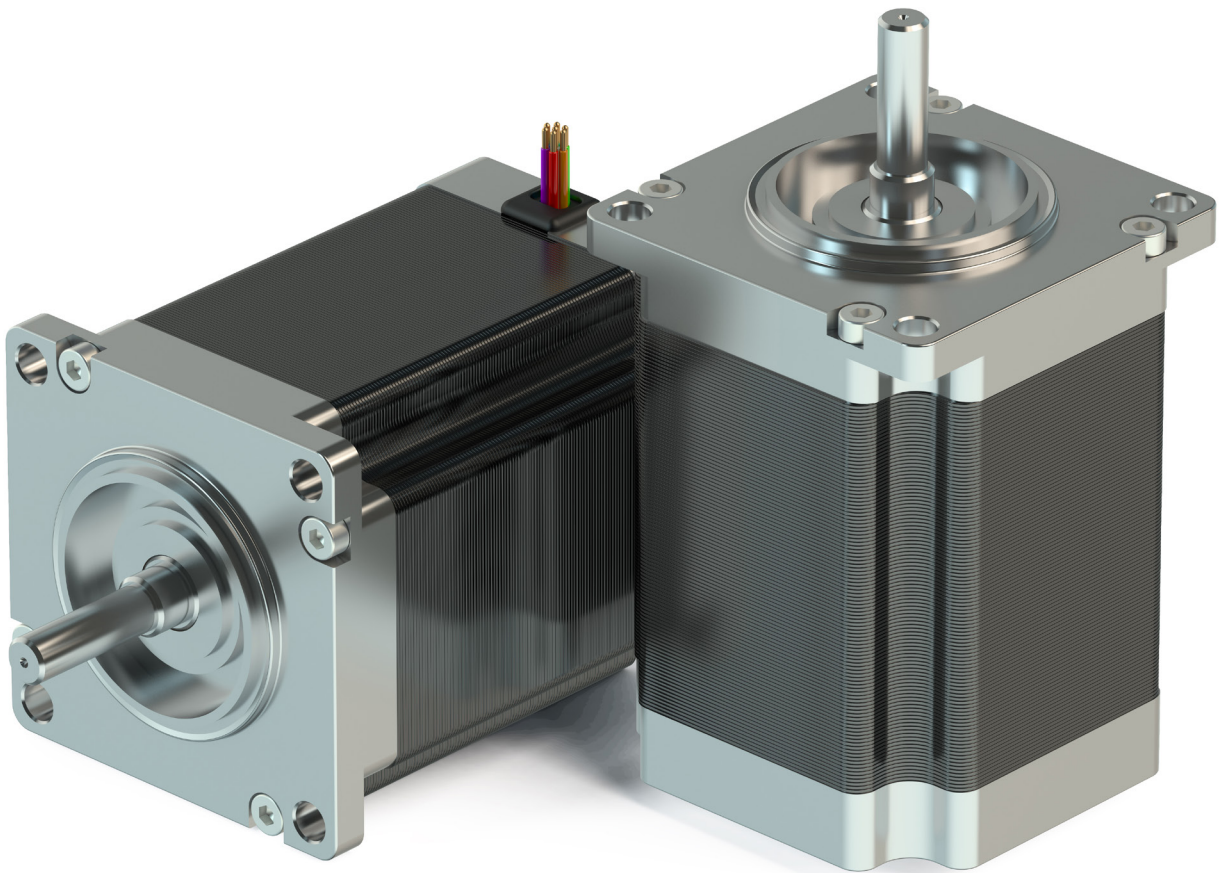
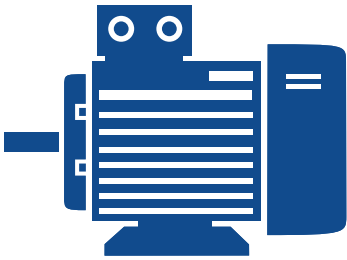


ESSENTIAL GUIDE TO STEPPER MOTOR CONTROLLERS/DRIVERS

Lou Frenzel, Contributing Editor





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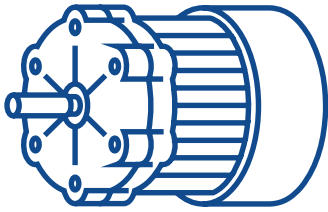
Introduction

Stepper motors are just one of several types of DC motors used in a range of electrical and electronic products. While the motor specifications are important, it is the electronic control circuitry that is the secret to achieving the desired features and performance. This white paper addresses the stepper motor control function and introduces several integrated circuits (ICs) that can provide superior control for many common applications.

