

5s–7s Battery Pack Reference Design With Low-Side MOSFET Control



Description

This reference design is a high cell voltage accuracy 5s–7s Lithium-ion (Li-ion), Lithium Iron phosphate (LiFePO4) battery pack design. The design monitors each cell voltage, pack current, cell and metal-oxide semiconductor field-effect transistor (MOSFET) temperature with high accuracy and protects the Li-ion, LiFePO4 battery pack against cell overvoltage, cell undervoltage, overtemperature, charge and discharge overcurrent and discharge short-circuit situations. The product adopts low-side N-channel MOSFET architecture and has strong driving on and off capability. These features make this reference design highly applicable for power tools and vacuum cleaner battery pack applications.

Resources

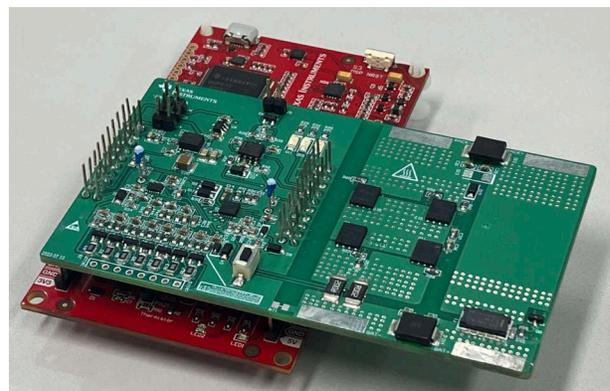
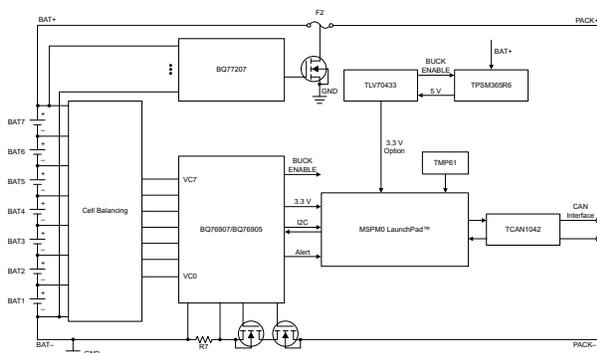
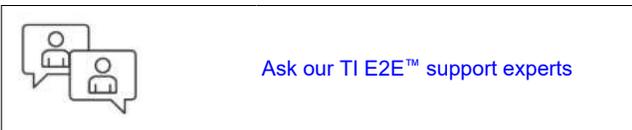
TIDA-010268	Design Folder
BQ76905, BQ76907	Product Folder
MSPM0L1106, TPSM365R6V5	Product Folder
TCAN1042HV	Product Folder
TLV704, TMP61	Product Folder

Features

- Battery pack designed for 5–7 cell Li-ion or LiFePO4 based, 30-A maximum continuous discharge current (BQ76905 and BQ76907 can support as low as 2 cells, with reasonable changes, this design can also support a minimum of 2-cell application)
- Monitors cell voltages, pack current, pack temperatures, balances cells, and protects by controlling charge or discharge FETs
- Hardware protection for overcurrent in discharge, short circuit in discharge, overvoltage, and undervoltage
- Robust battery cell protection with secondary protection: cell overvoltage, cell undervoltage, and overtemperature
- Ultra-small footprint, low on-resistance, low Qg and Qgd MOSFETs onboard for low-side MOSFET control
- Low quiescence current, ultra-low power state for shipment

Applications

- [Battery pack: cordless power tool](#)
- [Battery pack: vacuum cleaner, robot](#)
- [Other industrial battery pack \(1s-9s\)](#)



1 System Description

The battery packs of power and garden tools are increasingly using Li-ion, Li-polymer, or Li-iron phosphate cell types. This chemistry is good in both volumetric and gravimetric energy density. While this chemistry provides high energy density and thereby lower volume and weight as an advantage, the chemistries are associated with safety concerns and need 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 need to be monitored in a timely manner in case of some 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 focuses on battery pack applications for power tools or garden tools and is also an excellent choice for other 5–7-cell applications, such as vacuum cleaner battery pack. The design contains both primary and secondary protections to provide safe use of the battery pack. The primary protection protects the battery pack against all unusual situations, including: cell overvoltage, cell undervoltage, overtemperature, overcurrent in charge and discharge, and short-circuit discharge. The secondary protection supports independent cell overvoltage protection, open wire protection, and overtemperature protection. This design can achieve within ± 5 - mV cell voltage measurement accuracy at 25°C and ± 10 mV at 0°C to 60°C without any further calibrations.

1.1 Key System Specifications

Table 1-1. Key System Specifications

PARAMETER	CONDITIONS	SPECIFICATION RANGE			UNIT
		MIN	TYP	MAX	
Cell architecture	BQ76907	3		7	Series
	BQ76905	3		5	Series
Cell balancing peak current	Cell voltage: 4000 mV		64		mA
Charge current				30	A
Discharge current				30	A
Cell Voltage accuracy	25°C			± 5	mV
	0°C–60°C			± 10	mV
Pack current accuracy	< 2 A				mA
	> 2 A				%
Primary OV protection	Threshold		4200		mV
	Delay		2		s
Secondary OV protection	Threshold		4325		mV
	Delay		1		s
Primary UV protection	Threshold		2530		mV
	Delay		2		s
OCD protection - level 1	Threshold		10		A
	Delay	0.46		1103.795	ms
OCD protection - level 2	Threshold		30		A
	Delay	0.46		1103.795	ms
OCC protection	Threshold		10		A
	Delay	0.46		1103.795	ms

Table 1-1. Key System Specifications (continued)

PARAMETER	CONDITIONS	SPECIFICATION RANGE			UNIT
		MIN	TYP	MAX	
SCD protection	Threshold		100		A
	Delay	8	300	8112	μs
Overtemperature protection	Charge		55		°C
	Discharge		60		°C
Undertemperature protection	Charge		0		°C
	Discharge		-20		°C
Shutdown mode current consumption for total design			2		μA

WARNING

TI intends this reference design to be operated in a lab environment only and does not consider the board to be a finished product for general consumer use.

TI Intends this reference design to be used only by qualified engineers and technicians familiar with the risks associated with handling high-voltage electrical and mechanical components, systems, and subsystems.

Hot surface! Contact can cause burns. **Do not touch!** Some components can reach high temperatures > 55°C when the board is powered on. Do not touch the board at any point during operation or immediately after operating, because high temperatures can be present.

CAUTION

Do not leave the design powered when unattended.

