

# Design Guide: TIDA-010074

## 16S-17S Battery Pack Reference Design With Low Current Consumption



### Description

This reference design is a low standby and low ship mode current consumption 16S-17S LiFePO<sub>4</sub> Li-ion battery pack design for telecom battery backup and e-motorcycles. It was implemented for a 2-layer PCB. The 9S-15S AFE bq76940 monitors the lower 15 cells voltage and a two-channel general purpose amplifier LM2904B monitors the 16th and 17th battery cells voltage. The design protects the battery pack against overvoltage, undervoltage, overcurrent, and overtemperature, and it reduces energy consumption when in standby and shipping mode through a well-designed auxiliary power supply strategy and a highly efficient, low quiescent current DC/DC converter LM5164, therefore allows longer shipping time and idle time.

### Resources

<a href="#">TIDA-010074</a>	Design Folder
<a href="#">BQ76940 BQ76200</a>	Product Folder
<a href="#">LM2904B</a>	Product Folder
<a href="#">MSP430FR2155</a>	Product Folder
<a href="#">LM5164</a>	Product Folder
<a href="#">SN6501</a>	Product Folder
<a href="#">THVD1500</a>	Product Folder

### Features

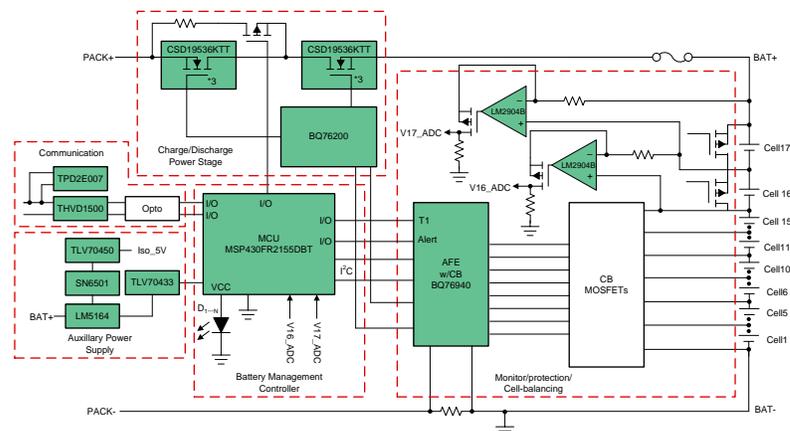
- Cost competitive 16S-17S LiFePO<sub>4</sub> Li-ion battery pack solution
- $\pm 5$ -mV cell voltage sensing accuracy for 16-17S battery cell at room temperature
- 100- $\mu$ A current consumption when in standby mode
- 5- $\mu$ A current consumption when in shipping mode
- Robust and programmable protection, including cell overvoltage and undervoltage, overcurrent discharge, short circuit, overtemperature and undertemperature
- Support 100-mA cell balancing
- High-side charging and discharging MOSFETs and support pre-discharge function

### Applications

- [Battery pack: e-bike, e-scooter, light electric vehicle \(LEV\)](#)
- [Other industrial battery pack \(>=10S\)](#)



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## 1 System Description

The telecom battery backup (BBU) market is growing rapidly because of 5G. Because of the weight limit and need for longer runtimes, battery cell chemistries are shifting to Li-ion, Li-polymer or Li-ion phosphate types. These chemistries are good in both volumetric and gravimetric energy density. While these chemistries provide high energy density, and thereby lower volume and weight as an advantage, they are associated with safety concerns and need more complex monitoring and accurate capacity gauging. Those concerns are undervoltage, overvoltage, overtemperature, overcurrent, overdischarge and charge current, all which contribute to the accelerating cell degradation and may lead to thermal runaway and explosion. Therefore, the pack current, temperature and each cell voltages should be timely monitored and protected in case of some unusual situations, including overvoltage, undervoltage, overdischarge current, short circuit, overtemperature and undertemperature. For battery pack applications like e-motorcycles, low current consumption, especially when in standby and ship mode, is important to extend the idle and storage time, without the battery pack becoming overdischarged. Another important feature is low BoM cost.

This design has two target applications: telecom BBU and e-motorcycle battery packs. It contains a 9S-15S AFE bq76940 for monitoring and protecting the voltage of the lower 15 battery cells. A two-channel amplifier LM2904B creates a voltage-to-current circuit for the 16th and 17th battery cell voltage measurement, and the protection is through firmware and for all unusual situations, including overvoltage, undervoltage, overdischarge current, short circuit, overtemperature and undertemperature. A high-side N-Channel MOSFET driver, bq76200, drives the charge and discharge. It also provides a channel to drive P-Channel MOSFET as precharge or predischage function. Meanwhile, this design carefully designs the auxiliary power, which achieves low ship mode and standby mode current consumption (5  $\mu$ A for ship mode and 100  $\mu$ A for standby mode).

## 1.1 Key System Specifications

Table 1 lists the detail features.

**Table 1. Key System Specifications**

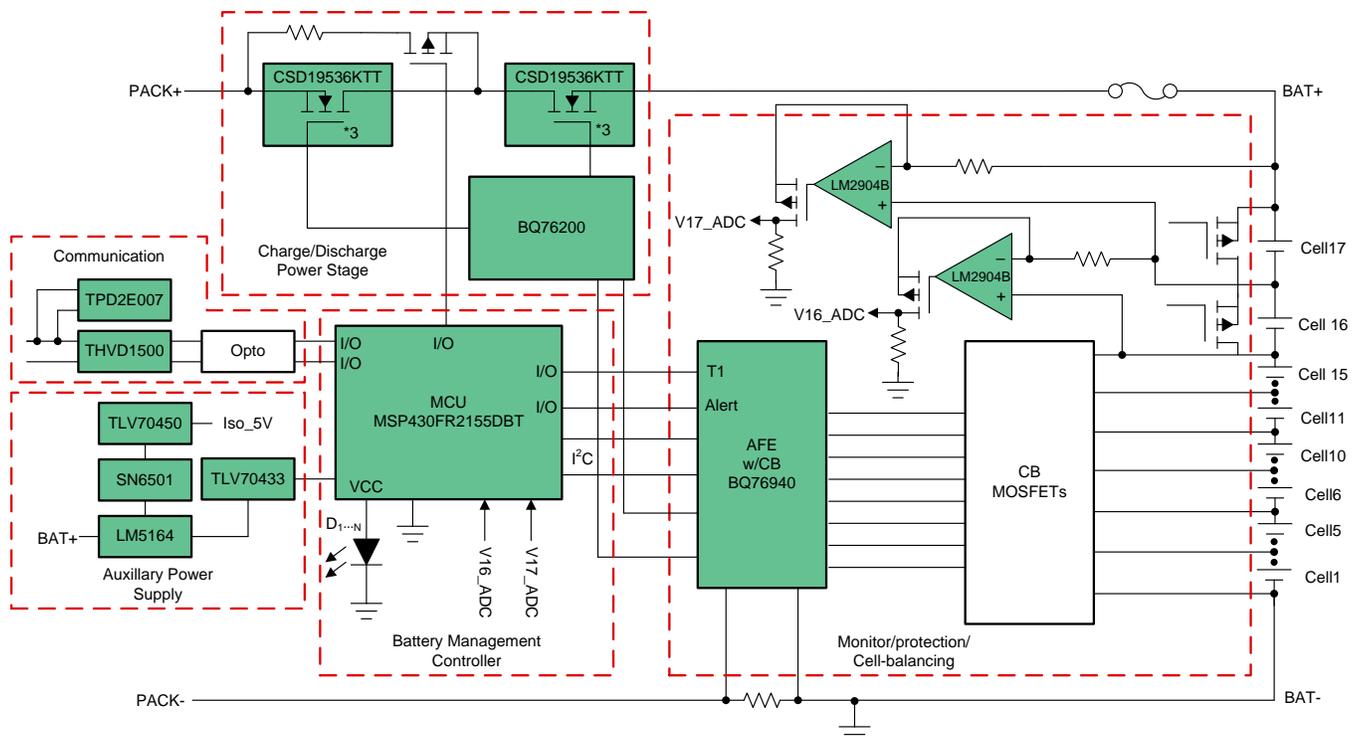
PARAMETER	CONDITIONS	SPEC RANGE			UNIT
		MINIMUM	TYPICAL	MAXIMUM	
Cell architecture	LiFePO <sub>4</sub> /Li-ion Battery	9S	16S	17S	
Stack Voltage			48	72	V
Cell Balancing Current				100	mA
Cell voltage sensing error	16th and 17th battery cell		±5	±10	mV
Charge Current			10		A
Discharge Current			20	30	A
Pre-discharge Current			0.2		A
Primary OV protection	Threshold(programable)		4200		mV
	Delay(programable)		2		s
UV protection	Threshold(programable)		3000		mV
	Delay(programable)		4		s
OCD protection	Threshold(programable)		11		A
	Delay(programable)		320		ms
SCD protection	Threshold(programable)		56		A
	Delay(programable)		70		µs
Overtemperature Protection	Charge(programable)		55		°C
	Discharge(programable)		60		°C
Undertemperature Protection	Charge(programable)		0		°C
	Discharge(programable)		-20		°C
Communication speed	RS-485		9600		bps
Standby mode current consumption			70	100	µA
Shipping mode current consumption			5		µA

