Design Guide: TIDA-010247

High-Side N-MOSFET Control (Up to 32s) Battery Pack Reference Design With Stacked Battery Monitor

TEXAS INSTRUMENTS

Description

This reference design is a high-side, N-channel MOSFET control (up to 32s) battery pack, using the stacked BQ769x2 battery monitor family. This design monitors each cell voltage, pack current, cell and MOSFET temperature and protects the battery pack for secure safe use. High-side N-channel MOSFET architecture and optimized driving circuits provide easy switch control. This reference design achieves low stand-by and ship-mode consumption and optimizes the current gaps between two groups. This reference design is for high-cell-count, high-voltage, battery-pack applications.

Resources

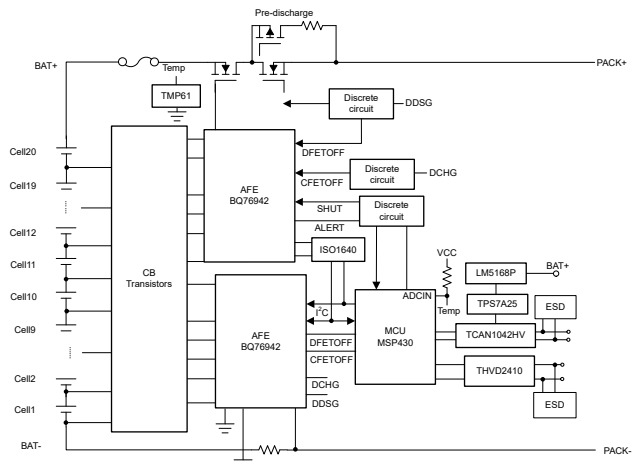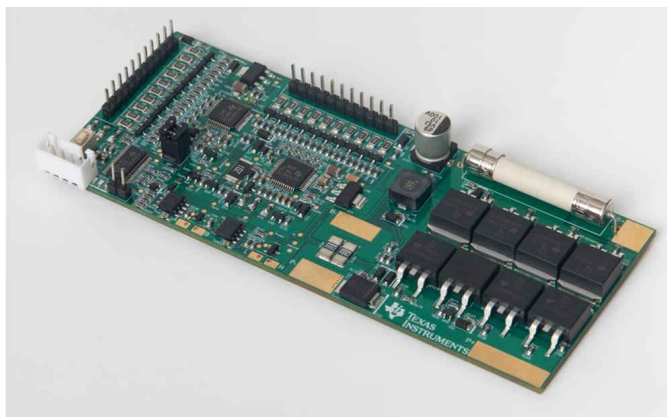|	
TIDA-010247	Design Folder
BQ76942, LM5168	Product Folder
ISO1640, TCAN1042HV	Product Folder
THVD2410, MSP430FR2155	Product Folder
TPS7A25, TM61, TPD2E007	Product Folder

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Features

- 300-µA consumption in standby mode
- 10-µA consumption in ship mode
- ±5-mV voltage accuracy at 25°C without calibrations
- Robust and programmable battery cell and system protections
- Reverse charger and high voltage on PACK side
- High-side N-channel MOSFETs and strong driving capability

Applications

- Battery pack: e-bike, e-scooter, light electric vehicle (LEV)
- Other industrial battery pack (>=10S)
- Portable power station
- Battery energy storage system

1 System Description

Because of the weight limit and longer endurance needs, the battery cell chemistry of the e-motorcycle, light electric vehicles, and garden tools battery packs is shifting from Lead-acid to Li-ion, Li-polymer, or Li-ion phosphate (LiFePO4) types and the pack voltage is shifting from 36 V or 48 V to 60 V or 72 V, or even higher. These battery chemistries are good in both volumetric and gravimetric energy density. While these battery chemistries provide high energy density and thereby lower volume and weight as an advantage, these battery products are associated with safety concerns and have a need for more accurate and complicated monitoring and protections. Those concerns are cell undervoltage (CUV) and cell overvoltage (COV), overtemperature (OT), both overcurrent in charge (OCC) and discharge (OCD), and short-circuit discharge (SCD), all of which contribute to the accelerating cell degradation and can lead to thermal runaway and explosion. Therefore, the pack current, cell temperature, and each cell voltage must be monitored in a timely manner in case of unusual situations. The battery pack must be protected against all these situations. Good measurement accuracy is always required, especially the cell voltage, pack current, and cell temperature. Precision is necessary for accurate protections and battery pack state of charge (SoC) calculations. This is especially true for LiFePO4 battery pack applications because of the flat voltage. Another important feature for battery-powered applications is the current consumption, especially when in ship mode or standby mode. Lower current consumption saves more energy and gives longer storage time without over-discharging the battery.

This design with two stacked BQ769x2 battery monitors to cover up to 32s battery cells, focuses on 60 V and higher e-motorcycle battery pack applications and is also designed for other high-cell applications, such as a mowing robot and garden tool battery pack, energy storage system battery packs, UPS battery packs, and so forth. The design contains full set protection to protect the battery pack against all unusual situations including: cell overvoltage, cell undervoltage, overtemperature, overcurrent in charge and discharge, and short-circuit discharge. With high-side MOSFET control, normal communication outside is allowed even during faults and MOSFETs in the off status. This design has carefully formed the auxiliary power architecture, which achieves an ultra-low ship mode (10 µA) and standby mode (300 µA) current consumption with a limited number of components and simple control strategy. Furthermore, the design gives optimization ideas to match the current within stacked groups.

