Analog Engineer's Circuit

Isolated Current-Sensing Circuit With ±250-mV Input Range and Single-Ended Output Voltage

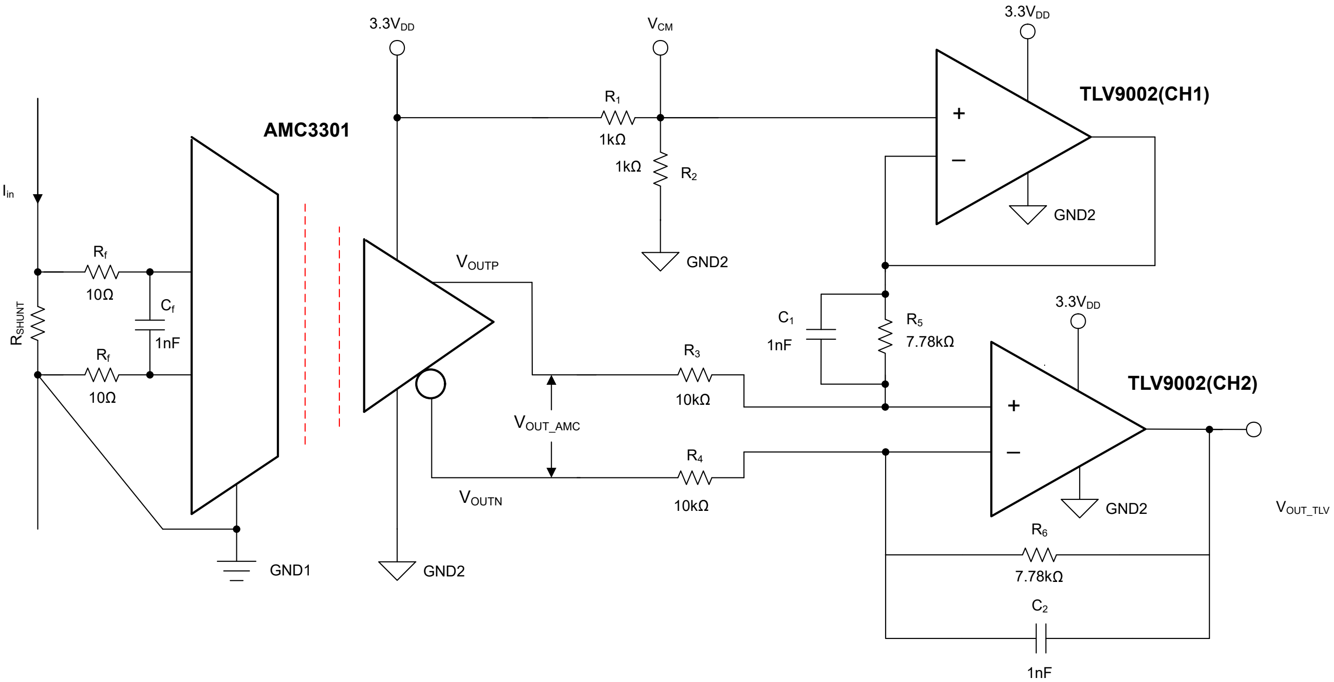
Data Converters

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}
–10 A	10 A	–250 mV	250 mV	55 mV to 3.245 V	3.3 V

Design Description

This isolated current sensing circuit can accurately measure load currents from, but not limited to, –10 A to 10 A with a nominal power dissipation of 2.5 W across a 25-mΩ shunt resistor. The linear range of the isolated amplifier input is from –250 mV to 250 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 8.2 V/V. A TLV9002 is used to transform the differential output signal to a single-ended signal that can be used with a single-ended ADC such as the ADS8326 as well as buffer the V_{CM} derived from a voltage divider. A 1.65-V reference voltage is used to set the final output voltage range and the common-mode voltage level.



