设计指南：TIDA-01576
具有 16 位 1MSPS 双路同步采样 ADC 的高精度模拟输入模块参考设计

说明

该参考设计使用精密 16 通道 16 位 1MSPS 双路同步采样 ADC 提供了精确测量 16 通道宽交流模拟输入（电压和电流）的解决方案，不仅可满足保护和测量要求（包括 IEC61850-9-2 采样要求），还能简化系统设计、提高跳闸时间性能和可靠性。模拟输入的相干采样（每周期样本可配置）以及可编程的过采样率可提高测量性能。该参考设计的性能已经在宽温度范围内进行了测试，并配置了内部或外部基准，未观察到明显的误差变化。警报功能可基于样本确定交流 AIM 故障，从而更快地检测故障。ADS8688A ADC 具有一个额外的辅助通道，可用于诊断数字隔离器电源的输出或对测得的模拟输入温漂进行补偿。

资源

TIDA-01576	设计文件夹
ADS8686S、REF5025	产品文件夹
ADS8688A、ADS8688	产品文件夹
INA188、OPA2188	产品文件夹
ISO7763、ISOW7841	产品文件夹
SN6505B、TPS65131	产品文件夹
TLV2171、TPS3840	产品文件夹
TPS7A39、TPS7A47	产品文件夹
LMT70、LM35	产品文件夹
UCC12050、UCC12040	产品文件夹
LM2903、OPA188	产品文件夹
REF6041、REF5040	产品文件夹
ISO7820、REG71055	产品文件夹
TPS79101、TPS7A4901	产品文件夹

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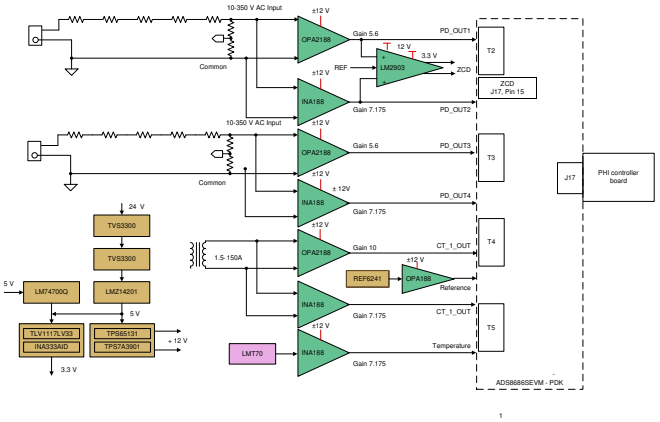
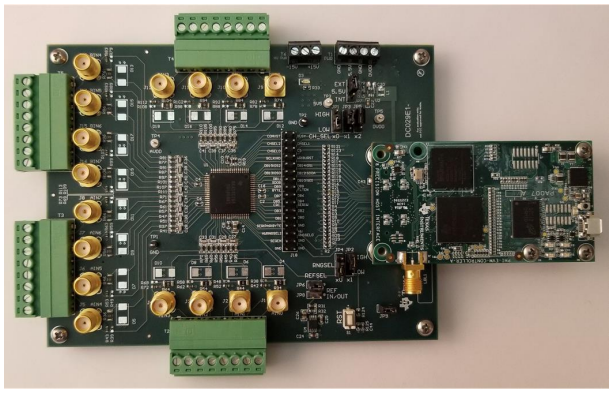
特性

- 此交流模拟输入模块设计采用了具有集成模拟前端的 ADS8688S 16 通道 16 位 1MSPS 双路同时采样 ADC
- 通过将 ADS8686SEVM-PDK 连接到带电压和电流传感器、增益调节放大器和集成板载双电源的 AFE 进行精度测试
- 提供可编程低通滤波器选项（15kHz、39kHz、376kHz），提高了系统性能和设计灵活性
- 提供用于配置 ADC 的选项，可实现 20% 超量程测量范围，从而提供了动态范围且不影响测量精度
- 数字电源电压范围为 1.8V 至 5V，最大限度地减少了外部逻辑的使用
- 所使用的增益调节放大器包括精密运算放大器和仪表放大器，可提供设计灵活性
- 交流电压输入范围为 10V 至 425V 时，观察到的测量精度在 ±0.2% 内；交流电流输入范围为 1A 至 120A 时，观察到的测量精度变化在 ±0.3% 内
- 在 -15°C 至 +80°C 温度范围内，观察到的测量误差变化在 ±0.1% 内
- 此外，展示了 ADS8686SEVM-PDK 与主机 PHI 控制器之间的隔离接口，该接口使用了带有外部隔离式直流/直流电源的数字隔离器，可在恶劣工作环境中提高性能和安全性。观察到 ADC 性能无变化。

应用

- 多功能保护继电器
- 变电站间隔控制器
- 独立合并单元 (SAMU)
- RTU、FTU、DTU 或 FRTU
- 适用于工厂自动化的 PLC





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1 System Description

Power system failures is one of the common problems faced by power generation, transmission, and distribution companies. Power outages result in loss of revenue and reduces generation capacity. Power utilities are working towards providing reliable power by using secondary protection, control, monitoring, and measurement systems to the power systems efficiency and reliability.

1.1 Introduction to Protection Relays

Digital protection relays detect defective lines, equipment, or other power system conditions that are abnormal or dangerous in nature. Digital protection relays detect and locate faults by measuring electrical quantities in the power system, which is different during normal and intolerable conditions. Measuring AC voltage and current inputs accurately over a wide input range is critical for the digital protection relays. The major functional components of a digital protection relay include data acquisition (analog filtering and sampling), measurement (phasor estimation), and logic (tripping, alarming, carrier send, and so on).

1.1.1 Multifunction Protection Relay for Generation, Transmission, or Distribution Applications

The key inputs for the functioning of the protection relay are AC voltages and currents. Most of the protection algorithms are based on the amplitude, frequency, and the phase of the AC voltages and currents. The AC AIM captures the output of the voltage and current transformers connected across the equipment being monitored. Depending on the monitored equipment and the protection function configured, the number of analog inputs can be 4, 8, 12, or 16.

1.1.2 Stand-Alone Merging Unit

The merging unit captures the voltage and current inputs from the equipment it connects to and provides the digital data to different IEDs using IEC 61850-9-2 protocol. Depending on the monitored equipment, the number of analog inputs can be 4, 8, 12, or 16.

1.1.3 Substation Bay Controller and Terminal Unit

The bay controller monitors analog and digital inputs from different primary equipments connected on the bay in a substation. The number of analog inputs depends on the bay controller configuration and can vary from 8 to 24.

1.2 Key System Specifications

表 1 shows the key system specifications for the high-accuracy, 16-channel AIM reference design.

表 1. Key System Specifications

SERIAL NUMBER	PARAMETER	DESCRIPTION	COMMENT
1	ADC	16-bit SAR ADC with configurable input ranges	SPI
2	Number of channels	16 channels with dual simultaneous sampling	
3	Input range	10 V, 5 V, 2.5 V	With programmable 20% overrange
4	Sampling rate	1-MHz	Meets IEC 61850-9-2 sampling requirements for protection and measurement. Provides programmable OSR for performance improvement.
5	Input impedance	Constant 1-MΩ input impedance front-end	
6	Digital isolation	Digital isolator with integrated power	Reinforced
7		Six-channel digital isolator with external isolated power	Reinforced, provides flexibility in digital isolator selection
8	internal filer	Programmable filter of 15 kHz, 39 kHz or 376 kHz	
9	AFE	Potential divider interfaced to Precision amplifier and instrumentation amplifier	With different gains to cover wide inputs
		Current sensor interfaced to Precision amplifier and instrumentation amplifier	With different gains to cover wide inputs
10	Host interface	SPI	Serial interface simplifies communication interface
11		Parallel	Parallel interface reduces firmware complexity
12	Diagnostics	Digital and analog power supply using auxiliary channels	Displayed on GUI
13		LED indication for alarm, power, and activity (chip select)	Visual indication
14	Power supply	Split-rail supply with LDO	Output programmable, low ripple
15		Isolated power supply using isolated DC/DC or transformer driver	Efficiency > 60%
16	Temperature compensation	Onboard analog temperature sensor for compensation measurement accuracy variation	Accuracy < ± 0.2%
17	Analog input connectors	Screw type connector	

2 System Overview

This reference design accurately measures AC voltage and current inputs using a precision 16-bit successive approximation (SAR) analog-to-digital converter (ADC) over a wide input range covering protection and measurement applications (including sampling requirements as per IEC 61850-9-2), simplifying system design and improving trip time performance and reliability. Two approaches for designing of AIM have been shown in this reference design. The first approach is using a 16-channel 16-bit SAR dual simultaneous sampling ADC. The second approach is using two 8-channel 16-bit ADCs connected together to increase the number of analog input channels to 16 using daisy chain mode or dual SDO output mode with the control input signals connected together and driven by common pins. The AIM is isolated from the host processor using a digital isolator with an integrated power converter. A complete AC AIM can be designed using only TI products, optimizing system cost and size. The alarm feature of ADS8688A identifies the AC analog input faults on a sample basis for faster fault detection. The ADS8688A ADC has an additional auxiliary channel to diagnose the supply output of the digital isolator.

2.1 Block Diagram

This reference design showcases the following configurations for improved system performance:

- 16-bit ADC ADS8686S based 16-channel analog input module
- 16-bit ADC ADS8686S based isolated interface module
- ADS8688A-based, 16-channel input with dual SDO for measurement of AC or DC analog input
- ADS8688A-based, isolated, 16-channel input with dual SDO using digital isolators with integrated power

The architecture choice depends on the size, input range and need for alarm features.

2.1.1 ADS8686S based analog input module

The section provides summary of AC analog input module based on ADS8686S. The advantage of ADS8686S based design is integration of two ADCs into a single device, provision for serial or parallel interface and provision for implementing coherent sampling. Extension of analog input channels being measured is required for multifunction secondary grid equipments for increasing the measurement dynamic range, diagnostics, feature enhancement, performance optimization and form factor reduction.

2.1.1.1 16-bit ADC ADS8686S based 16-channel analog input module

The ADS8686S based 16-channel AC analog input module consists of the analog front end board with the potential divider, current transformer, signal scaling amplifiers, zero cross detection comparators and split rail supplies. The AFE is interfaced to the ADS8686SEVM-PDK for performance evaluation. The module has the following functional blocks:

- Potential divider to scale the AC input voltage and Current transformer to transform the primary current to secondary current
- Gain scaling amplifier to scale the sensor output to ADC input range using precision op-amp or instrumentation amplifiers
- On board stable reference and high accuracy temperature sensor for measurement referencing and bench marking during temperature performance tests
- Zero cross detector for implementing coherent sampling using PHI controller (Digital)
- Split-rail power supply with dual LDO for powering the gain scaling amplifiers

- Interface connector to connect the output of the AFE board to ADS8686S EVM
- PHI controller board to connect the ADS8686SEVM-PDK to GUI for performance evaluation

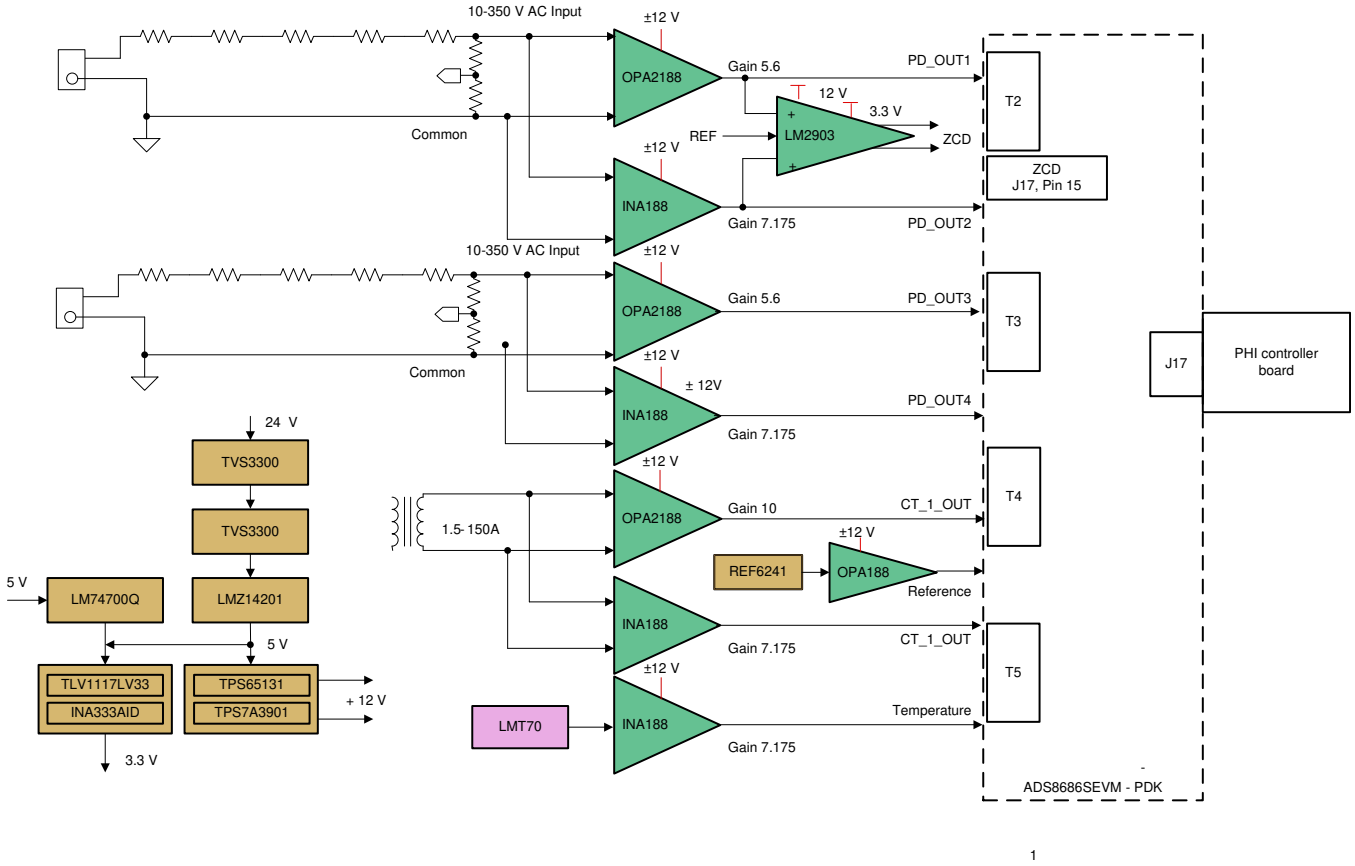

图 1. Isolated interface module for ADS8688SEVM-PDK and PHI controller interface

2.1.1.2 16-bit ADC ADS8686S based isolated interface module

The isolated interface module is used to isolate the PHI controller interface from the ADS8686SEVM-PDK based 16-channel AC analog input module and has the following functional blocks:

- High speed digital isolator for isolating the signals between the PHI interface board and ADS8686SEVM-PDK
- Interface connector provision to mount the ADS8686SEVM-PDK on one side of the board and the PHI controller on the other side of the board
- Provision to generate split-rail isolated supplies using transformer driver to power the gain scaling amplifiers
- Provision to generate isolated supply for ADC using high efficiency isolated DC/DC converter
- Provision to generate split rail isolated supply for gain scaling amplifiers using transformer driver and dual LDO
- Zero cross detector for implementing coherent sampling
- Provision to configure the ADC using jumper setting on the interface board and ADS8686SEVM-PDK

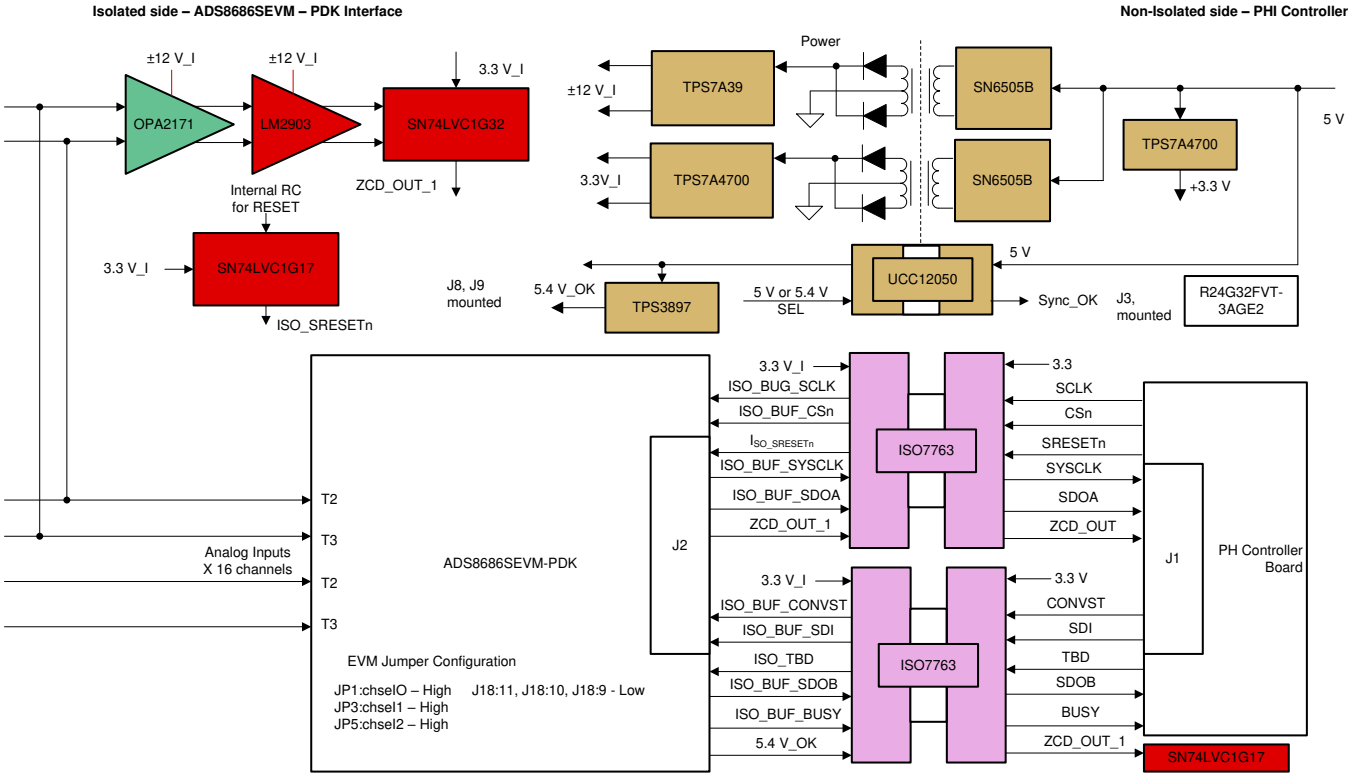

图 2. Isolated_ADS8688S_EVM_AFE_PHI_interface_module

2.1.2 ADS8688/ADS8688A based analog input module

This section provides details of different approaches to design of AC or AC analog input module using 8-channel 16-bit ADS8688/ADS8688A ADC. Advantages of using ADS8688A include availability multiple input ranges, capability to measure unipolar and bipolar and option to program alarms. This design can be used for AC or DC analog input modules and is scalable from 4 channels to 16 channels.