2 System Overview

2.1 Block Diagram

The reference design has the following sub-blocks:

- Primary protection device and low-side FET circuit
- Cells Balance circuit and secondary protection device
- Microcontroller (MCU) and controller area network (CAN) communication device circuit
- DCDC and low dropout (LDO) for additional power module

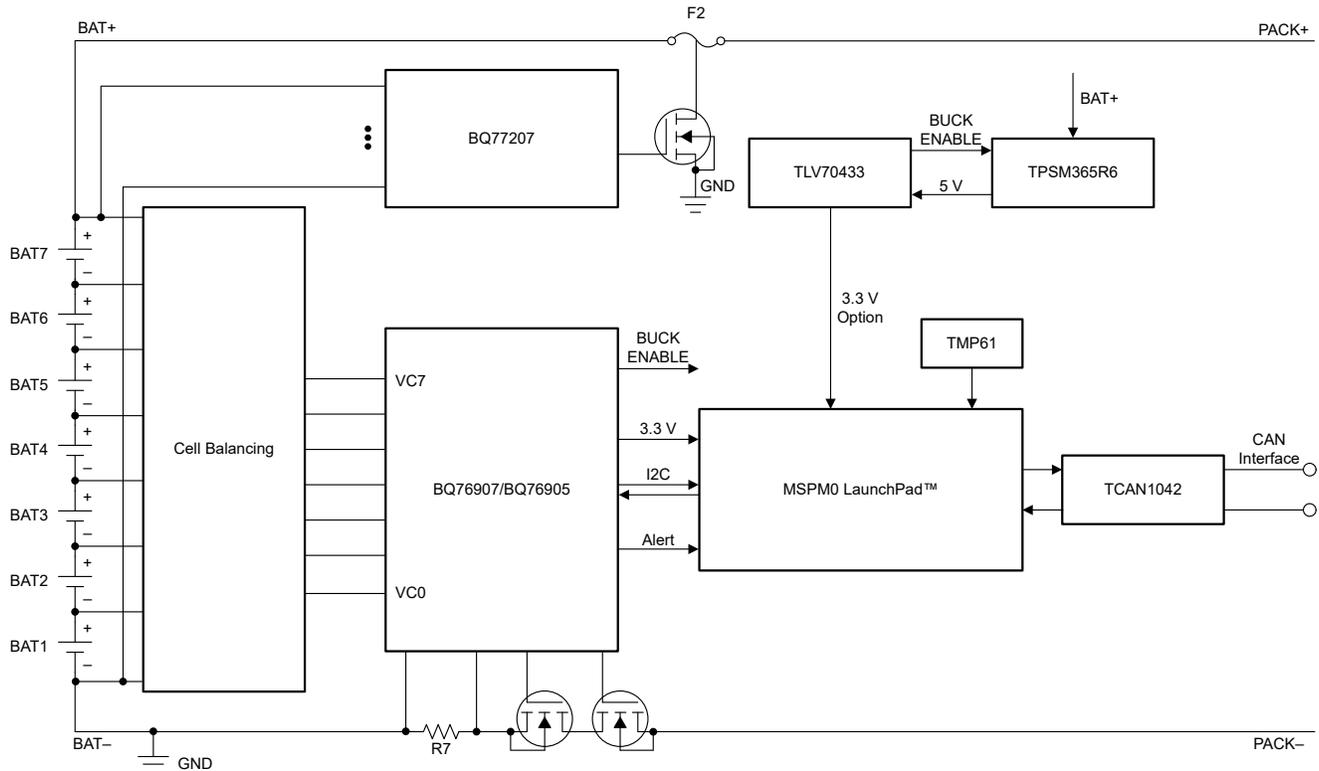


Figure 2-1. TIDA-010268 Block Diagram

2.2 Highlighted Products

The following highlighted products are used in this reference design. Key features for selecting the devices for use in this reference design are revealed in the following sections. Find more details of the highlighted devices in the respective product data sheet.

2.2.1 BQ76907

The BQ76907 product is a highly-integrated, accurate battery monitor and protector for 2-series to 7-series Li-Ion, Li-Polymer, and LiFePO4 battery packs. A high-accuracy voltage, current, and temperature measurement provides data for host-based algorithms and control. A feature-rich and highly configurable protection subsystem provides a wide set of protections which can be triggered and recovered completely autonomously by the device or under full control of a host processor. Integrated FET drivers drive low-side charge and discharge protection NFETs. A programmable LDO is included for external system use, with voltage programmable to 1.8 V, 2.5 V, 3.0 V, 3.3 V, or 5.0 V, capable of providing up to 20 mA. The BQ76907 device includes one-time-programmable (OTP) memory which TI programs to configure default device operation settings, for systems where a host processor is not available to configure the device. A 400-kHz I2C communication interface and ALERT interrupt output enable communication with a host processor. The device includes support for one external thermistor as well as an internal die temperature measurement.

2.2.2 BQ76905

The BQ76905 product is a highly-integrated, accurate battery monitor and protector for 2-series to 5-series Li-Ion, Li-Polymer, and LiFePO₄ battery packs. A high-accuracy voltage, current, and temperature measurement provides data for host-based algorithms and control. A feature-rich and highly-configurable protection subsystem provides a wide set of protections which can be triggered and recovered completely autonomously by the device or under full control of a host processor. Integrated FET drivers drive low-side charge and discharge protection NFETs. A programmable LDO is included for external system use, with voltage programmable to 1.8 V, 2.5 V, 3.0 V, 3.3 V, or 5.0 V, capable of providing up to 20 mA. The BQ76905 device includes one-time-programmable (OTP) memory which TI programs to configure default device operation settings, for systems where a host processor is not available to configure the device. A 400-kHz I2C communication interface and ALERT interrupt output enable communication with a host processor. The device includes support for one external thermistor as well as an internal die temperature measurement.

2.2.3 BQ77207

The BQ77207 family of devices provides a range of voltage and temperature monitoring including overvoltage (OVP), undervoltage (UVP), open wire (OW), and overtemperature (OT) protection for Li-ion battery pack systems. Each cell is monitored independently for overvoltage, undervoltage, and open-wire conditions. With the addition of an external NTC thermistor, the device can detect overtemperature conditions. An internal delay timer is initiated upon detection of an overvoltage, undervoltage, open-wire, or overtemperature condition. Upon expiration of the delay timer, the respective output is triggered into the active state (either high or low depending on the configuration). The overvoltage triggers the COUT pin if a fault is detected, and undervoltage triggers the DOUT pin if a fault is detected. If an under temperature, overtemperature, or open-wire fault is detected, then both the DOUT and COUT are triggered.

2.2.4 MSPM0L1106

MSPM0L110x microcontrollers (MCUs) are part of the MSP highly-integrated ultra-low-power 32-bit MSPM0 MCU family based on the enhanced Arm[®] Cortex[®]-M0+ core platform operating at up to 32-MHz frequency. These cost-optimized MCUs offer high-performance analog peripheral integration, support extended temperature ranges from -40°C to 105°C, and operate with supply voltages from 1.62 V to 3.6 V. The MSPM0L110x devices provide up to 64KB embedded flash program memory with 4KB SRAM. These MCUs incorporate a high-speed on-chip oscillator with an accuracy up to ±1.2%, eliminating the need for an external crystal. Additional features include a 3-channel DMA, 16 and 32-bit CRC accelerator, and a variety of high-performance analog peripherals such as one 12-bit 1.68-Msps ADC with configurable internal voltage reference, one general-purpose amplifier, and an on-chip temperature sensor. These devices also offer intelligent digital peripherals such as four 16-bit general purpose timers, one windowed watchdog timer, and a variety of communication peripherals including two UARTs, one SPI, and one I2C. These communication peripherals offer protocol support for LIN, IrDA, DALI, Manchester, Smart Card, SMBus, and PMBus. The TI MSPM0 family of low-power MCUs consists of devices with varying degrees of analog and digital integration letting customers find the MCU that meets the needs of the project. The architecture combined with extensive low-power modes is optimized to achieve extended battery life in portable measurement applications.

2.2.5 TCAN1042

This CAN transceiver family meets the ISO11898-2 (2016) High-Speed Controller Area Network (CAN) 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" suffix 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.

