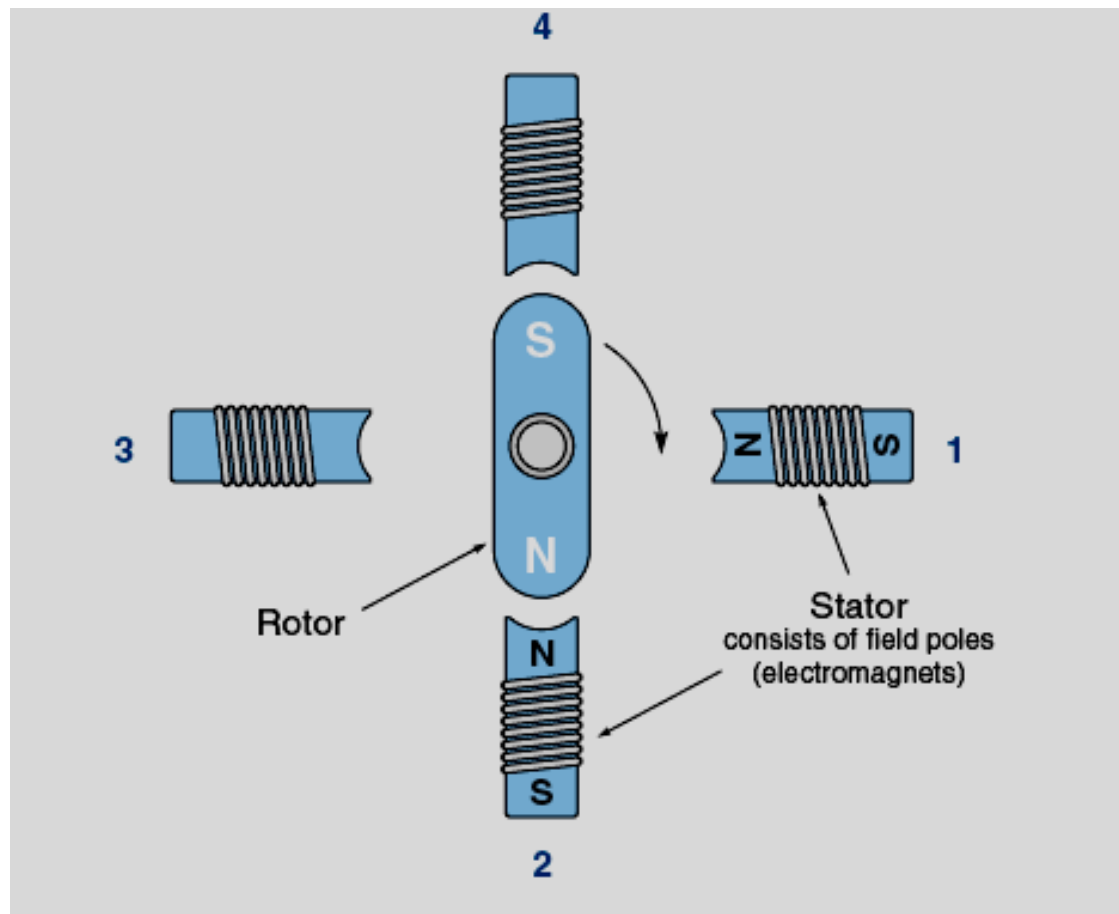


# Stepper Motors

**A stepper motor is a unique type of DC motor that rotates in fixed steps of a certain number of degrees. Step size can range from 0.9 to 90°. It consists of a rotor and stator. In this case, the rotor is a permanent magnet, and the stator is made up of electromagnets (field poles). The rotor will move (or step) to align itself with an energized field magnet. If the field magnets are energized one after the other around the circle, the motor can be made to move in a complete circle.**



Stepper motors are particularly useful in control applications because the controller

- **can know the exact position of the motor shaft without the need of position sensors.** This is done by simply counting the number of steps taken from a known reference position. Step size is determined by the number of rotor and stator poles
- **There is no cumulative error** (the angle error does not increase, regardless of the number of steps taken). In fact, most stepper motor systems operate open-loop—that is, the controller sends the motor a determined number of step commands and assumes the motor goes to the right place. A common example is the positioning of the read/write head in a floppy disk drive.
- **Steppers have inherently low velocity** and therefore are frequently **used without gear reductions**. A typical unit driven at 500 pulses/second rotates at only 150 rpm.
- Stepper motors **can easily be controlled** to turn at 1 rpm or less with complete accuracy.

There are **three types** of stepper motors:

1 -permanent magnet,

2- variable reluctance,

3- hybrid.

# PERMANENT-MAGNET STEPPER MOTORS

- The permanent-magnet (PM) stepper motor **uses a permanent magnet for the rotor.**  
The field consists of four poles (electromagnets).
- The motor works in the following manner: Assume the rotor is in the position shown with the south end up. When field coil 1 is energized, the south end of the rotor is attracted to coil 1 and moves toward it. Then field coil 1 is de-energized, and coil 2 is energized. The rotor pulls itself into alignment with coil 2. Thus, the rotor turns in 90° steps for each successive excitation of the field coils.
- The motor can be made to **reverse by inverting the sequence.**
- One desirable property of the PM stepper motor is that **the rotor will tend to align up with a field pole even when no power is applied** because the PM rotor will be attracted to the closest iron pole.
- **The detent torque is a desirable property in many applications because it tends to hold the motor in the last position it was stepped to, even when all power is removed.**

# EXAMPLE

A 15°/step stepper motor is given 64 steps CW (clockwise) and 12 steps CCW (counterclockwise). Assuming it started at 0°, find the final position.

## SOLUTION

After completing 64 steps CW and 12 steps CCW, the motor has ended up 52 steps CW ( $64 - 12 = 52$ ). Because there are 24 15°-steps per revolution ( $360^\circ/15^\circ = 24$ ),

$$\begin{aligned}\frac{52 \text{ steps}}{24 \text{ steps/rev}} &= 2\frac{1}{6} = 2 \text{ rev} + \frac{1}{6} \text{ rev} \\ &= 2 \text{ rev} + \frac{360^\circ}{6} \\ &= 2 \text{ rev} + 60^\circ\end{aligned}$$

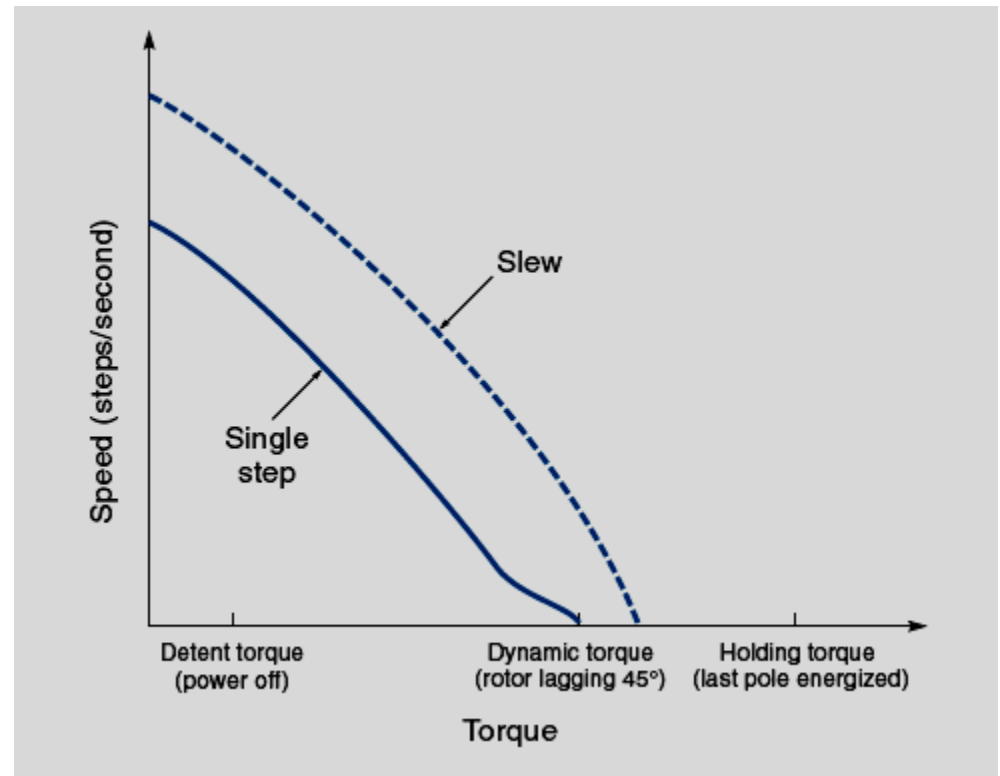
- Therefore, the motor has made two complete revolutions and is now sitting at
- 60° CW from where it started.

