

Measure Microamps to Amps or Reduce Power Dissipation by 99%, You Decide!

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Introduction

A required, but often overlooked, element of any industrial or automotive monitoring/control system is a current sensing circuit that can maintain accuracy over the entire load range. Many applications use circuits that can provide only moderate precision and dynamic range. In many cases the current sense solution is woefully inadequate, with poor resolution and significant power dissipation in the sense resistor. The LTC6102 addresses both of these problems while boosting performance via a comprehensive set of current sense features.

Why Use High Side Sense?

In many applications, the sense load is ground referred. The simplest way to measure current in these systems is low side sensing, which involves adding a small sense resistor between the load and the system ground (Figure 1). Almost any amplifier can be used to amplify the sense voltage, and no level translation is required.

Low side sensing, for all its simplicity, has several inherent problems. First, the sense resistor affects the return voltage on the load—where the return is now the sum of the system's ground potential and the voltage across the sense resistor. The load now floats above system ground by the sense voltage, which can be significant—a traditional low side current sense circuit of some precision requires a voltage around and above 100mV.

Of course, as the load current changes, the sense voltage reacts as it should, thus affecting the ground potential seen by the load. A moving ground reference is no reference at all, resulting in load errors and significant noise. Transient load currents can present the load with tremendous

ground noise, reducing the performance of the monitoring system and injecting this noise directly into the load.

Second, there may be coupling between the load and ground, due to shielding. This coupling can alter the effective resistance of the sense resistor, especially over frequency, thereby reducing system performance.

Finally, safety may be compromised. In the event that the sense resistor fails, or becomes disconnected, the ground node of the load is energized to the full supply voltage. This is a safety hazard, as the node that is normally connected to ground is now held at dangerous potentials. It may not be obvious that such a fault has occurred, so it may be assumed that the ground terminal of the load is held at a safe voltage. Low voltage circuitry tied to the grounded side of the load may also be damaged, thus requiring additional work and expense in repair.

High side sensing eliminates these problems by allowing the system load to be safely and securely referred to ground. The high side of the load can be measured relative to ground without the sense resistor noise. The sense resistance can be more carefully controlled. Most importantly, a fault in the sense resistor disconnects the load from the supply, not ground, so safety is assured.

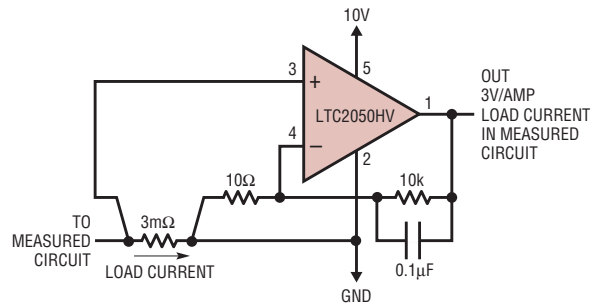


Figure 1. Classic high precision low side current sense

So, why isn't high side sensing used more often? The problem is that these advantages are tempered by a lack of simplicity. First, high supply voltages with high voltage transients demand a robust monitoring circuit. Second, the sense voltage must be accurately translated to ground. The LTC6102 addresses both of these problems with ease, while adding additional features to maximize accuracy and flexibility.

Solve the Dynamic Range Problem

It is no great technical feat to measure high load currents, but accurately monitoring high currents and low

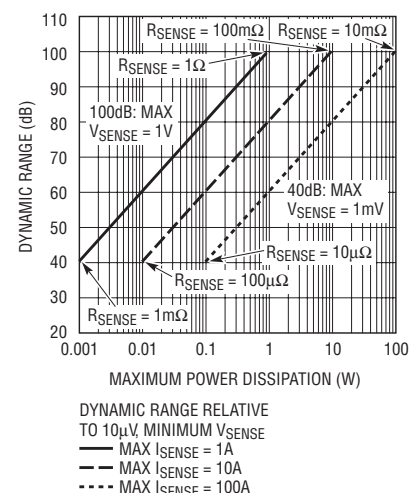


Figure 2. Dynamic range vs maximum power dissipation in R_{SENSE}

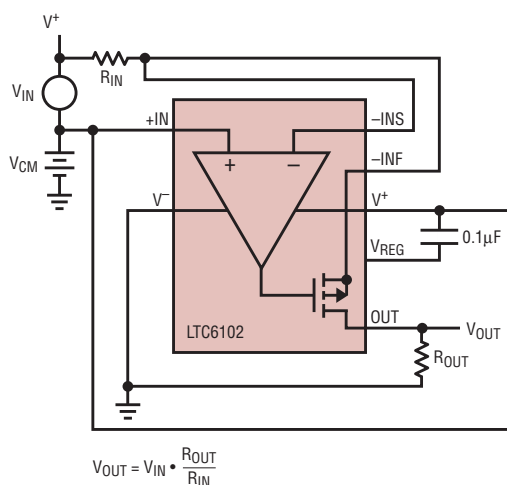


Figure 3. Level translation

currents on the same line, or resolving very small variations on large load currents, requires a monitoring circuit with a wide dynamic range. For example, a system that typically runs at 1A, but has dynamic loads up to 100A, would require at least 40dB of dynamic range for accurate measurement. If the typical load current must be measured with 1% accuracy, then 80dB of dynamic range is required. A battery system that calculates total battery charge over a range of load currents from 1mA to 100A would require 100dB or more!