2.1.2.1 ADS8688A-Based, 16-Channel AC AIM With Dual SDO

The ADS8688A-based, 16-channel AC AIM with dual SDO has the following functional blocks:

- 2× ADS8688A ADCs connected together to sample 16 channels of AC analog input with a ±10.24-V input range
- External reference for improving measurement accuracy between two ADCs
- LDOs to generate the required analog and digital power supply
- Host interface with dual SDO outputs
- LEDs driven by MOSFET for Alarm indication
- Host interface and GUI for evaluating the performance of the ADC

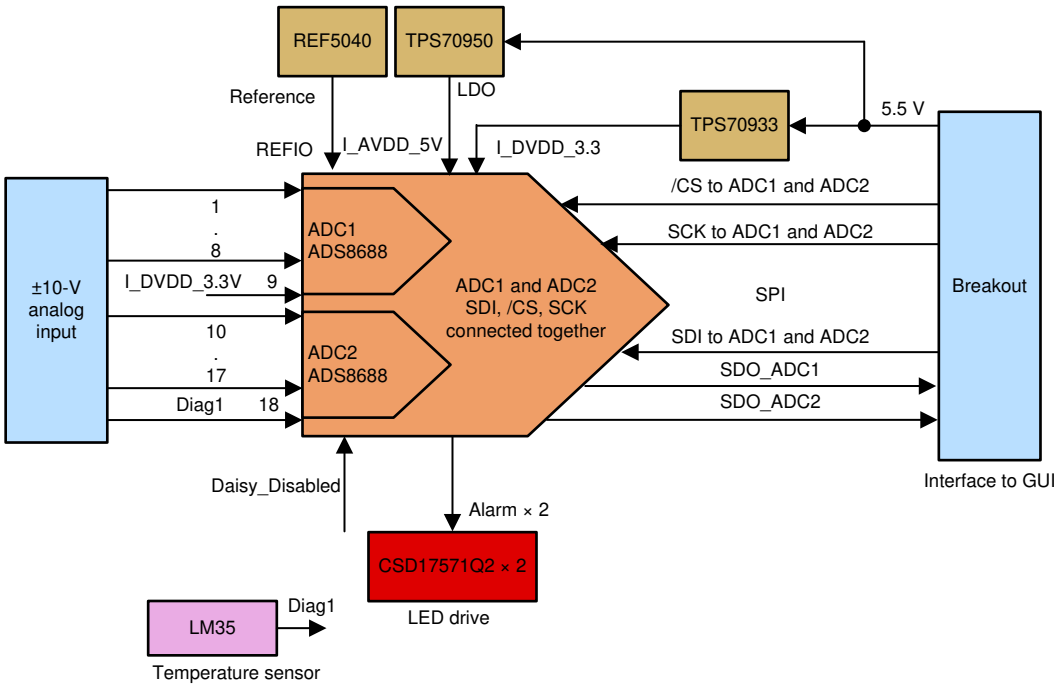

图 3. ADS8688A 16-Bit SAR ADC-Based 16-Channel AC AIM With Dual SDO Output

2.1.2.2 ADS8688A-Based, Isolated, 16-Channel AC AIM With Dual SDO using Digital Isolator With Integrated Power

The ADS8688A-based, isolated, 16-channel AC AIM with a dual SDO, digital isolator, and integrated power block diagram has the following functional blocks:

- ADS8688A-based, 16-channel input with dual SDO to measure AC or DC analog inputs with a ±10.24-V input range
- Host interface isolation provided using four-channel digital isolator with integrated power and two-channel digital isolator
- Provision for SCKL loop back from the ADC side to the host side for improved performance
- DC/DC converter and LDO to provide the required analog and digital power supply to the module
- Analog temperature sensor to compensate the measurement error due to ambient temperature variation
- Reference with integrated buffer for providing external reference to the ADCs for improved performance
- Host interface to evaluate the performance of the ADC using a PHI controller and GUI

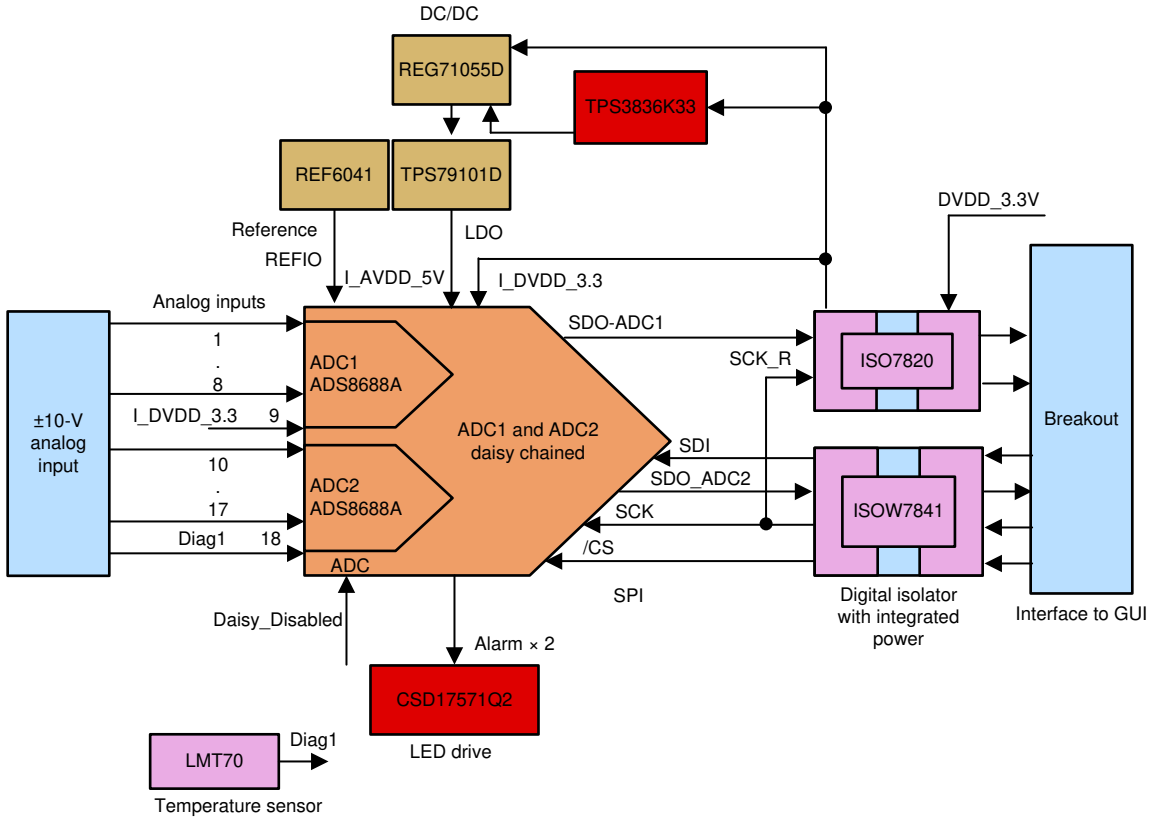

图 **4. ADS8688A 16-Bit SAR ADC-Based, Isolated 16-Channel AC AIM With ISOW7841 and Dual SDO**

2.2 Design Considerations

2.2.1 AC Current and Voltage Measurement Module

The data acquisition function in the protection relay is performed by the AC AIM and consists of the following subsystems.

2.2.1.1 Current Sensor Input

Current measurement sensors that can be used include current transformers, shunts, Rogowski coils, Hall effect or flux gate current sensors, optical current transformers, or low-power current transformers (LPCTs). In applications using shunt for current sensing, the required isolation is provided by the isolation amplifier or isolated delta-sigma modulator.

2.2.1.2 Voltage Sensor Input

Voltage measurement sensors that can be used include potential transformers, potential dividers, or capacitor voltage transformers. In applications, using potential divider for voltage measurement, the required isolation can be provided by the isolation amplifier or isolated delta-sigma modulator.

2.2.1.3 Signal Conditioning

A signal conditioning circuit is used to scale the voltage or current sensor output to the ADC range. A signal conditioning circuit depends on its application. The circuit can be a precision operational amplifier, instrumentation amplifier, programmable gain amplifier, or a differential or isolation amplifier. The amplifier selection depends on the accuracy and temperature drift requirements.

2.2.1.4 Host Interface

The ADC is interfaced to a host that captures the digital values from the ADC and computes the electrical parameters used for protection, measurement, and control and monitoring applications.

2.2.1.5 ADC

Accurate measurements of voltage and current inputs are key performance requirements for grid infrastructure applications. Selecting an ADC is critical to the digital protection relay performance, and the measurement accuracy for protection, monitoring, and control depends on the ADC selection. Key performance parameters for ADC selection include ADC architecture, ADC resolution, ADC input sampling method, ADC input type and range, ADC power supply, clock, and reference. Another important ADC requirement is scaling the sampling rate to meet IEC 61850-9-2 standards for both protection and measurement.

2.2.2 Need for Isolation, Challenges, and Solutions

Power system equipment that fail are responsible for a large proportion of power system outages and associated interruption of electricity supply to customers. Other causes of interruption include extreme weather conditions, among others. If failures can be predicted before they occur, action can be taken to reduce the occurrence of unplanned outages of equipment, thus contributing to meeting performance targets and reducing the cost of interruptions. The inputs are isolated using an isolation amplifier, isolated delta-sigma modulators, or current or potential transformers. Some of the common requirements for isolation of an AC AIM include isolation type (basic or reinforced), jitter in pS, power supply integrated with an isolator or external, and the number of channels for an I^2C, SPI, or UART interface.

2.2.3 Reference Design Advantage

This reference design uses ADS8686S (16-channel) or ADS8688A (with daisy chained or with Dual SDO output) and provides the following advantages during the design of AC or DC analog input module:

- Provision to measure 16 channels of analog inputs with programmable input ranges
- Provision for programmable input ranges of ±10V, ±5V and ±2.5V with 20% overange and programmable filters improves system performance
- Digital: 1.8 V to 5 V supply range provides design flexibility and minimizes use of external logic
- Provision to implement coherent sampling and program OSR further improves system performance
- Availability of serial or parallel host interface provides additional system design flexibility
- Bidirectional Inputs up to ±10.24 V can be measured using a single 5 V analog supply
- Availability of serial or parallel host interface provides additional system design flexibility
- Gain scaling amplifier and split rail power supply on the AFE can be fully reused reducing design time
- Provides reinforced isolation of the interface using digital isolator with integrated power or digital isolator with external isolated power

- Simplifies overall design by use of 6 channel digital isolator in a 16-Pin package
- Meets ADC dynamic specification including ENOB, SNR, and THD with isolated interface
- Provides isolation of the interface using a digital isolator with integrated power or external isolated power
- Provides options for power supply diagnostics (analog and digital supply) and alarm indication

2.3 Highlighted Products—System Design

2.3.1 ADS8686S ADC

Use of 16-channel ADC with dual simultaneous sampling capability simplifies design in applications requiring extension of analog input channels. Some of the key features of ADS8686S include

- 16-channel, 16-bit ADC with integrated analog front-end
- Dual simultaneous sampling: 8x2 channels
- Supply includes Analog: 5 V and Digital: 1.8 V to 5 V (no level translator required for 1.8V systems)
- Independently programmable input ranges with 20% overrange
- Programmable low-pass filter – 15 kHz, 39 kHz, 376 kHz

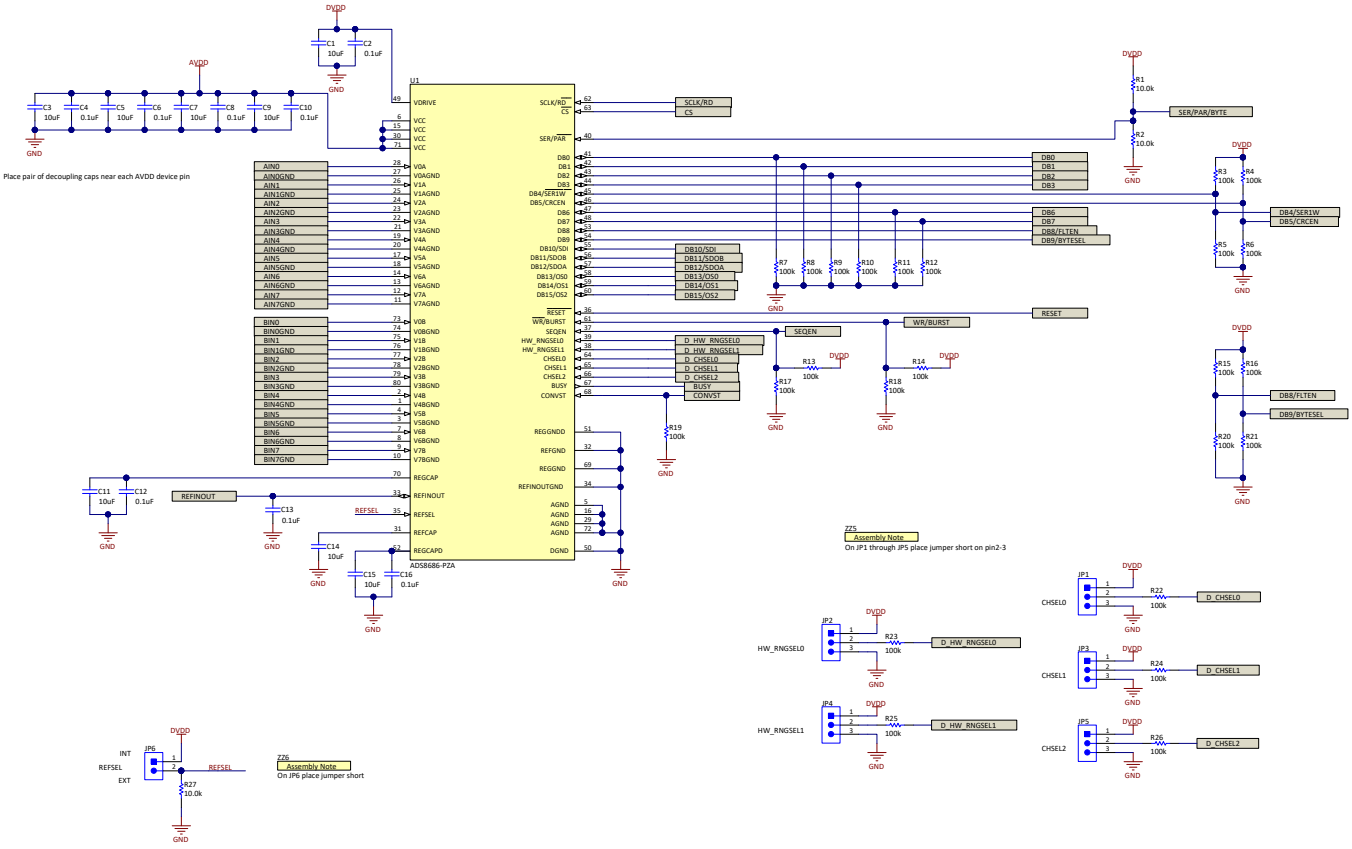

图 **5. Schematics of ADS8686S ADC configuration for 16 Analog inputs**

2.3.1.1 *ADS8686S*

The ADS8686S is a 16-channel data acquisition (DAQ) system based on a dual simultaneous-sampling, 16-bit successive approximation register (SAR) analog-to-digital converter (ADC). The ADS8686S features a complete analog front-end for each channel with an input clamp, 1-MΩ input impedance, independently programmable gain amplifier (PGA), programmable low-pass filter, and an ADC input driver. The device also features a low-drift, precision reference with a buffer to drive the ADCs. A flexible digital interface supporting serial, parallel, and byte communication enables the device to be used with a variety of host controllers. The ADS8686S can be configured to accept ±10-V, ±5-V, or ±2.5-V bipolar inputs with a 20%

overrange option using a single 5-V supply. The high input impedance allows direct connection with sensors and transformers, thus eliminating the need for external driver circuits. The ADS8686S has a highly configurable channel sequencer to reduce the sequencing overhead on the backend controller or processor. The high performance and accuracy, along with zero-latency conversions offered by this device make the ADS8686S a great choice for multiple industrial applications.

For more details, see the ADS8686S product page.

2.3.2 Analog front end with gain scaling amplifier and potential divider

The Voltage measurement AFE below includes the following subsystems :

- Potential divider to scale the AC input voltage for measurement
- Gain scaling amplifiers for scaling the potential divider output to ADC input range
- Gain scaling can be implemented using precision amplifiers or instrumentation amplifiers
- Use of instrumentation amplifier simplifies system design and improves
- The required ±12 V supply for the gain scaling amplifiers is generated using split-rail supply converter and dual LDO
- The gains for precision amplifier and the instrumentation are set to different values enabling more ADC measurement points

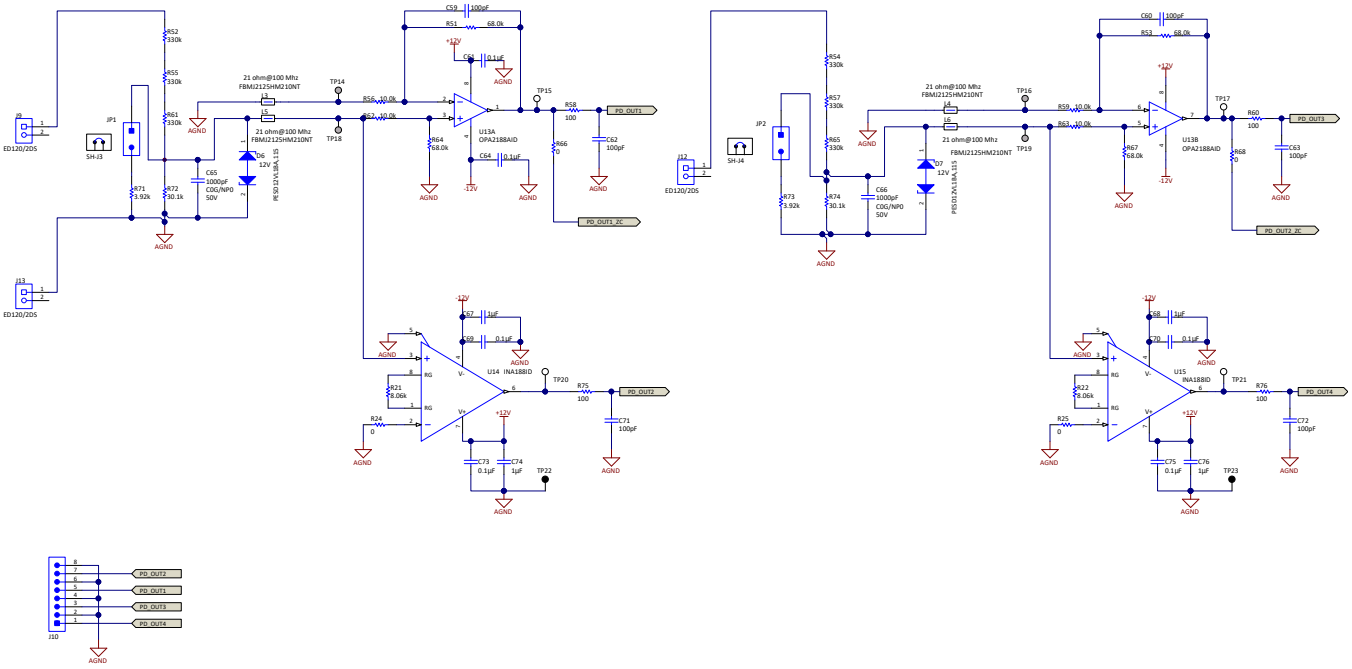

图 6. Schematics of AFE for Voltage Measurement with Potential_Divider and gainscaling_amplifier

2.3.2.1 OPA2188

The OPA2188 operational amplifier uses TI proprietary auto-zeroing techniques to provide low offset voltage (25 µV, maximum), and near zero-drift over time and temperature. This miniature, high-precision, low quiescent current amplifier offers high input impedance and rail-to-rail output swing within 15 mV of the rails. The input common-mode range includes the negative rail. Either single or dual supplies can be used in the range of 4 V to 36 V (±2 V to ±18 V). The amplifier can be configured for different gains. In this design the amplifier was configured for gain of 5.6 and 10. The gain configuration depends on the sensor output. The amplifier is used in differential configuration for improved performance.

