TI Designs: TIDA-00847

Size and Cost-Optimized Binary Input Module Reference Design Using Digital Isolator With Integrated Power

TEXAS INSTRUMENTS

Description

The TIDA-00847 design showcases size and cost-optimized architecture for a four-channel DC input binary input module (BIM) with improved measurement accuracy and status indication using only two TI products to simplify the system design. An MCU-based BIM improves measurement resolution, which improves system performance, including accurate and repeatable fault indications, and eliminates the need for multiple hardware versions (using the same design for multiple nominal voltage inputs), reducing design, testing, manufacturing, and field support efforts. In this TI Design, four input channels are configured as group isolated inputs to minimize cost per channel. A 10-bit ADC measures the DC inputs within ±3% ±1-V accuracy over a wide range. Pre-compliance tests for EMI and EMC have been performed.

Resources

TIDA-00847	Design Folder
ISOW7841	Product Folder
ISO7741	Product Folder
MSP430G2332	Product Folder
MSP430FR2111	Product Folder
LMV614	Product Folder
SN6505b	Product Folder
TPS3808	Product Folder
TPS22944	Product Folder
TPS60241	Product Folder
SN6501	Product Folder
TPS70933	Product Folder

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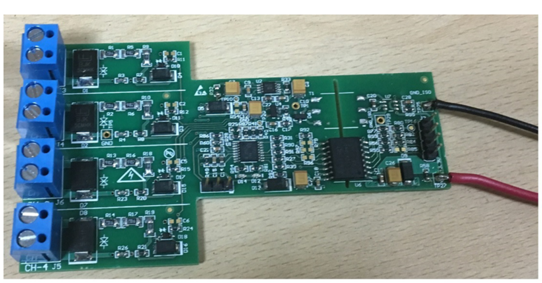
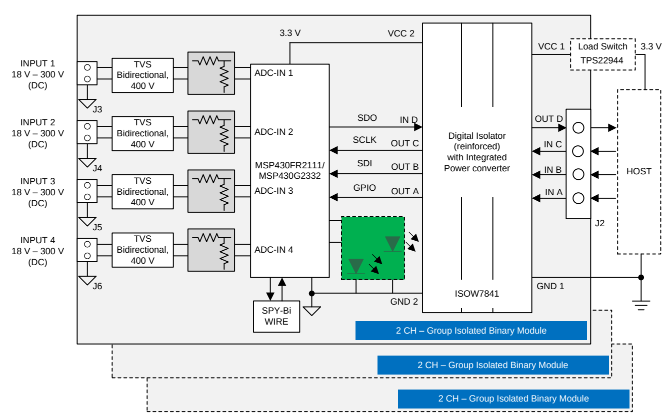


Features

- BIM Design Based on Reinforced Isolation ISOW7841 or ISOW7841F, Digital Isolator With Integrated High Efficiency, Power Converter With Soft-Start, and 75-mA Current Output (Quad With Various Configurations for GPIO or SPI or UART Interface), Simplifying System Design
- ISOW7841 DC Output Provides 46% Efficiency With Output Ripple of 100 mV for 70-mA Load (pkpk)
- MSP430G2332 or MSP430FR2111, MCU-Based Four-Channel DC Input or Two-Channel AC/DC Voltage Measurement Type BIM
- Signal Conditioning Based on LMV614 Op Amp With Gain of ×1 and ×3.4 for Increased Measurement Range, Stable Reference for DC Level Shifting The Inputs Using LM4041 and LMV551
- Two LEDs Provide Status Indication of Binary Input
- Accuracy ≤ ±3% of Measured Value ±1 V Over Entire Input Range
- Passes Pre-Compliance Tests for EMI and EMC as per IEC61000-4 and CISPR 22 Standards
- >300-kΩ Impedance for BIM Inputs With <1-mA Consumption at 276-V Input

Applications

- Multifunction Protection Relay
- Bay Controller
- Merging Unit
- Terminal Unit: RTU, FTU, DTU
- PLC for Factory Automation



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1 System Description

The binary inputs to the protection relay or other grid infrastructure end equipment are called under the following names:

- Binary input
- Digital input
- Control input
- Status indication input

These names are based on the functions they perform. These inputs are referred as binary inputs in this design guide. Binary inputs have wide applications. The binary input module specifications differ with OEMs. The binary inputs are designed as modules and based on application one or more modules are used. Below is the summary of some of the Applications, functionalities, and specifications. These inputs have galvanic isolation from internal circuits, generally optocoupler are used for isolation. Number of binary inputs per module can vary as 4, 8, 16, or 32. The binary inputs are organized in groups (depending upon application) with a common wire. In some of the applications the inputs are channel isolated.

Key specifications include nominal voltages of 24-V DC, 48 to 60-V DC, 110 to 125-V DC/AC, and 220-V DC/AC, ±20% or multi-voltage (24 to 250-V DC/AC), and power consumption per input of 2 to 6 mA with a maximum power dissipation of 0.45 W ±20% per input or a short peak current (> 25 mA).

1.1 BIM Application and Specifications

1.1.1 BIM Applications

Binary inputs are used in grid applications for substation battery monitoring, bay or substation interlocking, breaker status indication, general interrogations, LED tests, diagnostics (self-test), fault indication (alarm), and configuration changes (operated with new settings to perform different functionality).

1.1.1.1 Multifunction Protection Relay

Protection relays are connected across the primary equipment generating, transmitting, and distributing power to protect the equipment against faults that may damage the equipment. Protection relay inputs include AC voltage and current, DC transducer input, and binary inputs. The binary inputs indicating the status of the equipment being monitored for implementing the protection algorithm.

1.1.1.2 Bay Controller

The bay control unit provides fully automated control of substation switching devices. After the switching device is configured and the required interlocking is provided, the bay controller performs the required function independently. The status, alarm, diagnostics, and the interlocking inputs to the bay controller are provided by the BIM.

1.1.1.3 Merging Unit

The merging unit acquires AC currents or voltages from conventional current and voltage transformers (CTs and PTs). It converts these analog signals into digital values and transmits them using IEC 61850 standard using Ethernet connections. Along with the analog values, the status inputs provided by the primary equipment can be monitored and communicated. The status inputs to the merging unit are the binary inputs varying between 18- to 300-V DC.

1.1.1.4 Terminal Unit—RTU, FTU, DTU

In the electrical power industry, equipment such as RTU, DTU, and FTU are switch monitoring devices installed in the substation close to the feed breakers (a disconnector that is located in series at the end of a feeder, within a substation bay, in order to isolate the feeder from the system). These can be used for automated functions such as monitoring, protection, and communication in a ring network cabinet in the distribution substation and master station with the implementation of monitoring and fault identification, isolation, and power recovery of the fault in the distribution network. The monitored inputs can be AC analog input or DC transducer input of binary input. The binary inputs provide status or interlocking inputs.

1.1.2 TI Design Specifications for AC/DC BIM

Table 1 provides specification for a wide input two-channel AC or DC input BIM TI Design.

Table 1. AC/DC BIM—Electrical Specifications

SERIAL NUMBER	PARAMETERS	DESCRIPTION	COMMENTS
1	Number of inputs	2 with provision for status indication using LED	Inputs share common ground
2	Input voltage range	20- to 270-V AC, 15- to 300-V DC	Maximum voltage ≤ 300-V AC/DC
3	Signal frequency	DC or AC (50 or 60 Hz)	—
4	Measurement resolution	<1-V steps for values between 20- to 270-V AC, 15- to 300-V DC	—
5	Gain amplifier	Two gains: ×1, ×3.4	—
6	Measurement accuracy	±3% of measured value ± 1 V	Communicates through SPI to the host
7	Input impedance	≥ 300 kΩ	—
8	Solution approach	Low-cost, small pin count MCU, digital isolator with integrated power, gain amplifier	—
9	ADC	Internal 10-bit ADC using MSP430G2332	—
10	LED indication	Two LEDs provided for binary status indication	—
11	Binary input current or power consumption	< 1 mA at 300-V DC	Does not include wetting current
12	Response time	≥10 ms	Measurement averaged
13	Input wetting resistance	≥ 2.5 kΩ	PWM controlled
14	Isolator type	Digital isolator ISOW7841 or ISOW7841F with integrated power up to a 75-mA current output	Efficiency ≥ 46%
15	Isolation approach	Group isolated	Reinforced isolation
16	EMC tests	IEC 61000-4-2 ESD, IEC 61000-4-4 EFT, IEC 61000-4-5 Surge, IEC 61000-4-6 Immunity to radio frequency induced signals, IEC 61000-4-12 Ring wave immunity, IEC 61000-4-18 Damped oscillatory waves immunity	See Section 4.3
17	EMI tests	Emission tests as per EN 55022, class A, Conducted Emission, Radiated Emission	See Section 4.3

1.1.3 TI Design Specifications DC BIM

Table 2 provides specification for the wide input four-channel DC input BIM TI Design:

Table 2. Four-Channel DC BIM Electrical Specifications

SERIAL NUMBER	PARAMETERS	DESCRIPTION	COMMENTS
1	Number of inputs	4 with provision for status indication	Inputs share common ground
2	Operating voltage ranges: DC	18- to 264-V DC: Measurement	Maximum input ≤ 300-V DC
3	Measurement resolution	<1-V steps for nominal values (24 to 240 V)	—
4	Measurement accuracy	± 3.0% of measured value ± step size	SPI or UART interface to the Host
5	Input impedance	≥ 300 kΩ	—
6	Solution approach	Low-cost, small pin count MCU, digital isolator with integrated power	—
7	ADC	Internal 10-bit ADC using MSP430G2332 or MSP430FR2111	—
8	LED indication	Two LEDs provided for binary status indication	—
9	Binary input current or power consumption	< 1 mA at 300-V DC	—
10	Minimum response time	≥ 3 ms	Measurement averaged
11	Isolator type	Digital isolator ISOW7841 or ISOW7841F with integrated power up to a 75-mA current output or digital isolator with external transformer-based isolated power	Efficiency ≥ 46%
12	Isolation approach	Group isolated	Reinforced isolation
13	EMC tests	IEC 61000-4-2 ESD, IEC 61000-4-4 EFT, IEC 61000-4-5 Surge, IEC 61000-4-6 immunity to radio frequency induced signals, IEC 61000-4-12 Ring wave immunity, IEC 61000-4-18 Damped oscillatory waves immunity	See Section 4.3
14	EMI tests	Emission tests as per EN 55022, class A, Conducted Emission, Radiated Emission	See Section 4.3

2 System Overview

This TIDA-00847 design showcases space and cost-optimized architecture for a four-channel DC input binary module or two-channel AC or DC input binary module with improved measurement accuracy and status indication using different design approaches, simplifying the overall system design. An MCU-based binary module improves measurement resolution of the binary input, which in turn improves system performance including accurate and repeatable fault indications and eliminates the need for multiple hardware versions (use same design for multiple nominal voltage inputs). This reduces efforts in design, testing, manufacturing and field support. In this TI Design, four input channels are configured as group isolated inputs to minimize cost per channel. The binary inputs are isolated from the system interface using digital isolators with external isolated power or digital isolators with an integrated power converter.

2.1 Block Diagram

The wide input improved accuracy BIM is based on a digital isolator with integrated power or external power and an MCU with an internal ADC. Using an MCU simplifies the design improving system performance.

The BIM TI Design has the following hardware options:

- Four-channel DC BIM with integrated power converter-based digital isolator ISOW7841 and MSP430FR2111 MCU
- Four-channel DC BIM with integrated power converter-based digital isolator ISOW7841 and MSP430G2332 MCU
- Four-channel DC BIM with digital isolator ISO7741, transformer driver-based isolated power supply and MSP430G2332 MCU
- Two-channel AC/DC BIM with integrated power converter-based digital isolator ISO7841 and MSP430G2332 MCU

The customer can choose the design architecture based on the binary input type and the host interface requirement.

