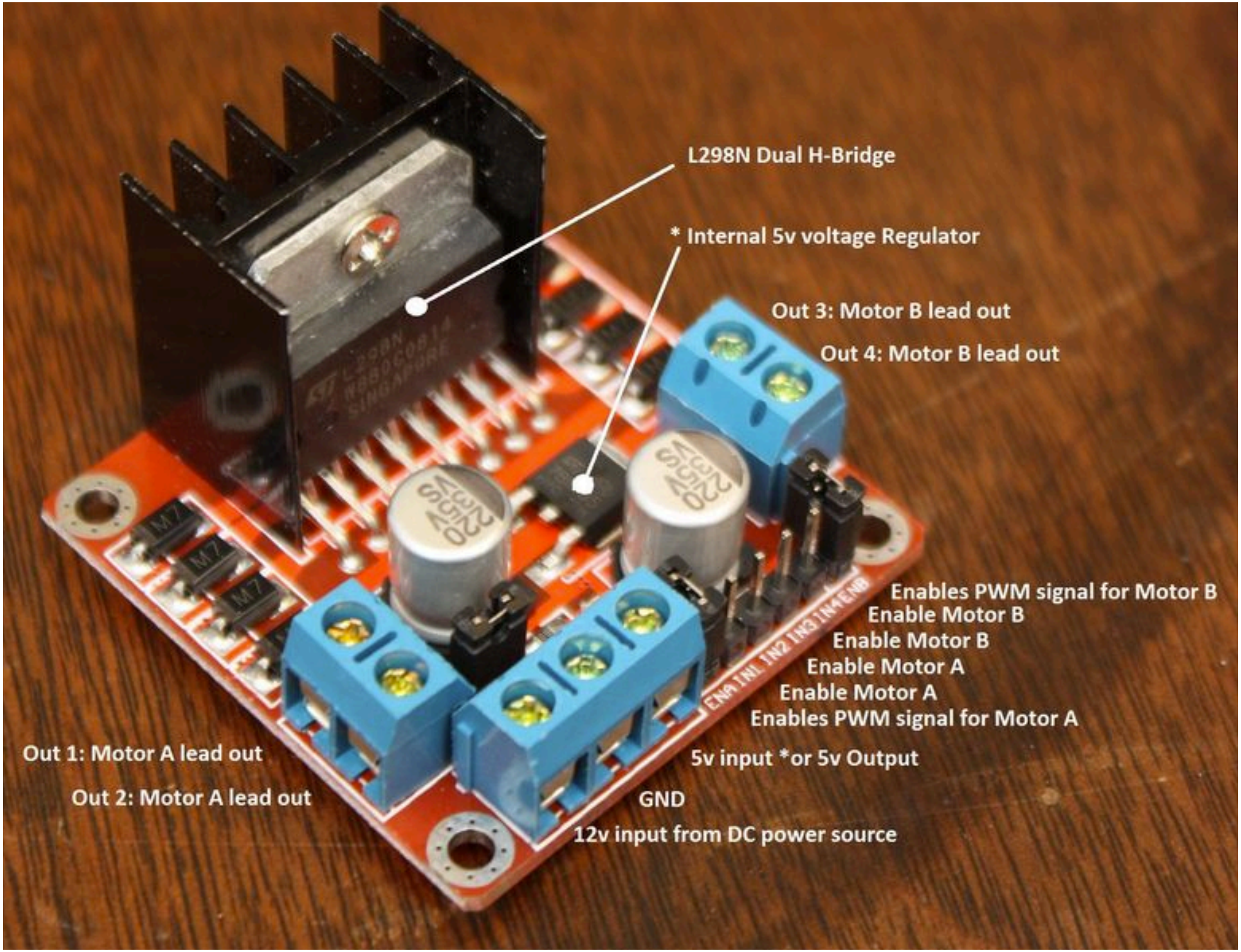
# L298N DC Stepper Motor Controller



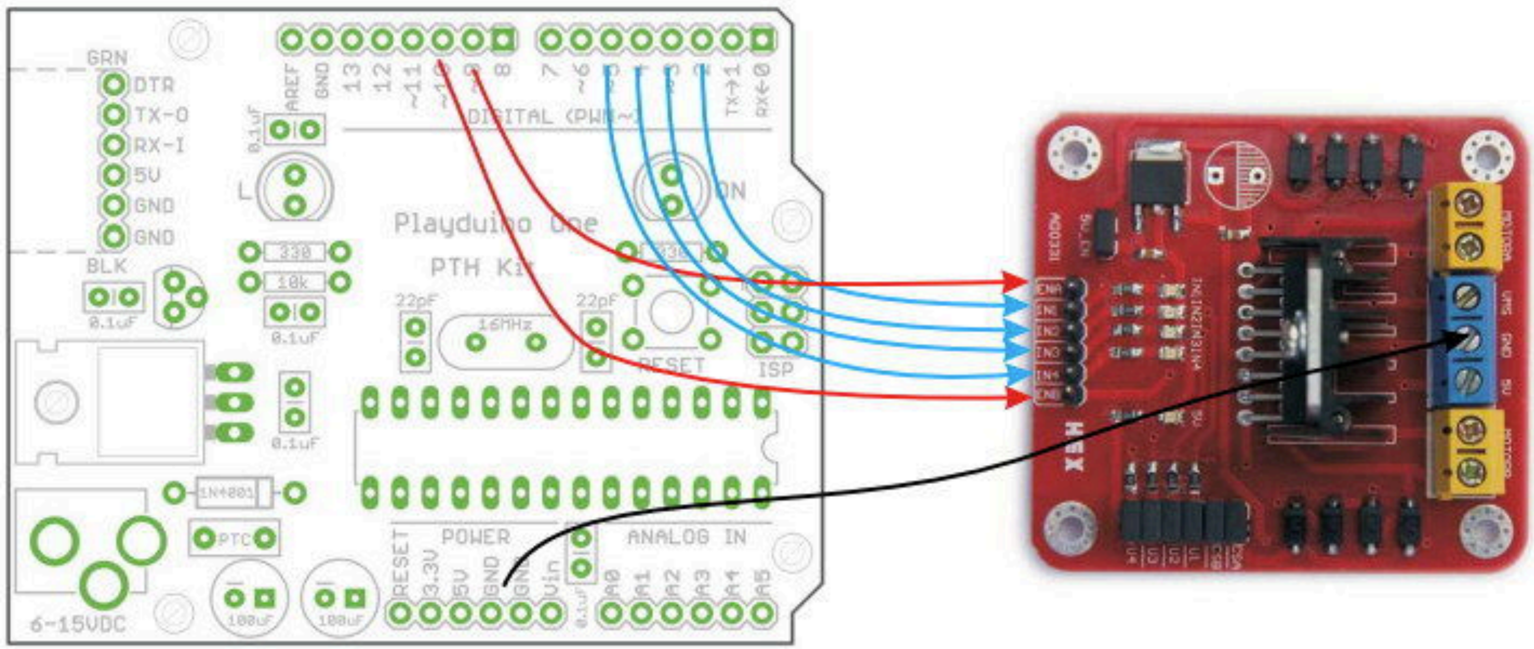
# L298N DC Stepper Motor