

# Increase Measurement Accuracy Using High-Speed Amplifiers for Low-Side Shunt Current Monitoring

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The need to accurately and quickly detect the load current through a low-side shunt resistor is a critical application in systems requiring overcurrent, 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 shunt-resistor that is placed between the load and ground. One common way to discretely implement low-side current monitoring is to use a current-sense amplifier in a difference configuration, as shown in Figure 1.

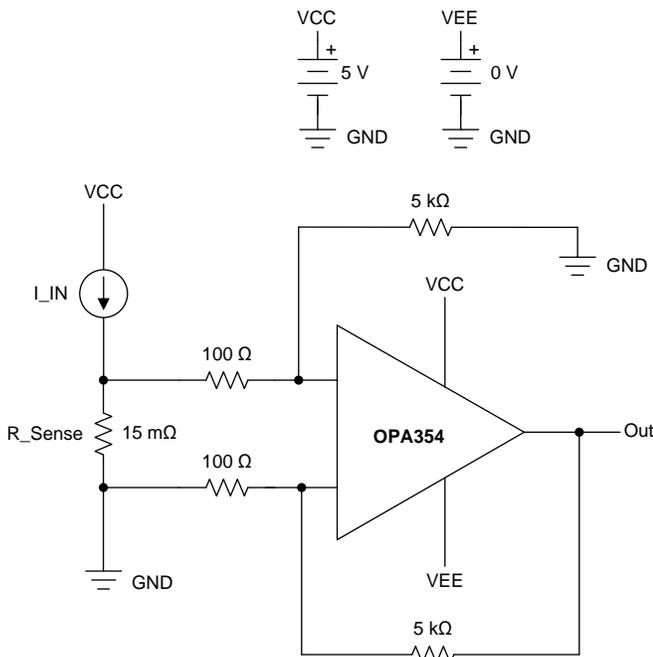
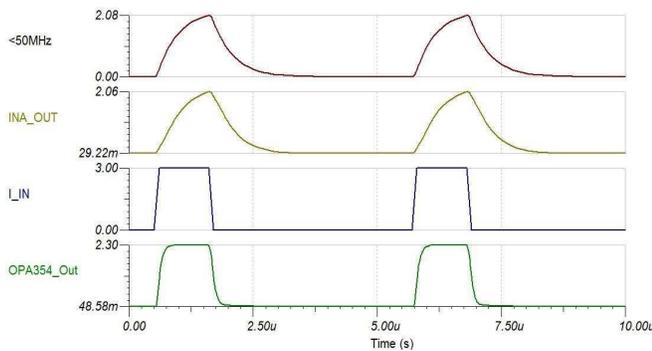


Figure 1. Low-Side Current Sensing Test Circuit Using the OPA354

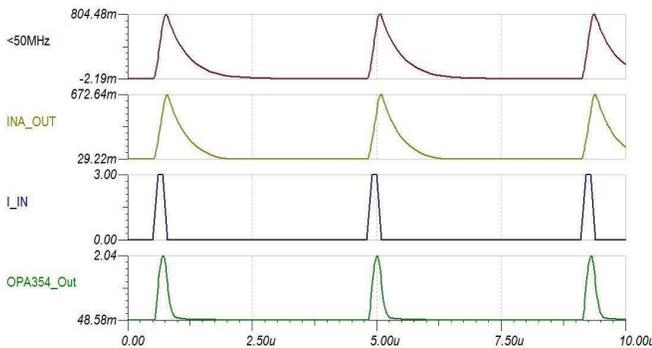
Traditionally, this low-side current measurement is done with a dedicated current sense amplifier or a lower-speed amplifier connected to an external shunt-resistor. However, in applications that are required to detect a small, high-speed transient pulse, these amplifiers tend to lack the adequate bandwidth needed

to replicate the pulse accurately in a single gain stage. A possible solution is to use multiple gain stages with a lower bandwidth device, thus increasing the amount of components and potentially increasing the shunt resistance in order to use a smaller gain. By having a large shunt-resistor, you introduce noise to your signal, increase the power dissipation, and cause ground disturbances. Instead, an alternative solution is 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 shunt-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 the OPA365. This device has a maximum input offset voltage as of 200  $\mu\text{V}$  and an input voltage noise of 4.5  $\text{nV}/\sqrt{\text{Hz}}$  at 100 kHz. Using an amplifier such as OPA365 allows you to implement the circuit in a single high-gain stage, save board space, keep the shunt-resistor low, and enable driving an analog-to-digital converter (ADC) with a single device. The OPA365 is available in an AEC-Q100 version (OPA365-Q1) that supports automotive applications.

