

Application Brief

Current Sensing in an H-Bridge



Arjun Prakash and Mubina Toa

Current Sensing Products

The semiconductor industry has always looked for improvements in creating technology that has the ability to enable higher power density systems. One such circuit is an H-bridge. As shown in [Figure 1](#) an H-bridge is a simple circuit consisting of 4 FET transistors connected between the load. An H-bridge is often used when the direction of the current is required to be controlled and managed from the supply to the load. If the load is highly inductive, the energy stored in the load can also be discharged safely to ground by controlling the H-bridge. H-bridge circuits are commonly used in motor control, DC-DC converters, audio sub systems and LED lighting control making systems more safe and reliable. H-bridge consisting of silicon FET transistors often achieve > 95% efficiency, while GaN FET transistors can allow for efficiencies beyond 99%. A higher efficiency H-bridge combined with current sense amplifiers to monitor, manage, and control the load currents leading to improvement in safety, reliable, and overall improvements in the power efficiency of an end equipment.

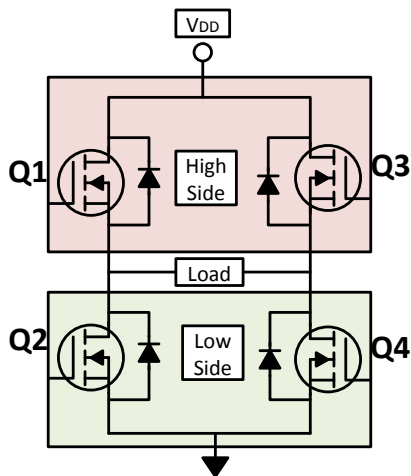


Figure 1. H-Bridge Circuit

Full H-Bridge Circuit Configuration and Control

The H-bridge can be controlled by turning ON and OFF the FETs. A pulse-width modulation (PWM) scheme is an effective method used in creating different waveforms to control the flow of current. By controlling the duty cycle of the PWM waveform

the current flowing to the load can be effectively controlled. [Figure 2](#) depicts the PWM waveform with different duty-cycles. By modulating the duty cycle of the PWM generator, the output current to the load can be precisely controlled.

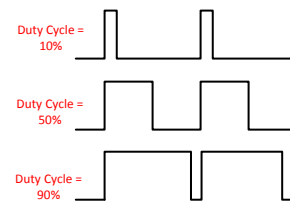


Figure 2. Pulse Width Modulation Scheme for H-Bridge

While controlling the H-bridge using PWM waveforms careful consideration must be taken into account to ensure there is no direct short from battery to ground. For example, in [Figure 1](#) Q1 and Q2 should never be turned on simultaneously. Such a scenario would create a high current shoot through which could damage the corresponding electronic drive circuitry. [Table 1](#) describes the possible states of a full H-bridge control.

Table 1. Operating States of an H-Bridge

Q1	Q2	Q3	Q4	State of Load
ON	OFF	OFF	ON	Current flows from H-bridge to the load
OFF	ON	ON	OFF	Direction of the current to the load is reversed
OFF	ON	OFF	ON	Provide safe path for the load to discharge to ground
ON	OFF	ON	OFF	Recirculation current stored in the load
OFF	ON	OFF	ON	Recirculation current stored in the load
ON	ON	OFF	OFF	Short circuit from battery to ground
OFF	OFF	ON	ON	Short circuit from battery to ground
ON	ON	ON	ON	Short circuit from battery to ground

Current Measurement in an H-Bridge for Motor Control

Bidirectional current sensing in a full H-bridge motor control is critical for safety and reliability to monitor and control a system. An accurate current

measurement in an H-bridge can control the torque of the motor precisely or precisely set the position in a stepper motor.

Figure 3 describes common locations to measure current in an H-bridge: high-side, in-line, and low-side. As motors are highly inductive, the PWM output tends to overshoot during low to high transitions and undershoot during high to low transition. The characteristics of overshoot and undershoot of an amplifier are important in selecting a correct component. A current sense amplifier that can sustain overshoot and undershoot conditions with a fast response time, and is able survive harsh requirements of an inductive system is critical. By providing valuable current sensing data to the system, this helps to detect anomalies in the motor or other inductive system features, which may lead to premature failures.

