

**Circuits from the Lab™**  
Reference Circuits

Circuits from the Lab™ reference circuits are engineered and tested for quick and easy system integration to help solve today's analog, mixed-signal, and RF design challenges. For more information and/or support, visit [www.analog.com/CN0185](http://www.analog.com/CN0185).

### Devices Connected/Referenced

AD7400A	Isolated Sigma-Delta Modulator
ADuM5000	Isolated DC-to-DC Converter
AD8646	Dual, 24 MHz, Rail-to-Rail, I/O Op Amp
ADP121	150 mA, Low Quiescent Current, CMOS Linear Regulator
ADP3301	High Accuracy, 100 mA, Low Dropout Linear Regulator
ADG849	3 V/5 V CMOS 0.5 Ω SPDT/2:1 Mux in SC70
ADR443	Ultralow Noise, LDO XFET® 3.0 V Voltage Reference

## A Novel Analog-to-Analog Isolator Using an Isolated Sigma-Delta Modulator, Isolated DC-to-DC Converter, and Active Filter

### EVALUATION AND DESIGN SUPPORT

#### Circuit Evaluation Boards

[CN-0185 Circuit Evaluation Board \(EVAL-CN0185-EB1Z\)](#)

#### Design and Integration Files

[Schematics, Layout Files, Bill of Materials](#)

### CIRCUIT FUNCTION AND BENEFITS

The circuit shown in Figure 1 is a complete low cost implementation of an analog-to-analog isolator. The circuit provides isolation of 2500 V rms (1 minute per UL 1577).

The circuit is based on the [AD7400A](#), a second-order, sigma-delta ( $\Sigma$ - $\Delta$ ) modulator with a digitally isolated 1-bit data stream output. The isolated analog signal is recovered with a fourth-order active filter based on the dual, low noise, rail-to-rail [AD8646](#) op amp. With the [ADuM5000](#) as the power supply for the isolated side, the two sides are completely isolated and use only one power supply for the system. The circuit has 0.05% linearity and benefits from the noise shaping provided by the modulator of the [AD7400A](#) and the analog filter. The applications of the circuit include motor control and shunt current monitoring, and the circuit is also a good alternative to isolation systems based on optoisolators.

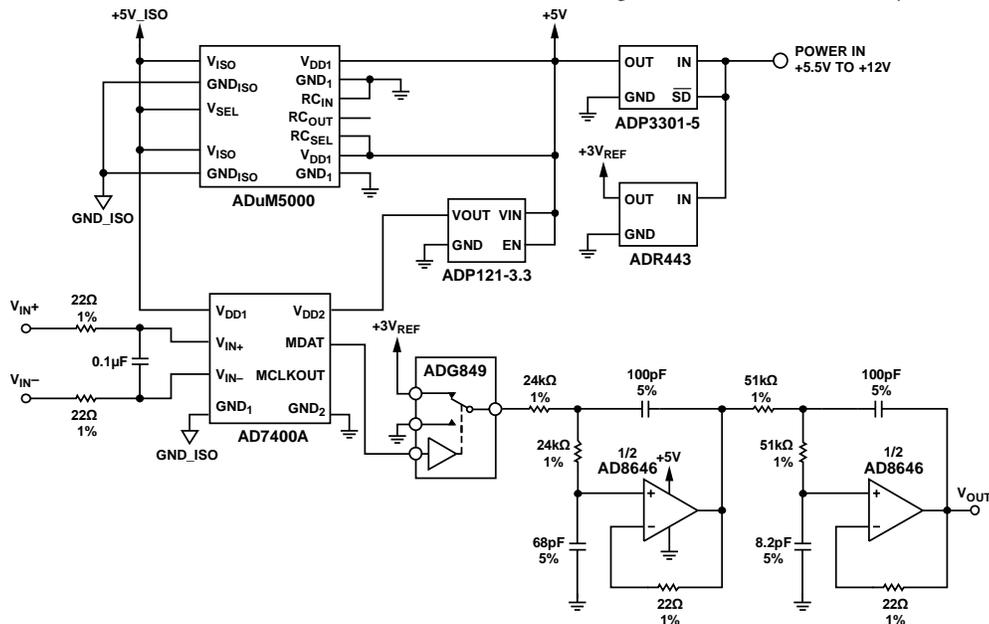


Figure 1. Analog Isolator Using [AD7400A](#) (Simplified Schematic: All Connections and Decoupling Not Shown)

#### Rev. B

Circuits from the Lab™ circuits from Analog Devices have been designed and built by Analog Devices engineers. Standard engineering practices have been employed in the design and construction of each circuit, and their function and performance have been tested and verified in a lab environment at room temperature. However, you are solely responsible for testing the circuit and determining its suitability and applicability for your use and application. Accordingly, in no event shall Analog Devices be liable for direct, indirect, special, incidental, consequential or punitive damages due to any cause whatsoever connected to the use of any Circuits from the Lab circuits. (Continued on last page)

