

## Common-Mode Step Response of Current Sense Amplifiers

by Paul Blanchard and Anna Fe Briones

### INTRODUCTION

Current sense amplifiers are one of the specialty amplifiers from Analog Devices, Inc., used to amplify small differential signals in the presence of large common-mode voltages. A typical application for a current sense amplifier is amplifying the voltage across a shunt resistor. Analog Devices offers a variety of current sense amplifiers that operate with supply voltages as low as 1.8 V and withstand input common-mode voltages as high as 600 V.

**Table 1. Supply Voltages and Input Common-Mode Voltages of Analog Devices Current Sense Amplifiers**

Device Number	V <sub>SUPPLY</sub>		Input Common-Mode Voltage	
	Min	Max	Min	Max
AD8293G80	1.8 V	5.5 V	1.8 V	5.5 V
AD626	2.4 V	10 V	-24 V	24 V
AD8274	2.5 V	18 V	-40.5 V	40.5 V
AD8279	4 V	36 V	-45.3 V	40.5 V
AD8210	4.5 V	5.5 V	-2 V	65 V
AD8207	4.5 V	5.5 V	-4 V	65 V
AD8418/AD8418A	2.7 V	5.5 V	-2 V	70 V
AD628	4.5 V	36 V	-120 V	120 V
AD629	5 V	36 V	-270 V	270 V
AD8479	5 V	36 V	-600 V	600 V

Many applications that use shunt resistors have common-mode voltages that vary as a function of time. Some examples of shunt applications with varying common-mode voltages are H bridge motor drivers, solenoid controllers, and dc to dc switching converters. In these applications, the common-mode voltages seen by the current sense amplifier vary, in PWM fashion, from a battery voltage to ground.

An ideal current sense amplifier does not react to the input common-mode variation. In practice, the current sense amplifier has a finite amount of common-mode rejection, typically specified at dc and in the order of 100  $\mu\text{V/V}$  or 80 dB.

**Table 2. CMRR of Analog Devices Current Sense Amplifiers**

Device Number	CMRR (dB)
ADA4830-1	65
AD8270	76
AD8210	80
AD8207	80
AD8203	82
AD8418/AD8418A	86
AD8207	90
AD8210	100
AD8211	120
AD8293G80	140

In addition to the output errors due to the dc common-mode rejection ratio (CMRR), there are errors associated with ac CMRR and the common-mode step response of the amplifier. This application note focuses on the common-mode step response of current sense amplifiers<sup>1</sup>.

<sup>1</sup> Protected by U. S. Patent No. 8,624,668; other patents pending.

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**REVISION HISTORY**

**10/15—Rev. 0 to Rev. A**

Change to Figure 3 .....	5
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**6/14—Revision 0: Initial Version**

## COMMON-MODE STEP RESPONSE

Ideally, current sense amplifiers produce an output based on the difference of its inputs regardless of the actual values of the inputs (that is, common-mode voltage). However, in practice, the amplifier output may change at different common-mode levels of its input. The varying output with varying common-mode input is referred to as the common-mode step response.

The common-mode step response of the amplifier may be especially important in applications with large changes in the input common-mode voltage; while the amplifier is recovering from the change in the input common-mode voltage, the output of the amplifier may not be valid due to the new offset induced by the new common-mode level. Thus, a long settling time of the amplifier (and thus the large error during that period) may seriously degrade the dynamic performance of the amplifier.

### COMMON-MODE STEP RESPONSE MEASUREMENT

Very fast and accurate common-mode step response of current sense amplifiers is challenging to achieve. It needs to have a stable and fast source, fully shielded connectors, and a properly designed circuit. Figure 1 shows the basic functional block diagram used for this measurement.

#### PWM Input

A PWM signal frequency of 0 Hz to 100 kHz is generated by a waveform generator and is used as the input signal of the MOSFET driver.

#### MOSFET Driver

The MOSFET driver injects a high current to the MOSFETs to achieve fast switching, thus eliminating too much heat dissipation. The current provided by the driver is in the range of hundreds of milliamperes or even amperes.

#### MOSFET

The output of the driver is a positive voltage, thus N-channel power MOSFETs are used. These MOSFETs can tolerate a voltage as high as 100 V, and they have typical rise and reverse recovery times of 35 ns and 115 ns, respectively. In addition, these MOSFETs have an  $R_{ON}$  of 44 m $\Omega$  (which is enough to maintain the integrity of the signal) and can dissipate power as high as 130 W. The output of these MOSFETs serves as the common-mode input voltage ( $V_{CM}$ ) of the current sense amplifier.

#### Current Sense Amplifier

A current sense amplifier amplifies the small differential signal in the presence of a large common-mode voltage. The current sense amplifiers tested in this application note have common-mode voltages as high as 80 V, and they are powered with a single 5 V supply.