## 2 System Overview

### 2.1 Block Diagram

Figure 1 shows the system diagram containing several sub systems: monitor, protection, cell-balancing, battery management controller, auxiliary power supply, charge or discharge power stage, and communication. The battery cell monitoring and balancing uses TI 9-15S AFE bq76940 to monitoring 1-15th cell voltage and pack current and temperature, it also integrates over voltage and under voltage hardware protection, cell balancing and charge and discharge FET drivers. The 16th and 17th battery cells are monitored through a voltage-to-current circuit designed with a two-channel amplifier LM2904B. There is a lower power MSP430™ MCU MSP430FR2155 which will configure AFE, read data from AFE and use 12-bit ADC to sample the 16th and 17th cell voltage and upload all the requested information to system side. The auxiliary power supply has a wide input, low quiescent current DC/DC converter LM5164, convert the battery voltage to 5 V. A transformer driver SN6501 generate the isolated 5 V for the isolated RS-485 transceiver THVD1500. And LDOs make the voltage more stable.

Figure 1. TIDA-010074 Block Diagram



### 2.2 Highlighted Products

#### 2.2.1 BQ76940

The BQ76940 of robust AFE device serves as part of a complete pack monitoring and protection solution for next-generation high-power systems, such as light electric vehicles, power tools, and uninterruptible power supplies. The BQ76940 is designed with low power in mind: Sub-blocks within the IC may be enabled or disabled to control the overall chip current consumption, and a SHIP mode provides a simple way to put the pack into an ultra-low power state. The BQ76940 supports 9 cells to 15 cells providing measurement of individual cell voltages. This AFE can measure a variety of battery chemistries, including Li-ion, Li-iron phosphate, and more. A coulomb counter is provided for current measurement. Three thermistors are provided for temperature measurement. Hardware protection features are configured by

registers set by the system controller and automatically switch off charge and discharge. Through I<sup>2</sup>C, a host controller can use the BQ76940 to implement many battery pack management functions such as monitoring (cell voltages, pack current, pack temperatures), protection (controlling charge or discharge FETs), and balancing. Integrated ADCs enable a purely digital readout of critical system parameters with calibration handled in TI's manufacturing process.

### 2.2.2 LM2904B

The LM358B and LM2904B devices are the next generation versions of the industry-standard LM358 and LM2904 devices, which include two high-voltage (36-V) operational amplifiers (op amps). These devices provide outstanding value for cost-sensitive applications, with features including low offset (300  $\mu$ V, typical), common-mode input range to ground, and high differential input voltage capability. The LM358B and LM2904B devices simplify circuit design with enhanced features such as unity-gain stability, lower offset voltage of 3 mV (maximum at room temperature), and lower quiescent current of 300  $\mu$ A (typical). High ESD (2 kV, HBM) and integrated EMI and RF filters enable the LM358B and LM2904B devices to be used in the most rugged, environmentally challenging applications. The LM358B and LM2904B devices are available in micro-size packages, such as TSOT-8 and WSON, as well as industry standard packages, including SOIC, TSSOP, and VSSOP.

### 2.2.3 BQ76200

The bq76200 device is a low-power, high-side, N-channel system. A high-side protection avoids ground disconnection in the system and also allows continuous communication between the battery pack and host system. The device has additional P-channel FET control to allow low-current pre-charge to a deeply depleted battery or pre-discharge to a capacitive load, and a PACK+ voltage monitor control for the host to sense the PACK+ voltage. The independent enable inputs allow CHG and DSG FETs to be turned on and off separately, offering great implementation flexibility in battery systems. The bq76200 device can be used with a companion Analog Front End device such as the bq76920, bq76930, and bq76940 family, a 3-series to 15-series Cell Analog Front End Monitoring, and a host microcontroller or dedicated state-of-charge (SOC) tracking gas gauge device.

### 2.2.4 MSP430FR2155

MSP430FR215x microcontroller (MCUs) is part of the MSP430™ MCU value line portfolio of ultra-low-power low-cost devices for sensing and measurement applications. The device includes a 12-channels 12-bit ADC and two comparators. The MSP430FR215x supports an extended temperature range from  $-40^{\circ}$  up to  $105^{\circ}$ 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  $\mu$ s. 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.

### 2.2.5 LM5164

The LM5164 synchronous buck converter is 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 solution cost. The LM5164 operates during input voltage dips as low as 6 V, at nearly 100 percent duty cycle if needed, making it 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 LM5164 delivers up to 1 A of output current. A constant on-time (COT) control architecture provides nearly constant switching frequency with excellent load and line transient response. Additional features of the LM5164 include ultra-low  $I_Q$  and diode emulation mode operation for

high light-load efficiency, innovative peak and valley overcurrent protection, integrated VCC bias supply and bootstrap diode, precision enable and input UVLO, and thermal shutdown protection with automatic recovery. An open-drain PGOOD indicator provides sequencing, fault reporting, and output voltage monitoring. The LM5164 is available in a thermally-enhanced, 8-pin SO PowerPAD™ package. Its 1.27-mm pin pitch provides adequate spacing for high-voltage applications.

### 2.2.6 THVD1500

THVD1500 is a robust half-duplex RS-485 transceiver for industrial applications. The bus pins are immune to high levels of IEC Contact Discharge ESD events eliminating need of additional system level protection components. The device operates from a single 5-V supply. The wide common-mode voltage range and low input leakage on bus pins make THVD1500 suitable for multi-point applications over long cable runs. THVD1500 is available in industry standard 8-pin SOIC package for drop-in compatibility. The device is characterized from –40°C to 125°C.

### 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 ideal power-management attachment to low-power microcontrollers, such as the MSP430. 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 x 3-mm SOT23-5 package, which is ideal for cost-effective board manufacturing.

### 2.2.8 SN6501

The SN6501 is a monolithic oscillator/power-driver, specifically designed for small form factor, isolated power supplies in isolated interface applications. The device drives a low-profile, center-tapped transformer primary from a 3.3-V or 5-V DC power supply. The secondary can be wound to provide any isolated voltage based on transformer turns ratio. The SN6501 consists of an oscillator followed by a gate drive circuit that provides the complementary output signals to drive the ground referenced N-channel power switches. The internal logic ensures break-before-make action between the two switches. The SN6501 is available in a small SOT-23 (5) package, and is specified for operation at temperatures from –40°C to 125°C.