2 System Overview

2.1 Block Diagram

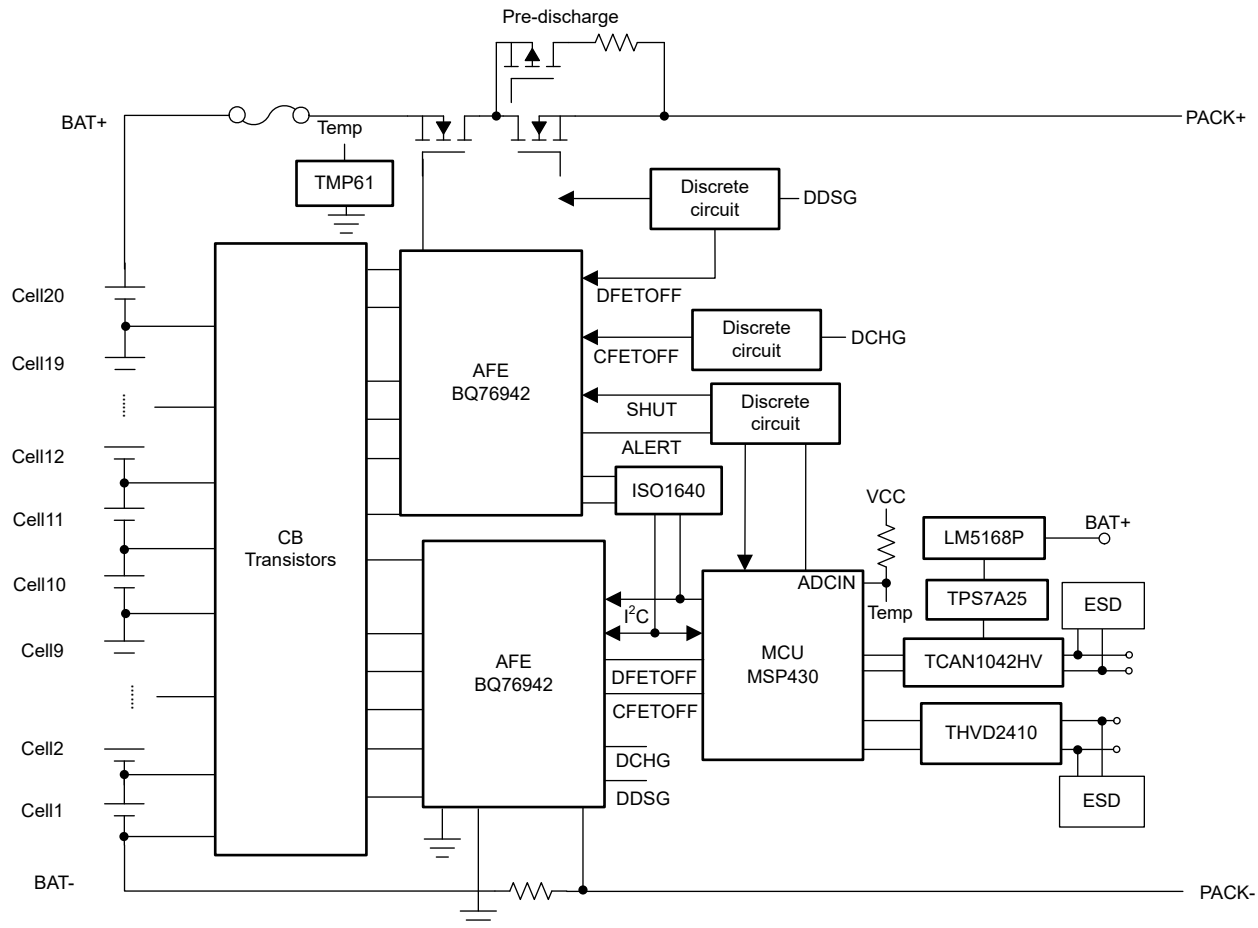Figure 2-1 shows the system block diagram.

Figure 2-1. TIDA-010247 Block Diagram

The design uses two stacked high-accuracy battery monitor and protector BQ769x2 devices from TI to monitor up to 32 series battery cells voltage, pack current and temperature data, and protect the battery pack from all unusual situations, including: COV, CUV, OT, OCD, OCC, and SCD. This BQ769x2 family has three devices: BQ76942 to cover 3s to 10s applications, BQ769142 to cover up to 14s applications, and the BQ76952 to cover up to 16s applications. These are pin-to-pin devices, so updating the design to match different battery cell applications with a limited number of component changes is easy. This design used the BQ76942 for tests.

There is a lower-power MSP430™ MCU MSP430FR2155 which communicates with both BQ76942 devices, deals with all system control strategies, and uploads all the requested information to the system side. Since the top BQ76942 references the top battery group as ground which is not the same ground with the MCU, isolation is required in the communication between the MCU and the top BQ76942. The ISO164x, a hot swappable, low-power, bidirectional isolated I2C interface, supports the stable isolated I^2C communication.

This design has both an RS-485 transceiver and a CAN transceiver. The CAN transceiver TCAN1042HV integrates level translation via the VIO terminal to allow for interfacing the transceiver I/Os directly to 1.8-V, 2.5-V, 3.3-V, or 5-V logic I/Os. The TCAN1042HV has ±70-V bus fault protection which is good enough to cover 60-V battery packs for light e-motorcycle. Since the MSP430FR2155 does not have an integrated CAN controller, CAN communication is not supported by this design. The THVD2410 is a half-duplex RS485 transceiver supporting a single 3-V to 5.5-V supply and designed for both 3.3-V and 5-V MCUs. The THVD2410 also supports ±70-V fault protection. This design uses a 120-V input, 0.3-A, ultra-low I_Q synchronous buck DC/DC converter LM5168 with a low I_Q, 18-V, 300-mA LDO TPS7A25 as the auxiliary power. A ±1%, 10-kΩ linear

thermistor with positive temperature coefficient and 0603 package TMP61 is utilized to monitor the MOSFET temperature and is measured by the MCU ADC.

2.2 Design Considerations

2.2.1 Auxiliary Power Strategy

With the requests of low current consumption in standby mode and ship mode and good thermal performance in normal mode, this design uses the auxiliary power strategy shown in Figure 2-2.
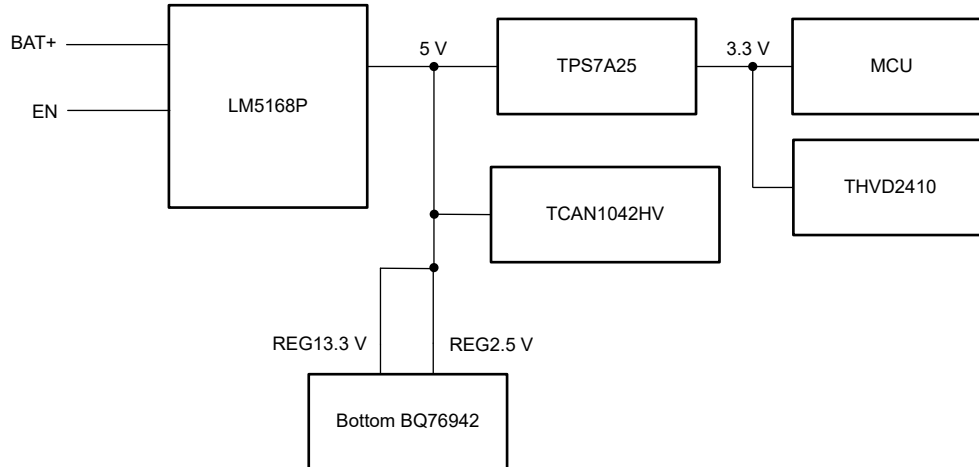