#### Common-Mode Step Response

The output of the current sense amplifier produces the common-mode step response waveform. This response may show a waveform with either a positive or negative peaking in the rising or falling edge depending on the dominance of either the inverting or the noninverting input.

Figure 2 shows the simplified schematic diagram for the measurement of the common-mode step response. The current sense amplifier modeled in this schematic diagram is the [AD8210](#).

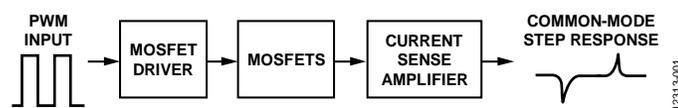


Figure 1. Functional Block Diagram

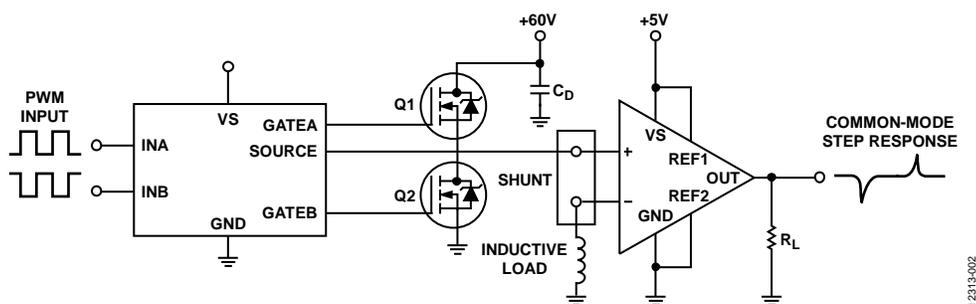


Figure 2. Simplified Schematic of Common-Mode Step Response Measurement of Current Sense Amplifiers (Decoupling and All Connections Not Shown).

## COMMON-MODE STEP RESPONSE RESULTS

Several Analog Devices current sense amplifiers configured in a shunt circuit were evaluated and compared to the most popular current sense amplifier from a competitor. The [AD8210](#), the first current shunt monitor evaluated, is a single-supply bidirectional current sense amplifier that can tolerate a common-mode voltage range of  $-2\text{ V}$  to  $+65\text{ V}$ . It has reference pins ( $V_{\text{REF}}$ ) used to adjust the output offset and a fixed gain of 20.

The [AD8207](#), a bidirectional difference amplifier configured as a current shunt amplifier, was also evaluated. It can resist a common-mode voltage range of  $-4\text{ V}$  to  $+65\text{ V}$  for a  $+5\text{ V}$  supply and  $-4\text{ V}$  to  $+35\text{ V}$  for a  $+3.3\text{ V}$  supply. It also features a zero drift core that provides a typical offset drift less than  $500\text{ nV}/^{\circ}\text{C}$  and a gain drift typically below  $10\text{ ppm}/^{\circ}\text{C}$ . It also has a fixed gain of 20.

The [AD8418](#) and [AD8418A](#) were also evaluated. These two current sense amplifiers feature a zero drift core that leads to a typical offset drift of  $0.1\text{ }\mu\text{V}/^{\circ}\text{C}$  throughout the operating temperature range and have common-mode voltage range of  $-2\text{ V}$  to  $+70\text{ V}$ . These two amplifiers are also fully qualified for automotive applications, include electromagnetic interference (EMI) filters, and patented circuitry to enable output accuracy with pulse-width modulation (PWM) type input common-mode voltages.

Figure 3 shows the comparison of the waveforms of the different Analog Devices current sense amplifiers with those of a competitor for an input common-mode voltage of  $60\text{ V}$ .

## COMMON-MODE STEP RESPONSE MEASUREMENT TECHNIQUES

To produce the accurate common-mode step response of a current sense amplifier, consider the connections, the components used, and the component placement.

### Connections

Ensure that connector leads, such as in power supply, waveform generator, input, output, scope probes, and other interface connectors, are as close as possible to the part or device under test (DUT) to avoid inducing or generating noise and interference in the wires.

Ensure that ground connections meet at only one point, single point ground, to avoid having different ground potentials in the system causing ground loop problems.

Instead of using the alligator clip for the ground of the scope probe, use a probe tip ground (like a coil of wire) and insert this in the probe. If this tip is unavailable, make a coil out of a solid or single-stranded wire and then solder this next to the probing points (input and output pins of current sense amplifiers) to measure only the desired signal, thus eliminating inductive noise that can cause unwanted ringing or peaking.

