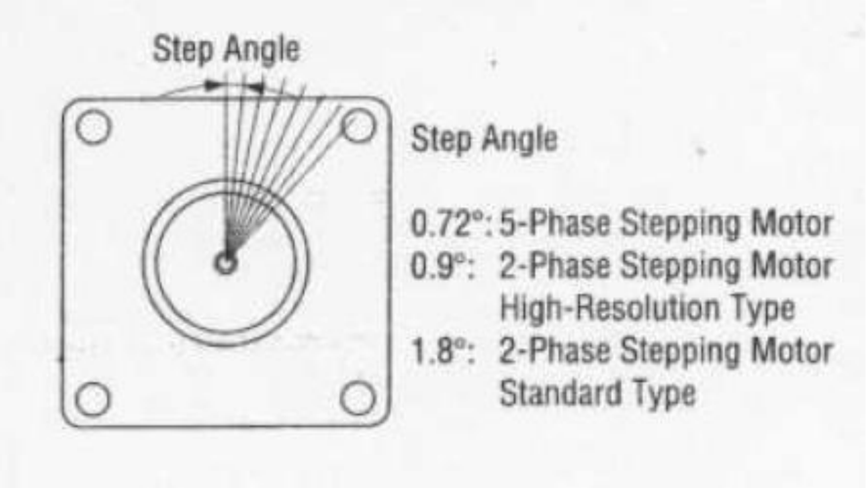
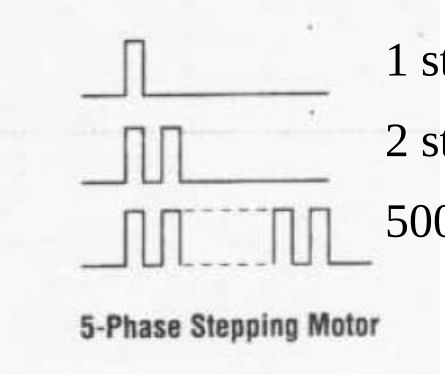
Stepper Motors

Characteristics of Stepper Motors

- Considered to be digital devices – motors take a small fixed rotational step when actuated
- Used for precision position control
  - Stepper motors are used to hold a specific rotational position and to move from one fixed rotational position to another.
- Have no brushes to wear out
- Have a high "holding" torque – when energized, they are difficult to rotate by hand
- Have a relatively low accelerating torque compared to d.c. motors

Fixed Rotational Steps

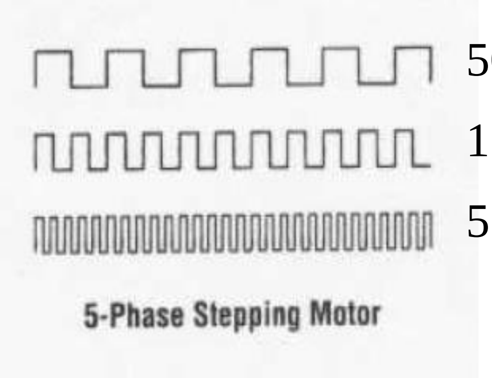




1 step = 0.72^0

2 steps = 1.44^0

500 steps = 360^0



500 Hz = 60 rpm

1 kHz = 120 rpm

5 kHz = 600 rpm

Advantages of Stepper Motors

- Low cost
- Long operating life & very reliable (absence of brushes or contacts means the life of the motor is dependant on the life of the bearing.)
- High torque at low speeds, full torque at standstill (with windings energized)
- A simple, rugged construction that operates in almost any environment
- The rotation angle of the motor is proportional to the input pulse count.
- Precise positioning and repeatability of movement (A good stepper motor has an accuracy of 3 – 5% of a step and this error is non cumulative from one step to the next.
- Excellent response to starting/stopping/reversing
- The motor responds to open-loop digital input pulses, making the motor simpler and less costly to control.
- It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.
- A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

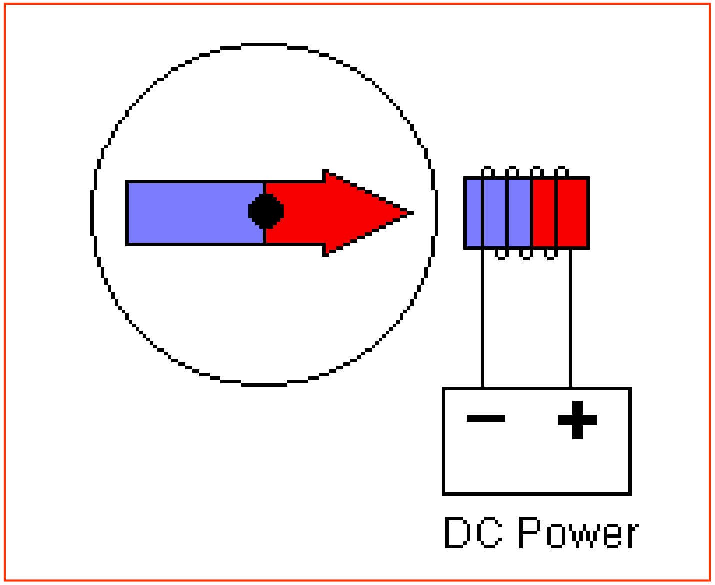
Disadvantages of Stepper Motors

- Low accelerating torque
- The resonance effect must be properly controlled and is often exhibited at low speeds
- The decreasing torque with increasing speed makes high speed operation difficult
- “Cogs” with no power applied

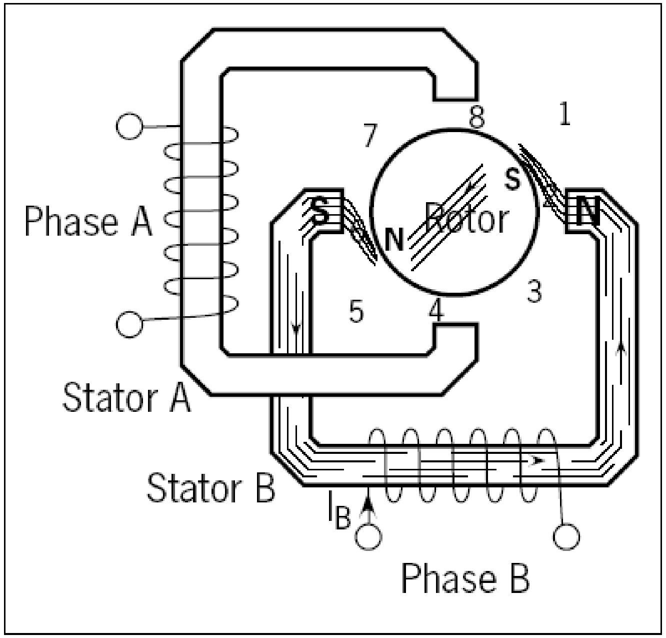
Types of Stepper Motors

- Permanent Magnet
  - Utilizes attraction (opposite magnetic poles) and repulsion (same magnetic poles) to rotate
  - Permanent magnet armature, soft iron stator
  - Coils on stator
- Hybrid
  - Mixture of variable reluctance and permanent magnet
  - Coils on stator
- Variable Reluctance
  - Utilizes variable reluctance effect to rotate
  - Only soft iron material in armature and stator
  - Coils on stator