Figure 2-2. Auxiliary Power Strategy

The design has a 120-V input, 0.3-A, ultra-low I_Q synchronous buck DC/DC converter LM5168P with a low I_Q 0.3-A LDO TPS7A25 as the main power source when the system is working in normal mode which requires hundreds of mA with normal CAN or RS-485 communications with the system side, giving the system better efficiency and thermal performance than LDOs only. The bottom BQ76942 regulator REG2 is configured to 5-V output which is the power source when the system is working in standby mode. The series diode on the BQ76942 regulator output makes sure all power is from the DC/DC converter in normal mode preventing the BQ76942 regulator circuits from overheating, so design the DC/DC output a little higher than 5 V, BQ76942 regulator output. Detailed component design guidance is available from the *LM5169 Quick Start Calculator*. When the system experiences a serious cell undervoltage and must enter ship mode, the MCU configures both of the BQ76942 devices to enter shutdown mode through an I2C command or RST_SHUT PIN and turns off the LM5168P output through the EN pin, which configures the system to very low current consumption mode. This design supports both charger attach and system attached wake up functions. Both methods wake up the bottom BQ76942 device and enable normal 3.3-V regulator REG1, then the MCU is powered on and enables the LM5168P through the EN pin. The whole system then returns to normal mode.

To cover 20s battery systems, two stacked BQ76942 devices are used to monitor cell voltage and temperature. Avoiding imbalance between the two stacked groups is important for longer lifetime. Although cell balancing is useful to balance all battery cells voltage equally, the best way is to avoid too much load gap between two groups. In this design, ISO1640, an isolated I2C interface, is used for communications between the MCU and top BQ76942 device. Small supply current gap between VCC1 and VCC2 of ISO1640 benefits the system. Another option is to use TI reinforced digital isolator with integrated power ISOW77xx to replace ISO1640 and powered from DC/DC.

2.2.2 High-Side N-Channel MOSFET

This design supports high-side N-channel MOSFET architecture and uses top the BQ76942 charge pump to drive the MOSFETs. Since the top BQ76942 references the top of the bottom stack for cell voltage measurement, when the top BQ76942 turns DSG MOSFET off, the voltage on the DSG pin of the top BQ76942 is the bottom stack voltage, which is too high to completely turn the DSG MOSFET off. This reference design adds some discrete components to make sure the DSG MOSFET turns off completely and quickly.

When DSG MOSFETs need to be off, the MCU or the bottom BQ76942 device turns on Q47. P-channel MOSFET Q48 is turned on to discharge Vgs of DSG MOSFET. The top BQ76942 drives TOP_DSG towards TOP_LD to turn off Q41, allowing Dri_Test to ground and turn off DSG MOSFET completely. When DSG

MOSFET is off, Q47 is able to turn off to save power. When the system needs to turn on DSG MOSFET, the system first makes sure Q47 is off and then drives TOP_DSG with the charge pump voltage, Q40 is on and charges Vgs of DSG MOSFET.

2.2.3 Stacked AFE Communication

To cover a 16s battery cell system or greater, two BQ769x2 devices can be cascaded to monitor up to 32s battery cells. This design tests two BQ76942 devices to monitor up to 20s battery cells for 60-V and 72-V battery packs. The bottom BQ76942 monitors the lower 10s battery cells and the top BQ76942 monitors the upper 10s battery cells, so the bottom BQ76942 shares the same ground with BAT– and MCU while the top BQ76942 references 10s stack voltage. Adding isolation is required when communicating with the top BQ76942 device or a discrete level shifter can be used here. This design uses an I2C isolator, ISO164x, for up to 400-kHz I2C communication baud rate and low power consumption. While using the discrete level shifter is acceptable for other signals like ALERT, RST_SHUT, DFETOFF, CFETOFF, and so forth, since these signals are not acting frequently. MCU issues commands and reads voltage, current, temperature date from the bottom BQ76942 directly and through ISO164x when communicating with the top BQ76942.

For the faults in the upper 10s battery cells, the top BQ76942 detects the faults and drives MOSFET off directly. The MCU can be made aware through ALERT or reading status registers and turn on Q47, to make sure DSG MOSFET is completely off. For the faults in lower 10s battery cells and current faults, the bottom BQ76942 detects them and informs the top BQ76942 to drive MOSFET off. For slow protections, like COV, CUV, OT, UT, OCD1, OCD2, alerting the MCU is acceptable when faults are triggered and the MCU then issues a command to turn off MOSFETs. While for short-circuit protections, which normally requires μs delay time, it is not fast enough if leveraging MCU firmware for the protections. This design adds discrete circuits to allow the bottom BQ76942 device to control MOSFET directly with the top BQ76942 device, avoiding further protection delay caused by MCU firmware.

2.3 Highlighted Products

2.3.1 BQ76942

The TI BQ76942 is a highly-integrated, high-accuracy battery monitor and protector for 3-series to 10-series Li-ion, Li-polymer, and LiFePO4 battery packs. The device includes a high-accuracy monitoring system, a highly-configurable protection subsystem, and support for autonomous or host-controlled cell balancing. Integration includes high-side charge-pump NFET drivers, dual-programmable LDOs for external system use, and a host communication peripheral supporting 400-kHz I2C, SPI, and HDQ one-wire standards. The BQ76942 is available in a 48-pin TQFP package.

2.3.2 LM5168

The LM5169 and LM5168 synchronous buck converters are designed to regulate over a wide input voltage range, minimizing the need for external surge suppression components. A minimum controllable on time of 50 ns facilitates large step-down conversion ratios, enabling the direct step-down from a 48-V nominal input to low-voltage rails for reduced system complexity and design cost. The LM516x operates during input voltage dips as low as 6 V, at nearly 100% duty cycle if needed, making the device an excellent choice for wide input supply range industrial and high cell count battery pack applications. With integrated high-side and low-side power MOSFETs, the LM5169 delivers up to 0.65-A of output current and the LM5168 delivers up to 0.3-A of output current. A constant on-time (COT) control architecture provides nearly constant switching frequency with excellent load and line transient response. The LM516x is available in FPWM or auto mode versions. FPWM mode provides forced CCM operation across the entire load range supporting isolated fly-buck converter applications. Auto mode enables ultra-low I_Q and diode emulation mode operation for high light-load efficiency.

