TI Designs

Non-Military Drone, Robot, or RC 4S1P Battery Management Solution Reference Design

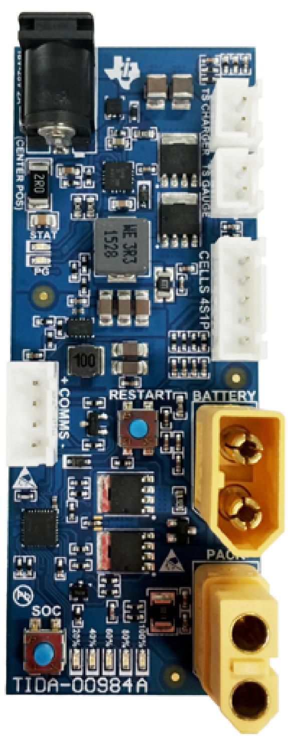
Overview

The TIDA-00984 is a subsystem design for a 4S1P battery management solution (BMS) for non-military drone, robot, or radio controlled (RC) projects and designs. This TI Design quickly adds gauging, protection, balancing, and charging to any existing design for a non-military drone, robot, or RC product. The board also adds advanced features to existing designs. The TIDA-00984 also tests the features of advanced battery management quickly and easily.

Resources

TIDA-00984	Design Folder
bq4050	Product Folder
bq24600	Product Folder
TPS62175	Product Folder

TI E2E™ Community — ASK Our E2E Experts

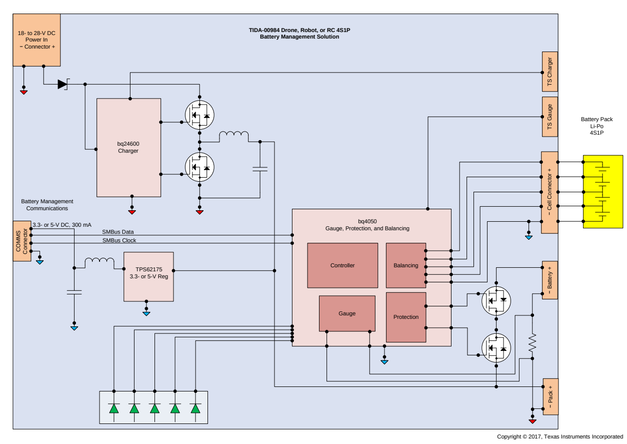


Features

- Compensated End-of-Discharge Voltage (CEDV) Gas Gauge Accurately Measures Available Charge in Li-Ion and Li-Polymer Batteries
- Integrated Cell Balancing While Charging
- Programmable Protection Features for Voltage, Current, Temperature, Charge Time Out, CHG/DSG FETs, and AFE
- Diagnostic Lifetime Data Monitor and Black Box Recorder for Battery
- Onboard 3.3- or 5-V, 500-mA Regulator to Run External Controller

Applications

- Battery Charger
- Battery Fuel Gauging
  – CEDV (bq4050)
  – Impedance Track (bq40Z50)
- Battery Protection
- Battery Pack Cell Balancing
- Onboard State of Charge (SOC)
- SMBus Communications for Advanced Status Updates



1 System Overview

1.1 System Description

The TIDA-00984 is designed using the best IC's and circuits available to provide a scalable battery management solution (BMS) for non-military drone, robot, or radio controlled (RC) projects and designs. For convenience and support, this board has a built-in charger, protection, cell balancing, gauging, and a 3.3-V (or 5-V) switching regulator to drive the controller or other external circuitry, all on one small PCB.

One of the biggest problems with adding a battery gauge to a non-military drone is the wide current range that is required. Many gauging algorithms do not work well when the motor drive current goes more than 3 to 5C more than the rated 1C rate of the battery. The bq4050 uses compensated end-of-discharge voltage (CEDV) for the gauging algorithm and works excellent in designs well above the 1C rate up to 25 to 50C rates.

This drone board is developed to support most 200-mm and 400-mm non-military drones using two-series (2S), three-series (3S), and four-series (4S) Li-Poly battery packs. Many robot projects, RC cars, RC planes, and RC helicopters have similar requirements for their battery packs, and this board works very well in all of these designs.

All of the IC's on this board are capable of supporting 2S to 4S; however, this board is specifically designed for 4S. See Section 2 for a better understanding of how to use this board and how to change this board to make it a 3S design.

This drone board has been designed to handle up to a 30-A peak and surge currents and up to 15-A continuous current to be able to handle the fast motor spin ups and rapid acceleration that is required for drones, robots and RC equipment. This battery is a 1.3-Ah rated capacity with a discharge rate of 25 C. The gauge parameter file was created to support 4S1P using this battery and the bq4050 with the CEDV gauging algorithm. The charger was set to 1.3 A for a 1 C charge rate. The board is scalable and can be used with battery packs with up to a 4-Ah capacity. The charger may be adjusted to charge at a 4-A charge rate by changing only the current level. All components are capable of charging at the 4-A charge rate.

This design is 100% compatible with the bq40Z50 Impedance tracking gauge IC. The gauge IC's are pin-to-pin compatible and may be changed on this board, or the user can design the board in a preferred gauging method.

A buck switching regulator was added to provide power for an external microcontroller. This regulator is adjustable by changing one resistor in the feedback resistor divider. The default setting is 3.3-V DC at 500 mA.

All of the connectors in this TI Design were selected to be low cost, available from many vendors and as standard to what is being used in the industry as is possible.

Use the TIDA-00984 TI Design to start testing advanced battery management quickly and easily. The TIDA-00984 design concept may be quickly inserted to add gauging, protection, balancing, and charging to any existing design without modifying the circuit. This design concept helps users test and qualify the BMS IC with little effort.

This TI Design can also add advanced features to any existing drone, robot, or RC project or design by doing the following:

1. Unplug the battery from the drone.
2. Plug the battery power connector into the TIDA-00984 battery connector on the board.
3. Plug the cell connector into the TIDA-00984 4S1P connector.
4. Plug the drone into the pack connector on the board.

All of the features of the TIDA-00984 are now ready to test or use.

NOTE: The user must verify that the designed operating specifications of the TIDA-00984 are within the proper operating range to work with the drone.

NOTE: If the battery is not the same battery that is used in this design guide, then collect data from the battery to create the CEDV gauge tables.

NOTE: The following is information is critical to the design; it may be necessary to update or change the parameters of the gauge to be compatible with the circuit. If the circuit draws more current than the settings that were used in this TI Design, it may be possible for the protection circuit in the gauge to disconnect the battery from the drone while in flight.

It is the responsibility of the user to adjust and verify all parameters in the default bq4050 parameter file before use. This file is only a good place to start, and not an absolute solution.

Figure 1 shows the hook-up block diagram.