Controller



# L298N DC Stepper Motor Controller

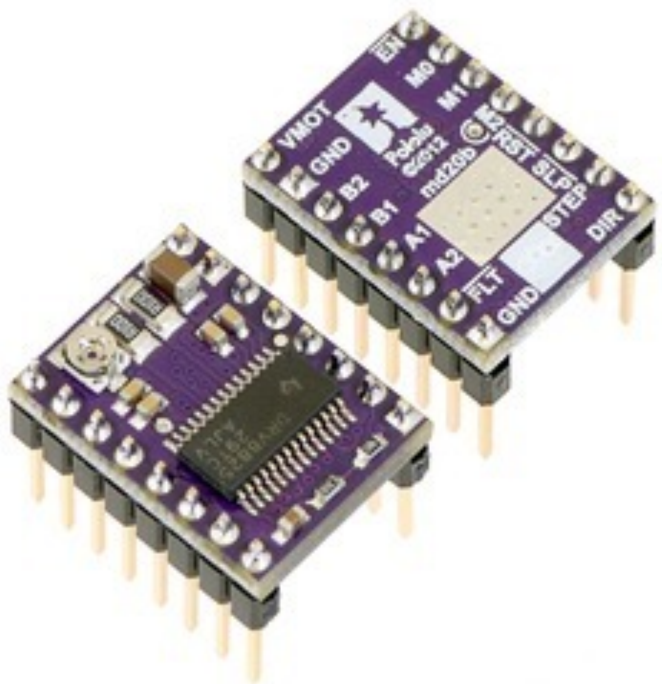


# L298N DC Stepper Motor Controller