For many current monitoring circuits, the dynamic range is limited at the high end by the maximum input voltage of the current sense amplifier, usually specified between 100mV and 500mV for integrated high side current sensing amplifiers. At the low end, input offset voltage limits the resolution. V_{OS} can be >1mV for many available integrated circuits, resulting in a dynamic range of 40dB–50dB, which is inadequate for many systems. The resolution is further degraded over temperature as the input offset can drift significantly.

The LTC6102 solves this problem by providing a maximum offset voltage of 10µV with a drift of less than 50nV/°C. The maximum input voltage of the part is 2V, giving a dynamic range of 106dB and a minimum resolution of 10µV. In simple terms, this allows a system to measure currents from 1mA to 200A without changing gain

or over-ranging. Current sense circuits that use the LTC6102 can easily be designed to provide high precision while accommodating temporary current surges or dropouts. This allows more accurate end-of-charge calculation and improved overall reliability.

Don't Need Dynamic Range? Trade in Dynamic Range for Reduced Power Loss

If you don't need to measure a large range of currents, the built-in dynamic range of the LTC6102 allows the use of very low value resistors. Reducing value of the sense resistor translates directly to improved power dissipation.

For instance, only 40dB of dynamic range is required for a system that must measure currents from 1A to 100A. Nevertheless, if a sense amplifier with 1mV input offset is used, then the maximum sense voltage must be no less than 100mV. At 100A, this dissipates 10W in the sense resistor. For accurate resistance at this high dissipation, a large, expensive custom sense resistor may be required, as well as a heat sink. The system must also be designed to provide the additional 10W, plus it must dissipate the resulting heat effectively.

If, however, the LTC6102 is used for this current measurement, then the maximum sense voltage can be reduced to 1mV without degrading performance. In fact, the low drift of the LTC6102 can provide improved precision over temperature when compared to other solutions. At the same time, dissipation is reduced to 100mW, a 99% reduction in power dissipation in the sense resistor, significantly simplifying or eliminating thermal design requirements.

Figure 2 shows the dynamic range vs power dissipation for 1A, 10A and 100A loads. Each line represents a fixed current. Dynamic range and power dissipation are optimized by adjusting the value of the sense resistor (R_{SENSE}). The sense resistor extremes are illustrated in the figure. It is easy

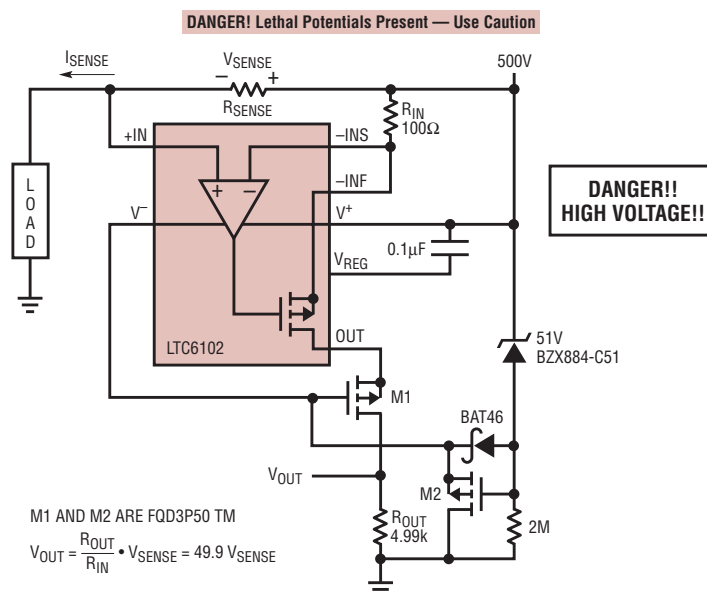


Figure 4. Simple 500V current monitor

to adjust the circuit performance using available sense resistor values. Dynamic range is the ratio between the maximum voltage across the sense resistor and the input offset of the LTC6102, while power dissipation is the power dissipated in the sense resistor at the listed current.