2.3.3 ISO1640

The ISO1640, ISO1641, ISO1642, ISO1643 and ISO1644 (ISO164x) devices are hot-swappable, low-power, bidirectional isolators that are compatible with I2C interfaces. The ISO164x supports UL 1577 isolation ratings of 5000 V_{RMS} in the 16-DW package, and 3000 V_{RMS} in the 8-D package. Each I2C isolation channel in this low emissions device has a logic input and open drain output separated by a double capacitive silicon dioxide (SiO2) insulation barrier. The ISO1642 and ISO1643 integrates two unidirectional CMOS isolation channels, while the ISO1644 integrates three unidirectional CMOS isolation channels which can be used for static GPIO isolation or to isolate a Serial Peripheral Interface (SPI) bus. This family includes basic and reinforced insulation devices certified by VDE, UL, CSA, TUV and CQC. The ISO1640, ISO1642, ISO1643, and ISO1644 have two isolated

bidirectional channels for clock and data lines and the ISO1641 has a bidirectional data and a unidirectional clock channel. The ISO164x family integrates logic required to support bidirectional channels, providing a much simpler design and smaller footprint when compared to optocoupler-based designs.

2.3.4 TCAN1042HV

This CAN transceiver family meets the ISO11898-2 (2016) High-Speed CAN (Controller Area Network) physical layer standard. All devices are designed for use in CAN FD networks up to 2Mbps (megabits per second). Devices with part numbers that include the "G" suffix are designed for data rates up to 5Mbps, and versions with the "V" have a secondary power supply input for I/O level shifting the input pin thresholds and RXD output level. This family has a low-power standby mode with remote wake request feature. Additionally, all devices include many protection features to enhance device and network robustness.

2.3.5 THVD2410

The THVD2410 and THVD2450 devices are ±70-V fault-protected, half-duplex, RS-422, RS-485 transceivers operating on a single 3-V to 5.5-V supply. Bus interface pins are protected against overvoltage conditions during all modes of operation providing robust communication in rugged industrial environments. These devices feature integrated IEC ESD protection, eliminating the need for external system-level protection components. Extended ±25-V input common-mode range provides reliable data communication over longer cable run lengths or in the presence of large ground loop voltages. Enhanced 250-mV receiver hysteresis provides high noise rejection. In addition, the receiver fail-safe feature provides a logic high when the inputs are open or shorted together. THVD24x0 devices are available in small VSSOP and VSON packages for space-constrained applications. These devices are characterized over ambient free-air temperatures from –40°C to 125°C.

2.3.6 TPS7A25

The TPS7A25 low-dropout (LDO) linear voltage regulator introduces a combination of a 2.4-V to 18-V input voltage range with very-low quiescent current (I_Q). These features help modern appliances meet increasingly stringent energy requirements, and help extend battery life in portable-power designs. The TPS7A25 is available in both fixed and adjustable versions. For more flexibility or higher output voltages, the adjustable version uses feedback resistors to set the output voltage from 1.24 V to 17.64 V. Both versions have a 1% output regulation accuracy that provides precision regulation for most microcontroller (MCU) references. The TPS7A25 LDO operates more efficiently than standard linear regulators because the maximum dropout voltage is less than 340 mV at 300 mA of current. This maximum dropout voltage allows for 92.5% efficiency from a 5.4-V input voltage (V_{IN}) to a 5.0-V output voltage (V_{OUT}). The power-good (PG) indicator can be used to either hold an MCU in reset until power is good, or for sequencing. The PG pin is an open-drain output; therefore, the pin is easily level-shifted for monitoring by a rail other than V_{OUT}. The built-in current limit and thermal shutdown help protect the regulator in the event of a load short or fault. For a higher output current alternative, consider the TPS7A26.

2.3.7 MSP430FR2155

The MSP430FR215x microcontroller (MCUs) is part of the MSP430TM MCU value line portfolio of ultra-low-power low-cost devices for sensing and measurement applications. The device includes a 12-channel, 12-bit ADC and two comparators. The MSP430FR215x supports an extended temperature range from –40° up to 105°C, so higher temperature industrial applications can benefit from the FRAM data-logging capabilities of the device. The extended temperature range allows developers to meet requirements of applications such as smoke detectors, sensor transmitters, and circuit breakers. The MSP430FR215x features a powerful 16-bit RISC CPU, 16-bit registers, and a constant generator that contribute to maximum code efficiency. The digitally-controlled oscillator (DCO) allows the device to wake up from low-power modes to active mode typically in less than 10 µs. The MSP430 ultra-low-power (ULP) FRAM microcontroller platform combines uniquely embedded FRAM and a holistic ultra-low-power system architecture, allowing system designers to increase performance while lowering energy consumption. FRAM technology combines the low-energy fast writes, flexibility, and endurance of RAM with the nonvolatile behavior of flash. MSP430FR215x is supported by an extensive hardware and software ecosystem with reference designs and code examples to get your design started quickly.

2.3.8 TMP61

The Thermistor Design Tool, offers complete resistance vs temperature table (RT table) computation, and other helpful methods to derive temperature and example C-code. The TMP61 linear thermistor offers linearity and consistent sensitivity across temperature to enable simple and accurate methods for temperature conversion. The low power consumption and a small thermal mass of the device minimizes the impact of self-heating. With built-in fail-safe behaviors at high temperatures and powerful immunity to environmental variation, these devices are designed for a long lifetime of high performance. The small size of the TMP6 series also allows for close placement to heat sources and quick response times. Take advantage of benefits over NTC thermistors such as no extra linearization circuitry, minimized calibration, less resistance tolerance variation, larger sensitivity at high temperatures, and simplified conversion methods to save time and memory in the processor. The TMP61 is currently available in a 0402 footprint-compatible X1SON package, a 0603 footprint-compatible SOT-5X3 package, and a 2-pin through-hole TO-92S package.

2.3.9 TPD2E007

This device is a transient-voltage suppressor (TVS) based electrostatic discharge (ESD) protection device designed to offer system-level ESD protections for a wide range of portable and industrial applications. The back-to-back diode array allows AC-coupled or negative-going data transmission (audio interface, LVDS, RS-485, RS-232, and so forth) without compromising signal integrity. This device exceeds the IEC 61000-4-2 (Level 4) ESD protection and is designed for providing system-level ESD protection for the internal ICs when placed near the connector. The TPD2E007 is offered in 4-bump PicoStar and 3-pin SOT (DGK) packages. The PicoStar package (YFM), with only 0.15 mm (maximum) package height, is recommended for ultra space-saving applications where the package height is a key concern. The PicoStar package can be used in either embedded PCB board applications or in surface mount applications. The industry standard SOT package offers straightforward board layout option in legacy designs.

3 Hardware, Software, Testing Requirements, and Test Results

The key performances of the TIDA-010247 were tested in a TI lab, the end equipment used and test processes and results are described in this section.

Table 3-1 describes the connections for TIDA-010247 board.