2.2.6 TPSM365R6V5

The TPSM365R6 is an easy-to-use, synchronous buck, DC-DC power module that operates from a 3-V to 65-V supply voltage. The device is intended for step-down conversions from 5-V, 12-V, 24-V, and 48-V supply rails. With an integrated power controller, inductor, and MOSFETs, the TPSM365R6 or TPSM365R3 delivers up to 600-mA DC load current with high efficiency and ultra-low input quiescent current in a very small design size. Although designed for simple implementation, this device offers flexibility to optimize the usage according to the target application. Control-loop compensation is not required, reducing design time and external component count. The TPSM365Rx can operate over a wide range of switching frequencies and duty ratios. If the minimum ON-time or OFF-time cannot support the desired duty ratio, the switching frequency gets reduced automatically, maintaining the output voltage regulation. With the right internal loop compensation the system design time with the TPSM365Rx reduces significantly with minimal external components. In addition, the PGOOD output feature with built-in delayed release allows the elimination of the reset supervisor in many applications. With a programmable switching frequency from 200 kHz to 2.2 MHz using the RT pin or an external clock signal. These features enable a flexible and easy-to-use platform for a wide range of applications. The pin arrangement is designed for a simple layout, requiring few external components.

2.2.7 TLV704

The TLV704 series of low-dropout (LDO) regulators are ultra-low quiescent current devices designed for extremely power-sensitive applications. Quiescent current is virtually constant over the complete load current and ambient temperature range. These devices are an excellent power-management attachment to low-power microcontrollers, such as the MSP430™ MCU. The TLV704 operates over a wide operating input voltage of 2.5 V to 24 V. Thus, the device is an excellent choice for both battery-powered systems as well as industrial applications that undergo large line transients. The TLV704 is available in a 3-mm × 3-mm SOT23-5 package, which is an excellent choice for cost-effective board manufacturing.

2.2.8 TMP61

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 minimize 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, a 0603 footprint and a 2-pin through-hole TO-92S package.

3 System Design Theory

3.1 Primary Protection Design

For the design of primary protection (BQ7690x), follow the design recommendations in the data sheet.

In addition, D2 and D16 were added to prevent the voltage drop of BAT and REGOUT after short circuit.

A wake-up circuit for the TS pin was added, because the TS pin maximum withstand voltage is 2.1 V. D7 and D8 was added as voltage regulator and protection. The voltage of cell1 fluctuates the moment S1 is triggered. After wake-up, voltage monitoring returns to normal.

A balancing circuit was also designed in this design. In this design, 100 Ω and 220 nF are selected for the input of VC0 to VC7. (Limit the external cell input resistance times external input capacity to 200 μs or below, and note that the recommended value of the input resistance is 10 Ω, too large an input resistance affects the sampling accuracy.) For external balancing circuit design detail, see the [Cell Balancing With BQ769x2 Battery Monitors](#) application note.

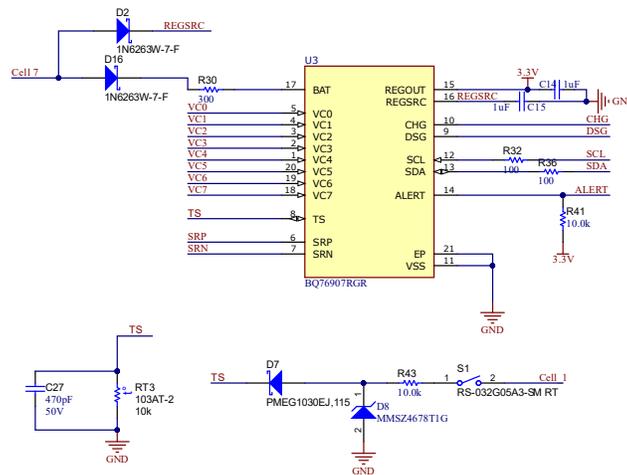


Figure 3-1. Primary Protection Design Circuit

3.2 Secondary Protection

The design also adds a secondary protection design, which is independent. This design uses COUT for overvoltage and overtemperature protection. The secondary protection BQ77207 cannot share RC with the primary protection because the device is calibrated using an RIN value = 1 kΩ. Using a value other than this recommended value changes the accuracy of the cell voltage measurements and V_{OV} trigger level.

4 Hardware, Software, Testing Requirements, and Test Results

4.1 Hardware Requirements

Figure 4-1 identifies different items on the TIDA-010268 board. Descriptions of these parts are provided in the following list:

- Connector J2 and J3: This connector is designed to connect with the MSPM0 LaunchPad™ Development Kit. A direct connection can be made with the MSPM0 LaunchPad or a separate control (such as connecting I2C to EV2400 and use the BQ studio for control).
- Connector J4: Shorting J4 can make the 3.3-V output by BQ7690x provide to the 3.3 V pin of J2.
- Connector J5: CAN interface, to use this enable 5-V Buck.
- Connector J6: Shorting J6 can make the 3.3-V output of the TLV704 provide current to the 3.3 V J2 pin. (If using TLV704, enable TPSM365R6V5RDNR first.)
- Connector J7: Shorting J6 can make the 5-V output of TPSM365R6V5RDNR provide current to the 5-V pin of J2. (If using TPSM365R6V5RDNR, set J2:BUCK EN pin to high.)
- Connector J8: Battery cell connector, connect cell7 to cell1 from left to right. If using less than 7 cells, short the corresponding pins according to the [BQ76907 2-Series to 7-Series High Accuracy Battery Monitor and Protector for Li-Ion, Li-Polymer, LiFePO4 \(LFP\), and LTO Battery Packs](#) data sheet.

