Isolated Current-Sensing Circuit With ±50-mV Input and Single-Ended Output

TEXAS INSTRUMENTS

Data Converters

Samiha Sharif

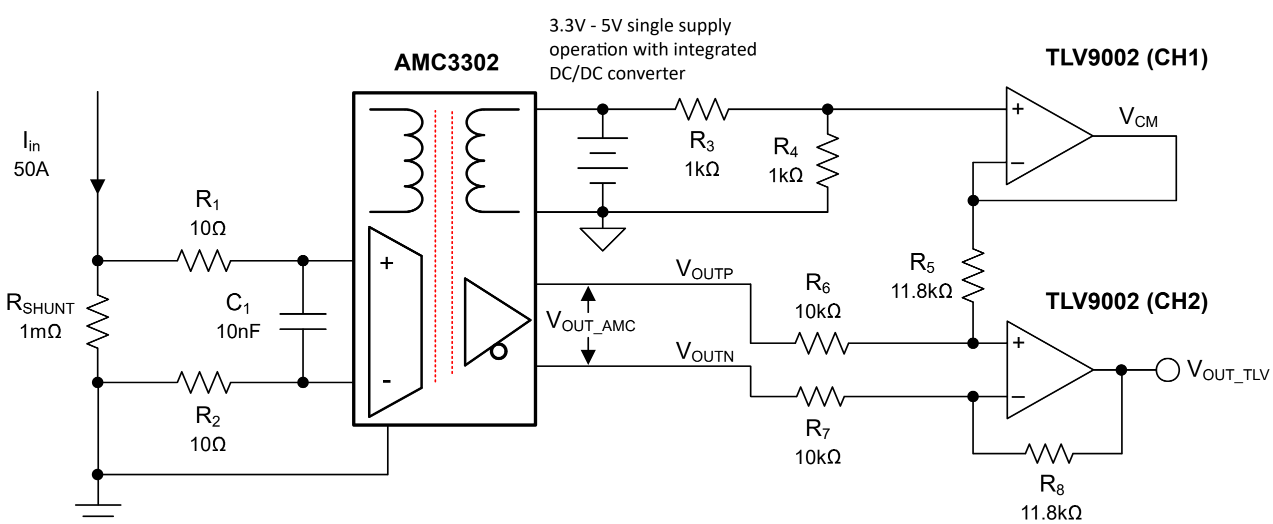
Design Goals

Current Source		Input Voltage		Output Voltage	Single Power Supply
$I_{IN\ MIN}$	$I_{IN\ MAX}$	$V_{IN\ DIFF,\ MIN}$	$V_{IN\ DIFF,\ MAX}$	$V_{OUT\ SE}$	V_{DD}
–50A	50A	–50mV	50mV	55mV to 4.945V	5V

Design Description

This isolated single-supply bidirectional current sensing circuit can accurately measure load currents from –50 A to 50 A. The linear range of the input is from –50 mV to 50 mV with a differential output swing of –2.05 V to 2.05 V and an output common-mode voltage (V_{CM}) of 1.44 V. The gain of the isolated amplifier circuit is fixed at 41 V/V. A secondary amplifier stage, using TLV9002, converts the differential output voltage to a single-ended output voltage of 55 mV to 4.945 V. The entire signal chain operates on a single 5.0 V rail.

This circuit is applicable to many high-voltage industrial applications such as Solar Inverters, Motor Drives and Protection Relays. The equations and explanation of component selection in this design can be customized based on the needs and system specification of the end equipment.



Design Notes

1. The AMC3302 was selected due to its accuracy, input voltage range, and the single low-side power requirements of the device.
2. The TLV9002 was selected for its low cost, low offset, small size, and dual channel.
3. Select a low impedance, low-noise source for AVDD which supplies the TLV9002 and AMC3302 as well as provides the common-mode voltage for the single-ended output.
4. For highest accuracy, use a precision shunt resistor with low temperature coefficient.
5. Select the current shunt for expected peak input current levels.
6. For continuous operation, do not run the shunt resistors at more than two-thirds the rated current under normal conditions as per IEEE standards. Further reducing the shunt resistance or increasing the rated wattage may be necessary for applications with stringent power-dissipation requirements.
7. Use the proper resistor divider values to set the common-mode voltage appropriately.
8. Select the proper values for the gain setting resistors on channel 2 of the TLV9002 so that the single-ended output has an appropriate output swing.

