LINEAR TECHNOLOGY
DESIGN NOTES

Ultraprecise Current Sense Amplifier Dramatically Enhances Efficiency and Dynamic Range – Design Note 423

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Introduction

Accurate current measurement is indispensable in many electronic systems. The current is usually measured by amplifying the voltage it generates across a small value resistance. For systems that require a large dynamic measurement range, the sense resistance must be increased or the precision of the amplifier must be improved. Increasing the value of the sense resistor has the detrimental effect of increasing power dissipation. The better option is to improve the precision of the sense amplifier.

Amplifier precision depends a great deal on the input offset voltage of the amplifier. Historically, current sense amplifiers on the market offered input offset voltage performance on the order of hundreds or even thousands of µV. With such parts, achieving a practical dynamic range of 8 to 10 bits can cost more than a Watt of power dissipation at full operating current. The LTC®6102 ultraprecise current sense amplifier reduces input error to a miniscule 10µV. This dramatic performance enhancement translates directly into a greater measurement dynamic range—16 bits is possible even while *lowering* power dissipation in the sense resistor—thus greatly expanding the gamut of current sensing design options.

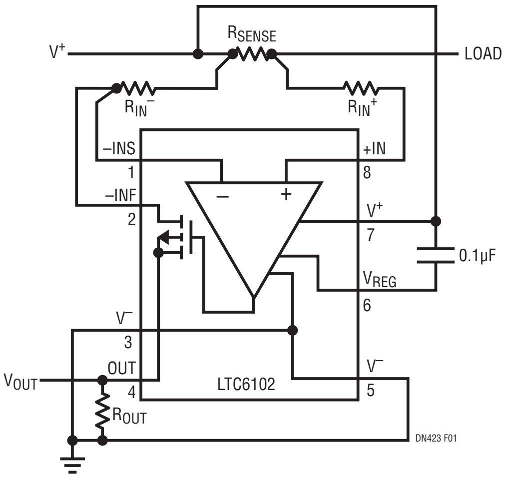

Figure 1. Ultraprecise Current Sensing with LTC6102

Precision Buys Efficiency

The LTC6102 is easily connected as shown in Figure 1.

The input voltage is developed by the sense resistor, and the voltage gain of the amplifier is set by the input and output resistors. The overall scaling is simply:

$$V_{OUT} = I_{LOAD}\left(R_{SENSE} \bullet \frac{R_{OUT}}{R_{IN^-}}\right)$$

The accuracy at small load currents is primarily set by the input offset voltage V_{OS}. The current measurement error I_{OFFSET}, due to the V_{OS}, is given by:

$$I_{OFFSET} = \frac{V_{OS}}{R_{SENSE}}$$

For a given current offset accuracy requirement, it can be seen that with a low V_{OS} that R_{SENSE} may be reduced accordingly, to sub-milliohms in many applications.

In most applications the circuit gain is selected so that V_{OS} translates to about 1LSB (least significant bit) in the analog-to-digital (ADC) acquisition system. Dynamic range is dictated by the maximum signal amplitude that the ADC can handle and how much power the R_{SENSE} resistor is permitted to dissipate.

Consider a comparison between two 8-bit sense amplifier solutions, one using a typical amplifier with V_{OS} = 500µV and one using the LTC6102, where V_{OS} = 10µV. The resolution of each is 20mA. The higher offset part requires a sense resistor of at least 25mΩ, whereas the LTC6102 only requires 500µΩ. At 5A, nearly full-scale current for this example, the R_{SENSE} power loss is 625mW with the higher offset part, but just 13mW with the LTC6102, a 98% reduction in wasted power.