Controlling a Permanent Magnet Motor

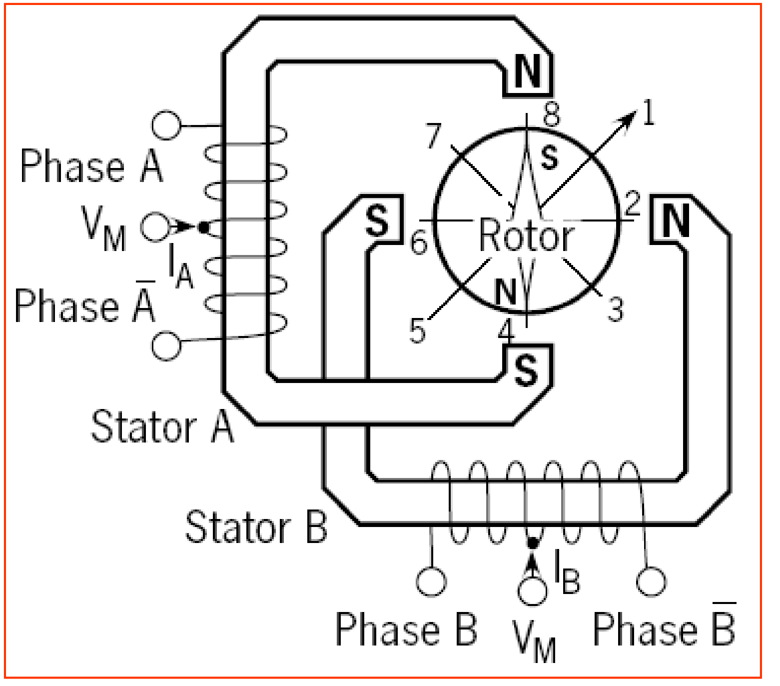


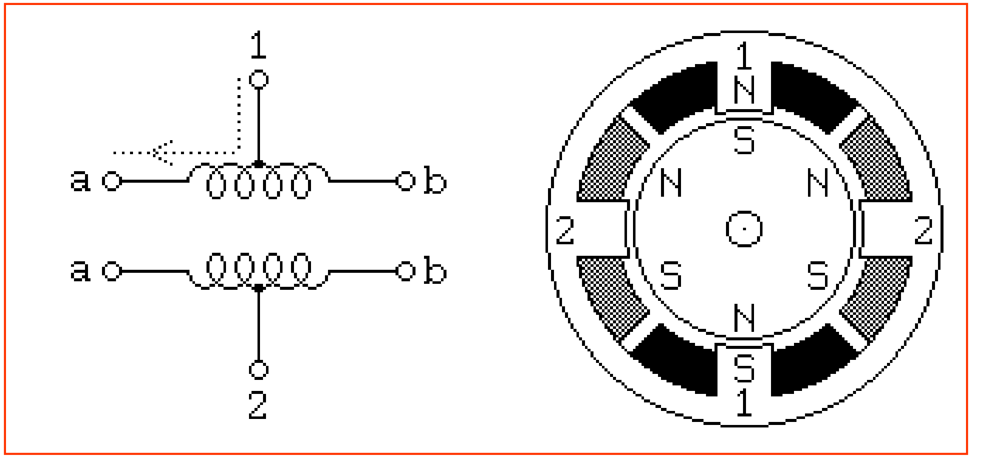
Concept



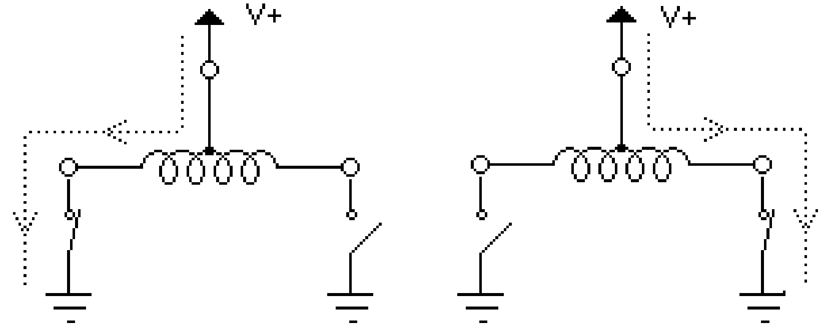
Two Pole Motor

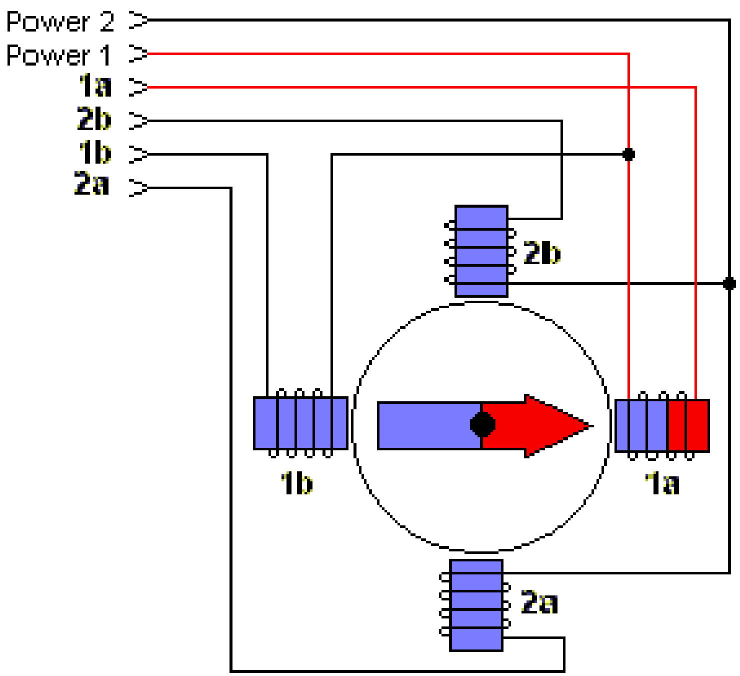
Unipolar Permanent Magnet Motor

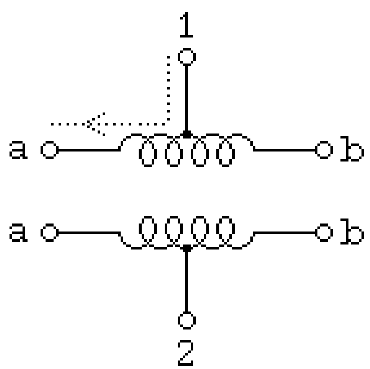




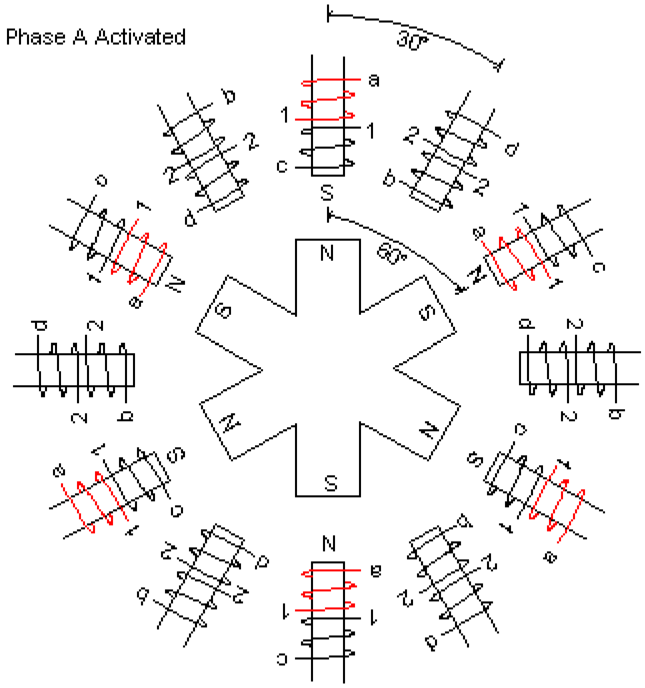
Driving Unipolar Motors

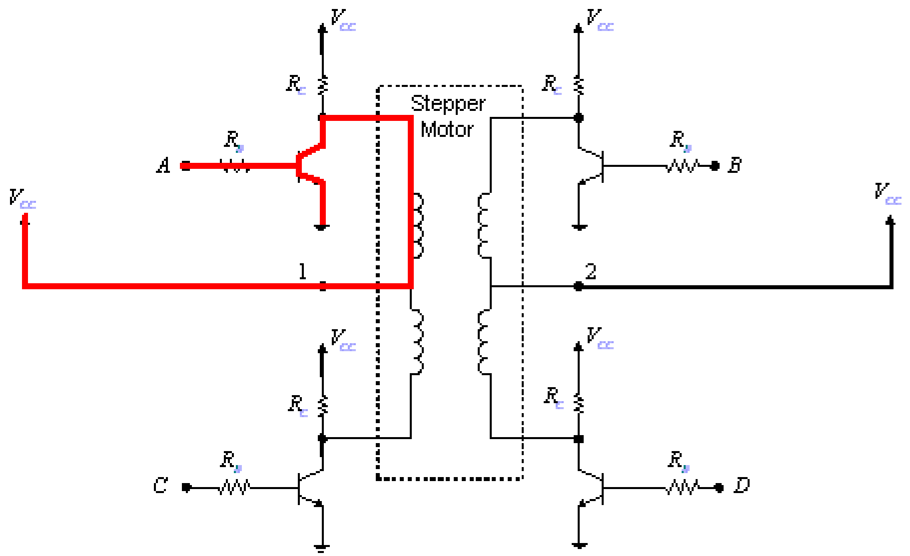






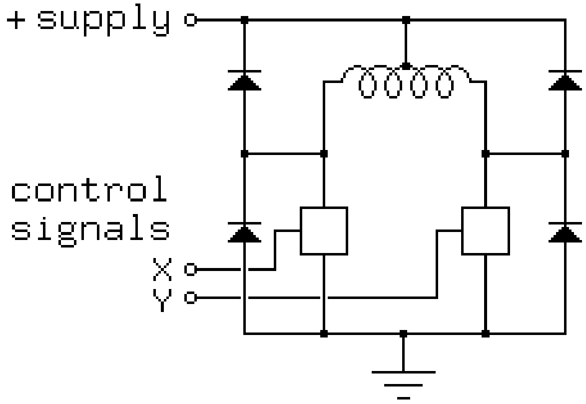
Controlling a Unipolar Permanent Magnet Motor



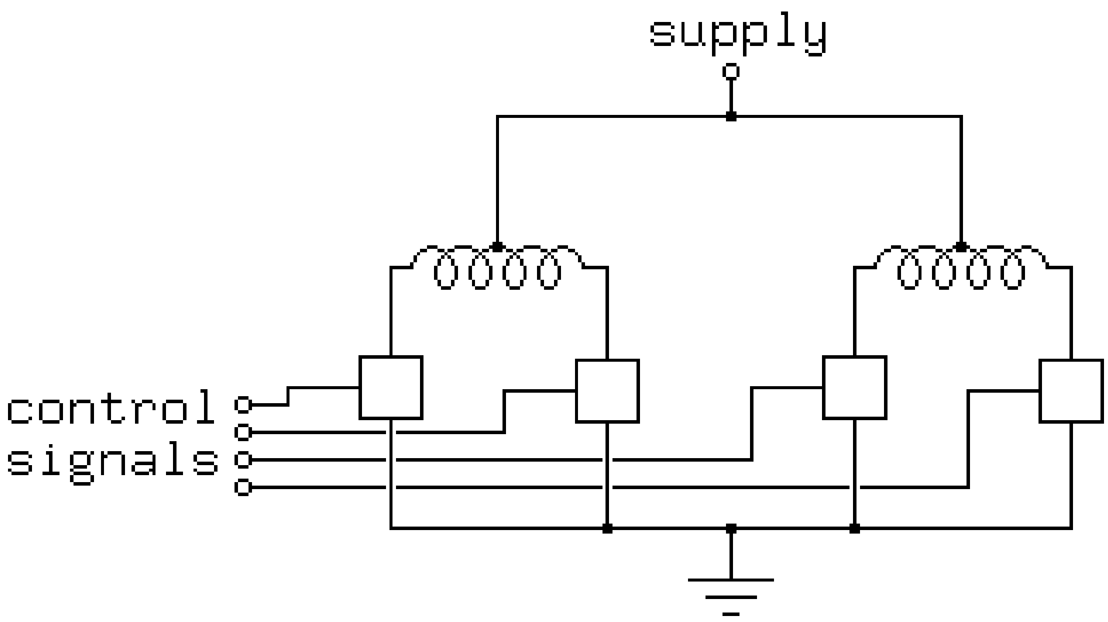


Note: phases A & C and phases B & D share the same physical stator pole.

Unipolar Motor Driver

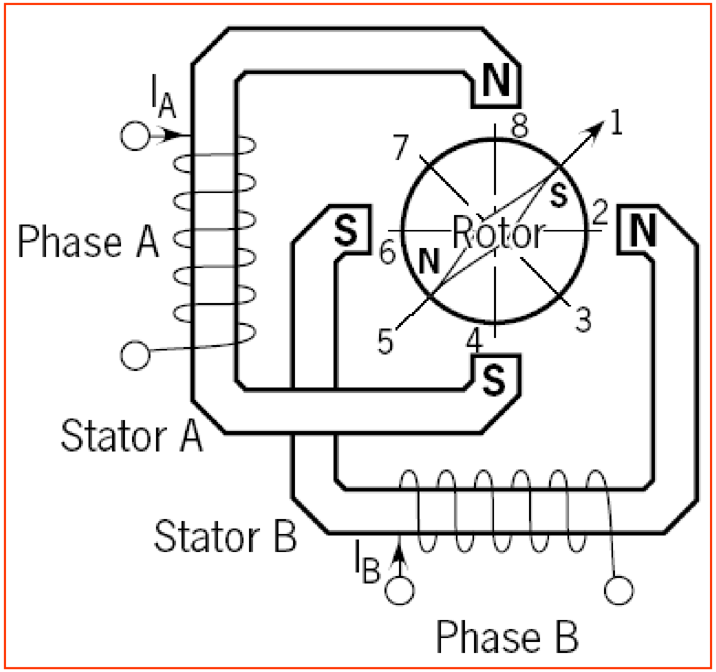


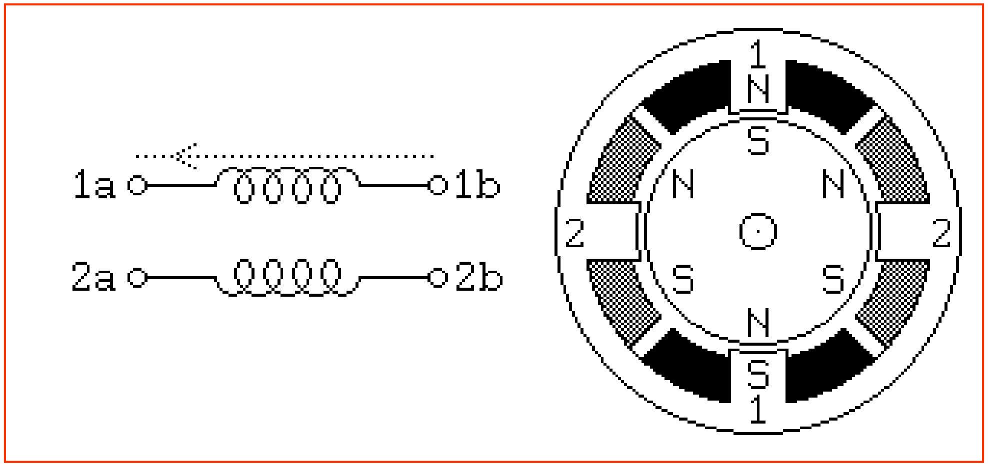
Requires 4 “freewheeling” diodes. Why?



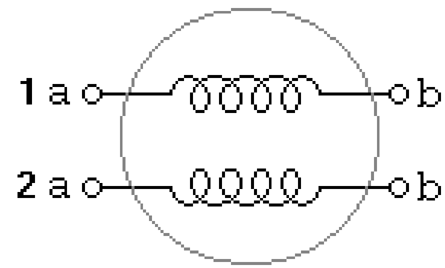
Bipolar Permanent Magnet Motor

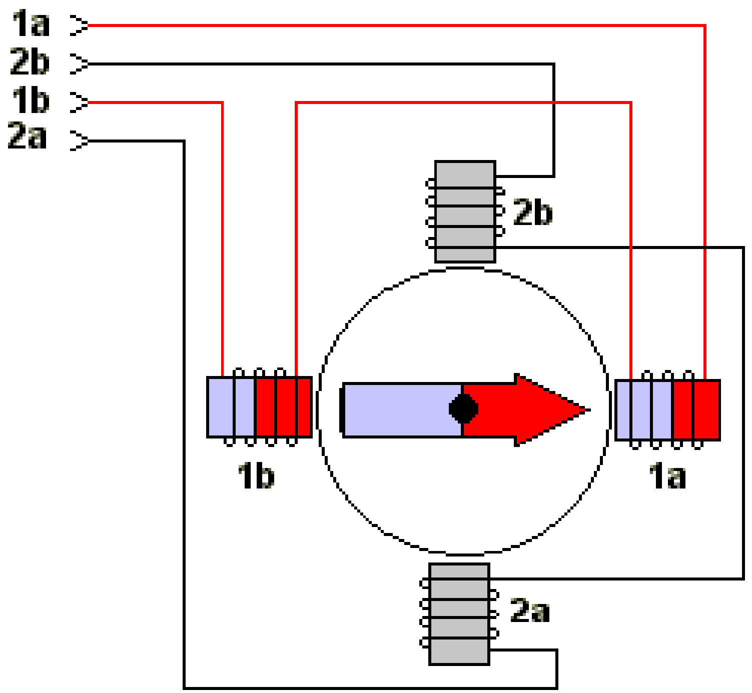
Most efficient for a given size motor.