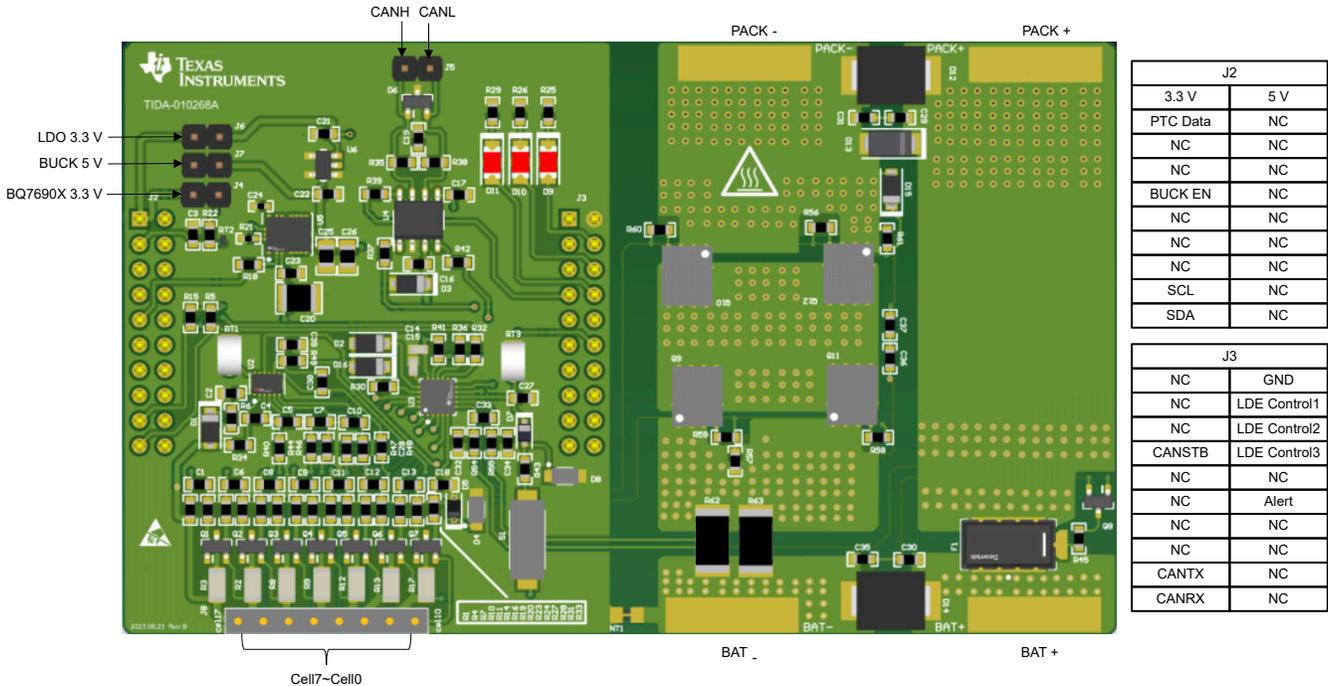


Figure 4-1. Hardware Board Overview

4.2 Software Requirements

To download the software files, contact your TI sales representative.

4.3 Test Setup

Follow this procedure for board bring-up and testing, also refer to Figure 4-1:

- Connect Cell7–Cell1 from left to right in J8. If using less than 7 cells, short the corresponding pins according to the BQ76907 and BQ76905 data sheet.
- Connect BAT+ to Cell7 and BAT– to Cell0
- Using the MSPM0L1306 LaunchPad, connect to J2, J3 or only connect J2:I2C pin with EV2400 and connect to the personal computer (PC)
- Choose whether to connect J5, J6, J7, or J8, according to the need
- Connect load in PACK+ or PACK–

The test set up for the discharge and charge tests were done in the TI lab.

Figure 4-2 shows the charge process setup example. DC source 1 configurations: 22 V–3 A. DC source 2 configurations: 18 V–0.5 A. Electronic load configurations: 18-V CV mode (For 5s test).

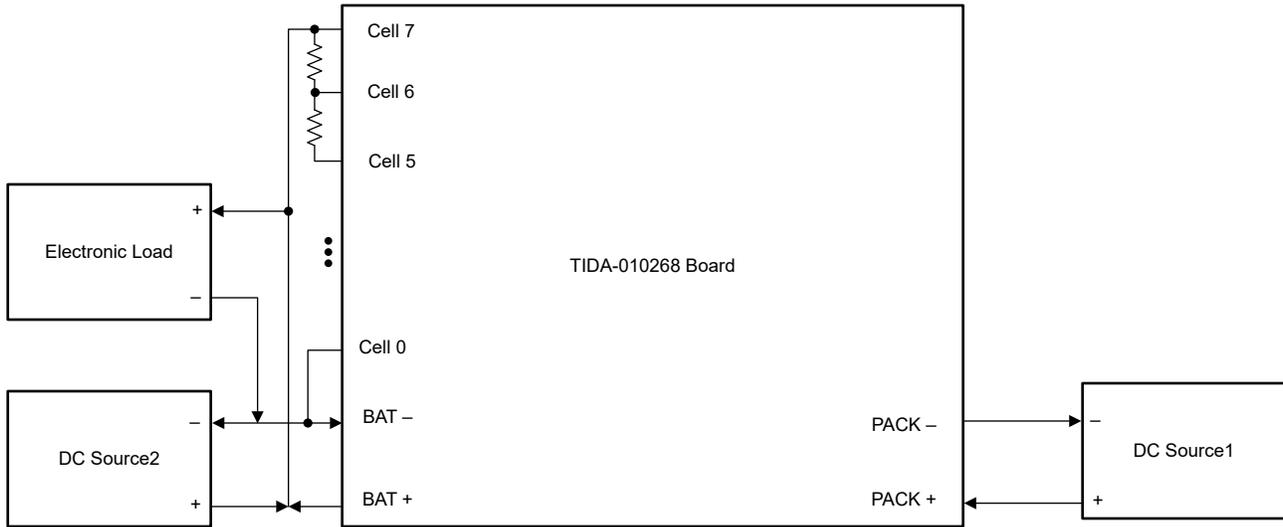


Figure 4-2. Charge Setup

Figure 4-3 shows the discharge process setup example. DC source 1 configurations: 18 V–10 A. Electronic load configurations: CC mode.

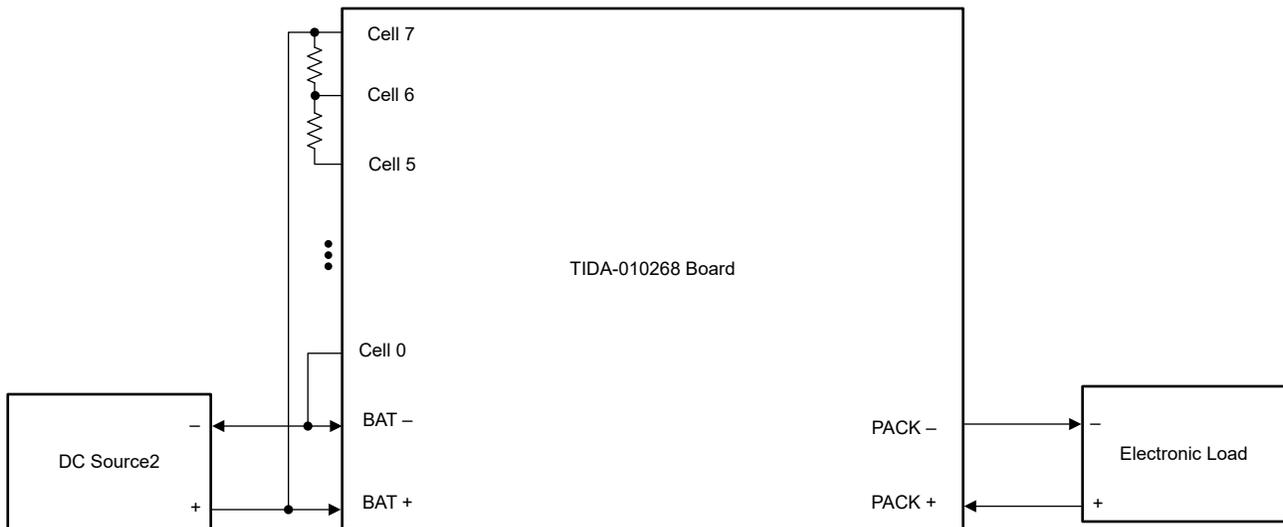


Figure 4-3. Discharge Setup

4.4 Test Results

4.4.1 Cell Voltage Accuracy

When testing cell voltage accuracy, do not use a resistor divider to simulate battery cells. Since there is some current flowing into cell input pins when doing ADC measurement, the resistor divider causes further voltage drop and makes the AFE readings lower than the actual value. The design uses a battery simulator for accuracy testing. Table 4-1 shows the cell voltage accuracy data without any further calibrations and under room temperature. All channels of cell voltage error are below ± 5 mV.