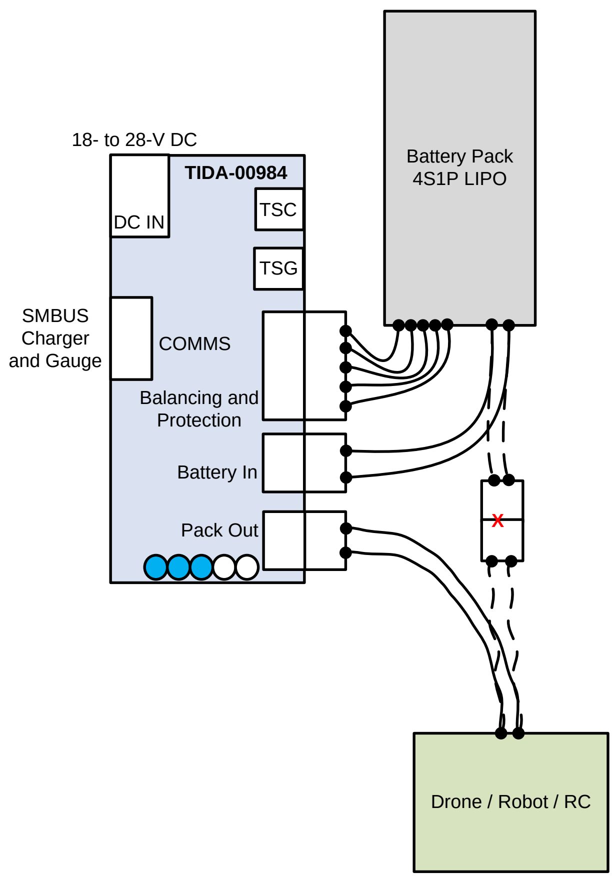


Figure 1. Hook-Up Block Diagram

1.2 Key System Specifications

Table 1. Collected Data and Set Parameters

PARAMETER	SPECIFICATION	VALUE	UNIT
Idle current for the gauge with regulator	Gauge active, MOSFETs on, gauge current for each cell, with a 3.3-V regulator	1.32	µA
Charger efficiency	24 V, 812-mA input; 13.971 V, 1301-mA output	93	%
Charge voltage	Measured charge voltage	16.73	V
Charge current max	Measured charge voltage at max	1.311	A
Charger input minimum	Minimum voltage the charger would turn on	18	VDC
Charger input maximum	Maximum voltage the charger preformed to spec	28	VDC
Voltage regulator	Voltage of the 3.3-V regulator	3.31	VDC
Max current from regulator	Measured current limit of the 3.3-V regulator	512	mA
Thermal test charger unit	(Ambient 23.8°C) 1.3-A charge cycle	43	°C
Thermal test under current for PCB	(Ambient 23.8°C) 10-A constant current load	72	°C
Pre-charge complete	Comes out of pre-charge	3	V
Pre-charge minimum voltage	Minimum pre-charge voltage	2	V
Series impedance	Battery connector to pack connector series impedance, including MOSFET RDS's	0.0325	Ω
OCD1 limit	Overcurrent limit during discharge	15000	mA
OCD1 delay	Overcurrent delay during discharge	20	S
OCD2 limit	Overcurrent limit during discharge	2,0000	mA
OCD2 delay	Overcurrent delay during discharge	10	S
AOLD limit	Analog front-end current overload limit	24	A
AOLD delay	Analog front-end current overload delay	15	ms
ASCD1 limit	Analog front-end short current limit 1	33	A
ASCD1 delay	Analog front-end short current delay 1	1,028	µs
ASCD2 limit	Analog front-end short current limit 2	44	A
ASCD2 delay	Analog front-end short current delay 2	244	µs

1.3 Block Diagram

Figure 2 shows the TIDA-00984 block diagram.

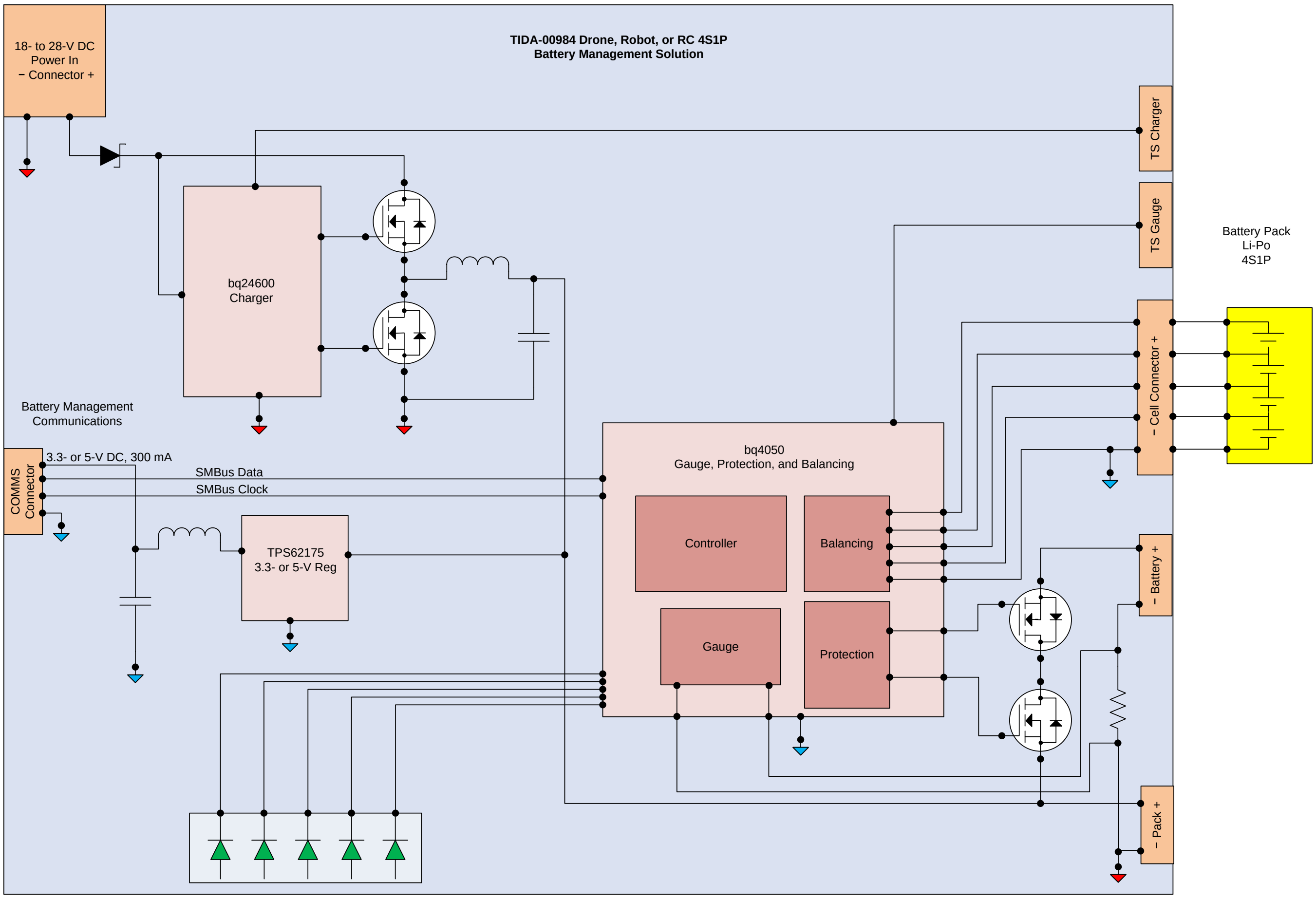


Figure 2. TIDA-00984 Block Diagram

1.4 Highlighted Products

1.4.1 bq4050 Gauge

The TI bq4050 device, incorporating CEDV technology, is a highly integrated, accurate, 2S to 4S cell gas gauge and protection solution, enabling autonomous charger control and cell balancing. The bq4050 device provides a fully integrated pack based solution with a flash programmable custom reduced instruction-set CPU (RISC), safety protection, and authentication for Li-Ion and Li-Polymer battery packs.

The bq4050 gas gauge communicates through an SMBus compatible interface and combines an ultra-low-power, high-speed TI bqBMP processor, high-accuracy analog measurement capabilities, integrated flash memory, an array of peripheral and communication ports, an N-CH FET drive, and an SHA-1 Authentication transform responder into a complete, high-performance battery management solution. The device also provides cell balancing while charging or at rest. This fully integrated, single-chip, pack-based solution provides a rich array of features for gas gauging, protection, and authentication for 1S, 2S, 3S, and 4S cell Li-Ion and Li-Polymer battery packs, including a diagnostic lifetime data monitor and black box recorder.