2.1.1 Four-Channel DC BIM With MSP430FR2111 or MSP430G2332 MCU and ISOW7841

Figure 1 shows a four-channel DC BIM with the following features:

- Digital isolator ISOW7841 with integrated power converter
- MSP430FR2111 or MSP430G2332 MCU for processing the binary input and communicating the measured values to the host
- TPS22944 for overload protection of BIM during output short or overload
- Terminals for connecting the binary inputs
- Connector for interfacing BIM to the host

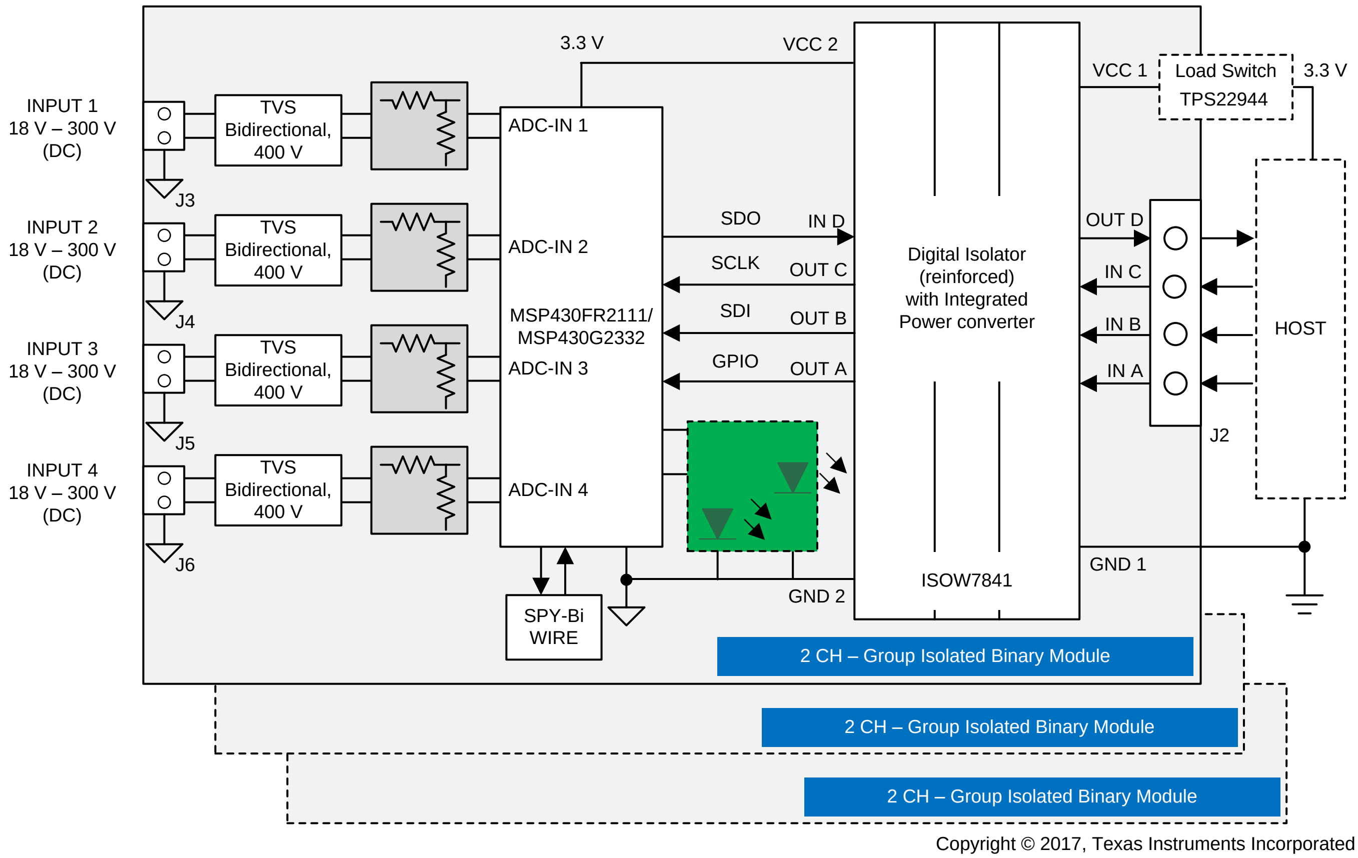

Figure 1. Four-Channel DC BIM With MCU and ISOW7841 Integrated Power Converter

2.1.2 Four-Channel DC BIM With MSP430G2332 and Digital Isolator

Figure 2 shows a four-channel DC BIM with the following features:

- Isolated power supply using the transformer driver SN6505B
- Signal isolation using the digital isolator ISO7741
- MSP430G2332 MCU for processing the binary input and communicating the measured values to the host
- LEDs for binary input status indication
- Terminals for connecting the binary inputs
- Connector for interfacing BIM to the host

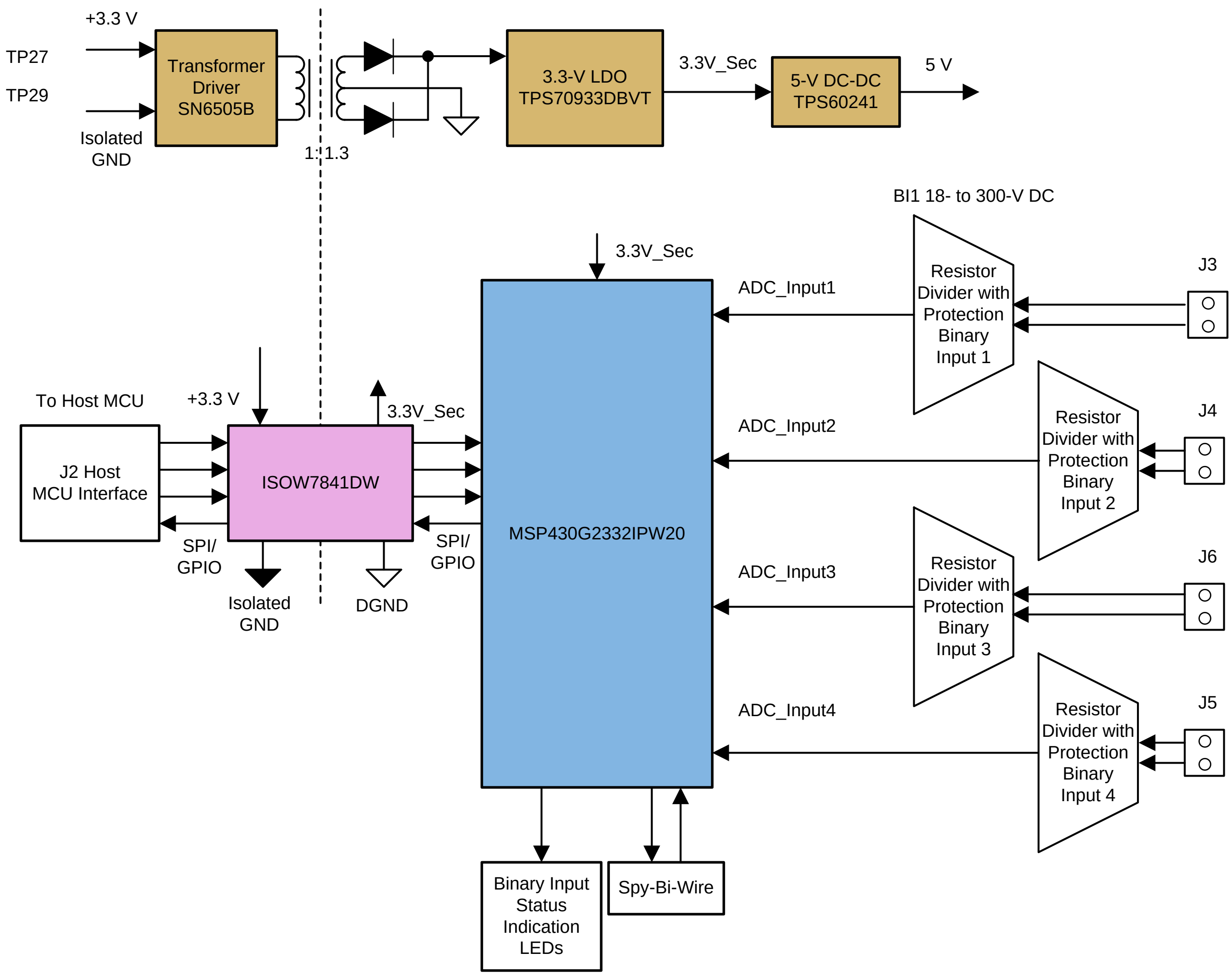

Figure 2. Four-Channel DC BIM With MSP430G2332 and ISO7741 With Transformer Driver

2.1.3 AC/DC BIM With ISOW7841

Figure 3 shows a two-channel AC or DC input BIM with the following features:

- Integrated power converter with the digital isolator ISOW7841
- Op amp for providing two gains for improved accuracy LMV614
- Reference LM4041 with buffer LMV551 for level shifting the input to unipolar ADC internal to MCU
- MSP430G2332 MCU for processing the binary input and communicating the measured values to the host
- LEDs for binary input status indication
- Terminals for connecting the binary inputs
- Connector for interfacing binary BIM to the host

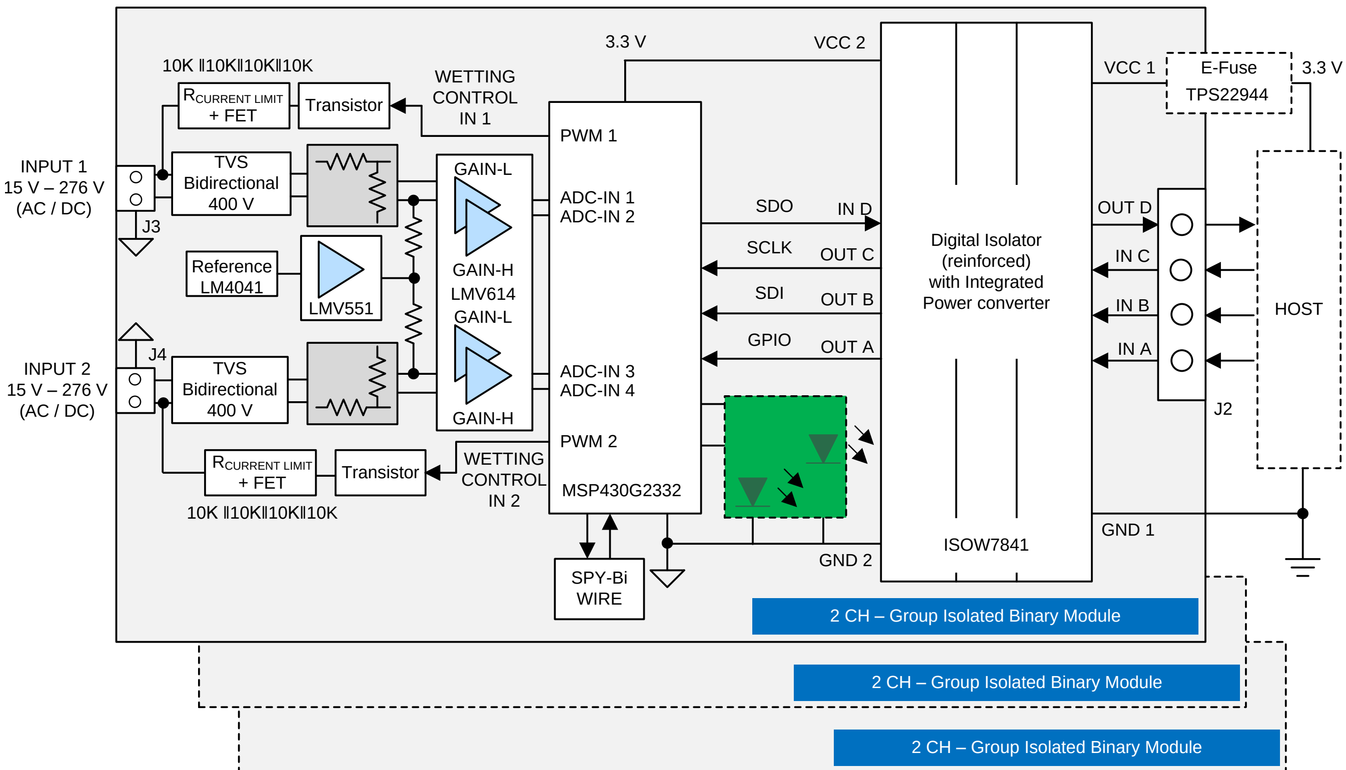

Figure 3. AC/DC BIM With ISOW7841 Integrated Power Converter

2.1.4 MCU

The following subsections detail the MCU used and its configuration.