Design Steps

1. Determine the transfer equation given the input current range and the fixed gain of the isolation amplifier.

$$V_{OUT} = I_{in} \times R_{shunt} \times 41$$

2. Determine the maximum shunt resistor value.

$$R_{shunt} = \frac{V_{inMax}}{I_{inMax}} = \frac{50\ mV}{50\ A} = 1\ m\Omega$$

3. Determine the minimum shunt resistor power dissipation.

$$Power\ R_{shunt} = {I_{inMax}}^2 \times R_{shunt} = 2500\ A \times 0.001\ \Omega = 2.5\ \mathrm{W}$$

4. To interface with a 5 V ADC, the AMC3302 and TLV9002 can both operate at 5 V so a single-supply can be used.
5. Channel 1 of the TLV9002 is used to set the 2.5 V common-mode voltage of the single-ended output of channel 2. With a 5 V supply, a simple resistor divider can be used to divide 5 V down to 2.5 V. Using 1 kΩ for R_4, R_3 can be calculated using the following equation.

$$R_3 = \frac{V_{DD} \times R_4}{V_{CM}} - R_4 = \frac{5\ V \times 1000\ \Omega}{2.5\ V} - 1000\ \Omega = 1000\ \Omega$$

6. The TLV9002 is a rail-to-rail operational amplifier. However, the output of the TLV9002 can swing a maximum of 55 mV from its supply rails. Because of this, the single-ended output should swing from 55 mV to 4.945 V (4.89 Vpk-pk).
7. The V_{OUTP} and V_{OUTN} outputs of the AMC3302 are 2.05 Vpk-pk, 180 degrees out of phase, and have a common-mode voltage of 1.44 V. Therefore, the differential output is ±2.05 V or 4.1 Vpk-pk. To stay within the output limitations of the TLV9002, the output of the AMC3302 needs to be amplified by a factor of 4.89 / 4.1. When $R_6 = R_7$ and $R_5 = R_8$, the following transfer function can be used to calculate R_5 and R_8.

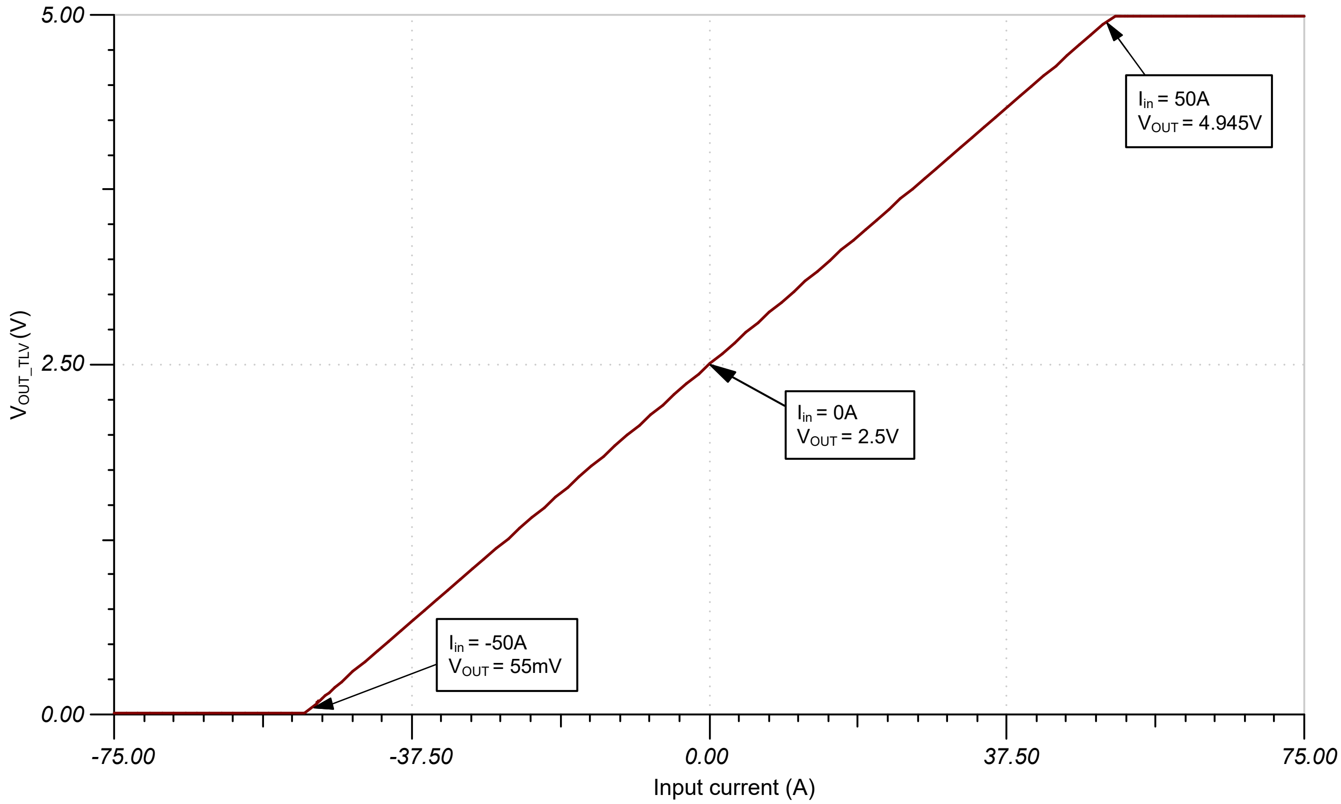
$$V_{OUT} = (V_{OUTP} - V_{OUTN}) \times \left(\frac{R_{5,8}}{R_{6,7}}\right) + V_{CM}$$

