ROHM SEMICONDUCTOR

Innovations Embedded

Controlling DC Brush Motors with H-bridge Driver ICs

ROHM Marketing USA

White Paper

Presented by ROHM Semiconductor

Controlling DC Brush Motors with H-bridge Driver ICs

Advanced-design integrated circuits combine control and protection functions; offer upgrade path from legacy designs and selection of control strategies

Introduction

DC brush motors are increasingly required for a broad range of applications including robotics, portable electronics, sporting equipment, appliances, medical devices, automotive applications, power tools and many others. The motor itself is a preferred alternative because it is simple, reliable and low cost. Equally important, advanced, fully-integrated "H-bridge" driver ICs are available to control the motor's direction, speed and braking. This paper will explore the basics of H-bridge drivers and discuss the advancement of the technology from discrete solutions to highly-integrated ICs. It will compare linear motor speed control with more advanced, higher-efficiency pulse-width modulation (PWM) techniques.

The reader will be introduced to ROHM's unique product family which incorporates numerous advanced features including high-efficiency PWM outputs, integrated timing and control circuitry as well as the unique capability of handling either analog or digital (PWM) speed control inputs. The paper will also describe the benefits of these advanced motor driver ICs particularly in terms of their exceptional efficiency, integrated fault protection, small package size, symmetrical pin configurations and pin-compatibility with earlier (linear output) models. Finally, a summary of the range of H-bridge ICs offered by ROHM including devices specified with 7 V, 18 V and 36 V V_{CC}, as well single packages containing two selected (matched) drivers is presented.

H-bridge Basics

The H-bridge circuit derives its name from the full-bridge circuit shown in **Figure 1**. The motor forms the crosspiece in the "H." Speed and direction are controlled as current flows through the motor in the direction determined by the position of the switches in the bridge. In this example, with switches "A" and "D" closed, the motor will operate in a clockwise (CW) direction. With "B" and "C" closed, the motor will operate in the counterclockwise (CCW) direction.

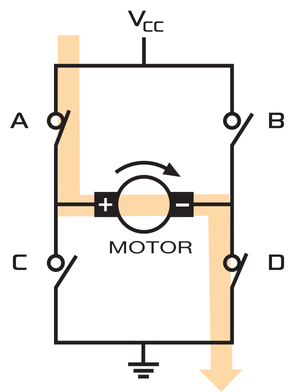

Figure 1. Simplified H-bridge Schematic

In the linear output control implementation, the motor speed control is determined by the voltage applied across the motor. In the PWM implementation, the speed is controlled by the width of series of pulses of equal voltage. In either case, motor direction is controlled via separate logic inputs.

While the concept is simple, implementation is anything but simple if discrete components are employed. Controlling the operation of the switches and preventing simultaneous closure of the CW and CCW control outputs, particularly when reversing the direction of the motor or changing speed by dynamic braking requires an H-bridge controller. The H-bridge controller is then connected to four devices forming the legs of the bridge. In a discrete solution the designer must deal with voltage control levels, timing to prevent shoot-through and the proper selection of the semiconductor switches. The discrete solution also requires additional circuitry for functions including overvoltage, overcurrent, overtemperature and electrostatic discharge (ESD) protection. All of this translates to a fairly complex design process resulting in a higher component count, larger footprint, and less reliable design solution than a fully-integrated LSI solution.

H-bridge Driver Topology

Integrated H-bridge drivers are constructed by combining a controller, output drivers and protection circuits into a single package. The first H-bridge drivers used bipolar power transistors and bipolar control circuitry. The bipolar outputs were typically operated in the linear mode to provide speed control. Simple IC processing made the circuit practical even though die sizes were large to optimize power dissipation. A limitation of the bipolar output devices was higher power dissipation, especially in the speed control mode.