Introduction to Stepper Motors

When choosing a small motor for use in an industrial, business, or consumer product, the first design decision is the type of motor. Of course, the two main categories are AC and DC motors. Assume that the power source is DC. There are three basic categories of DC motor: brushed, brushless (BLDC), and stepper motors. All of these create a shaft rotation produced by the interaction of a permanent magnet and an electromagnet. The method of applying and controlling the power to the motor determines the choice for a given application.

There are three types of steppers: permanent magnet (PM), variable reluctance (VR), and hybrid. The PM stepper is small so is used in applications where size is critical and the load is small. PM steppers have good torque. The VR stepper features better positioning resolution and precision, but it has poor or low torque. Hybrid steppers combine the best features of the other two types of steppers. They provide good torque as well as the desirable high resolution and precision. The most widely used type is the hybrid stepper.

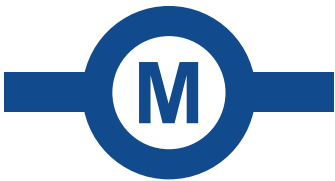
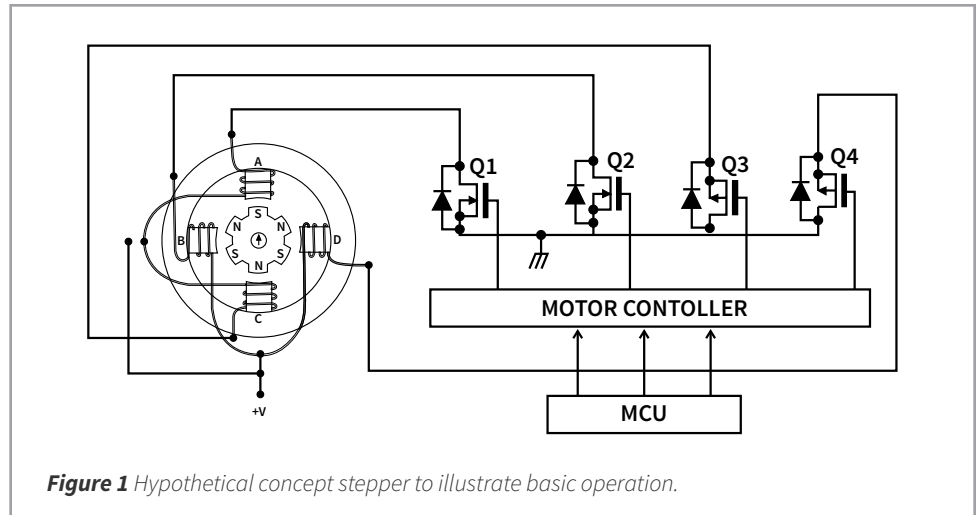


Stepper Motor Applications Steppers are used in more products than you probably realize. Any application that requires a shaft rotation in precise predictable increments without close-loop control and at relatively low speeds is a potential candidate for a stepper. Here is a list of just a few products that use steppers.

- Robots
- Factory automation motion control
- CNC machine tools (mill, drill, etc.)
- Printers, conventional
- Scanners
- 3D printers
- Thermal printers
- Laser cutters
- Surveillance cameras
- XY plotter
- Office machines (copiers)
- Gaming machines (slots)
- ATM machines
- Vending Machines
- Actuators
- Valve control

Stepper Motor Tutorial

Steppers rotate an output shaft one angular increment at a time. Typical step increments are 30, 15, 7.5, 5, 2.5 and 1.8 degrees. **Fig. 1** illustrates the basic concepts of how the stepper operates.