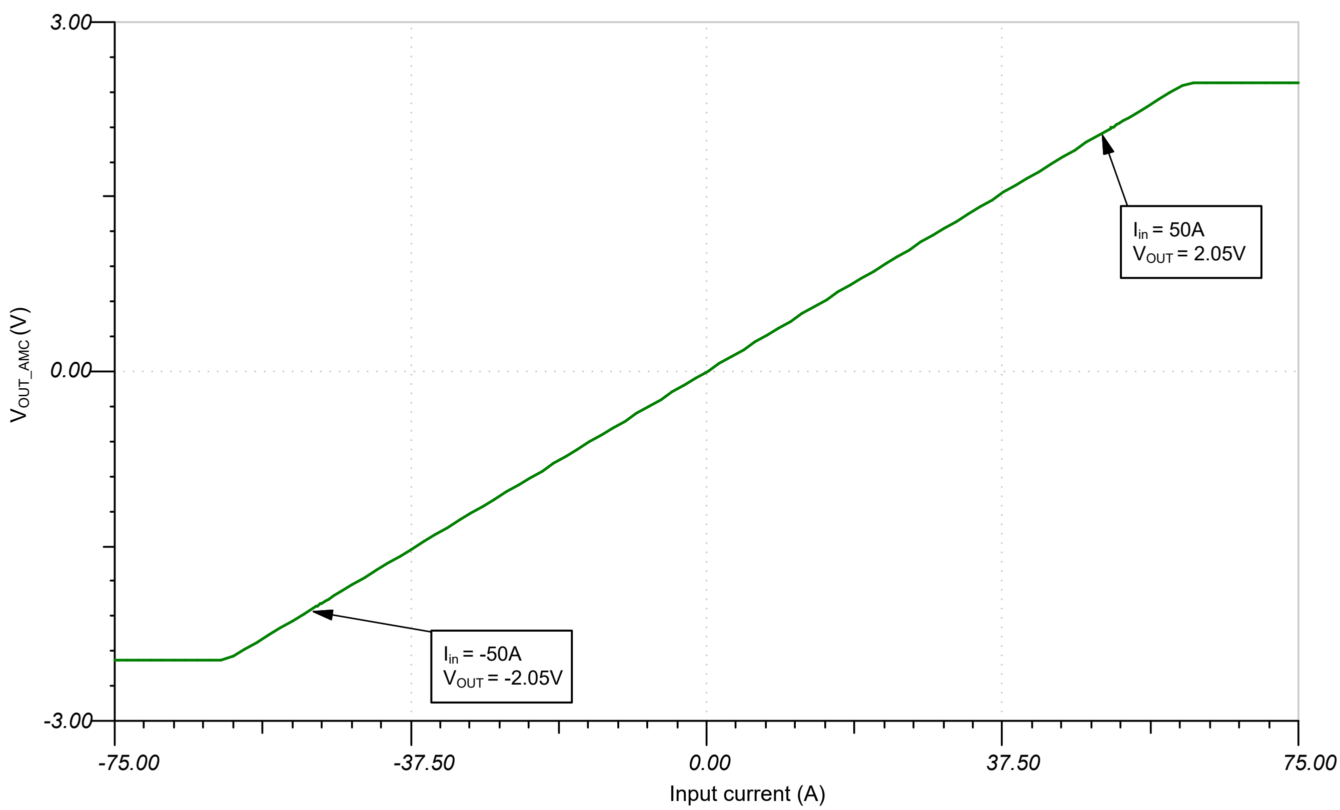
8. Using the previously calculated output swing of the TLV9002 and choosing R_6 and R_7 to be 10 kΩ, R_5 and R_8 can be calculated to be 11.93 kΩ using the following equation. To account for standard resistor values, use 11.8 kΩ resistors instead.