The use of power MOSFETs for the output devices was a natural transition for H-bridge drivers. In addition to the lower losses for a given voltage rating and smaller die size, voltage-controlled MOSFETs are easier to drive than the current-driven bipolar switches, facilitating efficient PWM control. In addition to higher efficiency, PWM provides tighter motor speed control as well as faster response. BiCMOS design for the control portion takes advantages of the strengths of bipolar and CMOS design providing high drive capability and low power dissipation. A comparison of the power dissipation characteristics of linear H-bridge drivers vs. the latest PWM output drivers is shown in Figure 2.

Ongoing improvements in power MOSFETs have increasingly shrunk the die size to handle a particular voltage and low on-resistance. Today, control circuitry and the four output drivers are offered in surface mount packages comparable to or only slightly larger than only one of the output switches required in a discrete implementation.

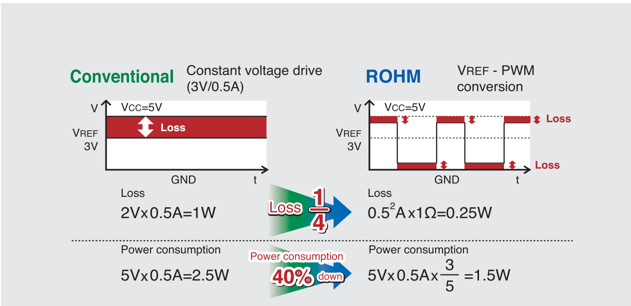

Figure 2. ***Comparison of linear vs. PWM implementation. In the linear implementation, at anything but full speed, the voltage drop across the control transistors results in significant power dissipation.***

In summary, the H-bridge motor driver IC provides a monolithic solution to the control and output functions required to control the direction and speed of DC brush motors. We will now discuss the latest ROHM implementation that allows designers to utilize a variety of control strategies, both analog and digital, while providing the precision and efficiency of PWM control.

The Ideal H-bridge Driver

With BiCMOS control and power MOSFET technology, the latest generation of ROHM devices represent the ideal integrated H-bridge driver. Figure 3 shows a block diagram of the functional elements. To handle either analog or digital inputs, the unit provides dual-mode speed control. V_{REF} provides the analog input. The chip converts the linear input at V_{REF} into efficient speed control using its internal PWM conversion circuitry. F_{IN} and R_{IN} are used with a microcontroller (MCU) or other digital logic inputs to control direction and speed.

The control logic takes input from the analog and digital source and efficiently controls the forward / reverse directions, speed and braking of the motor by switching the appropriate integrated power MOSFETs. ROHM's P-Channel / N-Channel high-power CMOS output provides low on-resistance without requiring a charge pump and the associated external capacitors needed for the N-Channel MOSFETs in the high side switches common in many integrated H-bridge drivers. Rugged recovery diodes built into the structure eliminate the need for additional external recovery diodes.

Combined bipolar and CMOS processing in a single chip design achieves less than 1 µA current in standby mode. This is an important consideration for portable, battery-powered applications.

To protect the motor and the driver, protective circuitry includes:

- Overvoltage protection (OVP)
- Undervoltage lockout (UVLO)
- Overcurrent protection (OCP)
- Thermal shutdown (TSD)
- Overlap (shoot-through) protection
- High ESD protection (4 kV)