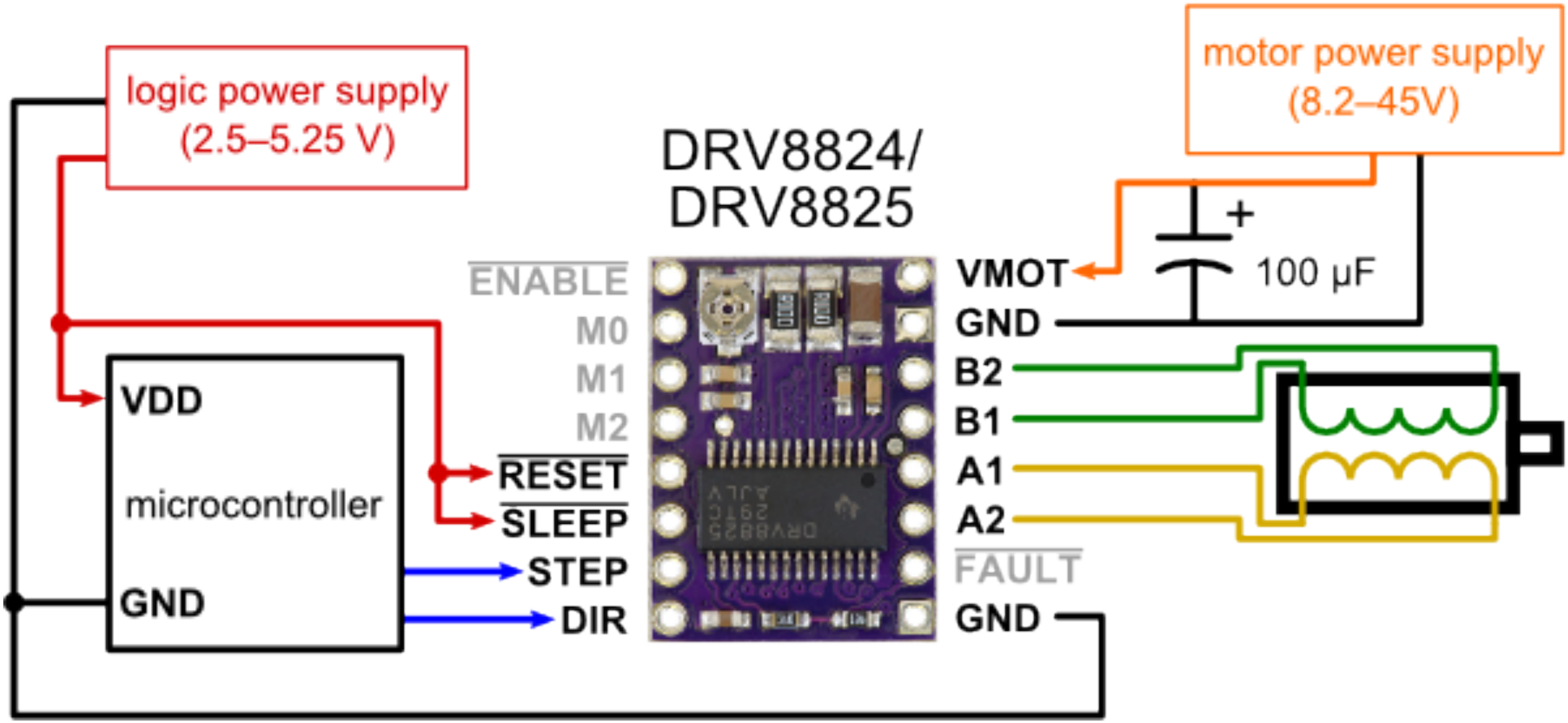

The red wirings are used to control DC motors by PMW, if not used or using stepper motor this can be removed