Table 3-1. Board Connections

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
BAT+	BAT+	Cell stack positive
BAT–	BAT–	Cell stack negative; this provides a reference for the electronics and the high current path from the cells
PACK+	PACK+	Charger positive or load positive
PACK-	PACK–	Charger negative or load negative
P1-1	3V3	SBW program connector 3.3 V
P1-2	SBCLK	SBW program connector SBCLK
P1-3	SBIO	SBW program connector SBIO
P1-4	GND	SBW program connector ground
P2-1	SCL	I2C communication SCL from bq76942, connect SCL_MCU or EV2400 SCL
P2-2	SCL_MCU	I2C communication SCL from MCU
P2-3	SDA	I2C communication SDA from bq76942, connect SDA_MCU or EV2400 SDA
P2-4	SDA_MCU	I2C communication SDA from MCU
P3	Cn	(n = 0 to 10) Cell monitor, balance, and electronics power connections. Bottom 10 series cells
P4	Cn	(n = 0 to 10) Cell monitor, balance, and electronics power connections. Top 10 series cells
P5-1	CAN-L	Low-level CAN BUS
P5-2	CAN-H	High-level CAN BUS
P6-1	RS485-A	RS485 Bus I/O port, A
P6-2	RS485-B	RS485 Bus I/O port, B
P7-1	DET	Charger and load detect IO
P7-2	GND	Charger and load detect IO ground

3.1 Hardware Requirements

Table 3-2 summarizes the equipment used for testing.

Table 3-2. Test Equipment Summary

EQUIPMENT	MODEL OR DESCRIPTION
Oscilloscope	Tektronix DPO 2024B
DC power supply	Chroma 62050P-100-100
Electronic load	Chroma 63106
Multimeter	Agilent 34401A
DC power supply	GW INSTEK GPS-3303C
Communication adapter	Texas Instruments EV2300 or EV2400
MSP430 programmer	MSP430 LaunchPad™
ESD simulator	NoiseKen ESS-S3011

The *Battery Management Studio (bqStudio) Software* is recommended when debugging the board for the first time.

3.2 Test Setup

Use the following procedures before running this design board. The design was constructed with 20S pack configurations. The board was tested using DC source and 4900-µF electrolytic capacitor in parallel to simulate the total pack. Twenty 1-kΩ resisters in series are used to divide the pack voltage and simulate 20s battery cells.

- DC source 1 configurations: 72 V – 3 A
- DC source 2 configurations: two channel 30 V – 0.5 A
- Electronic load configurations: 60-V constant voltage (CV) mode

Figure 3-1 shows the charge process setup example.
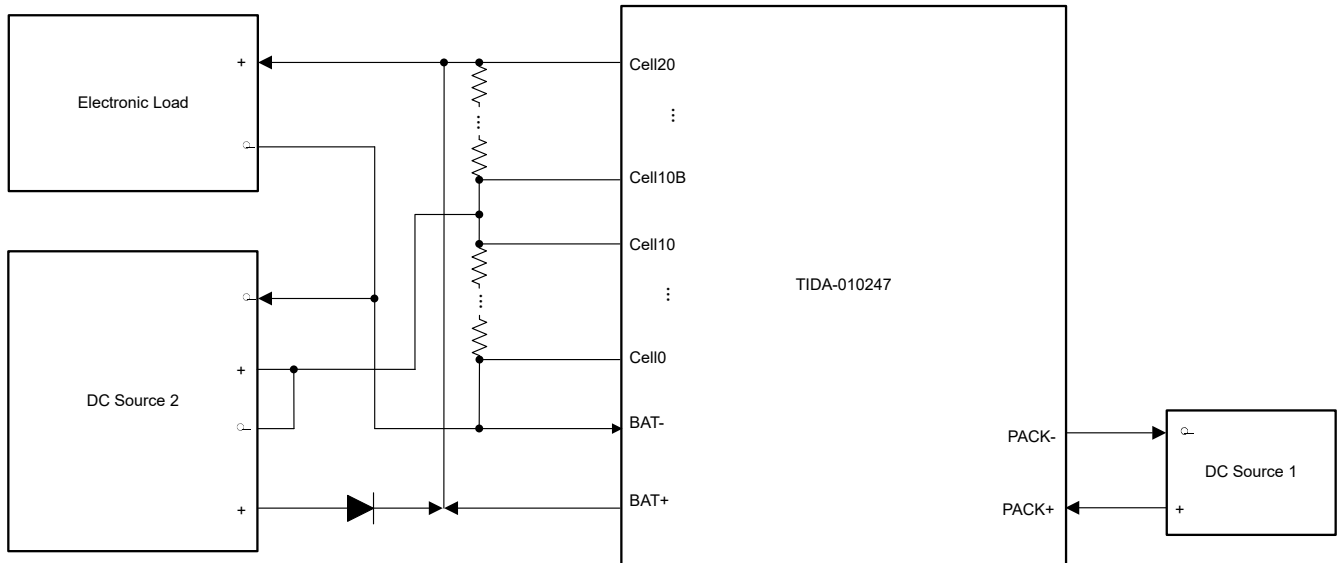
Figure 3-1. Charge Setup

Figure 3-2 shows the discharge process setup example using the following conditions.

- DC source configurations: 60 V – 20 A
- Electronic load configurations: constant current (CC) mode
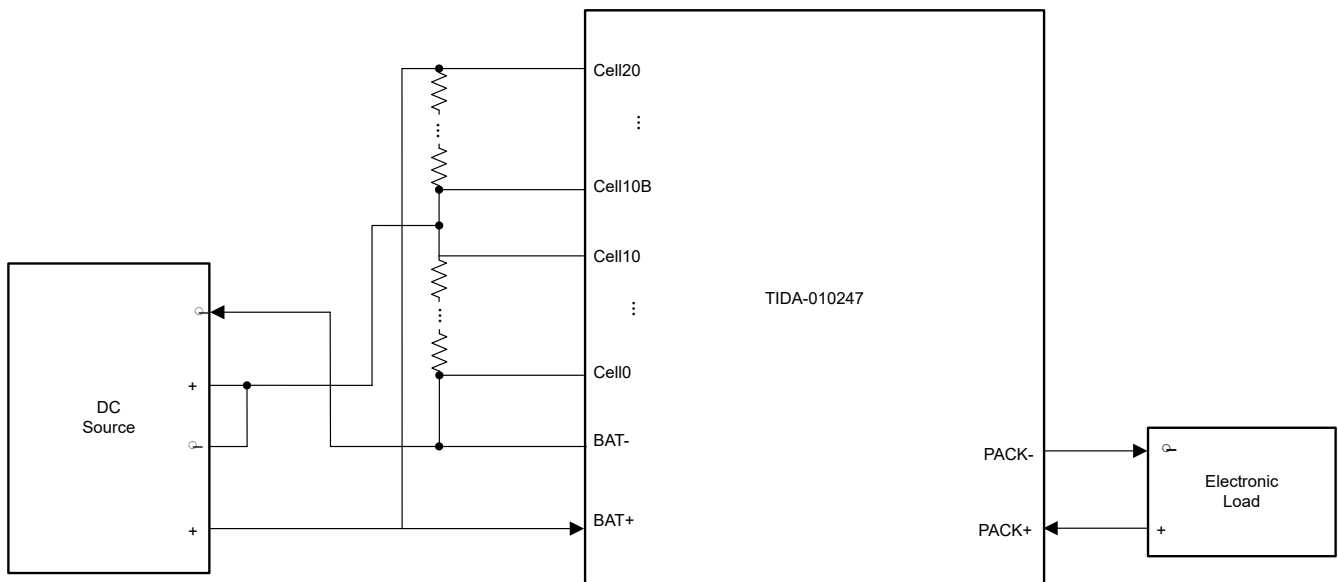
Figure 3-2. Discharge Setup