The motor is made up of a fixed magnetic stator with four poles that are wound with wire to produce multiple electromagnet coils. The direction of the coil windings or the direction of the current flow designates whether the pole magnet is energized to produce a north (N) or south (S) magnetic polarity. The coils of the opposing stator poles work together to form a phase. Poles A and C form one phase while poles B and D form another. The rotor is the gear-like device that is mounted on the motor output shaft. It is a permanent magnet with six rotor poles that are pre-magnetized with alternating N and S polarities.

To make the rotor rotate, sequences of DC pulses generated by an electronic controller are applied to the stator windings by the MOSFET switches Q1 – Q4. The resulting magnetic interaction between the PM rotor and the electromagnetic stator poles results in a step-by-step rotation. The rate (frequency) of the pulses determines the shaft speed. The number of rotor poles and stator poles determines the step increment.

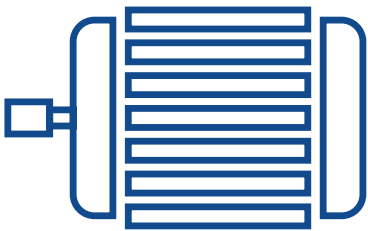
With the arrangement shown in **Fig. 1**, the step increment is 30 degrees. Real steppers have more poles to implement smaller step angles. Typical motors are available to produce step angles of 30, 15, 10, 7.5, 5, 2.5, and 1.8 degrees. Even smaller increments such as 0.9 degree are available. A popular choice is a 1.8-degree stepper. It takes 200 steps to make a full 360-degree rotation

The rotor in **Fig. 1** is hypothetical. The actual construction of a hybrid rotor is typically in cylindrical form made up of N and S pole segments. A second rotor cylinder is mounted adjacent to the first cylinder on the same shaft. Its magnets are offset from those on the first cylinder. This offset determines the minimal step angle of the motor. Specially shaped stator poles interact with the rotor magnets to produce stepping action. Actual rotor design is usually proprietary with the manufacturer.

Stepper Control

Stepper controllers are the circuits that drive the stator coils. These coils are organized in groups called "phases." By energizing each phase in sequence, the motor will rotate, one step at a time. With computer-controlled stepping, you can achieve very precise positioning and/or speed control.

Hybrid steppers are two-phase motors. The stator coils are energized in sequence to produce each step. There are two ways to apply power to stator windings: bipolar and unipolar.




Bipolar Control. In this method, the stator coils become magnetized in either the N or S direction by controlling the direction of current flow in the coil. This is usually accomplished with an H-bridge (See sidebar). By turning the MOSFETs on or off in the correct pattern, the direction of current can be changed, thereby determining the N or S condition of the stator pole.

Unipolar Control. Unipolar control also uses two phases, but the stator coils are center tapped; +DC is usually tied to the center tap. One end of the coil can be connected to ground through a control transistor, thereby establishing the direction of current flow and the N and S poles. The other end of the coil is not connected or left open. But its end of the magnetic core becomes the opposite polarity of the other end.

Alternately, the other end of the phase coil will be grounded, and the other end left open. This reversed the magnetic polarity. The state of MOSFET switches determines which end of the coil gets grounded.

Unipolar stepper motors require two switches per phase as opposed to bipolar stepper motors, but the torque is also reduced by half. As a result, unipolar stepper motors represent the history of the past.



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Stepping Modes. The standard mode is called full step. Pulses are applied to the coils sequentially, and the motor steps in its design increments. The pulses are such that only one phase at a time is enabled. Another arrangement is to apply the pulses such that they overlap, meaning that the coils are energized at the same time. The rotor then aligns itself half way between two coils. The result is a half-step that provides increased angular resolution. If a normal step is 1.8 degrees, the half step mode provides a 0.9-degree increment of rotation.

Stepper Motor Controllers/Drivers

Steppers require very special signals that make the stepper rotate. These are a sequence of pulses applied to the phase coils. The timing and sequencing are critical and must match the specific motor's requirements. A stepper controller IC is designed to provide the mix of signals needed to operate the motor. A driver is also usually needed because the controller IC cannot supply the high phase current needed in some applications. External power transistors are needed.

