Circuit Note
CN-0280

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Devices Connected/Referenced	
AD7401A	Isolated Sigma-Delta Modulator
AD8639	Auto-Zero, Rail-to-Rail Output Dual Op Amp
ADuM6000	Isolated, 5kV, DC-to-DC Converter
ADM8829	Switched-Capacitor Voltage Inverter
ADP121	150mA, Low Quiescent Current, CMOS Linear Regulator
ADP7104	20V, 500 mA, Low Noise, CMOS LDO
ADP7182	−30V, 200mA, Low Noise, Negative Linear Regulator

Robust Completely Isolated Current Sense Circuit with Isolated Power Supply for Solar Photovoltaic Converters

EVALUATION AND DESIGN SUPPORT

Design and Integration Files

Schematics, Layout Files, Bill of Materials

CIRCUIT FUNCTION AND BENEFITS

The circuit in Figure 1 is a completely isolated current sensor with an isolated power source. The circuit is highly robust and can be mounted close to the sense resistor for accurate measurements and minimum noise pickup. The output is a single 16 MHz bit stream from a sigma-delta modulator that is processed by a DSP using a sinc^3 digital filter.

The circuit is ideal for monitoring the ac current in solar photovoltaic (PV) converters where the peak ac voltage can be several hundred volts, and the current can vary between a few mA and 25 A.

CIRCUIT DESCRIPTION

The circuit uses a 1mΩ sense resistor to measure peak current up to ±25 A using a dual AD8639 low offset amplifier. The gain of the amplifier is set to 10 to take advantage of the full scale range of the AD7401A sigma delta modulator. Higher currents can be measured (up to ±50 A or ±100 A) by simply lowering the gain of the AD8639 accordingly to ensure that the full scale input range of the AD7401A is used to the maximum advantage.

The ±25 A current through the 1 mΩ resistor creates a voltage of ±25 mV. This is then amplified by the AD8639 to ±250mV and input to the AD7401A. The differential input of the AD7401A acts as the difference amplifier in the traditional three op amp instrumentation amplifier configuration.

With a typical offset voltage of only 3 μV, drift of 0.01 μV/°C, and noise of 1.2 μV p-p (0.1 Hz to 10 Hz), the AD8639 is well suited for applications in which dc error sources must be minimized. The solar panel application benefits greatly from nearly zero drift over the operating temperature ranges. Many systems can take advantage of the rail-to-rail output swing provided by the AD8639 to maximize signal-to-noise ratio (SNR).

A guard ring is used around the inputs of the current measurement circuit to prevent any leakages from entering this sensitive low voltage area. The BAT54 Schottky diodes protect the inputs of the AD8639 from transient over-voltages and ESD.

The single pole RC filter (102 Ω, 1 nF) has a differential mode bandwidth of 1.56 MHz and reduces the wideband noise at the input of the AD7401A.

The sigma-delta modulator requires a clock input from an external source like a DSP processor or FPGA. The clock frequency can range from 5 MHz to 20 MHz, and a frequency of 16 MHz was used for the circuit in Figure 1.The highly robust single bit stream output of the modulator can be processed directly by a sinc^3 filter where the data can be converted to an ADC word.