For more details, see the OPA2188 product page.

2.3.2.2 INA188

The INA188 is a precision instrumentation amplifier that uses TI proprietary auto-zeroing techniques to achieve low offset voltage, near-zero offset and gain drift, excellent linearity, and exceptionally low-noise density (12 nV/√Hz) that extends down to dc. The INA188 is optimized to provide excellent common-mode rejection of greater than 104 dB (G ≥ 10). Superior common-mode and supply rejection supports high-resolution, precise measurement applications. The versatile three op-amp design offers a rail-to-rail output, low-voltage operation from a 4-V single supply as well as dual supplies up to ±18 V, and a wide, high-impedance input range. These specifications make this device ideal for universal signal measurement and sensor conditioning (such as temperature or bridge applications). A single external resistor sets any gain from 1 to 1000. The INA188 is designed to use an industry-standard gain equation: G = 1 + (50 kΩ / RG). The reference pin can be used for level-shifting in single-supply operation or for an offset calibration. The amplifier is configured for a gain of 7.175 in this design.

For more details, see the INA188 product page.

2.3.3 ADS8686S input protection and buffering for improved reliability

During ADC input open condition, due to the internal PGA structure 2V DC output is measured by the ADC. Customer would prefer having output zero during input open condition. This is implemented by using a buffer at the input. See below schematics to implement buffering of the ADC inputs. The ADC inputs are protected against transients and overvoltage using flat clamp TVS. Use of flat clamp TVS improves overvoltage protection and transient protection performance. Refer to TIDA-010008 for more details.

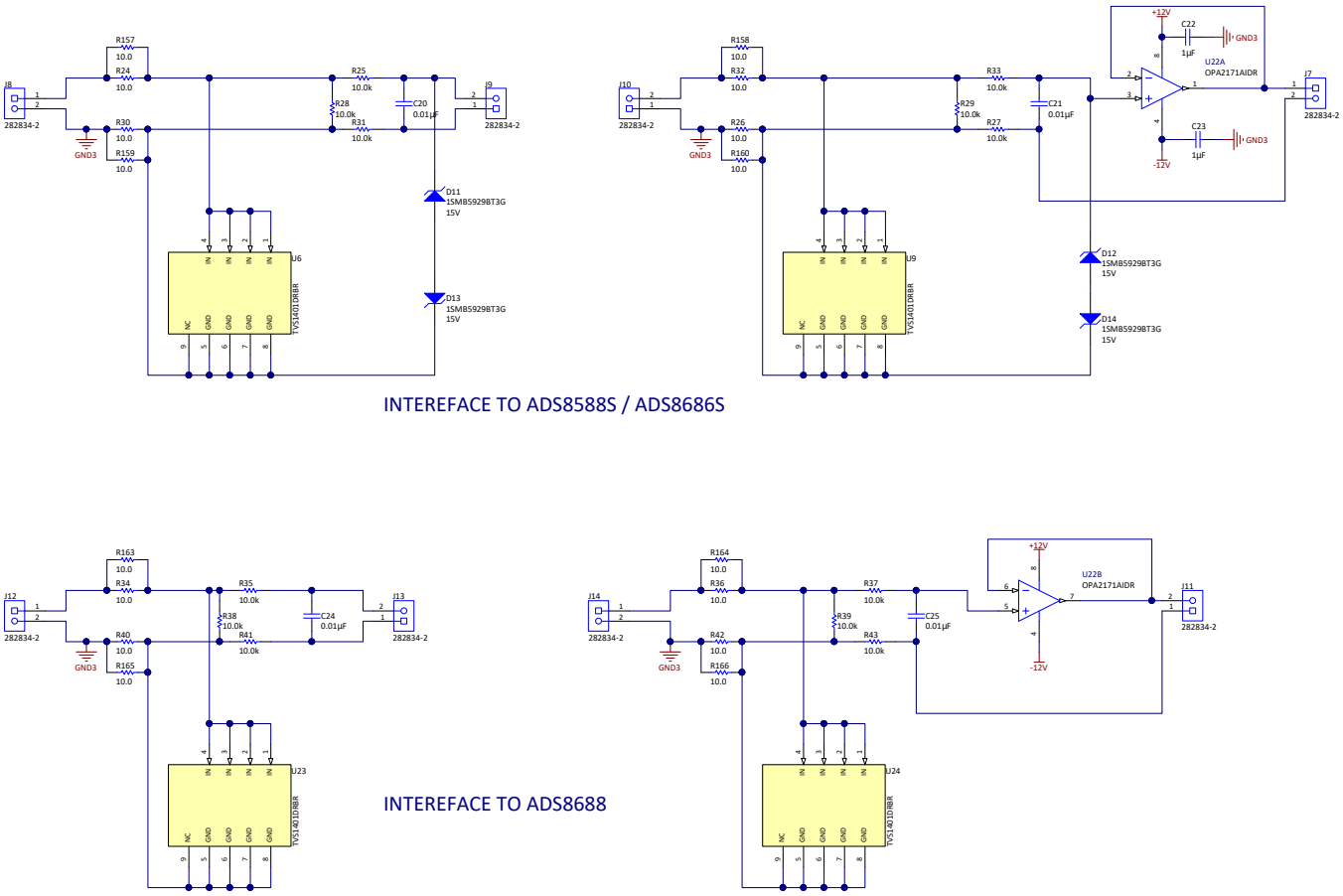

图 **7. Schematics of ADC input protection and buffering**

2.3.3.1 TLV2171

TLV2171 provides low offset, drift, quiescent current balanced with high bandwidth for the power. TLV2171 is specified from 2.7 V to 36 V. Input signals beyond the supply rails do not cause phase reversal. The input can operate 100 mV below the negative rail and within 2 V of the top rail during normal operation. The analog signal is buffered and applied to the ADC. An open at the input does not affect the ADC output. A split-rail power supply of ±10V or more is required to be generated for powering the amplifier.

For more details, see the TLV2171 product page.

2.3.3.2 TVS1401

The TVS1401 device shunts up to 30 A of IEC 61000-4-5 fault current to protect systems from high power transients or lightning strikes. The device survives the common industrial signal line EMC requirement of 1 kV IEC 61000-4-5 open circuit voltage coupled through a 42-Ω impedance. The TVS1401 uses a feedback mechanism to ensure precise flat clamping during a fault, keeping system exposure lower than traditional TVS diodes. The tight voltage regulation allows designers to confidently select system components with a lower voltage tolerance, lowering system costs and complexity without sacrificing robustness. The TVS1401 has a ±14 V operating range to enable operation in systems that require protection against reverse wiring conditions. The TVS1401 is used to protect the ADC or the op amp buffer at the input of the ADC against transients.

For more details, see the TVS1401 product page.

2.3.4 Generation of split-rail power supplies

This section provides approaches to generation of non isolated and isolated split-rail supplies.

2.3.4.1 Generation of non-isolated power supplies

The ADC can be configured for ±10 V, ±5 V, ±2.5 input ranges. The gain scaling amplifiers require split rail supplies of ±12 V to scale the analog signal to ADC input range including overrange. A split rail converter generates the required positive and negative output voltages and a dual LDO is used to regulate the Supply to ±12 V. The dual LDO output is configurable based on the application.

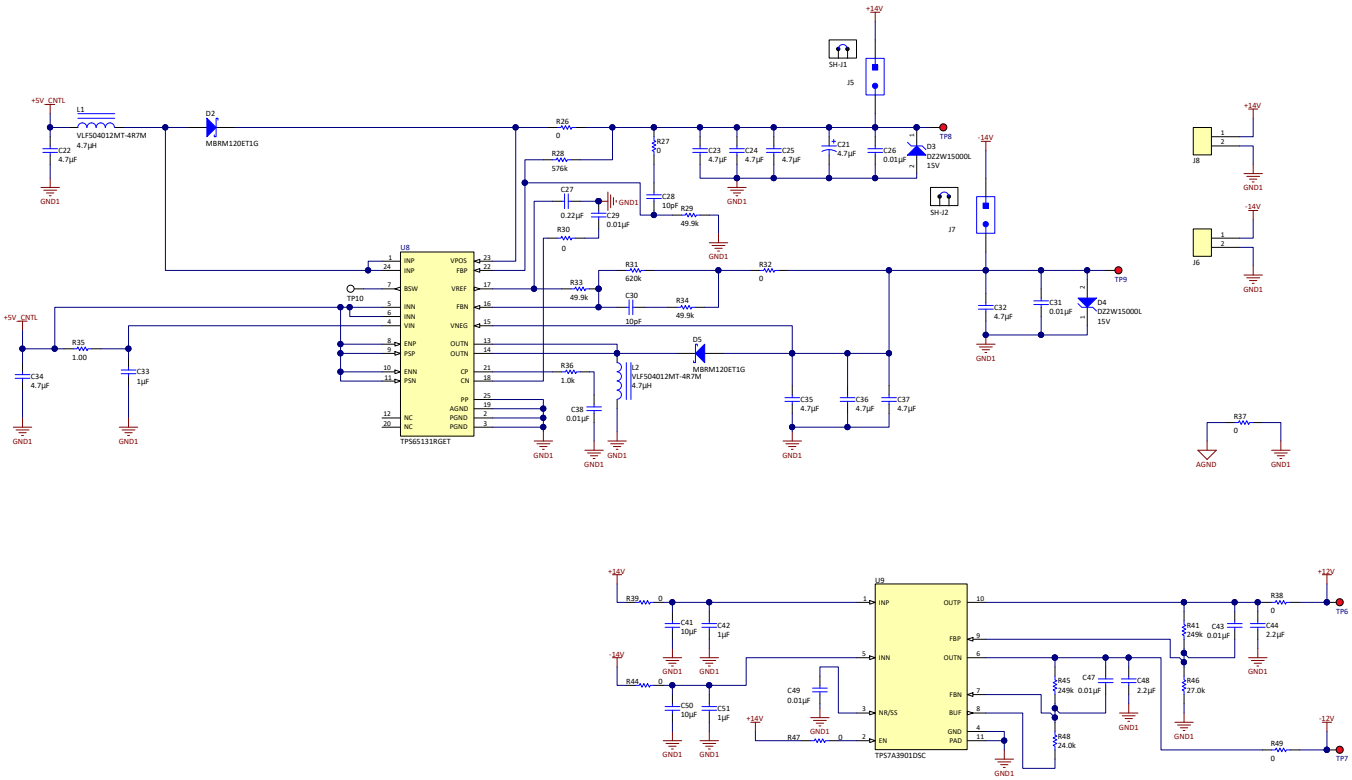

图 8. Schematics of Non-Isolated Split-Rail powersupply

2.3.4.1.1 TPS65131

The TPS65131 is dual-output DC-DC converter generating a positive output voltage up to 15 V and a negative output voltage down to –15 V with output currents in a 200-mA range in typical applications, depending on input voltage to output voltage ratio. With a total efficiency up to 85%, the device is ideal for portable battery-powered equipment. The input voltage range of 2.7 V to 5.5 V allows the devices to be powered from batteries or from fixed 3.3-V or 5-V supplies. Together with a minimum switching frequency of 1.25 MHz, the device enables designing small power supply applications because it requires only a few small external components. The converter operates with a fixed frequency PWM control topology and, if power-save mode is enabled, it uses a pulse-skipping mode at light-load currents. It operates with only 500-µA device quiescent current. Independent enable pins allow power-up and powerdown sequencing for both outputs. The device has an internal current limit overvoltage protection and a thermal shutdown for highest reliability under fault conditions. The device is configured to generate ±15 V in this design.

For more details, see the TPS65131 product page.

2.3.4.1.2 TPS7A39

The TPS7A39 device is a high-PSRR, positive and negative low-dropout (LDO) voltage regulator capable of sourcing (and sinking) up to 150 mA of current. The regulated outputs can be independently and externally adjusted to symmetrical or asymmetrical voltages, making this device an ideal dual, bipolar power supply for signal conditioning. The TPS7A39 also features high PSRR to eliminate power-supply noise, such as switching noise, that can compromise signal integrity. The internal reference voltage of the TPS7A39 can be overridden with an external reference to enable precision outputs, output voltage margining, or to track other power supplies. Additionally, the TPS7A39 has a buffered reference output that can be used as a voltage reference for other components in the system. These features make the TPS7A39 a robust, simplified solution to power operational amplifiers, digital-to-analog converters (DACs), and other precision analog circuitry. IN this design the LDO is configured to generate ±12 V.

For more details, see the TPS7A39 product page.

2.3.4.2 Generation of isolated power supplies

In isolated analog input configuration the ADS8686SEVM-PDK is isolated from the PHI interface board using high speed digital isolators. The isolated supply required for the ADC8686SEVM-PDK functioning and the split-rail supplies required for implementing gain scaling and zero cross is generated using a transformer driver and dual LDO.

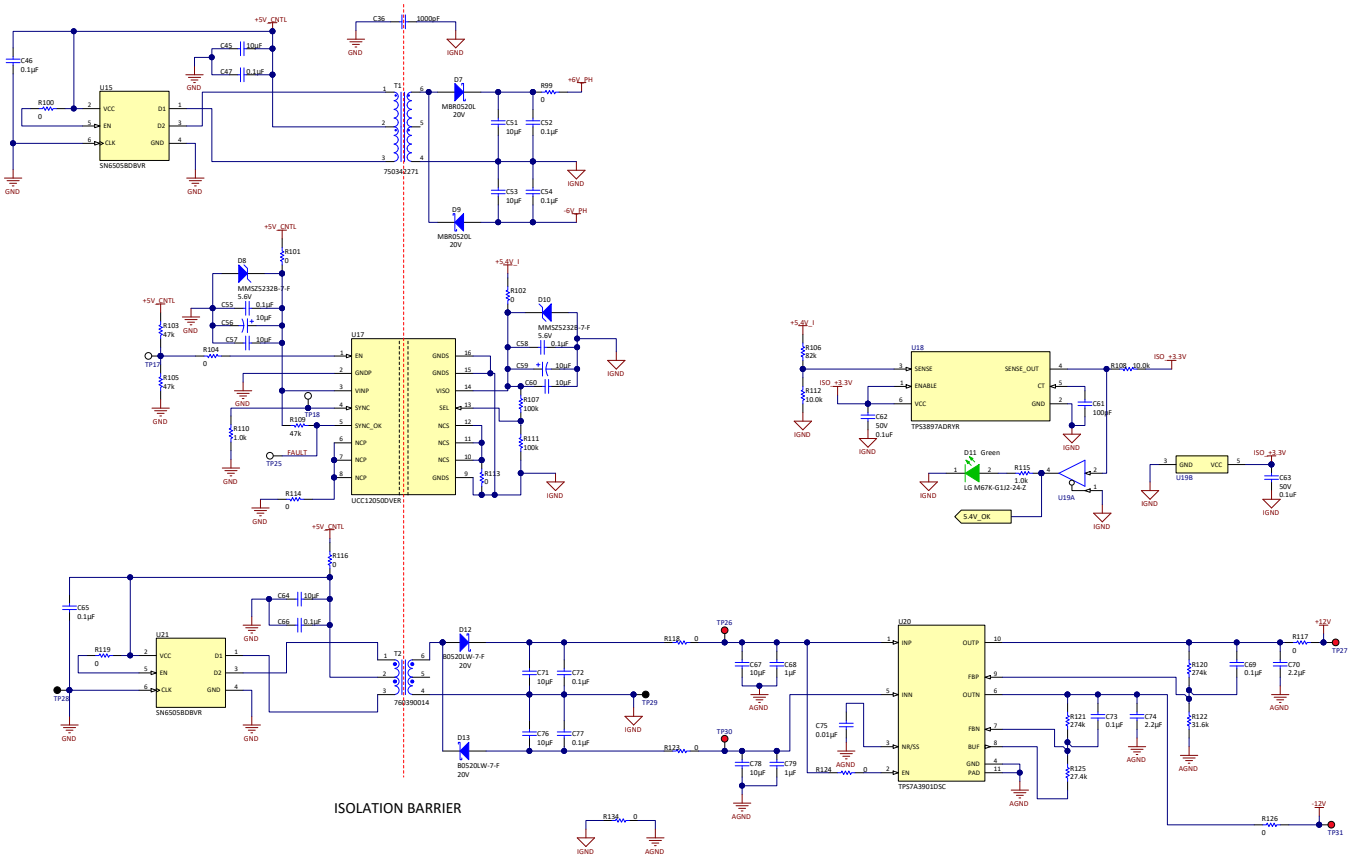

图 9. Schematics of Isolated Split-Rail and ADC powersupply

2.3.4.2.1 SN6505B

The SN6505B is a low-noise, low-EMI push-pull transformer driver, specifically designed for small form factor, isolated power supplies. It drives low-profile, center-tapped transformers from a 2.25 V to 5 V DC power supply. Ultra-low noise and EMI are achieved by slew rate control of the output switch voltage and through Spread Spectrum Clocking (SSC). . The device includes two 1-A Power-MOSFET switches to ensure start-up under heavy loads. The switching clock can also be provided externally for accurate placement of switcher harmonics, or when operating with multiple transformer drivers. The internal protection features include a 1.7 A current limiting, under-voltage lockout, thermal shutdown, and break-before-make circuitry. SN6505B has a 420 kHz internal oscillators for applications that require higher efficiency and smaller transformer size. The transformer driver has been configured to provide an output of 13V and is regulated to 12 V using dual regulator

For more details, see the SN6505B product page.

2.3.4.2.2 UCC12050

UCC12050 is a DC/DC converter with 5-kVRMS reinforced isolation rating designed to provide efficient, isolated power to isolated circuits that require a bias supply with a well-regulated output voltages. The device integrates a transformer and DC/DC controller with a proprietary architecture to provide 500 mW (typical) of isolated power with high efficiency and low EMI. The UCC12050 integrates protection features for increased system robustness. The device also has an enable pin, synchronization capability, and regulated 5-V or 3.3-V output options with headroom. The DC/DC converter is configured for 5.4V output and powers the ADC8686SEVM-PDK.

For more details, see the UCC12050 product page.

For cost optimized applications requiring basic isolation , UCC12040 can be considered.

UCC12040 is a DC/DC converter with 3-kVRMS basic isolation rating designed to provide efficient, isolated power to isolated circuits that require a bias supply with a well-regulated output voltages. The device integrates a transformer and DC/DC controller with a proprietary architecture to provide 500 mW (typical) of isolated power with high efficiency and low EMI.

For more details, see the UCC12040 product page.