## CIRCUIT DESCRIPTION

A block diagram of the circuit is shown in Figure 1. The analog input is sampled at 10 MSPS by the [AD7400A](#)  $\Sigma$ - $\Delta$  modulator. The 22  $\Omega$  resistors and 0.1  $\mu$ F capacitor form a differential input noise reduction filter with a cutoff frequency of 145 kHz. The output of the [AD7400A](#) is an isolated 1-bit data stream. The quantization noise is shaped by a second-order  $\Sigma$ - $\Delta$  modulator, which shifts the noise to the higher frequencies (see the [MT-022 Tutorial](#)).

To reconstruct the analog input signal, follow the data stream by an [ADG849](#) switch connected to a 3 V [ADR443](#) reference to stabilize the peak-to-peak output of the MDAT.

The signal is then filtered by an active filter whose order is higher than the order of the modulator. A fourth-order Chebyshev filter is used for better noise attenuation. Compared to other filter responses (Butterworth or Bessel), the response of the Chebyshev provides the steepest rolloff for a given filter order. The filter is implemented using the dual [AD8646](#), a rail-to-rail, input and output, low noise, single-supply op amp.

The [ADuM5000](#) is an isolated dc-to-dc converter based on Analog Devices, Inc., *iCoupler*<sup>®</sup> technology. It is used for the power supply to the isolated side of the circuit containing the [AD7400A](#). The *isoPower*<sup>®</sup> technology of the [ADuM5000](#) uses high frequency switching elements to transfer power through a chip-scale transformer.

The circuit must be constructed on a multilayer printed circuit board (PCB) with a large area ground plane. Proper layout, grounding, and decoupling techniques must be used to achieve optimum performance (see the [MT-031 Tutorial, Grounding Data Converters and Solving the Mystery of "AGND" and "DGND,"](#) the [MT-101 Tutorial, Decoupling Techniques](#), and the [ADuC7060/ADuC7061](#) evaluation board layout). Ensure that the PCB layout meets the emissions standards and isolation requirements between the two isolated sides (see the [AN-0971 Application Note](#)).

In order not to overdrive the [AD8646](#), the input signal must be lower than the power supply (5 V). The output of the [AD7400A](#) is a stream of 1s and 0s with an amplitude equal to the [AD7400A](#)  $V_{DD2}$  supply voltage. Therefore, the  $V_{DD2}$  digital supply is 3.3 V supplied by the [ADP121](#) linear regulator. Alternatively, if a 5 V supply is used for  $V_{DD2}$ , attenuate the digital output signal before connecting to the active filter. In either case, well regulate the supply because the final analog output is directly proportional to  $V_{DD2}$ .

The 5 V supply for the circuit in Figure 1 is supplied from an [ADP3301](#) 5 V linear regulator, which accepts an input voltage of 5.5 V to 12 V.

## Analog Active Filter Design

The cutoff frequency of the low-pass filter mostly depends on the desired bandwidth of the circuit. There is a trade-off between the cutoff frequency and noise performance, and there is more noise if the cutoff frequency of the filter increases. This is especially true in this design because the  $\Sigma$ - $\Delta$  modulator shapes the noise and moves a large portion into the higher frequencies. The cutoff frequency in this design is 100 kHz.

For a given cutoff frequency, the smaller the transition band of the filter is, the smaller the noise is that passes through the filter. Of all the filter responses (Butterworth, Chebyshev, Bessel, and so on), the Chebyshev filter was chosen for this design because it has a smaller transition band for a given filter order. However, this smaller transition band comes at the expense of a slightly worse transient response.

The fourth-order filter is made up of two second-order filters, with a Sallen-Key structure. The [Analog Filter Wizard](#) and the NI Multisim were used to design the filter. The parameters used include the following:

- Filter type = low-pass, Chebyshev, 0.01 dB ripple
- Order = 4
- $f_c$  = 100 kHz, Sallen-Key (updated format for clarity)

The recommended values generated by the program were used with the exception of the feedback resistors, which were reduced to 22  $\Omega$ .

## Measurements

The circuit has a gain of 4.6875 and an output offset voltage of 1.5 V. A differential signal of 0 V results in a digital bit stream of 1s and 0s, where each occurs 50% of the time. The [ADR443](#) output is 3.0 V; therefore, after filtering, there is a 1.5 V dc offset. A differential input of 320 mV ideally results in a stream of all 1s, which after filtering, yields a 3.0 V DC output. Therefore, the effective gain of the circuit is

$$GAIN = (3.0 - 1.5)/0.32 = 4.6875$$

From the measurements, the actual measured offset is 1.504V, and the gain is 4.69. The dc transfer function of the system is shown in Figure 2. Linearity was measured as 0.0465%.