2.1.4.1 MSP430G2332 for AC/DC BIM

The MSP430G2332 ultra-low-power mixed signal MCU with an internal 10-bit SAR ADC is configured to measure a two-channel input, AC or DC, with two gains for each input in this TI Design. The MCU is used to sample the analog input to compute the binary input amplitude and to communicate the computed amplitude values to the host through SPI, I^{2}C, or GPIO. The MCU is also used to control the wetting current and use LEDs to indicate system functionality.

2.1.4.2 MSP430G2332 for DC BIM

The MSP430G2332 ultra-low-power mixed signal MCU with 4KB non-volatile memory and an internal 10-bit SAR ADC is configured to measure a four-channel DC input in this TI Design. The MCU is used to sample the analog input to compute the binary input amplitude and to communicate the computed DC values to the host through SPI, I^2C, or GPIO.

2.1.4.3 MSP430FR2111 for DC BIM

The MSP430FR2111 ultra-low-power mixed signal MCU with a 4KB FRAM and an internal 10-bit SAR ADC is configured to measure a four-channel DC input in this TI Design. The MCU is used to sample the analog input to compute the binary input amplitude and to communicate the computed DC values to the host through SPI, I^2C, or GPIO.

2.1.5 Digital Isolator With Integrated Power ISOW7841

The BIM is isolated from the host interface using a digital isolator with an integrated power converter. The ISOW7841 device is used in this TI Design to provide the interface and the power isolation. High Efficiency and Low Emission Isolated Power with Integrated Quad Channel Digital Isolator has been used in this TI design to provide the interface and the power isolation

2.1.6 Digital Isolator With External Isolated Power

Alternative approach to isolated the BIM from the host is to use digital isolator and isolated power generated using transformer driver.

The ISO7741 device is used to isolate the BIM from the host. The isolator is configured in SPI. The power converter provides up to 0.5 W of power with high efficiency configured for 3.3-V input and 3.3-V output. The SN6505B and LDO TPS70933 LDO are used to generate the isolated power supply for the BIM.

The High-Speed, Low-Power, Robust EMC Quad-Channel 3/1 Digital Isolator is used to isolate the BIM from the host. The isolator is configured in SPI configuration. The power converter provides up to 0.5-W power with high efficiency configured for 3.3-V input and 3.3-V output. The Low-Noise 1-A Transformer Driver for Isolated Power Supplies, Internal Clock-160kHz is used to generate the isolated power supply for the BIM.

2.1.7 Signal Conditioning for AC/DC BIM

The signal conditioning circuit for AC/DC BIM consists of the following:

- Potential divider and input protection
- Gain amplifier and reference for level shifting the input
- Wetting current control circuit for generating the wetting current for BIM

For more information on potential divider and wetting current control, see the TIDA-00809 design.

2.1.8 Programming

The two-wire interface is made up of the SBWTCK (Spy-Bi-Wire™ test clock) and SBWTDIO (Spy-Bi-Wire test data I/O) pins. The SBWTCK signal is the clock signal and is a dedicated pin. In normal operation, this pin is internally pulled to ground. The SBWTDIO signal represents the data and is a bidirectional connection. To reduce the overhead of the two-wire interface, the SBWTDIO line is shared with the RST/NMI pin of the device. For more details, see Section 1.2.1.3 of the user's guide *MSP430™ Programming With the JTAG Interface* (SLAU320).

2.2 Highlighted Products—System Design

This section describes the TI products used in this TI Design with design calculations.

2.2.1 Binary Input application requirements

2.2.1.1 Wetting or Auto Burnishing

The binary inputs sense a change of state of the external device. When these external devices are located in a harsh industrial environment (either outdoor or indoor), their contacts can be exposed to various types of contamination. Normally, there is a thin film of insulating sulfidation, oxidation, or contaminants on the surface of the contacts, sometimes making it difficult or impossible to detect a change of the state.

This film must be removed to establish circuit continuity; an impulse of higher than normal current can accomplish this. The contact inputs with auto-burnish create a high-current impulse when the threshold is reached to burn off this oxidation layer as maintenance to the contacts. Afterwards, the contact input current is reduced to a steady-state current. Contact inputs with auto-burnishing allow currents up to 50 mA at the first instance when the change of state was sensed. Then, within 25 to 50 ms, this current is slowly reduced to 5 mA. The 50-mA peak current burns any film on the contacts, allowing for proper sensing of state changes.

2.2.1.2 EMC—Transient Overvoltage Stress

In industrial applications, lightning strikes, power source fluctuations, inductive switching, and electrostatic discharge (ESD) can cause damage to binary inputs by generating large transient voltages. The following tests have been considered in this TI Design:

- IEC 61000-4-2 ESD
- IEC 61000-4-4 EFT
- IEC 61000-4-5 Surge
- IEC 61000-4-6 Immunity to radio frequency-induced signals
- IEC 61000-4-12 Ring wave immunity
- IEC 61000-4-18 Damped oscillatory waves immunity

The level of protection can be further enhanced when using external clamping devices such as TVS diodes. The transients are clamped instantaneously (< 1 ns) and the damaging current is diverted away from the protected device.

2.2.1.3 EMI Conducted and Radiated Emissions as per EN55022 Class A

The emission test that are specified in the standard are as follows:

- Conducted Emission (CE) Class A as per EN55022
- Radiated Emission (RE) Class A as per EN55022 at a distance of 10 meters

NOTE: Add 10 dB(μV/m) when testing the performance in quasi peak, with the DUT placed at a distance of 3 meters.

2.2.1.4 Group Isolated Two-Channel, Wide AC/DC BIM TI Design Advantages

Advantages of the AC/DC BIM include:

- Using a digital isolator with integrated power simplifies the system design and increases reliability
- Cost-optimized solution
- Allows for measurement of wide AC/DC input voltage
- Indicates binary input status using LEDs
- Uses MCU to allow flexibility in terms of input voltage processing and wetting current control
- Reduces measurement error that could be caused due to bridge rectifier at the input
- Improves voltage input measurement accuracy by using multiple gains

2.2.1.5 Group Isolated Four-Channel, Wide DC BIM TI Design Advantages

Advantage of the DC BIM include:

- Using a digital isolator with integrated power simplifies the system design and increases reliability
- Cost-optimized solution
- Indicates binary input status using LEDs
- Allows for measurement of wide DC input voltage for up to four channels
- Cost- and size-optimized design using the MSP430G2332 or MSP430FR2111 MCU
- Using a microprocessor improves measurement accuracy

2.2.2 MCU

The following subsections detail the MCU interface as used in this TI Design.

2.2.2.1 *MSP430G2332 for AC/DC or DC BIM*

Table 3 details the MCU configuration to interface with the host through the digital isolator.

Table 3. MCU to Digital Interface for AC/DC or DC BIM With MSP430G2332

MCU PINS	CONFIGURATION	ALTERNATIVE	COMMENTS
Pin 7, P1.5/TA0.0/SCLK/A5/TMS	SCLK	GPIO	The MCU pin configuration depends on the implementation of the BIM functionality
Pin 13, P2.5	SS	GPIO	
Pin 14, P1.6/TA0.1/SDO/SCL/A6/TDI/TCLK	SDO	GPIO/SCK	
Pin 15, P1.7/SDI/SDA/A7/TDO/TDI	SDI	GPIO/SDA	

Figure 4 shows the MSP430G2332 configured for measuring AC or DC analog inputs and LEDs for binary input status indication and interfacing with digital isolator

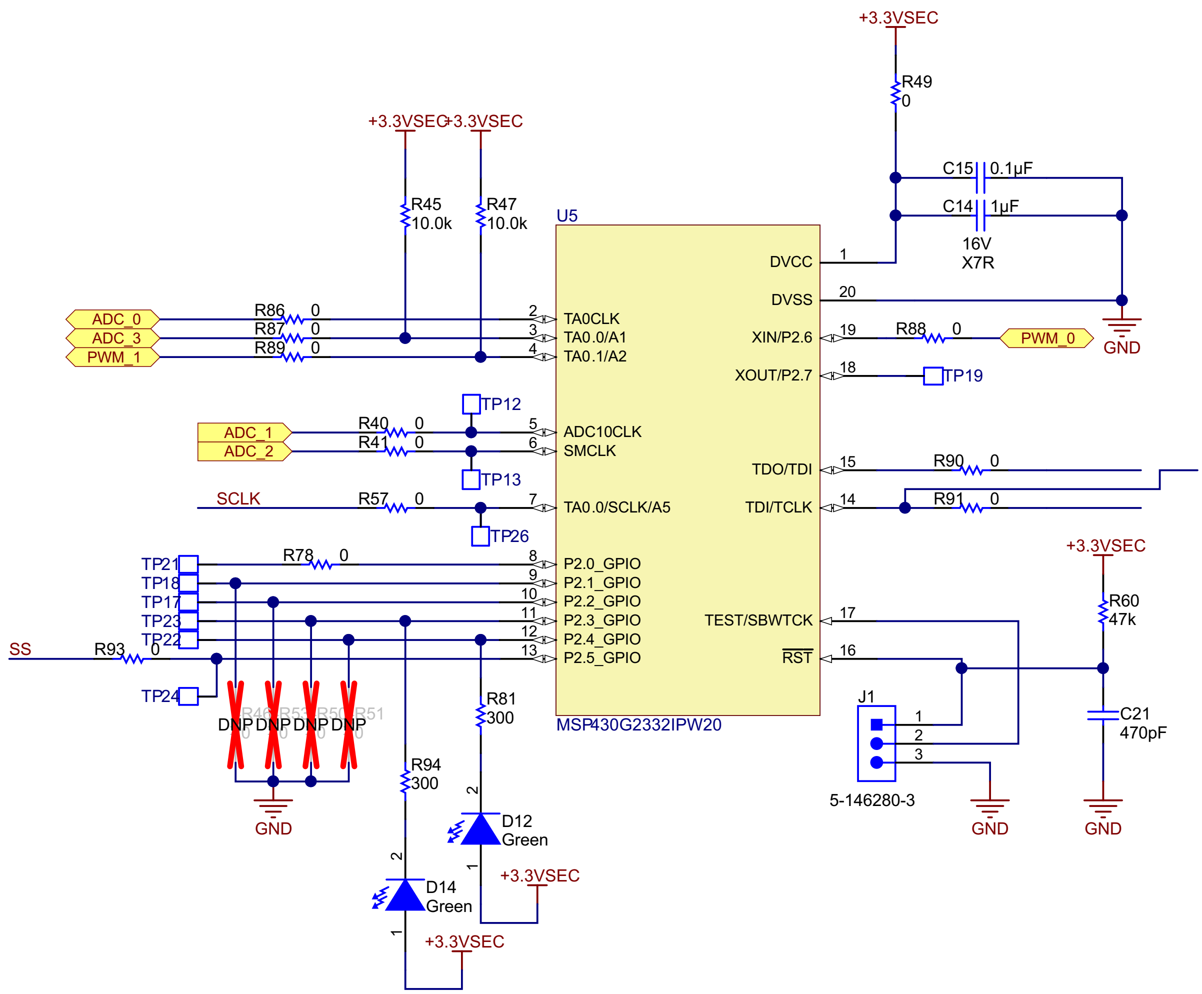

Figure 4. MSP430G2332 MCU Configuration Schematics With Interface to Digital Isolator

The MSP430G2x32 series of MCUs are ultra-low-power mixed signal MCUs with built-in 16-bit timers and built-in communication capability using the universal serial communication interface. The MSP430G2x32 series have 10-bit ADCs (see the MSP430G2332 product page).

Features:

- Low supply voltage range: 1.8 to 3.6 V
- Universal serial interface (USI) supporting SPI and I^2C
- 10-Bit 200-ksps ADC With Internal Reference, Sample-and-Hold, and Autoscan (MSP430G2x32 Only)
- Brownout detector
- On-chip emulation logic with Spy-Bi-Wire interface
- Package options TSSOP: 20 pin

2.2.2.2 MSP430FR2111 for DC BIM

Table 4 details the MCU configuration to interface with the host through the digital isolator.