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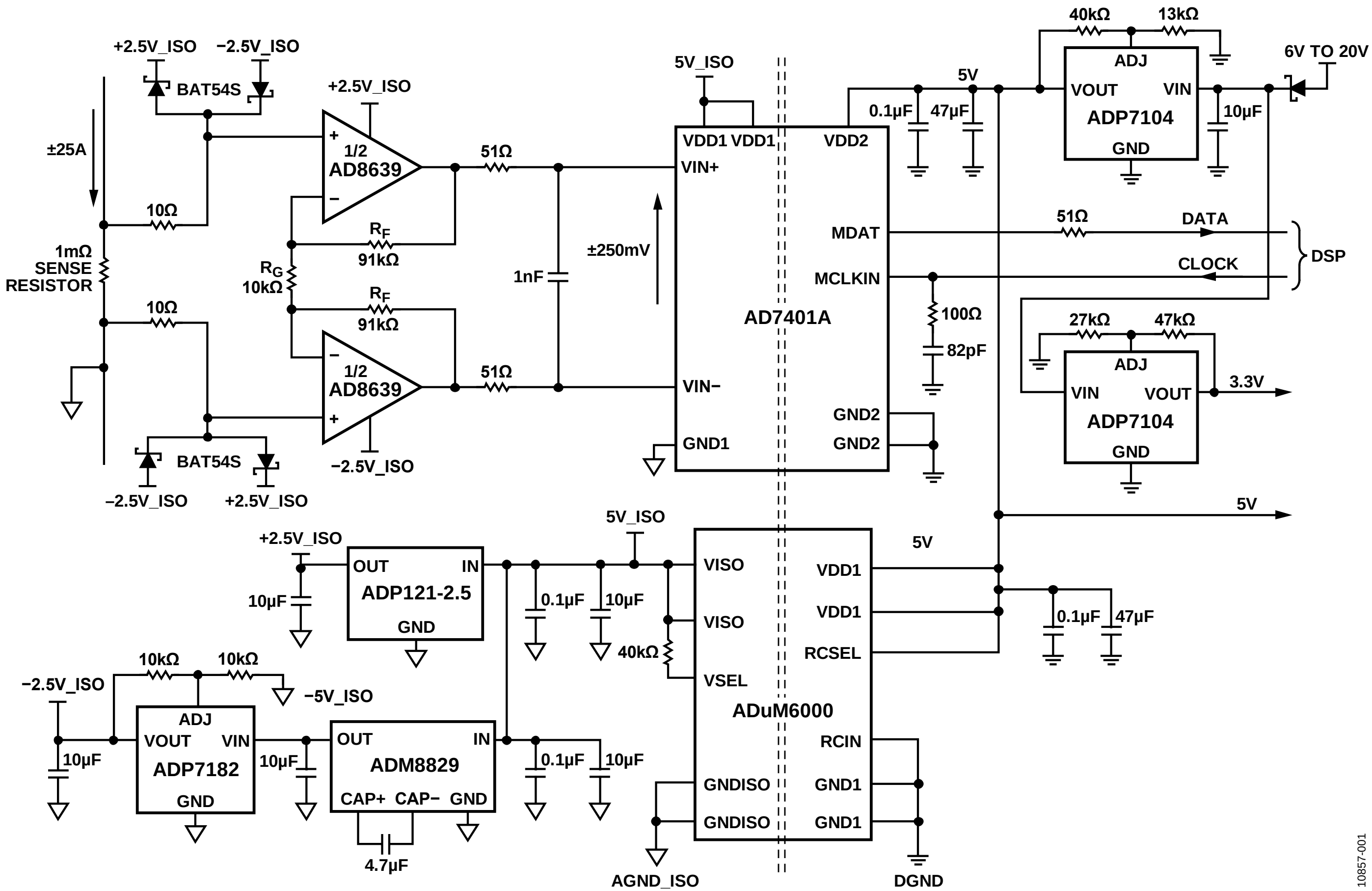

Figure 1. Isolated Current Sense Circuit (Simplified Schematic: All Connections and Decoupling Not Shown)

Both ac and dc information can be analyzed using the AD740x devices, thus not only monitoring ac performance but also any dc injection that may be present in the system. DC injection is important in solar applications because too much dc current injected into the grid may saturate any transformers in its path; therefore the dc current must be limited to the low milliampere range.

A key advantage using the AD740x devices is that they can be very close to the actual ac current path, while the DSP or FPGA can be a distance away or even on another board in the system. This increases the accuracy of the overall system by minimizing the effects of EMI/RFI.

Safety is accomplished using the isolation barrier of a 20 µm polyimide. Further information on this and the various approvals can be obtained from the relevant datasheets. The AD7401A can operate to voltages up to 891 V unipolar range or 565 V bipolar range, across its isolation barrier as shown in Table 1.