2.3.4.2.3 TPS3897

TPS3897 is a very small supervisory circuits that monitor voltages greater than 500 mV with a 0.25% (typical) threshold accuracy and offer adjustable delay time using external capacitors. The TPS3897 also has a logic enable pin (ENABLE or ENABLE) to power on and off the output. For example, when the input voltage pin (SENSE) rises above the threshold, and the ENABLE pin is high, then the output pin (SENSE_OUT) goes high after the capacitor-adjustable delay time. When SENSE falls below the threshold or ENABLE is low, then SENSE_OUT goes low. The supervisor is configured to provide a fault output at around 4.8V. The threshold is settable using resistors. In the design this is used for indication.

For more details, see the TPS3897 product page.

2.3.5 Precision Dual ADC

图 10 shows the ADC used and the configuration.

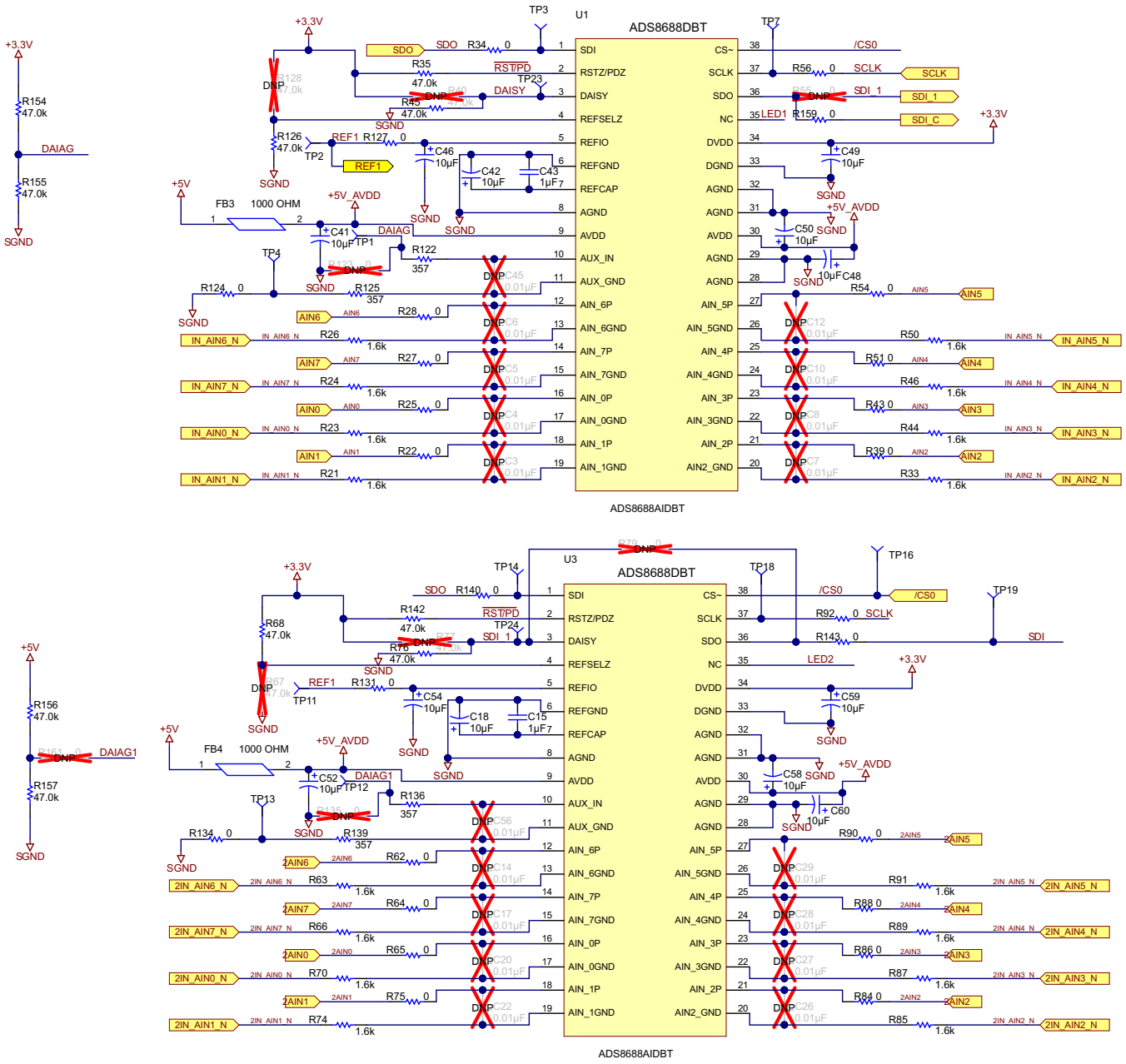

图 **10. Schematic of ADS8688A Interface**

2.3.5.1 16-Bit ADC ADS8688

The ADS8688 is an eight-channel, integrated data acquisition system based on a 16-bit SAR ADC, operating at a throughput of 500 kSPS. The devices feature integrated analog front-end circuitry for each input channel with overvoltage protection up to ±20 V, an eight-channel multiplexer with automatic and manual scanning modes, and an on-chip, 4.096-V reference with low temperature drift. Operating on a single 5-V analog supply, each input channel on the devices can support true bipolar input ranges of

±10.24 V, ±5.12 V, and ±2.56 V. The input range selection is software-programmable and independent for each channel. The devices offer a 1-MΩ constant resistive input impedance irrespective of the selected input range. The ADS8688 offers a simple SPI-compatible serial interface to the digital host and also support daisy-chaining of multiple devices. The digital supply operates from 1.65 to 5.25 V, enabling direct interface to a wide range of host controllers.

For more details, see the ADS8688 product page.

2.3.5.2 16-Bit ADC ADS8688A

The ADS8688A are 8-channel, integrated data acquisition systems based on a 16-bit successive approximation (SAR) analog-to-digital converter (ADC), operating at a throughput of 500 kSPS. The devices feature integrated analog front-end circuitry for each input channel with overvoltage protection up to ±20 V, a 8-channel multiplexer with automatic and manual scanning modes, and an on-chip, 4.096-V reference with low temperature drift. Operating on a single 5-V analog supply, each input channel on the devices can support true bipolar input ranges of ±10.24 V, ±5.12 V, ±2.56 V, ±1.28V and ±0.64V, as well as unipolar input ranges of 0 V to 10.24 V, 0 V to 5.12 V, 0 V to 2.56 V and 0 V to 1.28 V. The gain of the analog front-end for all input ranges is accurately trimmed to ensure a high dc precision. The input range selection is software-programmable and independent for each channel. The devices offer a 1-MΩ constant resistive input impedance irrespective of the selected input range. The ADS8688A offer a simple SPI-compatible serial interface to the digital host and also support daisy-chaining of multiple devices. The digital supply operates from 1.65 V to 5.25 V, enabling direct interface to a wide range of host controllers.

For more details, see the ADS8688A product page.

2.3.5.3 Low-Noise, Low-Drift, High-Precision Reference REF5040

The REF5040 is a low-noise, low-drift, very high-precision voltage reference. This reference is capable of both sinking and sourcing current and has excellent line and load regulation. Excellent temperature drift (3 ppm/°C) and high accuracy (0.05%) are achieved using proprietary design techniques. Combined with very low noise, these features make the REF5040 ideal for use in high-precision data acquisition systems.

For more details, see the REF5040 product page.

2.3.5.4 High-Precision Voltage Reference With Integrated High-Bandwidth Buffer REF6041

The REF6041 voltage reference has an integrated, low-output impedance buffer that enables the user to directly drive the REF pin of precision data converters while preserving linearity, distortion, and noise performance. Most precision SAR and Delta-Sigma ADCs switch binary-weighted capacitors onto the REF pin during the conversion process. To support this dynamic load, the output of the voltage reference must be buffered with a low-output impedance (high-bandwidth) buffer. The REF6000 family devices are well suited, but not limited, to drive the REF pin of the ADS88xx family of SAR ADCs and ADS127xx family of delta-sigma ADCs.

For more details, see the REF6041 product page.

2.3.6 Interface Isolation Using Digital Isolator With Integrated Power ISOW7841 Family

This section provides information on different digital isolator options to consider for the design of the AC AIM.

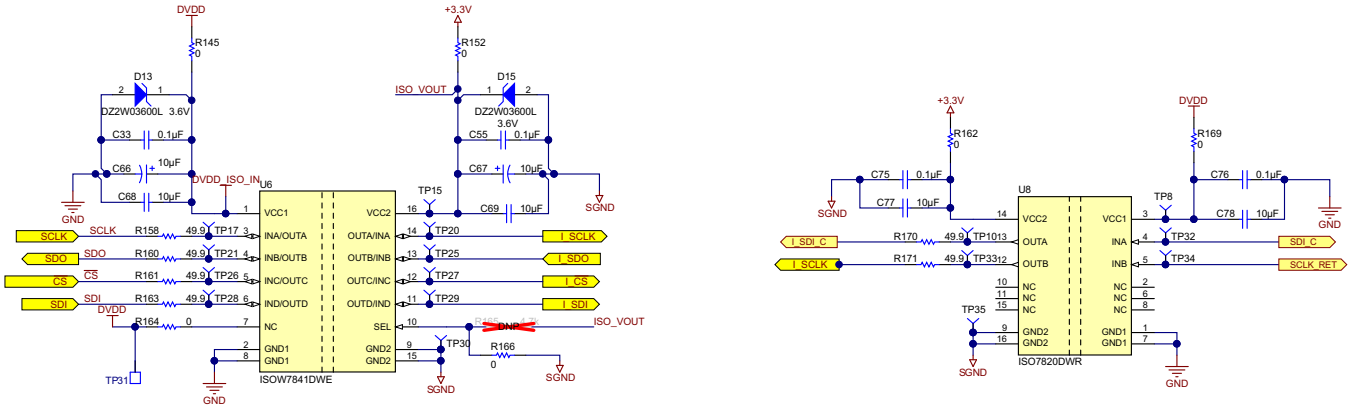

图 **11. Schematic of ISOW7841 Configuration for ADC Interface**

2.3.6.1 Digital Isolator With Integrated Power ISOW7841

The ISOW7841 is a high-performance, quad-channel reinforced digital isolator with an integrated high-efficiency power converter. The integrated DC/DC converter provides up to 650 mW of isolated power at high efficiency and can be configured for various input and output voltage configurations. Therefore, these devices eliminate the need for a separate isolated power supply in space-constrained isolated designs.

For more details, see the ISOW7841 product page.

2.3.6.2 Digital Isolator ISO7820

The ISO7820 is a high-performance, dual-channel digital isolator with 8000-V_{PK} isolation voltage. The isolator provides high electromagnetic immunity and low emissions at low power consumption, while isolating CMOS or LVCMOS digital I/Os. The ISO7820 device has two forward channels and no reverse-direction channel. If the input power or signal is lost, the default output is ‘high’ for the ISO7820 device and ‘low’ for the ISO7820F device. Used in conjunction with isolated power supplies, this isolator prevents noise currents on a data bus or other circuits from entering the local ground and interfering with or damaging sensitive circuitry.

For more details, see the ISO7820 product page.

2.3.7 Interface Isolation Using Digital Isolator ISO7763 Family

This section provides information on different digital isolator options to consider for the design of the AC AIM.

2.3.7.1 Digital Isolator ISO7763

The ISO776x devices are high-performance, six-channel digital isolators with 5000-V_{RMS} (DW package) isolation ratings per UL 1577. The ISO776x family of devices provides high-electromagnetic immunity and low emissions at low-power consumption, while isolating CMOS or LVCMOS digital I/Os. Each isolation channel has a logic-input and logic-output buffer separated by a silicon dioxide (SiO_2) insulation barrier. The ISO776x family of devices is available in all possible pin configurations such that all six channels are in the same direction, or one, two, or three channels are in reverse direction while the remaining channels

are in forward direction. Used in conjunction with isolated power supplies, this family of devices helps prevent noise currents on a data bus or other circuits from entering the local ground and interfering with or damaging sensitive circuitry. Through innovative chip design and layout techniques, the electromagnetic compatibility of the ISO776x family of devices has been significantly enhanced to ease system-level ESD, EFT, surge, and emissions compliance.

For more details, see the ISO7763 product page.

2.3.8 Power Supply

The ISOW7841 device can generate the required isolated power supply. An alternative approach to isolate the AIM from the host is to use a digital isolator and isolated power generated using a transformer driver.

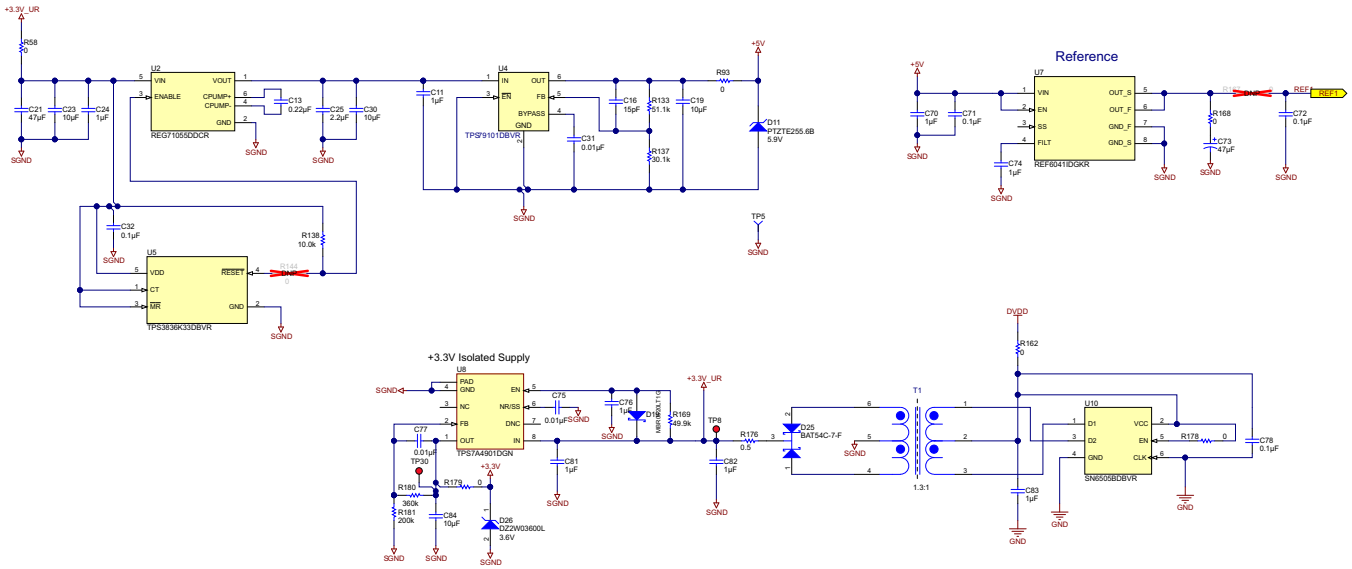

图 **12. Schematic of ADC Analog and Digital Power Supply**

2.3.8.1 5-V AVDD

This section provides details for generating a 5-V power supply for the ADCs.

2.3.8.1.1 REG71055

The REG71055D is a switched capacitor voltage converter that generates regulated, low-ripple output voltage from an unregulated input voltage. A wide input supply voltage from 1.8 to 5.5 V can be applied. The input voltage may vary above and below the output voltage and the output remains in regulation. The device works as step-up or step-down converters without the need of an inductor, providing low EMI DC/DC conversion.

For more details, see the REG71055 product page.

2.3.8.1.2 Isolated Power Supply Using Transformer Driver SN6505B or SN6501

The SN6505B is a low-noise, low-EMI push-pull transformer driver, specifically designed for small form factor, isolated power supplies. This device drives low-profile, center-tapped transformers from a 2.25- to 5-V DC power supply. The SN6505B includes a soft-start feature that prevents high inrush current during power-up with large load capacitors.

For more details, see the SN6505B product page.

2.3.9 Diagnostics and Protection

The following subsections describe the diagnostics and protection features.

2.3.9.1 Load Switch TPS22944

The TPS22944 load switch protects systems and loads in high-current conditions. The device contains a 0.4-Ω current-limited P-channel MOSFET that can operate over an input voltage range of 1.62 to 5.5 V. The load switch prevents current from flowing when the MOSFET is off. The switch is controlled by an on/off input (ON), which is capable of interfacing directly with low-voltage control signals. The TPS22944 includes thermal shutdown protection that prevents damage to the device when a continuous overcurrent condition causes excessive heating by turning off the switch.

For more details, see the TPS22944 product page. For details on the selection of load switches based on the power requirements, see 表 2.

表 2. Load Switch Selection Options

SERIAL NUMBER	PART NUMBER	DESCRIPTION
1	LM34902	300-mA Current Limited Power Switch
2	TPS2010	0.4-A, 2.7- to 5.5-V, Single High-Side MOSFET Switch IC, No Fault Reporting, Active-Low Enable
3	TPS22946	5.5-V, 0.2-A, 400-mΩ Selectable Current Limit Load Switch

2.3.9.2 Power-on Reset TPS3836K33

The TPS3836 family of supervisory circuits provides circuit initialization and timing supervision, primarily for DSP and processor-based systems. During power-on, RESET is asserted when the supply voltage VDD becomes higher than 1.1 V. Then, the supervisory circuit monitors VDD and keeps the RESET output active as long as VDD remains below the threshold voltage of VIT. An internal timer delays the return of the output to the inactive state (high) to ensure proper system reset. The delay time starts after VDD has risen above the threshold voltage VIT.

For more details, see the TPS3836K33 product page.

2.3.10 Board Layout With ISOW7841

The ISOW7841 integrated signal and power isolation device simplifies system design and reduces board area. The use of low-inductance micro-transformers in the ISOW7841 device necessitates the use of high-frequency switching, resulting in higher radiated emissions compared to discrete solutions. The ISOW7841 device uses on-chip circuit techniques to reduce emissions compared to competing solutions. Techniques such as lower supply operation, using interlayer stitching capacitance, filters, and common-mode chokes can further reduce radiated emissions at the system level.

For more details, see *Low-Emission Designs with ISOW7841 Integrated Signal and Power Isolator*.

2.3.11 Design Enhancements

The following subsections provide some of the design enhancement options.

2.3.11.1 Non-Simultaneous Sampling ADC Phase Compensation

The design uses a 16-bit, multiplexed input (non-simultaneous sampling) SAR based ADC with an integrated AFE circuit simplifying system hardware design and minimizing the number of components used. An additional phase delay is introduced between the input channels of a non-simultaneous sampling ADC as compared to simultaneous sampling ADC. The phase delay can be compensated in the software. In this design phase, correction is applied to all the analog channels and the results are provided.

A precision design implements an optimum software solution to compensate for the phase delay, and the same procedure is used to compensate 16 channels. For more details, see the *Phase-Compensated, 8-Ch, Multiplexed Data Acquisition System for Power Automation Reference Design*.

2.3.11.2 Multiplexed ADS86xx ADC Selection

The measurement accuracy of the AC MIN can be increased by using an external precision gain amplifier, a higher resolution ADC, or both. TI provides a range of ADCs to select based on the application requirement. The resolution varies from 12-bit to 18-bit. The ADS8698 18-Bit SAR ADC can measure the analog input with a higher resolution, resulting in improved measurement accuracy. 表 3 provides a range of SAR ADCs to consider.