3.3 Test Results

3.3.1 Cell Voltage Accuracy

This design does not do any calibrations to further improve the cell voltage accuracy since the BQ76942 already achieves ±5-mV accuracy at 25°C and ±10-mV accuracy from 0°C to 60°C. The cell voltage accuracy is exactly the same with the BQ76942. For more data see the *BQ76942 3-Series to 10-Series High Accuracy Battery Monitor and Protector for Li-Ion, Li-Polymer, and LiFePO₄ Battery Packs* data sheet.

3.3.2 Pack Current Accuracy

This design uses four 2-mΩ, 2-W, 50-PPM shunt resisters in parallel to measure pack current. The board offset was calibrated using the guidance of the *Calibration* section of the *BQ76942 Evaluation Module* user's guide. Then current gain was calibrated with 5-A discharging current and also followed the guidance of the *Calibration* section of the *BQ76942 Evaluation Module*. Write the *board offset and current gain* values with one-time-programmable (OTP) to the bottom BQ76942, otherwise the MCU has to store such data and write to the bottom BQ76942 every time the device wakes up from shutdown mode. Figure 3-3 shows the pack current accuracy data under room temperature. The maximum current error is below ±30 mA when the discharging current is below 5 A and ±0.5% when the discharging current is above 5 A.
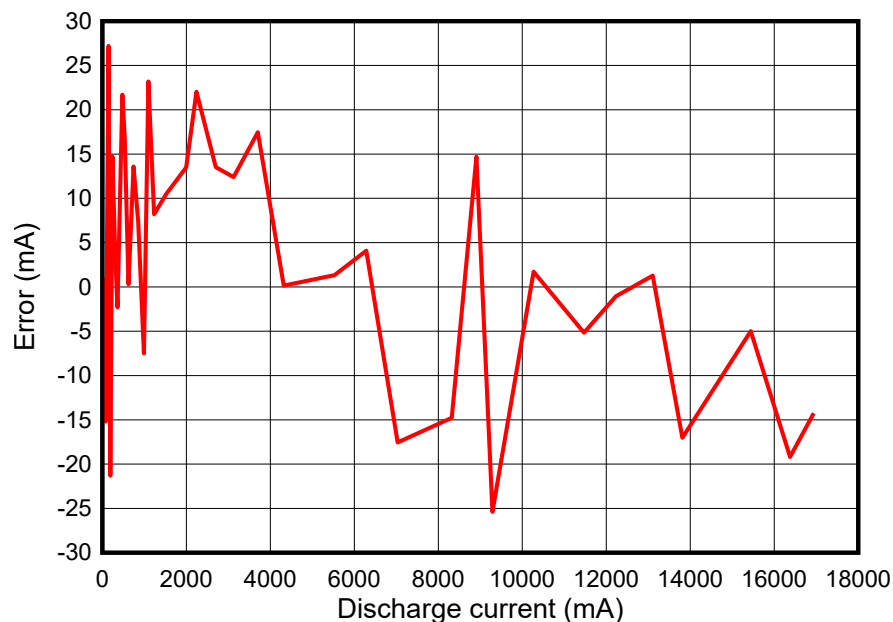
Figure 3-3. Pack Current Accuracy

3.3.3 Auxiliary Power and System Current Consumption

Due to the auxiliary power strategy, this design has very low current consumption, especially when in standby mode and ship mode. Because of the stacked architecture, the total system consumption is the maximum value of current out of the top stack and current back to the battery negative port. Current out of the top stack can be measured from the voltage across R218 and current back to the battery negative port is measured with a current meter.

Furthermore, the current consumption gaps between two stacked groups are optimized in this design to avoid further cell balancing between groups. If the groups current is exactly the same, no current is experienced into or out of cell10. Figure 3-4 shows the setup to test current consumption and Table 3-3 shows the test results of average system current consumption and average group imbalance current.
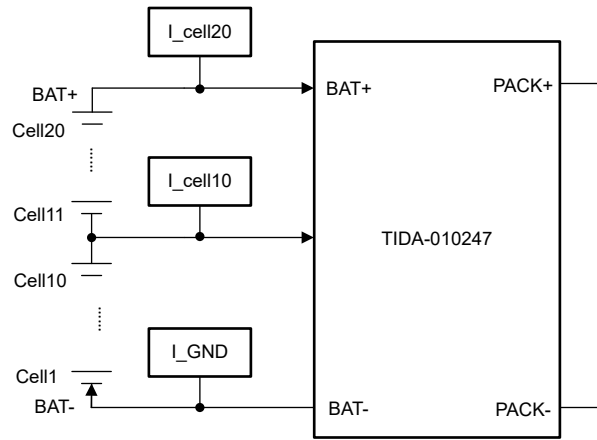
Figure 3-4. Current Consumptions Test Setup

Table 3-3. Current Consumption

DESCRIPTION		I_{cell20}	I_{cell10}	I_{GND}	CURRENT GAP (µA)	TOTAL CURRENT (µA)
Standby Mode (MOSFET off)	Current (µA)	131	46	177	46	177
Standby Mode (MOSFET on)	Current (µA)	273	-6	261	12	273
Ship Mode	Current (µA)	9	0	9	0	9

The *INA229_239EVM* and a 10-Ω resister is used to test the current. The total current consumption is less than 300 µA in standby mode with both charge and discharge MOSFETs either on or off. The imbalance between groups is less than 50 µA. The ship mode current consumption is less than 10 µA.