Table 1. Maximum Continuous Working Voltage[1] for AD7401A

Parameter	Max	Unit	Constraint
AC Voltage, Bipolar Waveform	565	V peak	50-year minimum lifetime
AC Voltage, Unipolar Waveform	891	V peak	Maximum CSA/VDE approved working voltage
DC Voltage	891	V	Maximum CSA/VDE approved working voltage

[1] Refers to continuous voltage magnitude imposed across the isolation barrier. See the AD7401A data sheet for more details.

Power Supply Configuration

The ADuM6000 is a 5 V isolated dc-dc converter which operates using an internal 625 kHz PWM to drive the 5 V dc power across the isolation barrier. This is rectified on the isolated side of the barrier and filtered.

The AD8639 op amp supplies are regulated to ±2.5 V for better noise performance. The +2.5 V is supplied by the low noise ADP121 low dropout regulator, which is driven from the +5 V isolated supply.

An ADM8829 switched capacitor voltage inverter is driven by the isolated +5 V and generates a −5 V output which is regulated to −2.5 V using the ADP7182 negative linear regulator.

Theory

The AD7401A is a second-order, sigma-delta (Σ-Δ) modulator that converts an analog input signal into a high speed, 1-bit data stream with on-chip digital isolation based on Analog Devices, Inc., *i*Coupler® technology. The AD7401A operates from a 5 V power supply and accepts a differential input signal of ±250 mV (±320 mV full scale). The analog modulator, eliminating the need for external sample-and-hold circuitry, continuously samples the analog input. The input information is contained in the output stream as a density of ones with a data rate up to 20 MHz. The original information is reconstructed with an appropriate digital filter. The processor side (non-isolated) can use a 5 V or a 3 V supply (VDD2).

Current measurement in solar applications requires isolated measurement techniques. The AD7401A is just one of many Analog Devices products that offer such isolation applications in ac measurements. This type of isolation is based on *i*Coupler® Technology.

Current transformers offer alternative methods of isolation known as galvanic isolation.

This document describes the typical performance of a current measurement module designed by Analog Devices using the AD7401A and the ADuM6000 devices.

Solar Photovoltaic (PV) Inverter System Application

A solar PV inverter converts power from a solar panel and transfers this power to the utility grid efficiently. Power from the solar panel, which is essentially a dc current source, is converted to ac current and fed onto the utility grid in phase with the frequency of the grid, and to a very high efficiency level (95% to 98%). The conversion can take one or more stages as shown in Figure 2. The first stage is typically a dc-to-dc conversion, where the low voltage and high current of the solar panel output is converted to high voltage and low current. The reason for this is to raise the voltage to a level compatible to the peak voltage of the grid. The second stage typically converts the dc voltage and current to ac voltage and current, typically using an H-Bridge circuit. (See Isolation Technology Helps Integrate Solar Photovoltaic Systems onto the Smart Grid, Analog Dialogue article).

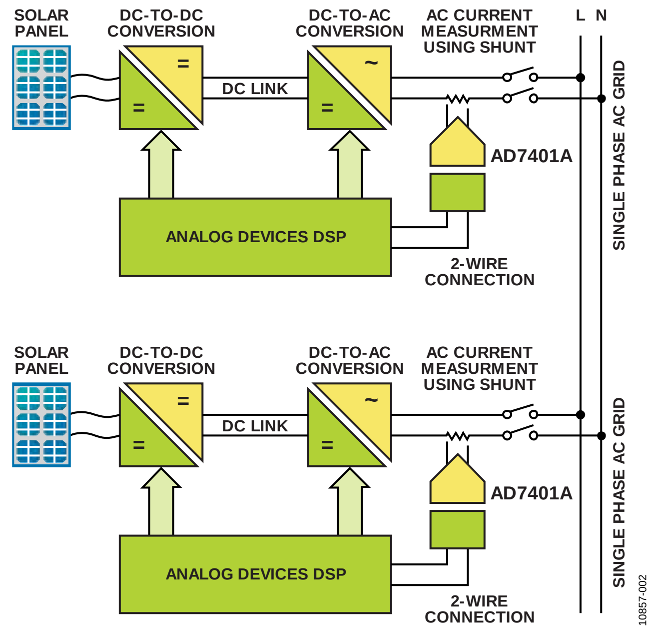

Figure 2. Solar PV Inverter System

Previous solar PV Inverters were simply modules that dumped power onto the utility grid. Solar inverters for new designs focus on safety, grid integration and cost reduction. To achieve this, Solar PV inverter designers are looking to new technology, some previously unused in existing solar inverter modules, to improve their performance and potentially reduce cost.