$$4.945 = (2.465\ V - 415\ mV) \times \left(\frac{R_{5,8}}{10\ k\Omega}\right) + 2.5$$

DC Transfer Characteristics

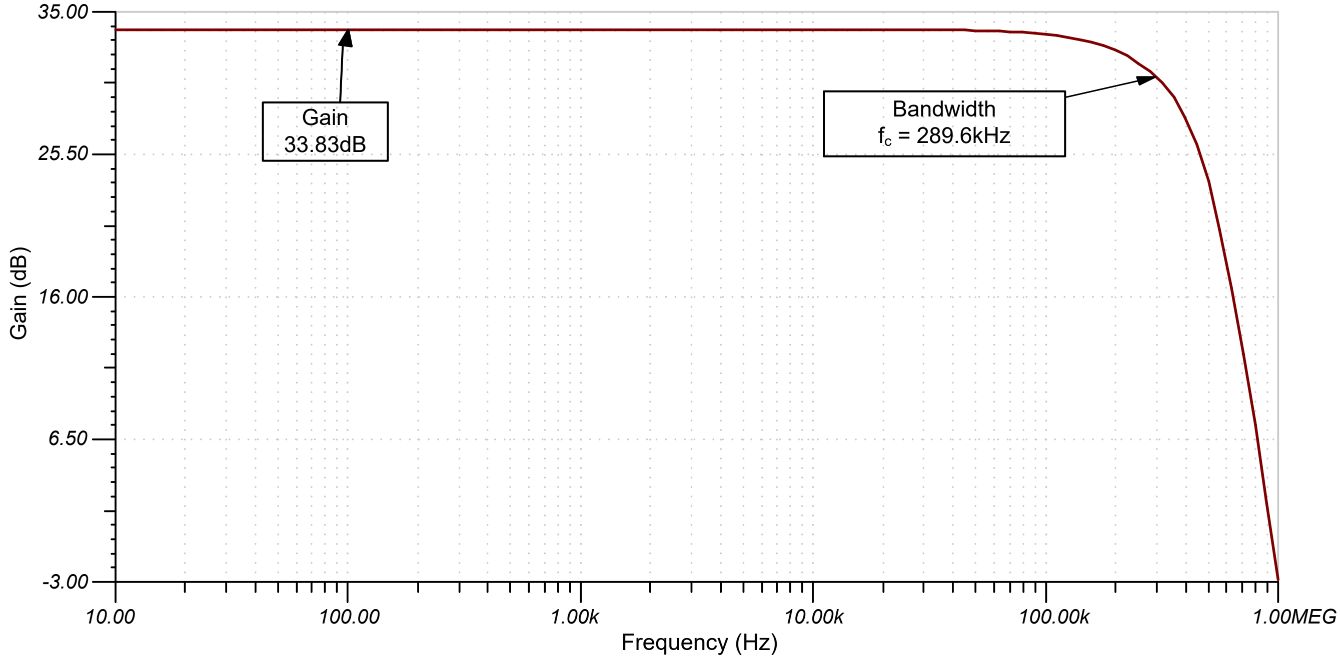
The following plots show the simulated DC characteristics of the single-ended output of the TLV9002 amplifier and the AMC3302 differential output. Both plots show that the outputs are linear at ±50 A.