Table 4-1. Cell Voltage Accuracy Data

MEASURING VOLTAGE (mV)	CELL 1 (mV)	CELL 2 (mV)	CELL 3 (mV)	CELL 4 (mV)	CELL 5 (mV)	CELL 6 (mV)	CELL 7 (mV)	CELL ERROR 1 (mV)	CELL ERROR 2 (mV)	CELL ERROR 3 (mV)	CELL ERROR 4 (mV)	CELL ERROR 5 (mV)	CELL ERROR 6 (mV)	CELL ERROR 7 (mV)
2000	2000	2000	1999	2000	2000	2000	2000	0	0	-1	0	0	0	0
2250	2250	2250	2249	2250	2249	2250	2250	0	0	-1	0	-1	0	0
2500	2500	2500	2499	2500	2500	2499	2500	0	0	-1	0	0	1	0
2750	2750	2750	2749	2750	2749	2750	2750	0	0	-1	0	-1	0	0
3000	3000	2999	2999	3000	2999	3000	3000	0	-1	-1	0	-1	0	0
3250	3250	3248	3249	3250	3249	3250	3250	0	-2	-1	0	-1	0	0
3500	3499	3498	3499	3500	3499	3499	3500	-1	-2	-1	0	-1	1	0
3750	3749	3748	3749	3750	3749	3750	3750	-1	-2	-1	0	-1	0	0
4000	3999	3998	3999	4000	3999	3999	4000	-1	-2	-1	0	-1	1	0
4250	4249	4248	4249	4250	4249	4249	4250	-1	-2	-1	0	-1	1	0

4.4.2 Pack Current Accuracy

This design uses two parallel 2-mΩ, 2-W, 50-PPM shunt resistors to measure pack current. Board offset was calibrated using the guidance of the calibration section of the data sheet. Next, Current Gain was calibrated with 2-A discharging current. Write the Board Offset and Current Gain values with OTP to BQ7690X; otherwise, the MCU has to store such data and write to BQ7690X every time the MCU wakes up from shutdown mode.

Figure 4-4 shows the pack current accuracy data under room temperature. The maximum current error is about ±10 mA when the discharging current is below 3 A and about ±0.5% when the discharging current is above 3 A.

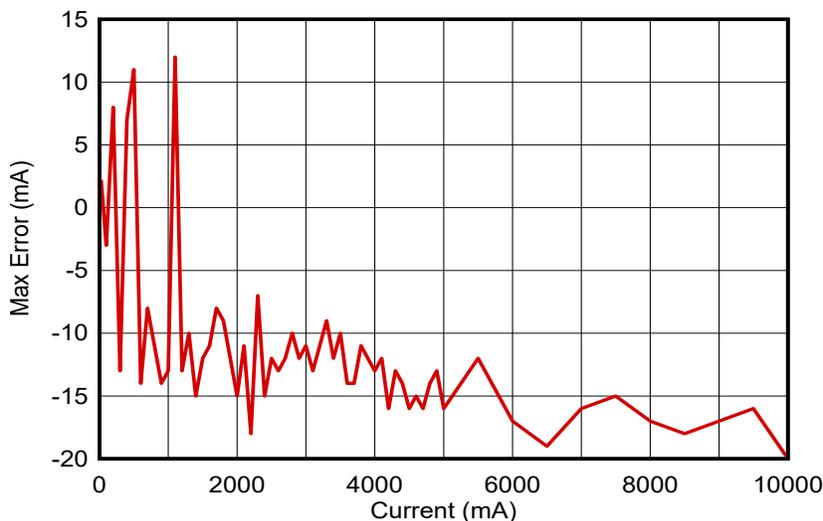
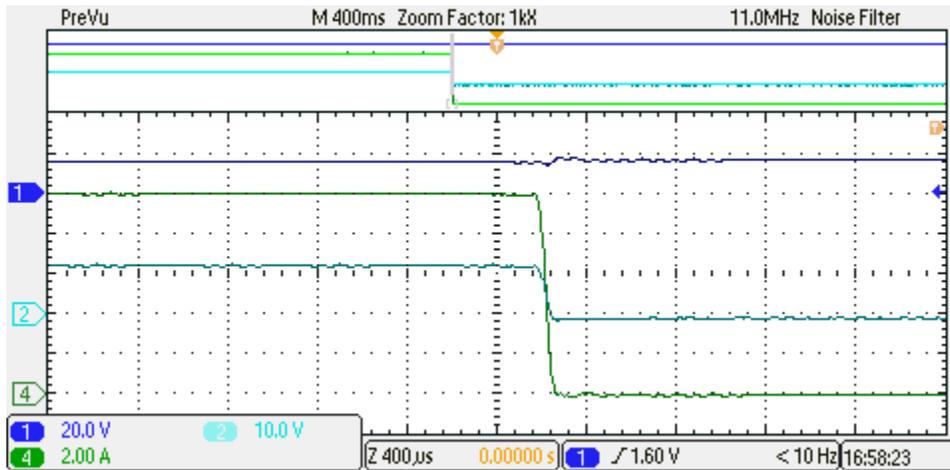


Figure 4-4. Pack Current Accuracy

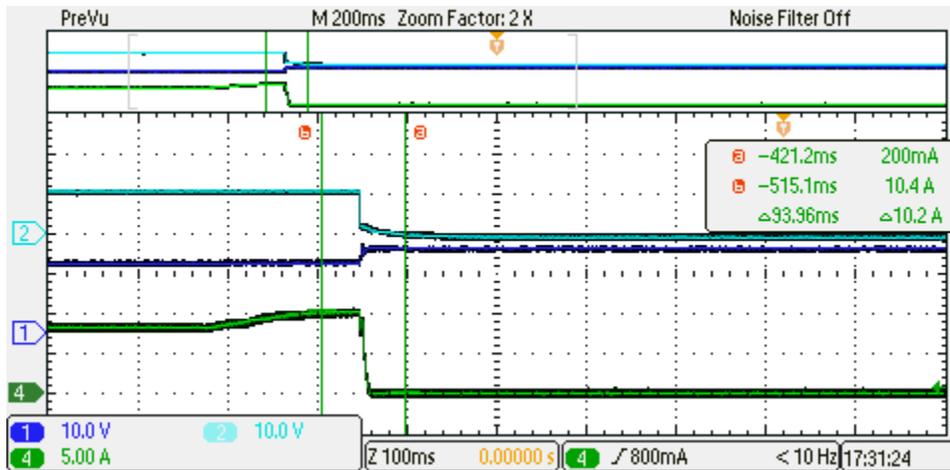
4.4.3 Protection

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, overtemperature and undertemperature protections. Furthermore, this design also monitors loss of system level faults, including: cell open wire, host watch dog, charge and discharge MOSFETs faults, overtemperature, and so on. Some of the protections were tested in a TI lab.