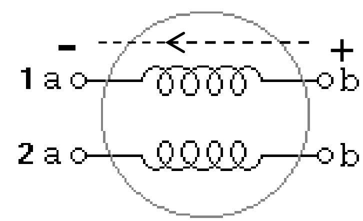


Driving Bipolar Motors

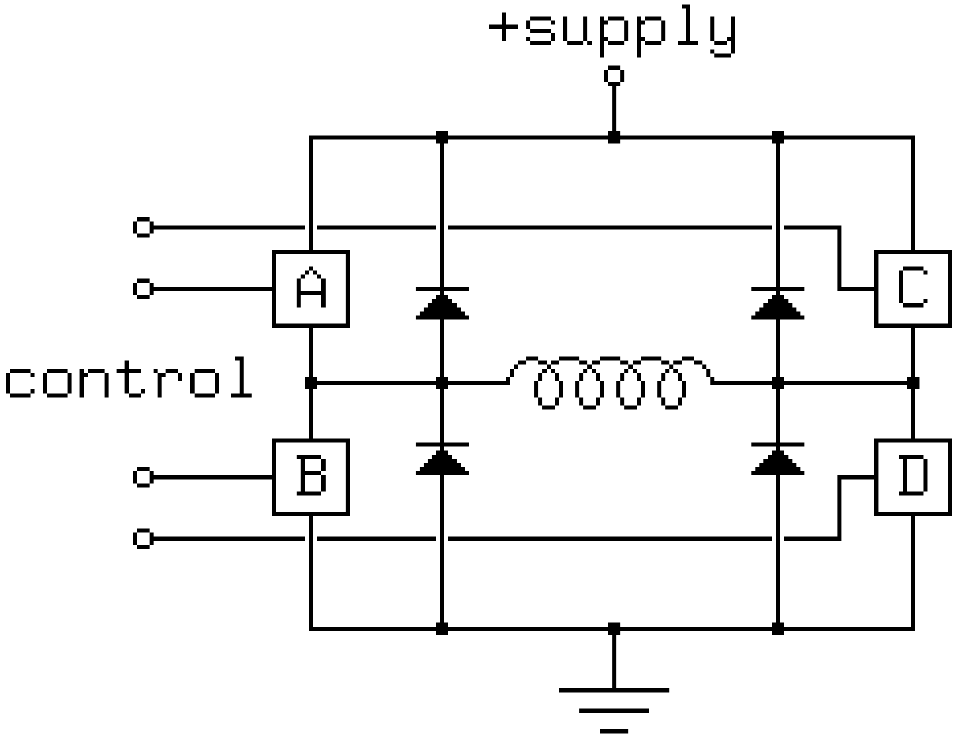




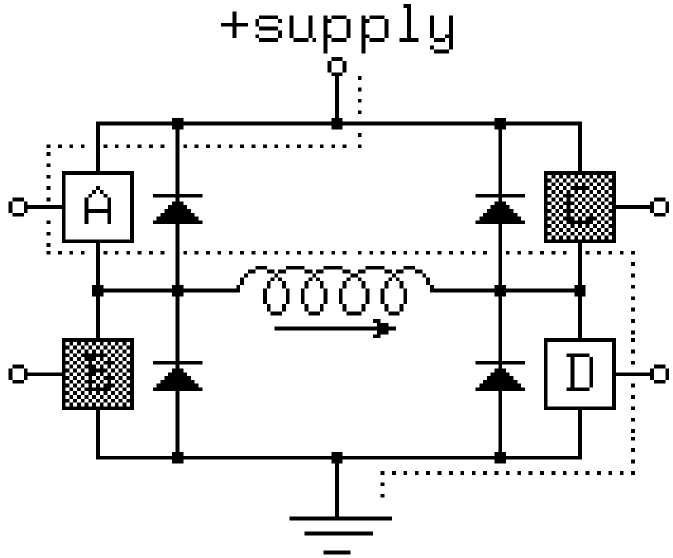
Requires current reversal in windings



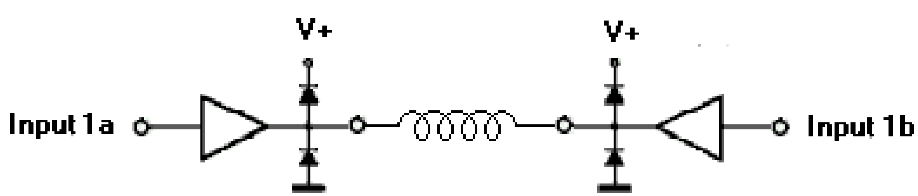
Bipolar Motor Driver



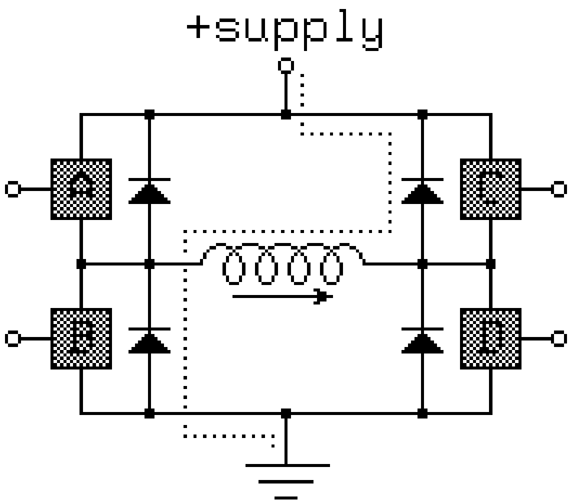
H Bridge Driver Operation

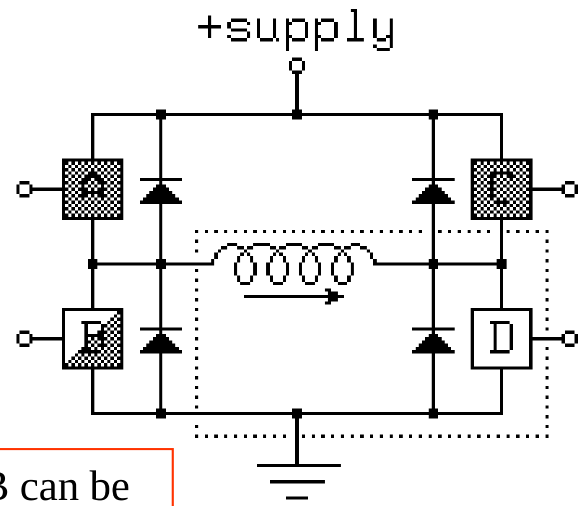


Concept: inputs can produce supply voltage or ground.