# Modes of Operation

single step and slew.

## Torque-Speed Curve

- **Detent torque** is the torque required to overcome the force of the permanent magnets (when the power is off).
- **Dynamic torque**, which is the maximum running torque, is obtained when the rotor is lagging behind the field poles by half a step.
- **Holding torque** results when the motor is completely stopped but with the last pole still energized.



## EXAMPLE

A stepper motor has the following properties:

Holding torque: 50 in. · oz

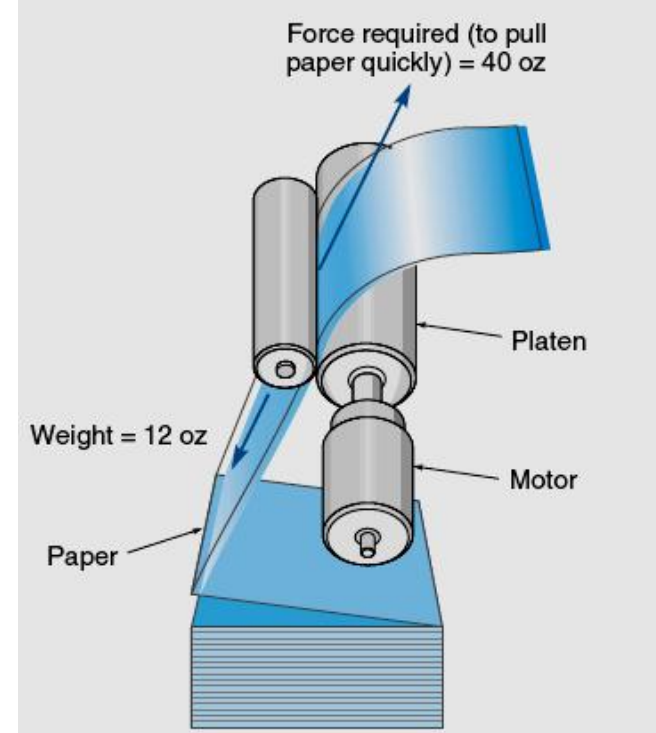
Dynamic torque: 30 in. · oz

Detent torque: 5 in. · oz

The stepper motor will be used to rotate a 1-in. diameter printer platen. The force required to pull the paper through the printer is estimated to not exceed 40 oz.

The static weight of the paper on the platen (when the printer is off) is 12 oz.

Will this stepper motor do the job?



## SOLUTION

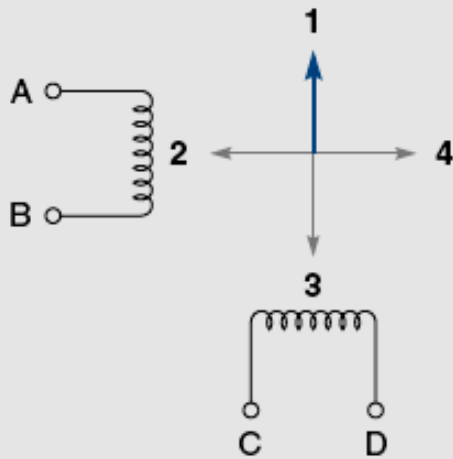
The torque required to rotate the platen during printing can be calculated as follows:

- Torque = force × radius = 40 oz × 0.5 in. = 20 in. · oz
- Therefore, the motor, with 30 in. · oz of dynamic torque, will be strong enough to advance the paper.
- The torque on the platen from just the weight of the paper is calculated as follows:  
Torque = force × radius = 12 oz × 0.5 in. = 6 in · oz
- When the printer is on, the powered holding torque of 50 in. · oz is more than enough to support the paper. However, when the printer is off, the weight of the paper exceeds the detent torque of 5 in. · oz, and the platen (and motor) would spin backward. Therefore, we conclude that this motor is not acceptable for the job (unless some provision such as a ratchet or brake is used to prevent back spinning).

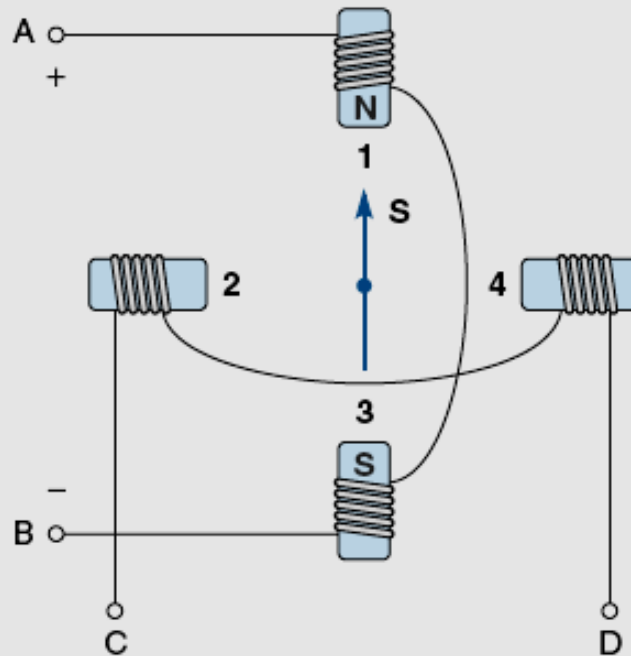


# Excitation Modes for PM Stepper Motors

## Two-Phase (Bipolar) Stepper Motors



(a) Symbol



(b) Wiring diagram

Circuit	Position
A+ B-	1
C+ D-	2
A- B+	3
C- D+	4

# Two-Phase (Bipolar) Stepper Motors, Half-step

## Circuits

A+ B- and C+ D-

A- B+ and C+ D-

A- B+ and C- D+

A+ B- and C- D+

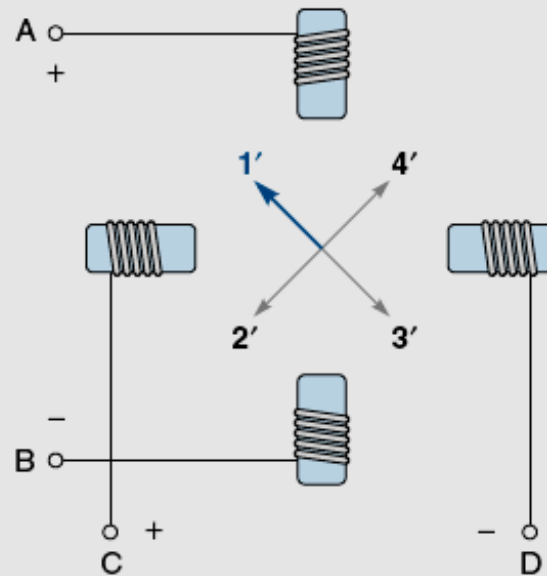
## Position

1'

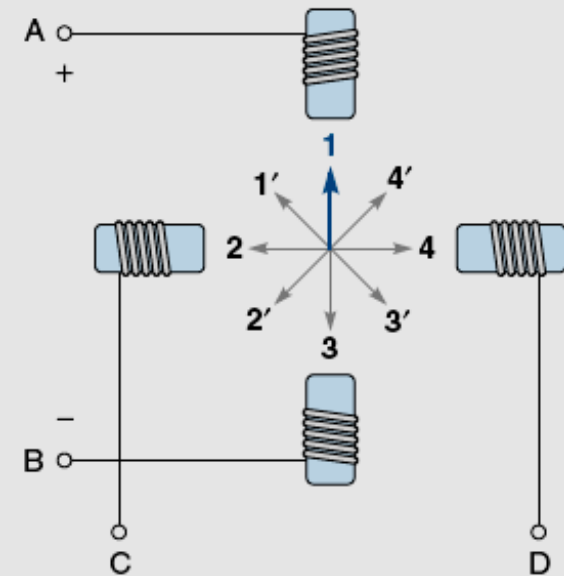
2'

3'