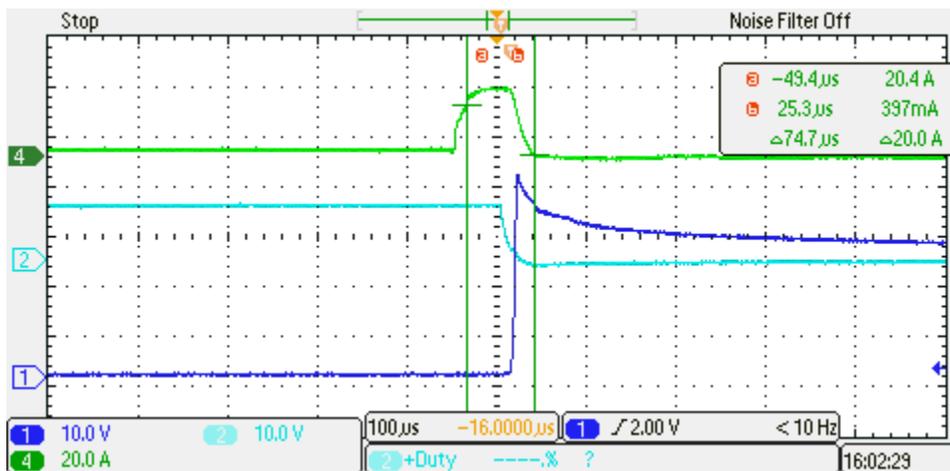
CH1 (Blue): Battery voltage, CH2 (Cyan): DSG V_{gs}, CH4 (Green): Discharge Current

Figure 4-5. Overcurrent Discharge (Set the Threshold to 10 A)



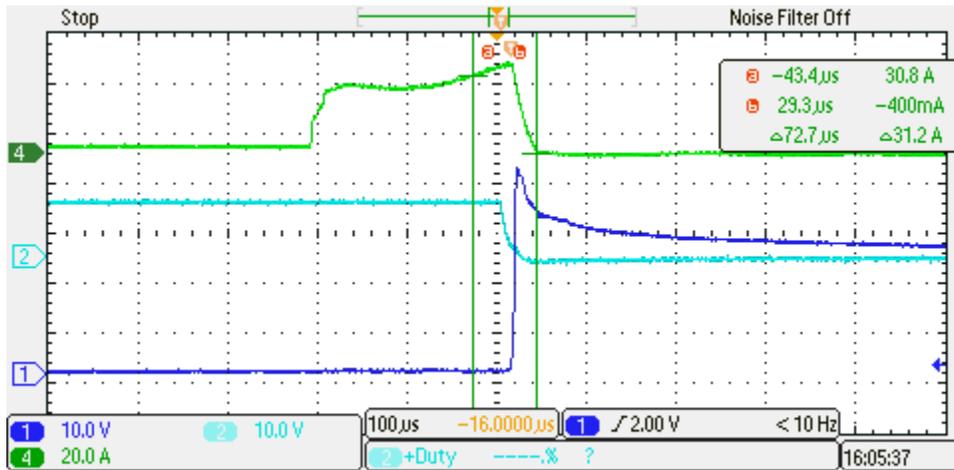
CH1 (Blue): Battery voltage, CH2 (Cyan): DSG V_{gs}, CH4 (Green): Discharge Current

Figure 4-6. Overcurrent Charge (Set the Threshold to 10 A)



CH1 (Blue): DSG V_{ds}, CH2 (Cyan): DSG V_{gs}, CH4 (Green): Discharge Current

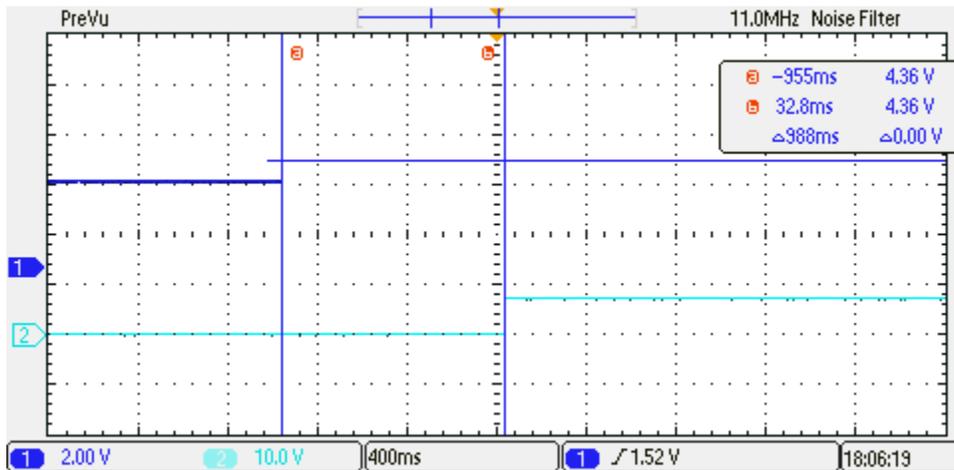
Figure 4-7. Discharge Short Circuit (Set the Threshold to 20 A)



CH1 (Blue): DSG V_{ds}, CH2 (Cyan): DSG V_{gs}, CH4 (Green): Discharge Current

Figure 4-8. Discharge Short Circuit (Set the Threshold to 30 A)

This design also includes the individual secondary protections to prevent the hazards from each cell overvoltage and overtemperature. This helps to pass some safety regulations without further work. Secondary overvoltage protections were tested in a TI lab.



CH1 (Blue): Cell 1 voltage, CH2 (Cyan): VcOUT

Figure 4-9. Secondary Overvoltage Protection

4.4.4 Cell Balancing

The design board supports external cell balancing with triode. The peak balancing current is 64 mA with 4-V cell voltage, approximately 50 mA flows through external balancing resistor about 14 mA flows through the BQ7690x device. Battery balancing can only be triggered by command. Figure 4-10 shows the external cell balancing performance. Cell balancing duty is about 82%.

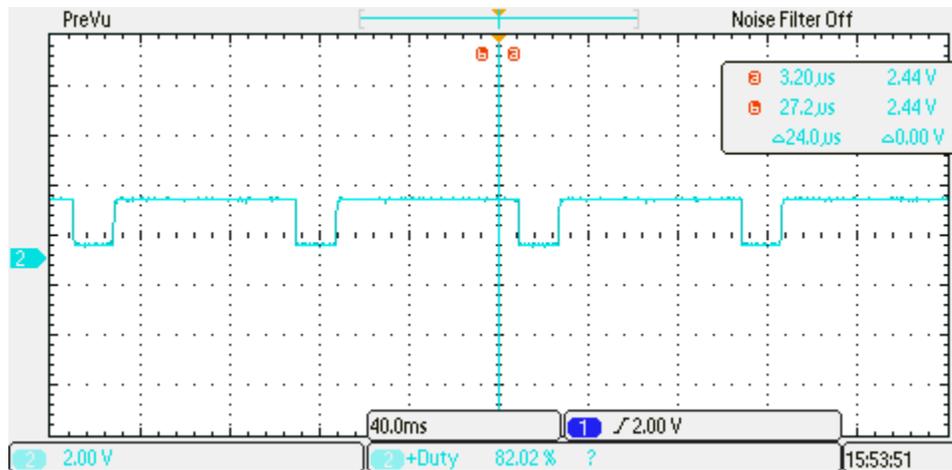
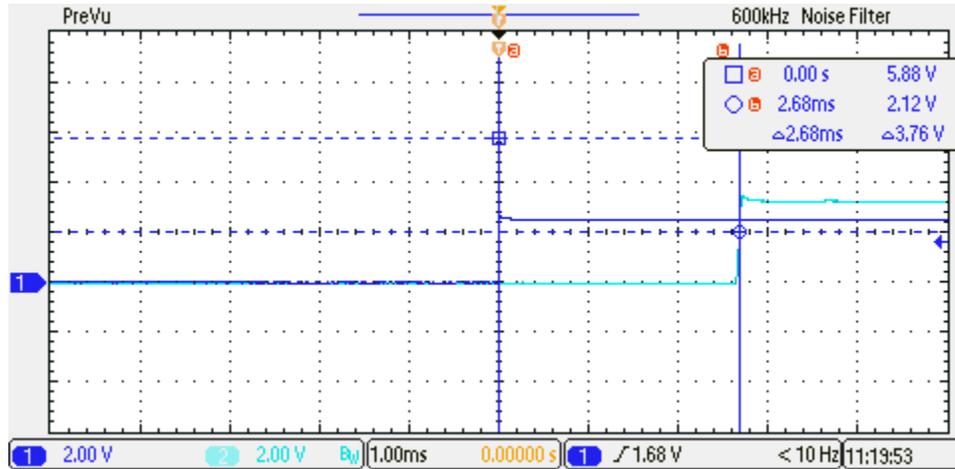