In the circuit the DSP controls the dc-to-dc converter and the dc-to-ac converter. The connection to the utility grid is typically made with a relay. The ac current measurement is performed by the AD7401A which measures current output to the grid, typically 25A.

Solar PV inverter systems may or may not have an isolation transformer at the output, mainly due to cost savings, but without a transformer, the solar PV inverter must measure the dc component of the output current. This current is known as *dc injection*, and its value is critical to the operation. Too much dc injection onto the grid may saturate any transformers in the path. The dc injection current must be limited to the low mA. Both of these tasks can be accomplished by the circuit in this application. Thus, cost savings can be accomplished because alternative methods like Hall effect current transducers may need two devices: one for the high current range and one for the lower current range.

Offset Performance of AD7401A

The offset of the AD7401A in the current measurement module was measured over temperature up to 125°C. The results are shown in Figure 3 and are in line with the data sheet specifications of the AD7401A. The maximum variation of offset measured over the temperature range with no current flowing in the shunt was approximately ±20 mA from −40°C to +125°C.

The following voltages were applied during the test.

- VDD_ISO = 5 V
- VDD_FPGA = 3.3 V
- MCLKIN = 16 MHz (EVAL-CED1Z with Altera FPGA , 256 Decimation Rate).
- VIN = 6 V @ 62 mA (Current sense module input supply voltage).

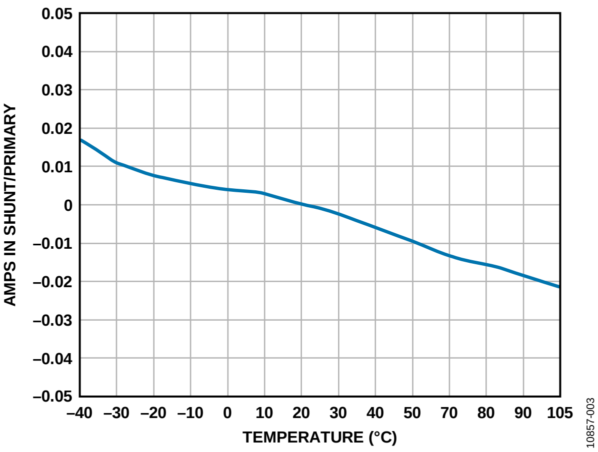

Figure 3. AD7401A Module Offset

Linearity Performance

The linearity of the module with currents up to ±28A was analyzed. As seen in Figure 4, Linearity of <±0.2% can be achieved after calibration. The voltages specified in the previous section were applied during the analysis. Figure 4 shows both full scale error and absolute error analysis defined as follows:

Full-Scale Error = $(V_{SHUNT} - V_{CALC}) / V_{FULLSCALE}$

Absolute Error = $(V_{SHUNT} - V_{CALC}) / V_{SHUNT}$

where

V_{SHUNT} = Current in the precision shunt(measured with a DVM)

V_{CALC} = Calculated current from the output of the ADC (AD7401A)

$V_{FULLSCALE}$ = Full-scale current range of the module (28 A).

The advantage of using the absolute error method is to analyze the errors in the lower range of measurement where errors can be highlighted. This is important for solar applications where dc injection can be measured in the low current range.