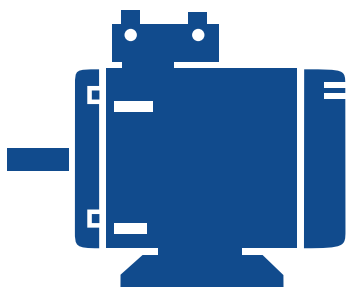
There are two basic ways to control steppers: a microcontroller or a special IC called a stepper motor controller/driver. Some products can be built with a specially programmed microcontroller whose outputs operate discrete external components (MOSFETs). Software and programming experience are required.

The alternate approach is to use a commercial IC product designed for stepper control. Using such a chip greatly simplifies stepper equipment design and time to market. Those controller ICs implement many beneficial control features. Some products require external components like MOSFET drivers. Some low power stepper controllers package the high-power drivers directly on-chip.

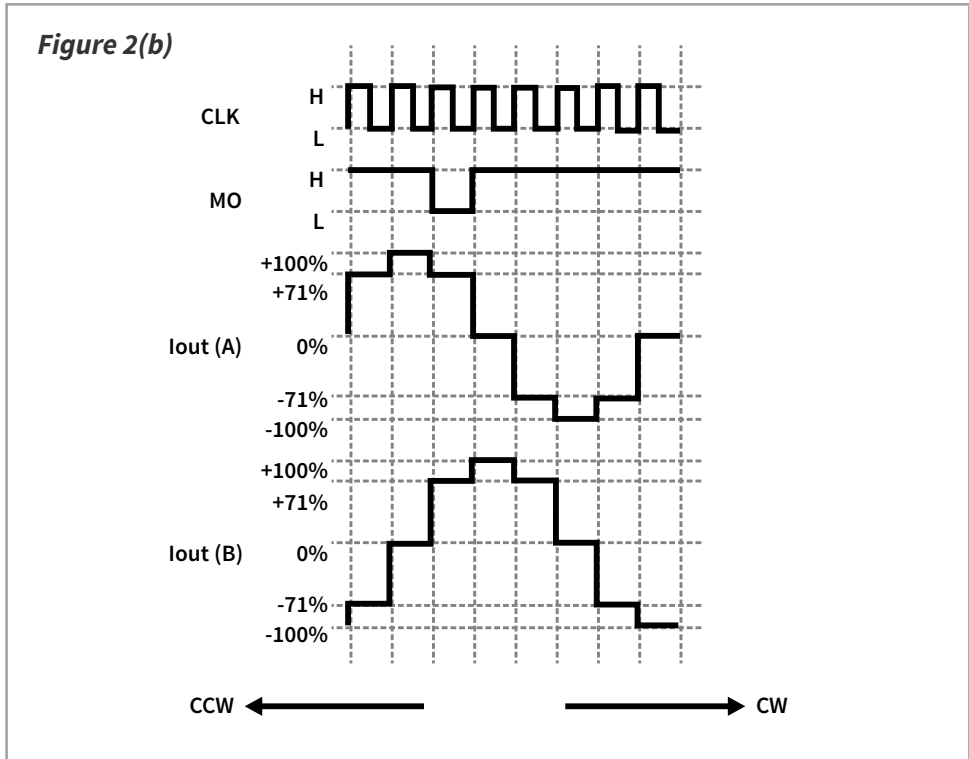
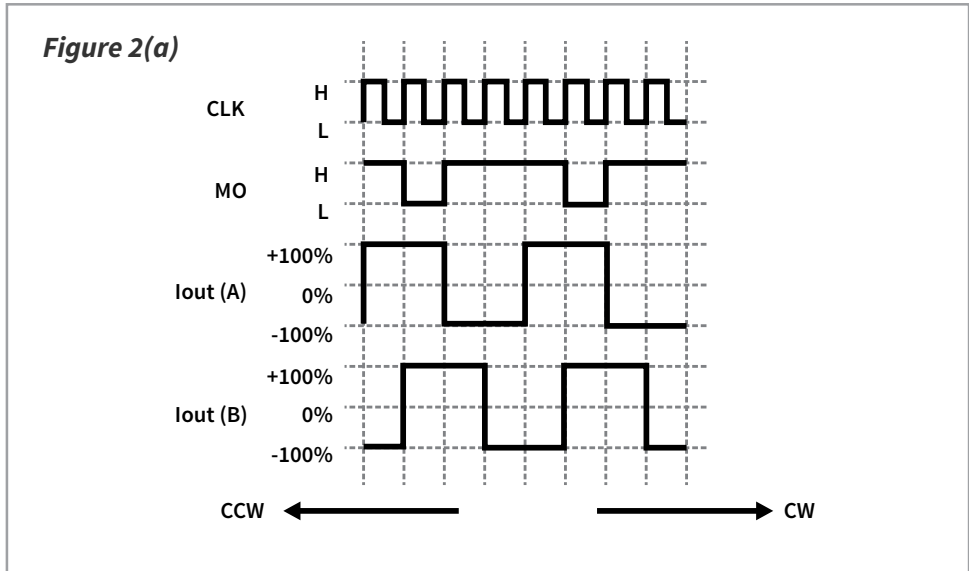
Most new products today contain a central embedded microcontroller (MCU). It is tempting to let that processor do the stepper controlling, as well. It may make sense in some designs for simple applications where a minimum of programming is needed. Other designs may require extensive programming extending the design time and cost. In such cases you should seriously consider a controller IC that will easily interface with an existing microcontroller. It might even provide new desirable features that can distinguish your product from others.

