Circuit Note
CN-0185

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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

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 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 circuit's applications include motor control and shunt current monitoring, and it is a good alternative to isolation systems based on opto-isolators.
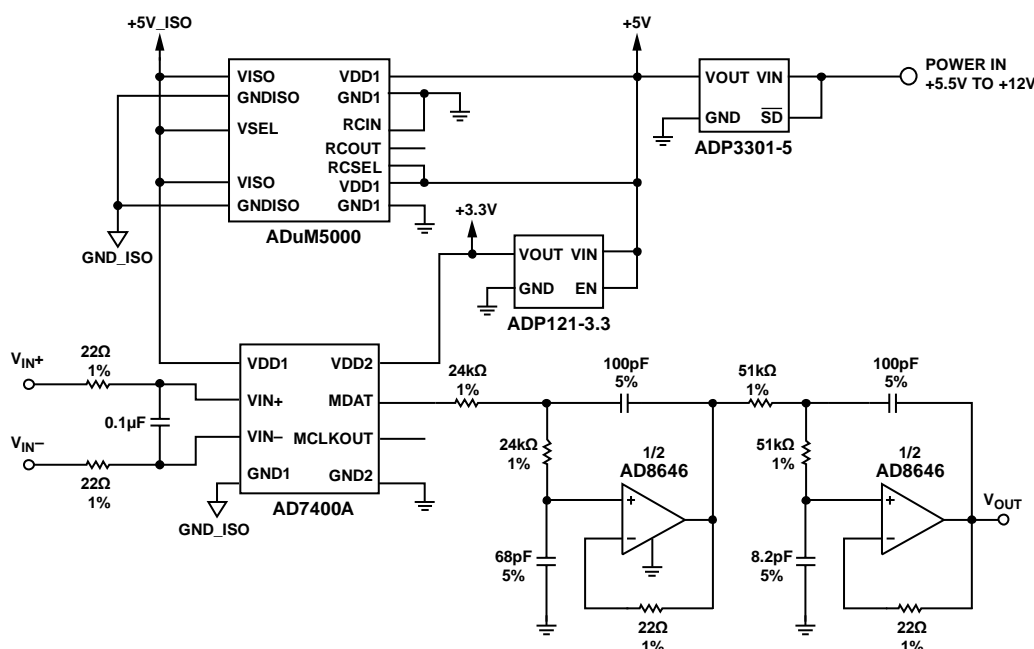

Figure 1. Analog Isolator using AD7400A (Simplified Schematic: All Connections and Decoupling Not Shown)

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 Ω resistors and the 0.1 μF 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 Tutorial MT-022).

To reconstruct the analog input signal, the data stream should be followed by a filter whose order is higher than the order of modulator. A fourth-order Chebyshev filter is used for better noise attenuation. Compared to other filter responses (Butterworth, Bessel, etc.), the Chebyshev response 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 *i*Coupler® technology. It is used for the power supply to the isolated side of the circuit containing the AD7400A. The *iso*Power® technology uses high frequency switching elements to transfer power through a chip-scale transformer.

The circuit must be constructed on a multilayer PC board with a large area ground plane. Proper layout, grounding, and decoupling techniques must be used to achieve optimum performance (see Tutorial MT-031, *Grounding Data Converters and Solving the Mystery of "AGND" and "DGND,"* Tutorial MT-101, *Decoupling Techniques*, and the ADuC7060/ADuC7061 Evaluation Board layout). Special care must be taken in the printed circuit board (PCB) layout to meet emissions standards and isolation requirements between the two isolated sides. (See Application Note AN-0971.)

In order not to overdrive the AD8646, the input signal should be lower than the power supply of AD8646, which is 5 V. The output of the AD7400A is a stream of 1's and 0's with an amplitude equal to the AD7400A VDD2 supply voltage. Therefore, the VDD2 digital supply is 3.3 V supplied by the ADP121 linear regulator. Alternatively, if a 5 V supply is used for VDD2, the digital output signal should be attenuated before connecting to the active filter. In either case, the supply should be well regulated because the final analog output is directly proportional to VDD2.

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 low-pass filter depends mostly on the desired bandwidth of the circuit. There is a trade-off between the cutoff frequency and noise performance, and there will be 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 was chosen to be 100 kHz.

For a given cutoff frequency, the smaller the transition band of the filter, the less noise is passed by the filter. Of all the filter responses (Butterworth, Chebyshev, Bessel, etc.), the Chebyshev filter was chosen for this design because it has a smaller transition band for a given filter order. This comes at the expense of slightly worse transient response.

The filter is fourth-order made up of two second-order filters with the Sallen-Key structure. The Analog Filter Wizard and Multisim were used to design the filter. The following parameters were input to the program: Filter Type: Lowpass, Chebychev 0.01 dB ripple, Order = 4, Fc = 100 kHz, Sallen-Key. The recommended values generated by the program were used with the exception of the feedback resistors, which were reduced to 22 Ω.