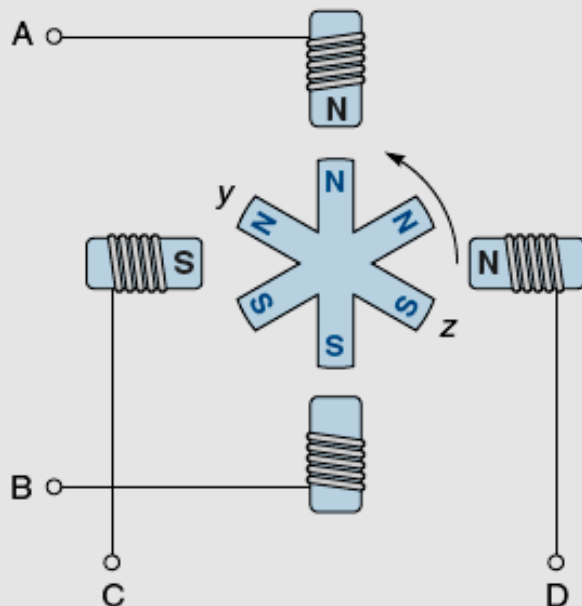
4'



(a) Dual excitation (energized for position 1)

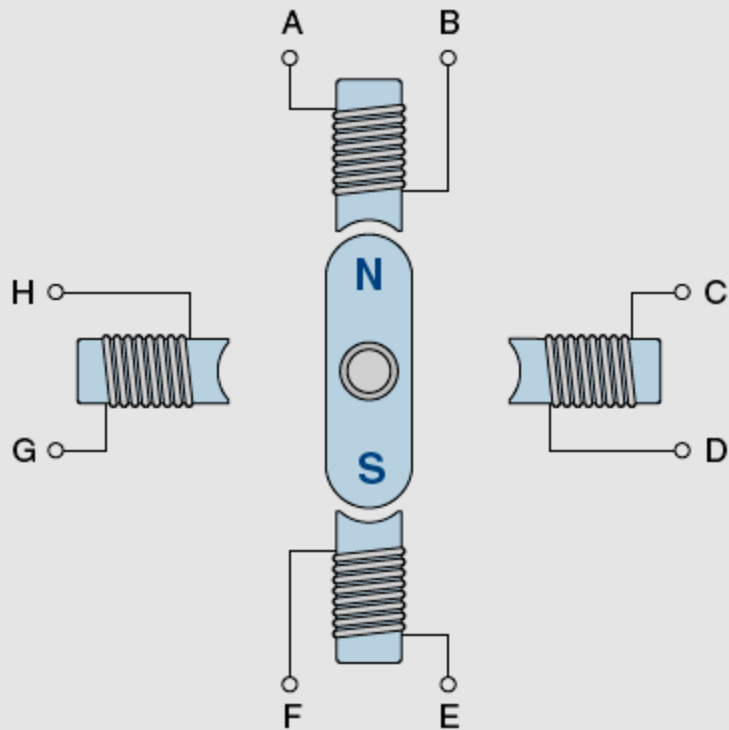


(b) Eight-step drive using "half-steps"



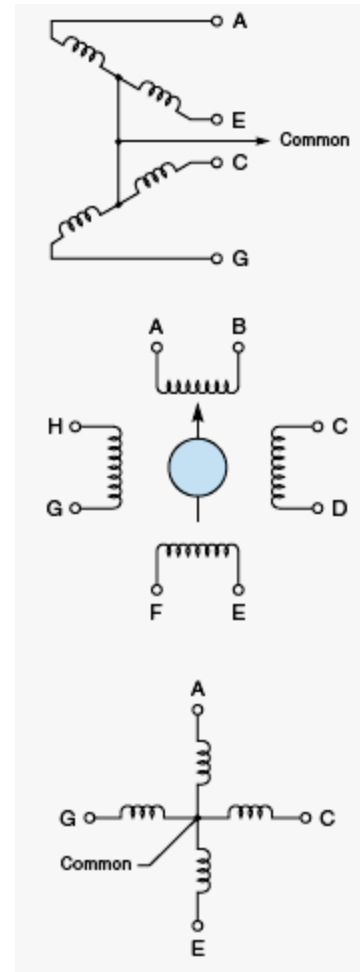
A 30 stepper motor  
with a six-pole rotor.

# ***Four-Phase (Unipolar) Stepper Motors***



(a) Wiring diagram

A	B
C	D
E	F
G	H

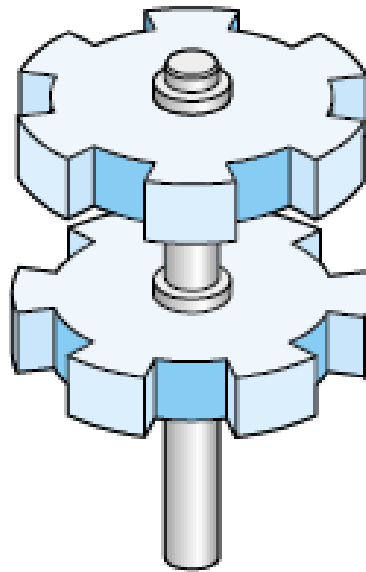


(b) Symbols

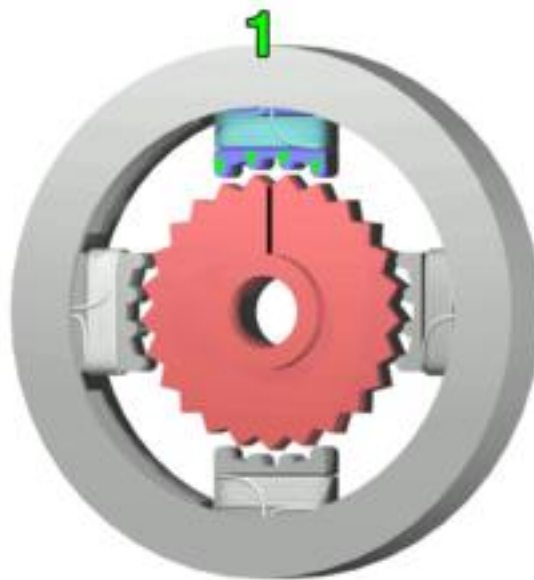
# **Available PM Stepper Motors**

- Almost all PM stepper motors available today have smaller step sizes than the simplified motors discussed so far. These motors are made by stacking two multi-poled rotors (offset by one-half step).
- Typical step sizes for four-phase PM stepper motors are  $30^\circ$ ,  $15^\circ$ , and  $7.5^\circ$ .

Stacked-rotor  
design allows  
smaller steps.