Figure 3 shows the bq4050 device, incorporating CEDV.

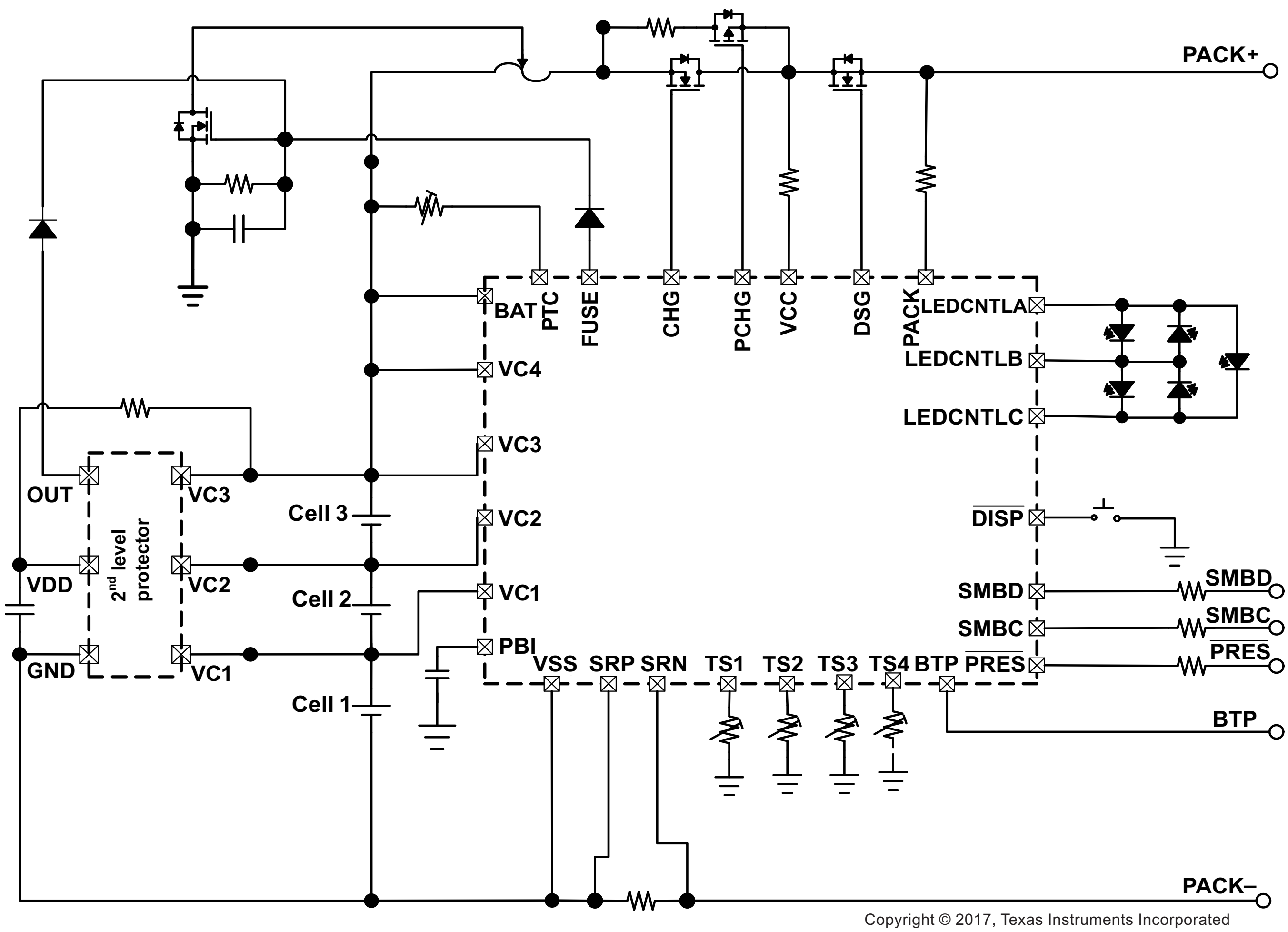


Figure 3. bq4050 Device, Incorporating CEDV

1.4.2 bq24600 Charger

The bq24600 is a highly integrated Li-ion or Li-polymer switch-mode battery-charge controller. It offers a constant-frequency synchronous PWM controller with high-accuracy charge current and voltage regulation, charge preconditioning, termination, and charge status monitoring.

The bq24600 charges the battery in three phases: preconditioning, constant current, and constant voltage. Charge is terminated when the current reaches a minimum level. An internal charge timer provides a safety backup. The bq24600 automatically restarts the charge cycle if the battery voltage falls below an internal threshold, and enters a low quiescent-current sleep mode when the input voltage falls below the battery voltage.

Figure 4 shows the bq24600 integrated Li-ion or Li-polymer switch-mode-battery-change controller.

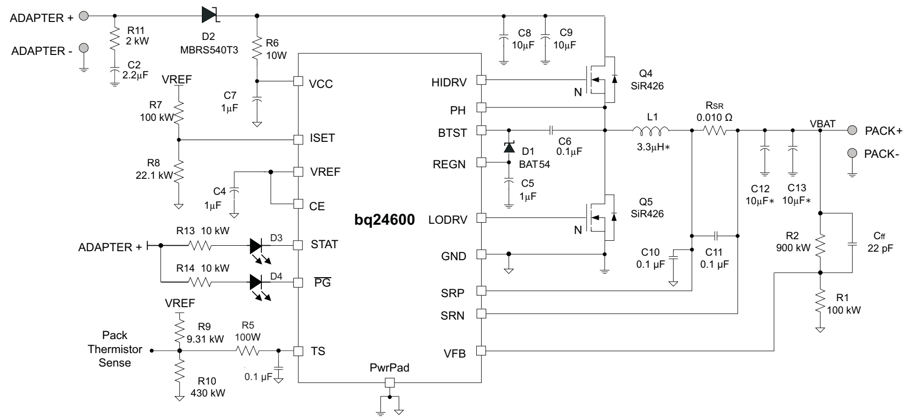


Figure 4. bq24600 Simplified Schematic

1.4.3 TPS62175 Regulator

The TPS62175 is a high efficiency synchronous step-down DC/DC converter, based on the DCS-Control™ topology. With a wide operating input voltage range of 4.75 to 28 V, the device is ideally suited for systems powered from multi-cell Li-Ion as well as 12 V and even higher intermediate supply rails, providing up to a 500-mA output current.

The TPS62175 automatically enters power save mode at light loads to maintain high efficiency across the whole load range. The device also features a sleep mode to supply applications with advanced power save modes like ultra-low-power microcontrollers. The power good output may be used for power sequencing or power on reset.

The device features a typical quiescent current of 22 µA in normal mode and 4.8 µA in sleep mode. In sleep mode, the efficiency at very low load currents can be increased by as much as 20%. In shutdown mode, the shutdown current is less than 2 µA and the output is actively discharged.

Figure 5 shows the TPS62175 high-efficiency synchronous step-down DC/DC converter.

