Automotive Current Monitoring Using High Speed Amplifiers

With vehicle electrification increasing and as fully electric vehicles become more mainstream, the number of electric motors and digital power control systems in automobiles are expanding. Many of these systems require high-speed current monitoring circuits to ensure proper operation and to protect against potentially damaging overcurrent conditions. One of the most effective ways to accomplish this function is to employ a low side current shunt monitoring circuit like the one shown in Figure 1.

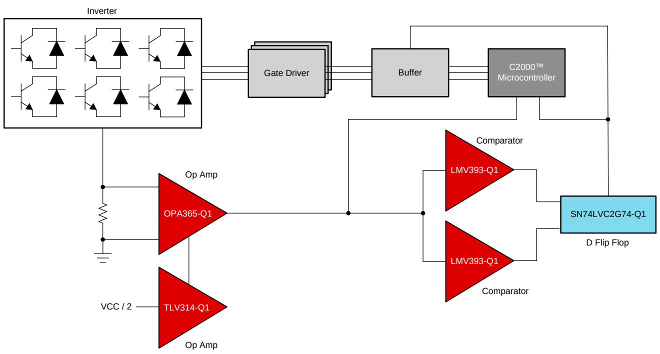

Figure 1. Automotive Current Monitoring Diagram

This circuit provides overcurrent and short-circuit protection with the use of two op amps, two comparators and a D-type flip-flop. The OPA365-Q1 operational amplifier (op amp) used in the circuit performs a differential voltage measurement across a shunt resistor. The voltage across the resistor corresponds to the current that flows though the inverter. It is important that the op amp used in this part of the circuit has low noise and low offset to minimize degradation of the low voltage signal measured across the shunt resistor. It is also critical that the amplifier has fast settling time and a high slew rate in order to achieve a fast response time to detect overcurrent or short-circuit conditions. High bandwidth also enables a single high-gain stage to be implemented in a single amplifier to drive the input of the comparator and analog to digital converter (ADC) in the circuit.

The zero-crossover, rail-to-rail, OPA365-Q1 CMOS op amp is ideal for this application. It has 50MHz of bandwidth, noise of only 4.5nV per root hertz and a low offset of only 100 micro volts. The device also features a fast settling time of only 0.3 micro seconds and a slew rate of 25 volts per micro second. The amplifier also has an operating temperature range of -40 to 125 degrees Celsius and is AEC Q100 grade 1 qualified for automotive applications. The key specifications for the OPA365-Q1 op amp are summarized in Table 1.

Table 1. OPA365-Q1 Key Specifications

OPA365-Q1 Key Specifications	
Bandwidth	50 MHz
Noise	4.5 nV/√Hz @ 100 kHz
Offset	100 µV
Settling Time	0.3 µs to 0.01%
Slew Rate	25 V/µs
Ambient Temperature	-40°C to 125°C
Package Size (Body)	2.9 mm x 1.6 mm SOT-23(5)

The TLV314-Q1 is used in the circuit as a voltage follower and functions as a source for the reference voltage. This amplifier provides high stability at unity gain and has the ability to drive capacitive loads up to 300 pF. In this circuit, the TLV314-Q1 provides a reference voltage of Vcc divided by 2 to the OPA365-Q1. With this configuration, the output voltage range of the OPA365-Q1 varies from 1/2 of Vcc to Vcc for one direction of shunt current and from 1/2 of Vcc to GND for the other direction of shunt current. This circuit is shown below in Figure 2.

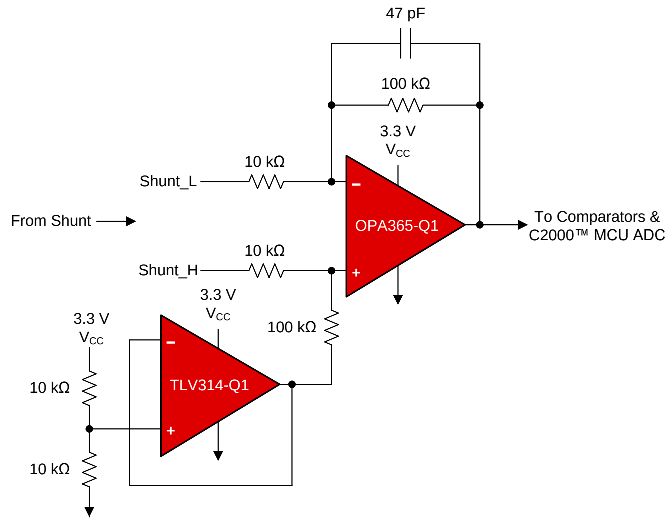

Figure 2. Reference Voltage Circuit

The output of the OPA365-Q1 is connected to the comparator circuit and the analog to digital converter input on the C2000™ microcontroller. The C2000 TMS320F28052 microcontroller is part of TI's Piccolo™ family of MCUs. It has a 12-bit, 3.75 mega sample per second ADC that is driven by the OPA365-Q1 amplifier and can be used to monitor or log the shunt current. The C2000 microcontroller has been specifically designed for use in automotive motor control and digital power applications.