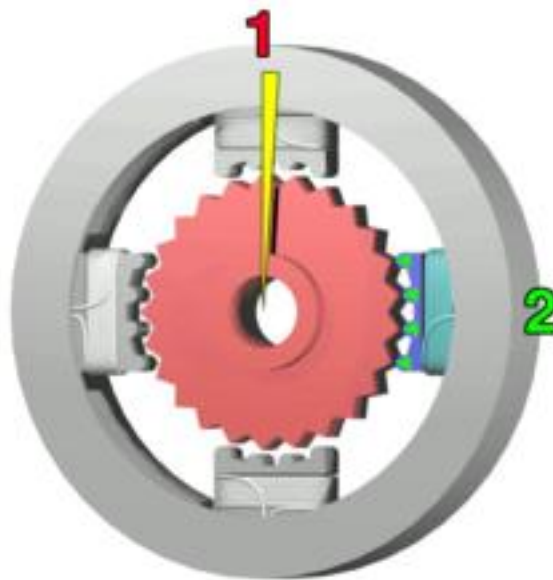


# Stepper Motor Speed and Direction Control



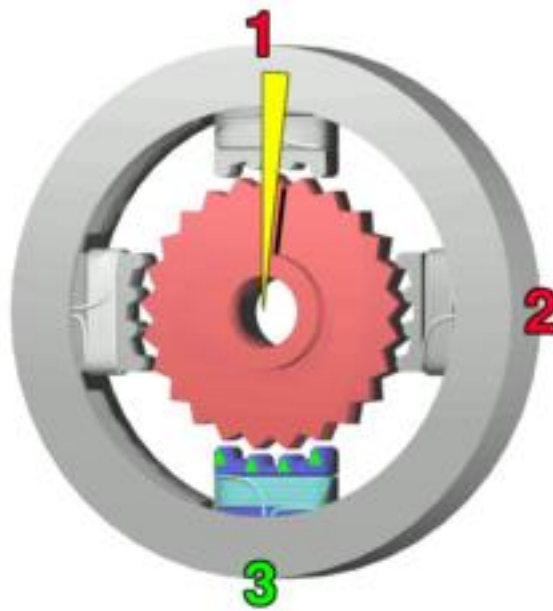
Step 1

# Stepper Motor Speed and Direction Control



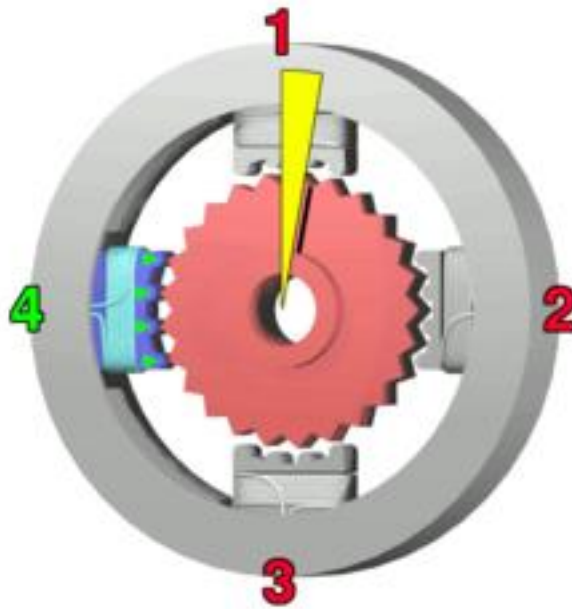
Step 2

# Stepper Motor Speed and Direction Control



Step 3

# Stepper Motor Speed and Direction Control

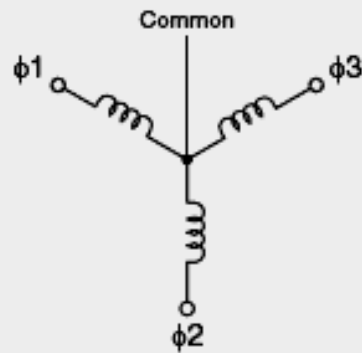


Step 4

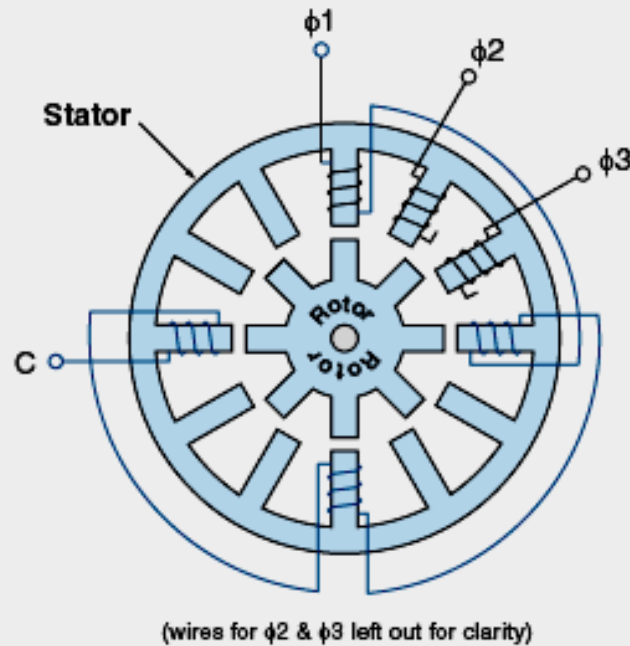


# VARIABLE-RELUCTANCE STEPPER MOTORS

The variable-reluctance (VR) stepper motor **does not use a magnet** for the rotor; instead, **it uses a toothed iron wheel**. The advantage of not requiring the rotor to be magnetized is that it can be made in any shape. Being iron, each rotor tooth is attracted to the closest energized field pole in the stator, but not with the same force as in the PM motor. **This gives the VR motor less torque than the PM motor.**



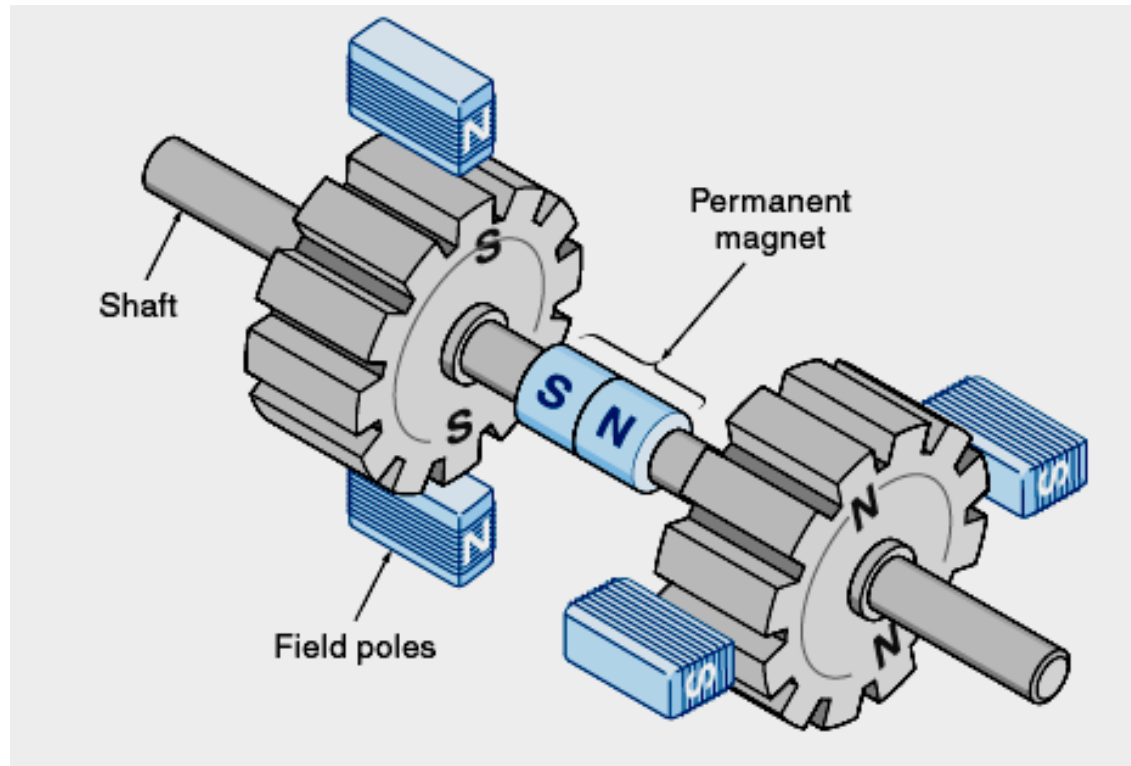
(a) Symbol



(b) Construction

# HYBRID STEPPER MOTORS

The hybrid stepper motor combines the features of the PM and VR stepper motors and is the type in most common use today. The rotor is toothed, which allows for very small step angles (typically  $1.8^\circ$ ), and it has a permanent magnet providing a small detent torque even when the power is off.

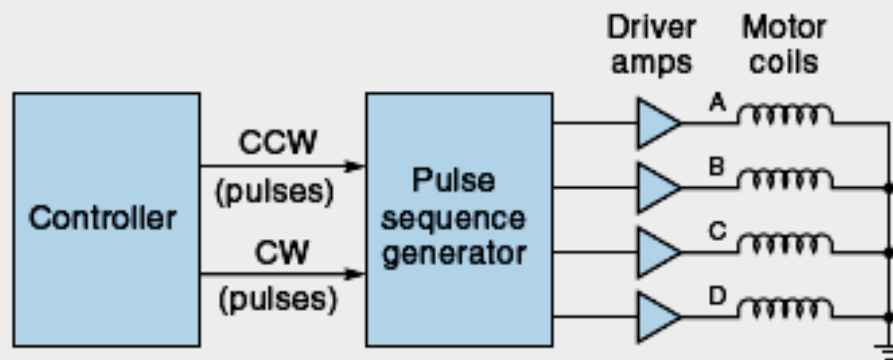


# STEPPER MOTOR CONTROL CIRCUITS

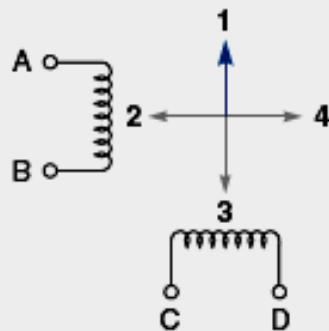
- The *controller* decides on the number and direction of steps to be taken (based on the application). The *pulse sequence generator* translates the controller's requests into specific stepper motor coil voltages.
- The *driver amplifiers* boost the power of the coil drive signals. It should be clear that the stepper motor is particularly well suited for digital control; it requires no digital-to-analog conversion, and because the field poles are either on or off.