表 **3. 8-Channel Multiplexed SAR ADC Selection**

ADC NUMBER	DESCRIPTION
ADS8698	18-Bit SAR ADC, 8 Channels, 500 kSPS, and Bipolar Inputs off 5-V Supply
ADS8688	16-Bit SAR ADC, 8 Channels, 500 kSPS, and Bipolar Inputs off 5-V Supply
ADS8678	14-Bit SAR ADC, 8 Channels, 500 kSPS, and Bipolar Inputs off 5-V Supply
ADS8668	12-Bit SAR ADC, 8 Channels, 500 kSPS, and Bipolar Inputs off 5-V Supply

2.3.11.3 Gain Amplifier Selection

A gain amplifier can be used to scale the input in applications where the sensor output is low for improvement of measurement accuracy. Gain amplifiers improve the measurement accuracy and dynamic range. 表 4 provides a range of op amps to consider.

表 **4. Gain Scaling Amplifier Selection**

OP AMP NUMBER	DESCRIPTION
OPA2180	0.1-µV/C Drift, Dual, Low-Noise, Rail-to-Rail, 36-V Zero Drift Op Amp
OPA2188	0.03-µV/°C, 6-µV Vos, Low-Noise, Rail-to-Rail Output, 36-V Zero-Drift Op Amp
OPA4188	0.03-µV/°C, 6-µV Vos, Low-Noise, Rail-to-Rail Output, 36-V Zero-Drift Op Amp
OPA4180	0.1-µV/C Drift, Quad, Low-Noise, Rail-to-Rail, 36-V Zero-Drift Op Amp
OPA4197	36-V, precision, Rail-to-Rail Output, Low Offset Voltage Op Amp
OPA2197	36-V, Precision, Rail-to-Rail Output, Low Offset Voltage Op Amp
INA821	High bandwidth (4.7MHz), low noise (7nV/√Hz), precision (35µV), low-power, instrumentation amp
INA826	Precision, 200-µA Supply Current, 36-V Supply Instrumentation Amplifier
PGA281	PGA281, Zero-Drift, High Voltage Programmable Gain Amplifier

2.3.11.4 Dual Output Power Supplies for Gain Amplifier

A dual power supply is required when using gain amplifiers. The dual power supply output can be > ±5.12 V or > ±10.24 V. 表 5 provides a range of power supplies to generate the required dual power supply from a single 5-V or 3.3-V input.

表 5. Dual Output DC/DC and LDO Selection

DEVICE	DESCRIPTION
TPS65131	Split-Rail Converter With Dual Positive and Negative Outputs (300 mA typ)
TPS7A39	Dual, 150-mA, Wide V_{IN}, Positive and Negative LDO Voltage Regulator
LM27762	Low-Noise, Positive- and Negative-Output Charge Pump With Integrated LDO
DCH010515D	Miniature, 1W, 3kVDC Isolated DC/DC Converters
ADS8686S	16-channel 16-bit 1-MSPS dual simultaneous-sampling ADC with integrated analog front end (AFE)
REF5025	2.5-V, 3-µVpp/V noise, 3-ppm/°C drift precision series voltage reference
INA188	36-V, Zero-Drift, Rail-to-Rail-Out Instrumentation Amplifier
OPA2188	0.03µV/°C, 6µV Vos, Low Noise, Rail-to-Rail Output, 36V Zero-Drift Operational Amplifier
TPS7A47	1-A, 36-V, low-noise, high-PSRR, low-dropout voltage regulator with enable
UCC12050	500 mW, high-efficiency, 5 kVRMS isolated DC-DC converter
UCC12040	500mW, high efficiency 3kVrms isolated DC-DC converter

2.3.11.5 Isolated Interface Approaches and Advantages

Two different approaches can provide isolated power and data interface using TI's digital isolator family.

2.3.11.5.1 Isolated Interface With Transformer Driver and Digital Isolator

As shown in 表 6, this approach consists of the following blocks that require multiple products:

- Digital isolator
- Isolation transformer
- Transformer driver
- LDO

The advantage of this approach is that the module can be a design using any of the digital isolators highlighted in 表 6 or with any of the digital isolator families, including devices with reinforced digital isolation or basic digital isolation.

表 6. Digital Isolator Families With External Isolated Power

SERIAL NUMBER	PART NUMBER	DESCRIPTION	INTERFACE TYPE
1	ISO7721	High-Speed, 5000-V_{RMS} Dual-Channel Digital Isolators	UART
2	ISO7740	High-Speed, Low-Power, Robust EMC Quad-Channel Digital Isolator	GPIO
3	ISO7841	High-Immunity, 5.7-kV_{RMS} Reinforced Quad-Channel 3/1 Digital Isolator, 100 Mbps	SPI
4	ISO7840	High-Immunity, 5.7-kV_{RMS} Reinforced Quad-Channel 4/0 Digital Isolator, 100 Mbps	GPIO
5	ISO7821	High-Immunity, 5.7-kV_{RMS} Reinforced Dual-Channel 1/1 Digital Isolator, 100 Mbps	UART
6	ISO7641	6-kV_{PK}, Low-Power Quad Channels, 150-Mbps Digital Isolators	SPI
7	ISO7763	High-Speed, Robust, EMC Six-Channel Digital Isolators	SPI
8	ISO7762	High-Speed, Robust, EMC Six-Channel Digital Isolators	SPI

2.3.11.5.2 Isolated Interface Using ISOW7841

In this approach, all of these components are integrated into one device, simplifying the design, reducing the solution size, and optimizing the cost, as shown in 图 13. In applications where the required interface matches with the ISOW784x family, this approach is recommended.

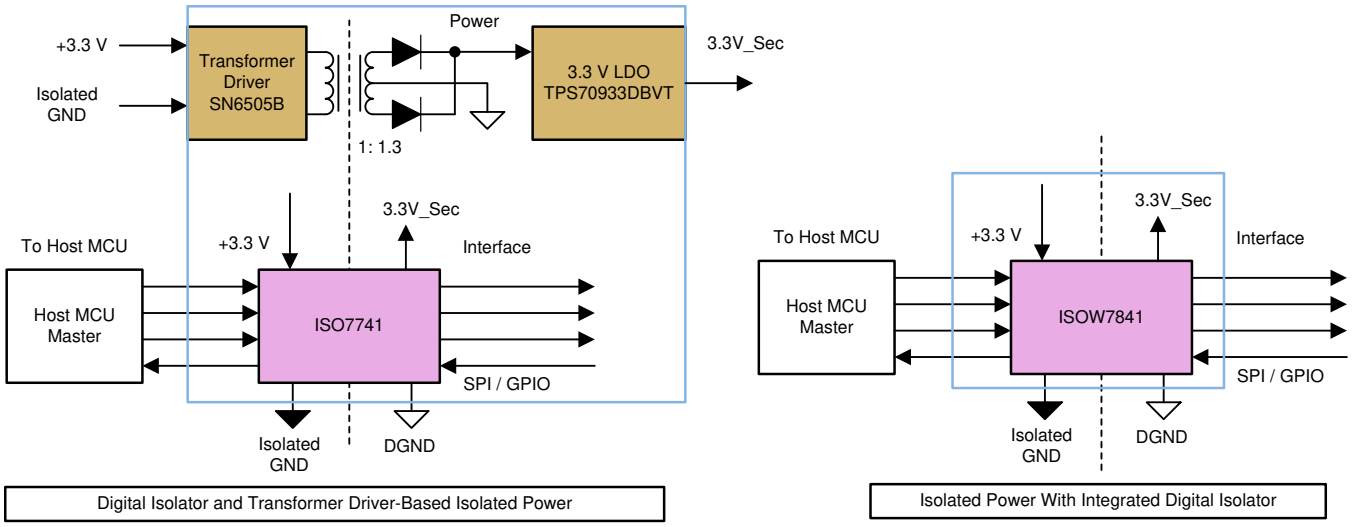

图 **13. ISOW7841 Integrated Data and Power**

The ISOW7841 with an integrated power converter provides the following advantages:

- Simplifies system design with increased reliability
- Provides current output > 65 mA with 46% efficiency
- Provides current limit and thermal overload protection
- Has a lower temperature rise and overall heat dissipation

2.3.12 Achieving Higher Output Efficiency With Transformer Driver SN6505B

The digital isolator with integrated power provides a peak efficiency of ≈ 48%. In applications requiring greater efficiencies with no space constraint, the SN6501 or SN6505 transformer driver can generate the isolated power. The transformer drivers provide efficiency between 60% to 75% as shown in 表 7.

表 **7. Transformer Driver Efficiency at Lower Output Currents**

OUTPUT VOLTAGE (V)	LOAD CURRENT (mA)	EFFICIENCY
4.022	8.4	61%
4.022	11.0	64%
4.022	19.0	71%
4.022	30.0	73%

2.3.13 Achieving Higher Efficiency With DC/DC Converters

表 8 provides details on the different DC/DC converters that can generate a split rail output up to 12 V for an AC AIM with high efficiency.

表 **8. DC/DC Converters for to Generate Isolated Split Rail Output**

DEVICE	DESCRIPTION	APPLICATION NOTE
TPS61040	Boost converter to generate an 18-V output from a single-cell Li-Ion battery (3 to 4.2 V)	TPS61040EVM-001
LM5001	±5-V isolated, low-noise, split rail generator (0.25 A, 2.5 W total)	RD-171
LM5002	Low-noise, split rail, non-isolated power supply	RD-184
LM2733	9- to 14-V_{IN}, isolated ±15-V/100-mA output flyback reference design	PMP10703

2.3.14 Interface With High-Precision ADCs With Serial Interface

The digital isolators ISOW7841 or ISO7741 can interface to ADCs or other TI products with SPI. 表 9 provides some of the options for an ADC interface.

表 **9. ADC to Interface With Data Acquisition Front-End With ISOW7841**

SERIAL NUMBER	TI ADC PART	ADC DESCRIPTION	INTERFACE TYPE
1	ADS8688 or ADS8688A	16-Bit, 500-kSPS, 8-Channel, Single-Supply, SAR ADCs With Bipolar Input Ranges	SPI-compatible interface with daisy chain
2	ADS8681	16-Bit, 1-MSPS, 5-V SAR ADC With Integrated Analog Front-End and Bipolar Inputs	multiSPI™ interface with daisy chain
3	ADS8588S, ADS8586S, ADS8584S, or ADS8578S	16-Bit, 200-kSPS, 8/6/4 Ch, Simultaneous-Sampling ADCs With Bipolar Inputs on a Single Supply	Serial interface
4	ADS131E08, ADS131E04, or ADS131E08S	Analog Front End for Power Monitoring, Control, and Protection	SPI data interface
5	ADS131A04	24-Bit, 128-kSPS, 4-Ch, Simultaneous Sampling, Delta-Sigma ADC	Multiple SPI data interface modes
6	ADS131A02	24-Bit, 128-kSPS, 4-Ch, Simultaneous Sampling, Delta-Sigma ADC	Multiple SPI data interface modes
7	ADS131M08	24-bit 32-kSPS 8-channel simultaneous-sampling delta-sigma ADC	SPI

2.3.14.1 Voltage Supervisor Selection and Options

During an output overload condition, the output of the ISOW7841 reduces proportional to the output current. To ensure the MCU operates within a specified range, consider an external programmable-delay supervisory circuit. The TPS3808 has been provided in this reference design. 表 10 provides a range of other supervisory circuits to consider:

表 10. Voltage Supervisor Selections

SERIAL NUMBER	PART NUMBER	DESCRIPTION
1	TPS3836	Nano-power supervisory circuits
2	TPS3837	Nano-power supervisory circuits
3	TPS3838	Nano-power supervisory circuits
4	TPS3839	Ultra-low-power, supply voltage supervisor
5	TPS3820	Voltage monitor with watchdog timer
6	TPS3840	Nanopower high-input voltage supervisor with manual reset and programmable-reset time delay

2.3.15 ADC Current Consumption

表 11 provides summary of the current consumption for different ADCs. The ISOW7841 can power all the ADCs listed with high efficiency.

表 11. Power Consumption of Different ADCs

POWER (NOMINAL, MAX)	ADS8686S (mA)	ADS8588S (mA)	ADS8688A (mA)	ADS131E08, ADS131E08S (mA)	ADS131A04 (mA)
Analog, AVDD_DYN, internal ref	59, 72	17.7, 24	13, 16	5.8	4.0
DVDD	0.6, 1mA	0.15, 0.3	0.5	1.0	0.8

2.3.16 Load Switch Selection

The load switch along with the ISOW7841 can protect against overload. The TPS22944 load switch protects systems and loads in high-current conditions. These devices contain a 0.4-Ω current-limited P-channel MOSFET that can operate over an input voltage range of 1.62 V to 5.5 V. Current is prevented from flowing when the MOSFET is off. The switch is controlled by an on/off input (ON), which is capable of interfacing directly with low-voltage control signals.

For more details, see the TPS22944 product page.

表 12. Load Switch Selection Options

SERIAL NUMBER	PART NUMBER	DESCRIPTION
1	LM34902	300-mA Current Limited Power Switch
2	TPS2010A	0.4-A, 2.7- to 5.5-V Single High-Side MOSFET Switch IC, No Fault Reporting, Active-Low Enable
3	TPS22946	5.5-V, 0.2-A, 400-mΩ Selectable Current Limit Load Switch
4	TPS22960	5.5-V, 0.5-A, 435-mΩ, 2-Channel Load Switch With Quick Output Discharge

2.3.17 ADC Measurement Performance With Higher Clock Frequency and Digital Isolator

In an isolated AC AIM, the ADC and MCU are on opposite sides of the isolation barrier. The SCLK signal experiences a delay, t_{PD_ISO}, as it travels from the MCU to the ADC. The ADC responds to the delayed version of SCLK with an SDO signal that experiences an additional delay of t_{PD_ISO} as it arrives at the MCU. Therefore, the total skew between the SCLK edge and the corresponding ADC data bit at the MCU is ($2 \times t_{PD\_ISO}$). This delay is acceptable as long as the data bit arrives at the MCU before the MCU performs a read operation.

In a standard SPI, a read event occurs on the opposite SCLK edge relative to the SCLK edge corresponding to a write event. For large values of f_{SCLK}, the t_{PD_ISO} requirement becomes challenging to meet. To mitigate this issue, an additional delay of t_{PD_ISO} is introduced in the already delayed version of SCLK by routing SCLK back across the isolation barrier to the MCU along with the SDO signal of the ADC through a multi-channel isolator. This rerouting results in minimal skew between the SDO and SCLK_RET so that the MCU can capture SDO relative to SCLK_RET without error. The following approaches can be used for returning SCLK across the isolation barrier.

2.3.17.1 ADS8681 Using Two Four-Channel Digital Isolators

图 14 provides the interface between the MCU and host interface by using multiple digital isolators.

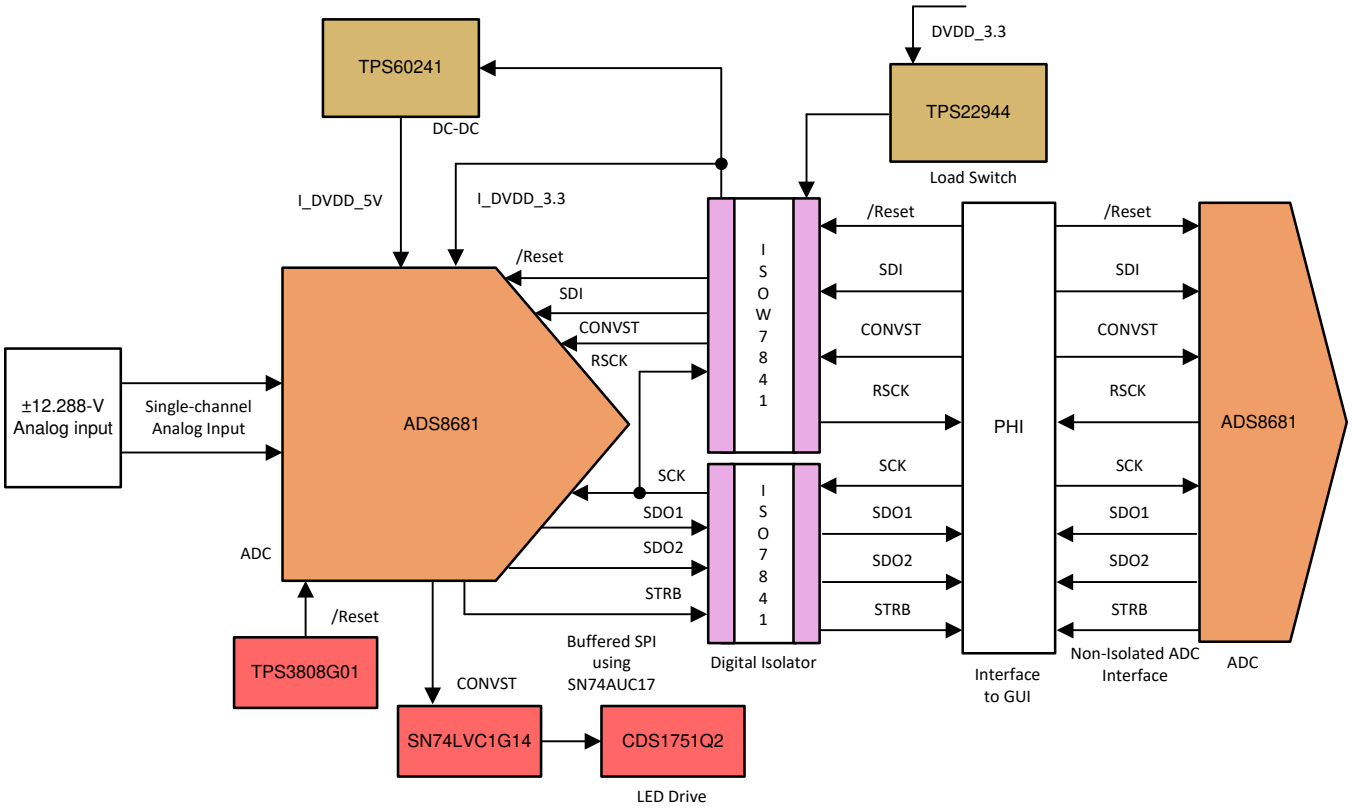

图 14. Block Diagram of ADS8681 Interface With SCK and RSCK Using Multiple Digital Isolators

表 13 provides the system performance with the SCLK returned back across the isolation barrier.

表 13. ADS8681 Performance With Clock Returned to Host From Isolated Side

TEST	INPUT RMS	INPUT RANGE	CH1 (500 KSPS) 60-Hz INPUT	CH1 (500 KSPS) 1-kHz INPUT	CH1 (1000 KSPS) 1-kHz INPUT
ENOB	8.2 V	±12.288 V	14.973	14.951	14.913
SNR	8.2 V	±12.288 V	91.913	91.825	91.630
THD	8.2 V	±12.288 V	–116.866	–110.437	–108.239

2.3.17.2 ADS8920B Using Single Digital Isolator With Integrated Power

图 15 provides the interface between the ADC and host interface by using a single digital isolator with the ADC using default configuration.

