Using High-Speed Amplifiers for Low-Side Shunt Current Monitoring to Increase Measurement Bandwidth

The need to accurately and quickly detect the load current through a low-side shunt resistor is a critical application in end equipment requiring protection from over current, feedback control loops, battery monitoring, and power supply monitoring. Load current is often measured using low-side current sensing, which is when the voltage is measured across a sense-resistor that is placed between the load and ground. One common way to discretely implement low-side current monitoring is by using a current sense amplifier in a difference configuration as shown in Figure 1 below.

![Figure 1. Low-Side Current Sensing Test Circuit Using the OPA354](image)

Traditionally, dedicated current sensing amplifiers, precision amplifiers or general-purpose amplifiers have been utilized in low-side current measurement applications. However, in applications where you need to detect small high speed transient pulses, these devices tend to lack the adequate bandwidth in order to replicate the pulse accurately in a single gain stage. A possible solution would be to use multiple gain stages with a lower bandwidth device, increasing the amount of components and potentially increasing the sense resistance in order to use a smaller gain. By having a large sense resistor you introduce noise to your signal, increase the power dissipation and cause ground disturbances. Instead, an alternative solution would be to use a single high speed amplifier. By using the high speed amplifier you have more gain-bandwidth, which allows you to use a single high gain stage with a small sense resistor. For current sensing applications, you want to choose an amplifier with low offset and noise so that it does not degrade the accuracy of low-voltage measurements. Consider a widely used op-amp such as OPA365. This device has a maximum input offset voltage as of 200 µV and an input voltage noise of 4.5 nV/√Hz at 100 kHz. Using an amplifier such as OPA365 will allow you to implement the circuit in a single high gain stage, save you board space, keep your sense resistor low, and enable you to drive the ADC with a single device. The OPA365 is available in an AEC-Q100 version (OPA365-Q1) to support automotive applications.

Choosing the correct amplifier will simplify detecting high current spikes that may cause damage to the system or reduce motor and servo efficiency, all while maximizing system efficiency. There are several benefits to using a high-speed amplifier solution over the traditional method. For example, in applications such as power supply monitoring, the duration of the pulse may be as low as 1 µs. Without being able to detect these transients, short duration pulses may go unnoticed causing some glitches or potential damage to the rest of the system. As shown in Figure 2 with a short duration of a 1-µs pulse input in a gain of 50, the OPA354 is able to reach 3-V output and is able to replicate the original input signal much closer than the 400 KHz INA and 20 MHz bandwidth op-amp. Looking at Figure 3, we introduced a 100-nA input pulse, in a gain of 50 and again the output response of the OPA354 is much closer than the other two devices.
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When using an op amp for measuring a small differential voltage signal from the shunt resistor, you want to make sure the op amp has enough bandwidth to make a precise and accurate measurement without introducing error to the signal for maximum system efficiency. Measuring short duration pulses can be a challenge, but by using a high-speed amplifier, you have high slew rates and plenty of bandwidth to track the input signal. This article used the OPA365 as an example, but there are many other suitable amplifiers offered by Texas Instruments. For automotive applications requiring AEC Q100 devices the OPA365-Q1 is available. For applications that need similar performance to the OPA365 or OPA365-Q1 but require higher bandwidth and higher slew rate, refer to the OPA83x or OPA2836-Q1 family which offers a slew rate of 560 V/µs with a gain bandwidth product of 120 MHz. For applications requiring even higher bandwidth and higher slew rate offered by the OPA365, the OPAx354 or OPAx354-Q1 offers a slew rate of 150 V/µs with a gain bandwidth product of 250 MHz. For applications requiring OPA365 performance but higher supply ranges, the LMH661x family offers supply up to 12.8 V (maximum). Table 1 gives you alternative device recommendations with parameter benefits and what the tradeoffs are of using each of the devices compared to the OPA365.

Table 1. Alternative Device Recommendations

<table>
<thead>
<tr>
<th>Device</th>
<th>Optimized Parameters</th>
<th>Performance Trade-Off</th>
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</thead>
<tbody>
<tr>
<td>OPAx836</td>
<td>Higher bandwidth, lower power consumption</td>
<td>IN to –V rail, slightly less output current</td>
</tr>
<tr>
<td>OPA2836-Q1</td>
<td>Dual channel, higher bandwidth, lower power consumption, automotive qualification</td>
<td>IN to –V rail, slightly less output current</td>
</tr>
<tr>
<td>OPAx354 / OPAx354-Q1</td>
<td>Higher bandwidth, higher slew rate, higher output current, automotive qualification (Q1)</td>
<td>Slightly higher offset and power consumption</td>
</tr>
<tr>
<td>LMH6618</td>
<td>Higher supply (maximum), higher bandwidth, lower Iq</td>
<td>Slightly higher noise and less output current</td>
</tr>
<tr>
<td>LMH6611</td>
<td>Higher supply (maximum), higher bandwidth, higher slew rate</td>
<td>IN to –V rail, slightly higher power consumption</td>
</tr>
<tr>
<td>LMH664x / LMH6642Q-Q1</td>
<td>Single, dual, quad channels, higher supply (maximum), lower Iq, automotive qualification (Q1)</td>
<td>IN to –V rail, slightly higher noise</td>
</tr>
</tbody>
</table>

In another example, you may have a three-phase inverter shunt sensing large negative phase voltages. These PWM duty cycles tend to be very small (at around 2 µs). The current-sense amplifier must be able to settle to < 1% in this time frame and in many cases drives the ADC. In applications such as a three-phase inverters, you want to maintain low distortion at the maximum rate at which the output will change with respect to time. In general, high-speed amplifiers offer slew rates > 25 V/µs and fast settling times of < 0.5 µs, making them ideal when you have a high rate of change in the output voltage caused by a step change on the input in the form of short current pulses. Having a high slew rate, larger bandwidth, and a fast settling high-speed amplifier contributes to keeping the detection time down to a few microseconds. By using a high-speed amplifier for motor control applications, you are able to get a fast and precise current measurement for the best dynamic motor control, minimum torque ripples, and minimal audible noise.
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