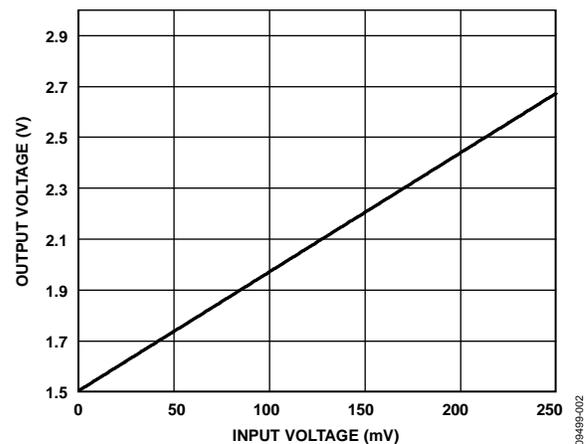


Figure 2. System DC Transfer Function

Figure 3 shows the output voltage with no dc offset voltage vs. the input frequency. The input signal voltage is 40 mV p-p, which causes an output signal of  $40 \times 4.6875 = 190$  mV p-p. Note that there is approximately 10 mV of peaking in the frequency response function, corresponding to about 0.42 dB.

The system has good noise performance, with a noise density of  $2.50 \mu\text{V}/\sqrt{\text{Hz}}$  at 1 kHz and  $1.52 \mu\text{V}/\sqrt{\text{Hz}}$  at 10 kHz.

A complete design support package for this circuit note can be found at [www.analog.com/CN0185-DesignSupport](http://www.analog.com/CN0185-DesignSupport).

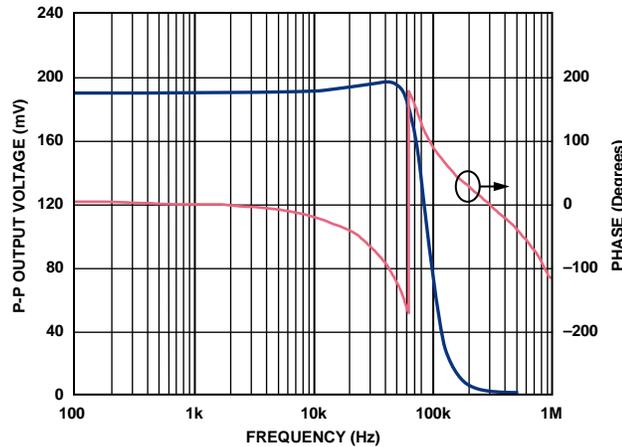


Figure 3. Frequency and Phase Response of the Circuit for a 40 mV Peak-to-Peak Input Signal

### COMMON VARIATIONS

The circuit can be used for isolated voltage monitoring and for current sensing applications where the voltage across a shunt resistor is monitored. The requirements of the input signal for the system are detailed in the [AD7400A](#) data sheet.

If the [ADuM6000](#) is used instead of the [ADuM5000](#), the entire circuit is rated to 5 kV.

The [ADP1720](#) or [ADP7102](#) linear regulator can be used as a substitute for the [ADP3301](#), if desired.

### CIRCUIT EVALUATION AND TEST

The circuit can be easily evaluated using a signal generator and an oscilloscope after powering on the circuit with a 6 V power supply.

#### Equipment Needed (Equivalents Can Be Substituted)

The following equipment is needed:

- A multifunction calibrator (dc source), Fluke 5700A
- A digital multimeter, Agilent 3458A, 8.5 digits
- A spectrum analyzer, Agilent 4396B
- A function generator, Agilent 33250A
- A power supply, 6 V

#### Setup and Test

The block diagram of the linearity measurement setup is shown in Figure 4. Connect the 6 V power supply to the [EVAL-CN0185-EB1Z](#) power terminal.

The dc input voltage is generated with the Fluke 5700A, and the Agilent 3458A DVM is used to measure the output. The dc output from the Fluke 5700A is stepped, and the data recorded with a 1 mV increase from 1 mV to 250 mV.

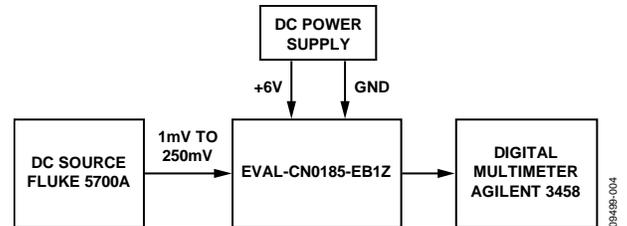


Figure 4. Test Setup for Measuring Linearity

To measure the frequency response, connect the equipment as shown in Figure 5. Set the 33250A function generator for a 40 mV peak-to-peak sine-wave output with a 0 dc offset. Then, sweep the frequency of the signal from 100 Hz to 500 kHz and record the data using the Agilent 4396B spectrum analyzer.