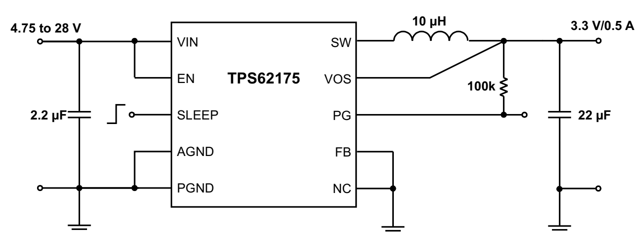


Figure 5. TPS62175 Typical Application Schematic

2 System Design Theory

The TIDA-00984 design concept was created to be able to be quickly inserted into an existing design. This TI Design adds gauging, protection, balancing, and charging to any existing design without modifying your circuit. This board can also add advanced features to any existing drone, robot, or RC project or design. Simply unplug the battery from the drone, plug the battery power connector into the TIDA-00984 battery connector on our board, and then plug the battery cell connector into the TIDA-00984 4S1P cell connector. *The user must press the restart button on the board before connecting any device to the PACK connector*. Restart initializes the gauge for the battery that was just connected. This restart process allows the user to swap batteries if it is decided to not keep this board married to the battery that it is connected to. Then pug the drone into the PACK connector on the TIDA-00984. All of the features of the TIDA-00984 are now ready to test or use.

Use this board as a pack-side gauge. Once this board is connected to a battery, they both must remain connected for the life of the battery. As a pack-side gauge, there are many features that come with this type of setup, including a diagnostic lifetime data monitor and black box recorder. The gauge will also remain accurate throughout the life of the battery.

If this board is to be used as a systems-side gauge, then there are a few details that must be considered. First, always fully charge the battery before connecting the battery to the board. Then, press restart to allow the gauge to initialize itself to the battery. Be aware that when using the bq4050 as a system-side gauge that the gauge cannot determine the age of the battery, so the gauge will have a higher chance of error in gauging than if it were a pack-side gauge. If the battery connected is not fully charged, the gauge may not be able to report the state of charge (SOC) accurately; however, the gauge will become more accurate the longer the battery is left connected and goes through several charge and discharge cycles.

2.1 *Communications*

The TIDA-00984 has a connector on the left side of the board labeled COMMS. Any microcontroller that is capable of SMBus may talk to the gauge. This can include the initialization file, changing parameters, and reading out all of the parameters and measured values like the SOC, health, status, and all of the diagnostic and black box information.

Figure 6 shows the COMMS connector.

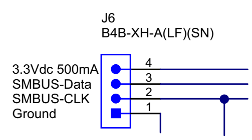


Figure 6. COMMS Connector

COMMS:

- Pin 4: 3.3-V (or 5-V), 500-mA supply to run external circuits including a microcontroller, radio, or other peripherals.
- Pin 3: SMBUS-Data
- Pin 2: SMBUS-Clk
- Pin 1: Ground

On the bench, you may use TI's Battery Management Studio (bqStudio) and the EV2300 or EV2400 interface. Download the bqStudio program from its TI website. See Section 3.2, bqStudio, and EV2300 for more information.

NOTE: TI recommends to not connect the drone until the parameters have been adjusted to meet the requirements for the battery and drone being used.

2.2 Gauging

The bq4050 is a CEDV gauge IC. This TI Design uses CEDV to gauge motor control applications with high current surges up to 25C of the batteries amp hour rating. The bq40Z50 uses Impedance Tracking™ (IT) and is more accurate overall, but does not like discharge rates more than 4C and will sometime give a higher than desirable error in SOC if used under continuous high current variations. If the application does not have high discharge rates, then switch to the bq40Z50 with IT technology.

The bq4050 is a fully integrated single cell, 2S, 3S, and 4S Li-Ion or Li-Polymer cell battery pack manager and protection IC. It uses a high-side N-CH protection FET drive, making the design simpler and more efficient. The cell balancing is integrated and works while charging. This IC has a full array of programmable protection features, authentication capabilities, SOC LED drive circuits, diagnostic, lifetime data monitor, and a black box recorder.

Setting up the gauge and creating the battery profile for the bq4050 gauge is easier for CEDV than other technologies. The Gauging Parameter Calculator (GPC) is a math calculation and simulation tool that helps the battery designer to obtain matching CEDV coefficients for the specific battery profile. The tool allows the user to increase the accuracy of the fuel gauge IC over temperature. The battery pack must use one of TI's CEDV algorithm-based fuel gauges like the bq4050. It accepts three pairs of log files that can be created with various user equipment or by using TI's bqStudio software with a CEDV evaluation board connected through USB.See TI's *Simple Guide to CEDV Data Collection for Gauging Parameter Calculator (GPC)* (SLUUB45) for more information on creating CEDV coefficients for the battery.

2.3 Protection

The TIDA-00984 has a full array of programmable protection features are extensive. The primary safety features include:

- Cell overvoltage protection
- Cell undervoltage protection
- Cell undervoltage protection compensated
- Overcurrent in charge protection
- Overcurrent in discharge protection
- Short circuit in charge protection
- Short circuit in discharge protection
- Over-temperature in charge protection
- Over-temperature in discharge protection
- Under-temperature in charge protection
- Under-temperature in discharge protection
- Over-temperature FET protection
- Pre-charge timeout protection
- Host watchdog protection
- Fast charge timeout protection
- Overcharge protection
- Overcharging voltage protection
- Overcharging current protection
- Over pre-charge current protection

The secondary safety features provide protection against:

- Safety overvoltage permanent failure
- Safety undervoltage permanent failure
- Safety over-temperature permanent failure
- Safety FET over-temperature permanent failure
- Fuse failure permanent failure
- PTC permanent failure
- Voltage imbalance at rest permanent failure
- Voltage imbalance active permanent failure
- Charge FET permanent failure
- Discharge FET permanent failure
- AFE register permanent failure
- Second level protector permanent failure
- Instruction flash checksum permanent failure
- Open cell connection permanent failure
- Data flash permanent failure
- Open thermistor permanent failure

All of these safety features are programmable, adjustable, and need to be set to the correct value for this TI Design. Once the user has a default file with the battery profile information, protection settings, standard operating settings, and AFE protection settings in place, the user can set up and test the battery management solution in the TIDA-00984 design.

Pay close attention to the AFE settings. If the AFE has the wrong settings, the AFE could trigger, causing the drone to fall out of the sky. The AFE detects overcurrent and cell shorts in the system and can disconnect the protection MOSFETs without the influence of the controller.

2.4 Cell Balancing

The device supports cell balancing by bypassing the current of each cell during charging or at rest. If the device's internal bypass is used, up to 10 mA can be bypassed and multiple cells can be bypassed at the same time. Higher cell balance current may be achieved by using an external cell balancing circuit. In external cell balancing mode, only one cell at a time may be balanced. The cell balancing algorithm determines the cells to be balanced based on the cell voltage until all cell voltages are within a programmable voltage range.

2.5 Charging

The output for the charger is set at 16.8 V for a 4S battery solution. The input voltage range for our charger is 1 V above the output voltage or 17.8 up to 28 V. This charger tested well at 18 to 24 V at the 1.3-A setting. If the charge current was set to 4 A, the dropout voltage would have been higher at 18.5 V. If this were a 3S solution, the output voltage would be set to 12.6 V. The input voltage would be 13.6 to 28 V.

The current limit was set to a 1 C rate of 1.3 Ah for the battery being used. While it is true that the battery can charge at a 5 C rate, there are many reasons not to charge above the 1C rate. If this was a pack-side solution and there was a proper NTC Thermistor for monitoring the battery temperature, then it would be acceptable to charge at a 2 C to 5 C rate.

NOTE: Do not charge at higher than a 1C rate when there is no temperature sensing or monitoring inside of the battery pack.

The charger feedback circuit uses a resistor divider to set the output voltage. A third resistor was added to the resistor divider as a 0-Ω resistor. The purpose of this extra resistor is to provide a more accurate feedback voltage by adding resistance to the top resistor to expand the resistance range if required.