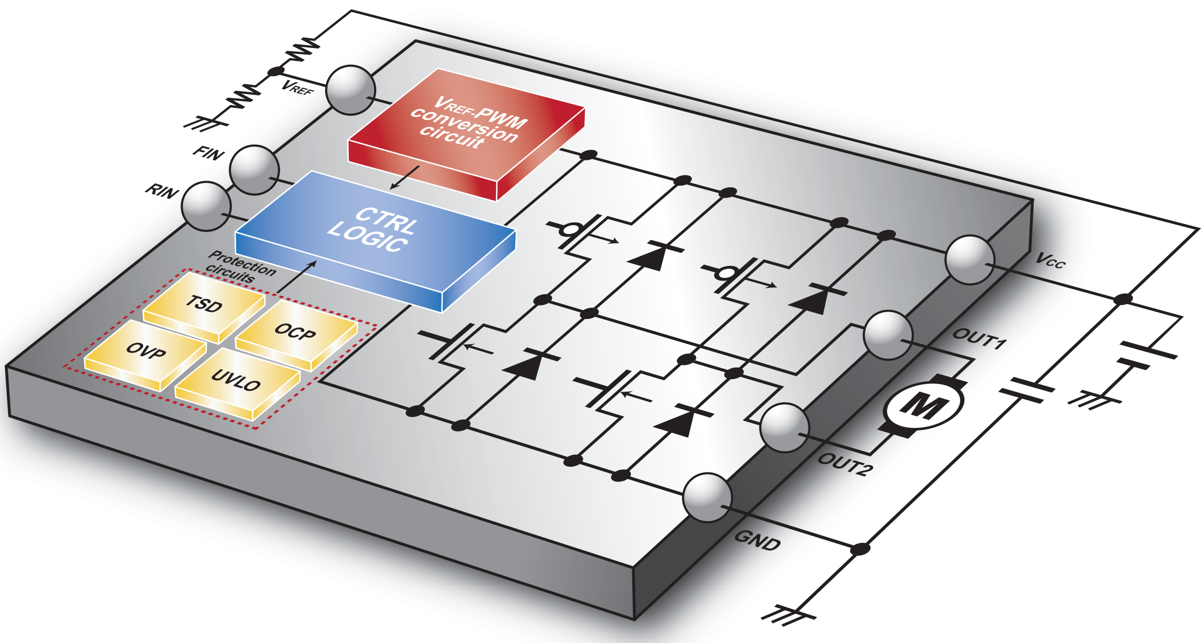

Figure 3. The ideal H-bridge driver includes flexibility for analog or digital operation and extensive protection circuitry.

Over- and undervoltage circuits keep the IC within its proper voltage operating range. OCP limits the current draw and essentially shuts the device down by forcing all driver outputs into a high impedance state in the event of a short circuit or other excessive current event such as a locked rotor. TSD protection can provide longer term protection when the chip is operating within its current capability but some other fault has occurred, such as an extremely high operating temperature environment or loss of adequate cooling in an enclosure or a deteriorated heatsink path.

From a timing standpoint, OCP is fast response protection and TSD is slower. For example, TSD provides back-up protection for faults that OCP cannot detect such as a soft short that is within the current limit but still causes an excessive temperature rise. OCP protects the MOSFET outputs and TSD protects the die. If the die temperature exceeds a predetermined limit, such as 175 °C, the IC will shut off.

For every H-bridge application, overlap timing circuitry is required to prevent shoot-through current spikes when switching direction or applying dynamic breaking. ROHM H-bridge drivers control this internally. If an MCU is used to directly control the output devices, a program must be written to ensure proper timing to avoid shoot-through problems.

A thorough design includes ruggedness to handle unexpected occurrences damaging the driver such as ESD. ROHM H-bridge ICs are specified to handle ESD voltages as high as 4 KV.

PWM Speed Control Techniques Using ROHM H-bridge Drivers

The latest ROHM H-bridge drivers provide PWM speed control through a variety of techniques to address the requirements of different applications.

MCU Control

With an MCU or other digital logic providing the PWM input, a circuit like the one in Figure 4 would be appropriate. The pulse train applied to the F_{IN} and R_{IN} lines controls the direction and the speed digitally from the MCU. Table 1 shows the logic for implementing PWM in the forward and reverse directions as well as brake and idle values. To complete the application, the V_{REF} is tied to V_{CC} and two external decoupling capacitors are connected from V_{CC} to motor and IC ground.

Analog Voltage Control

With directional inputs provided through the F_{IN} and R_{IN} pins according to Table 2, the V_{REF} input can be used to control the DC motor's speed.

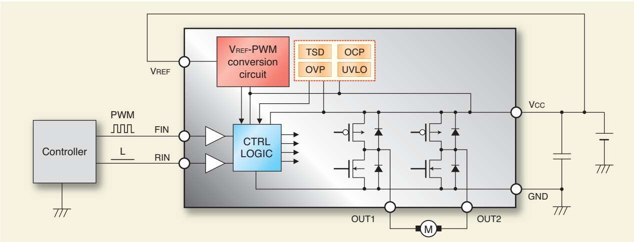

Figure 4. A digital controller, such as an MCU, can directly drive the control logic circuitry in the H-bridge driver.