Table 4. MCU to Digital Interface for DC BIM With FRAM-Based MCU

MCU PINS	CONFIGURATION	ALTERNATIVE	COMMENTS
Pin 9, P2.1/TB0.2	GPIO	—	The MCU pin configuration depends on the implementation of the binary BIM functionality
Pin 10, P2.0/TB0.1/COUT	GPIO	—	
Pin 11, P1.7/UCA0TXD/UCA0SIMO	GPIO	UART transmit	
Pin12, P1.6/UCA0RXD/UCA0SOMI	GPIO	UART receiver	

MSP430FR211x devices are an expansion of the MSP430 MCU value line. Ferroelectric random access memory (FRAM) is a non-volatile memory that combines the speed, flexibility, and endurance of SRAM with the stability and reliability of flash, all at lower total power consumption (see the MSP430FR2111 product page).

Features:

- MSP430FR2111 with 3.75 KB of program FRAM + 1KB of RAM
- Embedded MCU 16-bit RISC architecture up to 16 MHz
- Wide supply voltage range: 1.8 to 3.6 V (Operation voltage is restricted by SVS levels)
- Low-power FRAM Up to 3.75 KB of non-volatile memory
- Built-in error correction code (ECC)
- Enhanced serial communications enhanced USCI A (eUSCI_A) supports UART, IrDA, and SPI
- High-performance analog eight-channel 10-bit ADC, 200 ksps
- Package options 16-pin: TSSOP (PW16)

2.2.2.3 Input Voltage Calculations for AC/DC BIM

Table 5 provides the calculation for the maximum DC or AC voltage that can be applied to the AC or DC BIM with two gains.

Table 5. Maximum Input Voltage for AC/DC BIM

VOLTAGE INPUT	CALCULATIONS	VALUES
Maximum DC input allowed	DC offset in ADC counts	511
	ADC range in counts	1023 – 511 = 512
	Resistor divider ratio	301.1 kΩ / 1.1 kΩ = 273.72
	DC input ADC reference span	ADC_{REF} = 1.65 V
	Maximum input voltage	ADC_{REF} × Resistor divider ratio = > 300 V
Maximum AC input allowed	DC offset in ADC counts	511
	Peak ADC range in counts	1023 – 511 = 512
	RMS ADC range in counts	512 / 1.414 = 362
	Resistor divider ratio	301.1 kΩ / 1.1 kΩ = 273.72
	AC RMS ADC reference span	Avg_{REF} = 1.65 V / 1.414 = 1.1668
	Maximum input voltage	Avg_{REF} × Resistor divider ratio = > 300 V

2.2.2.4 Converting ADC Counts to Input Voltage for AC/DC BIM

Table 6 provides the calculation for converting the measured ADC counts to the applied input voltage. The applied input voltage may be AC or DC.

Table 6. Converting ADC Counts to Input Voltage for AC/DC BIM

ADC COUNT TO VOLTAGE	CALCULATIONS	VALUES
DC input low gain	ADC_{REF}	1.65
	Maximum input	450 V
	Gain factor	1
	Max ADC count for DC input	512
	DC voltage equivalent for one ADC count	Maximum input / (ADC count × Gain factor) = 0.878 V
DC input high gain	ADC_{REF}	1.65
	Maximum input	450 V
	Gain factor	3.4
	Max ADC count	512
	DC voltage equivalent for one ADC count	Maximum input / (ADC count × Gain factor) = 0.2582
AC input low gain	ADC_{REF} – peak	1.65
	Maximum input	315 V
	Gain factor	1
	Max ADC count	512 / 1.414 = 362
	RMS voltage equivalent for one ADC count	Maximum input / (ADC count × Gain factor) = 0.870
AC input high gain	ADC_{REF} – peak	1.65
	Maximum input	315 V
	Gain factor	3.4
	Max ADC count for RMS input	512 / 1.414 = 362
	RMS voltage equivalent for one ADC count	Maximum input / (ADC count × Gain factor) = 0.260

2.2.2.5 Calculations for DC BIM

Table 7 provides the calculation for calculating maximum DC input voltage and converting the ADC counts to the applied input voltage.

Table 7. Calculation for DC BIM

ADC COUNT TO VOLTAGE	CALCULATIONS	VALUES
Maximum DC input allowed	ADC range in counts	0 to 1023
	Resistor divider ratio	303.16 kΩ / 3.16 kΩ = 95.93
	ADC reference	ADC_{REF} = 3.3 V
	Maximum input voltage	ADC_{REF} × Resistor divider ratio = 315 V
Converting ADC count to voltage	VCC	3.3 V
	Maximum input	315 V
	ADC count for maximum input	1023
	DC Voltage equivalent for one ADC count	Maximum input / ADC count = 0.3076 V

NOTE: If the overall input voltage span is reduced by increasing the voltage output across the resistor divider, the accuracy at lower voltage can be improved

2.2.3 ISOW7841—Digital Isolator With Integrated Power

The ISOW7841 device has three forward and one reverse-direction channels and is interfaced to the host and the onboard binary input measurement input as shown in Figure 5.

Figure 5 shows the ISOW7841 device configured for SPI for isolating the BIM from the host. The ISOW7841 has the digital isolator integrated with a power converter, simplifying the design.

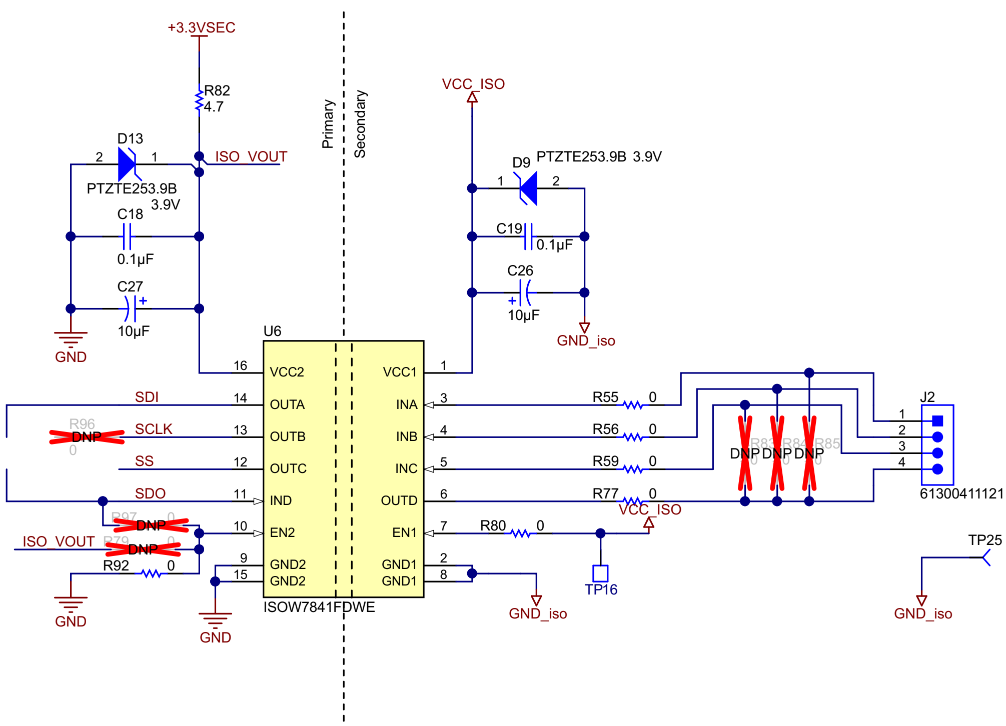

Figure 5. ISOW7841 Configured for Integrated Power and Data Interface

2.2.4 Digital Isolator With External Isolated Power

The ISO7741 device has three forward and one reverse-direction channels and is interfaced to the host and the onboard binary input measurement input as shown in Figure 6.

Figure 6 shows the ISO7741 configured for SPI for isolating the BIM from the host. The required isolated power is generated using the transformer driver and LDO.

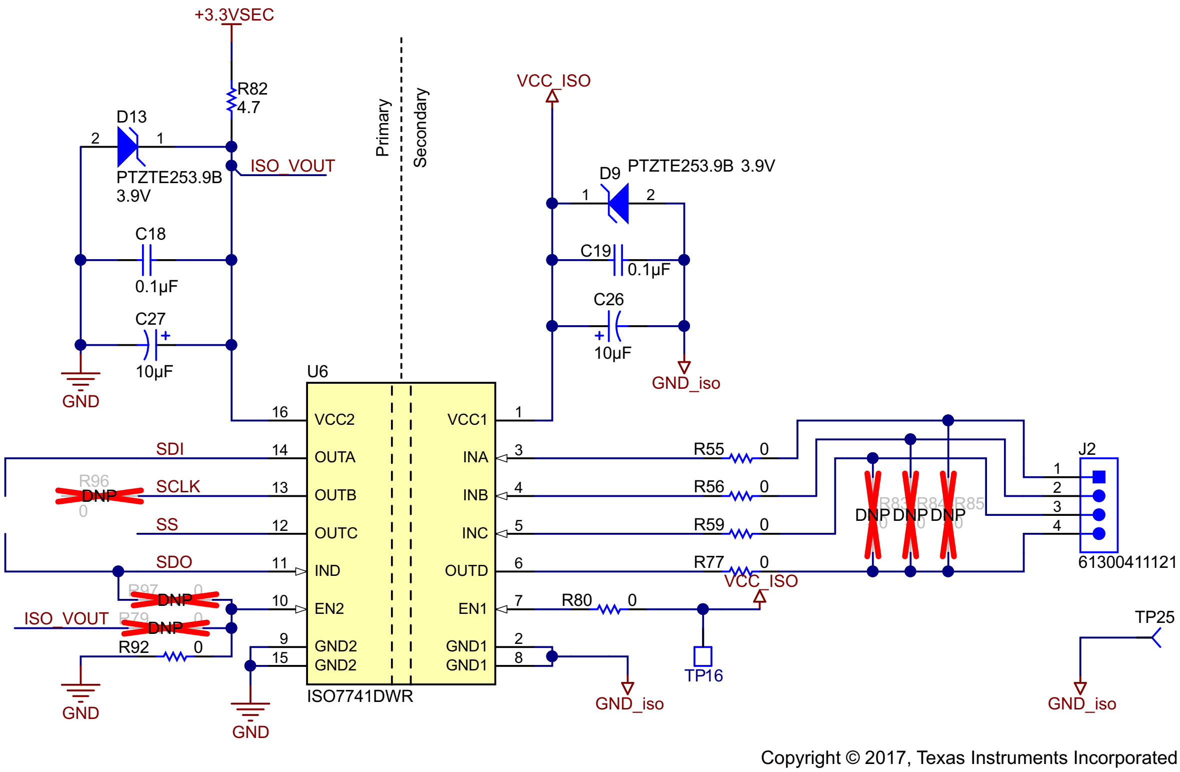

Figure 6. ISO7741 Configured for Digital Interface With External Isolated Power

The ISO774x devices are high-performance, quad-channel digital isolators with 5000-V_{RMS} (DW package) isolation ratings per UL 1577. This family of devices has reinforced insulation ratings according to VDE, CSA, TUV, and CQC. The ISO7741 device has three forward and one reverse-direction channels (see the ISO7741 product page).

Features:

- Signaling rate: Up to 100 Mbps
- Wide supply range: 2.25 to 5.5 V
- Wide temperature range: –55°C to 125°C
- Low power consumption:1.5 mA typical per channel at 1 Mbps
- Low propagation delay: 10.7 ns typical (5-V supplies)
- High CMTI: ±100 kV/µs typical with isolation barrier life (> 40 years)
- Wide-SOIC (DW-16)

2.2.4.1 Isolated Power Using SN6505B and LDO TPS70933

Figure 7 shows the isolated power supply circuit using the transformer driver and LDO.