# DRV8825 Stepper Motor Controller




- Simple step and direction control interface
- Six different step resolutions: full-step, half-step, 1/4-step, 1/8-step, 1/16-step, and 1/32-step
- Adjustable current control lets you set the maximum current output with a potentiometer, which lets you use voltages above your stepper motor’s rated voltage to achieve higher step rates
- Intelligent chopping control that automatically selects the correct current decay mode (fast decay or slow decay)
- 45 V maximum supply voltage
- Built-in regulator (no external logic voltage supply needed)
- Can interface directly with 3.3 V and 5 V systems
- Over-temperature thermal shutdown, over-current shutdown, and under-voltage lockout
- Short-to-ground and shorted-load protection

# DRV8825 Stepper Motor Controller



# ROCO222: Intro to sensors and actuators

Lecture 5

Stepper motor issues

# Advantages and disadvantages of steppers

**Advantages**

- Cheap and robust way to directly generate relatively high torque at low speeds so can drive many loads without gearing
- Long life with only bearing to wear out (no brushes)
- Stepper motor can be controlled without feedback
- Excellent positional repeatability
- Open loop - motors response to digital input pulses
- Brushless - no contact brushes to wear out
- Incremental steps - rotation angle proportional to the input pulse
- Standard NEMA frame sizes facilitates mounting and replacement of motors
- Failsafe – since just stops working and doesn’t go berserk if fails (e.g. unlike a servo motor if it loses its encoder signal)

# Advantages and disadvantages of steppers

**Disadvantages**

- Low efficiency since the motor draws substantial power regardless of load and must do so to hold a static position (otherwise it will loose position synchronization)
- Torque can fall of rapidly as speed increases
- Resonance can occur if not properly controlled and requires micro-stepping to ensure smooth movement. (last 2 issues now less of a problem using  the latest switching current limiting controllers)
- Synchronization will be lost if momentarily overloaded since lost steps cannot be noticed since there is no feedback
- Motors exhibit a low torque to intrinsic inertia ratio so have a high rotational time constant (i.e. cannot generate large angular accelerations)
- Stepper motor normally run very hot in high performance configurations (much too hot to touch)
- Not easy to operate at very high speeds (i.e. > 2000rpm)
- Motor normally generates a lot of acoustic noise at moderate to high speeds
- Low output power for size and weight (I.e. motors are heavy for output power they produce)

# Stepper motor design issues

- Above Curie temperature a permanent magnet will loose its magnetics.
- Needs to be higher than the operating temperature of the stepper motor it will no longer generate torque.
- Even before the Curie temperature the magnetic flux density will reduce

- As the speed of rotation of a stepper motor increases, permanent magnet steppers will induce a back EMF in the windings

- This will oppose the flow of current, and at high speeds it may drop significantly and thereby reduce available torque output