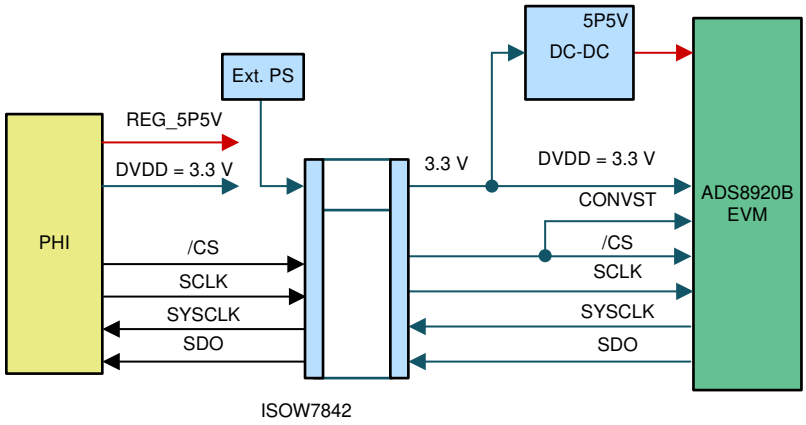

图 15. Block Diagram of ADS8920B Interface Using Single Digital Isolator

表 14 provides the system performance with the SCLK returned back across the isolation barrier.

表 14. ADS8920B Measurement Performance With Clock Fold Back

CONFIGURATION	INPUT FREQ	SNR (dB)	THD (dB)
ADS8920BEVM-PDK	2 kHz	96.10	–125.21
ADS8920BEVM-PDK + ISOW Adapter	2 kHz	96.05	–124.64
ADS8920BEVM-PDK + ISOW Adapter	50 Hz	96.16	–119.31

2.3.18 Temperature Compensation of Measured Analog Input for Improved Measurement Accuracy

The auxiliary ADC channel of the ADS8688 or ADS8668 can be used to measure ambient temperature for real-time compensation of the measured electrical parameters. There are two approaches to measure temperature.

2.3.18.1 Onboard High-Accuracy Analog Temperature Sensor Interface

The first approach is to use an onboard high-accuracy analog temperature sensor interface. 表 15 provides details of different sensors to consider interfacing to the auxiliary channel of ADC.

表 15. High-Accuracy Analog Temperature for Sensor for AC AIM

SENSOR	DESCRIPTION
LMT70	±0.1°C precision analog temperature sensor
LM35	±0.5°C temperature sensor with analog output with 30-V capability

2.3.18.2 Using Remote Temperature Sensor

The second approach is to use a remote temperature sensor, including resistance temperature detectors (RTDs). 表 16 lists some of the common types of RTDs used:

表 16. Common RTD Sensors for AC AIM

SENSOR	DESCRIPTION
100 Ω PT	Platinum
120 Ω NI	Nickel
10 Ω CU	Copper

The auxiliary ADC input can be configured to measure the analog temperature sensor output. For more details, see the Isolated, High-Accuracy Analog Input Module Reference Design Using 16-Bit ADC and Digital Isolator.

2.3.19 Improving Analog Input Measurement Accuracy Using 18-Bit ADC

The measurement accuracy of the AC AIM can be increased by using an external precision gain amplifier, a higher resolution ADC, or both. Precision gain amplifiers like the OPA4180, OPA4188, or INA188 can provide the required gain. The ADS8698 18-Bit SAR ADC can measure the analog input with higher resolution, resulting in improved measurement accuracy.

2.3.20 Design of Wide Input AC or DC Digital, Contact, or Binary Input Module

The TIDA-00847 reference design showcases a DC or DC BIM using a 10-bit SAR ADC internal to the MCU MSP430G2332. Most grid applications allow measurements of 16 digital or binary inputs with a DC voltage up to 300 V. The ADS8668 connected in a daisy-chain configuration with a 12-bit resolution can be used to implement a 16-channel group isolated DC BIM using only four TI products with improved accuracy performance over a wide input range.

2.3.21 DC Transducer Input Module With Unidirectional or Bidirectional Signal Input

This reference design can be designed as a DC AIM to measure unipolar or bipolar inputs ranging from 0 to 20 mA, 4 to 20 mA, 0 to 10 V, ±20 mA, and ±10 V. Similar reference designs include the TIDA-00550, TIDA-00764, TIDA-00164, TIDA-00119, and TIDA-00310. This reference design with an integrated digital isolator and power converter simplifies the module design.

3 Hardware, Testing Requirements, and Test Results

3.1 Required Hardware

This section describes the setup for performance testing of the AC AIM.

3.1.1 ADS868S based analog input module

The following subsections provide information on the different interface connectors for connecting power supply, host interface, and AC analog inputs.

表 **17. ADS8686S ADC based AIM connections**

CONNECTOR	FUNCTION	COMMENTS
Inputs to ADS8686SEVM-PDK	T2, T3, T4, T5	Connects to 16-channel ADC
ADC host interface	J17	Connects to the GUI and computer through USB
Voltage inputs to signal scaling AFE board	J9, J12, J13	Do not apply inputs above rated maximum voltage
5 V supply to signal scaling AFE board	J4	Option to connect 5 V or 24 V available
24V supply to signal scaling AFE board	J3	Option to connect 5 V or 24 V available
Analog output from the AFE board	J10, J11	Outputs are scaled to ADS8686S ADC input range
Isolated PHI controller board	J1	
ADC8686SEVM-PDK interface for isolated interface board	J2	
Interface board power supply	J6	generated non-isolated and isolated supplies

3.1.2 ADS8688/ADS8688A based AC AIM

The following subsections provide information on the different interface connectors for connecting power supply, host interface, and AC analog inputs.

3.1.2.1 16-Channel ADS8688A and ISOW7841-Based AC AIM

表 18 lists the different connectors used for applying the inputs and power supply for performance evaluation of the AC AIM.

表 **18. 16-Channel ADS8688A-Based AIM Connections**

CONNECTOR	FUNCTION	COMMENTS
J11.1, J11.8	DC power supply	Do not exceed 3.6-V inputs for proper performance
Analog Input 0 of ADC1 and ADC2	J2, J13	
Analog Input 1 of ADC1 and ADC2	J1, J14	
Analog Input 2 of ADC1 and ADC2	J5, J15	
Analog Input 3 of ADC1 and ADC2	J6, J16	
Analog Input 4 of ADC1 and ADC2	J8, J17	
Analog Input 5 of ADC1 and ADC2	J9, J18	
Analog Input 6 of ADC1 and ADC2	J4, J10	
Analog Input 7 of ADC1 and ADC2	J3, J12	

表 18. 16-Channel ADS8688A-Based AIM Connections (continued)

CONNECTOR	FUNCTION	COMMENTS
J11	PHI	For connecting the AC AIM to GUI

3.1.2.2 PHI Board Connections

To evaluate the ADC performance quickly, use the PHI board for evaluation. The PHI board is connected to the design board through a breakout board. The breakout board allows the PHI board to interface the signals from the reference design using wires. If users has their own signal processing board based on the TMS320C6748, AM3359, AM4372, or AM5278, the interface signals from the reference design can be directly connected to the processing board. 表 19 details the interface between the breakout board and the interface connector of the reference design for daisy chain configuration

表 19. PHI Board Connections for Daisy Chain

CONNECTOR J11	BREAK OUT BOARD CONNECTIONS	FUNCTION
1		DVDD
2	J4_8	/CS
3	J4_10	SCLK
4	J4_7	SDO (SDI from interface board)
5	J4_17	SDI1 (SDO1 from interface board)
6		
7	Not used	SCLK_RET
8	J5-22	GND

Contact TI for more details on the breakout board and the PHI connector.

表 20 details the interface between the breakout board and the interface connector of the reference design for a dual SDO output configuration.

表 20. PHI Board Connections for Dual SDO

CONNECTOR J11	BREAK OUT BOARD CONNECTIONS	FUNCTION
1		DVDD
2	J4_9	/CS
3	J4_10	SCLK
4	J4_7	SDO (SDI from interface board)
5	J4_17	SDI1 (SDO1 from interface board)
6	J4_18	SDI2 (SDO1 from interface board)
7	Not used	SCLK_RET
8	J5-22	GND

3.2 Testing and Results

3.2.1 Test setup

This section provides setup diagram for analog input modules

3.2.1.1 Test setup for ADS8686S based AC analog input module

The Below diagram provide information on the setup used for functional and performance testing of AC analog input module. The Test setup for testing the AC analog input module consists of :

- ADS8686SEVM-PDK interfaced to GUI through PHI controller
- The voltage and current inputs are applied to the signal condition AFE
- Analog input to the ADS8686SEVM-PDK is connected from the output of the signal conditioning AFE
- The isolated interface board has provision to connect to the ADS8686SEVM-PDK and PHI controller board
- The required non-isolated and isolated power including split-rail supplies are generated on-board and a 5 V supply is applied to the module

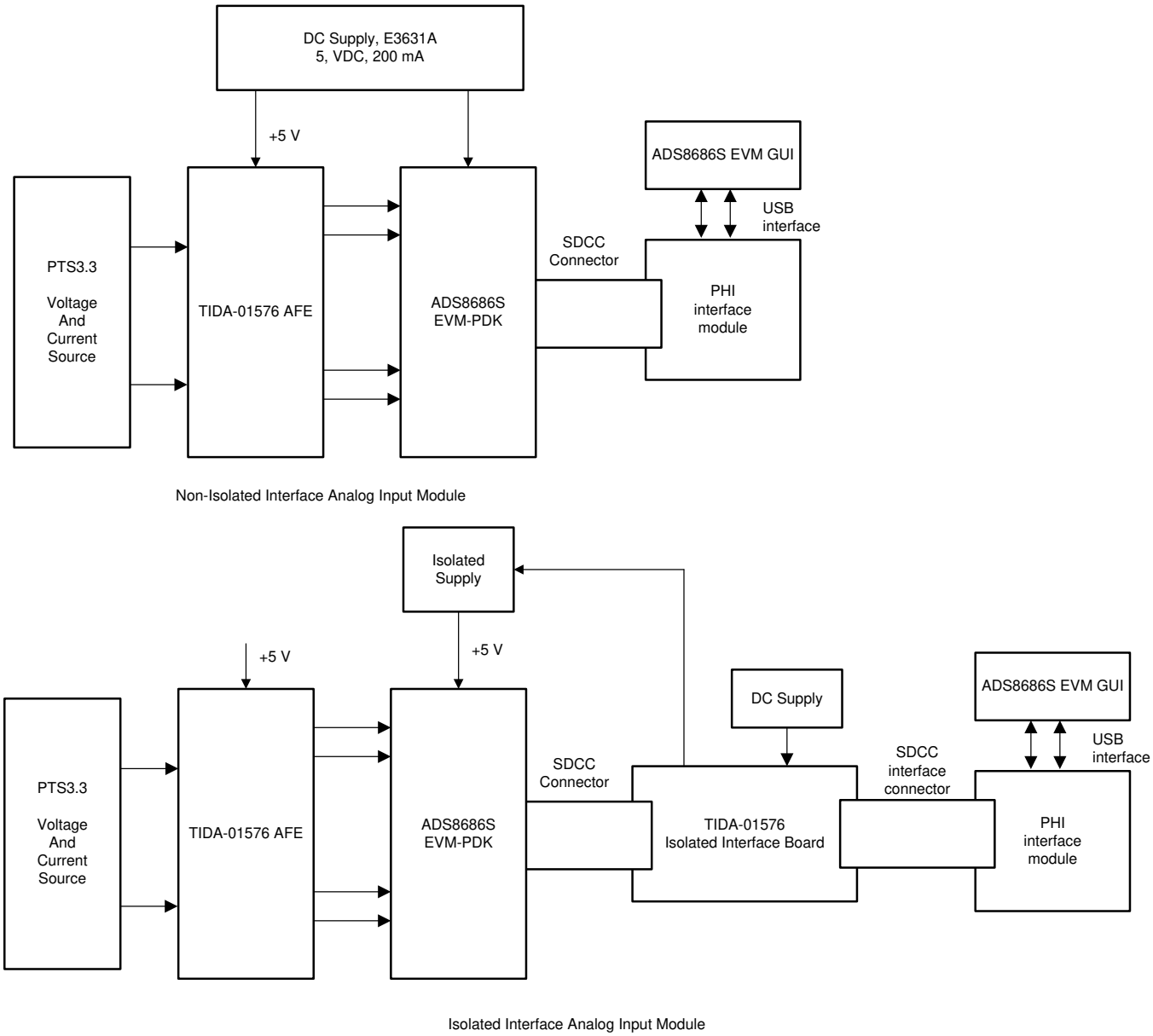

图 16. Test setup for ADS8686SEVM-PDK based analog input module

3.2.1.2 3.1.2 Test Setup for ADS8688A based 16-Channel analog input module

图 17 provides information on the setup used for functional and performance testing of the AC AIM.

The test setup for the AC AIM consists of:

- DC power supply (3.3 V)
- TIDA-01576 reference design board
- Function generator to simulate the AC analog inputs, ±10.24 max input
- PHI breakout board
- PHI controller and GUI for HMI and data capture

注: While testing, ensure the analog inputs do not exceed the ADC input range of ±10.24 V for proper operation. For the purpose of performance testing, PHI is used as the host.

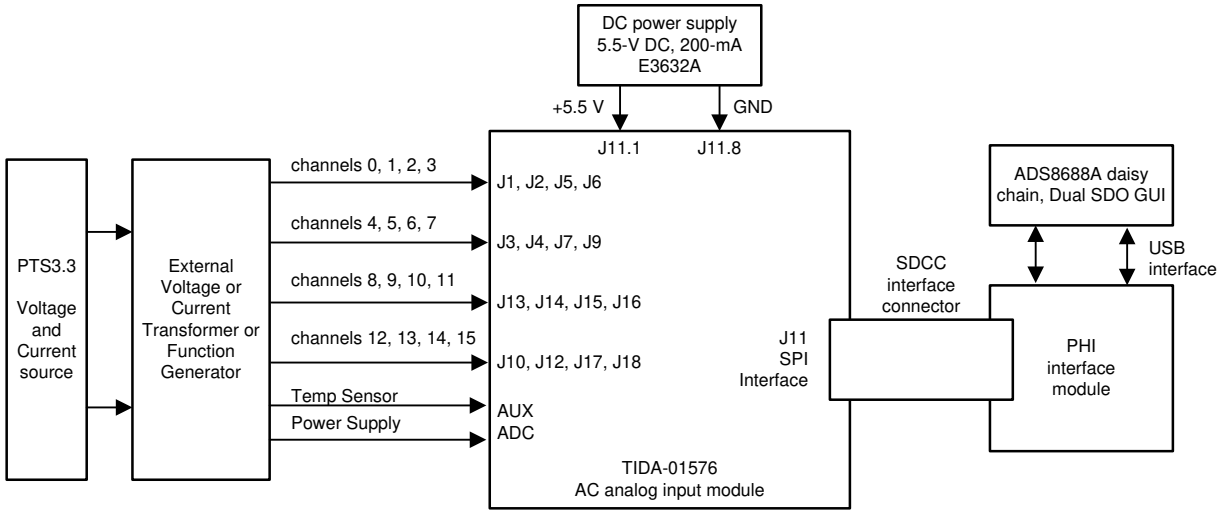

图 **17. Test Setup for Performance Testing of AC AIM**

The reference design board is designed to evaluate with any of the customer boards. The PHI board used to evaluate performance is not part of the reference design. Contact TI for details on the availability of PHI boards.

3.2.2 Test Results

Note the following test conditions for performance measurement of the AC AIM:

- The tests were performed using a function generator or programmable AC voltage and current source.
- GUI is used to evaluate performance.

3.2.2.1 ADS8686S ADC performance

Here is the summary of the tests performed on ADS8686S ADC based analog input module

表 21. ADS8686S test summary

Test type	Description
Functional testing	ADC operation with ±10 V, ±5 V and ±2.5 V input range
Functional testing	±10 V, ±5 V input range with 20% over range
Data interface	Serial and Parallel
Performance testing	Internal and external reference
Performance testing	Measurement accuracy testing over 5 V to 360 V
Performance testing	Measurement accuracy testing over 5 V to 360 V with 20% over range
Performance testing	1.2A to 120A with 20% over range
Performance testing	Measurement accuracy testing over -15 to 80 °c and 10 V to 280 V input
Functional testing	15KHz and 39KHz filter
Performance testing	Change in gain with same input for different input ranges and measurement accuracy at ±10 V, ±5 V and ±2.5 V including 20% over range input with same input maintained
Performance testing	Coherent sampling with programmable samples per cycle and number of cycles for data capture
Performance testing	OSR
Performance testing	Sequencer and Burst mode
Performance testing	Measurement of RMS values

Key differentiating features of ADS8686S includes:

- 20% input overrange with minimal performance variation
- Programmable digital filters improving performance
- Digital supply DVDD range 1.71V to 5.25 V with 5.25 V analog supply increasing design flexibility and optimizing system design

3.2.2.1.1 Test conditions

Test conditions for ADS8686S performance evaluation is listed below:

- AFE board with potential divider for measuring voltage input with input impedance >1.5MΩ and current transformer with a ration of 1:2500 used for current measurement
- ADS8686SEVM-PDK interfaced to the AFE for performance testing
- AFE gain amplifiers with different gains used for performance testing (covers different input steps of ADC)
- Same AFE used for all the test conditions during accuracy testing
- For temperature testing, ADC temperature was locally varied (using ThermoStream) maintaining the temperature of the ADS8688SEVM-PDK and AFE constant

- 256 samples per cycle and 5 cycles of samples were used for RMS computation
- Performance test repated on two devices and similar results were observed

3.2.2.1.2 ADS8686S performance evaluation GUI

GUI with capabilities to perform the following is used for performance testing:

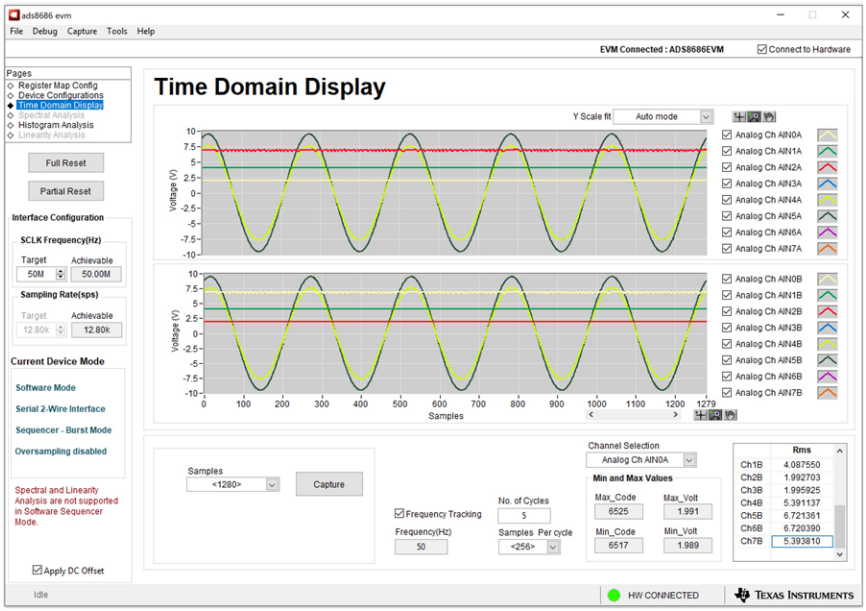

图 18. ADS8686S Performance Evaluation GUI

- Selection of sampling sequence, input range, overrange and channels
- Coherent sampling with option to set number of samples per cycle and number of cycles
- Filter frequency selection
- View RMS values for all the selected ADC channels
- Waveform display

3.2.2.1.3 Measurement accuracy performance testing

The following performance tests have been performed

3.2.2.1.3.1 Accuracy testing with ±10 V input range

The below table provides accuracy results for wide voltage and current inputs with ±10 V ADC input range, internal and external reference configuration and different filter frequency settings. The min value, max value and difference over wide input have been summarized.