The TIDA-00984 has two connectors for temperature monitoring: one for the charger and one for the gauge. This is available for use in testing and development, with the addition of a leaded thermistor. To test charging at a higher rate, use the charger thermistor port. To test discharging at a higher constant current or higher surge current rate, use the gauge temperature thermistor port. It is possible to use the gauge thermistor port to monitor the battery temperature during charging, but there will not be a current control mechanism available. The gauge will disable charging by turning off the charge MOSFET when the temperature goes to high. This is not the best method, but it will work. Remember to set the parameters for temperature monitoring the battery.

To use the thermistor ports for the charger or the gauge, remove the default 10k fixed resistor from the desired port and add a leaded thermistor to the appropriate connector. If an external thermistor is connected to the connector without removing the default 10k resistor, the temperature will always read about 25°C. If the default 10k resistor is removed and the external leaded thermistor is not added, then the device will read very high or max temperatures all of the time and the system will not operate.

2.6 MOSFETs

The PSMN013-30YLC mosfet for this TI Design was picked for its high power rating, low RDS, low parasitic inductance, and capacitance. The low gate drive voltage and the ultra-low QG, QGD, and QOSS for high system efficiencies at low and high loads were necessary to keep this design cool and efficient not only for the switching charger but for the constant on load switch capabilities for the AFE protection circuit.

This MOSFET is rated at a 32-A constant current,; however, the selected MOSFET de-rates to about 25 A at higher temperatures. The designer must know the current demands and design appropriately.

Table 2 shows the MOSFET parameters.

Table 2. MOSFET Parameters

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
V_{DS}	Drain-to-source voltage	25°C ≤ T_j ≤ 175°C	—	—	30	V
I_D	Drain current	T_{mb} = 25°C; V_{GS} = 10 V	—	—	32	A
P_{tot}	Total power dissipation	T_{mb} = 25°C	—	—	26	W
T_j	Junction temperature	—	–55	—	175	°C
STATIC CHARACTERISTICS						
R_{DSon}	Drain-to-source on-state resistance	V_{GS} = 4.5 V; I_D = 10 A; T_j = 25°C	—	14.4	16.9	mΩ
		V_{GS} = 10 V; I_D = 10 A; T_j = 25°C	—	11.6	13.6	mΩ

2.7 Battery

The Turnigy® B00TDH7LH6 nano-tech Li-Poly batteries use an advanced LiCo nano-technology substrate that allows electrons to pass more freely from anode to cathode with less internal impedance. This means higher voltage under load, straighter discharge curves, and excellent performance.

Figure 7 shows the Li-Poly battery used in this TI Design.

Figure 7. Li-Poly Battery

Capacity specifications:

- Voltage: 4S1P, 2 cell, 14.4 V (16.8-V DC max)
- Discharge: 25 C constant and 50 C burst
- Weight: 155 g (including the wires and plugs)
- Dimensions: 73 mm × 31 mm × 35 mm
- Balance plug: JST-XH
- Discharge plug: XT60 (60 A)

Advantages over traditional Li-Poly batteries:

- Power density reaches 7.5 kw/kg
- Less voltage sag during high rate discharge, giving more power under load
- Internal impedance can reach as low as 1.2 mΩ compared to that of 3 mΩ of a standard Li-Poly
- Greater thermal control, pack usually does not exceed 60°C
- Swelling during heavy load doesn't exceed 5%, compared to 15% of a normal Li-Poly
- Higher capacity during heavy discharge, more than 90% at 100% C rate
- Fast charge capable, up to 15 C on some batteries
- Longer cycle life, almost double that of standard Li-Poly technology

3 Getting Started Hardware

This section assumes a basic understanding of bqStudio and how it works. Please see the user's guide or operations manual before continuing[3].

3.1 Setup

Figure 8 shows the connector layout. See Figure 8 for the placement of the following connectors:

- Battery connections
- Communications
- Thermistors
- Charger input
- Pack connection

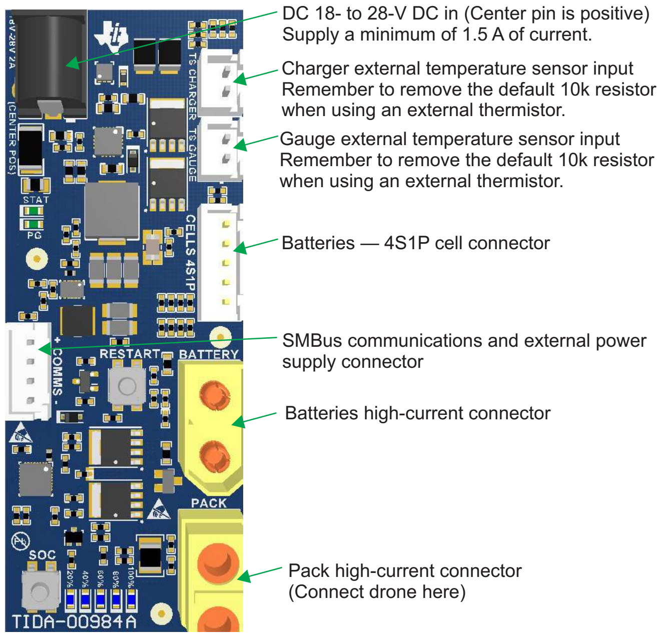


Figure 8. Connector Layout

3.2 bqStudio and EV2300

bqStudio offers a full suite of robust tools to assist with the process of evaluating, designing with, configuring, testing, or otherwise using TI battery management products. The EV2300 provides the hardware interface to communicate with the TIDA-00984 reference design.

1. Make sure the bqStudio software is installed.
2. Connect the EV2300 communications USB interface cable to the computer.
3. Connect the EV2300's SMBus communications cable to the TIDA-00984 communications connector.
4. Connect the battery's high current and cell connectors to the drone board.
5. Make sure the drivers for the EV2300 (EV2400) interface are installed.

NOTE: TI recommends to not connect the drone until the parameters have been adjusted to meet the requirements for the battery drone being used.

3.3 Gauge Initialization

The first time the TIDA-00984 is powered up, the bq4050 must be initialized. Some of the default parameters must be changed before loading the default parameter file. The provided default parameter file can be used as a starting point.

Hold down the RESTART button until the necessary default registers have been changed and the main FETs turned on.

NOTE: The bq4050 is initialized for a 3S from the factory and must be changed to 4S for this board.

3.4 Restart Button

Use the restart button when swapping the battery or when first initializing the TIDA-00984 PCB for the first time. The restart button is a current limited bypass switch that applies the battery voltage to the pack side of the MOSFETs in order to bring the gauge online. Remove all loads or connections from the pack connector before using the restart feature. Due to the current limiting in the restart bypass circuit, if there is an external load on the pack connector, the bypass switch will not have sufficient voltage to start the bq4050 gauge.

3.5 SOC Button

Press the SOC button to show the state of charge any time without needing a microcontroller or computer with bqStudio to communicate with the gauge. The bq4050 can drive a three-, four-, or five-segment LED display for remaining capacity indication or a permanent fail (PF) error code indication.

3.6 Loading the Default Setup File

To load the default setup file:

1. Download and save the default setup file to the computer.
2. Start the bqStudio software and establish a connection with the drone.
3. Import the default setup file into bqStudio once connected.
4. Take some time to look over the default setting and adjust the parameters to meet the requirements.
5. Write the new setup to the TIDA-00984 when the previous steps are completed.
6. Save the parameters to a file using a new name to represent the new default setup configurations.