### 2.2.9 TPD2E007

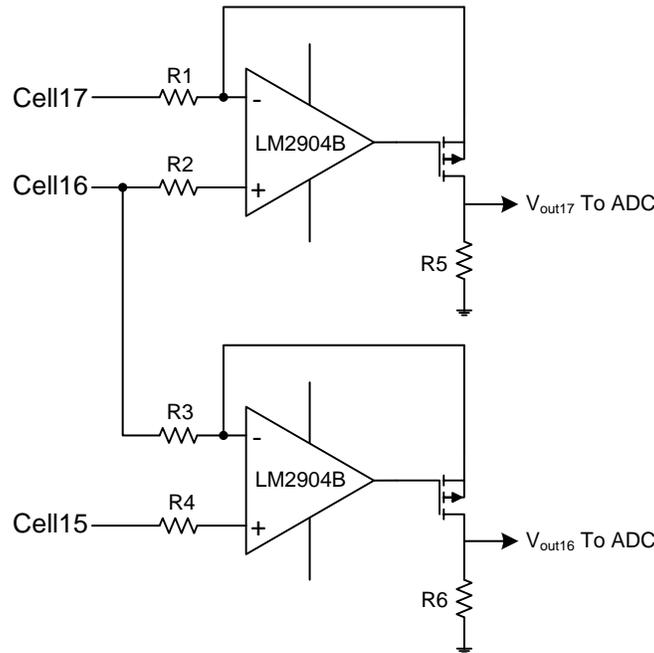
This device is a transient voltage suppressor (TVS) based electrostatic discharge (ESD) protection device designed to offer system level ESD solutions for wide range of portable and industrial applications. The back-to-back diode array allows AC-coupled or negative-going data transmission (audio interface, 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 ideal for providing system level ESD protection for the internal ICs when placed near the connector. The TPD2E007 is offered in a 4-bump PicoStar and 3-pin SOT (DGK) packages. The PicoStar package (YFM), with only 0.15 mm (MAX) package height, is recommended for ultra space saving application 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.

## 2.3 System Design Theory

### 2.3.1 16th and 17th cell voltage sensing circuit

To extend the cell voltage sensing capability to cover 17s maximum, we need to design a discrete circuit for the 16th and 17th cell voltage sensing. For e-motorcycle battery pack and telecom battery backup applications, good cell voltage sensing accuracy and low BoM cost are required. In this design, we use a voltage-to-current circuit to convert the 16th and 17th cell voltage to current which will flow through R5 and R6, and then MCU can read the voltage with 2 ADC channels. The circuit is shown in [Figure 4](#).

**Figure 2. 16th and 17th Cell Voltage Sensing Circuit**



The operation amplifier makes sure that the voltage across R1 and R3 is equal to the 17th and 16th cell voltage, so the 17th and 16th cell voltages are calculated with [Equation 1](#) and [Equation 2](#).

$$V_{\text{cell17}} = \frac{R1}{R5} V_{\text{out17}} \quad (1)$$

$$V_{\text{cell16}} = \frac{R3}{R6} V_{\text{out16}} \quad (2)$$

And because of the tolerance of R1, R5 and R3, R6, firmware trimming is necessary to hit the typical  $\pm 5$ -mV cell voltage sensing accuracy.

### 2.3.2 Auxiliary Power Supply Design

This auxiliary power circuit consists of a DC/DC BUCK converter, Isolated power supplies and several LDOs. The DC/DC buck converter is controlled by LM5164, a constant on-time (COT) control architecture device. The on-time is calculated with [Equation 3](#). In CCM, the operating frequency is programmed by the  $R_{\text{RON}}$  resistor and can be calculated using [Equation 4](#). Therefore the  $R_{\text{RON}}$  can be determined using [Equation 5](#).

$$t_{\text{on}} (\mu\text{s}) = \frac{R_{\text{RON}} (\text{k}\Omega)}{V_{\text{IN}} (\text{V}) \times 2.5} \quad (3)$$

$$F_{\text{SW}} (\text{kHz}) = \frac{V_{\text{OUT}} (\text{V}) \times 2500}{R_{\text{RON}} (\text{k}\Omega)} \quad (4)$$

$$R_{\text{RON}} (\text{k}\Omega) = \frac{V_{\text{OUT}} (\text{V}) \times 2500}{F_{\text{SW}} (\text{kHz})} \quad (5)$$

To decrease the standby power consumption, the light-load efficiency should be carefully designed. When at very light load, the switching loss is the main loss and to decrease the switching loss, the switching frequency is designed at a low value. In this design, the CCM frequency is designed as 100 kHz. Therefore the  $R_{\text{RON}}$  is 125 k $\Omega$ .

The buck inductor is calculated using [Equation 6](#), where  $\Delta I$  is the current decrease value when the main FET is off. In this design, the critical-mode load is designed at 300 mA, therefore L is 68  $\mu\text{H}$ .

$$L(H) = \frac{V_{OUT} (V) \times (1 - t_{on} (ms) \times F_{SW} (kHz))}{\Delta I (mA) \times F_{SW} (kHz)} \quad (6)$$

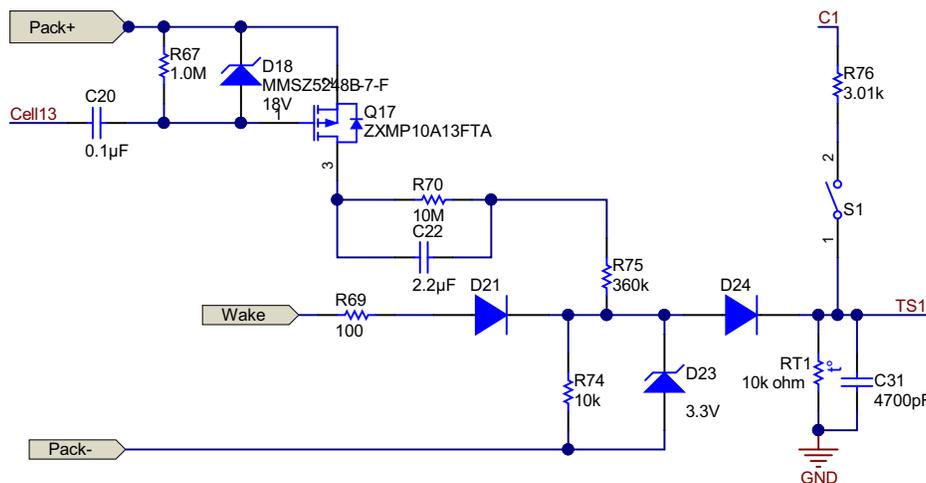
### 2.3.3 Pack Current Sensing Design

The pack-current sensing uses a high-accuracy resistor. To ensure accurate current measurement, the input voltage generated across the current sense resistor should not exceed  $\pm 125$  mV. For applications with a very high dynamic range, it is allowable to extend this range to absolute maximum of  $\pm 300$  mV for overload conditions where a protector device will be taking independent protective action. In such an overloaded state, current reporting and gauging accuracy will not function correctly. The normal current is designed as 30 A and the OCD threshold is designed as 60 A. Therefore, the current sensing resistor is designed less than 2.08 m $\Omega$ . A 2 m $\Omega$  with 50-ppm temperature coefficient and power rating of 5 W is used in this design.

### 2.3.4 Wake-up Circuit Design

When the battery pack is first time powered on or with very low battery voltage, the system enters the ship mode and the entire system, except for BQ76940, powers off to save power. In this mode, the BQ76940 device monitors the wake up command. This design gives two wake up methods, the first method is through a button that generates a wake-up signal on TS1 pin. The second method detects if the charger attached with the circuit shown in Figure 3. When a right charge is attached, Q15 is turned on and pull TS1 high, and because of C20 and C18, Q15 is turned off, generating a wake-up signal on TS1 pin. Wake signal is from the MCU and can also wake up the BQ76940 from shutdown mode.