Measurements

The AD7400A has a gain of 5.15 and an output offset voltage of 1.65 V (when operating on a 3.3 V supply). A differential signal of 0 V results in a digital bit stream of 1's and 0's, where each occurs 50% of the time. The digital output supply is 3.3 V; therefore, after filtering there will be a 1.65 V dc offset. A differential input of 320 mV ideally results in a stream of all 1's, which after filtering, yields a 3.3 V dc output. Therefore, the effective gain of the AD7400A is:

$$GAIN = (3.3 - 1.65)/0.32 = 5.15625$$

From the measurements, the actual measured offset is 1.641497 V, and the gain is 5.165. The dc transfer function of the system is shown in Figure 2. Linearity was measured to be 0.0465%.

The output voltage with no dc offset voltage versus input frequency is shown in Figure 3. The input signal voltage is 40 mV p-p. This causes an output signal of 40 × 5.165 = 207 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 μV/√Hz at 1 kHz and 1.52 μV/√Hz at 10 kHz.

A complete design support package for this circuit note can be found at http://www.analog.com/CN0185-DesignSupport.
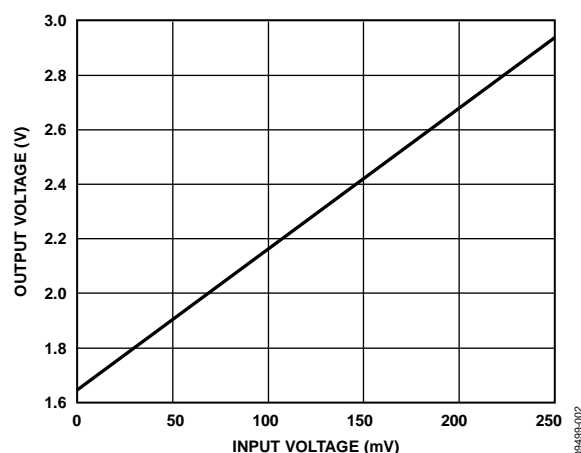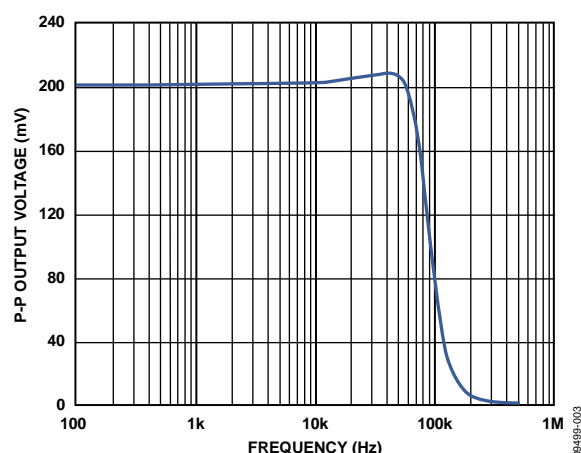
Figure 2. System DC Transfer Function

Figure 3. Frequency Response of Circuit for 40 mV p-p Input Signal.

COMMON VARIATIONS

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

If the ADuM6000 is used instead of the ADuM5000, then the entire circuit will be rated to 5 kV.

CIRCUIT EVALUATION AND TEST

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

Equipment Needed (Equivalents Can Be Substituted)

- Multifunction calibrator (dc source), Fluke 5700A
- Digital multimeter, Agilent 3458A, 8.5 digits
- Spectrum analyzer, Agilent 4396B
- Function generator, Agilent 33250A
- Power supply, +6 V

Setup and Test

The block diagram of 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 data recorded with 1 mV increase from 1 mV to 250 mV.

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 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.
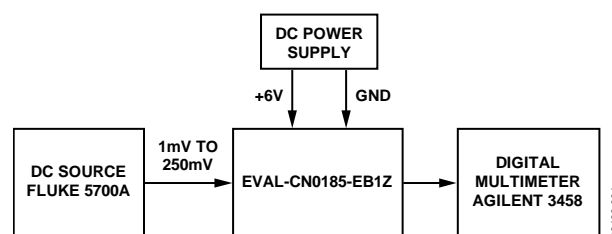

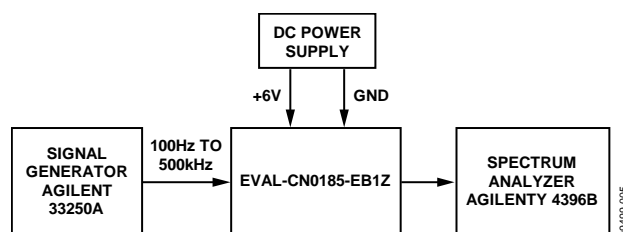Figure 4. CN-0185 Circuit Test Setup for Measuring Linearity

Figure 5. CN-0185 Circuit 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.

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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.

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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.

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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

REVISION HISTORY

4/11—Revision 0: Initial Version

ANALOG DEVICES

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многоканальный

+7 495 668 12 70

info@moschip.ru

Общество с ограниченной ответственностью «МосЧип»   ИНН 7719860671 / КПП 771901001
Адрес: 105318, г.Москва, ул.Щербаковская д.3, офис 1107

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Офис по работе с юридическими лицами:

105318, г.Москва, ул.Щербаковская д.3, офис 1107, 1118, ДЦ «Щербаковский»

Телефон: +7 495 668-12-70 (многоканальный)

Факс: +7 495 668-12-70 (доб.304)

E-mail: info@moschip.ru

Skype отдела продаж:
moschip.ru   moschip.ru_6
moschip.ru_4   moschip.ru_9