表 22. Measurement accuracy performance for ±10 V input range

Test type	ADC input range and applied AC input range	ADC channel	% Error measured		
			Minimum	Maximum	Difference

表 **22. Measurement accuracy performance for ±10 V input range (continued)**

Accuracy testing with external reference configured, 39 KHz filter	±10 V input range with 10 V to 290 V	5A	-0.112	-0.032	0.080
		5B	-0.088	-0.011	0.077
		6A	-0.091	-0.007	0.084
		6B	-0.110	-0.032	0.078
	±10 V input range with 10 V to 360 V	4A	-0.144	-0.077	0.067
		4B	-0.191	-0.094	0.097
		7A	-0.188	-0.121	0.067
		7B	-0.138	-0.042	0.096
	±10 V input range with 1.2 A to 123 A	4A	-0.208	0.188	0.396
		7B	-0.206	0.188	0.394
	±10 V input range with 1.95 A to 165 A	5A	-0.217	0.209	0.427
		6B	0.057	0.288	0.231
Accuracy testing with internal reference configured, 39 KHz filter	±10 V input range with 10 V to 290 V	1A	-0.077	0.023	0.100
		1B	-0.056	0.039	0.095
		2A	-0.056	0.042	0.097
		2B	-0.073	0.016	0.088
	±10 V input range with 10 V to 360 V	0A	-0.094	-0.005	0.090
		0B	-0.150	-0.053	0.096
		3A	-0.146	-0.051	0.095
		3B	-0.102	-0.005	0.097
Accuracy testing with external reference configured, 15 KHz filter	±10 V input range with 10 V to 290 V	5A	-0.104	-0.033	0.071
		5B	-0.080	-0.016	0.064
		6A	-0.084	-0.011	0.072
		6B	-0.102	-0.016	0.087
	±10 V input range with 10 V to 360 V	4A	-0.138	-0.046	0.092
		4B	-0.185	-0.094	0.091
		7A	-0.183	-0.091	0.091
		7B	-0.133	-0.041	0.092

3.2.2.1.3.2 Accuracy testing with ±10 V input ranges with OSR and 20% overrange

The below table provides accuracy results for wide voltage and current inputs with ±10 V ADC input range including 20% overrange, internal and external reference configuration. The min value, max value and difference over wide input have been summarized.

表 **23. Accuracy testing with ±10 V, OSR and overrange**

Test type	ADC input range and applied AC input range	ADC channel	% Error measured		
			Minimum	Maximum	Difference

表 **23. Accuracy testing with ±10 V, OSR and overrange (continued)**

Accuracy testing with external reference configured, 39 KHz filter	±12 V input range with 10 V to 350 V	5A	-0.073	-0.008	0.065
		5B	-0.045	0.020	0.064
		6A	-0.034	0.031	0.065
		6B	-0.093	-0.028	0.065
	±12 V input range with 10 V to 430 V	4A	-0.075	-0.033	0.042
		4B	-0.140	-0.064	0.076
		7A	-0.168	-0.110	0.057
		7B	-0.064	0.028	0.092
	±12 V input range with 1.5 A to 138 A	4A	-0.157	0.314	0.471
		7B	-0.116	0.398	0.515
	±12 V input range with 2.4 A to 192 A	5A	-0.166	0.364	0.530
		6B	-0.071	0.266	0.337
Accuracy testing with external reference and X8 OSR configured, 39 KHz filter	±10 V input range with 10 V to 290 V	5A	-0.111	-0.012	0.099
		5B	-0.088	0.009	0.096
		6A	-0.090	0.009	0.099
		6B	-0.109	-0.012	0.097
Accuracy testing with external reference and X8 OSR configured, 39 KHz filter	±10 V input range with 10 V to 360 V	4A	-0.149	-0.043	0.107
		4B	-0.193	-0.093	0.100
		7A	-0.192	-0.096	0.096
		7B	-0.143	-0.041	0.102

3.2.2.1.3.3 Accuracy testing with ±5 Vinput ranges with OSR and 20% overrange

The below table provides accuracy results for wide voltage and current inputs with ±5 V ADC input range including 20% overrange and external reference configuration. The min value, max value and difference over wide input have been summarized.

表 **24. Accuracy testing with ±5 V range and 20% overrange**

Test type	ADC input range and applied AC input range	ADC channel	% error measured		
			Minimum	Maximum	difference
Accuracy testing with external reference configured, 39 KHz filter	±5 V input range with 5 V to 145 V AC input	5A	-0.105	0.059	0.165
		5B	-0.090	0.063	0.153
		6A	-0.088	0.077	0.165
		6B	-0.110	0.043	0.153
	±5 V input range with 5 V to 180 V AC input	4A	-0.140	0.034	0.174
		4B	-0.186	-0.064	0.122
		7A	-0.181	-0.012	0.170
		7B	-0.134	0.043	0.177
	±6 V input range with 5 V to 175 V AC input	5A	-0.085	-0.013	0.072
		5B	-0.068	0.025	0.093
		6A	-0.066	0.011	0.077
		6B	-0.103	-0.015	0.088
	±6 V input range with 5 V to 215 V AC input	4A	-0.120	--0.012	0.108
		4B	-0.171	-0.068	0.104
		7A	-0.178	-0.050	0.128
		7B	-0.094	0.028	0.122

3.2.2.1.4 Temperature performance testing with external reference

This section summarizes linear and rapid temperature variation tests with external reference configured.

3.2.2.1.4.1 Accuracy variation with rapid temperature variation

The below table provides accuracy results for rapid temperature variation. Measurements were performed for fixed input voltage. Min value, max value and difference have been summarized.

表 **25. Random temperature variation test results**

Test Type	Input voltage V		% error measured		
		ADC channel	Minimum	Maximum	Difference
Accuracy testing with external reference configured and Rapid temperature cycling in °C with ±10 V input range, 39 KHz filter 50, -5, 25, -15, 30, 80, -15, 30	280	5A	-0.122	-0.066	0.057
		5B	-0.098	-0.042	0.056
		6A	-0.101	-0.045	0.056
		6B	-0.121	-0.064	0.056
		4A	-0.148	-0.083	0.065
		4B	-0.196	-0.130	0.065
		7A	-0.193	-0.128	0.065
		7B	-0.143	-0.078	0.066

3.2.2.1.4.2 Accuracy variation with linear temperature variation

The below table provides accuracy performance results for linear temperature variation. Measurements were performed by varying the input voltage and the min value, max value and difference over wide input have been summarized.

表 **26. Linear temperature variation test results**

Test type	Input voltage V	ADC input channel	% error measured		
			Minimum	Maximum	Difference
Accuracy testing with external reference configured and Linear temperature variation in °C with ±10 V input range, 39 KHz filter 25, 55, 80, 25, -15, 25	280	5A	-0.121	-0.063	0.058
		5B	-0.096	-0.039	0.057
		6A	-0.093	-0.042	0.050
		6B	-0.119	-0.061	0.058
		4A	-0.147	-0.119	0.028
		4B	-0.194	-0.164	0.030
		7A	-0.191	-0.162	0.029
		7B	-0.142	-0.112	0.030
	200	5A	-0.112	-0.085	0.027
		5B	-0.086	-0.062	0.024
		6A	-0.089	-0.065	0.024
		6B	-0.108	-0.083	0.025
		4A	-0.133	-0.096	0.037
		4B	-0.180	-0.144	0.036
		7A	-0.179	-0.141	0.037
		7B	-0.129	-0.092	0.037
	50	5A	-0.070	-0.029	0.041
		5B	-0.047	-0.009	0.038
		6A	-0.047	-0.011	0.036
		6B	-0.069	-0.029	0.040
		4A	-0.102	-0.054	0.048
		4B	-0.150	-0.102	0.048
		7A	-0.143	-0.099	0.044
		7B	-0.097	-0.051	0.046
	10	5A	-0.043	-0.014	0.030
		5B	-0.026	-0.001	0.025
		6A	-0.026	0.009	0.035
		6B	-0.048	-0.023	0.025
		4A	-0.100	-0.062	0.038
		4B	-0.137	-0.116	0.020
		7A	-0.135	-0.098	0.037
		7B	-0.076	-0.041	0.035

3.2.2.1.5 Temperature performance testing with internal reference

This section summarizes linear and rapid temperature variation tests with internal reference configured.

3.2.2.1.5.1 Accuracy variation with rapid temperature variation

The below table provides accuracy results for rapid temperature variation. Measurements were performed for fixed input voltage. The min value, max value and difference have been summarized.

表 **27. Rapid temperature variation test results**

Test Type	Input voltage V	ADC channel	% Error measured		
			Minimum	Maximum	Difference
Accuracy testing with internal reference configured and Rapid temperature cycling in °C with ±10 V input range, 39 KHz filer 50, -5, 25, -15, 30, 80, -15, 30	280	5A	-0.082	-0.023	0.060
		5B	-0.059	0.000	0.059
		6A	-0.062	-0.003	0.059
		6B	-0.081	-0.021	0.060
		4A	-0.104	-0.033	0.071
		4B	-0.151	-0.080	0.071
		7A	-0.150	-0.078	0.072
		7B	-0.098	-0.028	0.070

3.2.2.1.5.2 Accuracy variation with linear temperature variation

The below table provides accuracy results for linear temperature variation. Measurements were performed by varying the input voltage. The min value, max value and difference over wide input have been summarized.

表 **28. Linear temperature variation test results**

Test type	Input voltage V	ADC channel	% Error measured		
			Minimum	Maximum	Difference
Accuracy testing with internal reference configured and Linear temperature variation in °C with ±10 V input range, 39 KHz filer 25, 55, 80, 25, -15, 25	280	5A	-0.077	-0.029	0.048
		5B	-0.053	-0.003	0.049
		6A	-0.055	-0.009	0.046
		6B	-0.075	-0.025	0.050
		4A	-0.103	-0.023	0.080
		4B	-0.150	-0.094	0.056
		7A	-0.148	-0.096	0.052
		7B	-0.098	-0.044	0.054
	200	5A	-0.062	-0.018	0.045
		5B	-0.041	0.005	0.046
		6A	-0.044	0.002	0.046
		6B	-0.063	-0.018	0.045
		4A	-0.086	-0.035	0.051
		4B	-0.135	-0.083	0.052
		7A	-0.133	-0.081	0.052
		7B	-0.083	-0.031	0.052
	50	5A	-0.028	0.035	0.064
		5B	-0.007	0.057	0.064
		6A	-0.006	0.054	0.061
		6B	-0.027	0.036	0.063
		4A	-0.061	0.013	0.073
		4B	-0.110	-0.042	0.067
		7A	-0.104	-0.035	0.069
		7B	-0.057	0.015	0.072
	10	5A	-0.002	0.028	0.030
		5B	0.014	0.043	0.030
		6A	0.014	0.046	0.032
		6B	-0.005	0.021	0.026
		4A	-0.059	-0.018	0.040
		4B	-0.100	-0.075	0.025
		7A	-0.102	-0.075	0.027
		7B	-0.043	-0.011	0.032

3.2.2.1.6 PGA (input ranges) gain error performance

This sections summarizes the ADC performance with different input ranges.

3.2.2.1.6.1 Accuracy testing at different input range configurations with fixed AC input applied

The below table provides accuracy results for different input ranges maintaining the same input for all the configurations. The measurement error have neem summarized.

表 **29. PGA measurement performance**

Test type	Input range	AD channel	% Error measured	Difference	Input range	% Error measured	Difference
Accuracy testing with external reference configured and 5 V to 290 V input range, 50V input applied, 39 KHz filer	±12 V	5A	-0.029	0.074	5B	-0.002	0.074
	±10 V	5A	-0.049		5B	-0.027	
	±6 V	5A	-0.025		5B	-0.008	
	±5 V	5A	-0.051		5B	-0.037	
	±3 V	5A	-0.076		5B	-0.051	
	±2.5 V	5A	-0.099		5B	-0.076	
	±12 V	6A	0.011	0.086	6B	-0.049	0.059
	±10 V	6A	-0.028		6B	-0.049	
	±6 V	6A	-0.011		6B	-0.042	
	±5 V	6A	-0.034		6B	-0.056	
	±3 V	6A	-0.050		6B	-0.091	
	±2.5 V	6A	-0.076		6B	-0.101	
Accuracy testing with external reference configured and 5 V to 350 V input range, 50V input applied	±12 V	4A	-0.057	0.085	4B	-0.122	0.085
	±10 V	4A	-0.073		4B	-0.123	
	±6 V	4A	-0.028		4B	-0.077	
	±5 V	4A	-0.049		4B	-0.095	
	±3 V	4A	-0.095		4B	-0.148	
	±2.5 V	4A	-0.112		4B	-0.163	
	±12 V	7A	-0.132	0.072	7B	-0.043	0.110
	±10 V	7A	-0.119		7B	-0.069	
	±6 V	7A	-0.085		7B	-0.002	
	±5 V	7A	-0.088		7B	-0.042	
	±3 V	7A	-0.156		7B	-0.074	
	±2.5 V	7A	-0.157		7B	-0.112	

3.2.2.1.7 ADS8686SEVM-PDK connected to AFE performance testing with isolated interface

Isolated interlace performance testing for ADS8686S ADC was tested by isolating the ADS8686SEVM-PDK from PHI controller using the TIDA-01576 isolated interface board. The ADC configurations are hardwired and the interface is serial interface. Some of the configuration jumpers are provided on the interface board and the other jumper configurations are made on the ADS8686SEVM-PDK.

Some of the setting made are :

- OSR – all three pins (J18:11, J18:12, J18:13) are set to zero
- Channel select – set to channel 7 (J18:5, J18:4, J18:3)
- Range select configuration using JP2 (D_HW_RNGSEL0) and JP4 (D_HW_RNGSEL1)
- JP6 mounted to select external reference
- J18:8 made high to enable burst mode

No change in performance due to isolated interface. The interface clock speed was adjusted due to the digital isolator delay and the ADC was interfaced with lower clock speed.

3.2.2.2 ADS8688 ADC Performance

This section details the different tests performed on this reference design and the performance results. A custom GUI is used to analyze performance. Contact TI fir availability of GUI for performance analysis.

3.2.2.2.1 ADS8688A Time Domain Measurement Performance for Dual SDO With Isolated Interface

图 19 (snapshot of the GUI) shows the performance analysis of the time domain done on the reference design. The time domain analysis includes a display of the waveform and RMS values.

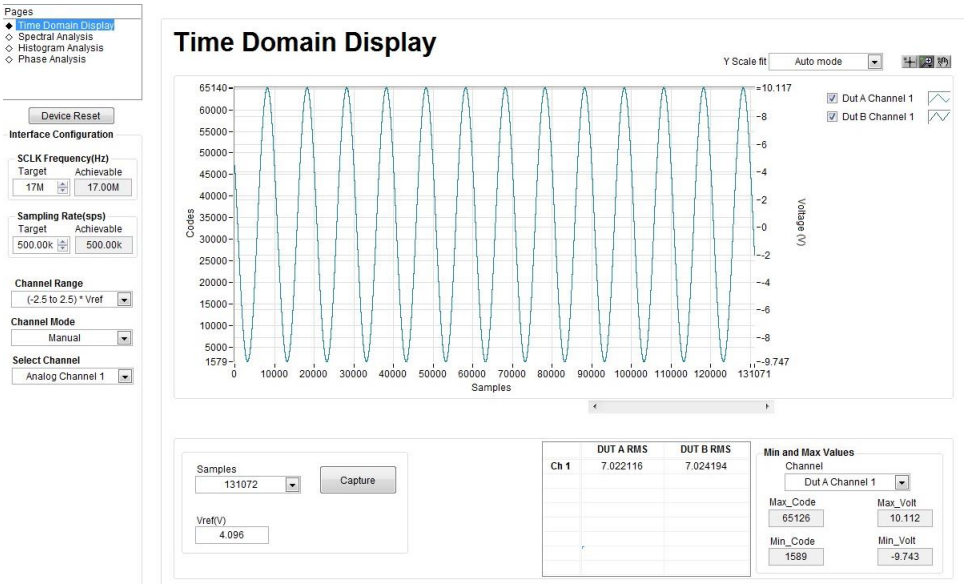

图 19. Time Domain Analysis of ADS8688A ADC Using GUI and PHI controller

3.2.2.2.2 ADS8688A Time Domain Measurement Performance for Dual SDO With Isolated Interface

图 20 shows the spectral analysis tests done on the design board. The spectral analysis is captured for DUT A and DUT B.

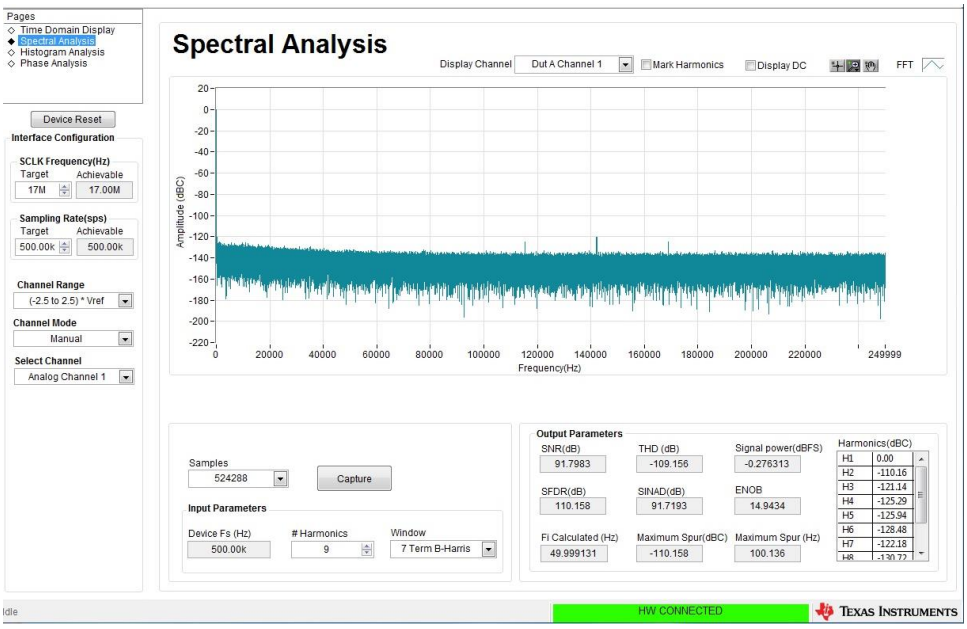

图 20. Spectral Analysis of ADS8688A ADC Using GUI and PHI controller

3.2.2.2.3 ADS8688A Measurement Performance for Dual SDO With Isolated Interface

This section provides details of different tests performed on this reference design and the performance results. 表 30 provides performance test results for the ADS8688A ADC. A custom GUI is used to analyze performance. Contact TI for availability of GUI for performance analysis with different input ranges.