**Figure 3. Wake-Up Circuit**



### 3 Hardware, Software, Testing Requirements, and Test Results

#### 3.1 Required Hardware and Software

##### 3.1.1 Hardware

This design has no hardware available for any board requests. The test is executed on a discrete circuit connected with TIDA-010030. Texas Instruments offers the total schematic and BoM for reference.

##### 3.1.2 Software

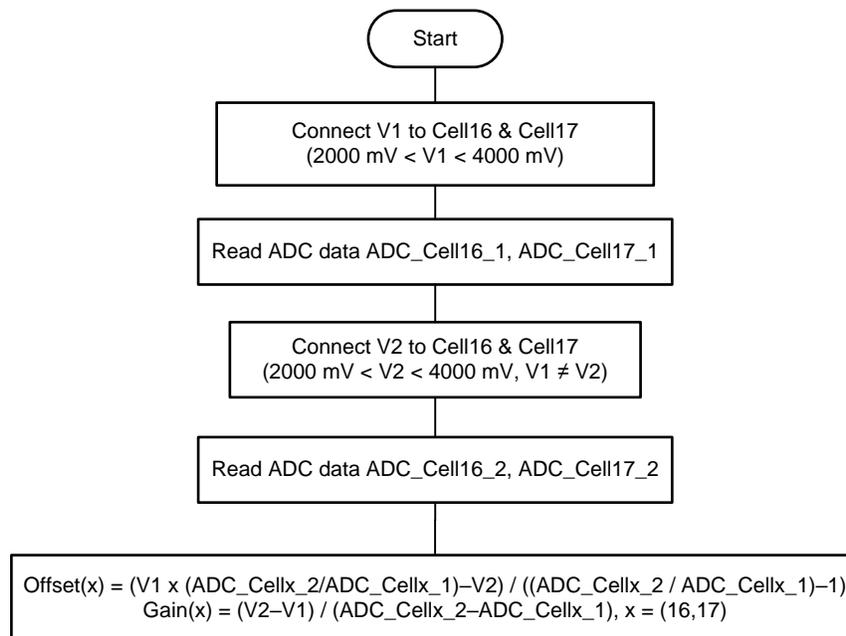
###### 3.1.2.1 Using the bq769X0 Eval Software

Download the bq769X0 Eval Software from Texas Instruments. It can act as a host controller to read voltage, current and temperature data from bq76940. See the [bq76930 and bq76940 Evaluation Module user's guide](#) to learn how to use this tool.

###### 3.1.2.2 16th, 17th cell voltage trimming

To get typical  $\pm 5$ -mV high cell voltage sensing accuracy for the 16th and 17th cell voltage, trimming is necessary to eliminate the impacts of resistors tolerance, reference tolerance, amplifier input voltage offset. The firmware program flow chat is list as [Figure 4](#).

**Figure 4. Cell Voltage Trimming Program Flow Chat**



And to receive  $\pm 10$ -mV cell voltage-sensing accuracy across entire temperature range, low-temperature coefficient resistors, low-temperature drift amplifier, and ADC are required.

## 3.2 Testing and Results

### 3.2.1 Test Setup

This design is tested on a discrete circuit connected with TIDA-010030. [Table 2](#) summarizes the equipment used for testing. The discrete circuit samples the upper 16th and 17th cell voltage and TIDA-010030 monitors the lower 15 cells. But because TIDA-010030 is designed as 13S design, VC8 is shorted to VC9, VC13 is shorted to VC14 in bq76940. So you need to separate them and monitor 15 cells, as we show in the TIDA-010074 schematic page 3. There are below changes for TIDA-010030: 1) remove bq34z100-g1; 2) remove ISO1042; 3) use P1.0 and P1.1 as ADC channels for the 16th and 17th cell voltage sensing; 4) the Vin of LM5164 should be Cell17 (BAT+) . Other changes please refer the TIDA-010074 schematic.

So the discrete circuit should be connected to the upper of TIDA-010030, and together monitor total 17 series battery cells. The output signals of the discrete circuit are connected to TIDA-010030 MCP430 P1.0 and P1.1 for 16th and 17th cell voltage sensing. The control signals also comes from MSP430 general purpose IOs. User can refer the schematic or choose their prefer IO PINs. The input of LM5164 should be change to the highest cell voltage BAT+.

**Table 2. Test Equipment Summary**

EQUIPMENT	MODEL OR DESCRIPTION
Oscilloscope	Tektronix DPO 3054
DC Power supply	Chroma 62050P-100-100
Electronic load	Chroma 63106
Multimeter	Agilent 34401A
Communication adapter	Texas Instruments EV2300 or EV2400
MSP430 programmer	MSP430 LaunchPad™
Battery cell	INR18650 MH1 3200 mAh

### 3.2.2 Test Results

#### 3.2.2.1 Boot

The DC/DC powers the 3.3-V MCU is powered by the DC/DC converter, LM5164, and the input of the LM5164 is controlled by two signals: REGOUT from the BQ76940 and SYS from the MCU. Either of them will enable the input of the LM5164, and therefore, enable the MCU power supply. When the board is powered on for the first time, the board is in ship mode. The entire system, except for the BQ76940, is not powered on. Choose either of the following methods to wake the system up. The first method is through pressing the S1 button. [Figure 5](#) shows BQ76940 TS1 PIN and REGOUT PIN voltage waveform. The REGOUT PIN is set high after 1-ms delay from when the S1 button is pressed. The second method to wake the board is to attach a charger. When the battery pack has low battery voltage, the board will also enter ship mode. When in this mode, wake the board up by attaching a charger. [Figure 6](#) shows the test result. Both methods generate a rising edge on TS1 PIN. Then, set REGOUT high to enable the MCU power supply. When the MCU is powered on, it will set SYS high. The entire system has stable power supply regardless if the BQ76940 is in shutdown or normal mode.

Figure 5. Wake up With Button

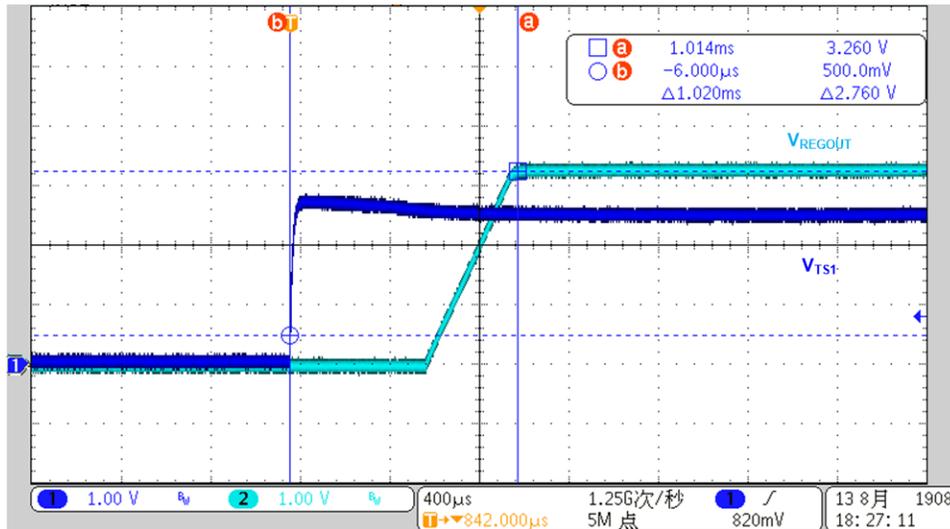
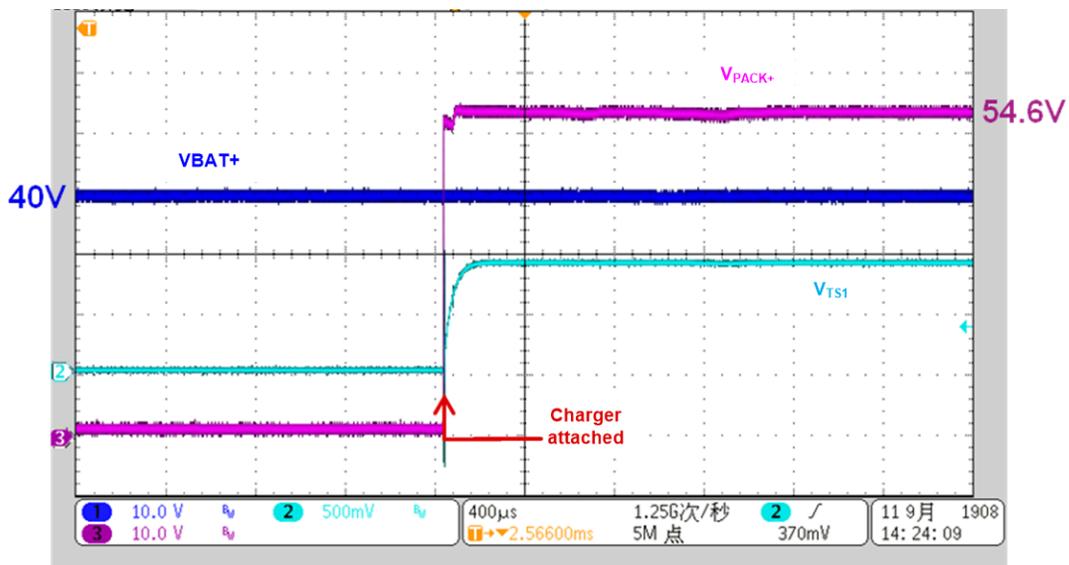