3.7 Understanding the AFE

The AFE is the analog front-end for the gauge. The AFE does not rely on the controller in the gauge. The device is based on comparators to provide instant responses to input conditions. Setting the parameters for the AFE is very important to using this gauge in a motor control environment like that in a drone. If the overcurrent protection is not set correctly, then the protection could activate while the drone is in flight. This error could cause the drone to fall out of the sky. If set to high, in the event of a crash, the protection circuit may not turn on and burn up the TIDA-00984 protection circuit or it could cause the battery to become shorted and that could be much worse as Lithium cells can catch on fire if shorted. Measure and verify the currents that will be supplied to the motors in the drone. Capture these currents with a scope and make sure the AFE is set appropriately to protect the drone.

Read the bq4050 datasheet and fully understand how the AFE works as this is a key element to using any gauge and protection circuit with a drone.

4 Testing and Results

4.1 Test Setup

Figure 9 shows the TIDA-00984 test bench.

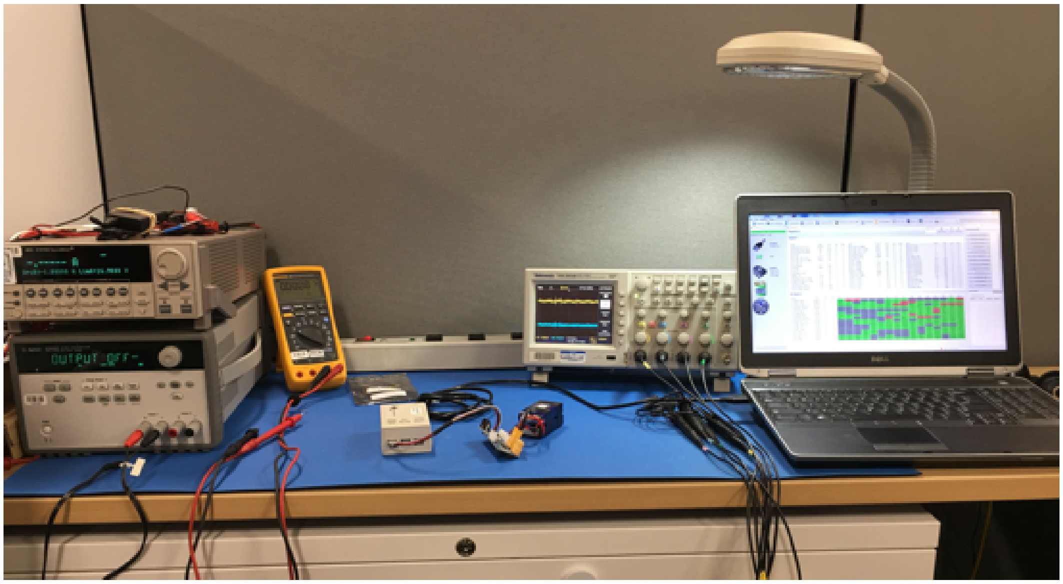


Figure 9. TIDA-00984 Test Bench

Test equipment used:

- Dell® laptop running bqStudio
- EV2300 USB interface
- Modified SMBus four-pin connector (one end of the standard cable was removed and the JST four-pin connector was added. See the schematic for the correct pin out configuration)
- Tektronix® TDS 2024B oscilloscope
- Fluke™ 189 Multimeter
- Keithley™ 2612 SourceMeter
- BK precision 8502 electronic load
- Agilent™ E3649A power supply
- Flir™ i7 thermography camera
- TIDA-00984 drone, robot, or RC 4S1P BMS
- Turnigy 1300-mAh 4S1P battery 50C

Figure 9 shows the TIDA-00984 drone setup.

The initial testing on the TIDA-00984 board was completed using the listed test equipment to supply power and load the board. All of the basic tests on this board were completed using the 4S1P battery and electronic test equipment. For a better understanding of actual application specifications, see the TIDA-00984 product page (http://www.ti.com/tool/TIDA-00982) as it was fully tested with a real drone. The main difference between these boards is the cell count of the battery used.

The plots shown in Figure 10 through Figure 13 were first captured using the bqStudio software by communicating with the gauge on the TIDA-00984 board. The plots were created after the bqStudio captured the data. All of this data and more is available to the user not just from the bqStudio but by using a microcontroller on the drone to capture in real time. This data can then be relayed back to the operator with the use of an onboard transmitter and a receiver at the operator.

4.1.1 Charging

The bq24600 is set to a max charge voltage of 16.8 V and charges at 1.3 A. Connect a 4S1P discharged battery to the battery connector and cell connector. Connect the drone board to the drone. (The drone should be fixed to a test board to prevent take off.) Connect the charger input power (set to > 18 V, current limited to 1.5 A) charge to full while logging the voltage, current, capacity, and SOC from the gauge.

Figure 10 shows the TIDA-00984 1.3-A charge cycle.

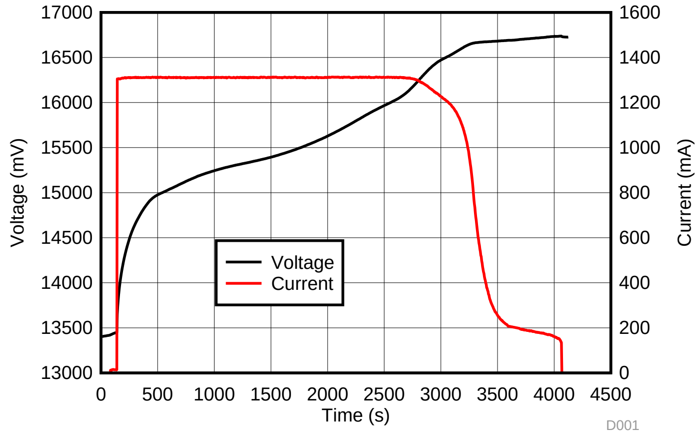


Figure 10. TIDA-00984 1.3-A Charge Cycle

Figure 11 shows all of the cell voltages and currents for the 1.3-A charge cycle. One can see the balancing circuits bringing the voltages into alignment.

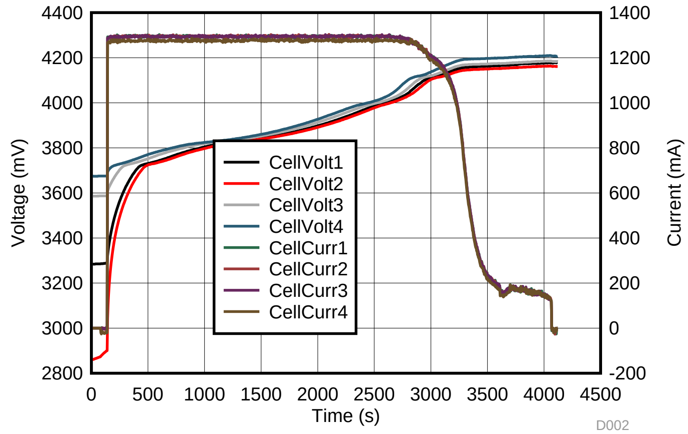


Figure 11. TIDA-00984 1.3-A Charge, Voltage, and Current for All Four Cells

4.1.2 Discharging

The discharge cycle consisted of using an electronic load that was set to a 10-A constant current and discharge the battery. Connect a 4S1P charged battery to the battery connector and cell connector. Connect the drone board to the drone. (The drone should be fixed to a test board to prevent take off). Connect the electronic load to the pack connector that is set to 10 A. Discharge to 0% SOC while logging the voltage, current, capacity, temperature, and SOC from the gauge.