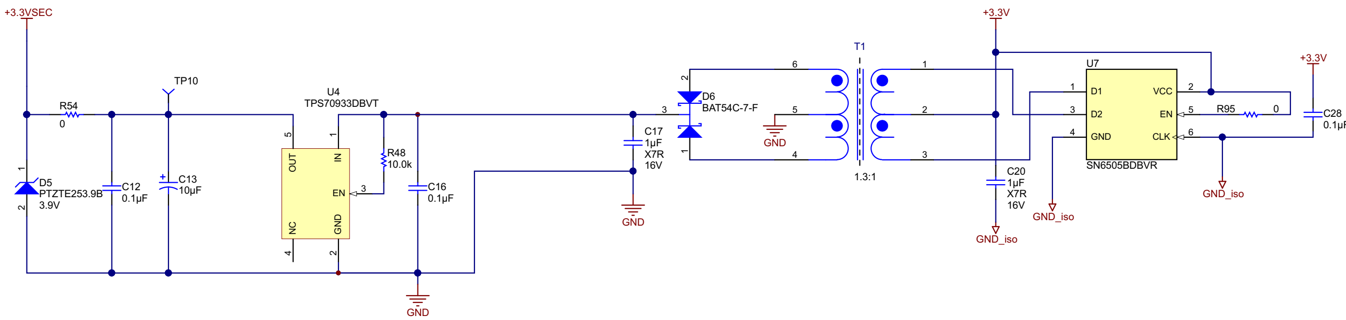

Figure 7. Transformer Driver-Based Isolated Power for Digital Isolator Interface

The SN6505 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- to 5-V DC power supply. The SN6505 includes a soft-start feature that prevents high inrush current during power up with large load capacitors. The SN6505 is available in a small 6-pin SOT23/DBV package. The device operation is characterized for a temperature range from –55°C to 125°C (see the SN6505B and TPS709 product pages).

Features:

- Push-pull driver for transformers
- Wide input voltage range: 2.25 to 5.5 V
- High output drive: 1 A at a 5-V supply
- Spread spectrum clocking
- Synchronization of multiple devices with external clock input
- Slew-rate control

Alternatively, consider the SN6501 Low-Noise, 350-mA, 410-kHz Transformer Driver for isolated power supply generation.

2.2.5 Signal Conditioning

This TI Design has two gains to measure AC or DC input voltage up to 300 V. The gains are provided using operational amplifiers (op amps). The gains are set to 1 and 3.4. The gains can be adjusted based on the input range and the accuracy requirement.

2.2.5.1 Gain Amplifier LMV614

The LMV614 devices are quad low-voltage, low-power op amps. They are designed specifically for low-voltage, general-purpose applications. Other important product characteristics are rail-to-rail input or output, low supply voltage of 1.8 V, and a wide temperature range (see the LMV614 product page).

2.2.5.2 Reference LM4041

The LM4041-N precision voltage reference is available in SOT-23 surface-mount packages. The advanced design of the LM4041-N eliminates the need for an external stabilizing capacitor while ensuring stability with any capacitive load, thus making the LM4041-N easy to use. Further reducing the design effort is the availability of a fixed (1.225 V) and adjustable reverse breakdown voltage. The minimum operating current is 60 µA for the LM4041-N 1.2 and the LM4041-N ADJ. Both versions have a maximum operating current of 12 mA (see the LM4041-N product page).

2.2.5.3 Reference Buffer LMV551

The LMV551 is a high-performance, low-power op amp. They feature 3 MHz of bandwidth while consuming only 37 µA of current per amplifier, which is an exceptional bandwidth to power ratio in this op amp class. These ultra-low-power amplifiers are unity gain stable and provide an excellent solution for ultra-low-power applications requiring a wide bandwidth (see the LMV551 product page).

2.2.6 Other Hardware Options

The following subsections provide options for improving the performance of the digital isolator with the integrator power converter. In applications requiring multiple DC voltage for operation, a low ripple 3.3- to 5-V DC-DC converter can be used. During an output load short condition, the input current drawn is ≈ 130 mA. This current is drawn from the power source continuously. To protect the BIM under this condition, a load switch can be used. During output overload the output of the ISOW784x droops. To overcome the devices malfunction during voltage droop, the voltage supervisor can be used.

2.2.6.1 3.3- to 5-V High-Efficiency DC-DC Converter TPS60241

The TPS60241 devices are a family of switched capacitor voltage converters, ideally suited for voltage-controlled oscillator (VCO) and phase-locked loop (PLL) applications that require low noise and tight tolerances. Its dual-cap design uses four ceramic capacitors to provide ultra-low output ripple with high efficiency, while eliminating the need for inefficient linear regulators. The TPS60241 works with a 2.7- to 5.5-V input voltage providing a 5-V output. The devices work equally well for low EMI DC–DC step-up conversion without the need for an inductor. The high switching frequency (typical 160 kHz) promotes the use of small surface-mount capacitors, saving board space. The shutdown mode of the converter conserves battery energy (see the TPS60241 product page).

2.2.6.2 Load Switch TPS22944

The TPS22944 load switch protects systems and loads in high-current conditions. The devices contain a 0.4-Ω current-limited P-channel MOSFET that can operate over an input voltage range of 1.62 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 (see the TPS22944 product page).

Table 8 details the selection of load switches based on the power requirements.

Table 8. 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

2.2.6.3 Data Interface Selection

TI provides MSP430G23xx and MSP430FR21xx family of cost-optimized small pin count MCUs that are well suited for BIM applications. Based on the interface required, consider the devices listed in Table 9:

Table 9. MSP430 MCU Family Devices Selection

INTERFACE TYPE	DEVICES
SPI	MSP430G2332
	MSP430FR2111
	MSP430G2203
I^2C	MSP430G2332
	MSP430FR2111
	MSP430G2203
UART	MSP430FR2111
	MSP430G2203 or MSP430G2553

2.2.7 ISOW7841 Advantages

Two different approaches can be considered for providing isolated power and data interface using TI's digital isolator family.

2.2.7.1 Isolated Interface With Transformer Driver and Digital Isolator

This approach consists of the following bocks that require multiple products as shown in Table 10.

- Digital isolator
- Transformer driver
- Isolation transformer
- LDO

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

Table 10. 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, 100Mbps	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-kVpk Low-Power Quad Channels, 150-Mbps Digital Isolators	SPI

2.2.7.2 Isolated Interface Using ISOW7841

All these components are integrated into one device, simplifying the design as shown in Figure 8 and reducing the solution size and optimizing the cost. In applications where the required interface matches with the ISOW784x device family, this solution is recommended.

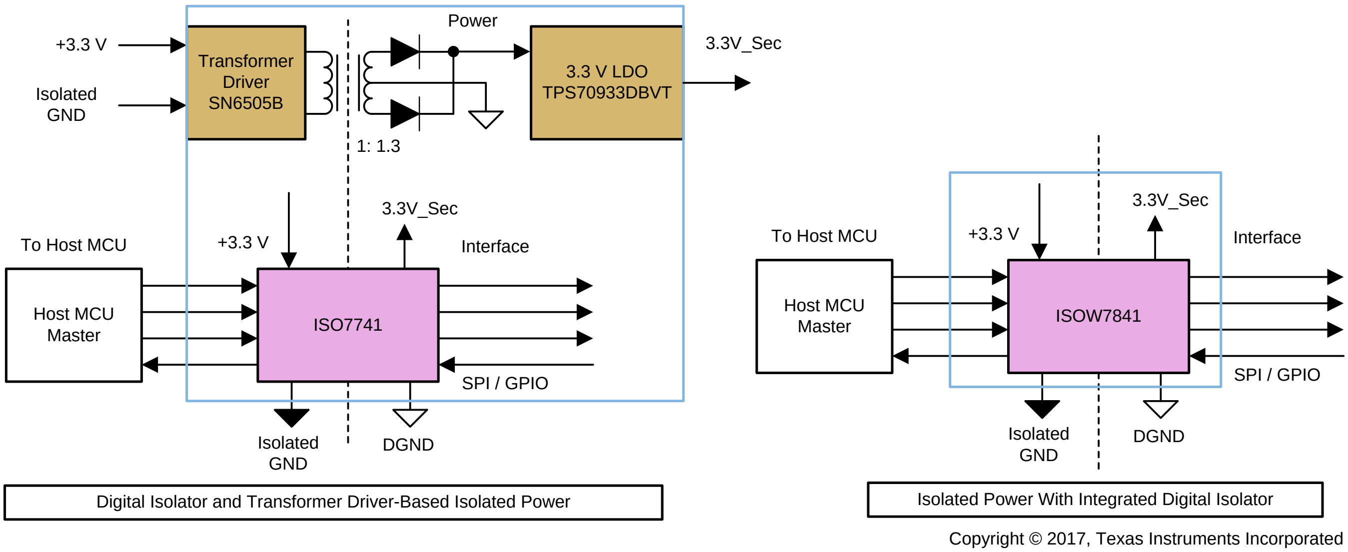

Figure 8. ISOW7841 Integrated Data and Power

The ISOW7841 with 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
- Lower temperature rise and overall heat dissipation

2.2.8 Design and Layout Guidelines for ISOW7841

To help ensure reliable operation at data rates and supply voltages, adequate decoupling capacitors must be located as close to supply pins as possible. The input supply must have an appropriate current rating to support output load and switching at the maximum data rate required by the end application. Because the device has no thermal pad to dissipate heat, the device dissipates heat through the respective GND pins. Ensure that enough copper is present on both GND pins to prevent the internal junction temperature of the device from rising to unacceptable levels.

See Section 12 of the ISOW784x datasheet for more details (SLLSEY2).

2.2.9 Interface With High-Precision ADCs With Serial Interface

The digital isolators ISOW7841 or ISO7741 can be used to interface to ADCs, DACs, or other TI products with SPI. Table 11 provides some of the options for an ADC interface.

Table 11. 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 or ADS8668	16-bit, 1-MSPS, 5-V SAR ADC with Integrated Analog Front-End and Bipolar Inputs	multiSPI™ interface with daisy-chain
3	ADS8588S	16-Bit, 200-kSPS, 8/6/4 Ch, Simultaneous-Sampling ADCs with Bipolar Inputs on a Single Supply	Serial interface
4	ADS131E08 or 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

2.2.9.1 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, an external programmable-delay supervisory circuit can be considered. The TPS3808 has been provided in this TI Design. Table 12 lists other devices to also consider:

Table 12. 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

2.2.9.2 LED Indication for BIM Status

The advantage of using an MCU is the status of the BIM can be shown to the user (annunciator or annunciation). The design allows for LED that can be used for status indication. Based on the design, LEDs can be used to indicate status of individual binary inputs. To drive the LEDs, the options in Table 13 can be used:

Table 13. Options to Drive BIM Status LED

SERIAL NUMBER	PART NUMBER	DESCRIPTION
1	CSD17571Q2	30 V, 20 mΩ, SON 2×2 NexFET™ power MOSFET
2	TLC5916	Constant-current LED sink drivers

3 Getting Started Hardware

This section provides information on connecting the BIM for functional and performance testing. See TIDA-00847_Safety_User_Guide.docx before connecting the inputs.

3.1 AC/DC BIM

Table 14 provides information on the different interface connectors for connecting DC power supply, host interface, and binary inputs (AC or DC).

Table 14. AC/DC BIM Connections

FUNCTIONS	INPUT	SIGNAL NAME	PINS
Power connections	Power supply	+3.3V	TP27
		Ground	TP29
Input voltage	Binary input 1	Positive input	J3-1
		Negative input	J3-2
	Binary input 2	Positive input	J4-1
		Negative input	J4-2
Host interface	SPI	SCK	J2-2
		SDI	J2-1
		/CS	J2-3
		SDO	J2-4
		GND	TP25

CAUTION

HIGH VOLTAGE: Binary input voltage can vary between 20 to 300 V. Ensure the voltage source is switched off while connecting the binary inputs and do not touch the input terminal during testing

3.2 DC BIM

Table 15 provides information on the different interface connectors for connecting the DC power supply, host interface, and DC binary inputs.

Table 15. DC BIM Connections

FUNCTIONS	INPUT	SIGNAL NAME	PINS
Power connections	Power	+3.3V	TP27
		Ground	TP29
Input voltage	Binary input 1	Positive input	J3-1
		Negative input	J3-2
	Binary input 2	Positive input	J4-1
		Negative input	J4-2
	Binary input 3	Positive input	J6-1
		Negative input	J6-2
	Binary input 4	Positive input	J5-1
		Negative input	J5-2
Host interface	SPI	SCK	J2-2
		SDI	J2-1
		/CS	J2-3
		SDO	J2-4
		GND	TP25

CAUTION

HIGH VOLTAGE: Binary input voltage can vary between 20 to 300 V. Ensure the voltage source is switched off while connecting the binary inputs and do not touch the input terminal during testing.

4 Testing and Results

Note the following test conditions for performance measurement of the BIM:

- All measurements in this section are RMS values.
- The source uncertainty is ±0.1%.
- Take care to not open the current source outputs during testing.
- The inputs must be connected with the AC voltage and current source output programmed to zero and the output switched OFF.
- DC offset was performed and the DC values were subtracted during RMS computation.
- The 30-V DC input was connected for all the EMC tests.
- 110 V was connected for CE.