Design Notes

1. The AMC3301 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 package.
3. Select a low impedance, low-noise source for AVDD which supplies the TLV9002 and AMC3301 as well as provides the common-mode voltage for the single-ended output.
4. For highest accuracy, use a precision shunt resistor with a low temperature coefficient.
5. Select the current shunt for expected peak input current levels.
6. For continuous operation, it is recommended that the shunt resistors are not run 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 on channel 1 of the TLV9002.
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.

   $$V_{OUT} = I_{in} \times R_{shunt} \times 8.2$$

2. Determine the maximum shunt resistor value.

   $$R_{SHUNT} = \frac{V_{inMax}}{I_{inMax}} = \frac{250\text{mV}}{10\text{A}} = 25\text{m}\Omega$$

3. Determine the minimum shunt resistor power dissipation.

   $$\text{Power } R_{SHUNT} = I_{inMax}{}^{2} \times R_{SHUNT} = 100\text{A} \times .025\Omega = 2.5\text{W}$$

4. To interface with a 3.3V ADC, the AMC3301 and TLV9002 can both operate at 3.3-V supply voltages so a single-supply can be used.
5. Channel 1 of the TLV9002 is used to set the 1.65-V common-mode voltage of the single-ended output of channel 2. With a 3.3-V supply, a simple resistor divider can be used to divide 3.3 V down to 1.65 V. Using 1 kΩ for R2, R1 can be calculated using the following equation.

   $$R_1 = \frac{V_{DD} \times R_2}{V_{CM}} - R_2 = \frac{5\text{V} \times 1000\Omega}{2.5\text{V}} - 1000\Omega = 1000\Omega$$

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. To meet this requirement, the single-ended output of the TLV9002 should swing from 55 mV to 3.245 V (3.19 Vpk-pk) .
7. The V_{OUTP} and V_{OUTN} outputs of the AMC3301 are 2.05 Vpk-pk, 180 degrees out of phase, and have a common-mode voltage of 1.44V. Therefore, the differential output is ±2.05 V or 4.1 Vpk-pk.

   In order to stay within the output limitations of the TLV9002, the output of the AMC3301 needs to be attenuated by a factor of 3.19/4.1. When $R_3 = R_4$ and $R_5 = R_6$, the following transfer function for the differential to single-ended stage can be used to calculate R_5 and R_6.

   $$V_{OUT\_TLV} = (V_{OUTP} - V_{OUTN}) \times \left(\frac{R_{5,6}}{R_{3,4}}\right) + V_{CM}$$

8. Using our previously calculated output swing of the TLV9002 and choosing R_3 and R_4 to be 10kΩ, R_5 and R_6 can be calculated to be 7.78kΩ using the equation below.

   $$3.245 = (2.465\text{V} - 415\text{mV}) \times \left(\frac{R_{5,6}}{10k\Omega}\right) + 1.65$$

   Using standard 0.1% resistor values, a 7.77 kΩ can be used. This will provide a maximum output swing within the limitations of the TLV9002.

9. Capacitors C1 and C2 are placed in parallel to resistors R5 and R6 to limit high frequency content. When $R_5 = R_6$ and $C_1 = C_2$, the cutoff frequency can be calculated using the following equation.