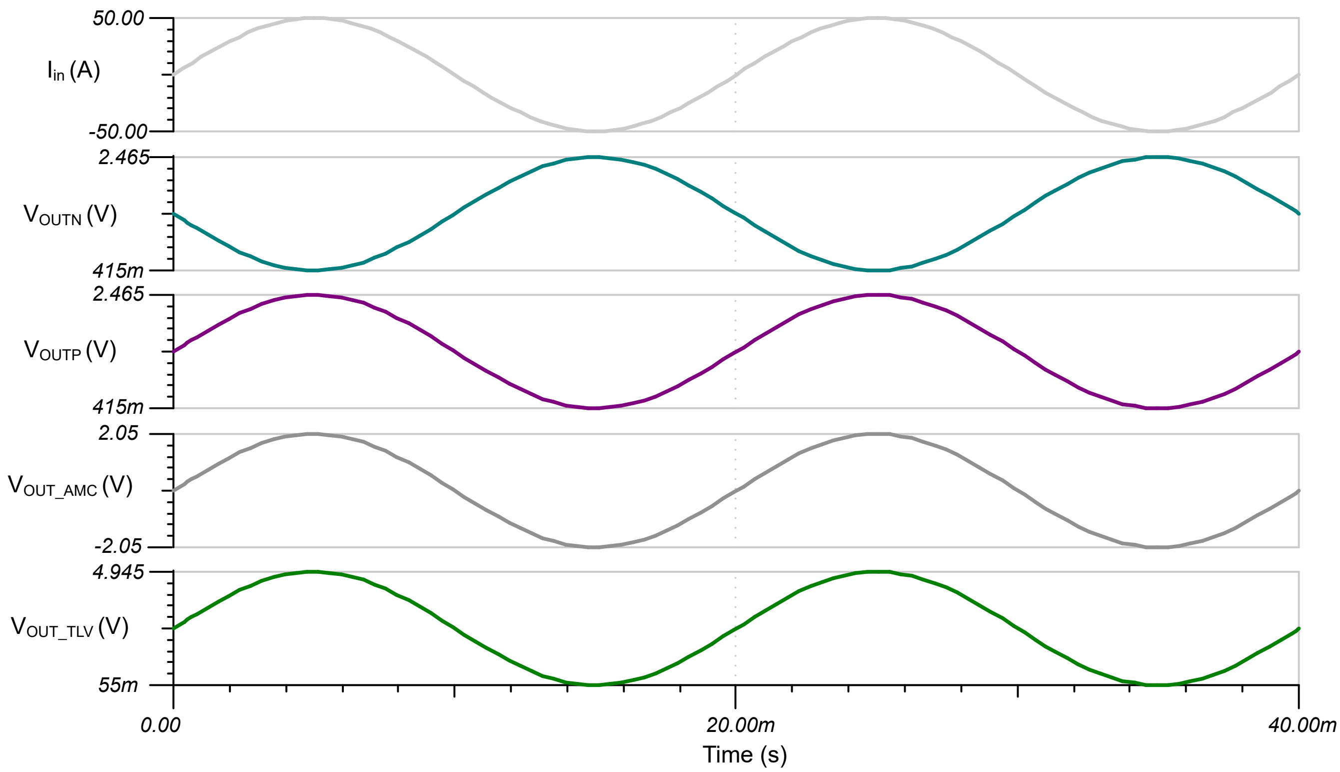
Closed-Loop AC Simulation Results

The following AC sweep shows the AC transfer characteristics of the single-ended output. Since the AMC3302 has a gain of 41 V/V and a gain of 1.2 V/V is applied with the differential to single-ended conversion, the gain of 33.83 dB shown in the following is expected.



Transient Simulation Results

The following transient simulation shows the output signals of both the AMC3302 and TLV9002 from –50 A to 50 A. The differential output of the AMC3302 is ±2.05 Vpk-pk as expected and the single-ended output is 4.89 Vpk-pk and swings from 55 mV to 4.945 V.



Design References

See *Analog Engineer's Circuit Cookbooks* for TI's comprehensive circuit library.

Texas Instruments, *Interfacing a Differential-Output (Isolated) Amp to a Single-Ended Input ADC* application brief.

Design Featured Isolation Amplifier

AMC3302	
Working voltage	1200 V_{RMS}
Gain	41 V/V
Bandwidth	340 kHz TYP
Linear input voltage range	±50 mV
AMC3302	

Design Differential to Single-Ended Amplifier

TLV9002	
V_{CC}	1.8 V to 5.5 V
V_{inCM}, V_{out}	Rail-to-Rail
V_{os}	400 µV
I_q	60 µA
UGBW	1 MHz
SR	2 V/µs
TLV9002	

Design Alternate Isolation Amplifier

AMC3301	
Working voltage	1200 V_{RMS}
Gain	8.2 V/V
Bandwidth	334 kHz TYP
Linear input voltage range	±250 mV
AMC3301	

Design Alternate Differential to Single-Ended Amplifier

TLV6002	
V_{CC}	1.8 V to 5.5 V
V_{inCM}, V_{out}	Rail-to-Rail
V_{os}	750 µV
I_q	75 µA
UGBW	1 MHz
SR	0.5 V/µs
TLV6002	

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265