# Controlling the Two-Phase Stepper Motor

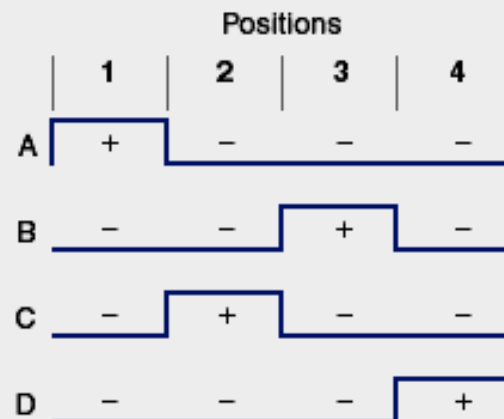
Controlling the two-phase bipolar stepper motor requires polarity reversals, making it more complicated than four-phase motor controllers.



Block diagram of stepper motor control circuit.

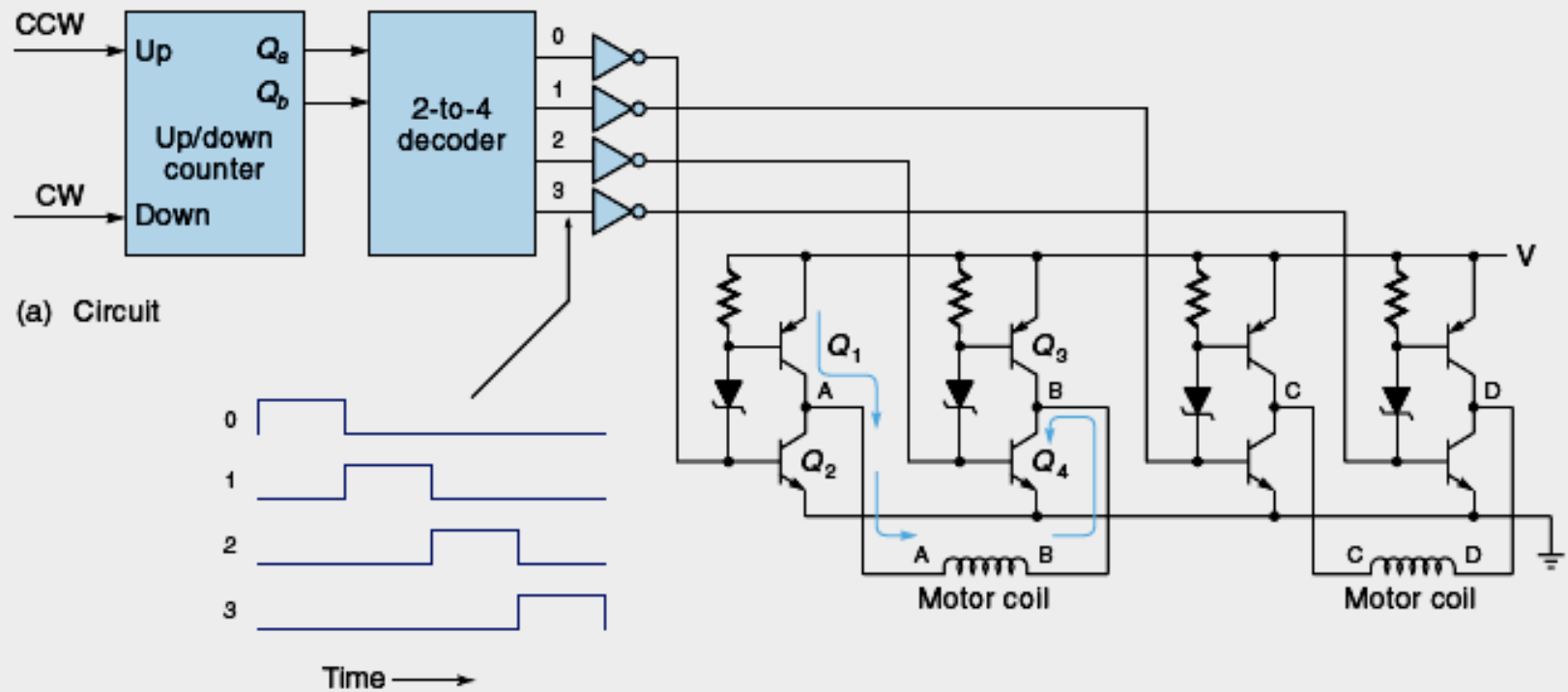


(a) Rotor positions



(b) Timing diagram  
(for CCW stepping "single excitation")

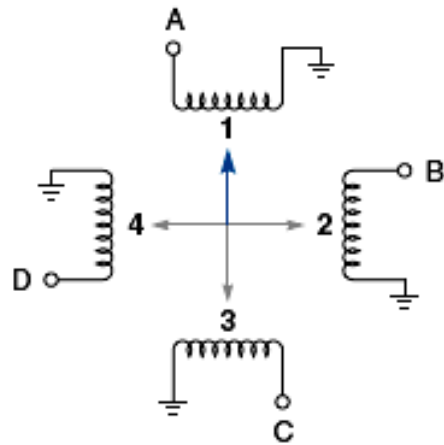
Two-phase (bipolar) stepper motor operation.



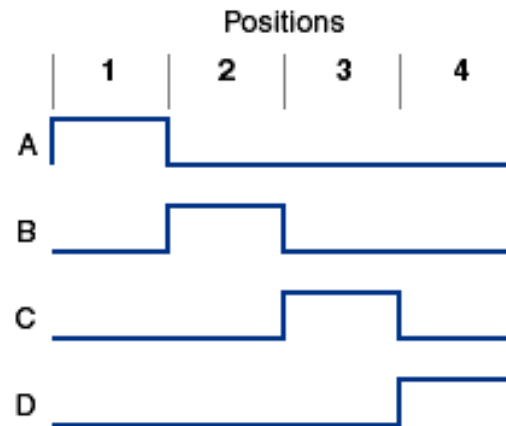
(b) Output of 2-to-4 decoder

Complete interface circuit  
for a two-phase (bipolar)  
stepper motor.