Figure 4-10. External Cell Balancing

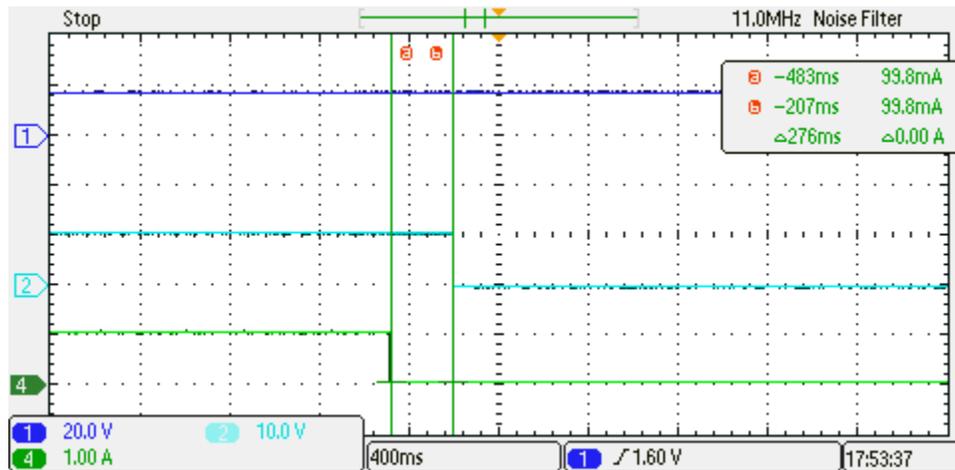
4.4.5 Working Modes Transition

The BQ76905 has 4 working modes: normal mode, sleep mode, deep sleep mode, and shutdown mode. When the pack is charging or discharging, the pack is in normal mode. Sleep mode is when no charging nor discharging, the pack is waiting for charger or load attachment. Deep sleep mode is a low current consumption mode, internal LDO is active can keep MCU powered. 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, only wake by external trigger. Different working mode transition are shown in Figure 4-11 to Figure 4-14.



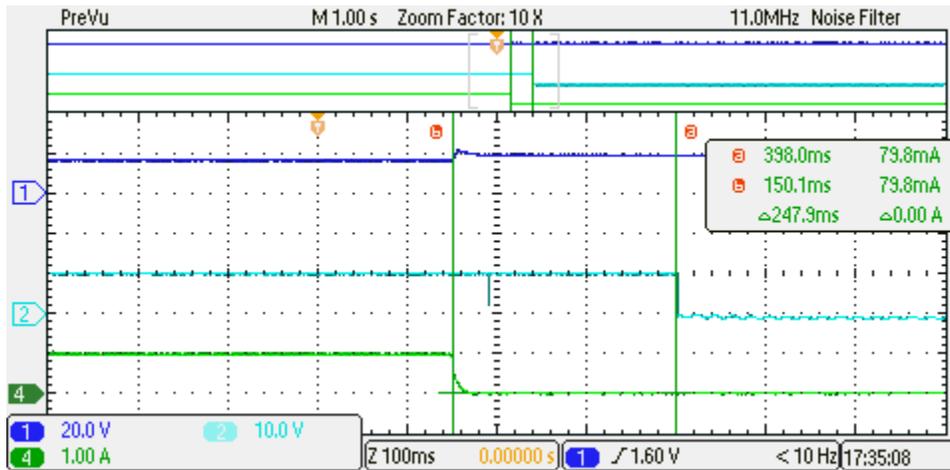
CH1 (Blue): Trigger signal, CH2 (Cyan): 3.3-V output

Figure 4-11. Deep Sleep Mode to Normal Mode



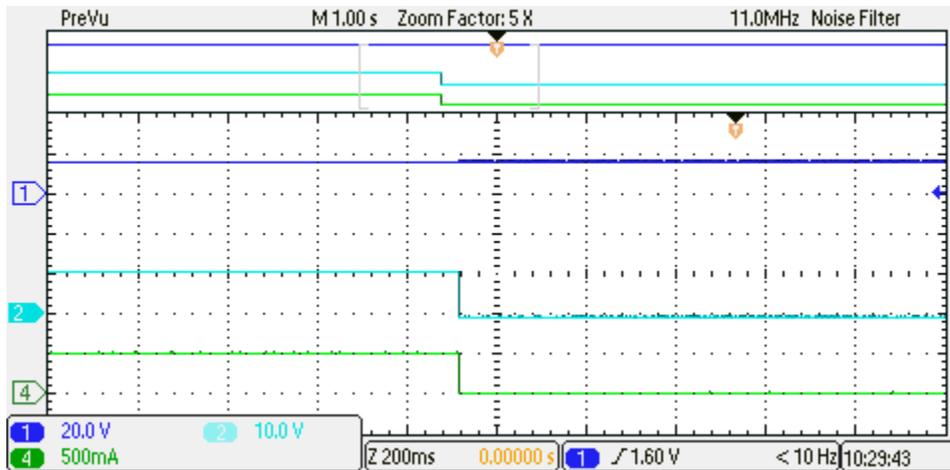
CH1 (Blue): Battery voltage, CH2 (Cyan): DSG V_{gs}, CH4 (Green): Discharge Current

Figure 4-12. Discharge Mode to Sleep Mode



CH1 (Blue): Battery voltage, CH2 (Cyan): CHG V_{gs}, CH4 (Green): Charge Current

Figure 4-13. Charge Mode to Sleep Mode



CH1 (Blue): Battery voltage, CH2 (Cyan): CHG V_{gs}, CH4 (Green): Charge Current

Figure 4-14. Charge to Deep Sleep Mode (Enter Deep Sleep Mode Through I2C Command)

4.4.6 Thermal Performance

Figure 4-15 and Figure 4-16 show the thermal test in 18 V_{DC} discharge current at about 15 A, the current waveform, and the thermal result.(Green:discharge Current, Blue:DSG V_{gs})