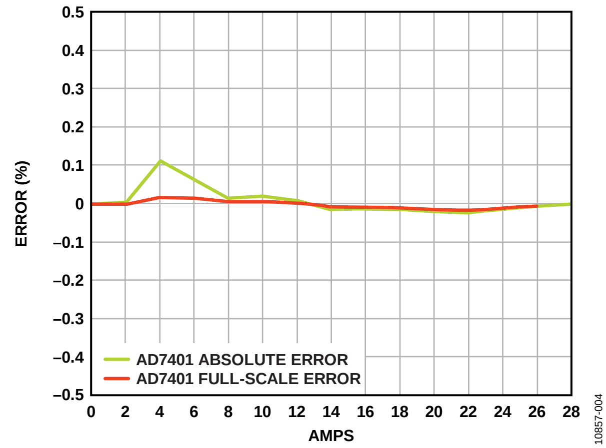

Figure 4. AD7401A Linearity Performance

SINC3 Filter Performance

The AD7401A is specified for a decimation rate (DR) of 256. However, it is possible to use this device at higher decimation rates. For a DR = 256, the response of a sinc3 filter is shown in Figure 5 where the output data rate is 62.5 kHz, and the FFT noise floor is shown in Figure 6.

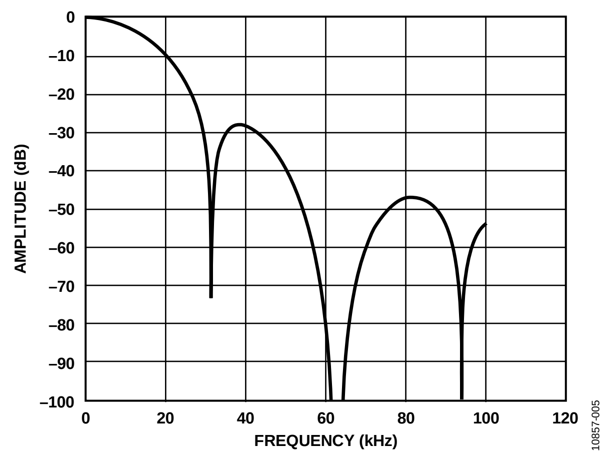

Figure 5. Sinc3 Filter Response for Decimation Rate = 256, Output Data Rate = 62.5 kHz

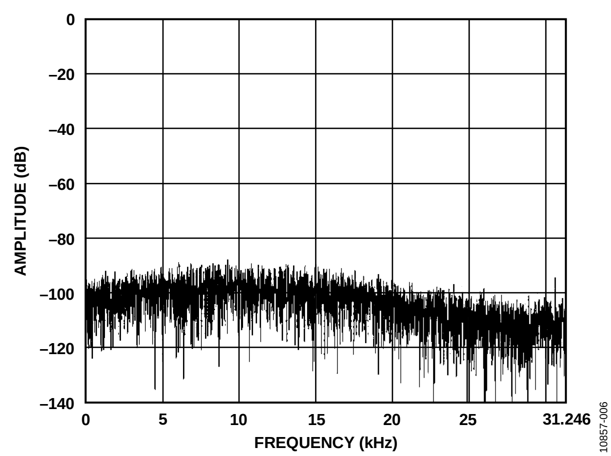

Figure 6. 16K-Point FFT Showing Noise Floor for Decimation Rate = 256, Output Data Rate = 62.5 kHz

For higher decimation rates, the sinc3 Filter response is greater improved. For a DR = 1024, the response of a sinc3 filter is shown in Figure 7 where the data rate is 15.6 kHz This improves the noise performance of the system as shown in Figure 8, however at a reduced data rate.

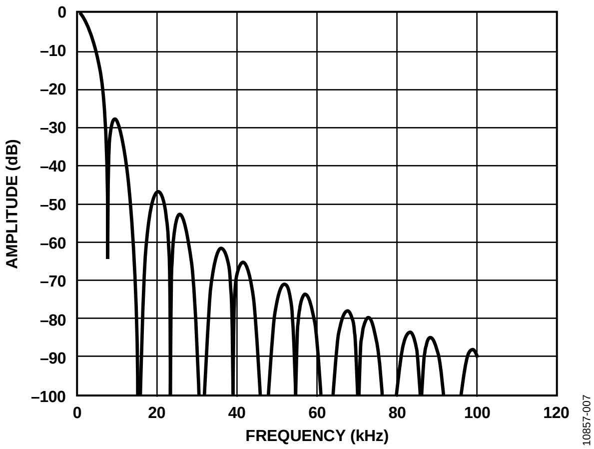

Figure 7. Sinc3 Filter Response for Decimation Rate = 1024, Output Data Rate = 15.6 kHz