Auxiliary power start-up is tested and illustrated in Figure 3-5.
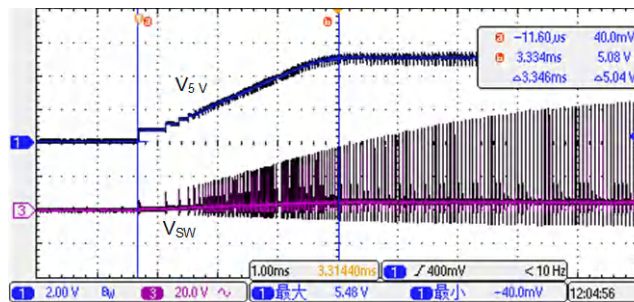
Figure 3-5. DC/DC Start-Up

This design also considers the faults of DC/DC output short circuited. Figure 3-6 shows the DC/DC short circuit test results. DC/DC is disabled by the MCU when output is short circuited to prevent thermal issues.
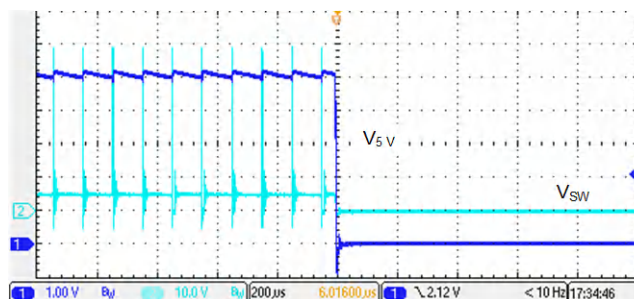
Figure 3-6. DC/DC Output Short Circuit

3.3.4 Protection

The design integrates a full set of battery cell protections, including: cell overvoltage, cell undervoltage, two levels of overcurrent discharge, overcurrent charge, discharge short circuit, and overtemperature and undertemperature protections. Furthermore, this design also monitors lots of system-level faults, including: cell open wire, host watch dog, charge and discharge MOSFETs faults, MOSFETs overtemperature, and so on. Some of the protections were tested in a TI lab.
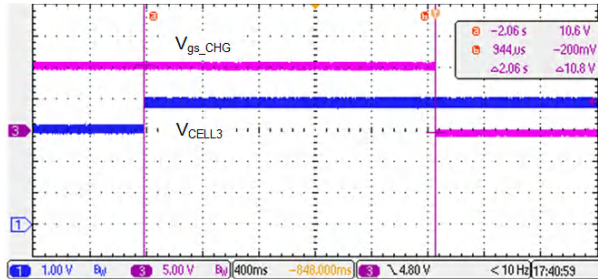
Figure 3-7. Cell Overvoltage Protection
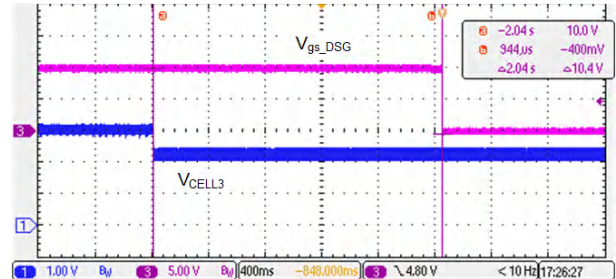
Figure 3-8. Cell Undervoltage Protection
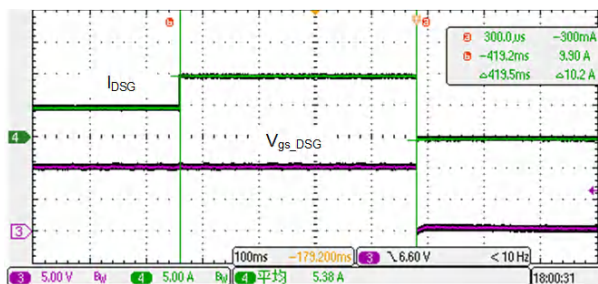
Figure 3-9. Overcurrent Discharge Protection
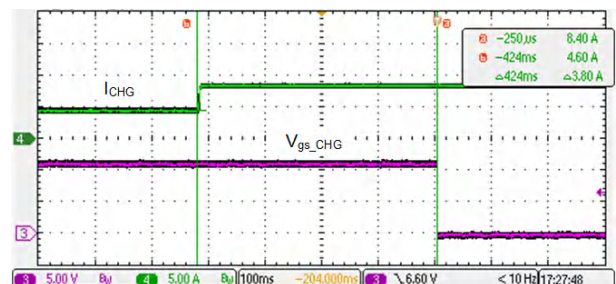
Figure 3-10. Overcurrent Charge Protection
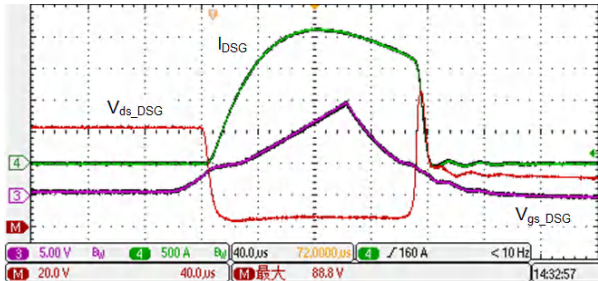
Figure 3-11. Short-Circuit Discharge Protection
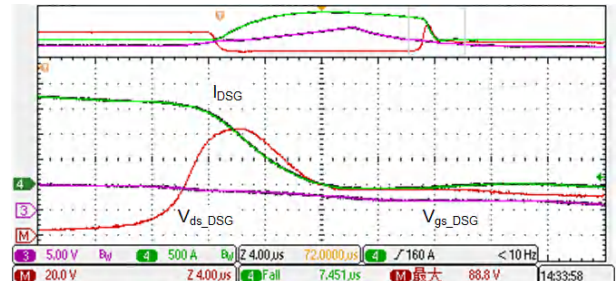
Figure 3-12. Short-Circuit Discharge Protection - MOSFET Off
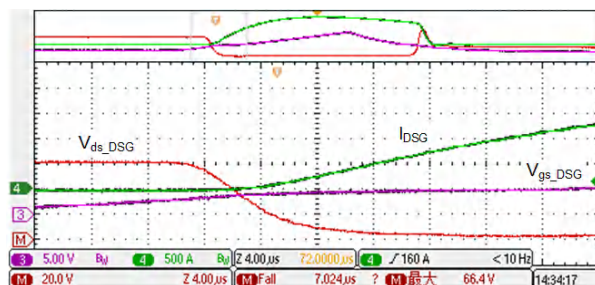
Figure 3-13. Short-Circuit Discharge Protection - MOSFET On