# Controlling the Four-Phase Stepper Motor

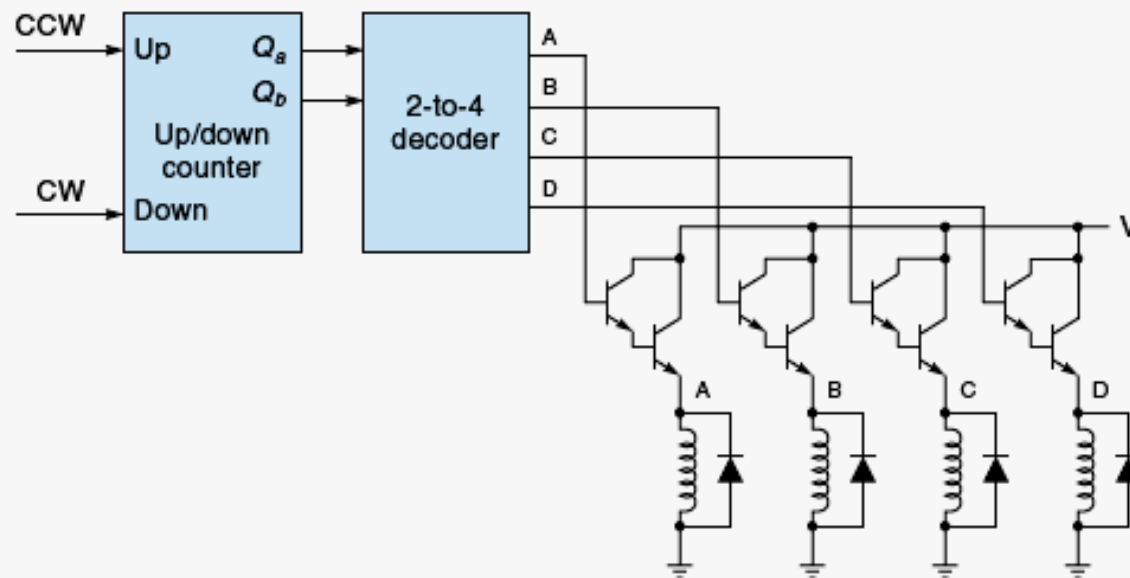


(a) Rotor positions

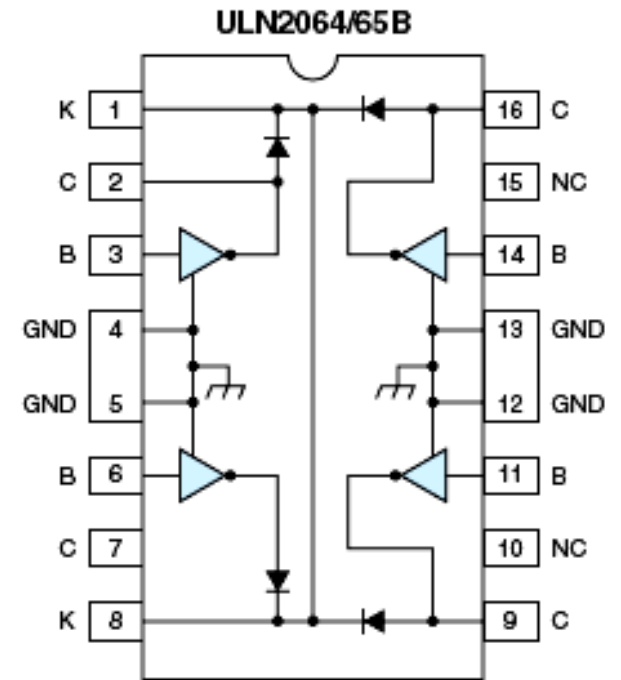
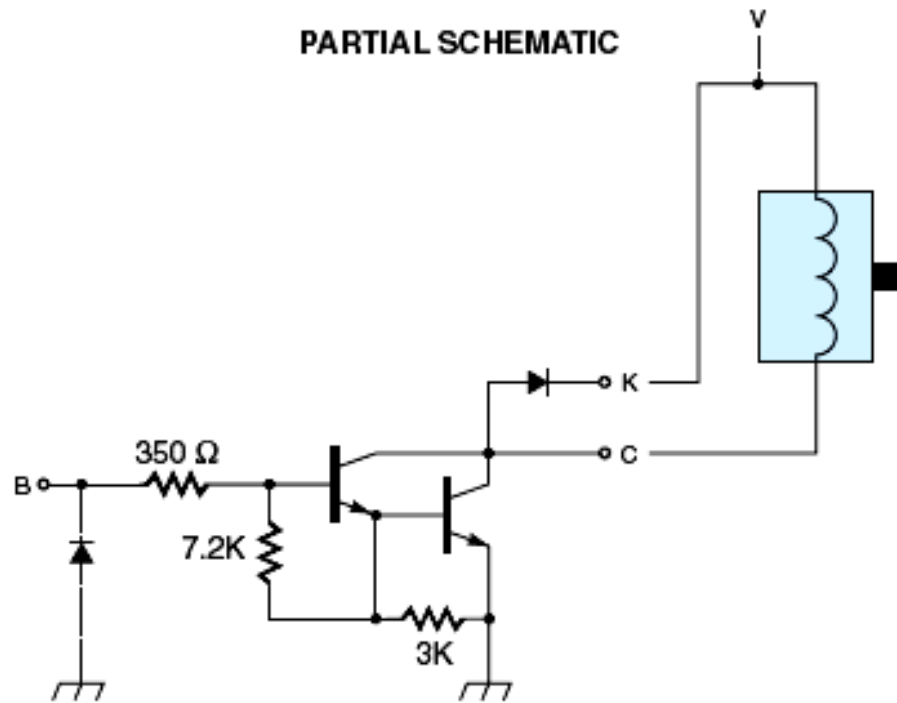


(b) Timing diagram for CW stepping

Four-phase (unipolar) stepper motor operation.

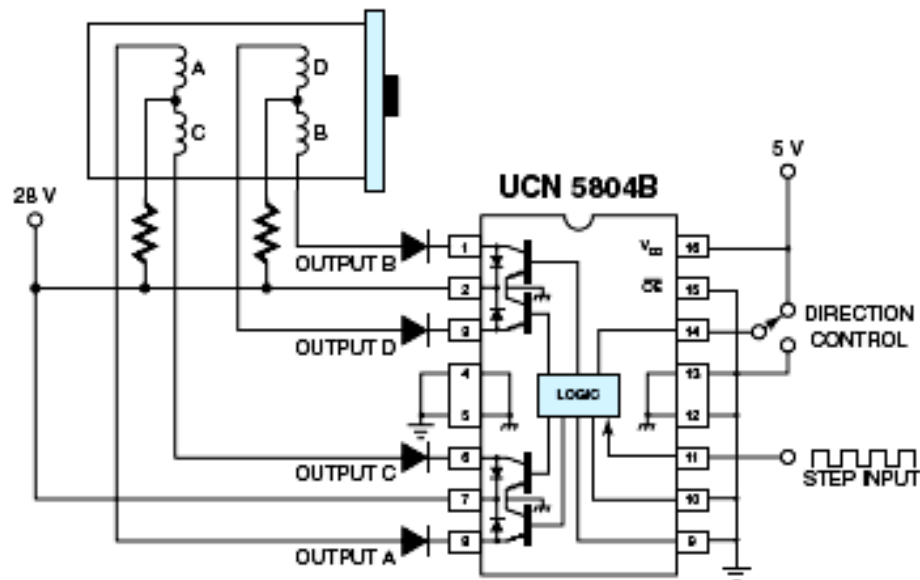


Complete interface for a four-phase stepper motor (simplified for clarity).



The Allegro ULN-2064B with four Darlington 1.5-A switches. (Courtesy of Allegro MicroSystems)

A unipolar stepper motor translator/driver (Allegro UCN-5804B).  
(Courtesy of Allegro MicroSystems)



WAVE-DRIVE SEQUENCE

Half Step = L, One Phase = H				
Step	A	B	C	D
POR	ON	OFF	OFF	OFF
1	ON	OFF	OFF	OFF
2	OFF	ON	OFF	OFF
3	OFF	OFF	ON	OFF
4	OFF	OFF	OFF	ON

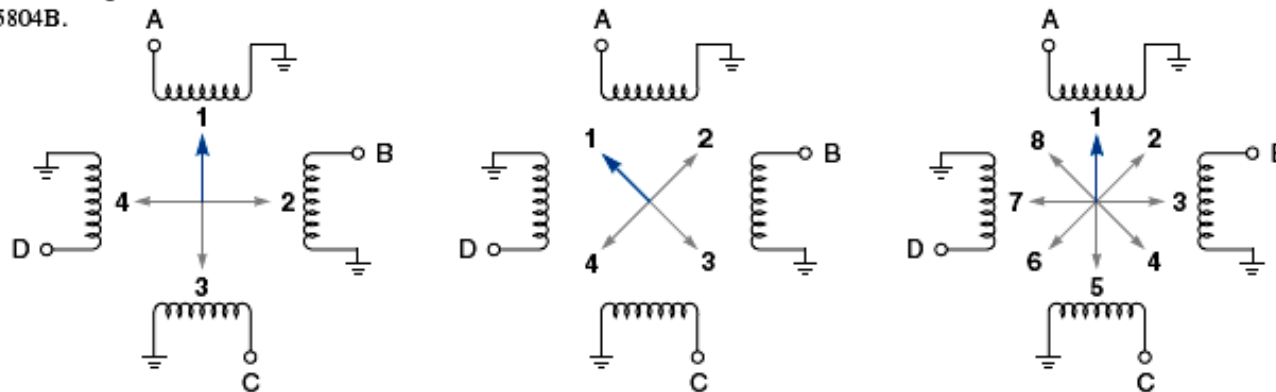
TWO-PHASE DRIVE SEQUENCE

Half Step = L, One Phase = L				
Step	A	B	C	D
POR	ON	OFF	OFF	ON
1	ON	OFF	OFF	ON
2	ON	ON	OFF	OFF
3	OFF	ON	ON	OFF
4	OFF	OFF	ON	ON