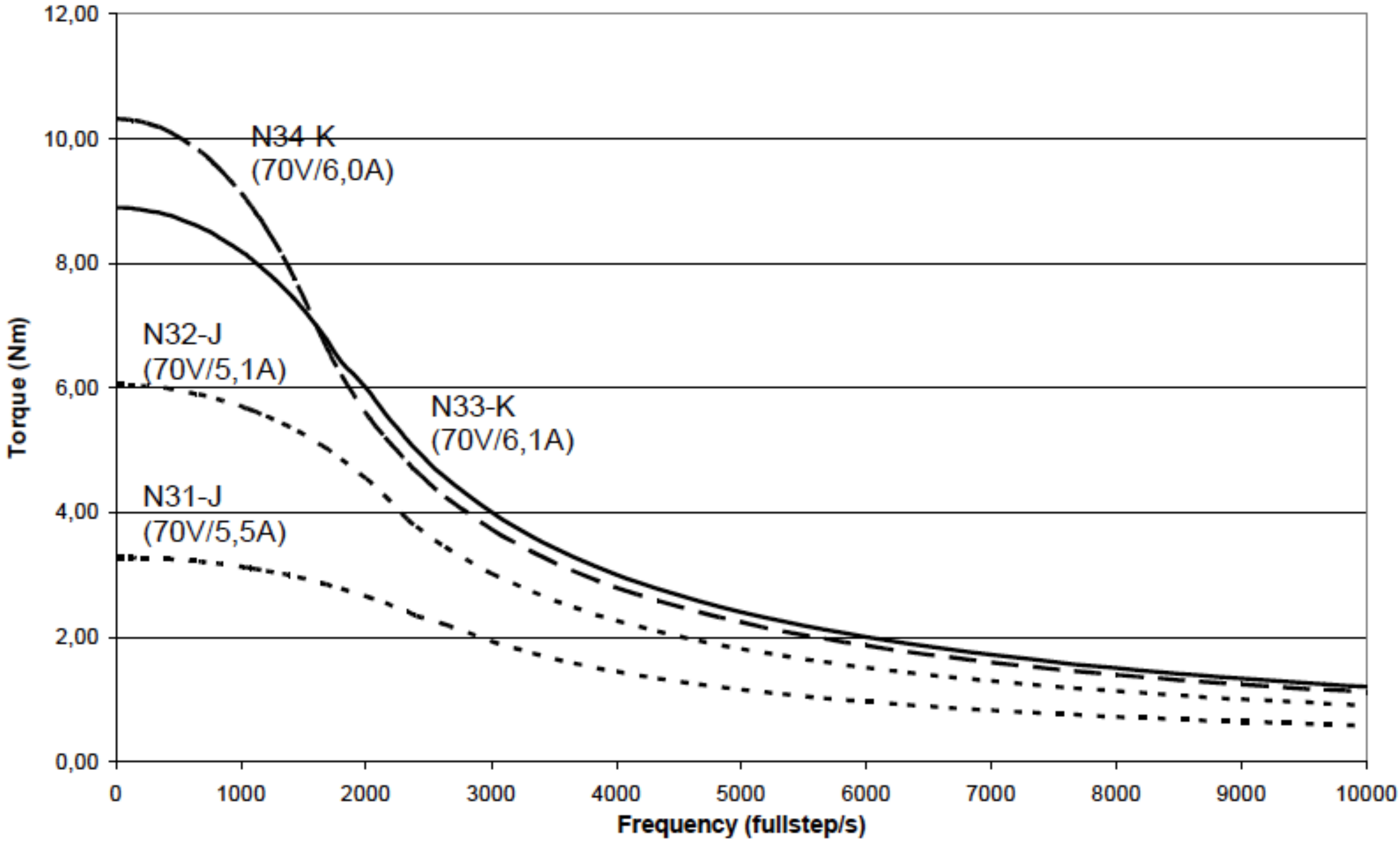
- Therefore higher supply voltages are needed to run at high rotational speeds

- Since simple H-bridge drive circuits limit current in the steppers using the resistance of the windings, this places a limit of the maximum applied voltage that can be used with such drive circuits

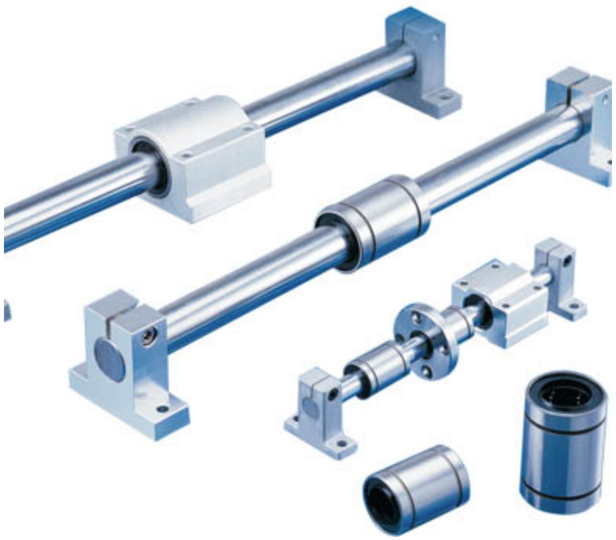
- The issues of back EMF induced by stepper rotation can be much more elegantly dealt using constant current stepper drives that regulate the current