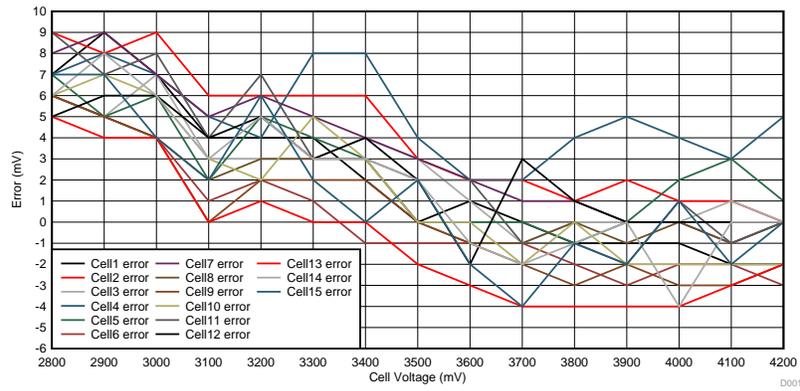
Figure 6. Wake up With Charger



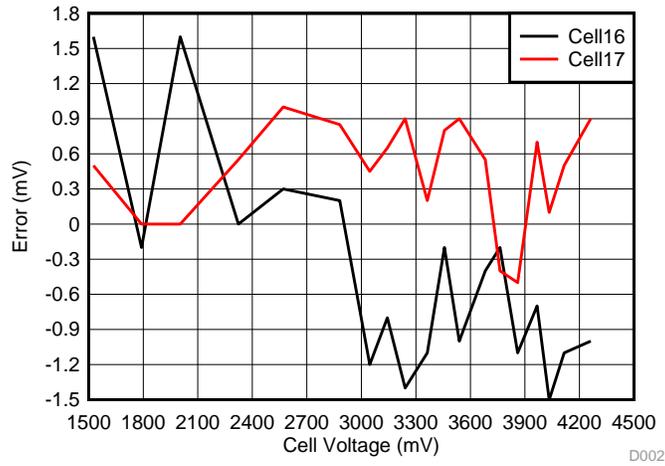
### 3.2.2.2 Cell Voltage Sensing Accuracy

Figure 7 shows the BQ76940 cell voltage measurement accuracy at room temperature. The voltage error is typically below  $\pm 10$  mV. The BQ76940 measures the voltage across the current sensing resistor and sends the voltage data out through I<sup>2</sup>C. The firmware should do the calculation and gets the current information. Before measuring the 16th and 17th cell voltage, the board needs trimming to get better accuracy. The trimming process is listed in Figure 4. After trimming, the 16th and 17th cell voltage sensing accuracy at room temperature (25°C) is listed in Figure 8, Figure 9, and Figure 10 show the high temperature (50°C) and low temperature (0°C) cell voltage sensing accuracy.

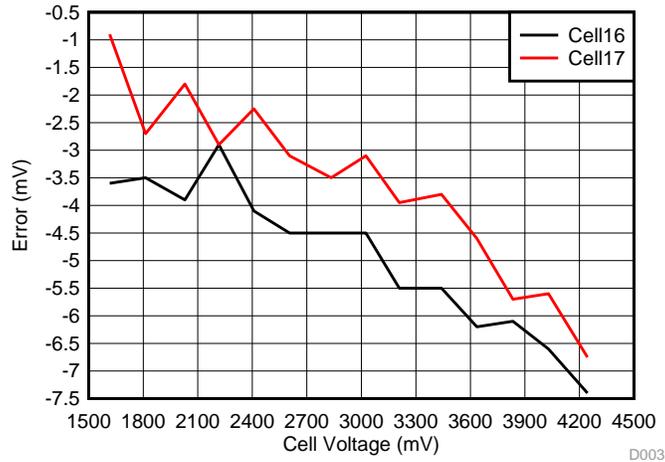
**Figure 7. Cell 1–15 Voltage Sensing Accuracy**



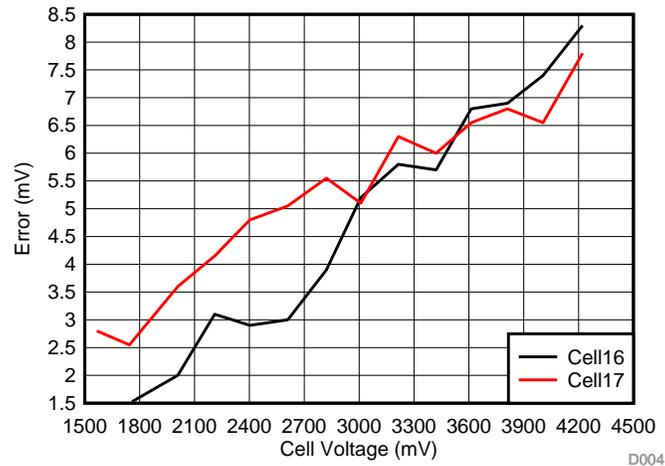
**Figure 8. 16th and 17th Cell Voltage Sensing Accuracy at 25°C**



**Figure 9. 16th and 17th Cell Voltage Sensing Accuracy at 50°C**

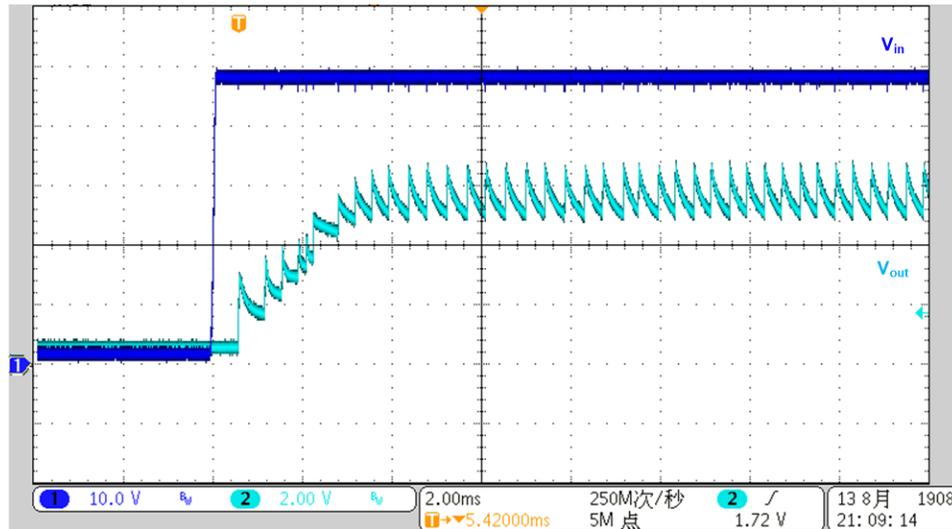


**Figure 10. 16th and 17th Cell Voltage Sensing Accuracy at 0°C**



**3.2.2.3 DC/DC Buck**

This design is powered by a buck converter. To decrease light load consumption, LM5164 enters DCM and decrease switching frequency. Figure 11 shows the buck converter start-up waveform.