Print Your Own Sense Resistors

With the ultralow sense resistance capability offered by the LTC6102, the printed circuit foil itself can be used as a practical sensing element. A circuit board using 1oz

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copper has a nominal sheet resistivity of 500µΩ/square. The value drops proportionally for thicker foils and rises for thinner foils. A trace of width W and length L (in any identical units) has the following resistance:

$$R_{SENSE} \approx 500\mu\Omega \bullet \frac{L}{W}$$

The length of the resistor is simply the spacing between the Kelvin taps along the trace. One ounce copper can generally carry up to about 100mA/mil of trace width (or 4A/mm), which constrains the minimum size of the resistor structure. Another constraint is reproducibility, so the larger, the better. Ultimately the thickness tolerance and tempco of the copper limit the accuracy a printed resistor can have.

Figure 2 shows a printed structure for the 5A circuit example discussed previously. In this layout, the L/W factor is set to 1 (for R_{SENSE} = 500µΩ) and the size is dictated mainly by the accuracy of printed circuit etching.

Using copper for the sense resistance means that the scaling of the circuit is nearly proportional to absolute temperature, about +0.4%/°C at room temperature. In applications where the current is being monitored for overload protection, the tempco may be convenient, in that a fixed protection threshold will automatically correspond to lower current at higher temperature. For stable measurements, a software calibration and temperature correction approach can be used, or the tempco can be compensated by using a copper-based resistor for R_{IN}^-, such as a small surface mount inductor with known resistance properties (>10Ω readily available, e.g. Vishay IMC series).

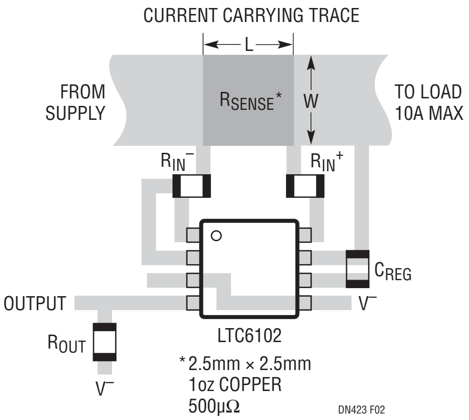

Figure 2. LTC6102 Layout Using Printed Sense Resistance

Data Sheet Download

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Design Tips and Details

If you are not printing your own sense resistors, and need the accuracy of off-the-shelf components, be sure to specify 4-wire (Kelvin) sense resistors for best results. Such resistors are designed so that the resistance is well calibrated between the sensed taps, thus eliminating the error from solder resistance in the load path.

Accurately measuring microvolt level signals raises the real possibility of stray thermocouple effects due to dissimilar metallic interconnections. Figure 1 shows the use of an R_{IN}^+ that is generally identical to R_{IN}^-. The purpose of this extra resistor is to provide identical metallurgical conditions to both amplifier inputs for minimizing thermocouple effects, as well as to minimize DC bias current imbalance.

The R_{IN}^- value is selected to conduct about 500µA at times of peak measured current I_{PEAK}. The voltage drop on R_{IN}^- is equal to the voltage drop on R_{SENSE}, so:

$$R_{IN^-} \ge \frac{I_{PEAK} \bullet R_{SENSE}}{0.0005}$$

Gain accuracy of the overall circuit is established mainly by the quality of the resistors used. This allows the designer to optimize the cost vs performance tradeoff in each specific application.

To minimize copper loss errors in the feedback loop of the LTC6102, the inverting sense input (–INS) and the inverting feedback connection (–INF) have been kept separate so that a Kelvin connection to R_{IN}^- can be made. This connection can also be seen in the suggested layout of Figure 2.

Figure 2 shows the V⁺ connections tied to the load side of R_{SENSE}, whereas Figure 1 shows a tie-in to the supply side. The LTC6102 will work in either configuration. The difference is that the Figure 2 connection will also include the LTC6102 quiescent supply current (300µA typically) in the measured load current. Supply voltages from 4V to 100V are supported.

Conclusion

The LTC6102 is the industry's highest precision current sense amplifier. The exceptional accuracy allows for dramatic reduction in the R_{SENSE} resistance, thereby improving efficiency, dynamic range and current handling.

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dn423f LT/TP 0907 451K • PRINTED IN THE USA

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