Current Supply Monitoring with the TL431LI-Q1

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Introduction

Current monitoring for an automotive system is crucial to diagnose early failure as well as monitoring levels in subsystems such as the battery. Monitoring current off an automotive 12-V battery provides critical data for a variety of applications such as module current consumption, load diagnostics, and load feedback control. This can be done in multiple ways, including using an Analog-to-Digital converter (ADC) with a shunt based approach, or using a shunt-based current sense amplifier positioned to carry out the measurements similarly. Although these shunt-based approaches are similar in intent, they differ a bit in implementation but still benefit from more accuracy coming from a voltage reference.

Current sensing is done in two ways: high-side and low-side sensing. In a high-side configuration, the sense resistor is placed between the positive supply and the load, while in a low-side configuration, the resistor is placed between the load and common ground. The difference in these approaches comes into consideration when susceptibility to ground disturbance, parasitic error, and detection of load shorts is of concern implementing a low-side approach. In automotive applications, areas such as battery management systems and motor currents require a need for high-accuracy current supply monitoring and this is able to be mitigated with using precision voltage references.

Current Supply Monitoring with an ADC and Isolation Amplifier

A shunt based current approach is usually taken for monitoring motor current drive, as an example. Isolation needs to occur between the sense point (motor) and the transmission point (ADC). The isolation amplifier allows for a low likelihood of the low-power digital hardware getting damaged due to abnormally large voltage transients. Below in Figure 1 is an example implementation with this device, which can be used to achieve a precise current measurement while providing excellent isolation from the input to the output and supporting large peak currents through the device. The TL431LI-Q1 is a precision shunt voltage reference connected to the ADC (in this example the ADS7263) which provides the extra accuracy required to obtain the measurements.

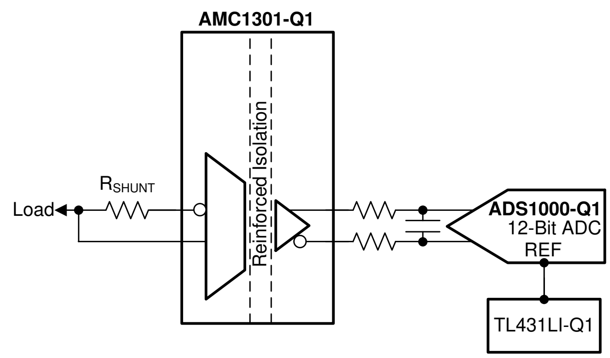

Figure 1. High Voltage Current Monitoring

In this example, the AMC1301-Q1 precision isolation amplifier provides galvanic isolation between the high and low voltage sides. This amplifier has a very high transient immunity, very low non-linearity, and very low offset error. The isolation amplifier also allows us to connect the output directly as shown to a differential ADC as shown with the ADS1000-Q1. The TL431LI-Q1 precision shunt voltage reference allows for the system to minimize gain and noise error.

Current Supply Monitoring with a Current Sense Amplifier

Current monitoring can provide additional information with what is going on in the system. This information can range from knowing how much battery life you have left to knowing a part is beginning to fail. To get this information, current monitoring must be done accurately. If an absolute value of the current being drawn from a power supply needs to be measured (for example), a current sense amplifier may need to be implemented.

Current sense amplifiers are dedicated amplifiers developed specifically to accommodate high voltage input levels, while keeping the lower voltage components following the amplifier within the linear input range and protecting them from overvoltage conditions. Please read application note SBOA211: Low-Cost Bidirectional Current Sensing Using INA181 to get an idea for the challenges faced in current monitoring. The design highlighted in this application note implements the TL431LI-Q1 for the most accurate current measurements. In this example, the design is shown with an INA240-Q1 and a TL431LI-Q1 to highlight the automotive use cases in this technical note. This example use-case would be done for a "divided-down" voltage of the motor voltage, such that, the INA240-Q1's input voltage is not exceeded.