HALF-STEP DRIVE SEQUENCE

Half Step = H, One Phase = L				
Step	A	B	C	D
POR	ON	OFF	OFF	OFF
1	ON	OFF	OFF	OFF
2	ON	ON	OFF	OFF
3	OFF	ON	OFF	OFF
4	OFF	ON	ON	OFF
5	OFF	OFF	ON	OFF
6	OFF	OFF	ON	ON
7	OFF	OFF	OFF	ON
8	ON	OFF	OFF	ON

Modes of operation



(a) Wave-drive

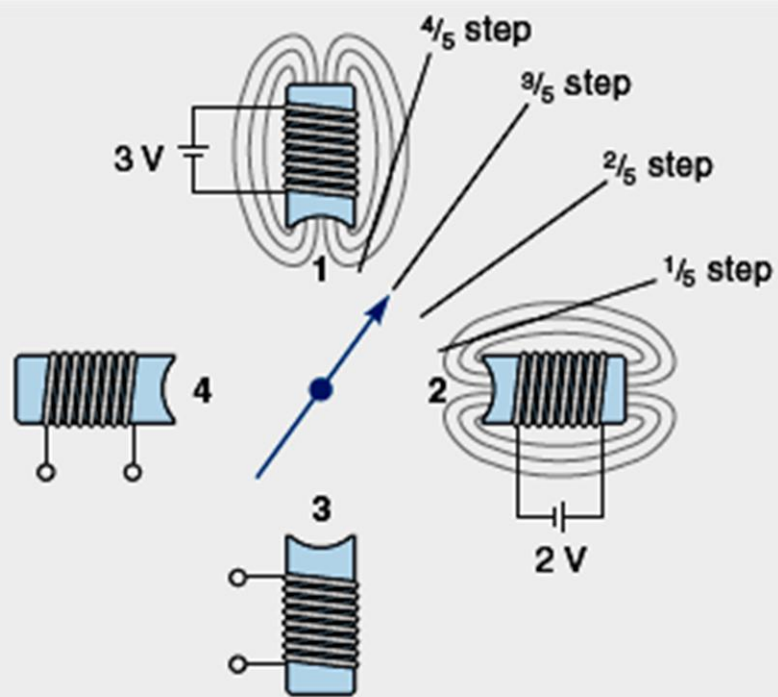
(b) Two-phase

(c) Half-step

Three modes of operation for the Allegro UCN-5804B.



- **Microstepping**, a technique that allows a stepper motor to take fractional steps, works by having two adjacent field poles energized at the same time, similar to half-steps described earlier. In microstepping the adjacent poles are driven with different voltage levels, as demonstrated in Figure .In this case, pole 1 is supplied with 3 V and pole 2 with 2 V, which causes the rotor to be aligned as shown—that is, three-fifths of the way to pole 1. Figure 8.27(b) shows the voltages (for poles 1 and 2) to get five microsteps between each “regular” step. The different voltages could be synthesized with pulse-width modulation (PWM). The most commonly used microstep increments are  $1/5$ ,  $1/10$ ,  $1/16$ ,  $1/32$ ,  $1/125$ , and  $1/250$  of a full step. Another benefit of microstepping (for delicate systems) is that it reduces the vibrational “shock” of taking a full step—that is, taking multiple microsteps creates a more “fluid” motion.
- Two other points on microstepping: It does not require a special stepper motor, only special control circuitry, and the actual position of the rotor (in a microstepping system) is very dependent on the load torque.



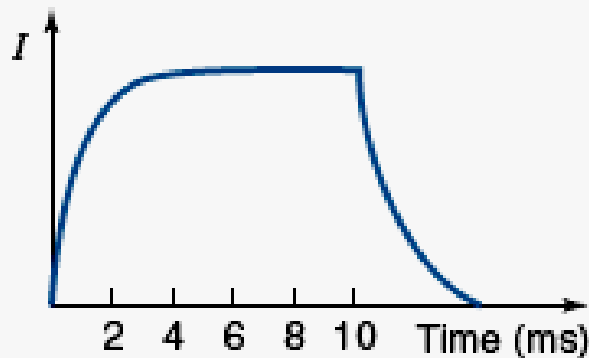
(a)

Pole 1	Pole 2	Position
5 V	0 V	Pole 1 (full step)
4 V	1 V	$\frac{4}{5}$ step
3 V	2 V	$\frac{3}{5}$ step
2 V	3 V	$\frac{2}{5}$ step
1 V	4 V	$\frac{1}{5}$ step
0 V	5 V	Pole 2 (full step)

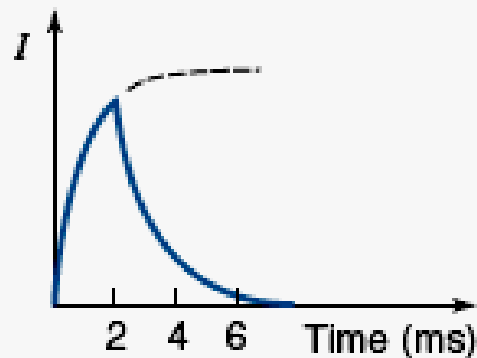
(b)

# Improving Torque at Higher Stepping Rates

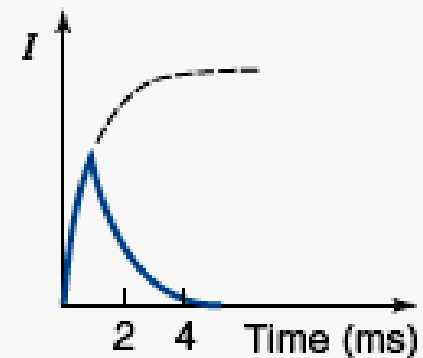
- It is important that the stepper motor develop enough torque with each step to drive the load. If it doesn't, the motor will stall (not step). When steps are missed, the controller no longer knows the exact position of the load, which may render the system useless.
- At higher stepping rates, **two problems occur**. **First**, if the load is accelerating, extra torque is needed to overcome inertia; **second**, the available motor torque actually diminishes at higher speeds. Recall that motor torque is directly proportional to motor current and that the average current decreases as the stepping rate increases.



(a) 100 steps/second



(b) 500 steps/second



(c) 1000 steps/second

To improve the torque , there are 3 methods:

1-ballast resistors, to reduce the time constant

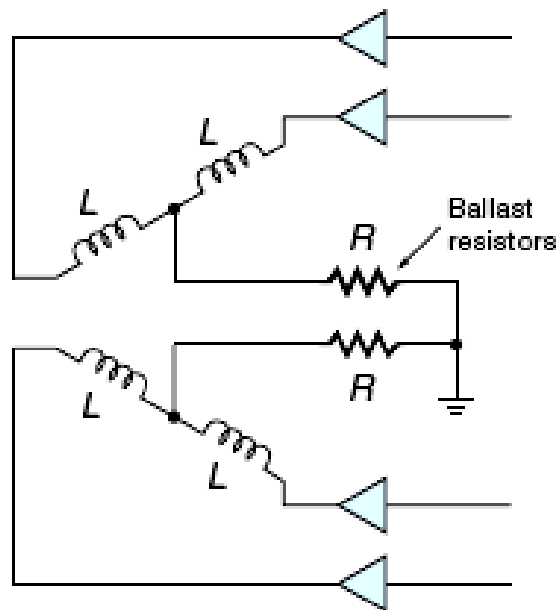
$$\tau = \frac{L}{R}$$

where

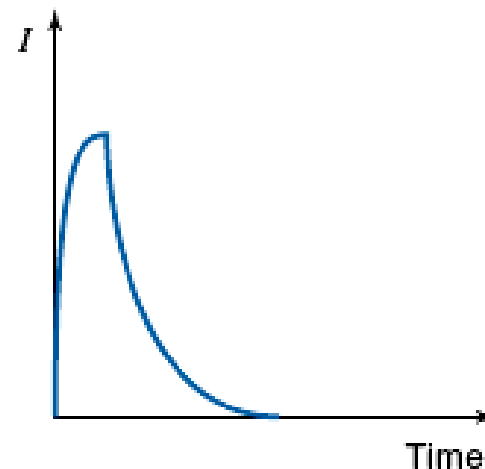
$\tau$  = time constant

$L$  = motor inductance

$R$  = motor coil resistance



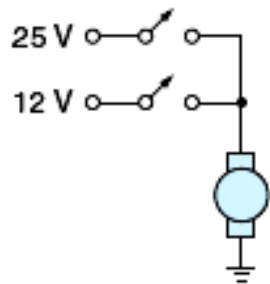
(a) Motor coils and ballast resistors



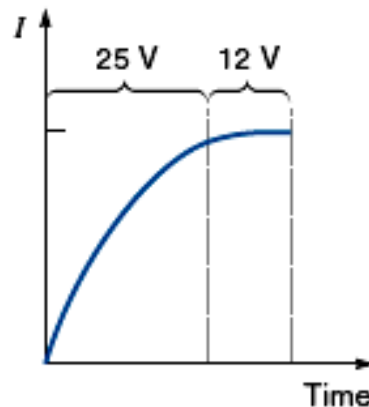
(b) Coil current at 1000 steps/second with ballast resistor