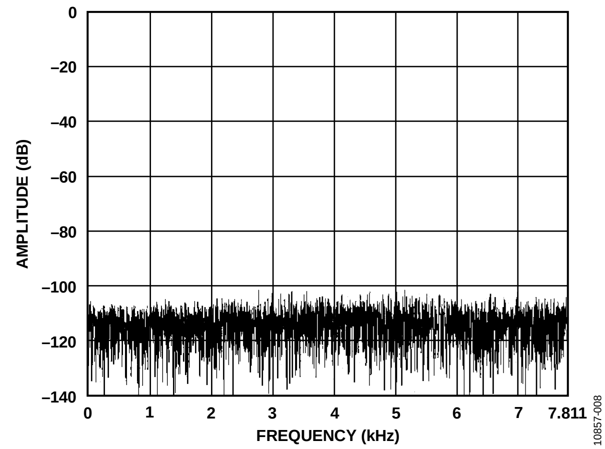

Figure 8. 16K-Point FFT Showing Noise Floor for Decimation Rate = 1024, Output Data Rate = 15.6 kHz

Layout Considerations

Special care must be taken during printed circuit board (PCB) layout to meet emissions standards. See the AN-0971 Application Note for board layout recommendations. An example of such a layout is shown in Figure 9. The key to the layout is to ensure a good overlap between Layer 3 (Floating Plane) and Layer 2 (Ground) .This simple overlap keeps emissions to a minimum in the system. Figure 10 shows the top view of the PCB layout, and Figure 11 shows a photo of the actual board.