Other H Bridge Operating Modes





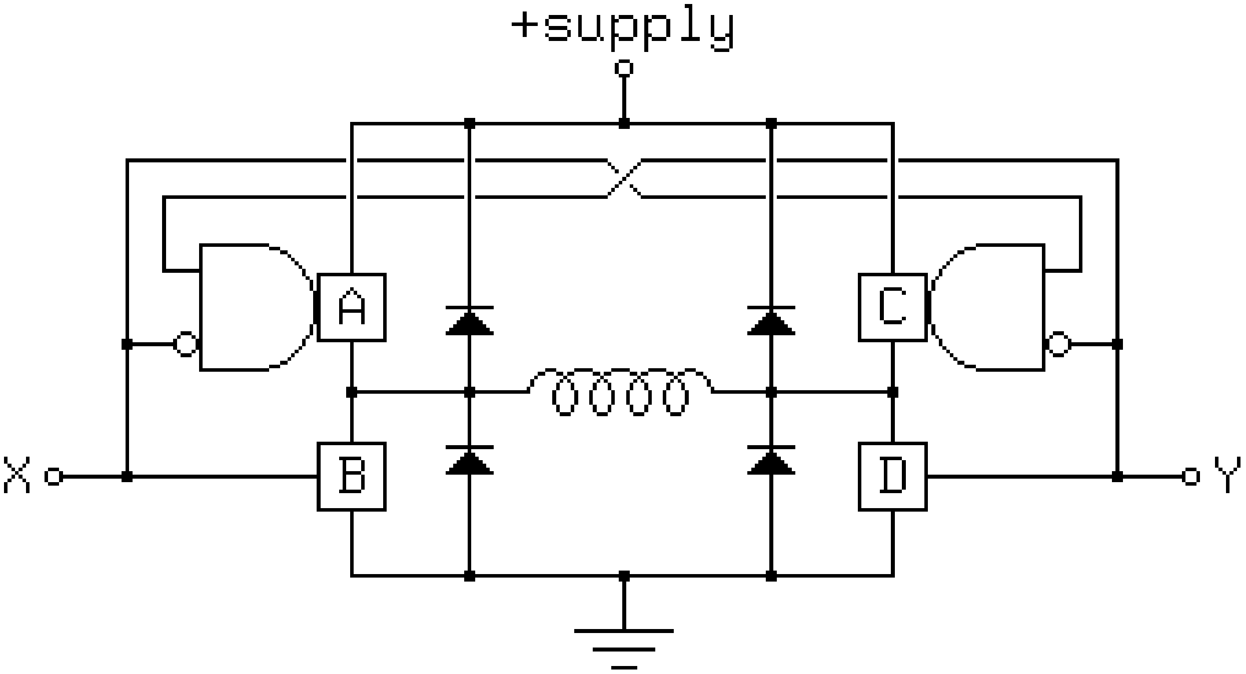
B can be on or not

Fast Decay Mode

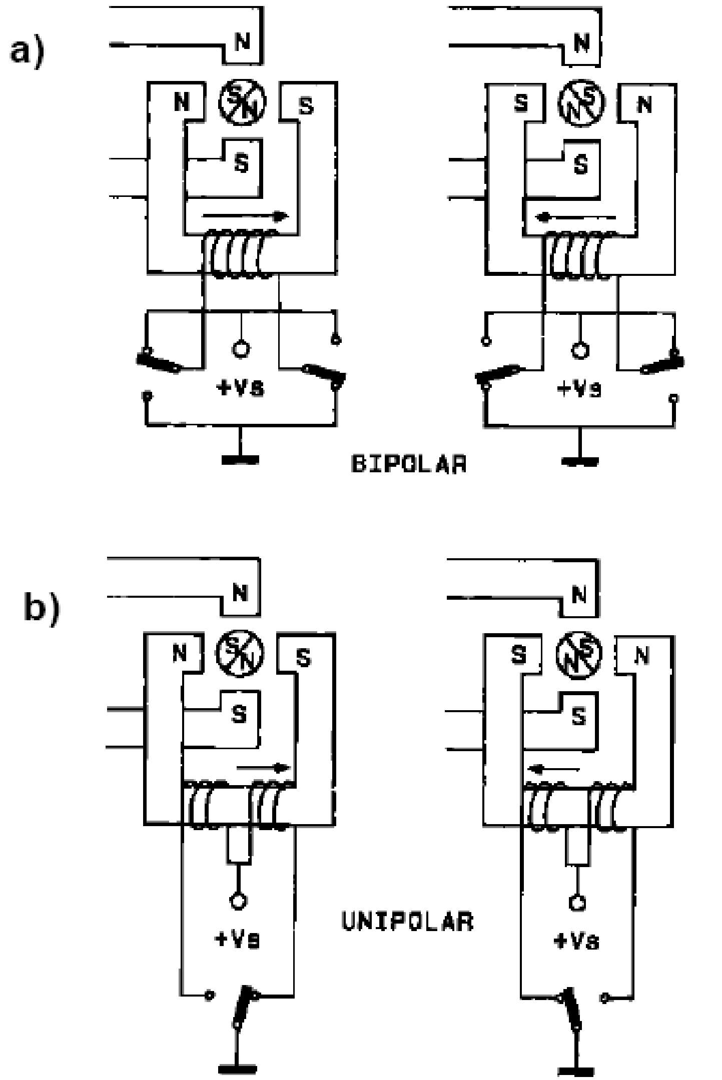
Slow Decay Mode

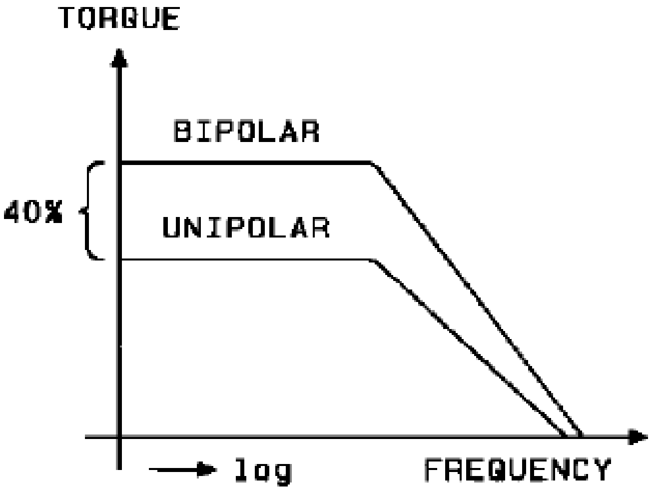
Speed ⇒ Current Decay in the Motor

Preventing Short Circuits

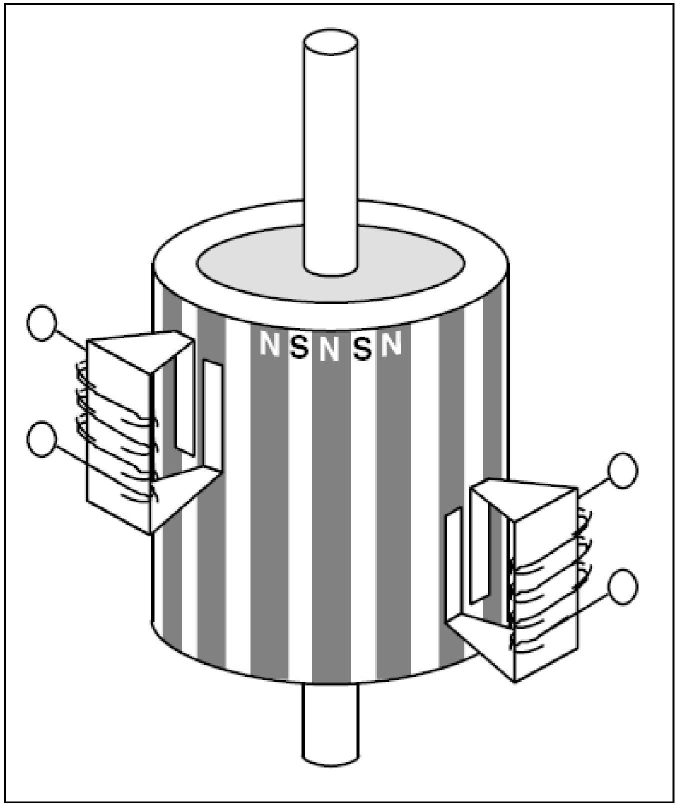


Unipolar vs. Bipolar

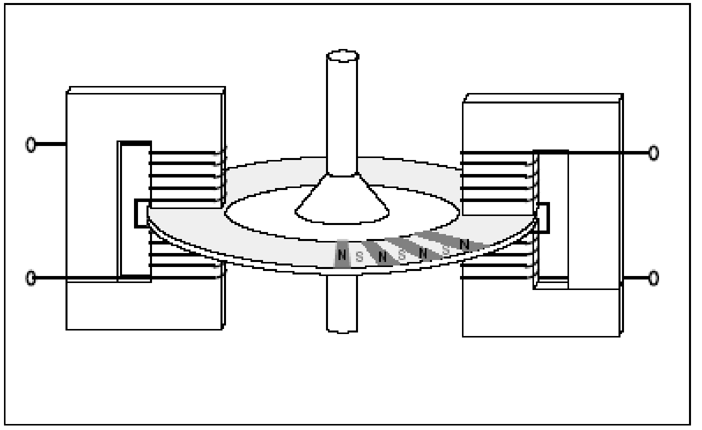




Permanent Magnet Motor

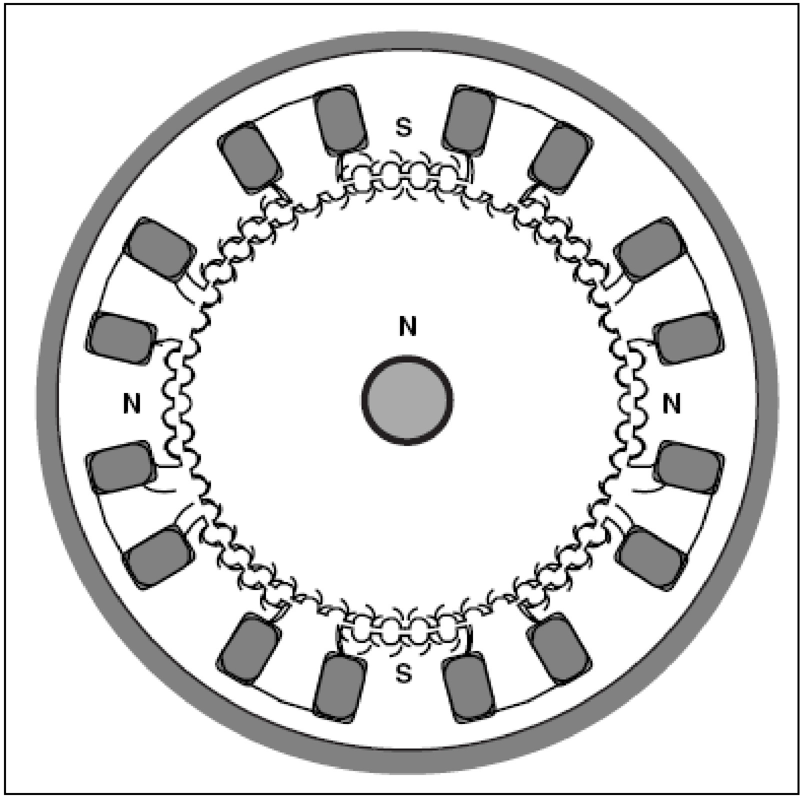


Canstack



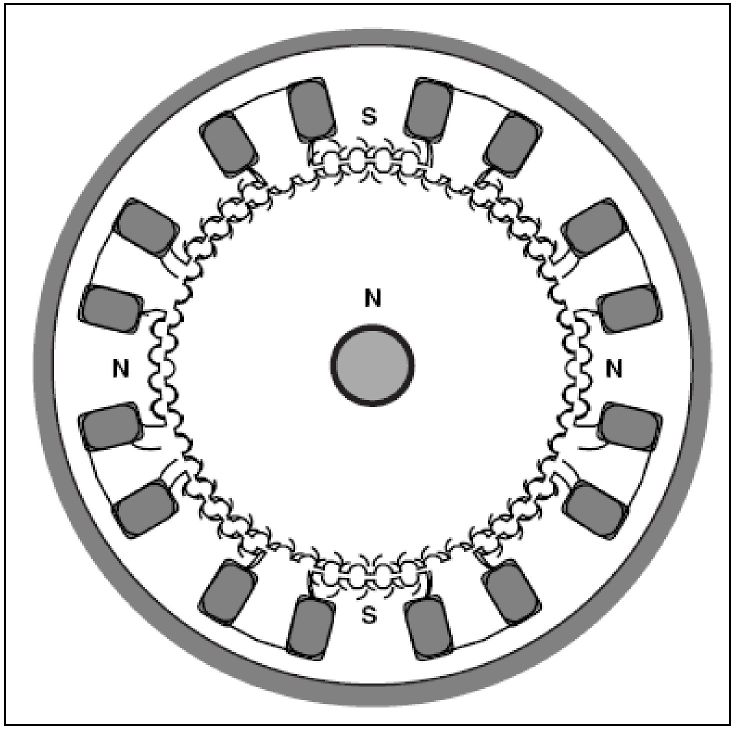
Disk Magnet Motor

Hybrid Motor

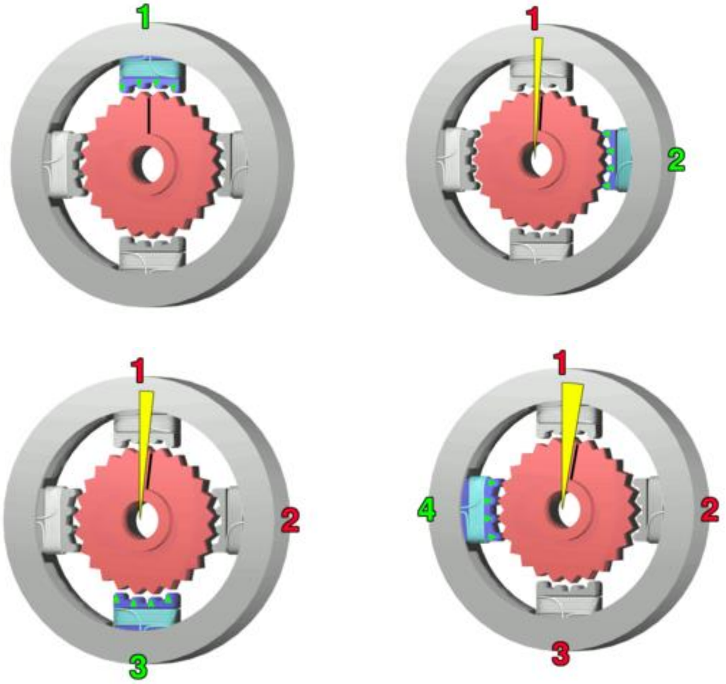


Behaves like a permanent magnet motor

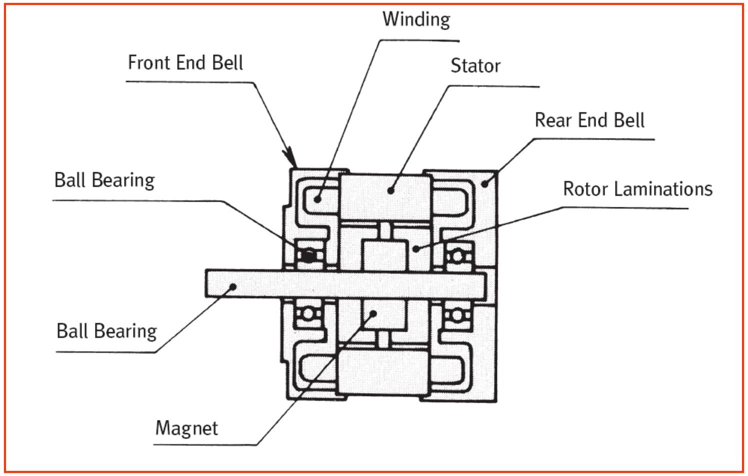
Hybrid Motor

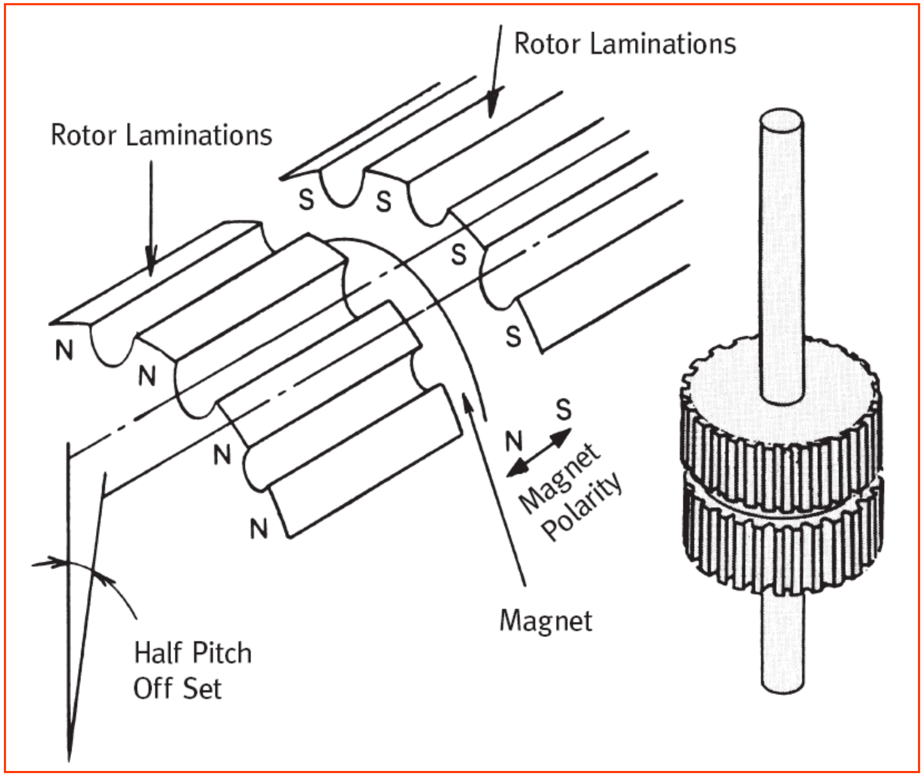


Behaves like a permanent magnet motor but with very small steps.