Modern “Smart” IC Controllers

This paper describes some recently introduced stepper controllers and drivers from Toshiba that offer some sophisticated features that provide unique benefits that constitute “smart” control.



The TB67S128FTG is a two-phase bipolar stepper controller designed to operate one motor. It features pulse width modulation (PWM) for control. The motor controller can provide full-, half-, and quarter-step operations. Microstepping modes can implement division factors of 8, 16, 32, 64, and 128. **Fig. 2a** shows the phase drive pulses for standard full-step operation. For half-step operations, multiple voltage steps are applied, as in **Fig. 2b**. For finer angle increments such as quarter-stepping, the phase pulses are faster, and more pulses are applied. The phase voltages are phase-shifted stepped sinusoids. See **Fig. 2c**.



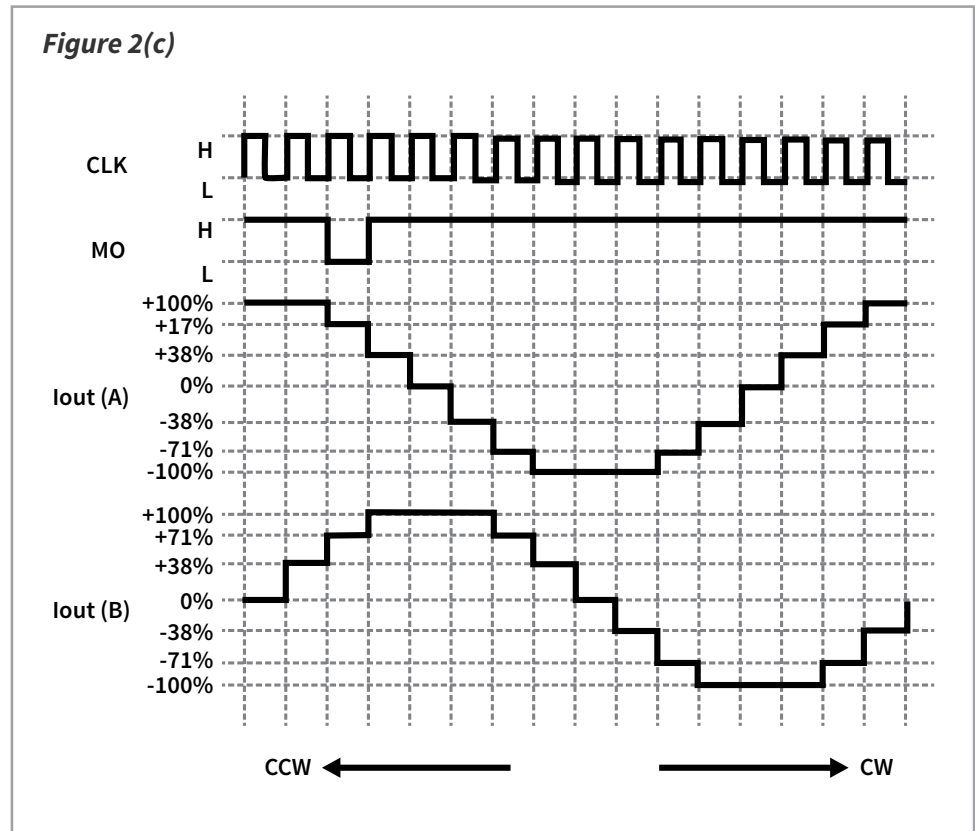
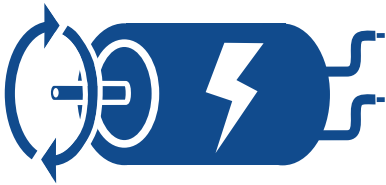