Choosing the correct amplifier simplifies detection of 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 in current-sensing circuit. For example, in applications such as power-supply monitoring, the duration of the pulse may be as low as 1  $\mu\text{s}$ . Without being able to detect these transients, short-duration pulses may go unnoticed, and thus cause glitches or potential damage to the rest of the system. As shown in Figure 2, with a short-duration 1- $\mu\text{s}$  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 a 400-kHz or a 20-MHz bandwidth op amp. As Figure 3 shows, 100-nA input pulse in a gain of 50 is introduced, and again the output response of the OPA354 is much closer than the other two devices.



**Figure 2. Output Response With a 3-A, 1-µs Input Into 15 mΩ With a Gain of 50 vs an Integrated and Lower-Bandwidth Device**



**Figure 3. 100-nA Pulse Input Into 15 mΩ With a Gain of 50 vs an Integrated and Lower-Bandwidth Device**

In another example, a three-phase inverter shunt-resistor is sensing large negative phase voltages. These PWM duty cycles tend to be very small (around 2 µs). The current sense amplifier must be able to settle to < 1% in this time frame, and in many cases drive an ADC. In applications such as three-phase inverters, maintain low distortion at the maximum rate at which the output changes with respect to time. In general, high-speed amplifiers offer slew rates > 25 V/µs and fast settling times of < 0.5 µs. These features make high-speed amplifiers a great choice when a high rate of change exists in the output voltage that is caused by a step change on the input in the form of short current pulses. High slew rate, larger bandwidth, and fast settling high-speed amplifiers contribute to keeping the detection time down to a few

microseconds. Use a high-speed amplifier for motor-control applications to provide a fast and precise current measurement for the best dynamic motor control, minimum torque ripple, and minimal audible noise.

For maximum system efficiency when using an op amp to measure a small differential voltage signal from the shunt-resistor, make sure the op amp has enough bandwidth to make a precise and accurate measurement without introducing error to the signal. Measuring short duration pulses are a challenge, but by using a high-speed amplifier, high slew rates and plenty of bandwidth are available to track the input signal. This article used the OPA354 as an example, but there are many other available amplifiers offered by Texas Instruments. For automotive applications that require higher supply ranges or higher bandwidth, see [Table 1](#). The amplifiers listed in [Table 1](#) give alternative recommendations with optimized parameter benefits, and what the performance trade-offs are of using each of the devices.

**Table 1. Alternative Device Recommendations**

Device	Optimized Parameters	Performance Trade-Offs
<a href="#">OPA836</a>	Higher bandwidth, lower power consumption	IN to -V rail, slightly less output current
<a href="#">OPA2836-Q1</a>	Dual channel, higher bandwidth, lower power consumption, automotive qualification	IN to -V rail, slightly less output current
<a href="#">OPA354</a> <a href="#">OPA354-Q1</a>	Higher bandwidth, higher slew rate, higher output current, automotive qualification (Q1)	Slightly higher offset and power consumption
<a href="#">LMH6618</a>	Higher supply (maximum), higher bandwidth, lower I <sub>Q</sub>	Slightly higher noise and less output current
<a href="#">LMH6611</a>	Higher supply (maximum), higher bandwidth, higher slew rate	IN to -V rail, slightly higher power consumption
<a href="#">LMH6642</a> <a href="#">LMH6642Q-Q1</a>	Single, dual, quad channels, higher supply (maximum), lower I <sub>Q</sub> , automotive qualification (Q1)	IN to -V rail, slightly higher noise

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