Direct PWM control

Input		Output
FIN	RIN	
PWM	L	Forward
L	PWM	Reverse
H	H	Brake
L	L	Idle

Table 1. This table shows the application of the PWM pulse train and logic inputs to control speed, direction, and brake and idle status.

Figure 5 shows a simple voltage divider providing the variable voltage source to the internal PWM circuitry. This voltage could also be supplied from a variable voltage source (potentiometer, resistor array) that allows for operator control of the motor speed. This design works best with a regulated power supply. Note: a microcontroller is not required for this approach; the F_{IN} and R_{IN} inputs could come from two switches.

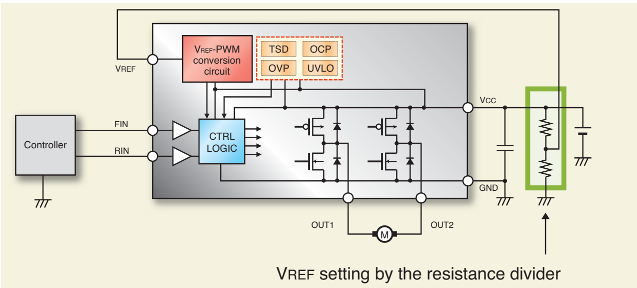

Figure 5. Simple analog speed control using a voltage divider input.

VREF input control

Input		Output
FIN	RIN	
H	L	Forward
L	H	Reverse
H	H	Brake
L	L	Idle

Table 2. Truth table for the control of direction, brake and idle status.

Fixed Speed From an Unregulated Supply

With the resistor divider input tied to V_{CC}, if the line voltage changes, the motor speed will change. A fixed speed can be accurately established with a Zener diode in the lower leg of the voltage divider as shown in Figure 6. In spite of line voltage fluctuations, the motor will be controlled at the same speed.

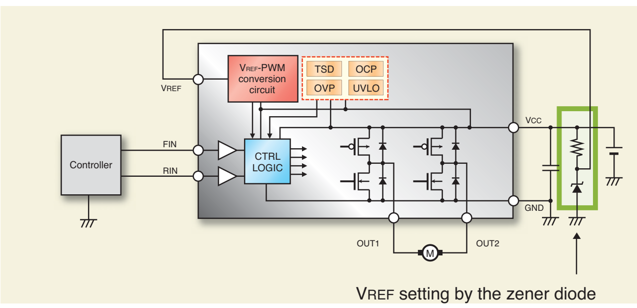

Figure 6. A Zener diode provides a reference for constant speed operation.

Simplified Digital Speed Control

The output of a digital to analog converter (DAC) could drive the V_{REF} providing the analog control voltage to the driver converting the signal into a PWM output shown in Figure 7.

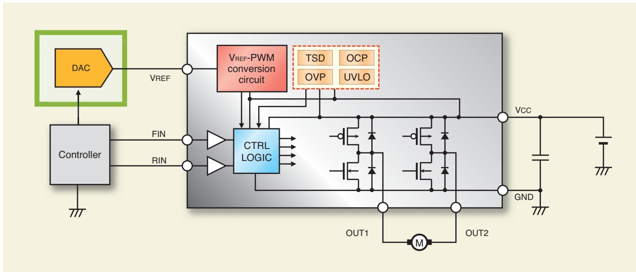

Figure 7. With a DAC, a digital voltage converted to analog can provide the V_{REF} input.

Soft-Start Control with Analog Input

The soft-start technique shown in Figure 8 uses a capacitor and two diodes so the voltage builds slowly to the full input. The motor starts slow and slowly reaches its target speed.