Figure 2 Examples of the phase pulses A and B generated by the controller chip for full step (a), half step (b) and quarter step (c). MO is a chip monitor/control signal. The percentages shown indicate the percentage of the total available phase current used by each step.

Some typical specifications for this device are:

- Maximum motor output voltage: 50V
- Maximum motor output current: 5A
- Internal logic voltage: 5V
- Internal clock oscillator frequency: 1 MHz to 25 MHz
- Power dissipation: 1.2 W
- Operating temperature range: -40° to +85°C
- Package: P-VQFN64

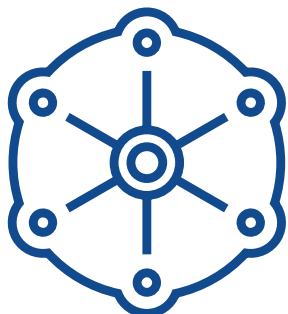
Some major benefits of the TB67S128FTG are:

- A thermal shutdown function (TSD) that shuts off the outputs at a nominal 160°C +
- Over current detection (ISD) with a typical threshold of 7.2A
- Power on reset (POR) will turn the outputs on when the excess conditions end
- Open motor load sensing (OMD)
- A consolidated error detection output (TSD/ISD/OPD)
- Under voltage lock out (UVLO)



Toshiba stepper controller/drivers offer some unique benefits not found in competitive devices.

Toshiba stepper controller/drivers offer some unique benefits not found in competitive devices. One of these is the Active Gain Control (AGC). The AGC benefit monitors and adjusts motor drive current according to the motor's load torque. It optimizes the motor current based upon the torque needed. This ability prevents stalling and reduces motor current to decrease heat in the motor and the controller, thereby improving overall efficiency. The [data sheet](#) has more detail.



One more key feature is the Advanced Current Detect System (ACDS) that monitors the motor current without an external sense resistor. This reduces PCB layout and reduces the BOM.

The Toshiba line of stepper drivers includes additional similar devices that feature AGC. These are the TB67S249FTG, TB67S289FTG, and TB67S279FTG. These lower power drivers have maximum current ratings of 4.5A, 3.0A, and 2.0A, respectively. They are pin-to-pin compatible and are rated at 50V. The package is a 7mm x 7mm QFN48.

In addition to the unique AGC and ACDS capability, these ICs greatly reduce power consumption. Other features are the built-in error detection functions such as thermal shut down, over-current protection, under-voltage lock-out, and motor-load open detection and an error-detection output flag.

A special case in this series is the TB67S285FTG. This driver is similar to the others but features a 3-wire serial interface for external control.

The Flexible H-Bridge One of the factors to be controlled in some applications is direction of rotation of the motor shaft. That is generally achieved by simply reversing the current direction in the motor coils. The fact is, this is harder to do than you think. Special circuits are often required. One superior method of reversing the current in a motor is to use an H-bridge. This is a bridge circuit made with semiconductor switches arranged in an H configuration. Fig. 3 shows the typical arrangement.