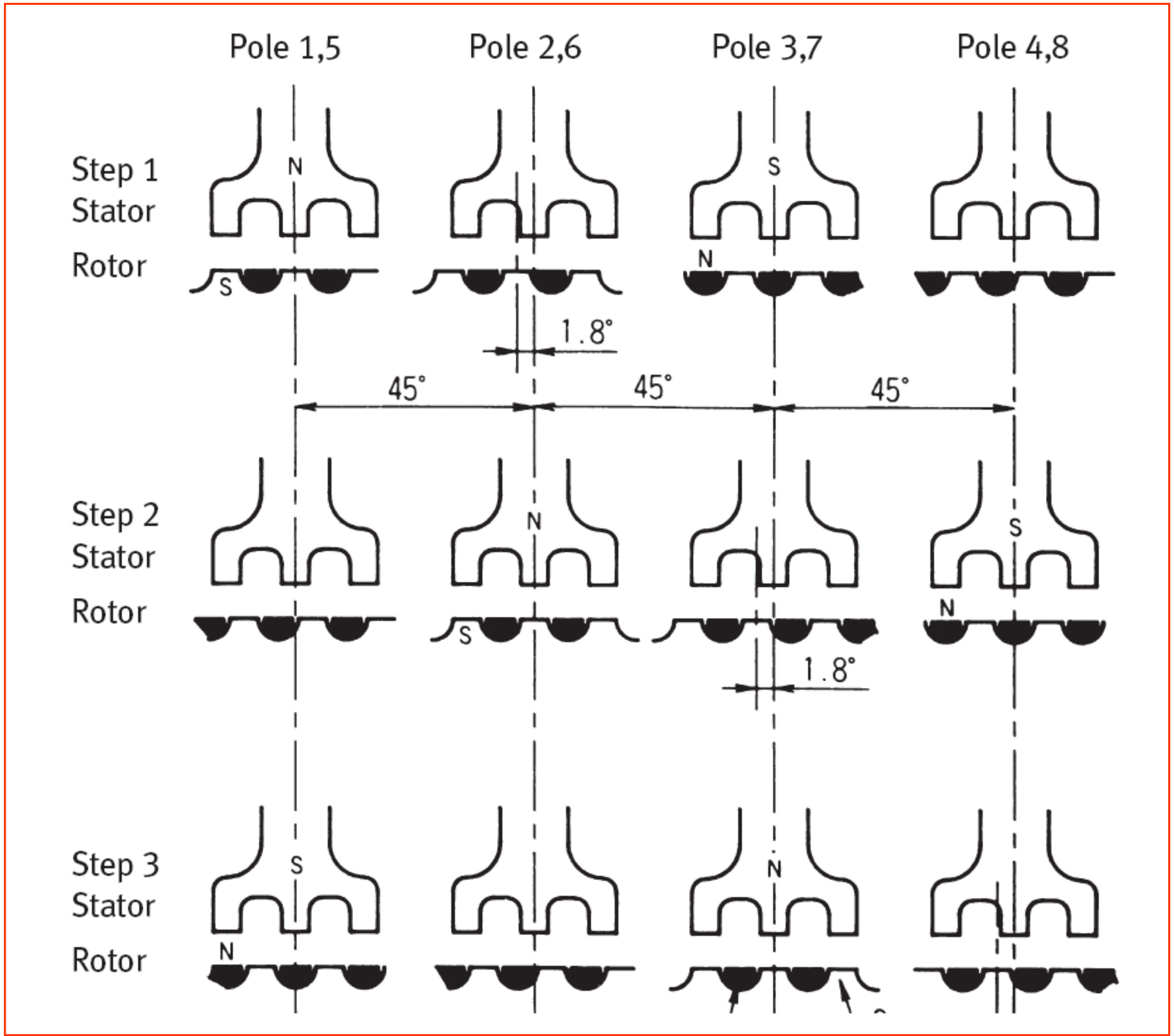


Hybrid Motor Details

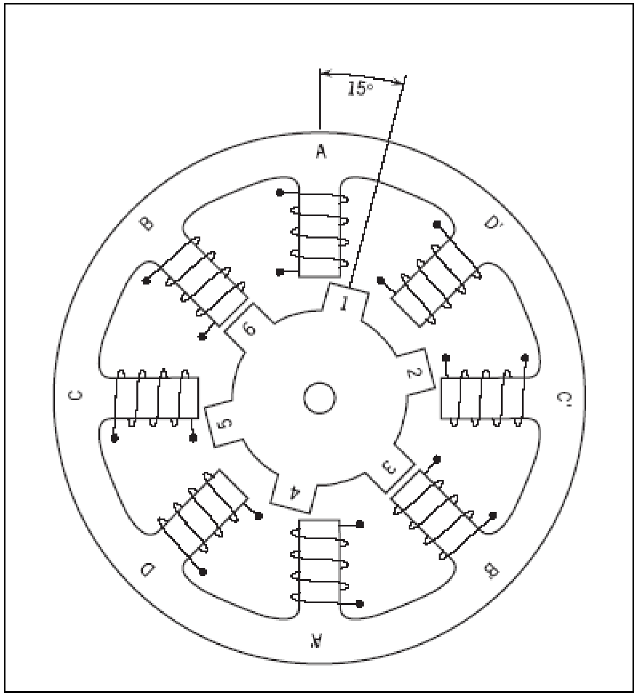


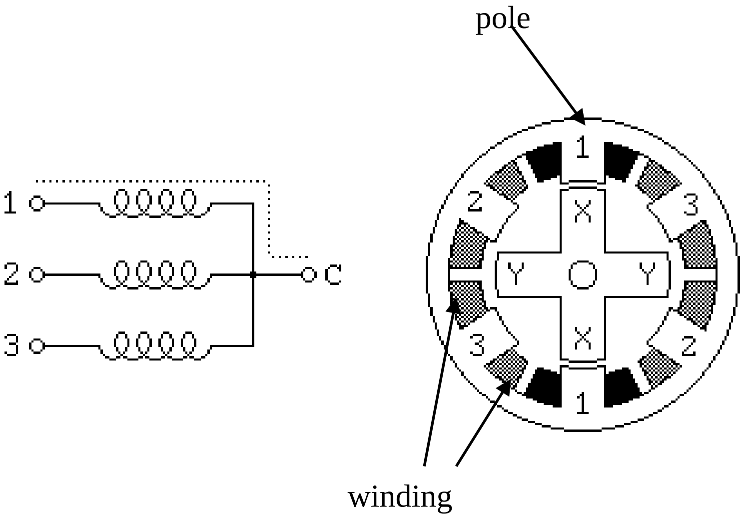


Hybrid Motor Wave Excitation



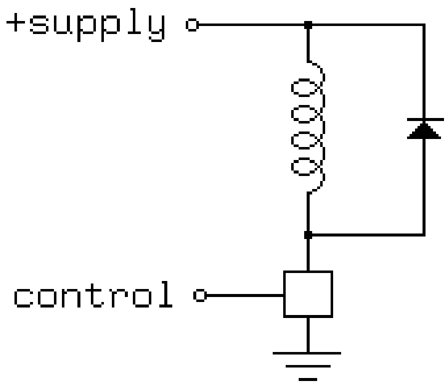
Variable Reluctance Motor

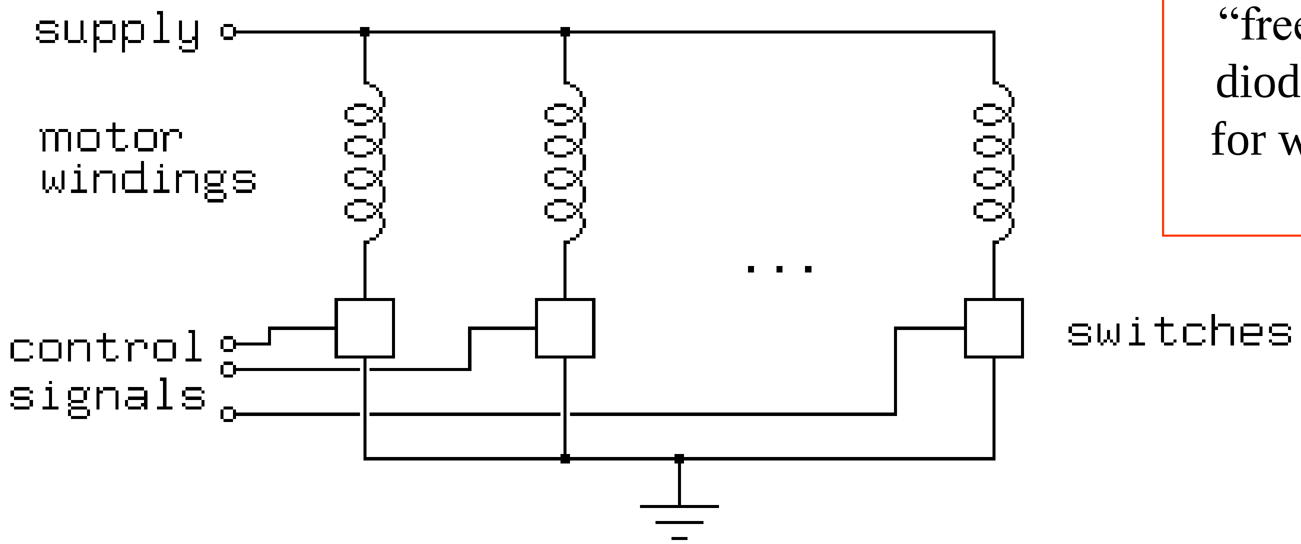




The same electromagnetic effect as the solenoid or magnetic levitation.

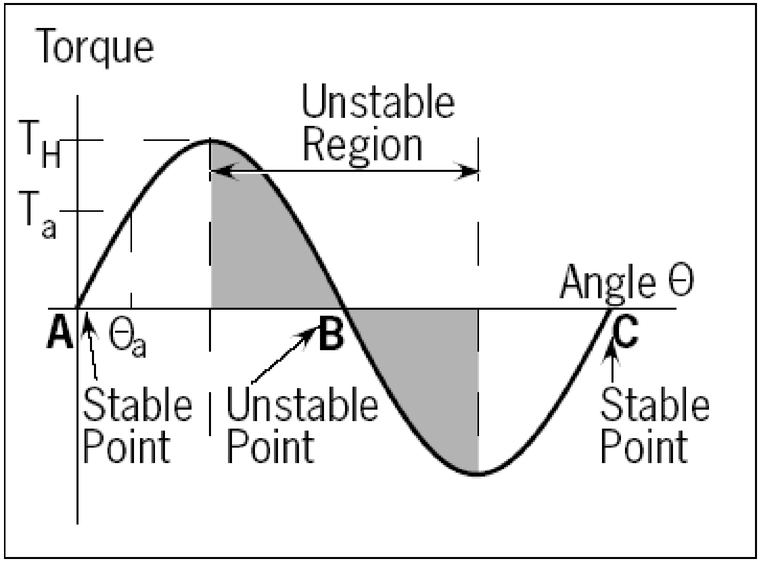
Variable Reluctance Driver

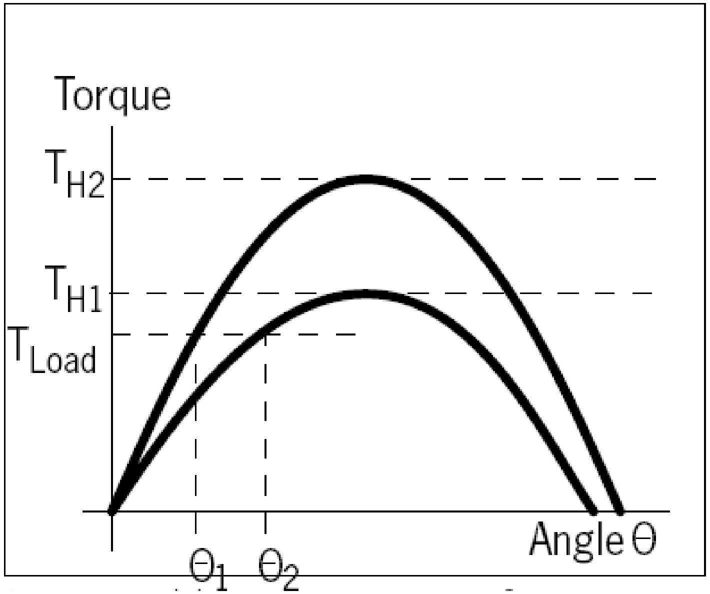




As before, “freewheeling” diode is needed for when switch opens.