## 2- bilevel drive.

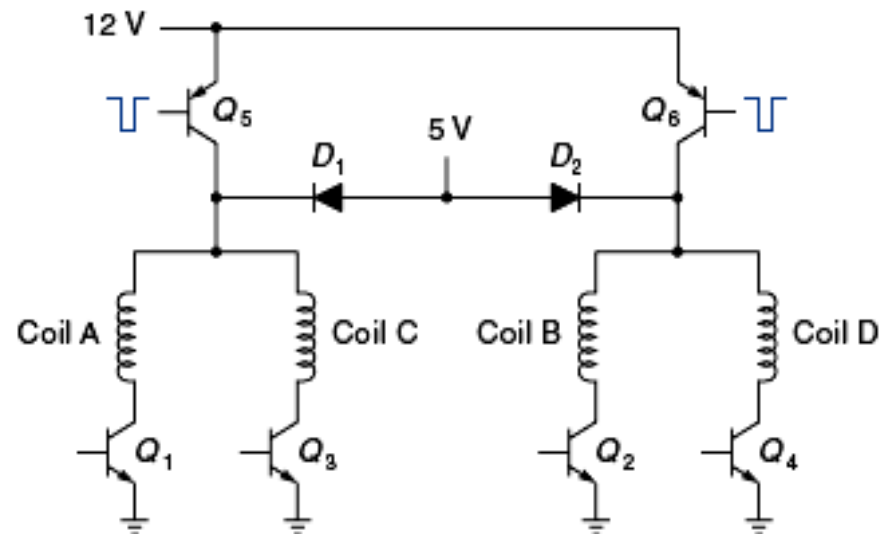
- In this approach, a high voltage is momentarily applied to the motor at the beginning of the step to force a fast in-rush of current. Then a lower voltage level is switched on to maintain that current.
- When the desired current level is reached, the 25-V circuit is switched off, and the 12-V circuit is switched on, which keeps the current at the desired level for the rest of the step time.
- Figure shows a bilevel-drive interface circuit. In this case, the higher voltage is 12 V, and the lower voltage is 5 V. The 12-V is switched through either  $Q_5$  or  $Q_6$  in response to a pulse from a timing circuit (not shown). The 5-V is applied through  $D_1$  and  $D_2$ . These diodes keep the 12-V pulses from backing up into the 5-V power supply.
- The bilevel drive is more complex but allows the stepper motor to have more torque at higher stepping rates.



(a) Circuit

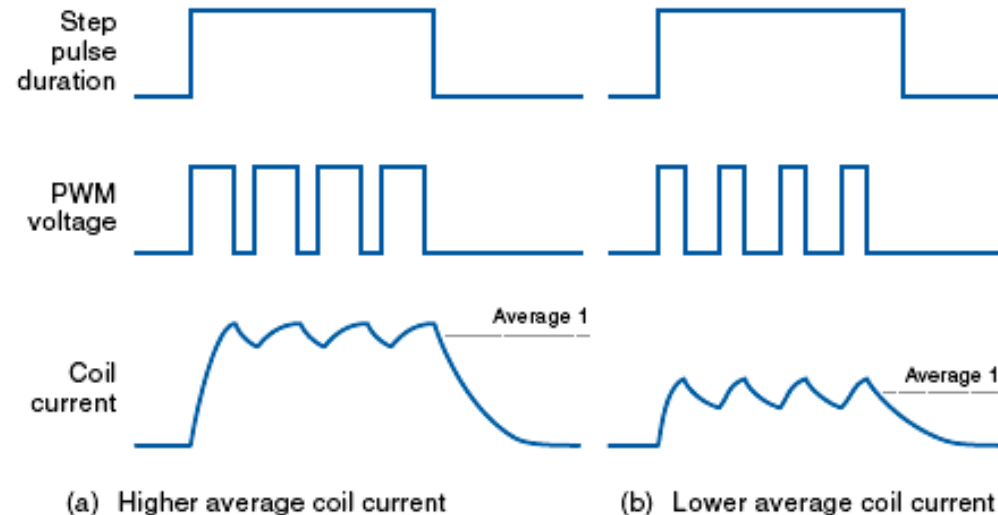


(b) First, 25 V is applied, then 12 V



### 3- constant current chopper drive.

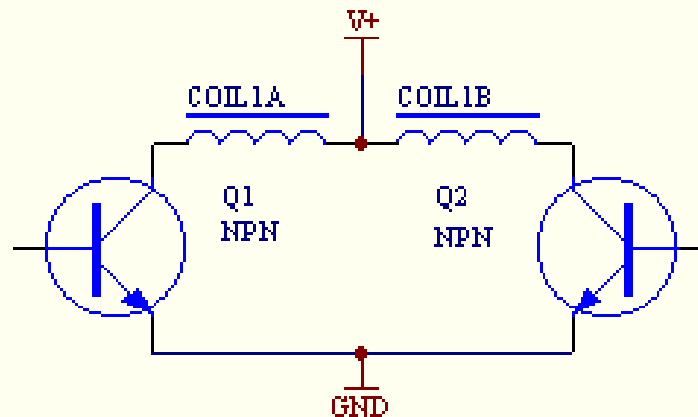
- Using PWM techniques, this driver circuit can deliver almost the same current to the motor at all speeds. A chopper-drive waveform works in the following manner: A relatively high voltage is switched to the motor coil, and the current is monitored. When the current reaches a specified level, the voltage is cut off. After a short time, the voltage is reapplied, and the current again increases, only to be cut off, and so on. Thus, in the same way that a thermostat can maintain a constant temperature by switching the furnace on and off, the chopper drive maintains a constant average current (within each drive pulse) by rapidly switching the voltage on and off.
- In summary, the chopper drive is another technique for providing good torque at high stepping rates. Stepper motor driver ICs are available, such as the Allegro A2919SB, with built-in PWM constant current capability.



# Stepper Motor Speed and Direction Control

## ❑ Center tapped drives

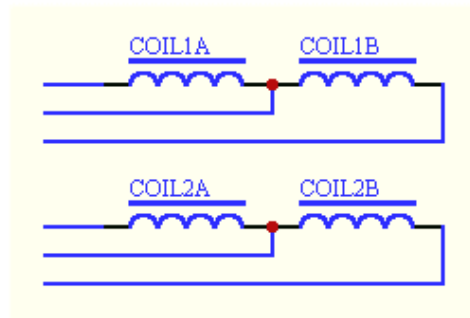
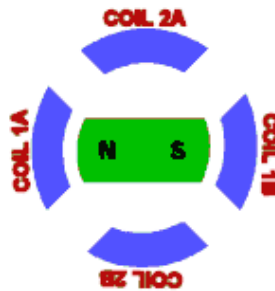
- Note that this diagram only show the circuitry required to drive coil 1 and a duplicate set is requited to drive coil 2.
- Also note that this circuit does NOT include the necessary protection devices.
- Center tapped drives are generally simple drives where the drive accepts a simple logic compatible drive signal.



# Stepper Motor Speed and Direction Control

## ❑ Center tapped drives

- In order to move the stepper motor to a specific location, a series of drive signals have to be sent.
- This provides 4 distinct stopping locations.



Coil 1A	1	0	0	0
Coil 1B	0	0	1	0
Coil 2A	0	1	0	0
Coil 2B	0	0	0	1

**Single step drive sequence**