**Figure 11. Buck Start up**


### 3.2.2.4 Standby Mode

For e-motorcycle battery pack application, standby mode refers to two kind of scenarios: when the battery pack is outside of the e-motorcycle and when the battery pack is put inside of the e-motorcycle but not running. Because this design is for using the same charge and discharge port, the charger is only attached in the first scenario. The battery pack in the first scenario should be able to detect if the charger is attached or if the battery pack is put inside of the e-motorcycle. The battery pack in the second scenario should be able to detect if load is on or if the battery pack is plugged in outside of the e-motorcycle.

Figure 12 shows the standby test waveforms in the first scenario. The dark blue curve is the pre-discharge MOSFET drive voltage and the green curve is PMON of the BQ76200, which controls a switch to measure PACK side voltage. The light blue curve is the PACK side voltage. The first pulse of PMON is to measure PACK voltage with pre-discharge MOSFET off. If the charger is attached, the voltage should be equal to charger voltage. If not, the pre-discharge will be turned on. After a short time delay, the PACK voltage will be measured again. If the battery pack is put in the e-motorcycle, a large capacitor will be connected between PACK+ and PACK-, therefore, the measured voltage is lower than the battery voltage.

Otherwise, the PACK voltage is equal to the battery voltage. The detection sequence happens every 200 ms, which will not cause obvious delay. In the second scenario, the pre-discharge MOSFET is mostly on. If load is on, there will be a voltage drop across the resistor series with the pre-discharge MOSFET, therefore, the measured voltage is lower than the battery voltage. If not, the pre-discharge will turn off. After a some time delay, the PACK voltage is measured. If the battery pack is plugged outside of the e-motorcycle, the output capacitor is much smaller, which will cause a larger voltage drop. The waveforms are shown in Figure 13.

Figure 12. Standby Scenario 1 Test Waveforms

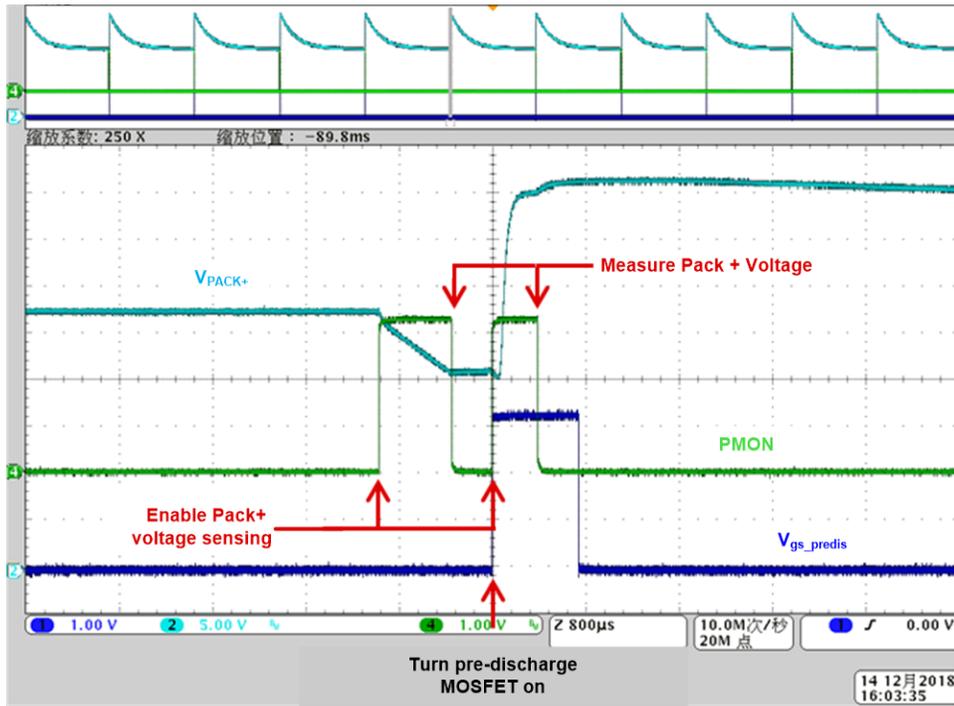
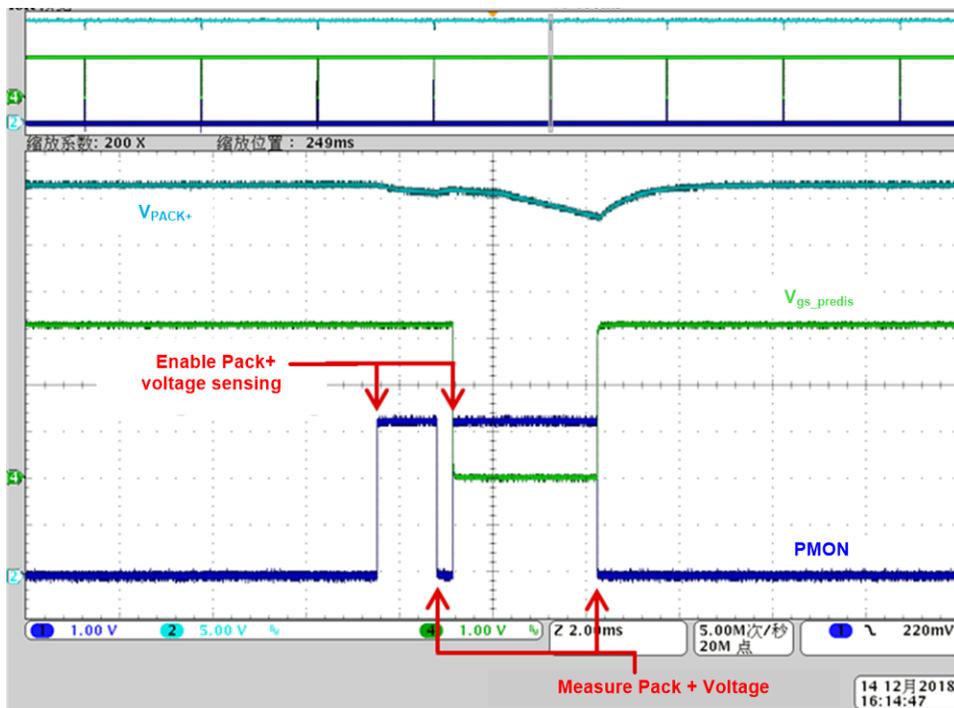


Figure 13. Standby Scenario 2 Test Waveforms



When in standby mode in the second scenario and when the load is turned on, the pre-discharge MOSFET will allow a small current to power the system. The charge and discharge MOSFETs are turned on after some delay. [Figure 14](#) shows the test waveforms. The purple curve is the discharge MOSFET drive voltage, the blue curve is the PACK side voltage, and the green curve is the discharge load. [Figure 15](#) shows the test waveforms when the load is off and when the system enters standby mode in the second scenario.

