Low-Side Current Sense Circuit Integration

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Discrete implementations of current sense amplifiers are commonly used for low side current sensing applications. Low-side current sensing is when the voltage is measured across a sense resistor that is placed between the load and ground. Figure 1 shows the configuration for low side current sensing.

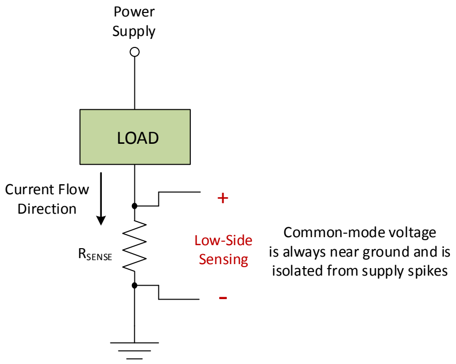

Figure 1. Low-side Current Sensing

When used as current sense amplifiers, discrete solutions sense and gain up the voltage generated across a low side sense resistor. Figure 2 shows two techniques that can be used to sense low-side currents.

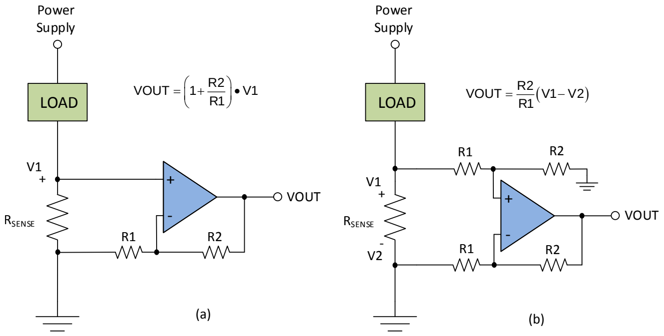

Figure 2. Discrete Implementations for Low-Side Sensing Configurations

The first technique shown in Figure 2a., achieves a signal sided measurement using two external gain-setting resistors. The single sided measurement uses the fewest components but does not sense at the ground side of the resistance. For low value sense resistors, or designs that can have high ground currents, this technique suffers from reduced accuracy.

The second approach shown in Figure 2b, uses a classical difference amplifier topology to sense the voltage drop directly across the sense resistor. This method delivers a higher level of accuracy, especially when higher currents are sensed, because any voltage drops from the resistor to the PCB ground are removed.

Even though discrete implementations are commonly used to implement low-side current sensing, careful selection of op-amp is needed in order to achieve optimal performance. For example, consider a widely used op-amp such as the LM321. This device has an input offset voltage as high as 7 mV. For current sensing applications, the offset voltage greatly impacts the accuracy when small differential voltage signals are measured. To increase the differential signal, and reduce the measurement error, the value of the sense resistor must be increased. A larger sense resistor value will result in increased power dissipation and will require a larger, more expensive, higher wattage resistor. The LM321 also has a slew rate of 0.4 V/µs and a gain bandwidth product of 1 MHz. When configured as gain of 20 current-sense amplifier, the bandwidth would be reduced to approximately 50 kHz. The low bandwidth and slew rate offered by the LM321 make this a poor design choice in applications where fast current signals need to be monitored, or over-current events need to be detected. The limitations of the of the output swing and input common mode range also restrict the areas which the device can operate, especially if the output of the current sense amplifier is connected to a lower voltage analog to digital convertor (ADC).

In contrast, the INA180 features a maximum offset of 150 µV, allowing accurate current sensing measurements with lower wattage, cost effective resistors. Also, with a 350 kHz bandwidth (G=20) and 2 V/µs slew rate, the INA180 can quickly track input current changes, making the device a good choice for motor control and over current detection applications. The INA180 can swing to within 30 mV to the positive supply and operate with common voltages up to 26V independent of the device supply voltage allowing the device to operate well with lower voltage ADCs.

Another factor to consider when implementing a discrete current sense amplifier is the PCB layout. R1 and R2 need to be placed as closely as possible to the operational amplifier and the current sense resistor. By placing these components close to the op-amp, the likelihood of noise pickup on the operational amplifier positive input is reduced. Since many current sense amplifiers are used with DC/DC convertors the placement of the entire current sense circuit needs to be carefully considered to avoid radiated noise by the DC/DC power supplies. The difference amplifier gain can be calculated by the equations shown in Figure 2. However, any increase or decrease in the gain will affect the solution stability and bandwidth. The stability of the op-amp requires special consideration in applications where a capacitive load is present to avoid oscillations or excessive output ringing.