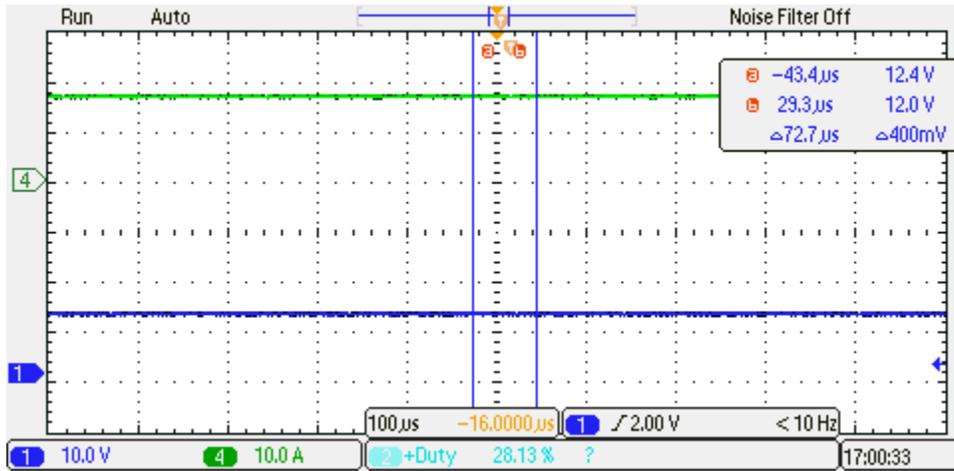


Figure 4-15. Discharge in 15 A



Figure 4-16. Thermal Image in Discharge 15 A

Figure 4-17 and Figure 4-18 show the thermal test in 18 V_{DC} discharge current at about 30 A, the current waveform, and the thermal result. (Green: discharge Current, Blue: DSG V_{gs}, Cyan: Battery voltage)

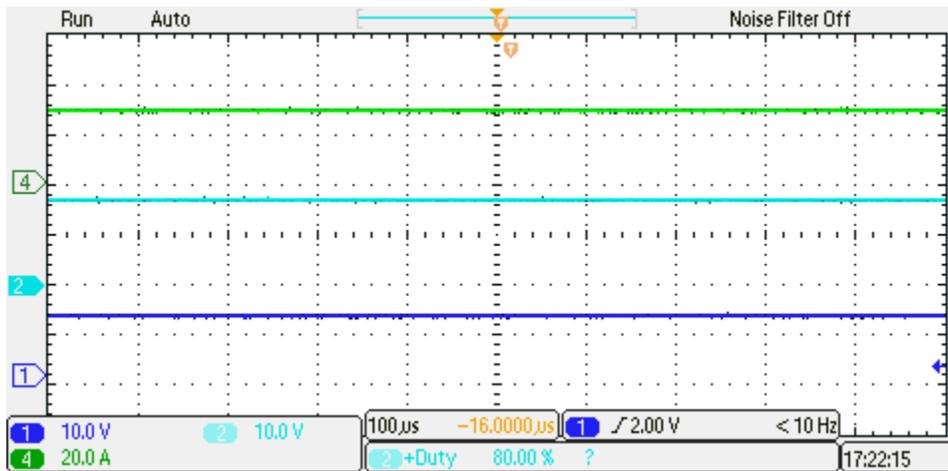


Figure 4-17. Discharge in 30 A

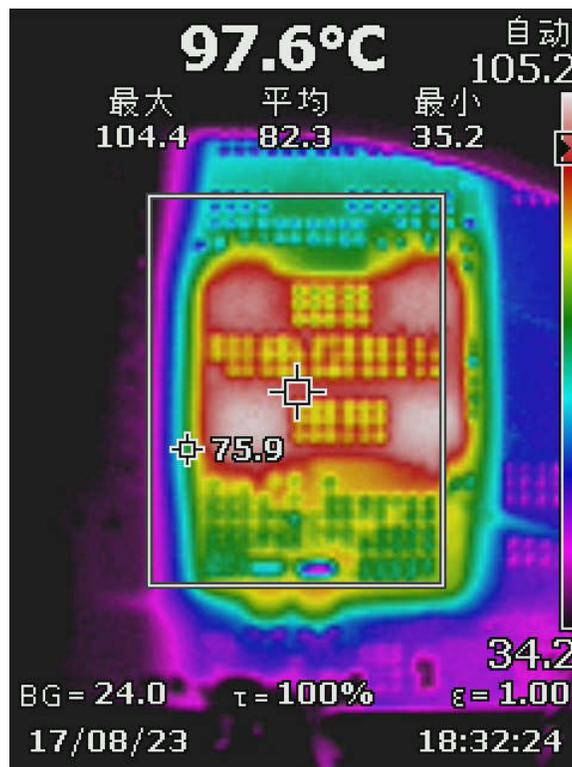


Figure 4-18. Thermal Image in Discharge 30 A

5 Design and Documentation Support

5.1 Design Files

5.1.1 Schematics

To download the schematics, see the design files at [TIDA-010268](#).

5.1.2 BOM

To download the bill of materials (BOM), see the design files at [TIDA-010268](#).

5.2 Tools and Software

Tools

[Battery Management Studio \(bqStudio\) Software](#) Tools to assist with the process of evaluating, designing with, configuring, testing, or otherwise utilizing TI Battery management products.

5.3 Documentation Support

1. Texas Instruments, [BQ76907 2-Series to 7-Series High Accuracy Battery Monitor and Protector for Li-Ion, Li-Polymer, LiFePO4 \(LFP\), and LTO Battery Packs](#) data sheet
2. Texas Instruments, [BQ76905 2-Series to 5-Series High Accuracy Battery Monitor and Protector for Li-Ion, Li-Polymer, LiFePO4\(LFP\), and LTO Battery Packs](#) data sheet
3. Texas Instruments, [BQ77207 Voltage and Temperature Protection for 3-Series to 7-Series Cell Li-Ion Batteries with Internal Delay Timer](#) data sheet
4. Texas Instruments, [MSPM0L110x Mixed-Signal Microcontrollers](#) data sheet
5. Texas Instruments, [TCAN1044V Fault-Protected CAN FD Transceiver with Standby Mode and 1.8-V IO Support](#) data sheet
6. Texas Instruments, [TCAN1042 Fault Protected CAN Transceiver with CAN FD](#) data sheet
7. Texas Instruments, [TPSM365R6, TPSM365R3 3-V to 65-V Input, 600-mA/300-mA, 4- \$\mu\$ A No-Load \$I_Q\$ Synchronous Buck Converter Power Module in a HotRod™ QFN Package](#) data sheet
8. Texas Instruments, [TLV704 24-V, 150-mA, 3.2- \$\mu\$ A Quiescent Current, Low-Dropout Linear Regulator](#) data sheet
9. Texas Instruments, [TMP61 \$\pm\$ 1% 10-k \$\Omega\$ Linear Thermistor With 0402 and 0603 Package Options](#) data sheet

5.4 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.

Linked content is provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's [Terms of Use](#).

5.5 Trademarks

TI E2E™, MSP430™, LaunchPad™, and E2E™ are trademarks of Texas Instruments.

Arm® and Cortex® are registered trademarks of Arm Limited.

All trademarks are the property of their respective owners.

6 About the Author

JENSON FANG is a System Engineer in Texas Instruments where he is responsible for developing appliance systems related to Motor control and BMS design, and other appliances-related systems.

JAYDEN LI is a Field Application Engineer in China, who got his master's degree of Electrical Engineering in Nanjing University of Aeronautics and Astronautics. Jayden focuses on BMS applications and supports diverse customers covering a variety of end applications, like power tools, vacuum cleaners, e-bikes, residential ESS, and so forth.

SHUANG FENG is a Field Application Engineer in China who got his master's degree of circuit and system design at XIDIAN University. He supported Jenson for the development of this reference design. He focuses on diverse industrial applications.

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on [ti.com](https://www.ti.com) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2024, Texas Instruments Incorporated