Figure 14. Standby Scenario 2 Detect Load

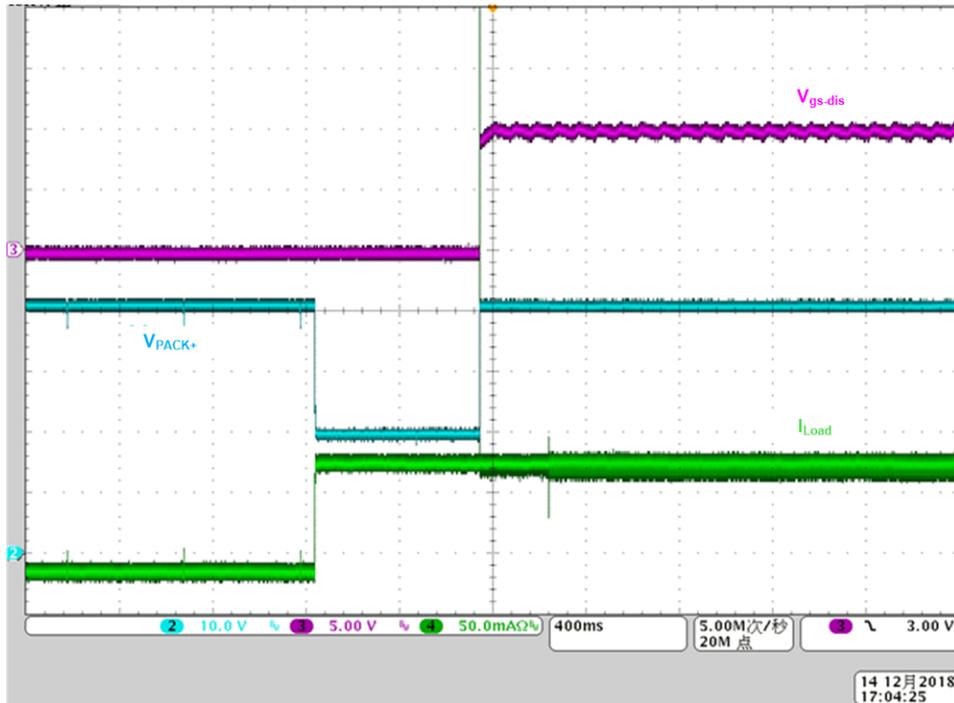
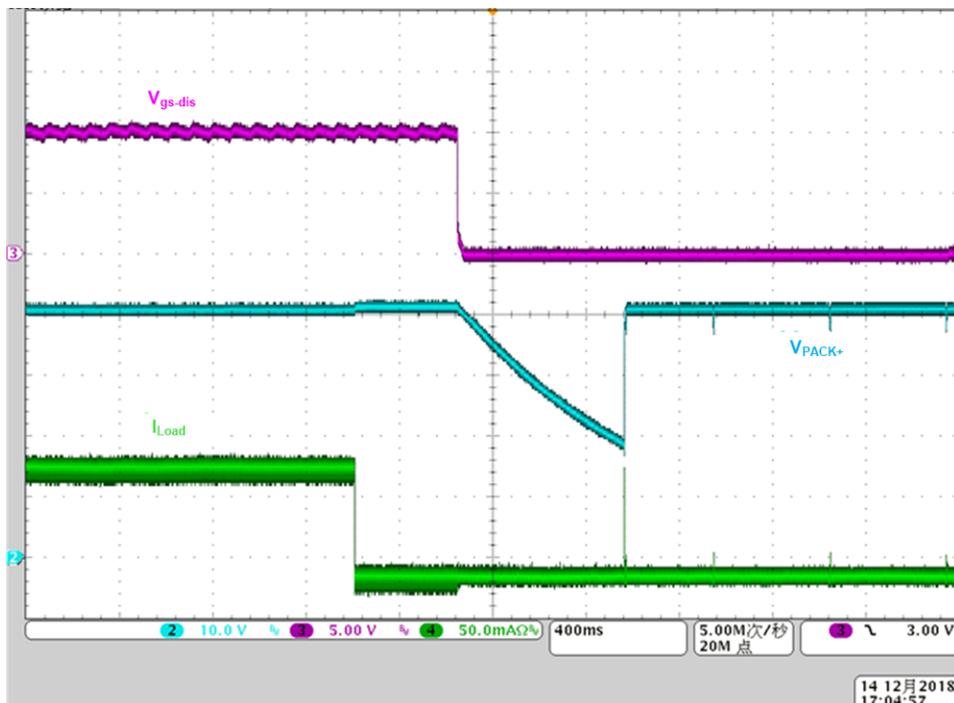
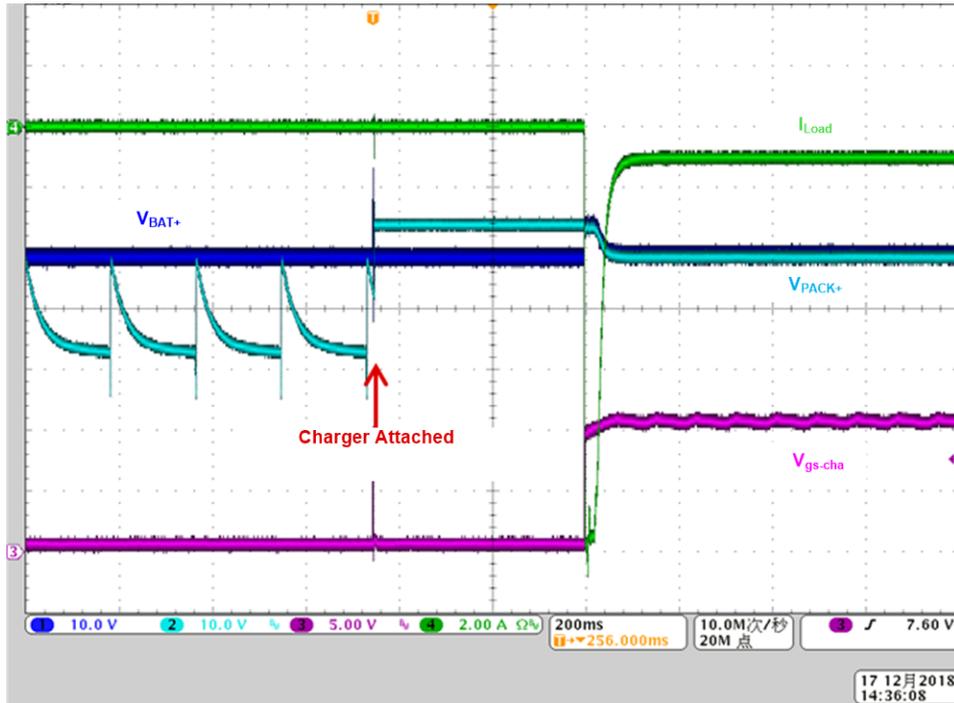