Precision Level Translation

Unlike many application-specific current sensing amplifiers, the architecture of the LTC6102 is similar to standard operational amplifiers. The design includes high impedance inputs and external feedback as well as low input offset. This allows the LTC6102 to be used in a variety of voltage amplification circuits as well as current sensing applications. Because of its inherent level translation capability, the LTC6102 can amplify a wide variety of signals while simultaneously rejecting the common-mode component.

Figure 3 shows a level translation circuit that amplifies a voltage signal. The LTC6102 mirrors the input voltage onto R_{IN} , which is then translated to R_{OUT} . It is important to note that in this circuit the supply pin of the LTC6102 is tied to the negative terminal of the input signal. Both input pins are within a few microvolts of the supply pin, so the input voltage may exceed the full scale input range of the LTC6102 without introducing an error in the output. This circuit works as long as the current through R_{IN} , defined as V_{IN}/R_{IN} , does not exceed

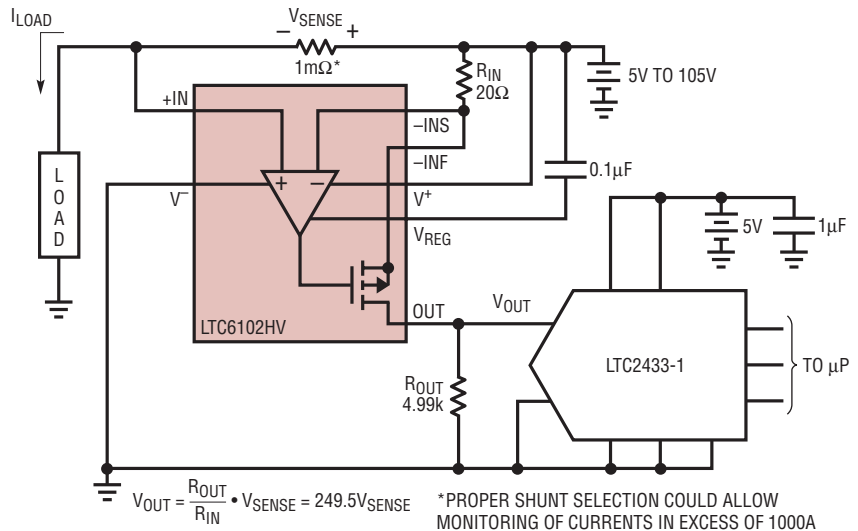


Figure 5. 10A current sense with 10mA resolution and 100mW maximum dissipation

the maximum output current of the LTC6102. If $R_{IN} = 10k\Omega$, then the input voltage can be as large as 10V. The gain is still set by R_{OUT}/R_{IN} , so either gain or attenuation may be chosen to allow the input signal to be translated to a useful output signal.

Simple and Flexible Design

The high precision and wide dynamic range of the LTC6102 are just the tip of the iceberg. A collection of features make the part easy to use, robust and flexible for many applications.

Wide Supply Range

The LTC6102 is specified for operation from 4V to 60V, and survives 70V supplies. The LTC6102HV is specified for operation up to 100V, with a maximum of 105V. In addition, just a few

external components can increase the operating voltage to several hundred volts or more without a loss of precision (Figure 4).

High Impedance Inputs

Unlike current-steering type sense amps that have input bias currents of several microamperes, the LTC6102 has $<100pA$ input bias, allowing measurement of very small currents.

Simple, Flexible Gain Control

The gain of the LTC6102 can be set with two external resistors. Gain error is limited only by these external components, not poorly specified internal resistors or saturation voltages. The external input resistor allows a wide choice of gains, as well as control of input and output impedances. For example, choosing a small input resistor allows large gain with relatively small output impedance, reducing noise and making it easier to drive an ADC without additional buffering.

Open-Drain Output

Additional flexibility and performance are provided by the open drain output. With no internal pull down device, the minimum output voltage is not limited by a saturation voltage, so the output can drive all the way to ground. The output can also be referred to a voltage above ground simply by connecting the output resistor to that voltage. The sensing circuit can be physically

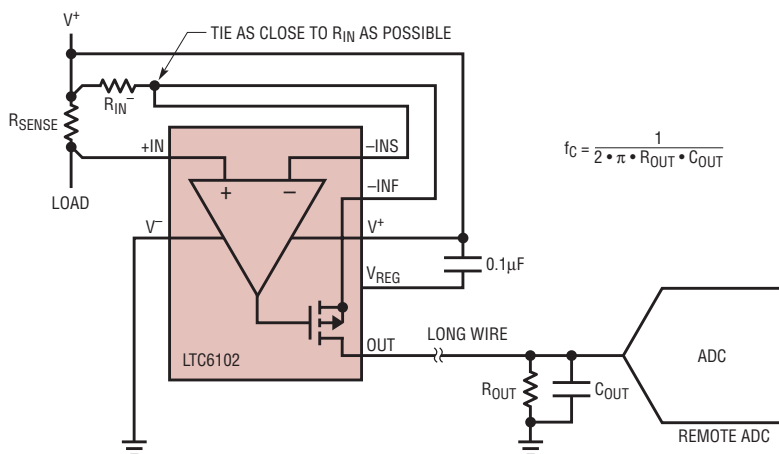


Figure 6. Remote current sense with simple noise filter

located far from the ADC without losing accuracy due to the resistance of the long output wire. The output can also be cascaded for additional level-shifting capability.