$$f_c = \frac{1}{2 \times \pi \times R_{5,6} \times C_{1,2}}$$

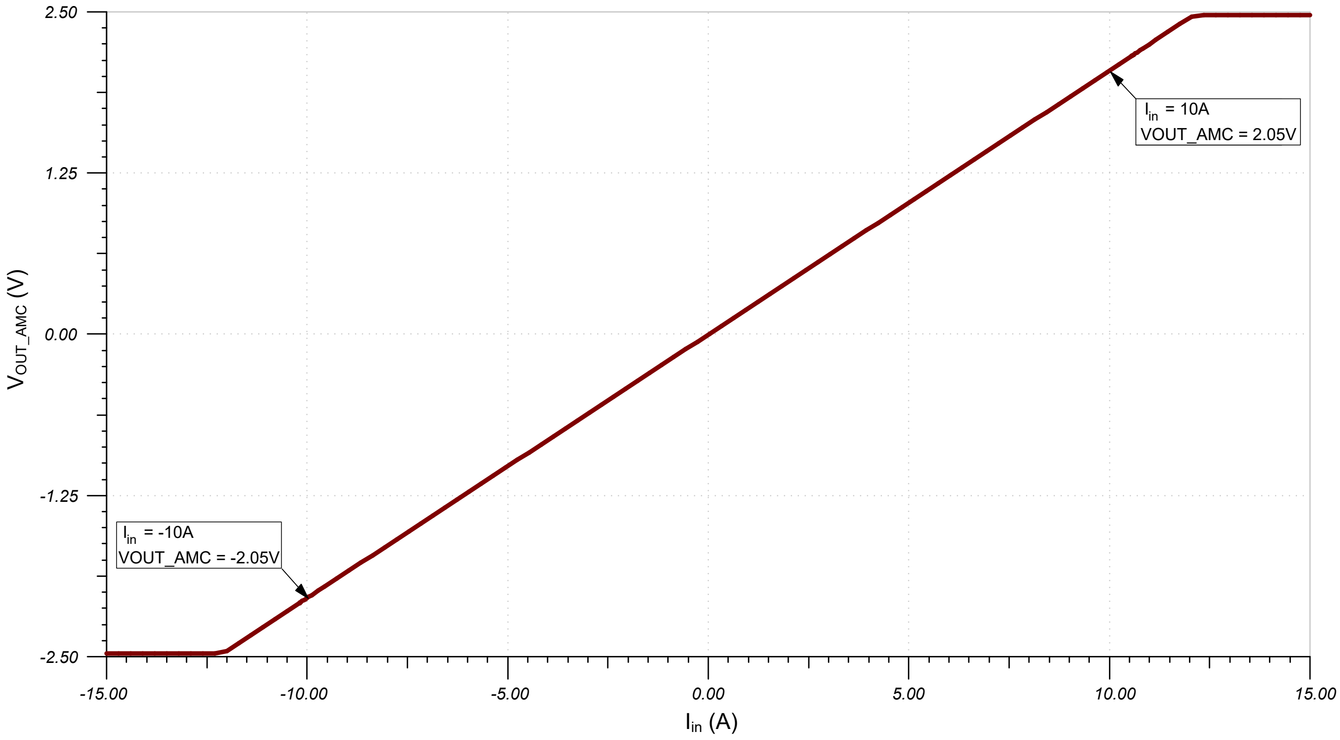
When the C1 = C2 = 1 nF and R5 = R6 = 7780 Ω, the cutoff frequency can be calculated to be 20.45 kHz.

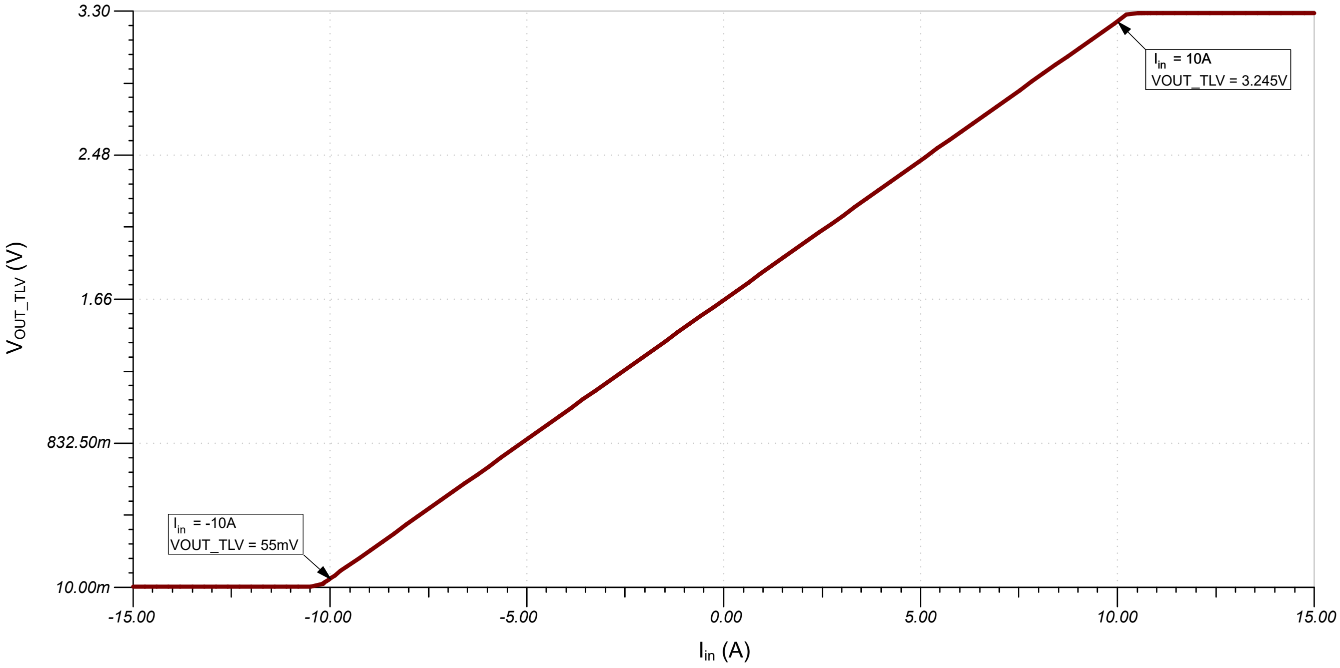
$$f_c = \frac{1}{2 \times \pi \times 7780\Omega \times 1nF} = 20.45kHz$$