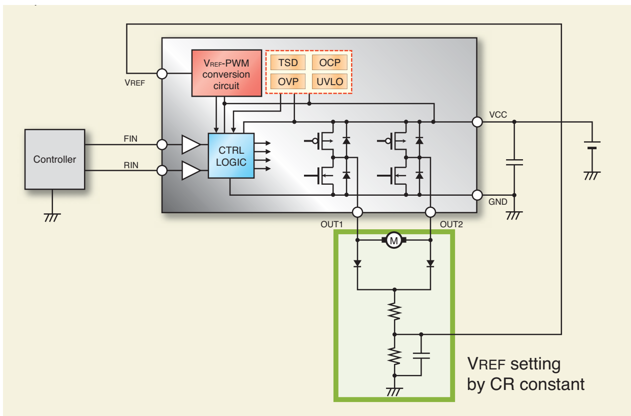

Figure 8. Adding a soft-start function simply requires adding a capacitor and two diodes.

7 V DC Low Voltage, Battery-powered	18 V DC Power supply and battery-powered	36 V DC Power supply and high voltage, battery-powered
Robotics	Cordless power tools	Marine pumps
Toys and games	Instrumentation	Automotive pumps
Handheld printers	Home appliances	Automotive fuel cells
Camera Lenses	Vacuum pumps	Automotive actuators
Navigation systems	Encoders	Aerospace actuators
Fans	Auto antenna	Security actuators
Instrumentation	Actuators	Diaphram pressure pumps
Medical pumps	Pumps	Power tools and robotics
Radio antennas	Sprayer and washer systems	Gearbox drivers
Actuators	Micro motors in appliances (refrigerator)	Vending machines
Security locks	Gearbox drivers	Copiers
Sporting Equipment		Printers
		Fans

Table 3. Popular applications for H-bridge drivers.

Selecting the Right H-bridge Driver for the Application

Due to the variance of operating voltages, in order to provide the ideal solution it is important to pick the correct H-bridge driver.
Table 3 shows several popular applications and voltage selection criteria.

Multiple Voltage and Current Configurations Optimize Performance

To meet the requirements of these applications, ROHM offers H-bridge drivers rated for maximum operating voltages of 7 V, 18 V and 36 V with 0.5 A, 1.0 A and 2.0 A current ratings in single and dual channel packages.

Typically, individual applications have operating voltages ranging between 3-5 V, 6-15 V or 18-32 V. However each ROHM driver operate with any V_{CC} below its maximum limit. The lower V_{CC} max. devices provide higher efficiency since the output MOSFETs trade off higher voltage with higher on-resistance. So selecting the appropriate V_{CC} max. optimizes the power consumption and avoids added expense for a higher voltage rating.

Low-Profile Packaging

The low-profile ROHM packages are all within 2.2 mm (some as thin as 1.5 mm), which is especially important in portable products.

Dual-Channel Versions Offer Matched Performance

For applications requiring more than a single independently operated motor, such as printers, robotics, toys and games, ROHM's dual-channel H-bridge drivers offer independent control of each channel in space saving packages featuring symmetrical pin configuration.

Flexible Control Strategies

ROHM H-bridge drivers provide several options for controlling direction, speed, brake and idle, as described in detail on pages 4-5, above.

ROHM drivers feature an internal V_{REF} to PWM conversion circuit for simple analog speed control in addition to digital input control levels of 2.0-5.0 V TTL from an external MCU.

Migration from Linear Control to PWM

The latest generation of ROHM H-bridge drivers are pin-compatible with earlier models. Applications using V_{REF} linear control can easily migrate to the latest design without any modifications to an existing PCB layout and obtain the advantages of PWM functionality.

Many of these advanced PWM H-bridge drivers are pin compatible with ROHM's existing linear output line-up, providing added efficiency and eliminating the potential for board placement errors.

Putting It All Together

This paper has presented the basics of H-bridge driver technology and the important benefits of ROHM's product family including:

- High efficiency
- Minimal external components
- Low power consumption
- Low power dissipation
- Internal shoot-through protection
- ESD protection
- Fast response time
- Built-in fault protection

To get more details on the complete line of ROHM H-bridge driver ICs, visit:
www.rohmsemiconductor.com/h-bridge.html
At this site you will find a comprehensive product selection guide, product datasheets and additional application information.

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