Figure 15. Load Off to Standby Scenario 2

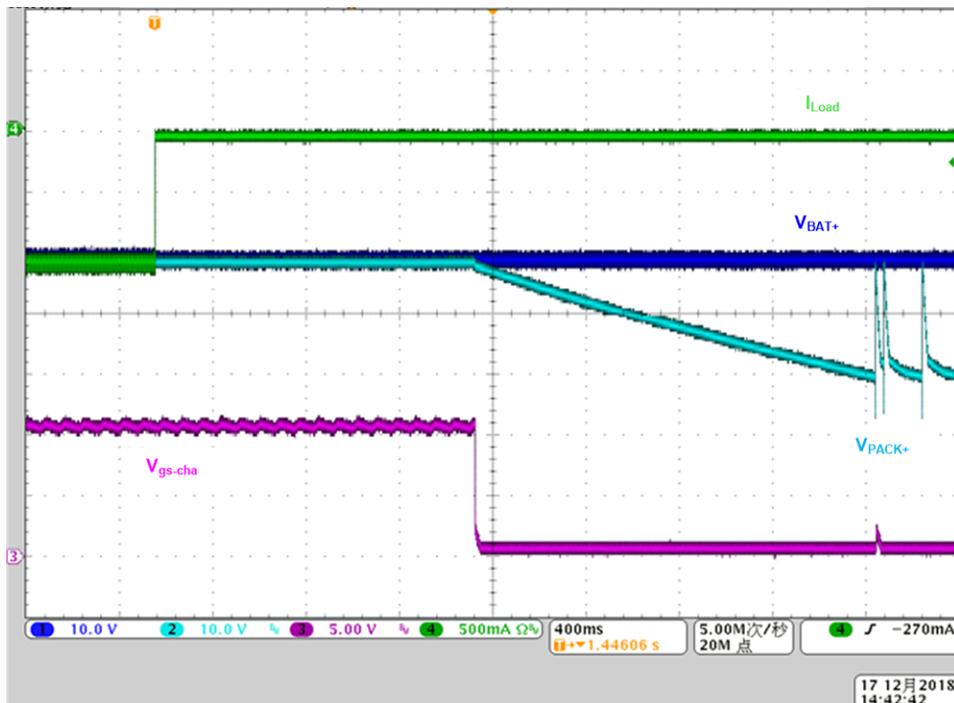


When in standby mode in the first scenario and the charger is attached, **Figure 16** shows the resulting test waveforms. The purple curve is the charge MOSFET drive voltage, the light blue curve is the PACK side voltage, the dark blue curve is the battery voltage, and the green curve is the discharge load. When the charger MOSFET is turned on, the PACK side voltage is clamped to the battery voltage. **Figure 17** shows the test waveforms when the charger is removed and the system enters standby mode in the first scenario.

**Figure 16. Standby Scenario 1 Detect Charger**



**Figure 17. Charger Removed to Standby Scenario 1**



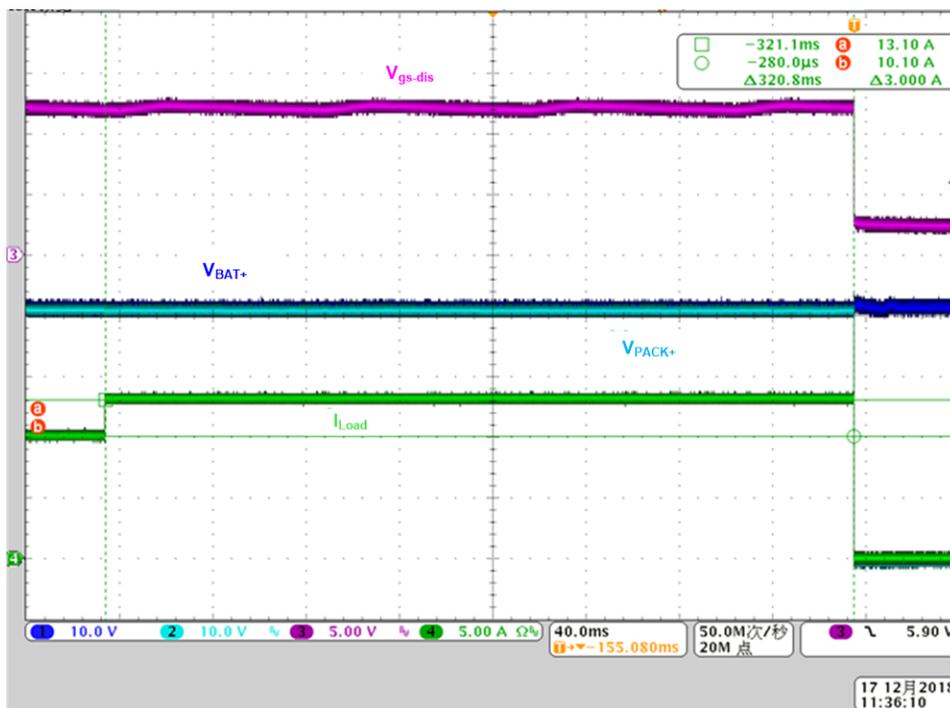
For telecom battery backup application, the charge and discharge MOSFETs are always on in standby mode, and the pre-discharge MOSFET is not using. In this case, both bq76940 and bq76200 are in normal model, the host just need to update the cell voltage, current, temperature data regularly for battery protection.

For both applications, the standby current consumption is less than 100  $\mu$ A.

### 3.2.2.5 Protections

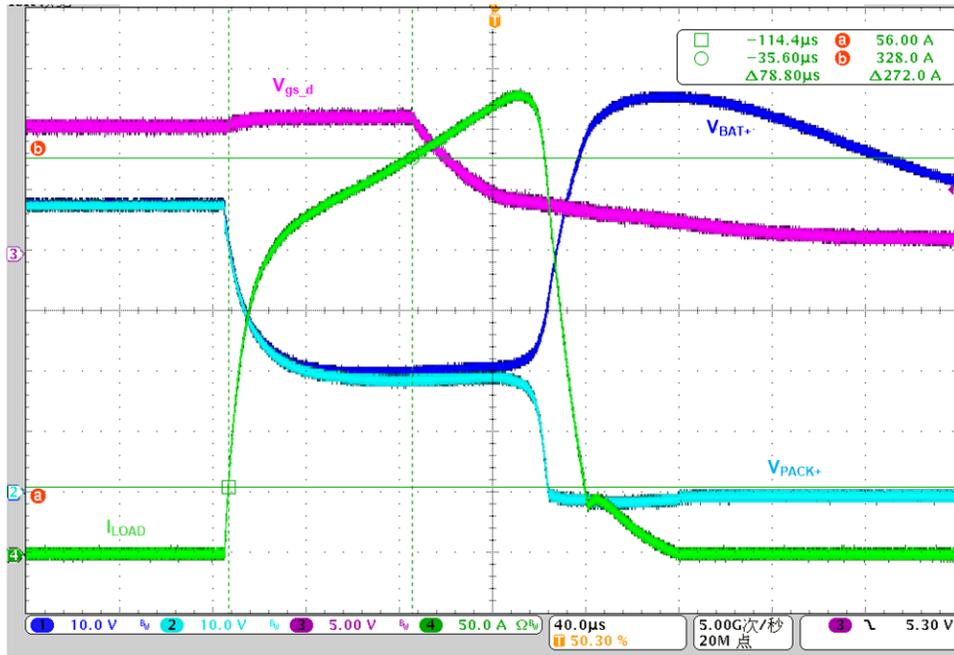
The firmware configures the OCD threshold at 11 mV which turns out about 11-A discharge current with the delay is set at 320 ms. Figure 18 shows the waveform. The green curve is discharge current, the dark blue curve is the battery voltage, the light blue is the PACK side voltage, and the purple curve is the discharge MOSFET drive voltage. When the discharge current is switched from 10.1 A to 13.1 A after a 320-ms delay, the discharge MOSFET is turned off to stop the discharging.

Figure 18. Overcurrent Discharge Protection



To test the designs short circuit protection feature, a switch is used to short PACK+ to PACK-. Figure 19 illustrates the SCD triggered. The purple curve is the discharge load, the dark blue curve is the PACK side voltage, the light blue curve is the battery voltage, and the green curve is the discharge MOSFET drive voltage. When the switch shorts PACK+ and PACK-, the current increases quickly to the SCD threshold, 56 A. Meanwhile, the PACK side voltage is pulled to a low value. After a delay of about 78.8  $\mu$ s, the discharge MOSFET is turned off and stops the discharging.

Figure 19. Short-Circuit Discharge Protection



## 4 Design Files

### 4.1 Schematics

To download the schematics, see the design files at [TIDA-010074](#).

### 4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-010074](#).

### 4.3 Altium Project

To download the Altium Designer® project files, see the design files at [TIDA-010074](#).

## 5 Related Documentation

1. Texas Instruments, [bq76930 and bq76940 Evaluation Module User's Guide](#)
2. Texas Instruments, [bq769x0 3-series to 15-series Cell Battery Monitor Family for Li-Ion and Phosphate Applications Data Sheet](#)
3. Texas Instruments, [LM5164 100-V Input, 1-A Synchronous Buck DC/DC Converter with Ultra-low  \$I\_Q\$  Data Sheet](#)

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