Table 2 describes the advantages and disadvantages of measuring currents in an H-bridge at multiple locations.

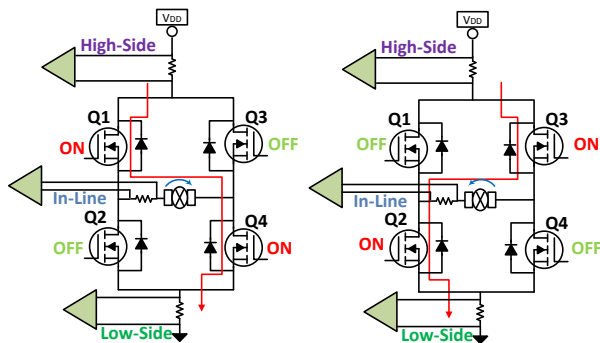


Figure 3. Current Sensing Locations in an H-Bridge Control

Table 2. Current Sensing in an H-Bridge

Current Measurement	Pros	Cons
High-Side	Detect shorted load from battery for diagnostics	High voltage common-mode amplifier
In-Line	Direct motor current measurement, low-bandwidth amplifier	High dv/dt signals. PWM settling time
Low-Side	Low-cost, low common-mode voltage	Unable to detect shorted load

The INA240 current sense amplifier can operate from a common-mode voltage ranging from -4 V to 80 V . In an H-bridge application, the INA240 can be used regardless of whether the measurement location is high-side, in-line, or low-side. A low offset of ($25\text{ }\mu\text{V}$) and low voltage offset drift ($0.25\text{ }\mu\text{V}/^\circ\text{C}$) combined with a low gain error (0.2%) and gain drift ($2.5\text{ ppm}/^\circ\text{C}$) makes it applicable for precise measurements regardless of system temperature. In addition to high performance DC specifications,

the INA240 is also designed to operate and reject dv/dt transients enabling real time load current measurements at the in-line measurement location. The system level benefits of in-line sensing enables higher power density by lowering the processing power requirements for closed loop control system.

Alternate Device Recommendations

The INA241 is the ultra-precise analog current sense amplifier. The INA241 can be used in high-voltage bidirectional applications paired with 1-MHz bandwidth to offer fast response time with precise operation for in-line control within H-bridge applications. The INA241 can measure currents at common-mode voltages of -5 V to 110 V and survive voltages between -20 V to 120 V .

The INA253 is an ultra-precise current sense amplifier with an integrated low inductive, precision $2\text{-m}\Omega$ shunt with an accuracy of 0.1% with a temperature drift of $< 15\text{ ppm}/^\circ\text{C}$. The INA253 is limited to applications that need $\pm 15\text{ A}$ of continuous current at $T_A = 85^\circ\text{C}$. The INA253 integrated shunt is internally Kelvin connected to INA240 amplifier. The INA253 provides the performance benefits of INA240 amplifier with the inclusion of precision shunt providing a total uncalibrated system gain accuracy of $< 0.2\%$.

The INA281 can be used in high-voltage applications such as high-side current sensing in a motor. The INA281 can measure currents at common-mode voltages of -4 V to 110 V and survive voltages between -20 V to 120 V , making it versatile for a variety of applications where voltage can swing negative.

An option for low-side sensing is the INA381 which is a cost-optimized current sense amplifier with an integrated comparator which serves to reduce PCB footprint size and simplifies design.

Table 3. Alternate Device Recommendations

Device	Optimized Parameter	Performance Trade-Off
INA241	V_{cm} range: $-5\text{- to }110\text{-V}$ bidirectional	I_Q is slightly greater
INA281	V_{cm} range: $-4\text{ V to }110\text{ V}$	Unidirectional
INA381	Integrated comparator	V_{cm} limited to 26 V
INA253	Integrated shunt $2\text{ m}\Omega$, V_{CM} range: $-4\text{ V to }80\text{ V}$	$\pm 15\text{-A}$ maximum continuous current

Table 4. Related TI Application Briefs

Document	Title
SBOA160	Low-Drift, Precision, In-Line Motor Current Measurements With PWM Rejection
SBOA176	Switching Power Supply Current Measurements
SBOA163	High-Side Current Overcurrent Protection Monitoring
SBOA187	Current Mode Control in Switching Power Supplies

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2022, Texas Instruments Incorporated