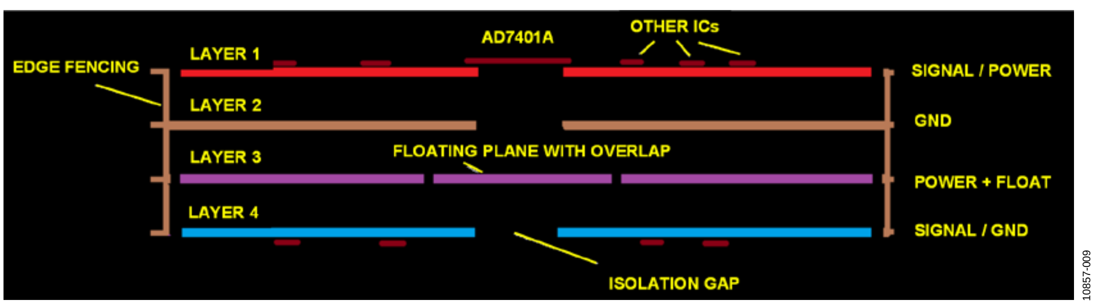

Figure 9. 4-Layer Board Example

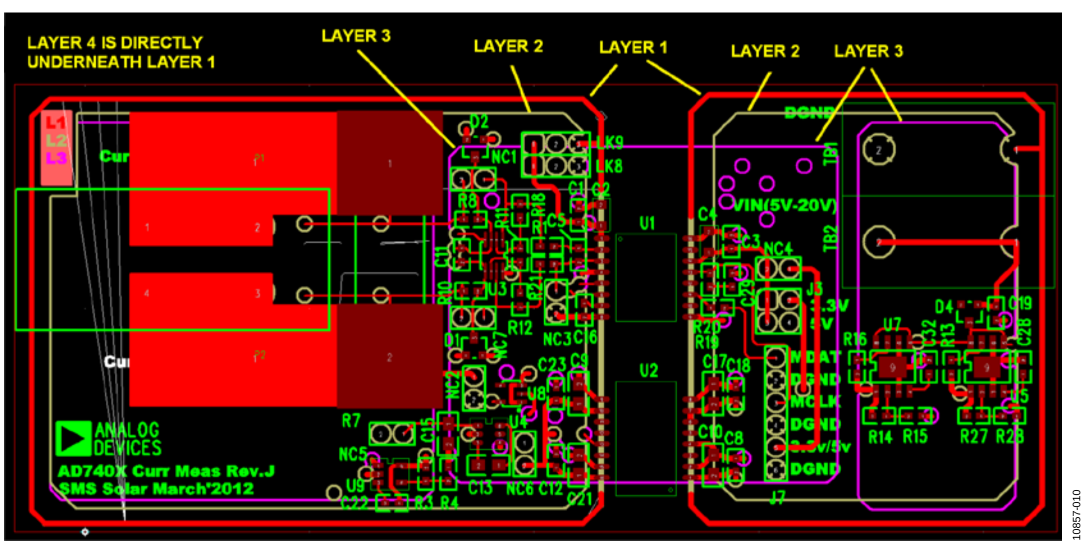

Figure 10. Proposed Layout for Current Measurementt

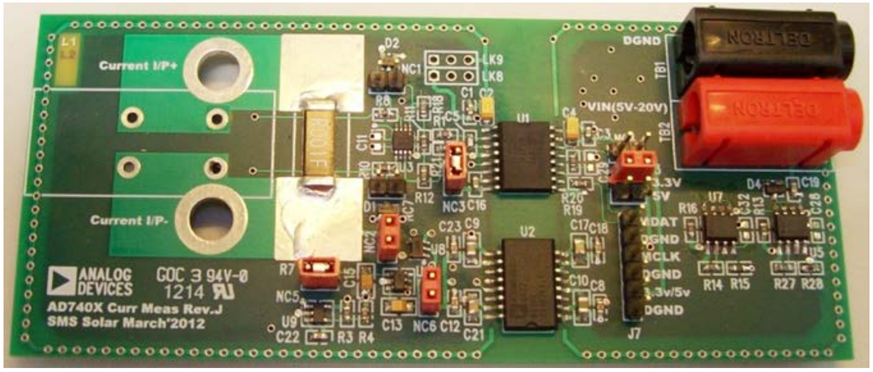

Figure 11. Photo of Current Measurement Board

Analog Devices isolated ADCs and *iso*Power devices meet the needs of the Solar Industry, and provides new technology advances required for Power systems. This leads to improved performance in grid integration using this new technology from the conventional methods used in solar inverters today.

COMMON VARIATIONS

The AD8638 op amp is a single version of the AD8639.

Other members of the AD7401A sigma-delta modulator family include the AD7400 that includes a 10 MHz on-chip clock.

CIRCUIT EVALUATION AND TEST

Equipment Needed

- DC source capable of 28A output at 100V to simulate source.
- 6.5 digit DVM and calibrated shunt to measure input current
- EVAL-CN0280-EB1Z evaluation board
- 6 V, 200 mA power supply
- 7 V, 2 A power supply
- EVAL-CED1Z converter evaluation and development board software.
- Example code for implementing the sinc3 filter can be found in the AD7401A data sheet.

Functional Block Diagram

A functional block diagram of the test setup is shown in Figure 12.

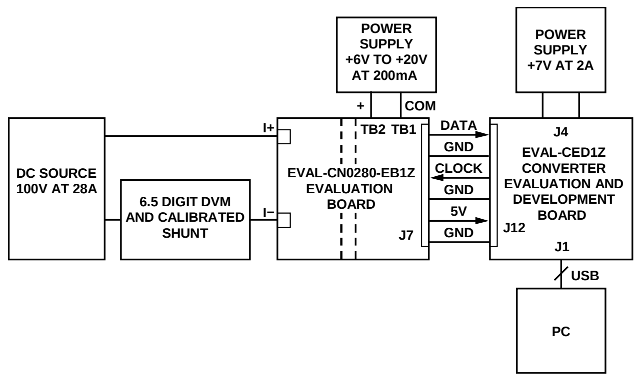

Figure 12. Test Setup Functional Diagram

LEARN MORE

CN-0280 Design Support Package: http://www.analog.com/CN0280-DesignSupport

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Data Sheets and Evaluation Boards

AD7401A Data Sheet

AD8639 Data Sheet

ADuM6000 Data Sheet

ADM8829 Data Sheet

ADP121 Data Sheet

ADP7104 Data Sheet

ADP7182 Data Sheet

REVISION HISTORY

10/13—Revision 0: Initial Version