Table 16 details the tests done on the BIM side (VCC2 and GND2 side of the digital isolator) and the source.

Table 16. Power Source Used for Testing

TESTS	TEST PORT	POWER SOURCE	COMMENTS
IEC61000-4-2	Binary inputs	Battery source regulated to 3.6 V	Test 1: ESD power earth was referenced to GND1
IEC61000-4-4, IEC61000-4-5	Binary inputs	DC voltage source (table top) 3.45 V	EFT and surge generator power earth was referenced to GND1
IEC61000-4-6	Binary inputs	Battery source regulated to 3.6 V	Test equipment influences DC power supply (source) performance
IEC61000-4-12, IEC61000-4-18	Binary inputs	Battery source regulated to 3.6 V	Ring wave generator power earth was referenced to GND1
EN55022 CE and RE	Binary inputs	Battery source regulated to 3.6 V	Looking for emission from the BIM only

4.1 Test Setup

Figure 9 provides information on the setup used for functional and performance testing of the AC/DC BIM.

4.1.1 AC/DC BIM Connection

The setup to test the BIM consists of the following:

- DC power supply (3.3 V, 200 mA)
- AC or DC input voltage (20 to 300 V)
- TIDA-00847 AC/DC BIM with ISOW7841
- GUI for firmware upgrade and data capture

NOTE: While testing, ensure the inputs do not exceed the range specified for proper operation.

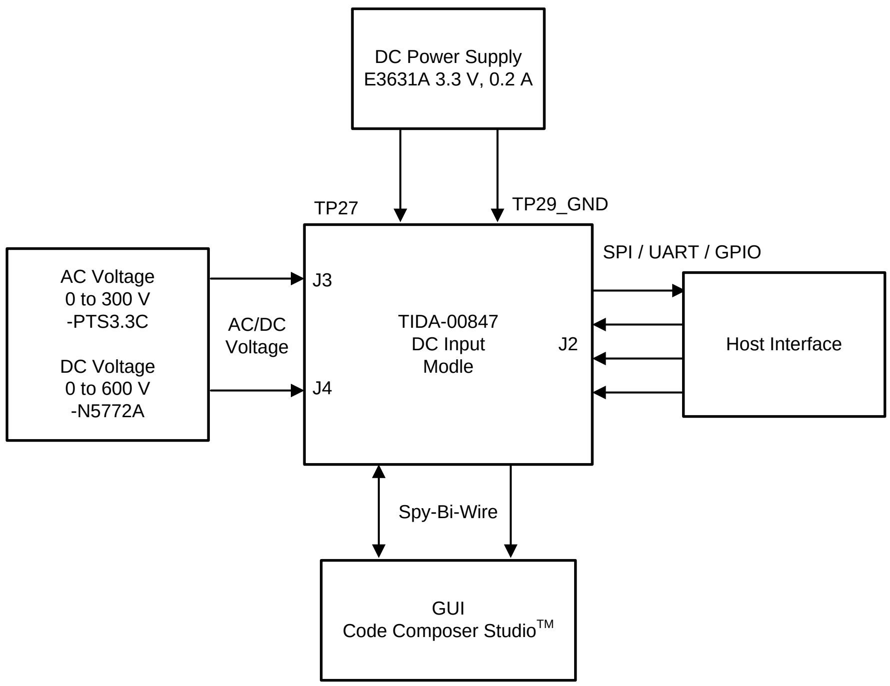

Figure 9. Test Setup for AC/DC BIM Performance Testing

4.1.2 DC BIM Connection

The setup to test the BIM consists of the following:

- DC power supply (3.3 V, 200 mA)
- DC input voltage (20 to 300 V)
- TIDA-00847 DC BIM with ISOW7841 or ISO7741

NOTE: While testing, ensure the inputs do not exceed the range specified for proper operation.

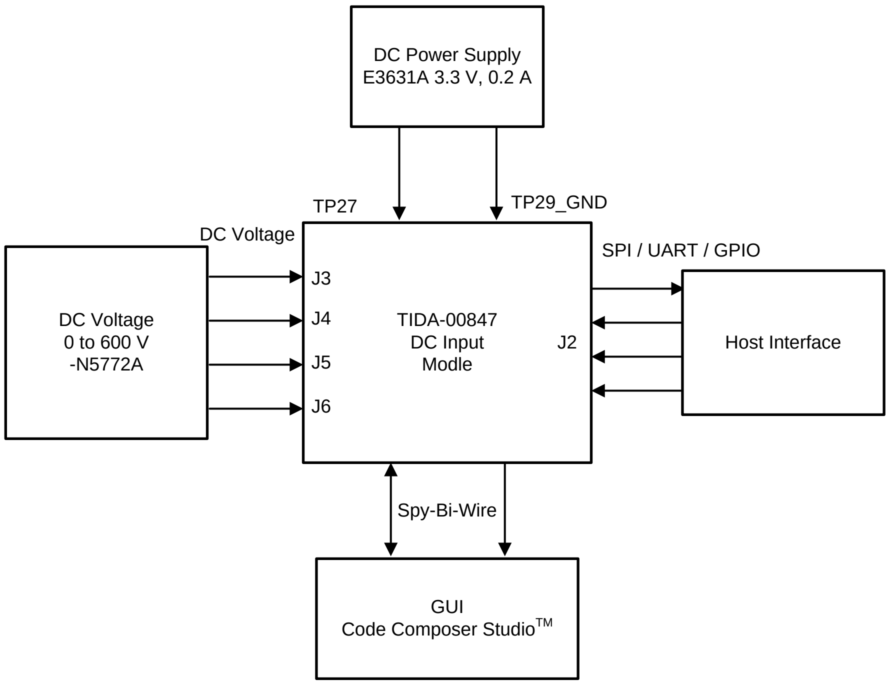

Figure 10. Test Setup DC BIM Performance Testing

4.2 Functional Testing

Table 17 provides information on the different functional tests done on the BIMs.

Table 17. Functional Test Observations

PARAMETER	SPECIFICATION	MEASUREMENT
Isolated supply ISOW7841 output	3.3 V	3.36
Output ripple on isolated supply for ISO7841	100 mV	≈ 100 mV
DC current from supply under short circuit on VISO (in mA)	135	< 135
Transformer driver based isolated supply	3.3 V	3.32 V
3.3- to 5-V DC-DC converter	5 V	5 V
ISOW7841-based digital isolator functionality	Communication functionality	OK
ISO7741 Digital isolator functionality	Communication functionality	OK
MCU programming	Spy-Bi-Wire	OK
LED indication	Port toggling	OK
Potential divider ration for DC input BIM	300:2.2	OK
Reference output	1.65 V	1.645
Op-amp gain for AC/DC measurement	×1 , ×3.4	OK
DC input measurement accuracy	±3% of measured value ± 1 V	OK

4.2.1 ISOW7841 Load Regulation Testing

Load regulation was tested by varying the output load from 20 to 100 mA and input of 3.3 V applied at the input of the power connector. Table 18 provides the test results for load regulation.

Table 18. 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 in 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 was < ±1%.

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

Line regulation was tested by varying voltage from 3.6 V to 2.3 V with an approximate 80-mA load at the output of the power connector. Table 19 provides the test results for line regulation.

Table 19. 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%	—	0.210	—
3.0	3.373	0.086	0.201	43.02%	—	0.227	—
2.7	3.380	0.086	0.229	37.84%	—	0.255	—
2.6	3.330	0.085	0.231	36.96%	—	0.257	UVLO recover
2.5	3.200	0.082	0.222	36.96%	—	0.248	—
2.4	3.000	0.076	0.214	35.94%	—	0.240	—
2.3	0	—	—	—	—	0	UVLO

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

4.2.3 ISOW7841 Ripple Measurement

Figure 11 shows DC output ripple in mV on isolated supply (pkpk) with a 20-MHz bandwidth, C_{LOAD} = 20 µF, I_{ISO} = 80 mA. The measurements were done near to the load, away from the ISOW7841 power output pins.

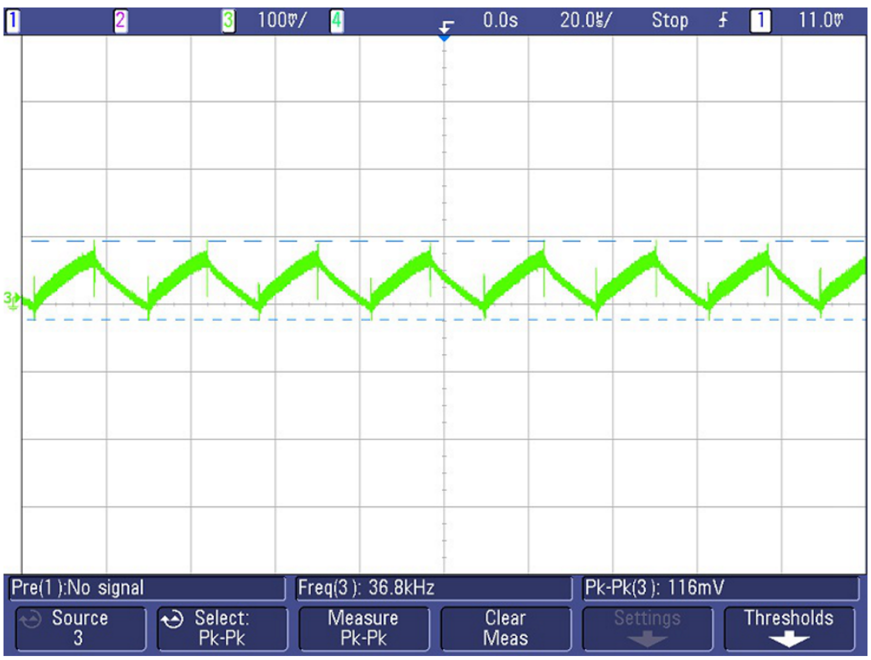

Figure 11. ISOW7841 DC Output Ripple

4.2.4 ISOW7841 Input Switching Current

Figure 12 shows the input switching current measured for DC input current of 160 mA. The input voltage applied is 3.3-V DC.

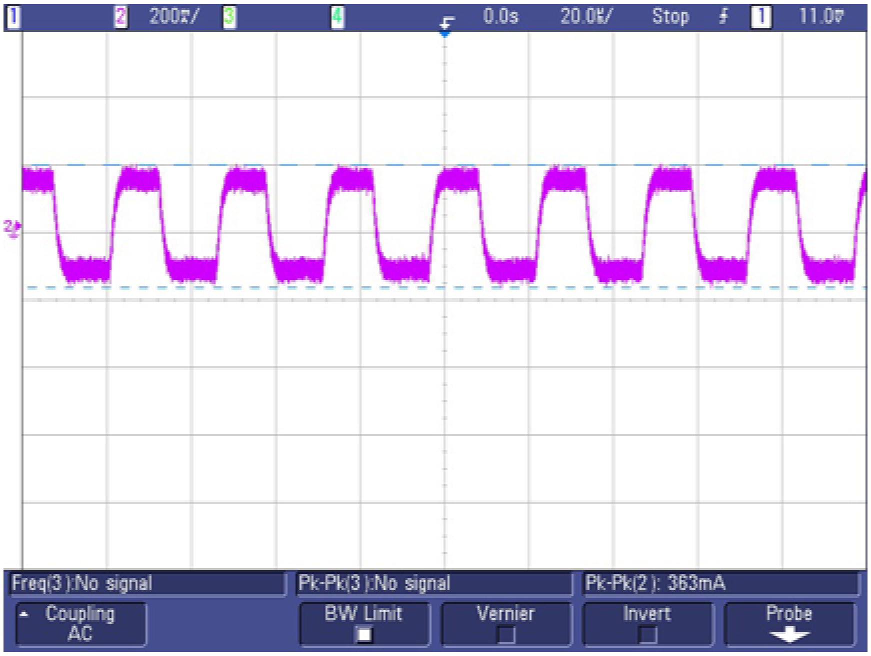

Figure 12. Input Switching Current for 75-mA Output Loading

4.2.5 ISOW7841 Hotspot Monitoring

The output of the ISOW7841 was loaded for 80 mA and the hotspot was monitored after 30 minutes. Figure 13 shows the hotspot measurements on the ISOW784x evaluation module.