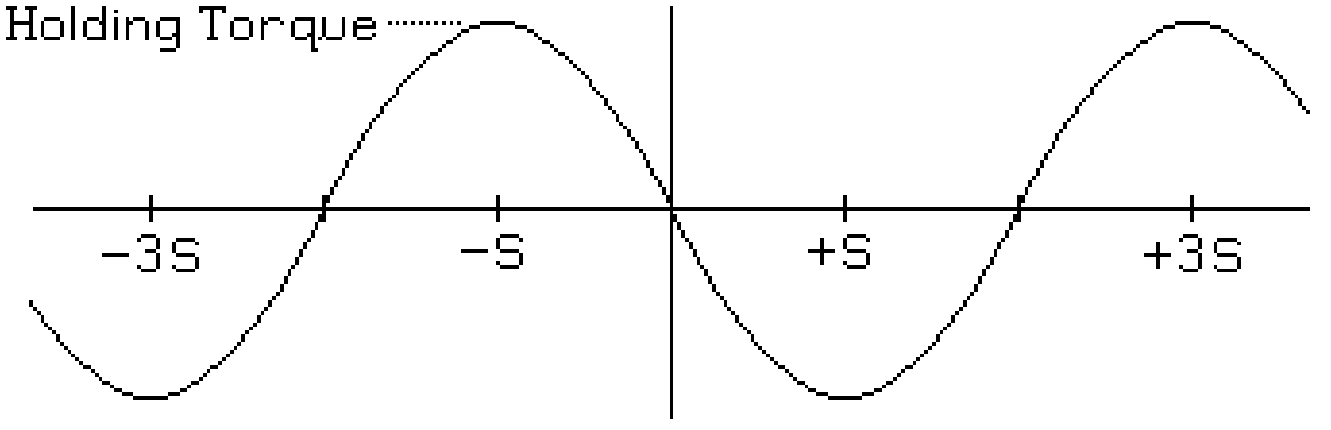
Torque Vs. Angle





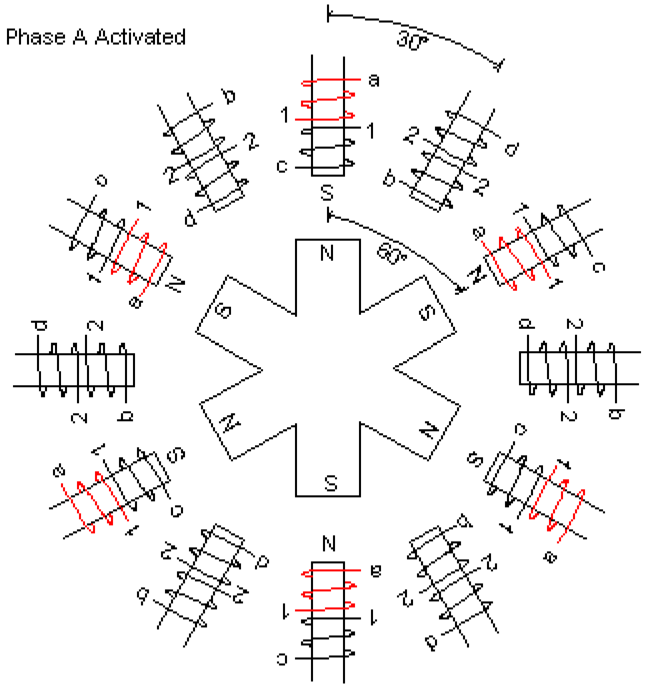
At different holding torques

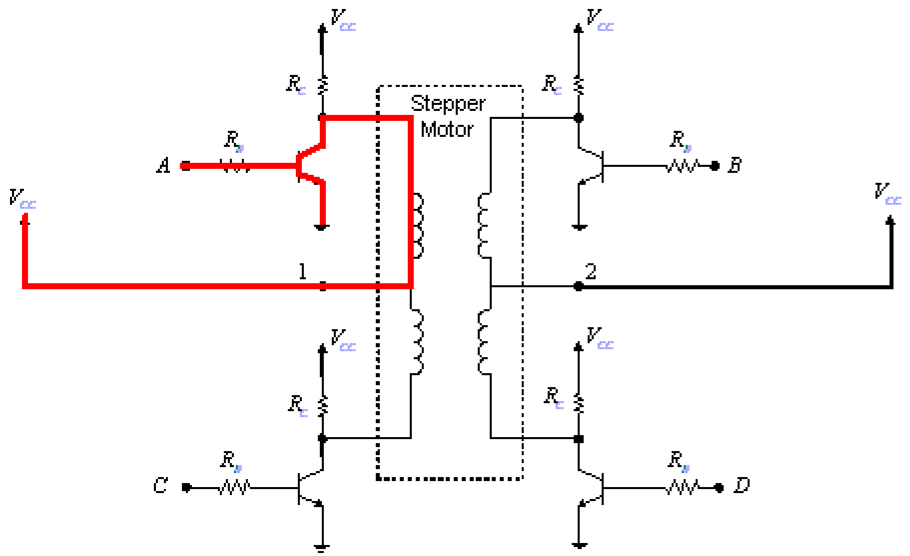
Wave Excitation



One winding on at a time

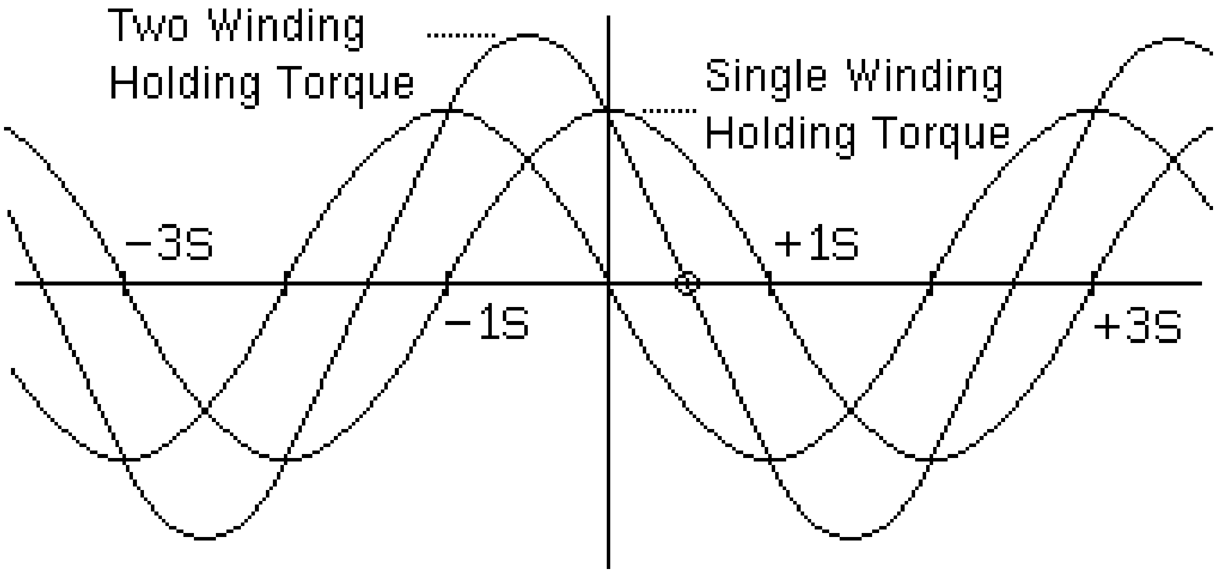
Controlling a Unipolar Permanent Magnet Motor





Note: phases A & C and phases B & D share the same physical stator pole.

Full Step Excitation

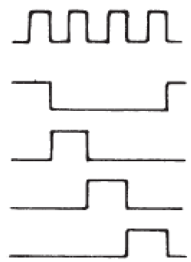
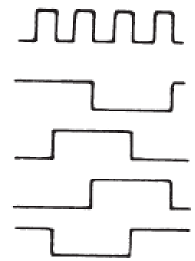
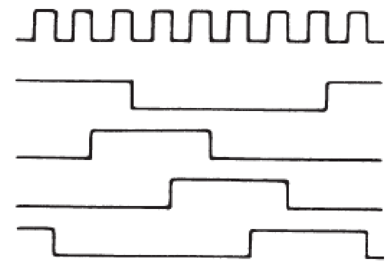


Two windings on at a time

Half Step Excitation

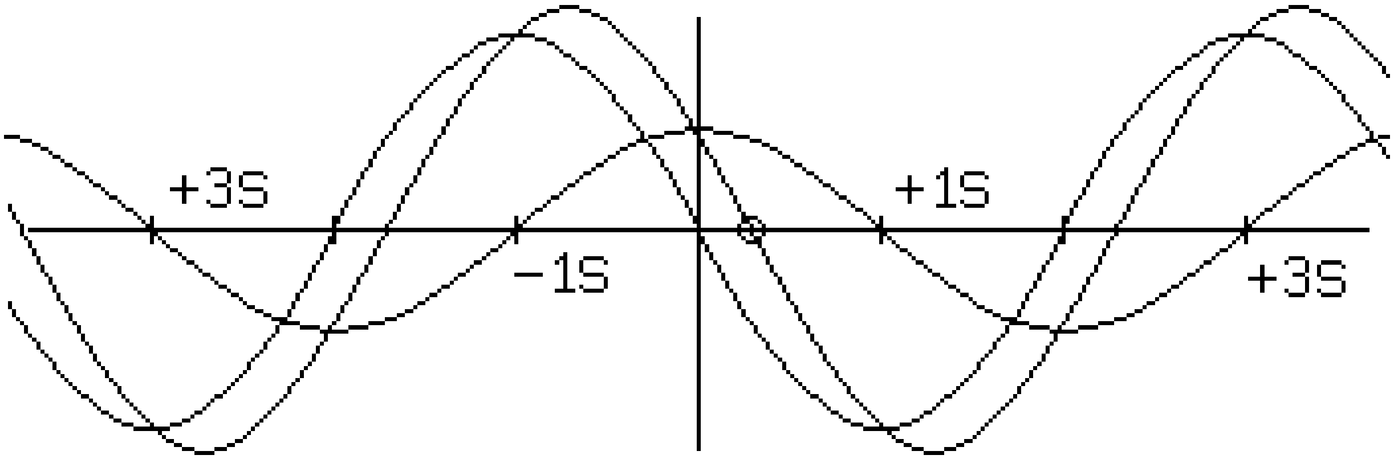
- Mixture of Wave Drive and Full Step Excitation
- One winding on followed by two followed by one, etc.
- Torque varies with step
- Finer stepping

Summary of Excitation Methods

		Excitation Method		
		Single Phase	Dual Phase	1-2 Phase
Switching sequence	Pulse phase A phase B phase A phase B			
Features		Hold & running torque reduced by 39% Increased efficiency. Poor step accuracy.	High torque Good step accuracy.	Poor step accuracy. Good resonance characteristics. Higher pulse rates. Half stepping