Design Simulations

DC Simulation Results

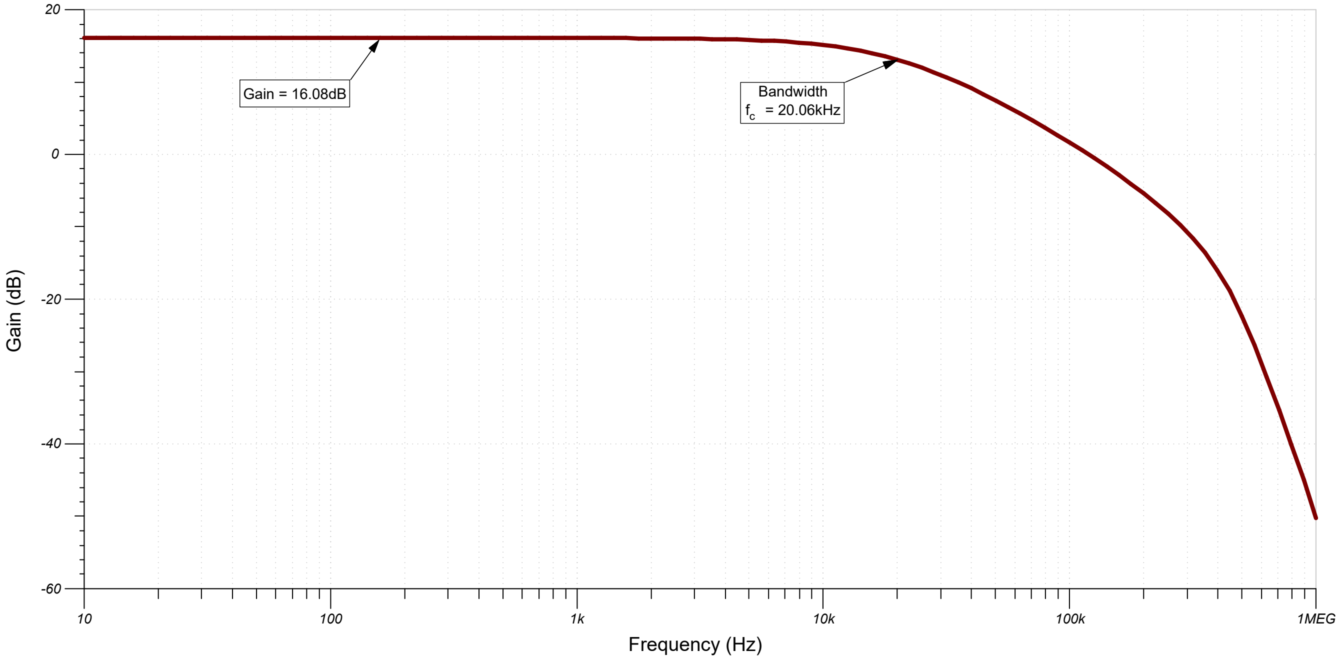
The following plots show the simulated DC characteristics of the AMC3301 differential output and single-ended output of the TLV9002 amplifier. Both plots show that the outputs are linear at ±10 A.