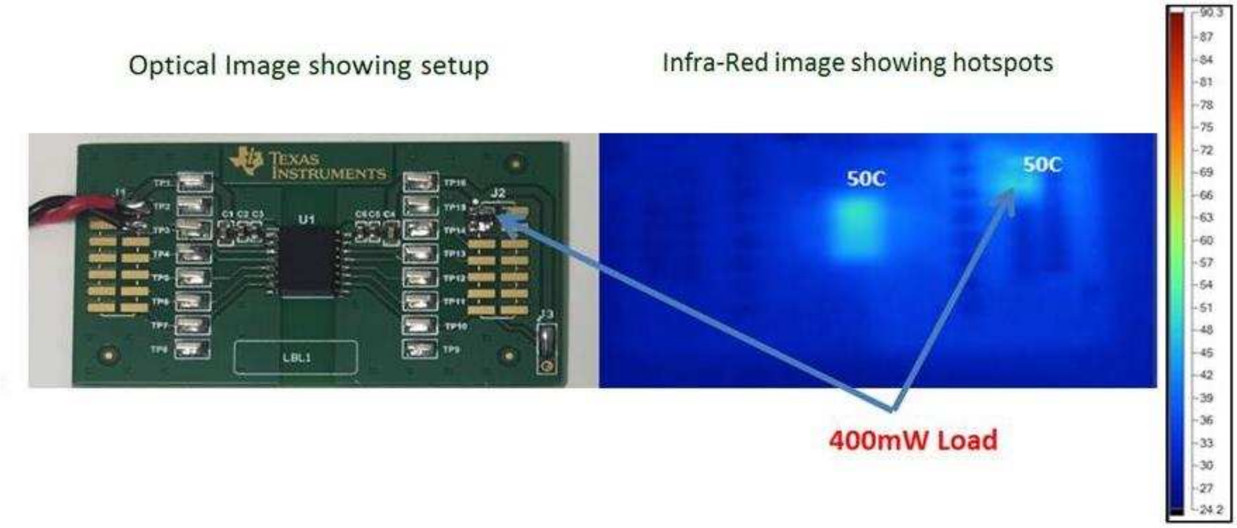

Figure 13. ISOW7841 Hotspot Capture With 80-mA Load

4.3 Performance Testing

This section provides information on the performance tests that are performed on the BIM.

4.3.1 Voltage Measurement Accuracy

NOTE: The reading in Table 20 is the measurements taken without any calibration. The accuracy can be improved by introducing software calibration. The errors observed can be further improved by doing a gain calibration. To ensure that the results are less than ±3.0% of measured value ±1 V (programmable step size), applying gain calibration is recommended. The gain calibration can be applied on the host side or BIM side.

4.3.1.1 Error in % of Measured Value for AC/DC BIM

Table 20 summarizes the accuracy performance for different configuration of BIMs with different gains for AC or DC inputs.

Table 20. Measurement Accuracy for AC/DC BIM

VOLTAGE INPUT (V)	INPUT TYPE	GAIN	A0 AND A3	A4 AND A1
15 to 48	AC, 50 Hz	High gain × 3.4	Within ±1.5% ±1 V	Within ±1.5% ±1 V
48 to 276		Low gain × 1	Within ±1.5% ±1 V	Within ±1.5% ±1 V
15 to 48	DC	High gain × 3.4	Within ±1.5% ±1 V	Within ±1.5% ±1 V
48 to 320		Low gain × 1	Within ±1.5% ±1 V	Within ±1.5% ±1 V

Figure 14 provides the DC measurement for the four ADC inputs configured to measure DC inputs with two gains.

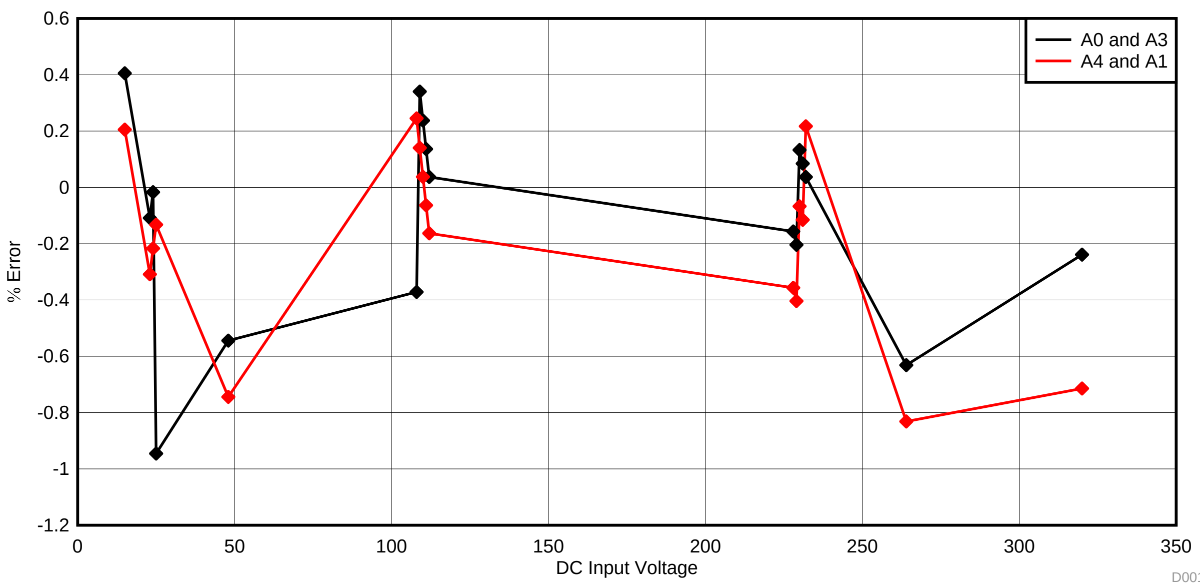

Figure 14. DC Input Voltage versus % Error of Measured Value Plot

4.3.1.2 Error in % of Measured Value for DC BIM

Table 21 summarizes the accuracy performance for BIM with different combinations for digital isolators and MCUs.

Table 21. Measurement Accuracy for DC BIM

MODULE TYPE	MEASUREMENT ACCURACY FOR INPUT CHANNELS			
	CH1	CH2	CH3	CH4
DC BIM with MSP430G2332 and ISOW7841	Within ±1.2% ±1 V	Within ±1.2% ±1 V	Within ±1.2% ±1 V	Within ±1.2% ±1 V
DC BIM with MSP430G2332 and ISO7741	Within ±1.2% ±1 V	Within ±1.2% ±1 V	Within ±1.2% ±1 V	Within ±1.2% ±1 V
DC BIM with MSP430FR2111 and ISOW7841	Within ±1.5% ±1 V	Within ±1.2% ±1 V	Within ±1.2% ±1 V	Within ±1.2% ±1 V

4.3.2 Wetting Current Measurement

The wetting current required for binary inputs are generated using a fixed resistor and PWM control. The short time overload withstand capability of the resistors are used during generation of wetting current. Table 22 provides the current measured with duty cycle changed.

Table 22. Wetting Current Measurement at Different Voltage Inputs (DC Only)

DC VOLTAGE (V SWITCHED FOR 50 ms)	IMPEDANCE (kΩ)	INPUT 1 CURRENT (mA)	DUTY CYCLE	INPUT 2 CURRENT (mA)	DUTY CYCLE
24	2.5	≈ 9	N/A	≈ 9	N/A
110		≈ 44	N/A	≈ 44	N/A
230		≈ 44	50%	≈ 44	50%

4.3.3 Digital Isolator Functional Testing Using SPI

After the MSP430G2332 starts up, there is a 3- to 5-second initial delay before the MCU starts accepting packets from the MSP430FR5969. During this delay, the LED should be turned off for this entire duration. Also, the watchdog is disabled during this time interval. Once the initial delay has passed, the watchdog and communication to the MSP430FR5969 is enabled. The watchdog is cleared whenever a packet is received from the MSP430FR5969. If the time interval between successive packets received by the MSP430G2332 is greater than 660 ms, then the watchdog would restart the MSP430G2332.

For the communication, the MSP430FR5969 sends a one-character packet to the MSP430G2332 once every 50 ms using a 500-kbps SPI clock. The value of the actual character sent is equal to the value of the previous character sent incremented by 1. Every time the MSP430FR5969 sends a packet to the MSP430G2332, the state of the green LED2 on the MSP430FR5969 LaunchPad™ is toggled.

Once the MSP430G2332 receives a packet, it toggles the P2.4 pin, connected to an LED on the board. The MSP430G2332 would then echo the packet received from the MSP430FR5969 back to the MSP430FR5969. Whenever a packet is received from the MSP430G2332, the MSP430FR5969 verifies if the packet has the expected value. If the packet has the expected devalue, LED1 on the LaunchPad would toggle its state.

To connect the proper SPI pins from the MSP430FR5969 LaunchPad to the MSP430G2332, the FET emulation jumpers had to be removed. As a result, for programming the MSP430FR5969, the TI FET tool was used instead of the direct USB connection option. The following pins on the MSP430FR5969 LaunchPad were used for connecting to MSP430G2332 P1.5 of MSP430FR5969 LaunchPad to P1.5 (SCLK, pin 7) of MSP430G2332. TXD on the emulation header of the MSP430FR5969 LaunchPad to P1.7 (SDI, pin 15) of the MSP430G2332. RXD of the emulation header of the MSP430FR5969 LaunchPad to P1.6 (SDO, pin 14) of the MSP430G2332.

4.3.3.1 MSP430FR5969 LaunchPad

The MSP-EXP430FR5969 LaunchPad Development Kit is an easy-to-use MCU development board for the MSP430FR5969 MCU. It contains everything needed to start developing quickly on the MSP430FRxx FRAM platform, including onboard emulation for programming, debugging, and energy measurements. The board features onboard buttons and LEDs for integration of a simple user interface. The MSP430FR5969 MCU features embedded FRAM, a non-volatile memory known for its ultra-low-power, high endurance, and high-speed write capabilities (see the MSP-EXP430FR5969 product page).

4.4 EMC Pre-Compliance Testing

The following EMC tests listed in Table 23 were performed.

Table 23. EMC Tests

TESTS	PORTS	STANDARDS
ESD	Binary input terminals	IEC61000-4-2
Surge	Binary input terminals	IEC61000-4-5
EFT	Binary input terminals	IEC61000-4-4
Immunity to radio frequency induced signals	Binary input terminals	IEC 61000-4-6
Ring wave immunity	Binary input terminals	IEC 61000-4-12
Damped oscillatory waves immunity	Binary input terminals	IEC 61000-4-18

Table 24 provides information on the different criteria use to indicate the performance of the device under test.

Table 24. Performance Criteria

CRITERIA	PERFORMANCE (PASS) CRITERIA
A	The module must continue to operate as intended. No loss of function or performance even during the test.
B	Temporary degradation of performance is accepted. After the test, the module must continue to operate as intended without manual intervention.
C	During the test, loss of functions accepted, but no destruction of hardware or software. After the test, the module must continue to operate as intended automatically, after manual restart, or power off/power on.

4.4.1 Note on Performance Testing

The following voltages were applied to the BIM for testing:

- Power supply for BIM operation: 3.3 to 3.6 V
- Binary input for measurement: 30-V DC

Performance testing procedure: To test the BIM performance, a 10-kHz clock was generated by the MCU, the output was connected to the ISOW7841/ISO7741 input, and the output of the isolator was looped back to three inputs or the ISOW7841 or ISO interfaced to the MCU. The MCU blinks an LED if it receives back the pulse. On power up, the module clock is off and the clock is generated by applying a sequence of input to the ISOW7841 digital input.

4.4.2 Power Supply Connection

Depending on the test performed, the power was connected to the host side of the ISOW7841 as shown in Table 25.