Wave **Full Step** **Half Step**

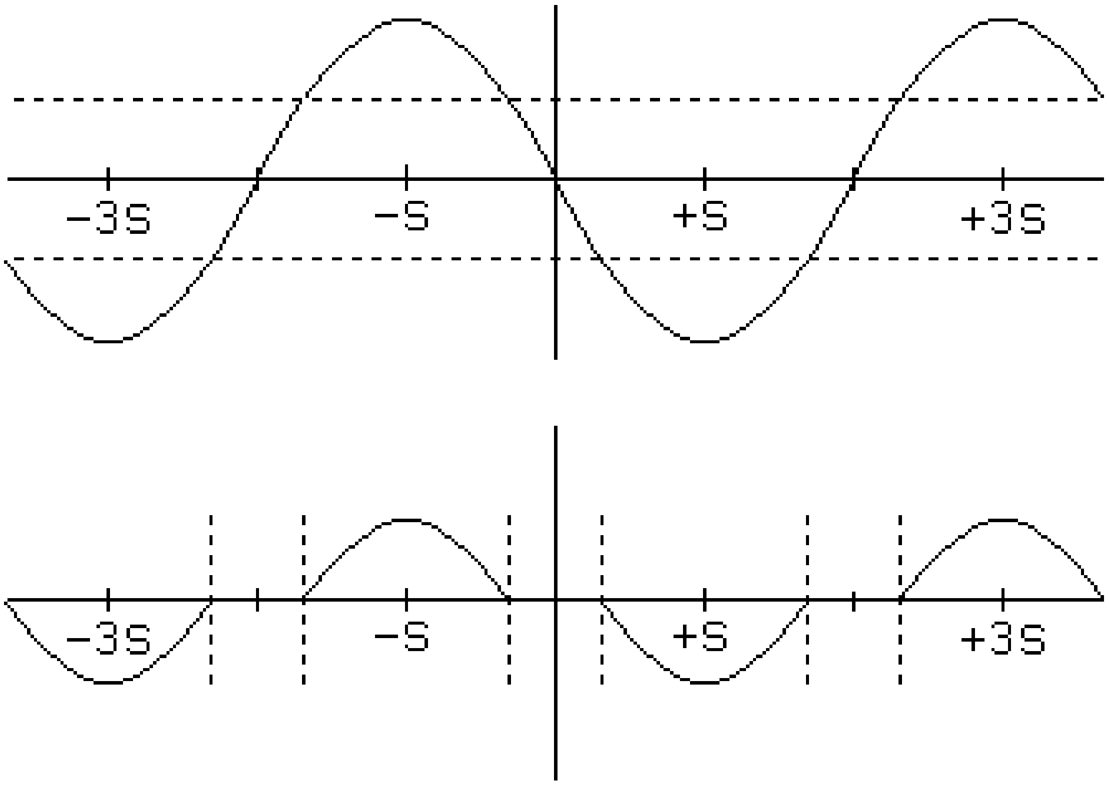
MicroStep Excitation



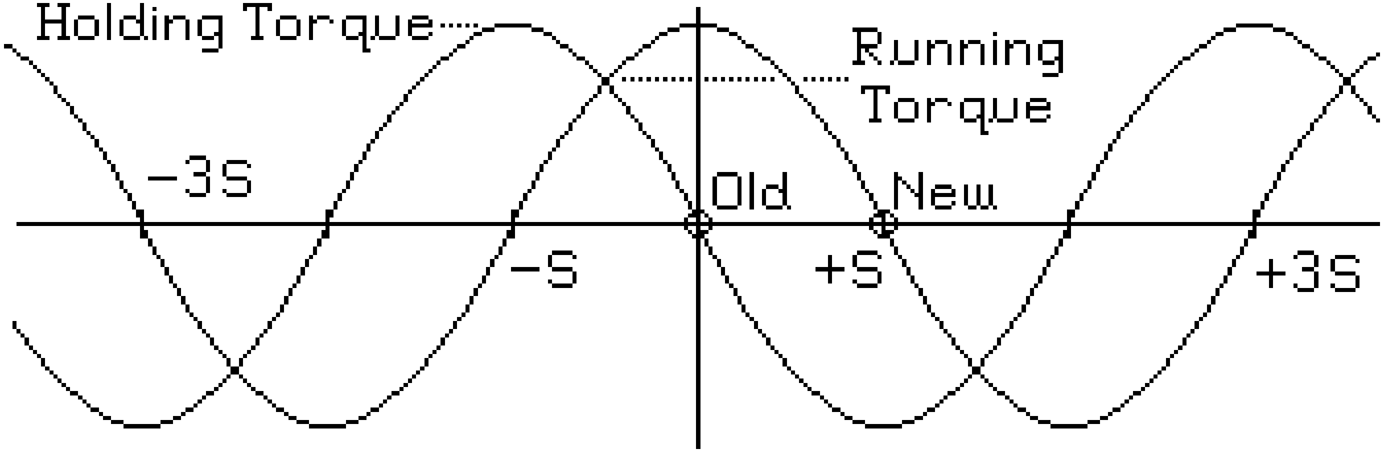
Current in windings is varied

Very Fine Stepping Angle

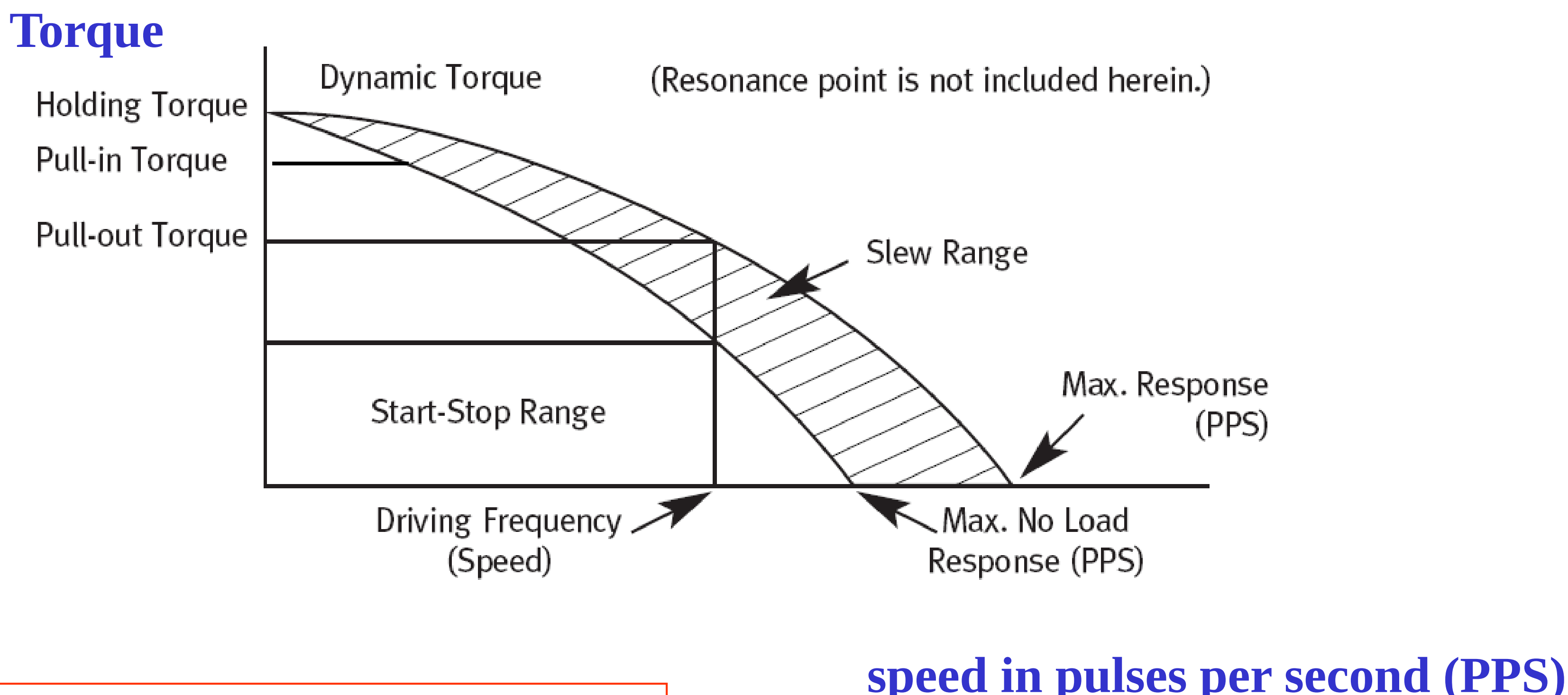
Torque to Overcome Friction



Torque Vs. Angle When Rotating



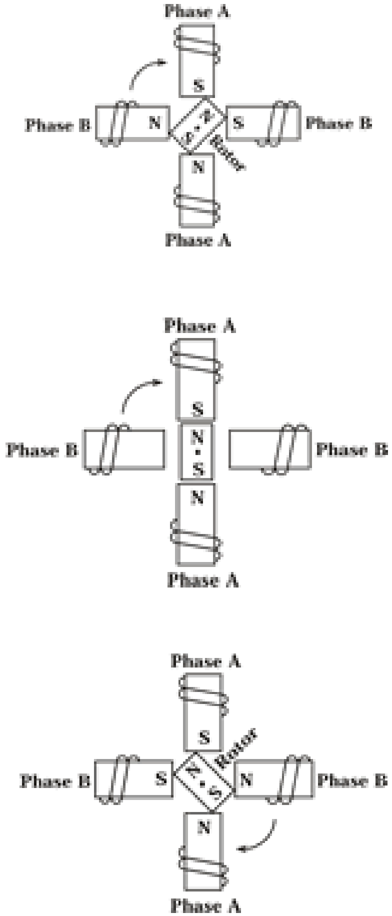
Torque vs. Speed

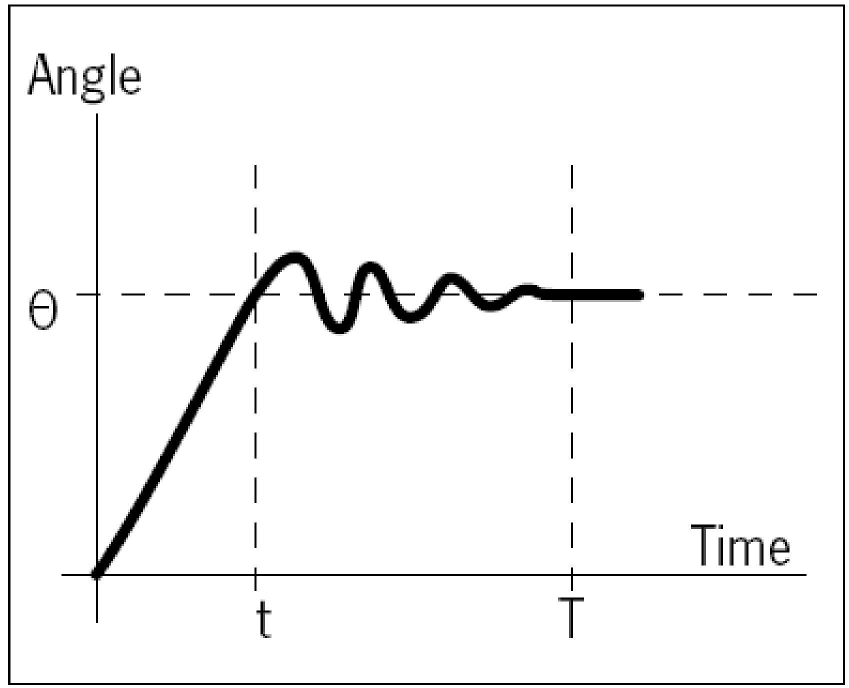


Pull-in Torque: the maximum torque, for a given speed, where a load can be accelerated into synchronism from a standstill.
Pull-out Torque: the maximum torque that can be applied to a step motor operating at a given speed without losing synchronism.

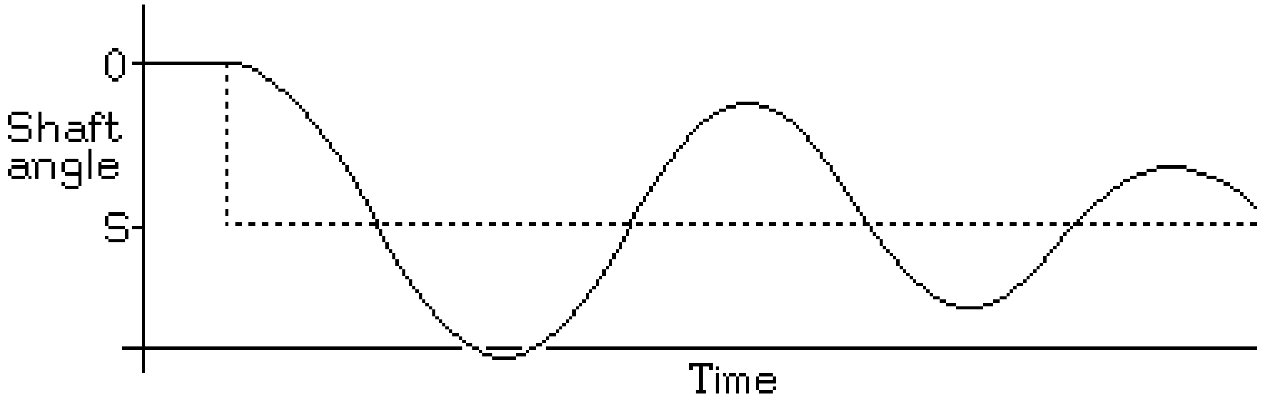
Slew Range: The region between the pull-in and pull-out torque curves. A motor may operate in this range, but cannot start, stop, or reverse without ramping.

Trajectory for a Step





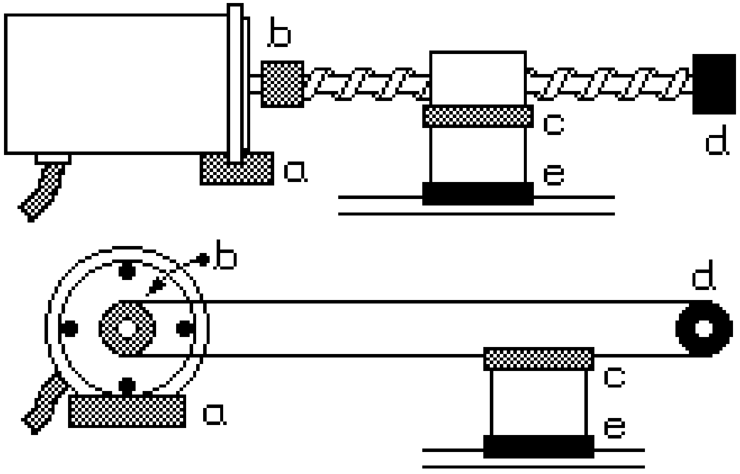
Angular Trajectory Vs. Time



What happens when the frequency of stepping is the same as this frequency?

Controlling Resonance

- In driver by shorting unused switches to provide damping
- In a mechanism with elastic couplings