# Typical Stepper torque characteristics

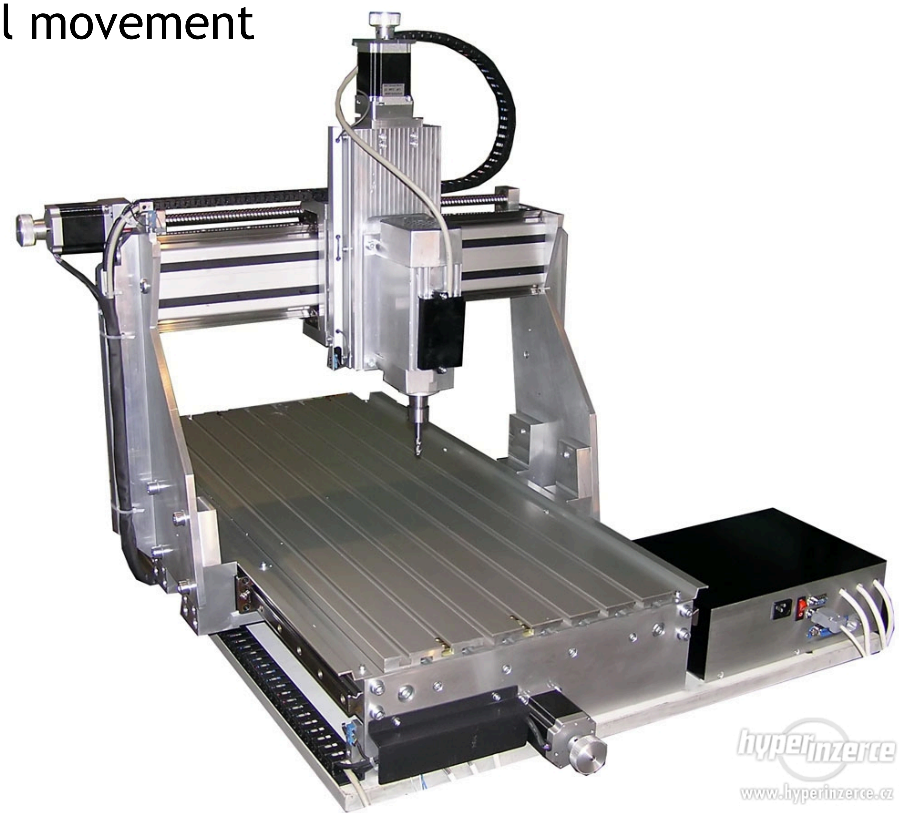
**Size N3** (selected windings, at 70V)



# CNC mill using steppers



- Using linear bearing to implement low friction high precision tool movement



- Using a stepper to directly drive a ball screw on each axis to generate linear movement

- Here simple CNC using ZYX control of a router to cut material
- Larger machines move the table and not the cutter mechanism

# Servo motor versus stepper motor

- Fast and responsive 100K RPM+
- No lost counts
- Smaller increments of motion
- Lower pole count
- Better efficiencies / linearity's
- High acceleration rates possible
- Expensive

- Comparatively cheap
- Very reliable and limited by bearing life
- Good torque at low
- Lots of current handling to operate micro stepping modes – lots of heat => inefficient
- Can get resonance effects
- Large size
- Can be quite heavy
- Don't work at high speeds > 2000rpm

# Wide range of standard NEMA frames


- NEMA stepper units have standard frames sized
- This facilitates exchanging units and upgrading

# Geared Stepper Motor


- Stepper motors can also be sourced with gearboxes attached
- Provides extra torque and reduces granularity in output