Table 25. Power Supply Connection

TESTS	TEST PORT	POWER SOURCE	COMMENTS
IEC61000-4-2	Binary inputs	Battery source regulated to 3.6 V	Test 1: ESD power earth was referenced to GND1
IEC61000-4-4, IEC61000-4-5	Binary inputs	DC voltage source (table top) 3.45 V	EFT and surge generator power earth was referenced to GND1
IEC61000-4-6,	Binary inputs	Battery source regulated to 3.6 V	Test equipment influences DC power supply (source) performance
IEC61000-4-12, IEC61000-4-18	Binary inputs	Battery source regulated to 3.6 V	Ring wave generator power earth was referenced to GND1
EN55022 CE and RE	Binary inputs	Battery source regulated to 3.6 V	Looking for emission from the BIM only

4.4.3 IEC61000-4-2 ESD Test

The IEC610004-2 electrostatic discharge (ESD) test simulates the electrostatic discharge of an operator directly onto an adjacent electronic component. An electrostatic charge usually develops in low relative humidity and on low-conductivity carpets or vinyl garments. The capacity of the body can be charged to several kilovolts and is discharged when contact is made with an electronic unit or system. The discharges are harmless to humans, but not too sensitive, electronic equipment. The resulting currents cause interference or even component damage.

The test conditions are as follows:

- Five positive and five negative pulses
- Contact discharge

Table 26. ESD Test Observations for ISOW7841

TEST STANDARD	TEST VOLTAGE (kV)	OBSERVATION 2-CHANNEL AC/DC	OBSERVATION 4-CHANNEL DC	OBSERVATION 4-CHANNEL DC_FRAM
IEC61000-4-2	2	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A
IEC61000-4-2	4	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A
IEC61000-4-2	6	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A
IEC61000-4-2	8	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A
IEC61000-4-2	9	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A

NOTE: The same was tested with the ISO7741 for all of these conditions. The performance test as per Section 4.4.1 was done before, during, and after the tests and there was no change in performance.

4.4.4 IEC61000-4-4 EFT Test

Industrial measurement and control equipment nearly always use conventional control units containing relays or other electro-mechanical switching devices. Fluorescent lamp ballast units and insufficiently suppressed motors (hair dryers, vacuum cleaners, drills, and so on) are found everywhere in the public power supply.

The test conditions are as follows:

- EFT, DM
- 5 and 100 kHz
- 1 minute
- Positive and negative

Table 27. EFT Test Observations for ISOW7841

TEST STANDARD	TEST VOLTAGE (kV)	OBSERVATION 2-CHANNEL AC/DC	OBSERVATION 4-CHANNEL DC	OBSERVATION 4-CHANNEL DC_FRAM
IEC61000-4-4	1.0	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A
IEC61000-4-4	2.0	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A
IEC61000-4-4	2.5	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A

NOTE: The same was tested with the ISO7741 for all of these conditions. The performance test as per Section 4.4.1 was done before, during, and after the tests and there was no change in performance.

4.4.5 IEC61000-4-5 Surge Test

Surge events are generated by lightning phenomena, switching transients, or protection devices in the power distribution system. A surge is influenced by the propagation path resulting in different forms depending upon where a measurement is taken. Combination wave generators (CWG) simulate a surge event in power lines close to or within buildings.

The test conditions are as follows:

- DM
- positive and negative polarity
- 5 pulses

Table 28. Surge Test Observations for ISOW7841

TEST STANDARD	TEST VOLTAGE (kV)	OBSERVATION 2-CHANNEL AC/DC	OBSERVATION 4-CHANNEL DC	OBSERVATION 4-CHANNEL DC_FRAM
IEC61000-4-5	1.0	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A
IEC61000-4-5	2.0	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A
IEC61000-4-5	2.5	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A

NOTE: The same was tested with the ISO7741 for all of these conditions. The performance test as per Section 4.4.1 was done before, during, and after the tests and there was no change in performance.

4.4.6 IEC61000-4-6 Conducted Susceptibility

This test is defined as a product's relative ability to withstand electromagnetic energy that penetrates it through external cables, power cords, input/output (I/O) interconnects, or chassis. In order to verify immunity, electromagnetic energy in the frequency range of 150 kHz to 80 MHz is induced into the product through each cable and interconnect and the product is expected to operate within the set criteria. The upper limit of the frequency range can go up to 100 MHz depending on the applicable standard.

The test conditions are as follows:

- 10-V EMF at 1-kHz 80% am
- 150 kHz to 80 MHz
- Dwell time of 0.5 seconds every 1 seconds

Table 29. Conducted Susceptibility Test Observations for ISOW7841

TEST STANDARD	DWELL TIME (SEC)	OBSERVATION 2-CHANNEL AC/DC BIM	OBSERVATION 4-CHANNEL DC BIM
IEC61000-4-6	0.5	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A
IEC61000-4-6	1.0	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A

NOTE: The same was tested with the ISO7741 for all of these conditions. The performance test as per Section 4.4.1 was done before, during, and after the tests and there was no change in performance.

4.4.7 IEC61000-4-12 and IEC61000-4-18 Ring Wave and Damped Sine Wave

The ring wave (non-repetitive) appears at the terminals of equipment as a consequence of switching in power and control lines, as well as a consequence of lightning. The ring wave test is applicable to equipment connected to AC mains. The damped oscillatory wave (repetitive) appears at the terminals of equipment as a consequence of switching with restriking of the arc. The damped oscillatory wave test is applicable to equipment used in high-voltage substations (static relays). But with a frequency of 1 MHz only, this test has existed for a long time under IEC 255-4, appendix E5: High frequency disturbance test, also known as ANSI/IEEE C.37.90a-1989, and has been transferred to IEC 60255-22-1: Electrical disturbance tests for measuring relays and protection equipment (1-MHz burst disturbance tests).

Table 30 provides the observation for ring wave tests done at different test levels. The test conditions are as follows:

- DM 100 kHz
- 40 pulses per second positive and negative polarity
- Pulses applied for 2 seconds every 10 seconds
- Test duration of 1 minute positive and negative polarity

Table 30. Ring Wave Test Observations for ISOW7841

TEST STANDARD	TEST VOLTAGE (kV)	OBSERVATION 2-CHANNEL AC/DC	OBSERVATION 4-CHANNEL DC
IEC61000-4-12	0.5	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A
IEC61000-4-12	1.0	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A
IEC61000-4-12	2.0	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A

Table 31 provides the observation for damped sine wave tests done at different test levels. The test conditions are as follows:

- DM 1 MHz ± 10% 1 MHz
- 400 pulses per second
- Positive and negative polarity
- Pulses applied for 2 seconds every 10 seconds

Table 31. Damped Sine Wave Test Observations for ISOW7841

TEST STANDARD	TEST VOLTAGE (kV)	OBSERVATION 2-CHANNEL AC/DC	OBSERVATION 4-CHANNEL DC
IEC61000-4-18	0.5	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A
IEC61000-4-18	1.0	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A
IEC61000-4-18	2.0	Passed. No power supply droops. Meets Criteria A	Passed. No power supply droops. Meets Criteria A

NOTE: The same was tested with the ISO7741 for all of these conditions. The performance test as per Section 4.4.1 was done before, during, and after the tests and there was no change in performance.

4.5 EMI Pre-Compliance Testing as per CISPR 22

Conducted emission measures any signals generated by equipment that appear on its power supply port and which can, therefore, be conducted into the power supply, and potentially disturb other ship's equipment. Radiated emission measures any signals radiated by equipment that can potentially disturb other equipment. For radiated emission testing, a common-mode filter was connected at the 3.3-V DC input of the ISOW7841 BIM. The power supply was connected using wires, and hence a common-mode filter was used. Figure 15 provides the conducted emission plots for average and quasi-peak emission as per CISPR 22.

Figure 15. Conducted Emission Plot for ISOW7841-Based BIM

Figure 16 provides the radiated emission plots for quasi-peak emission as per CISPR 22.

Figure 16. Radiated Emission Plot for ISOW7841-Based BIM at 3 m

Table 32 summarizes the conducted and radiated emission test observations for different configurations of BIMs and digital isolators.

Table 32. Conducted Emission Test and Radiated Emission Observations for ISOW7841

TEST CONDITION	STANDARD	LIMIT	OBSERVATION 2-CHANNEL AC/DC	OBSERVATION 4-CHANNEL DC	OBSERVATION 4-CHANNEL DC_FRAM	OBSERVATION 4-CHANNEL DC WITH ISO7741
0.15 to 0.50 MHz, Class A	CISPR 22, CE	< 79 dB(µV) quasi peak	Meets Class B emission requirements by > 10 dB(µV)	Meets Class B emission requirements by > 10 dB(µV)	Meets Class B emission requirements by > 10 dB(µV)	Meets Class B emission requirements by > 10 dB(µV)
0.5 to 30 MHz, Class A	CISPR 22, CE	< 73 dB(µV) quasi peak	Meets Class B emission requirements by > 10 dB(µV)	Meets Class B emission requirements by > 10 dB(µV)	Meets Class B emission requirements by > 10 dB(µV)	Meets Class B emission requirements by > 10 dB(µV)
30 to 230 MHz, Class A measured at 3 meters	CISPR 22, RE	< 50 dB(µV/m) quasi peak	Meets Class A emission requirements by > 10 dB(µV)	Meets Class A emission requirements by > 10 dB(µV)	Meets Class A emission requirements by > 10 dB(µV)	Meets Class B emission requirements by > 10 dB(µV)
230 to 1000 MHz, Class A measured at 3 meters	CISPR 22, RE	< 57 dB(µV/m) quasi peak	Meets Class A emission requirements by > 10 dB(µV)	Meets Class A emission requirements by > 10 dB(µV)	Meets Class A emission requirements by > 10 dB(µV)	Meets Class B emission requirements by > 10 dB(µV)

NOTE: Radiated emission was tested with horizontal and vertical antenna polarization. The performance test as per Section 4.4.1 was done before, during, and after the tests and no change in performance was observed.

4.6 *Test Results Summary for BIMs*

Table 33 summarizes the test done on the BIM and observations. The BIM measures the DC voltage or AC voltage input accurately and also meets pre-compliance standard requirements for EMC tests as per IEC60000-4 series and CISPR 22 Class A.

Table 33. Test Results Summary

TEST	OBSERVATION
Power supply: ISOW7841 output	OK
Transformer drive-based power supply output	OK
MCU programming: MSP430G2332 or MSP430FR2111	OK
Wetting current for AC/DC type binary input module	OK
Gain and reference stage performance	OK
AC/DC input voltage measurement accuracy	OK
DC voltage measurement accuracy	OK
Digital isolator functional performance	OK
IEC6-1000-4-2	Pass
IEC6-1000-4-4	Pass
IEC6-1000-4-5	Pass
IEC6-1000-4-6	Pass
IEC6-1000-4-12	Pass
IEC6-1000-4-18	Pass
EN55022 CE Class A and Class B	Pass
EN55022 RE Class A	Pass

5 Design Files

5.1 Schematics

To download the schematics, see the design files at TIDA-00847.

5.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00847.

5.3 PCB Layout Recommendations

5.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-00847.

5.4 Altium Project

To download the Altium project files, see the design files at TIDA-00847.

5.5 Gerber Files

To download the Gerber files, see the design files at TIDA-00847.

5.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-00847.

6 Related Documentation

1. Texas Instruments, *EMC Compliant, Isolated, 2-Channel Binary or Digital Input Module for Wide AC/DC Input Reference Design*, TIDA-00809 Design Guide (TIDUBY6)
2. Texas Instruments, *EMC-Compliant Digitally Isolated 2-Channel, Wide DC Binary Input Module*, TIDA-00420 Design Guide (TIDU858)

6.1 Trademarks

7 Terminology

BIM— Binary input module

MCU— Microcontroller unit

AC — Alternating current

DC — Direct current

CE— Conducted emission

RE— Radiated emission

8 About the Authors

KALLIKUPPA MUNIYAPPA SREENIVASA is a systems architect at Texas Instruments where he is responsible for developing reference design solutions for the industrial segment. Sreenivasa brings to this role his experience in high-speed digital and analog systems design. Sreenivasa earned his bachelor of engineering (BE) in electronics and communication engineering (BE-E&C) from VTU, Mysore, India.

AMIT KUMBASI is a systems architect at Texas Instruments Dallas where he is responsible for developing subsystem solutions for Grid Infrastructure within Industrial Systems. Amit brings to this role his expertise with defining products, business development, and board level design using precision analog and mixed-signal devices. He holds a master's in ECE (Texas Tech) and an MBA (University of Arizona).

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

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

- Deleted LMV551 from Resources 1
- Added SN6501 from Resources 1
- Changed MCU name from MSP430G2111 to MSP430FR2111 throughout design 7
- Changed MCU name from MSP430FR2332 to MSP430G2332 throughout design guide 8
- Added CE to Section 7 40
- Added RE to Section 7 40

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