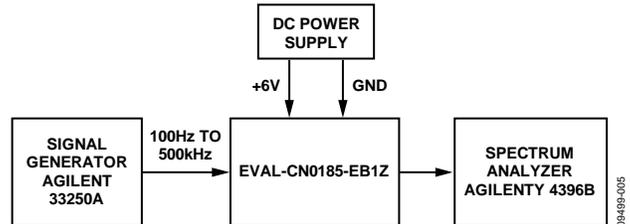


Figure 5. Test Setup for Measuring Frequency Response

**LEARN MORE**

CN0185 Design Support Package:

<http://www.analog.com/CN0185-DesignSupport>

ADIsimPower™ Design Tool, Analog Devices.

Analog Filter Wizard Design Tool, Analog Devices.

Cantrell, Mark. Application Note AN-0971, *Recommendations for Control of Radiated Emissions with isoPower Devices*. Analog Devices.

Chen, Baoxing, John Wynne, and Ronn Kliger. *High Speed Digital Isolators Using Microscale On-Chip Transformers*, Analog Devices, 2003.

Chen, Baoxing. *iCoupler® Products with isoPower™ Technology: Signal and Power Transfer Across Isolation Barrier Using Microtransformers*, Analog Devices, 2006.

Chen, Baoxing. "Microtransformer Isolation Benefits Digital Control." *Power Electronics Technology*. October 2008.

Ghiorse, Rich. Application Note AN-825, *Power Supply Considerations in iCoupler® Isolation Products*, Analog Devices.

Krakauer, David. "Digital Isolation Offers Compact, Low-Cost Solutions to Challenging Design Problems." *Analog Dialogue*. Volume 40, December 2006.

MT-022 Tutorial, *ADC Architectures III: Sigma-Delta ADC Basics*, Analog Devices.

MT-023 Tutorial, *ADC Architectures IV: Sigma-Delta ADC Advanced Concepts and Applications*, Analog Devices.

MT-031 Tutorial, *Grounding Data Converters and Solving the Mystery of "AGND" and "DGND,"* Analog Devices.

MT-101 Tutorial, *Decoupling Techniques*, Analog Devices.

USB 2.0 Specifications, USB Implementers Forum, Inc.

Wayne, Scott. "iCoupler® Digital Isolators Protect RS-232, RS-485, and CAN Buses in Industrial, Instrumentation, and Computer Applications." *Analog Dialogue*. Volume 39, October 2005.

Zumbahlen, Hank. Application Note AN-649, *Using the Analog Devices Active Filter Design Tool*, Analog Devices.

**Data Sheets and Evaluation Boards**

[AD7400A Data Sheet](#)

[AD7400A Evaluation Board](#)

[ADuM5000 Data Sheet](#)

[ADuM5000 Evaluation Board](#)

[AD8646 Data Sheet](#)

[ADP121 Data Sheet](#)

[ADP3301 Data Sheet](#)

[ADG849 Data Sheet](#)

[ADR443 Data Sheet](#)

**REVISION HISTORY****9/13—Rev. A to Rev. B**

Added ADR443.....	Throughout
Changes to Devices Connected/Referenced Section and Figure 1 .....	1
Changes to Circuit Description Section, Measurements Section, and Figure 2.....	2
Changes to Figure 3.....	3
Change to Data Sheets and Evaluation Boards Section .....	4

**4/13—Rev. 0 to Rev. A**

Changes to Figure 1.....	1
Changes to Figure 3 and Common Variations Section .....	3

**4/11—Revision 0: Initial Version**

(Continued from first page) Circuits from the Lab circuits are intended only for use with Analog Devices products and are the intellectual property of Analog Devices or its licensors. While you may use the Circuits from the Lab circuits in the design of your product, no other license is granted by implication or otherwise under any patents or other intellectual property by application or use of the Circuits from the Lab circuits. Information furnished by Analog Devices is believed to be accurate and reliable. However, Circuits from the Lab circuits are supplied "as is" and without warranties of any kind, express, implied, or statutory including, but not limited to, any implied warranty of merchantability, noninfringement or fitness for a particular purpose and no responsibility is assumed by Analog Devices for their use, nor for any infringements of patents or other rights of third parties that may result from their use. Analog Devices reserves the right to change any Circuits from the Lab circuits at any time without notice but is under no obligation to do so.