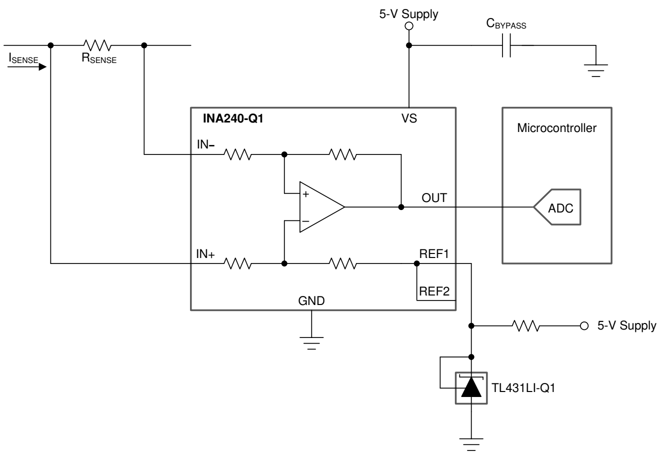

Figure 2. Current Sensing with INA240-Q1 and TL431LI-Q1

As shown in Figure 2 above, the measurements here are handled by the INA240-Q1 across a shunt resistor (R_{SENSE}). The information is then fed to a microcontroller with an internal ADC via the output, and the TL431LI-Q1 is connected to the reference pins of the current sense amplifier to improve the accuracy of the solution. For the INA240-Q1, connecting both reference pins together and then to a reference voltage results in an output voltage equal to the reference voltage for the condition of shorted input pins or a 0-V differential input. The output voltage decreases below the reference voltage when the IN+ pin is negative relative to the IN– pin and increases when the IN+ pin is positive relative to the IN– pin. This technique is the most accurate way to bias the output to a precise voltage.

Table 1. Worst-Case Error for a 720-W Inverter Application Using a Current Sense Amplifier

Parameter	Calculation	INA240-Q1 and TL431LI-Q1
Offset Error	% Offset Error = Offset Voltage/V_{SENSE}	25 µV/0.02%
Gain Error	INA240-Q1 Gain Error = 0.2%	0.2%
V_{REF} Error	% V_{REF} Error = $V_{ref(max-typ)}$ + $V_{I(dev)}$	39 mV/1.625%
Worst-Case Wattage Error	% Total Error = $\sqrt{(0.02^2 + 0.2^2 + 1.625^2)}$	19.3 W/2.68%

Table 1 assumes a few conditions for error calculations. The calculations use the TL431LIBx grade device, as well as the standard automotive grade 1. The worst-case wattage error for calculation is done for a 720-W inverter application. Further calculations and explanations for similar devices are outlined in Low-Cost Bidirectional Current Sensing Using INA181.

Conclusion

Vehicles are becoming more electrified—not just electric vehicles or hybrid-electric vehicles, but even gasoline and diesel powered machines. It becomes more critical to accurately monitor the current consumed to ensure performance as well as long-term reliability. Current sensing is critical for essential operations such as motor control, DC/DC, battery monitoring, and other diagnostic subsystems. The performance of any current sensor solution mainly depends on the device specifications such as accuracy, bandwidth, linearity, and precision. Designing a system that satisfies all the required specification is a challenging task.

Using a high precision voltage reference can immediately help mitigate a source of error for a current sensing solution. Two technologies with similar shunt architectures such as the ADC monitoring solution and the current sense amplifier solution both require this voltage reference need to ensure precise measurements. A designer's ability to manage sources of error in measurement solutions determines the robustness for critical systems in automotive, as such in current sensing.

Table 2. Alternative Device Recommendations

Device	Optimized Parameters	Performance Trade-Off
TL431-Q1	Higher $I_{KA(MAX)}$	Temperature drift, I_{ref}, $I_{I(dev)}$
LM4041-N-Q1	Minimum I_{KA}; Temperature coefficient	Cathode current rating
TLV431-Q1	Minimum I_{KA}	Initial accuracy; Cathode current rating; Temperature coefficient

Table 3. Adjacent Tech Notes

SNOAA00	Designing With the Improved TL431LI
SBOA211	Low-Cost Bidirectional Current Sensing Using INA181
SBOA165	Precision current measurements on high-voltage powersupply rails
SNVA865	Implementing Voltage References and Supervisors Into Your Traction Inverter Design

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