Figure 12 shows a 10-A discharge cycle from fully charged to fully discharged.

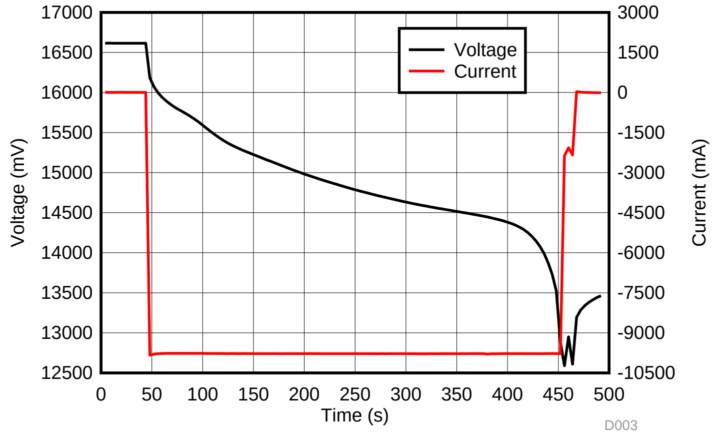


Figure 12. TIDA-00984 10-A Discharge Cycle

Figure 13 shows the relationship of SOC to MOSFET temperature during the high current 10-A discharge.

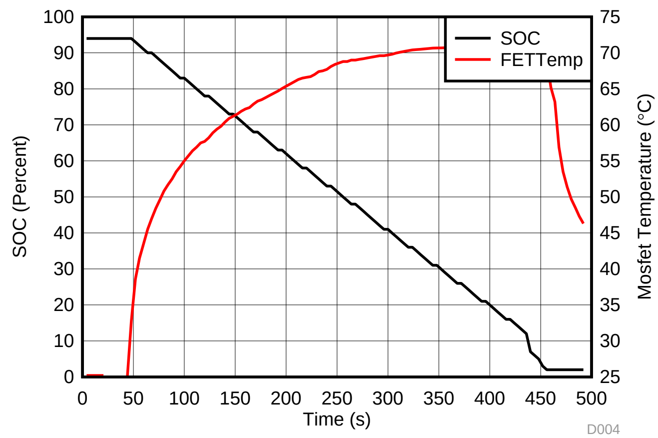


Figure 13. TIDA-00984 10-A Discharge SOC and MOSFET Temperature

4.1.3 Thermal

All tests were completed using a Flir i7 thermal camera and a laser measuring thermometer.

4.1.3.1 Thermal Charge at 1C

At a 1 C charge rate, follow these steps to verify that the charger is operating within normal specifications:

1. Run the charger at full charge current.
2. Measure the PCB and circuitry for thermal conditions.
3. Connect a 4S1P discharged battery to the battery connector and cell connector.
4. Connect a DC 18-V supply set to 2 A to the DC charger input jack.
5. Record the ambient temperature.
6. Turn on the charger for 30 minutes and record the temperature of the charger and MOSFETs.

Figure 14 shows the TIDA-00984 temperature during a 1C charge.

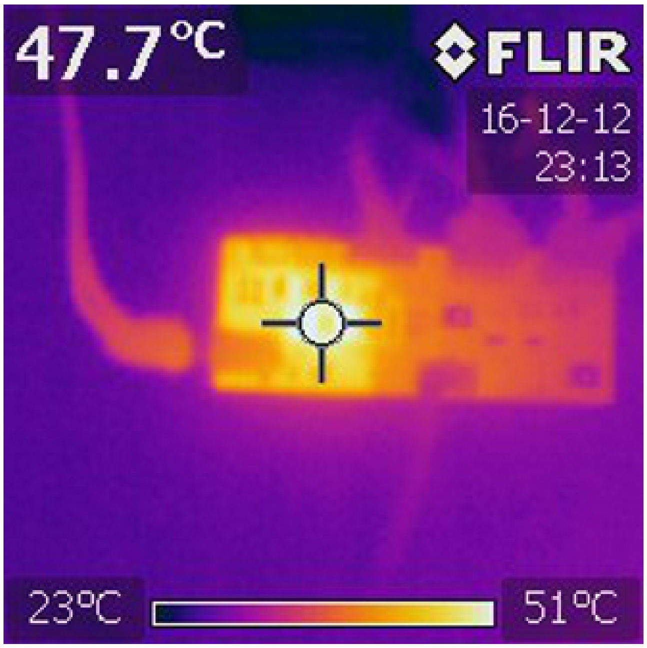


Figure 14. TIDA-00984 Temperature During 1.3-A Charge

4.1.3.2 Thermal Discharge at 10 A

At a 10-A discharge rate, follow these steps to verify that the protection switches are operating within normal thermal specifications:

1. Discharge at a 10-A current and measure the PCB circuitry and thermal conditions.
2. Connect a 4S1P charged battery to the battery connector and cell connector.
3. Connect an electronic load to the pack connector and set to 10 A.
4. Record the ambient temperature.
5. Turn on the load for 5 minutes and record the temperature of the protection MOSFETs and the battery pack.

Figure 15 shows the TIDA-00984 maximum temperature of pack during a 10-A discharge.

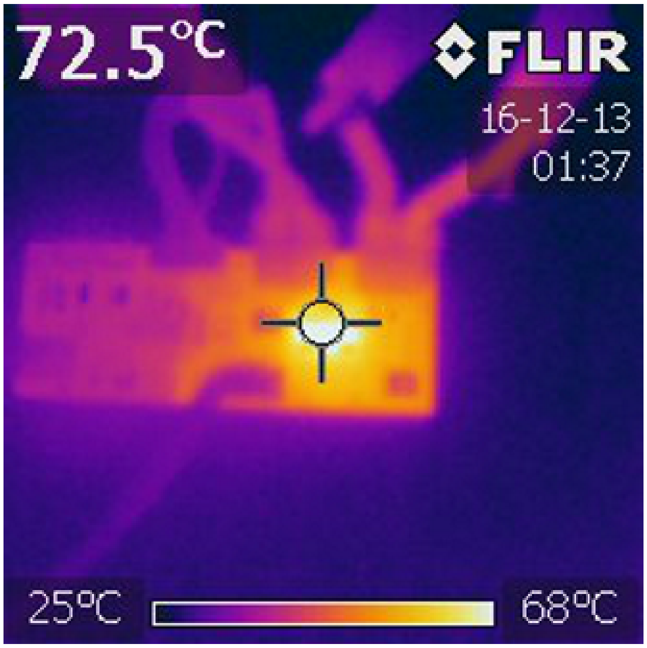


Figure 15. TIDA-00984 Temperature During 10-A Discharge

5 Design Files

5.1 Schematics

To download the schematics, see the design files at http://www.ti.com/tool/TIDA-00984.

5.2 Bill of Materials

To download the bill of materials (BOM), see the design files at http://www.ti.com/tool/TIDA-00984.

5.3 PCB Layout Recommendations

5.3.1 Layout Guidelines

As for all switching power supplies, the PCB layout is an important step in the design, especially at high peak currents and high switching frequencies. If the layout is notcompleted carefully , the buck charger or the buck converter may show stability problems as well as EMI problems. Therefore, use wide and short traces for the main current path and for the power ground paths. The input and output capacitors as well as the inductors should be placed as close as possible to the IC. For the buck charger and the buck converter, the first priority is the output capacitors, including the 0.1-µF bypass capacitor. Next, the input capacitor must be placed as close as possible between VIN or VCC and VSS. Last in priority is the buck charger and the buck converter's inductor, which must be placed close to SW for the converter and as close to the charger mosfets as possible. For the charger, the output capacitor must be placed as close as possible between the inductor and VSS. Place the buck converter inductor as close as possible between the switching node SW and VOS. TI recommends using vias and bottom traces for connecting the inductors to their respective pins.