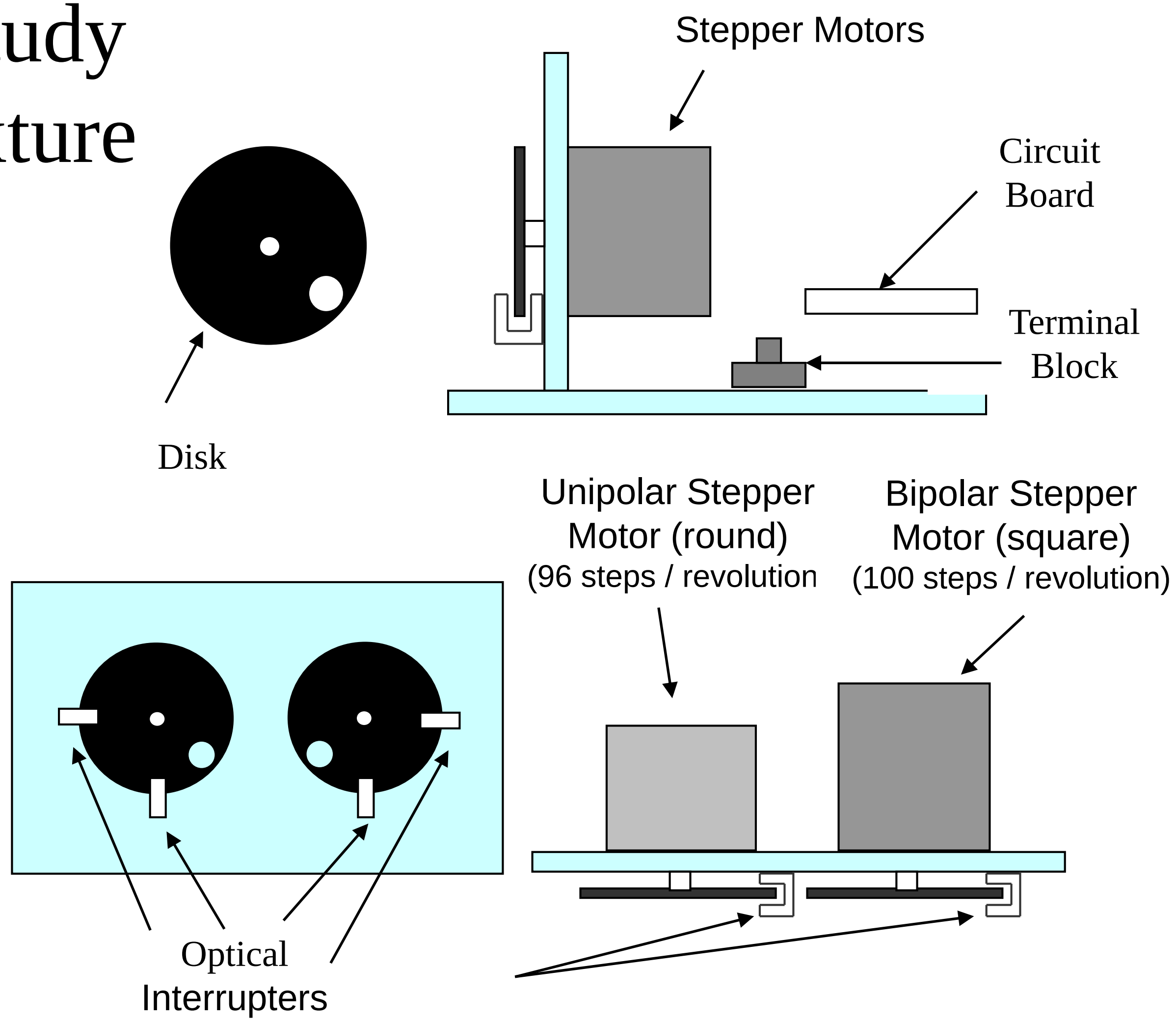


Controlling Resonance with Stepping Speed

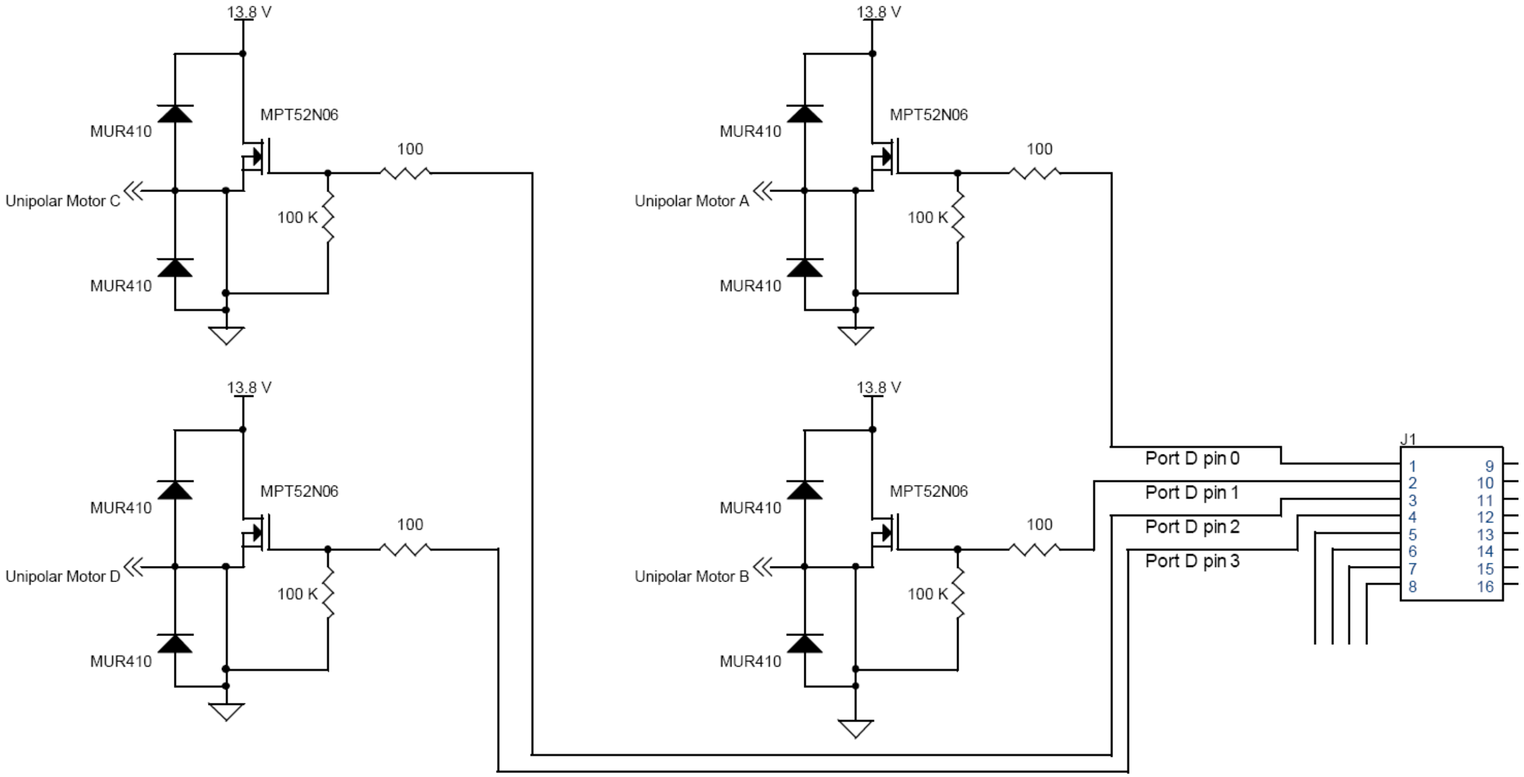
Current Vs. Time

Inductance Reduces Available Torque

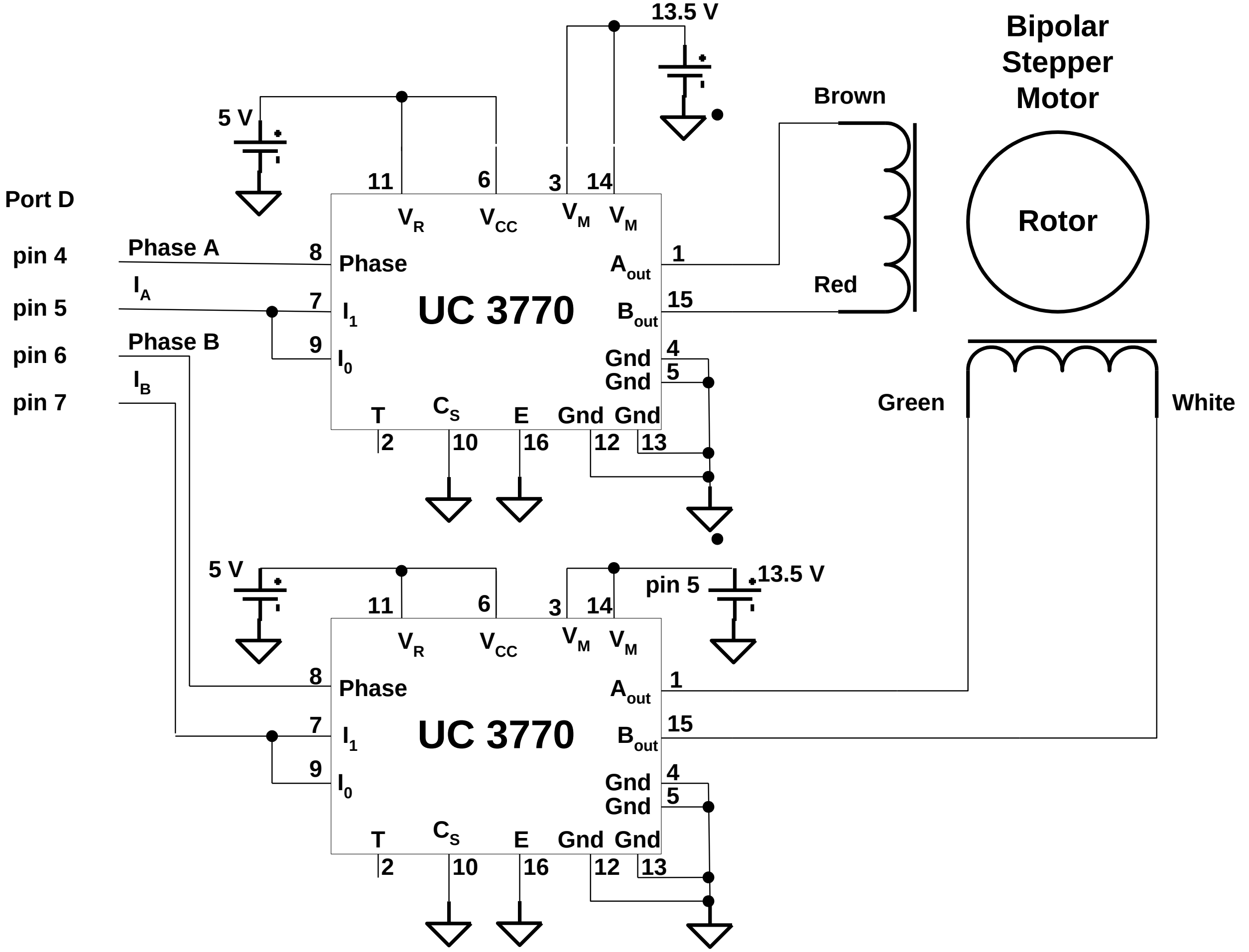
Case Study
Test Fixture



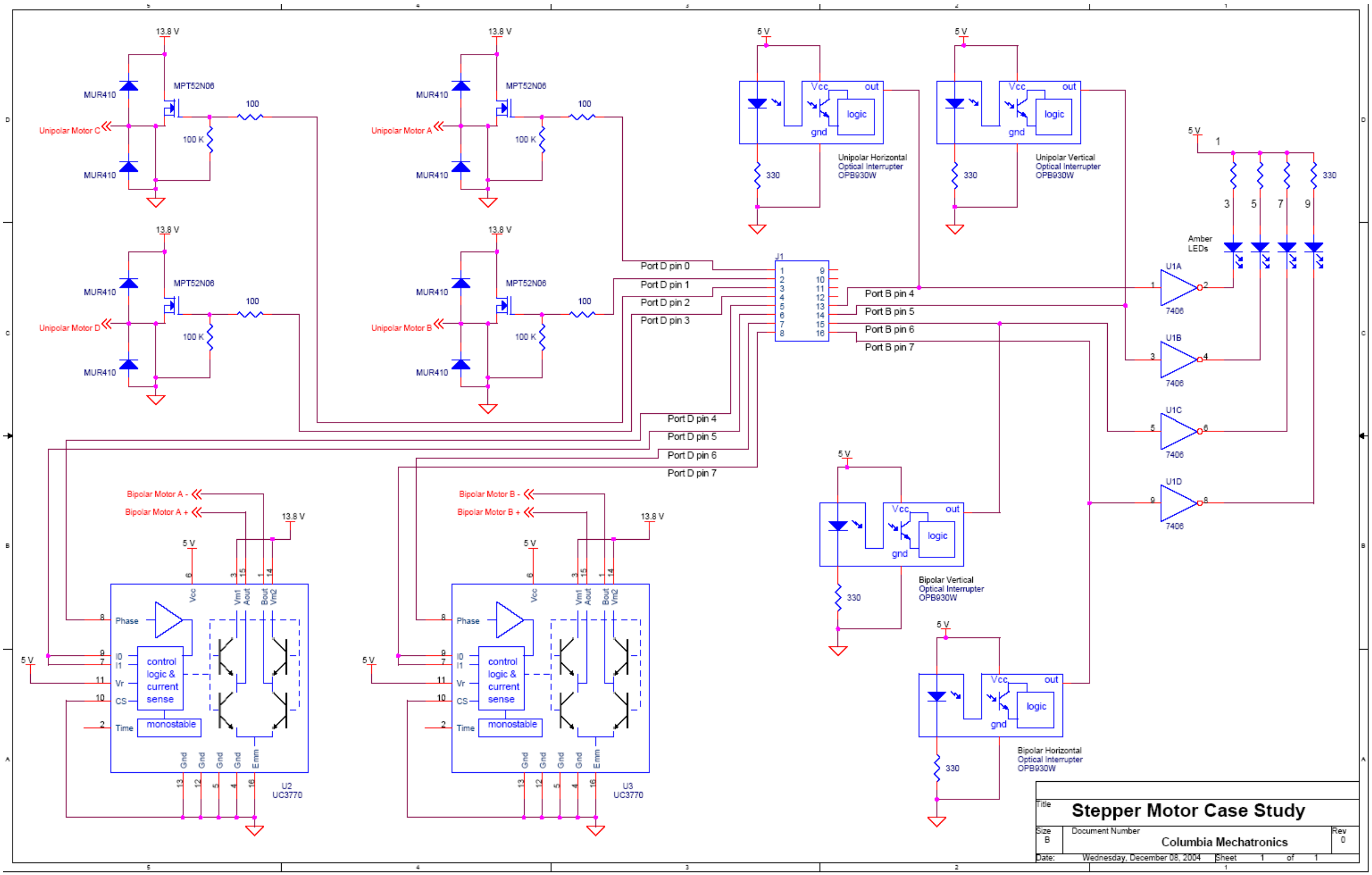
Unipolar Motor Driver



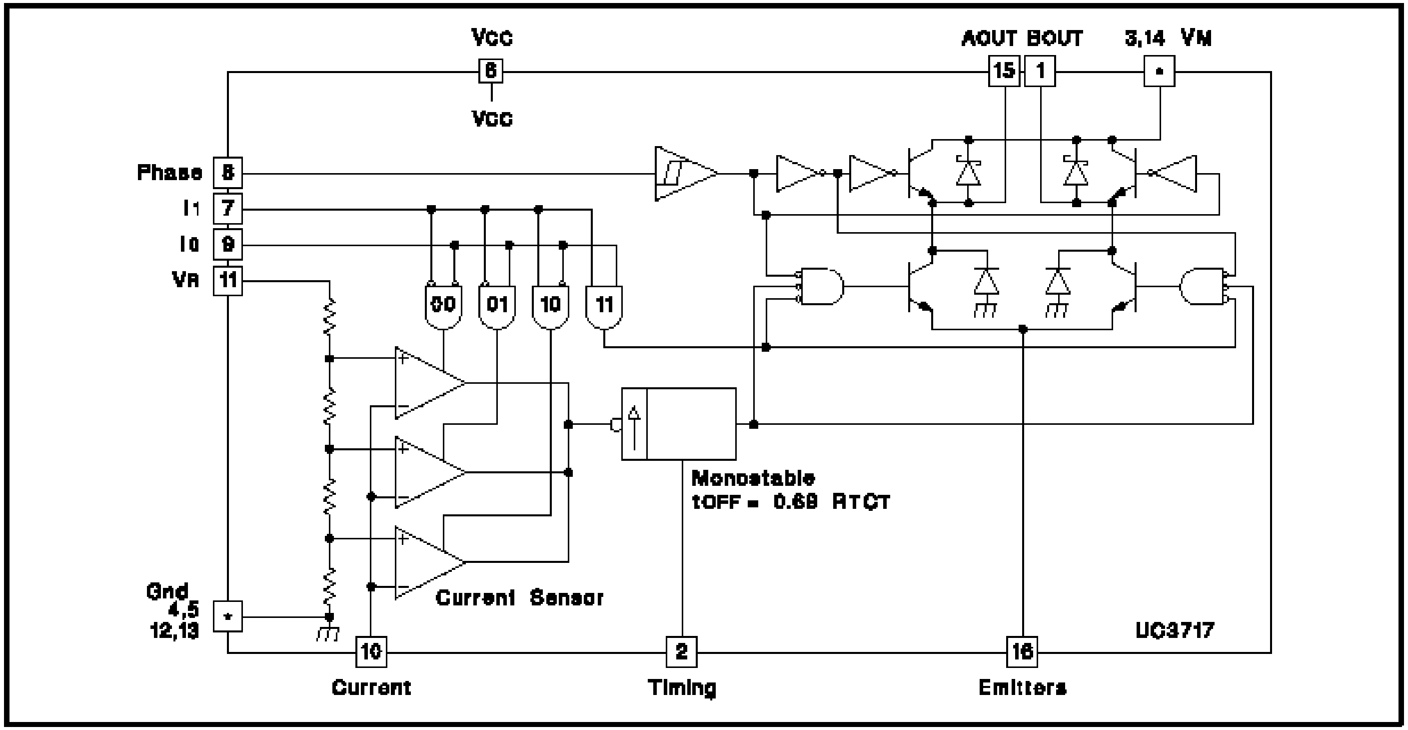
Bipolar Stepper Motor Driver



Case Study Circuit

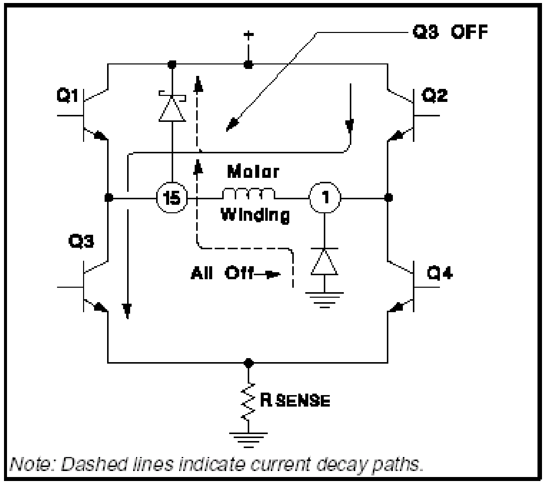


Driver Block Diagram



Driver Operation

I_0	I_1	**Current Level**
0	0	100 %
1	0	60 %
0	1	19 %
1	1	No Current



7