# Example stepper motor data sheet

## Technique parameter

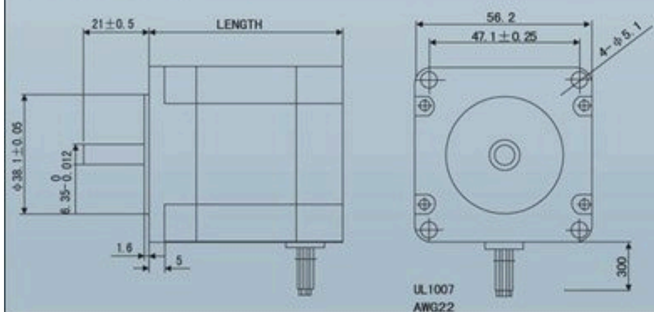
| Item | Specifications |
|---|---|
| Step Angle Accuracy | ±5%(full step, no load) |
| Resistance Accuracy | ±10% |
| Inductance Accuracy | ±20% |
| Temperature Rise | 80℃Max.(ratod current, 2 phase on) |
| Ambient Temperature | −10℃−+50℃ |
| Insulation Class | B |
| Dielectric Strength | 500VAC for one minute |
| Shaft Radial Play | 0.06Max.(450 g−load) |
| Shaft Axial Play | 0.08Max.(450 g−load) |

## Technique Specification

| Model | | Step angle | Motor length | Rated current | Phase resistance | Phase inductance | Holding torque | | lead wire | Rotor inertia | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 单出轴 Single Shaft | 双出轴 Double Shaft | ° | L(mm) | A | Ω | mH | Oz-in | kgf.cm | No. | g.cm² | kg |
| 57BYGH41-601A | 57BYGH41-601B | 1.8 | 41 | 1.0 | 5.7 | 5.4 | 55 | 3.9 | 6 | 120 | 0.47 |
| 57BYGH41-602A | 57BYGH41-602B | 1.8 | 41 | 2.0 | 1.4 | 1.4 | 55 | 3.9 | 6 | 120 | 0.47 |
| 57BYGH41-401A | 57BYGH41-401B | 1.8 | 41 | 2.8 | 0.7 | 1.4 | 76 | 5.5 | 4 | 120 | 0.47 |
| 57BYGH51-601A | 57BYGH51-601B | 1.8 | 51 | 1.0 | 6.6 | 8.2 | 100 | 7.2 | 6 | 275 | 0.65 |
| 57BYGH51-602A | 57BYGH51-602B | 1.8 | 51 | 2.0 | 1.65 | 2.2 | 100 | 7.2 | 6 | 275 | 0.65 |
| 57BYGH51-401A | 57BYGH51-401B | 1.8 | 51 | 2.8 | 0.83 | 2.2 | 140 | 10.1 | 4 | 275 | 0.65 |
| 57BYGH56-601A | 57BYGH56-601B | 1.8 | 56 | 1.0 | 7.4 | 10 | 125 | 9.0 | 6 | 300 | 0.7 |
| 57BYGH56-602A | 57BYGH56-602B | 1.8 | 56 | 2.0 | 1.8 | 2.5 | 125 | 9.0 | 6 | 300 | 0.7 |
| 57BYGH56-401A | 57BYGH56-401B | 1.8 | 56 | 2.8 | 0.9 | 2.5 | 175 | 12.6 | 4 | 300 | 0.7 |
| 57BYGH76-601A | 57BYGH76-601B | 1.8 | 76 | 1.0 | 8.6 | 14 | 187 | 13.6 | 6 | 480 | 1.0 |
| 57BYGH76-602A | 57BYGH76-602B | 1.8 | 76 | 2.0 | 2.25 | 3.6 | 187 | 13.5 | 6 | 480 | 1.0 |
| 57BYGH76-401A | 57BYGH76-401B | 1.8 | 76 | 2.8 | 1.13 | 3.6 | 263 | 18.9 | 4 | 480 | 1.0 |

◆ We also manufacture products according to customer's requirements.

## Dimensions




## Wiring Diagram