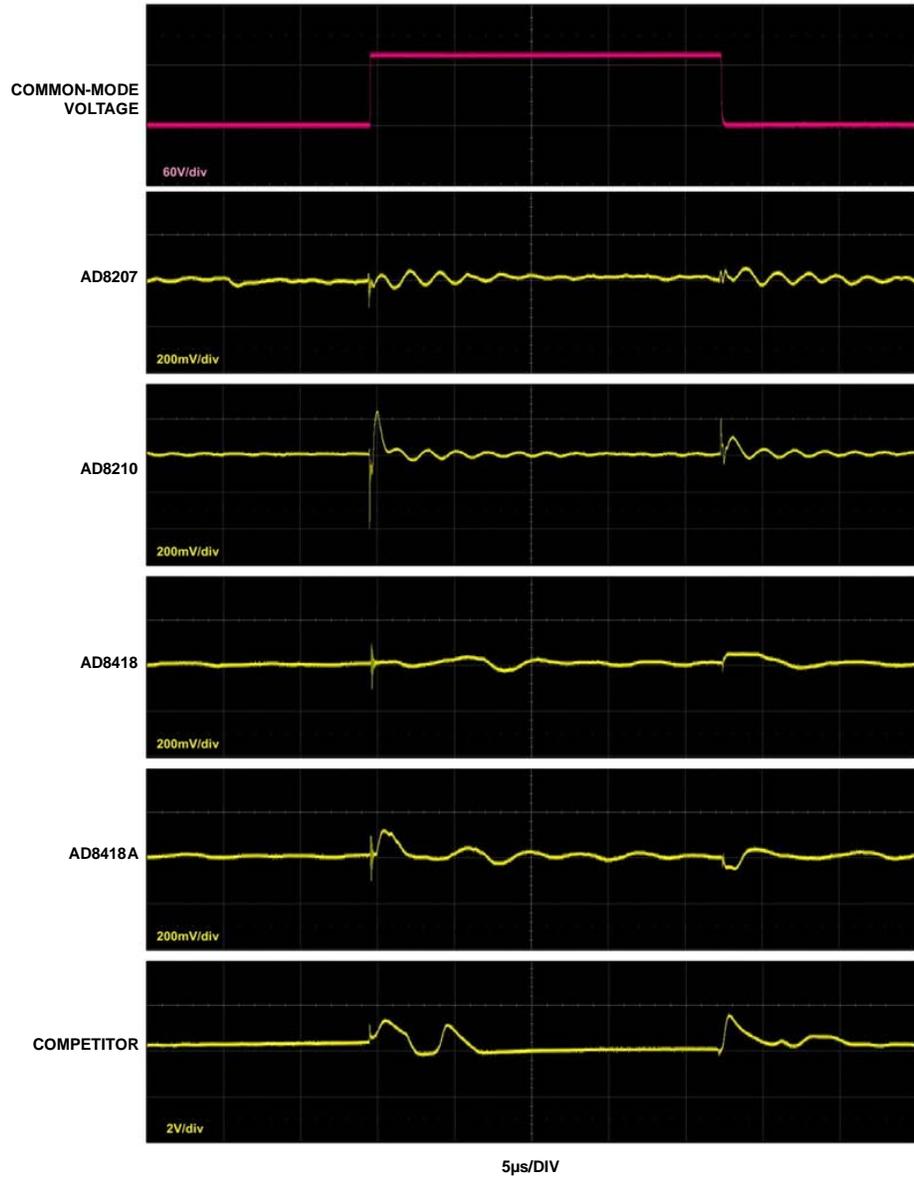


Figure 3. Common-Mode Step Response Measurement of Current Sense Amplifiers from Analog Devices and from a Competitor

**Components Used**

Add bypass capacitors in the power supplies to reduce the ripple voltage in the circuit and do not take them for granted. Ceramic capacitors are good for this usage because of their high stability, high efficiency, and low loss.

Because the input common-mode voltage used in this application note is 60 V, ensure that the load resistor of the MOSFET driver has a large power rating so that it can tolerate the high current flowing through it.

To minimize losses caused by often charging and discharging of the MOSFET diode, ensure that MOSFETs have short reverse recovery time.

**Component Placement**

Discrete devices comprising the MOSFET driver circuit, including the MOSFETs, and place the current sense circuit as close as possible to the MOSFET driver to minimize ac impedance and to avoid noise or interference generated by long traces.

**CONCLUSION**

Analog Devices current sense amplifiers, as tested and verified, experience overshoot or undershoot of less than 700 mV. The competing product has almost 2 V overshoot. The Analog Devices current sense amplifiers described in this application note stabilized faster for both the rising and falling edges of the input common-mode voltage than the competing product. In addition, these amplifiers actually reject very high input common-mode voltages of up to 60 V. With these advantages over the competing product, Analog Devices current sense amplifiers are useful in preventing circuit faults, in preventing over discharged batteries, and in maintaining the health of certain systems, such as battery monitors, power regulators, electric vehicles, generators, and motor controls.

**FOR FURTHER INFORMATION**

Additional information on the patent for improved common-mode step response for auto-zero amplifiers listed and described in the Introduction section can be found in the Improved Common Mode Step Response for Autozero Amplifiers patent document on the web.

In addition, the following data sheets may be helpful:

- [AD8210](#)
- [AD8207](#)
- [AD8418](#)
- [AD8418A](#)