表 30. ADS8688-Based Isolated Dual SDO Output AC AIM Performance Test Board 1

TESTS	INPUT (V)	INPUT RANGE (V)	ADC1 CH1	ADC2 CH1	ADC 1 CH7	ADC2 CH7
ENOB	7	±10.24	14.9896	15.005	15.009	14.9923
	3.45	±5.12	14.79	14.78	14.79	14.779
SNR	7	±10.24	92.858	92.118	92.078	92.074
	3.45	±5.12	90.95	90.865	90.91	90.866
THD	7	±10.24	–108.95	–114.742	–111.125	–110.579
	3.45	±5.12	–107.75	–108.05	–109.5	–106.1

These tests are repeated with the second board. 表 31 shows the results.

表 31. ADS8688-Based Isolated Dual SDO Output AC AIM Performance Test Board 2

TESTS	INPUT (V)	INPUT RANGE (V)	ADC1 CH1	ADC2 CH1
ENOB	7	±10.24	14.975	14.9913
	3.45	±5.12	14.775	14.775
SNR	7	±10.24	91.98	92.038
	3.45	±5.12	90.808	90.805
THD	7	±10.24	–109.35	–113.565
	3.45	±5.12	–107.2	–107.341

The AIM meets the ADC performance requirements in isolated interface configuration.

3.2.2.2.4 Measurement With DUTB Configured as External Reference

The tests in 节 3.2.2.2.3 are repeated with a change in the reference configuration. DUT A is configured for internal reference and DUT B is configured for external reference. The reference output of DUT A is connected to DUT B.

表 32. ADS8688-Based Isolated Dual SDO Output With Reference Configuration Changed

TESTS	INPUT (V)	INPUT RANGE (V)	ADC1 CH1	ADC2 CH1
ENOB	7	±10.24	14.9746	14.943
	3.45	±5.12	14.779	14.804
SNR	7	±10.24	91.96	91.7983
	3.45	±5.12	90.7826	90.928
THD	7	±10.24	–111.097	–109.56
	3.45	±5.12	–109.978	–110.888

The AIM meets the ADC performance requirements with DUT A configured for internal reference and DUT B configured for external reference.

3.2.2.2.5 Measurement With Non-Isolated Interface and Daisy

The tests in 节 3.2.2.2.3 are repeated with the board configured in daisy chain mode and using a non-isolated interface. 表 33 shows the results.

表 **33. ADS8688-Based AC AIM Performance With Daisy Chain**

TESTS	INPUT (V)	INPUT RANGE (V)	ADC1 CH1	ADC2 CH1
ENOB	7	±10.24	14.81	14.75
	3.45	±5.12	14.3	14.31
SNR	7	±10.24	91.011	90.963
	3.45	±5.12	89.01	89.1
THD	7	±10.24	–101.646	100.51
	3.45	±5.12	–96.3	–96.25

3.2.2.2.6 Measurement With ADC Interfaced to ISOW7841

表 34 provides performance test results for the ADS8688 with different input ranges interfaced using the ISO7841 digital isolator with integrated power.

表 **34. ADS8688A-Based, Isolated AC AIM Performance With ISOW7841**

TESTS	INPUT	INPUT RANGE (V)	CHANNEL 1	CHANNEL 7
ENOB	7	±10.24	14.9	14.9
	3.5	±5.12	14.77	14.77
	1.75	±2.56	14.51	14.51
	0.875	±1.28	13.64	13.63
	0.4375	±0.64	12.69	12.7
SNR	7	±10.24	91.47	91.51
	3.5	±5.12	90.66	90.7
	1.75	±2.56	89.11	89.12
	0.875	±1.28	83.87	83.83
	0.4375	±0.64	78.14	78.23
THD	7	±10.24	–111.02	–112.64
	3.5	±5.12	–111.06	–112.9
	1.75	±2.56	–111.26	–112.9
	0.875	±1.28	–106.44	–106.29
	0.4375	±0.64	–99.82	–101.74

3.2.2.2.7 Voltage Measurement

With the GUI, calculate RMS voltage by using the acquired samples. 表 35 shows the results.

表 **35. RMS Values for Analog Input**

INPUT (V)	ADC1 CH7	ADC2 CH7
7.0215	7.02211	7.024194
5.0149	5.017767	5.019232
2.5063	2.5134	2.5142

The RMS measurement can be improved by measuring the DC offset and compensating the DC offset from the measured samples before computing the RMS values.

3.2.2.2.8 ADC Measurement Accuracy

A performance test of the ADC inputs or measurement accuracy is performed by applying a known input voltage and capturing the AC voltage measured by the ADC on the GUI. 表 36 details the measurement errors observed with different inputs values.

表 **36. ADC Measurement Accuracy for 50-Hz Voltage Input**

±10.24-V RANGE	DUT A CH1		DUT B CH1	
ACTUAL INPUT (mV)	MEASURED INPUT (mV)	% ERROR	MEASURED INPUT (mV)	% ERROR
0.05015	0.0501	–0.1	0.0501	–0.1
0.10028	0.1002	–0.08	0.1003	0.02
0.2506	0.2507	0.04	0.2507	0.04
0.5015	0.5013	–0.04	0.5014	–0.02
1.003	1.0021	–0.09	1.0024	–0.06
2.007	2.006	–0.05	2.0066	–0.02
3.008	3.0079	–0.003	3.0088	0.027
5.017	5.0144	–0.052	5.0158	–0.024
7.027	7.0197	–0.104	7.0218	–0.074

The measurement error is within ±0.2% of the measured values over the entire input range. The GUI allows the user to calculate the DC offset and compensate for the DC offset during the ADC sampling and RMS calculation.

3.2.2.3 ISOW7841 Isolated Power Supply Testing

3.2.2.3.1 ISOW7841 Load Regulation Testing

Load regulation is tested by varying the output load from 20 to 100 mA and applying an input of 3.3 V at the input of the power connector. 表 37 provides the test results for load regulation.

表 **37. ISOW7841 Load Regulation Test**(1)

INPUT VOLTAGE (V)	INPUT I (SUBTRACTING NO LOAD I) (A)	POWER	OUTPUT VOLTAGE (V)	OUTPUT CURRENT (A)	POWER (W)	EFFICIENCY	OBSERVATIONS	LOAD (R)
3.3	0.057	0.188	3.340	0.022	0.073	39.064%		150
3.3	0.081	0.267	3.340	0.033	0.112	41.734%		100
3.3	0.101	0.333	3.364	0.044	0.148	44.409%		75
3.3	0.124	0.409	3.364	0.055	0.185	45.215%		150|100
3.3	0.144	0.475	3.364	0.067	0.225	47.289%		150|75
3.3	0.168	0.554	3.364	0.078	0.262	47.268%		100|75
3.3	0.184	0.607	3.364	0.085	0.285	46.876%		39
3.3	0.262	0.865	3.380	0.122	0.413	47.772%		27
3.3	0.254	0.838	3.043				Overcurrent clamp	22

(1) No load input current: 0.026 A

Observation: Load regulation observed is < ±1%.

3.2.2.3.2 ISOW7841 Line Regulation (Input versus Output Voltage Variation) Testing

Line regulation is tested by varying voltage from 3.6 to 2.3 V with an approximate 80-mA load at the output of the power connector. 表 38 provides the test results for line regulation.

表 **38. Line Regulation (Input versus Output Voltage Variation) and UVLO**

VOLTAGE (V)		CURRENT (A)		EFFICIENCY	LOAD in RR	SUPPLY I (A)	OBSERVATIONS
INPUT	OUTPUT	OUTPUT I	INPUT I				
3.6	3.363	0.086	0.174	49.55%	39	0.200	
3.3	3.360	0.086	0.184	46.82%	39	0.210	
3.0	3.373	0.086	0.201	43.02%	39	0.227	
2.7	3.380	0.086	0.229	37.84%	39	0.255	
2.6	3.330	0.085	0.231	36.96%	39	0.257	UVLO recover
2.5	3.200	0.082	0.222	36.96%	39	0.248	
2.4	3.000	0.076	0.214	35.94%	39	0.240	
2.3	0					0	UVLO

Observation: Line regulation observed is < ±3 mV/V.

3.2.2.3.3 ISOW7841 Ripple Measurement

图 21 shows a DC output ripple in mV on isolated supply (pkpk) with a 20-MHz bandwidth, C_{LOAD} = 20 µF, and I_{ISO} = 80 mA. The measurements are done near to the load, away from the ISOW7841 power output pins.

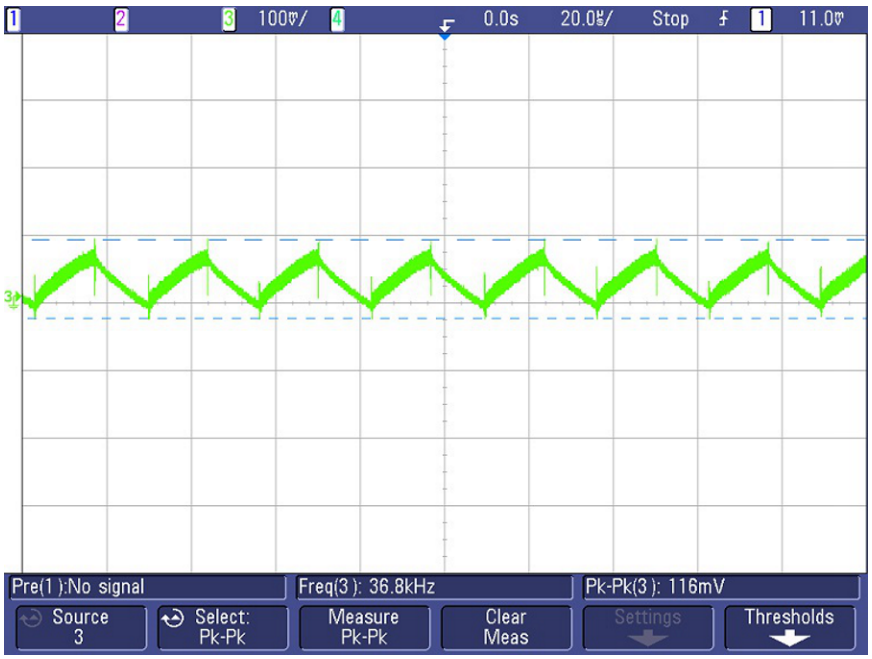

图 **21. ISOW7841 DC Output Ripple**

3.2.2.3.4 ISOW7841 Input Switching Current

图 22 shows the input switching current measured for a DC input current of 160 mA. The input voltage applied is 3.3-V DC.

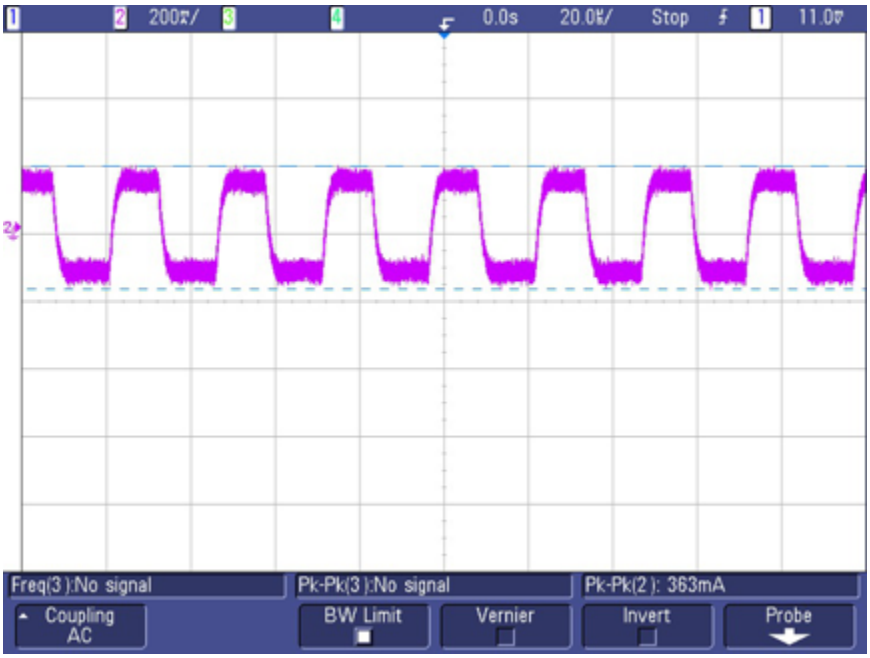

图 **22. ISOW7841 Input Switching Current for 75-mA Output Loading**

3.2.2.3.5 ISOW7841 Device Hotspot Monitoring

The output of the ISOW7841 is loaded for 80 mA, and the hotspot is monitored after 30 minutes. 图 23 shows the hotspot measurements on the ISOW784x evaluation module.

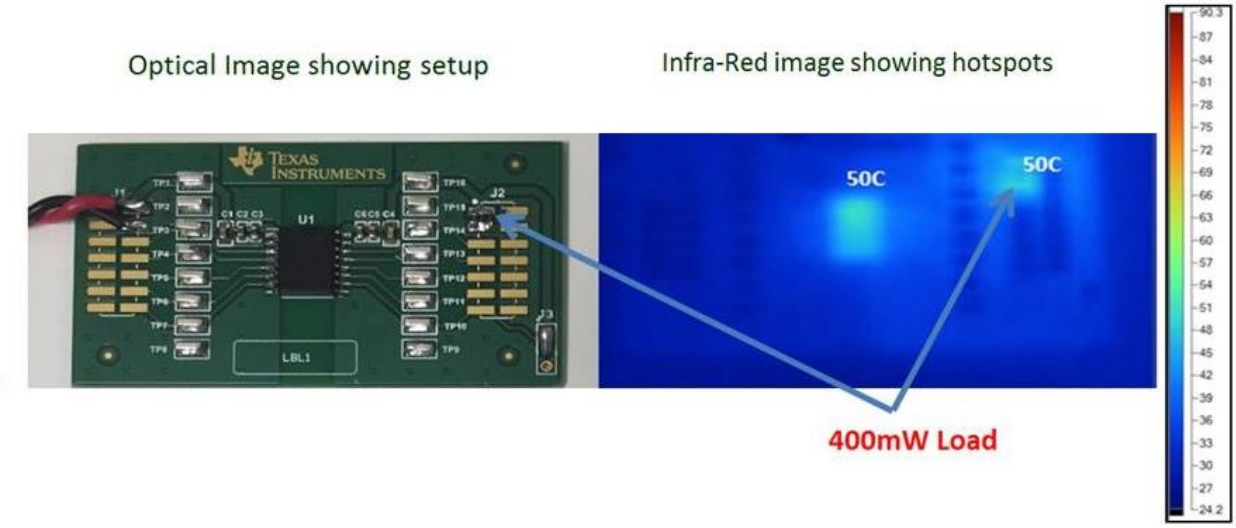

图 **23. ISOW7841 Hotspot Capture With 80-mA Load**

3.2.2.4 Test Results Summary for AC AIM

表 39 summarizes the tests and observations for the AC AIM based on ADS8686S:

表 **39. Test Results Summary**

Test	Observation
16-channel functional testing	OK
Configuration or ±10 V or ±5 V or ±2.5 V input range	OK
Configurable channel sequencer	OK
Configuration of 20% overrange	OK
Voltage measurement accuracy from 10 V to 425 V	OK
Current measurement accuracy from 1A to 120A	OK
Serial or Parallel interface to host	OK
OSR configuration and performance testing	OK
ADS8686S performance with isolated interface	OK

4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-01576.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-0576.

4.3 PCB Layout Recommendations

4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01576.

4.4 Altium Project

To download the Altium project files, see the design files at TIDA-01576.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01576.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01576.

5 Related Documentation

1. Texas Instruments, *Isolated Power Architecture Reference Fesign for Communication and Analog Input/Output Modules*
2. Texas Instruments, *Non-Isolated Power Architecture with Diagnostics Reference Design for Orotection Relay Modules*
3. Texas Instruments, *16-Bit 1-MSPS Data Acquisition System With Isolated Inputs for High-Voltage Common-Mode Rejection Design Guide*
4. Texas Instruments, *20-Bit, 1-MSPS Isolator Optimized Data Acquisition Reference Design Maximizing SNR and Sample Rate Design Guide*
5. Texas Instruments, *Size and Cost-Optimized Binary Input Module Reference Design Using Digital Isolator With Integrated Power Design Guide*
6. Texas Instruments, *Low-Emission Designs With ISOW7841 Integrated Signal and Power Isolator Design Guide*
7. Texas Instruments, *Eight-Channel, Isolated, High-Voltage Analog Input Module With ISOW7841 Reference Design Guide*
8. Texas Instruments, *Isolated, High-Accuracy AIM Ref Design Using 16-Bit ADC and Digital Isolator Design Guide*
9. Texas Instruments, *High Accuracy Analog Front End Using 16-Bit SAR ADC with ±10V Measurement Range Reference Design*
10. Texas Instruments, *High-Efficiency, Low-Emission, Isolated DC/DC Converter-Based Analog Input Module Reference Design*

5.1 商标

6 Terminology

AFE — Analog front end

OSR — oversampling rate

AC — Alternating current

AIM— Analog input module

DC — Direct current

PHI— Precision host interface

RMS — Root mean square

RTD— Resistance temperature detectors

7 About the Authors

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修订历史记录

注：之前版本的页码可能与当前版本有所不同。

Changes from Original (December 2017) to A Revision **Page**

- 已更改 将标题从*基于 16 位 1MSPS 双路同步采样 ADC 的高精度模拟输入模块参考设计* 更改为*具有 16 位 1MSPS 双路同步采样 ADC 的高精度模拟输入模块参考设计*..... 1
- 已更改 更改了“说明” 和 “特性”，以包括基于 ADS8686S ADC 的 AIM 1
- 已删除 删除了“采用 ISO7763 的 ADS8688A 隔离模拟输入模块”部分..... 1
- 已更改 更改了方框图和电路板图 2
- 已更改 key system specifications 4
- 已更改 *Onboard analog temperature sensor for compensation of onboard temperature variation* to *Onboard analog temperature sensor for compensation measurement accuracy variation* 4
- 已添加 Added ADS8686S based AIM description and related products including ADC, gain amplifiers, non- isolated and isolated power supply 5
- 已添加 Two approaches for designing of AIM have been shown in this reference design. The first approach is using a 16-channel 16-bit SAR dual simultaneous sampling ADC. The second approach two 8-channel 16-bit ADCs have been connected together to increase the number of analog input channels to 16 using daisy chain mode or dual SDO output mode with the input signals connected together and driven by common pins. 5
- 已删除 Two ADCs have been connected together to increase the number of analog input channels to 16 using daisy chain mode or dual SDO output mode with the input signals connected together and driven by common pins. 5
- 已更改 block diagram for ADS8686S based AIM and isolated interface modules 5
- 已添加 the following devices: DCH010515D, ADS8686S, REF5025, INA188, OPA2188, TPS7A47, UCC12050, and UCC12040..... 25
- 已添加 test setup diagram, GUI and test results for ADC8686S based AIM 35
- 已更改 *AC AIM* to *AC AIM based on ADS8686S*..... 52
- 已添加 TIDU562B..... 54
- 已添加 TIDUEP9..... 54
- 已添加 reference to High Accuracy Analog Front End Using 16-Bit SAR ADC with ±10V Measurement Range Reference Design..... 54
- 已添加 High-efficiency, low-emission, isolated DC/DC converter-based analog input module reference design..... 54

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