The bridge is made up of MOSFET switches. DC voltage is applied to the bridge as shown. The motor (M) is connected across the bridge. Control logic is used to turn the MOSFETs off or on. If Q1 and Q4 are turned on, electron current flow will be through Q4, then the motor from right to left and through Q1. Q2 and Q3 are off at this time.

To reverse the current flow through the motor, Q1 and Q4 are turned off, and Q2 and Q3 are turned on by the controller. Electron flow is then through Q2, the motor (M) from left to right, and Q3.

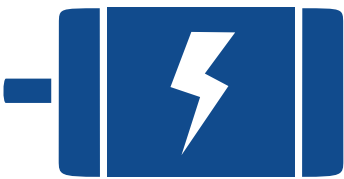
While the H-bridge is mainly used to control motor direction of rotation, it can be used for other functions. Stepper motor pulses can be applied via the H-bridge. Or pulse width modulation (PWM) pulses may be applied for speed control in brushed motors.

A Dual H-Bridge Driver

Another new IC for stepper motor use is the Toshiba TC78H653FTG dual H-bridge driver. This MOSFET driver targets low-voltage applications such as battery-operated and mobile devices. Examples include cameras, printers, electronic locks, smart meters, and toys.

This latest chip is specifically designed to operate at low voltage (1.8 volts) and high current (4 A). Its very low “on” resistance improves motor torque since more voltage gets to the motor and greatly minimizes losses and heat dissipation. This chip contains two MOSFET H-Bridge drivers similar to those shown in **Fig. 3**. It is capable of driving a single two-phase stepper or two brushed motors. Some highlights of this IC include:

- DC operating voltage range: 1.8 to 7.5V
- Stepping output current: 2A
- Typical output “on” resistance: 0.11 ohms
- Available protection modes of thermal shutdown (TSD), over-current detection (ISD) and under-voltage lockout (UVLO)
- Selectable modes: Forward, Reverse, Stop, and Brake
- Can also drive two brushed DC motors
- Package: P-VQFN16 (3 mm x 3 mm)



For more details, [view the data sheet and application note](#).

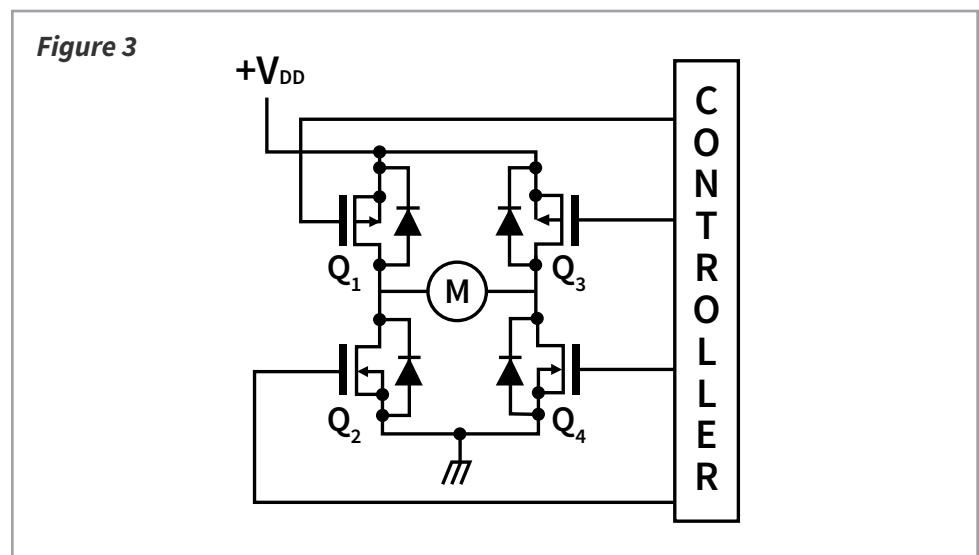


Figure 3 The popular H-bridge used for controlling the direction of current flow in a brushed motor (M) or in a two-phase stepper.