High Speed

The LTC6102 can support signals up to 200kHz, allowing the monitoring of fast-changing load currents. High speed also allows the LTC6102 to settle quickly after load transients, providing uninterrupted precision.

Fast Response Time

Protection circuitry must often react within microseconds to avoid system or load damage during fault conditions. The LTC6102 can respond to an input transient in 1μs. The output signal may then be used to turn off a MOSFET pass device or turn on a load protection circuit before system damage occurs.

Kelvin Input

The copper traces on the PC Board add to R_{IN} , creating a gain error that drifts 0.4%/°C. By connecting $-IN$ very near to R_{IN} , this effect is minimized, so very small (1Ω or less) input resistors may be used. Small input resistors allow large gains with relatively small output impedance. Reducing the effect of parasitic series resistance also helps maintain large dynamic range, even with relatively large input resistors.

All That and Small Size, Too

Today's applications don't just require precision; they also need it in the smallest package possible. In order to meet that demand, the LTC6102 is available in a 3mm × 3mm DD package, which requires no more board than a SOT-23. Where space is not such a premium, or where a leaded package is desired, the LTC6102 is also available in an 8-lead MSOP package.

Applications


Figure 5 depicts a simple current sensing circuit. R_{SENSE} converts the load current to a sense voltage. The LTC6102 applies a gain of 249.5 and shifts the level of the signal from the positive supply to ground. The sense resistor value may be chosen to maximize the dynamic range by setting a large maximum sense voltage (V_{SENSE}), or to limit power dissipation by choosing a smaller value. The high gain is made possible by both the Kelvin input, which allows the use of a small input resistor with little gain error, and the very low input offset, which produces less than 2.5mV error at the output. The small input resistor allows R_{OUT} to be set to 4.99k, which is small enough to be compatible with high resolution converter inputs. The addition of an LTC2433-1 is a simple way to convert the result.

For systems that are subjected to electrical interference, or for remote sensors, a capacitor may be placed

across R_{OUT} to filter the output, reducing noise and high frequency interference (Figure 6). This adds a simple pole to the output without affecting the DC result. In remote sensing, the LTC6102 should be placed in the sensor location, and the output can be run long distances to a converter. Since the output is current, not voltage, there is no loss in the wire. The output resistor and capacitor should be placed at the processor end of the wire to reduce noise and ensure accuracy.

Conclusion

Many current sensing applications can benefit from a high side sense method. High side current sensing circuits must be able to work at high voltages determined by the supply range, even under fault conditions, and must usually level-shift the signal to ground or another reference level. They must accomplish these tasks while preserving the precision and accuracy of the signal. The LTC6102 zero-drift current sensing amplifier offers the highest precision DC specifications. Wide supply range, low input offset and drift, accurate gain, fast response, and simple configurability make the LTC6102 and LTC6102HV ideal for many current sensing applications.

For a complete guide to current sense applications, visit www.linear.com/currentsense. 

LTC3850, continued from page 12

to operate with a main input voltage approaching the programmed output voltage, its duty cycle can be as high as 97%.

Dual Output, 5A Regulator with DCR Sensing

Figure 3 shows the schematic for a 500kHz, 2-output regulator requiring no sense resistors. By using the inductor's DC resistance as the current sense element, the application dissipates as little power as possible—at full load current, efficiency is well above 90%, as Figure 4 shows.

Dual Output, 15A Regulator with Sense Resistors

Figure 5 shows the schematic for an efficient 400kHz, 2-output regulator. Figure 6 shows that this circuit's core occupies less than a square inch on a 2-layer board. Peak inductor current is limited to 25A by the maximum current sense threshold looking across the sense resistor (50mV / 2mΩ). Taking inductor ripple current into account, the output current limit is around 20A for each channel. Higher load current will cause the LTC3850 to protect the power stage using current foldback.

Conclusion

The LTC3850 delivers copious features in small packages. Available in 4mm × 4mm 28-pin QFN (0.4mm lead pitch), 4mm × 5mm 28-pin QFN (0.5mm lead pitch), or 28-pin narrow SSOP, it can run at high efficiency using DCR sensing and Burst Mode operation. Tracking, strong on-chip drivers, multiphase operation, and external sync capability fill out its menu of features. Ideal for notebook computers, PDAs, handheld terminals and automotive electronics, the LTC3850 delivers multiphase power to mission critical applications. 