Since a short circuit or overcurrent condition can potentially be harmful, a comparator-based shut-off circuit with an extremely fast response time is also implemented. This comparator-based circuit can disable the gate drivers in the system much faster than the MCU. In the circuit, the OPA365-Q1 differential op amp output is connected to the inputs of the dual channel LMV393-Q1 comparator. This device integrates two comparators into a single package and provides a cost-effective, space-saving design for this portion of the circuit. The comparators have trigger levels that correspond to an overcurrent condition. One comparator is set up in an inverted configuration to make it possible to detect current peaks in the shunt resistor in the opposite direction. When a overcurrent or short-circuit current occurs on one of the phases of the inverter, the responsible comparator detects it and changes its output state accordingly. The dual comparator circuit is shown in Figure 3.

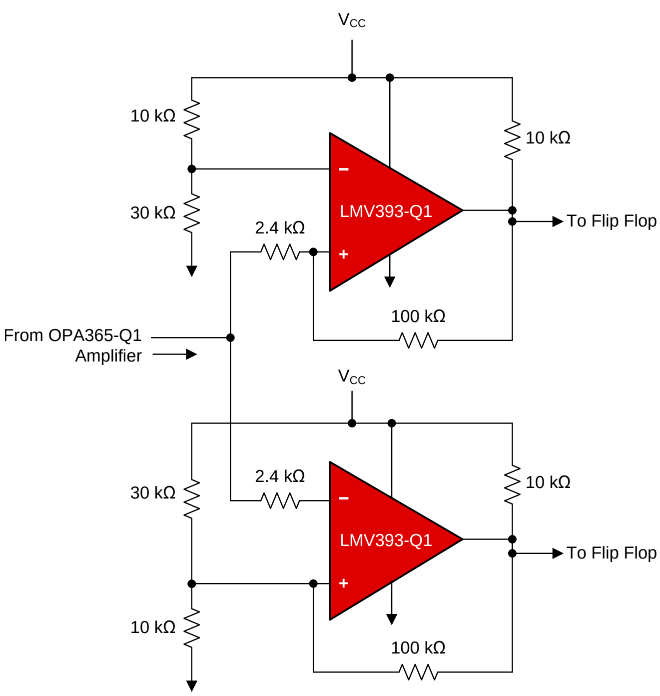

Figure 3. Dual Comparator Circuit

When the comparator changes state, it triggers the SN74LVC2G74-Q1 D flip-flop in the circuit to disable the buffer between the MCU and gate drivers. When the buffer is disabled, the gate driver input signals are pulled down through the low-side resistors connected to each control line and the gate drivers force the Insulated-Gate Bipolar Transistors or IGBTs in the system to turn off. This comparator based circuit has a very fast response time that can potentially help prevent damage from occurring to the system in the event of a short circuit fault.

This current monitoring circuit is featured in a TI Design, or reference design, for a high-voltage, high-power motor drive circuit for automotive heating, ventilation and air conditioning (HVAC) compressors. The reference design features a three-phase inverter drive which is based on a discrete IGBT for driving brushless DC (BLDC) motors for automotive A/C compressors using sensorless torque control. More information about the TI Design, including full design schematics, can be downloaded from the following web link: http://www.ti.com/tool/tida-01418. The circuit board for the reference design is shown in Figure 4.

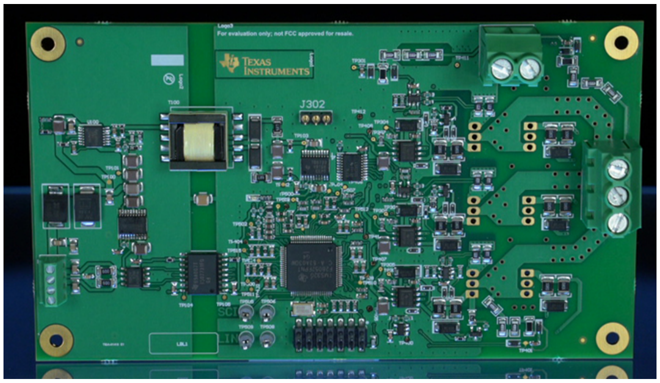

Figure 4. TI Design TIDA-01418 Circuit Board

With the number of electric motors and digital power systems increasing in automobiles the need for high-speed current monitoring systems is becoming more important. The zero-crossover, rail-to-rail, OPA365-Q1 op amp is in integral part in these systems. It has fast settling time and a high slew rate in order to achieve a fast response time to detect overcurrent or short-circuits in these systems to prevent potentially damaging conditions from occurring.

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