The weaknesses of the discrete solution for current measurements are addressed by the circuit shown in Figure 3. The INA180 integrates the gain-setting resistors, reducing PCB area and improving the accuracy over discrete implementations that use external resistors. Since the resistors are incorporated into the integrated circuit, the matching and drift characteristics of the resistors are extremely good. This offers reduced gain error and improved common-mode rejection over low-cost discrete implementations. The INA180 is available in precision gains of 20, 50, 100, and 200 V/V.

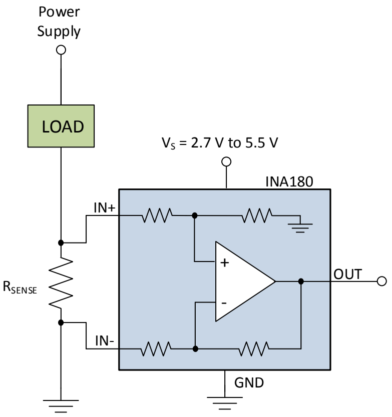

Figure 3. Low-Side Current Sensing with INA180 Current Sense Amplifier

Since the INA180 integrates the gain setting resistors many of the layout concerns that exist with discrete implementations are no longer of concern. The bandwidth and capacitor load stability are optimized for each gain-setting with max capacitive loads specified in the datasheet. The integration of the gain-setting resistors reduces PCB area, noise susceptibility, and simplifies the layout.

The INA180 provides an elegant way to upgrade from an existing discrete design. The first step to realize the advantages of an integrated current sense solution is the replace the discrete solution with the INA180.

The INA180 is offered in both SOT23 and SC70 packages. There are two pinout versions of the SOT23 pinout to allow maximum compatibility with operational amplifiers in that package. Since the pin-out of the INA180 matches most discrete solutions there is no need to change the PCB layout to realize the performance advantages of an integration. The next step would be to remove the external gain-setting resistors and populate the input resistors with zero ohm resistors. Figure 4 shows a typical layout for both a single ended and fully differential operational amplifier designs, as well as the required changes needed to realize the migration to the INA180.

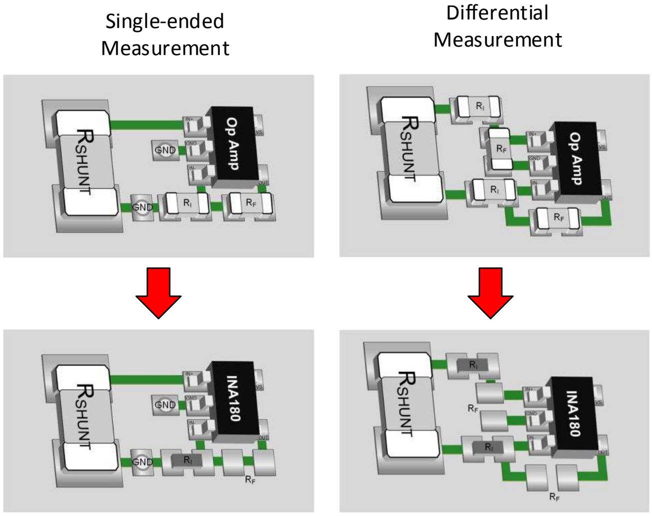

Figure 4. Discrete solution to INA180 PCB migration techniques

Alternate Device Recommendations

For applications that need INA180 performance but bi-directional current sensing capability refer to the INA181. For applications requiring higher performance, the INA199 series of devices provide low offset (150 µV Max at 12V common-mode) and gain error (1% Max).

Table 1. Alternative Device Recommendations

Device	Optimized Parameters	Performance Trade-Off
INA199	Accuracy	Slightly higher cost
INA210 - INA215	Highest Accuracy	Higher cost

Table 2. Adjacent Tech Notes

SBOA161	Low-Drift, Low-Side Current Measurements for Three Phase Systems
SBOA167	Integrating The Current Sensing Signal Path
SBOA169	Precision, Low-Side Current Measurement

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