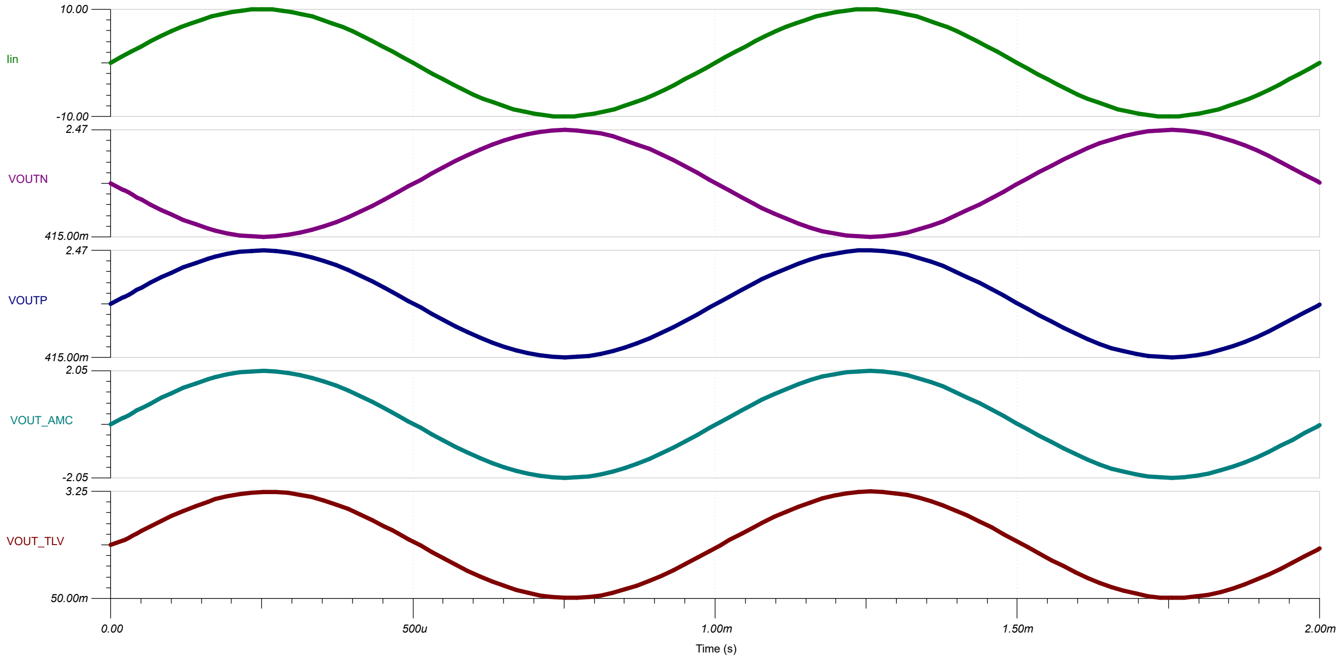
Closed-Loop AC Simulation Results

The following AC sweep shows the AC transfer characteristics of the single-ended output. Using the previously-calculated cutoff frequency illustrated in the last equation, shows that the simulation closely matches the simulation. Since the AMC3301 has a gain of 8.2 V/V and a gain of 0.778 V/V is applied with the differential to single-ended conversion, the gain of 16.11 dB shown in the following image is expected.



Transient Simulation Results

The following transient simulation shows the output signals of both the AMC3301 and TLV9002 from –10 A to 10 A. The differential output of the AMC3301 is ±2.05 Vpk-pk as expected and the single-ended output is 3.19 Vpk-pk and swings from 55 mV to 3.245 V.



Design References

See *Analog Engineer's Circuit Cookbooks* for TI's comprehensive circuit library and the *Interfacing a Differential-Output (Isolated) Amp to a Single-Ended Input ADC* application brief for more information on the differential to single-ended output conversion.

Design Featured Isolated Amplifier

AMC3301	
Working voltage	1200 V_{RMS}
Gain	8.2 V/V
Bandwidth	300 kHz TYP
Linear input voltage range	±250 mV
AMC3301	

Design Alternate Isolated Amplifier

AMC3330	
Working voltage	1200 V_{RMS}
Gain	2 V/V
Bandwidth	310 kHz TYP
Linear input voltage range	±1000 mV
AMC3330	

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