The short circuit discharge protections are tested with the following processes:

1. Both charge and discharge MOSFET are off with DET floating
2. PACK port shorted together with air switch
3. Turn on both charge and discharge MOSFET on with DET connected
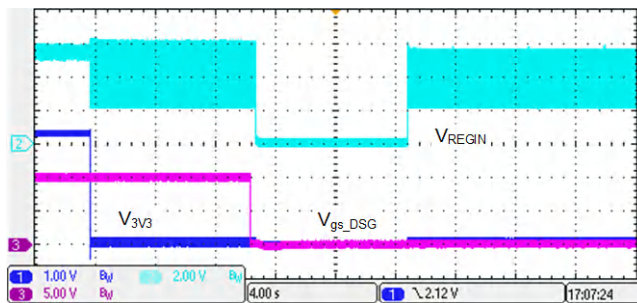
Figure 3-14. 3.3-V Short and HWD Protections

When 3.3 V is shorted, the MCU is powered off and both BQ76942 devices detect HWD after some delay. Since TIDA-010247 configures MCU wake up from entering lower power mode (no communication with the BQ76942 to save power) every 5s, observe a range of 5s to 10s delay with 10s HWD delay configurations.
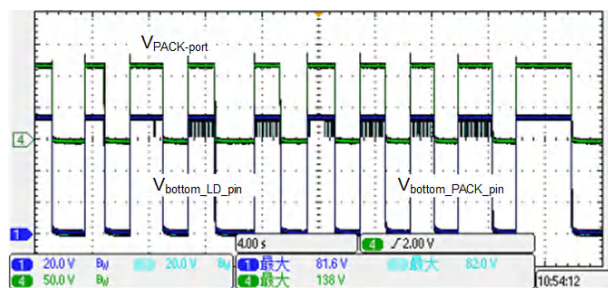

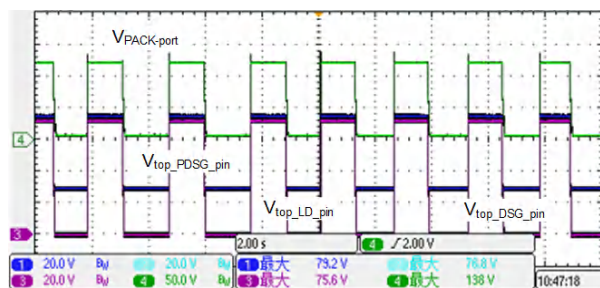**Figure 3-15. 120 V On-PACK Port – Bottom AFE Maximum Voltage**

Figure 3-16. 120 V On-PACK Port – Top AFE Maximum Voltage

The 120-V on PACK port test is carried out with both CHG and DSG MOSFET off with DET floating.

3.3.5 Working Modes Transition

This design has three working modes: normal mode, standby mode, and ship mode. When the pack is charging or discharging, the pack is in normal mode. Sleep mode is when there is no charging nor discharging, the pack is waiting for a charger or load attachment. Shutdown mode is a very low current consumption mode which saves energy and helps to avoid battery over discharge when the pack or cell voltage is low. Figure 3-17 shows different working mode transitions.
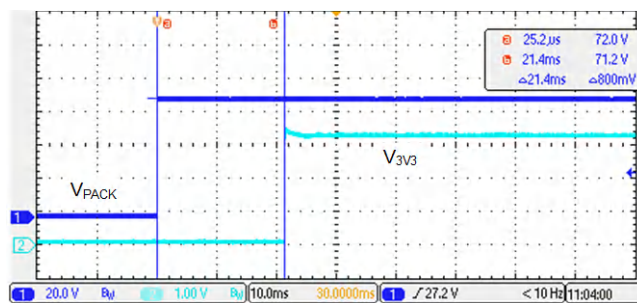
Figure 3-17. Ship Mode to Normal Mode

When TIDA-010247 is in ship mode and both BQ76942 devices are in shutdown mode. The bottom BQ76942 detects charger attached on PACK side and wakes up to normal mode, enabling REG1 or REG2 to power on the MCU.

3.3.6 ESD Performance

The ESD performance of this design was tested in a TI lab per IEC 61000 - 4 - 2. Isolated DC source and a resister divider are used to simulate a battery pack. ESD contact discharge was tested and the test results are listed in Table 3-4.

Table 3-4. ESD - Contact Discharge

VOLTAGE	APPLIED TERMINAL					
	PACK+	PACK–	CANH	CANL	RS485A	RS485B
2 kV	PASS	PASS	PASS	PASS	PASS	PASS
–2 kV	PASS	PASS	PASS	PASS	PASS	PASS
4 kV	PASS	PASS	PASS	PASS	PASS	PASS
–4 kV	PASS	PASS	PASS	PASS	PASS	PASS
8 kV	PASS	PASS	PASS	PASS	PASS	PASS
–8 kV	PASS	PASS	PASS	PASS	PASS	PASS

4 Design and Documentation Support

4.1 Design Files

4.1.1 Schematics

To download the schematics, see the design files at TIDA-010247.

4.1.2 BOM

To download the bill of materials (BOM), see the design files at TIDA-010247.

4.2 Tools and Software

Tools

EV2400	USB-based PC interface board for battery fuel (gas) gauge evaluation module
LM5169 Quick Start Calculator	LM5163 and LM5164 converter quickstart design tool
BQ769X2-THERMISTOR-COEFF-CALCULATOR	BQ76952, BQ76942 thermistor temperature optimizer - calculate the thermistors coefficients for T range
INA229_239EVM	INA229 and INA239 evaluation module

Software

BQSTUDIO	Battery Management Studio (bqStudio) Software
CCSTUDIO	Code Composer Studio™ integrated development environment (IDE)

4.3 Documentation Support

1. Texas Instruments, *BQ76942 3-Series to 10-Series High Accuracy Battery Monitor and Protector for Li-Ion, Li-Polymer, and LiFePO4 Battery Packs* data sheet
2. Texas Instruments, *BQ769x2 Calibration and OTP Programming Guide* application note
3. Texas Instruments, *How to stack battery monitors for high-cell-count industrial applications* E2E™ forum
4. Texas Instruments, *Using DC/DC Buck Converters With Ultra-Low Quiescent Current for Industrial Battery-Pack Applications* application brief

4.4 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

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4.5 Trademarks

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5 About the Author

Ryan Tan, system manager from the SEM Industrial Grid Infrastructure and Power Delivery team, focuses on battery pack and energy storage system applications and has created several designs to address industrial battery pack design challenges.

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