TI TechNotes

Current Sensing in an H-Bridge

Arjun Prakash, Current Sensing Products

The semiconductor industry has always looked for improvements in creating technology that has the ability to enable higher power efficiency 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. H-Bridges 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 and overall improvements in the efficiency of an end equipment.

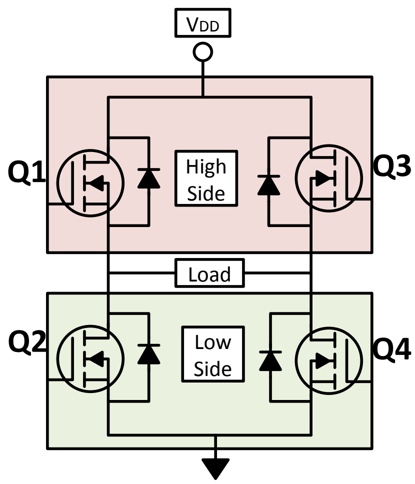

Figure 1. H-Bridge Circuit

Full H-Bridge Circuit Configuration and Control

The H-bridge can be controlled by turning ON and OFF the FETs. A pulse width modulation scheme (PWM) 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.

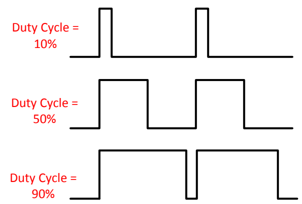

Figure 2. Pulse Width Modulation Scheme for H-Bridge

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

Bi-directional current sensing in a full H-bridge motor control is critical for safety, monitoring and feedback control. 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 can survive the harsh requirements of an inductive system and provide valuable current information that can detect abnormalities of the motor which can lead to early failure. Table 2 Describes the advantages and disadvantages of measuring currents in a H-bridge at multiple locations.

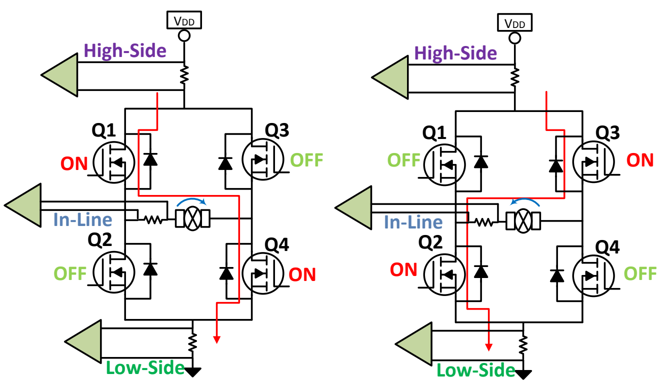

Figure 3. Current Sensing Locations in an H-Bridge Control

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 -4V to 80V. In a 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 (25µV) and low voltage offset drift (0.25µV/°C) combined with a low gain error (0.2%) and gain drift (2.5ppm/°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 efficiency by lowering the processing power requirements for closed loop control system. For low-side current sensing needs one of the important specifications for a current sense amplifier would be that it support negative common mode voltages. The INA240 can support -4V of common mode voltage. As low-side sensing offers very little benefit over high-side and in-line current sensing it is the most cost effective location to monitor basic current functionality.

Alternate Device Recommendations

The INA253 is the most accurate current sense amplifier with an integrated low inductive, precision 2mΩ shunt with an accuracy of 0.1% with a temperature drift of <15ppm/°C. The INA253 is limited to applications that need < +/-15A of continuous current at T_A = 85°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 LMP8601 can be used in applications such as automotive powertrain where the common-mode voltage can swing below ground. The LMP8601 can measure currents at common mode voltages as low as -22V.

Table 3. Alternate Device Recommendations

Device	Optimized Parameter	Performance Trade-Off
LMP8601	V_{cm} range: -22 V to 60 V	Bandwidth, Accuracy
LMP8640HV	Bandwidth: 950kHz	Slew rate, Longer step response settling
INA253	Integrated shunt 2mΩ, V_{CM} range: -4 V to 80 V	+/-15A maximum continuous current

Table 4. Related TI TechNotes

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