To minimize noise pickup by the high-impedance voltage setting nodes, place the external resistors so that the traces connecting the midpoints of each divider to their respective pins are as short as possible. When laying out the non-power ground return paths (for example, from resistors and CREF), TI recommends using short traces as well, separated from the power ground traces and connected to VSS. Using the short traces avoids ground shift problems, which may occur due to superimposition of power ground current and control ground current. The PowerPAD must not be used as a power ground return path.

The remaining pins are either NC pins that must be connected to the PowerPAD as shown in Figure 16 and Figure 17 or digital signals with minimal layout restrictions.

During board assembly, contaminants such as solder flux and even some board cleaning agents may leave residue that may form parasitic resistors across the physical resistors or capacitors and from one end of a resistor or capacitor to ground, especially in humid, fast airflow environments. This may result in the voltage regulation and threshold levels changing significantly from those expected per the installed components. TI recommends that no ground planes be poured near the voltage setting resistors or the sample and hold capacitor. In addition, the boards must be carefully cleaned, possibly rotated at least once during cleaning, and then rinsed with de-ionized water until the ionic contamination of that water is well above 50 MΩ. If this is not feasible, TI recommends that the sum of the voltage setting resistors be reduced to at least five times below the measured ionic contamination.

Figure 16 shows the layout guidelines.

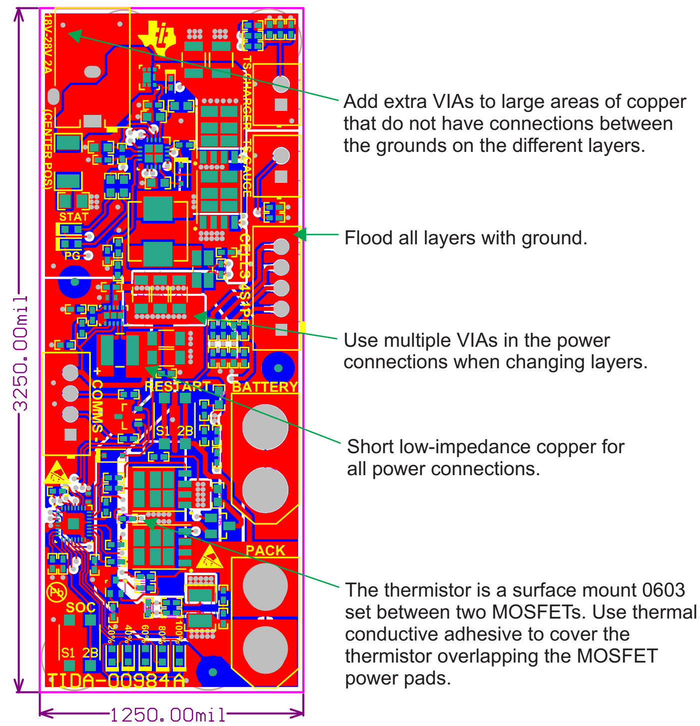


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Figure 16. Layout Guidelines

Figure 17 shows the layout guidelines ground.

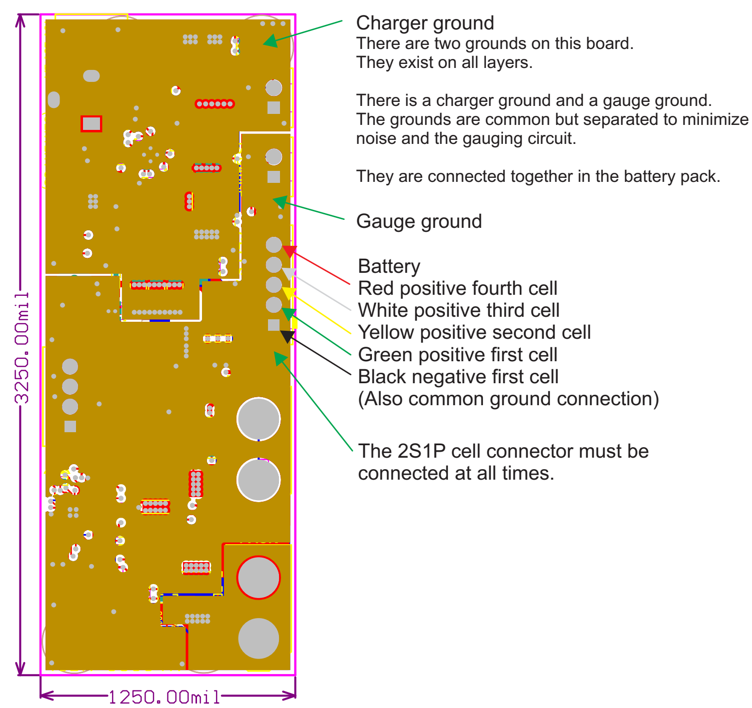

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Figure 17. Layout Guidelines Ground

5.3.2 Thermal Considerations

Implementing ICs in low-profile and fine-pitch surface-mount packages typically requires special attention to power dissipation. Many system-dependent issues such as thermal coupling, airflow, added heat sinks, and convection surfaces, and the presence of other heat-generating components affect the power dissipation limits of a given component. There are three basic approaches for enhancing thermal performance:

- Improving the power-dissipation capability of the PCB design
- Improving the thermal coupling of the component to the PCB
- Introducing airflow in the system

For more details on how to use the thermal parameters in the dissipation ratings table, see the *Thermal Characteristics of Linear and Logic Packages Using JEDEC PCB Designs* Application Note (SZZA017) and the *Semiconductor and IC Package Thermal Metrics* Application Note (SPRA953).

5.3.3 Layout Prints

To download the layout prints for each board, see the design files at http://www.ti.com/tool/TIDA-00984.

5.4 Altium Project

To download the Altium project files, see the design files at http://www.ti.com/tool/TIDA-00984.

5.5 Gerber Files

To download the Gerber files, see the design files at http://www.ti.com/tool/TIDA-00984.

5.6 Assembly Drawings

To download the assembly drawings, see the design files at http://www.ti.com/tool/TIDA-00984.

6 References

1. Texas Instruments, TI Gauging Parameter Calculator, GAUGEPARCAL (http://www.ti.com/tool/gaugeparcal)
2. Texas Instruments, TI Gauging Parameter Calculator for CEDV gauges, GPCCEDV (http://www.ti.com/tool/gpccedv)
3. Texas Instruments, *Simple Guide to CEDV Data Collection for Gauging Parameter Calculator (GPC)*, User's Guide (SLUUB45)

6.1 Trademarks

All trademarks are the property of their respective owners.

7 Terminology

The nomenclature for cell configuration is xSyP, which is shorthand for *how many cells are in series and how many are in parallel*. More cells in series will raise the voltage, while more in parallel raises the capacity in terms of ampere-hours (mAh or Ah). Since P = I × V, calculate the watt-hours by multiplying nominal voltage by nominal ampere-hours. Li-ion batteries typically have a nominal voltage of 3.7 V, with some newer ones averaging 3.8 V. They typically charge up to 4.2 V and discharge down to 3.0 V, so calculate the voltage range of an entire pack by multiplying those limits by the number of series cells.

NOTE: Some newer cells with advanced electrolytes support charging up to 4.35 V and even higher, so check the battery or cell datasheet to get the full picture.

The next letter seen thrown around is *C*, as in *C-rate*. It is a way to specify charging or discharging current as a ratio of the nominal battery capacity. Think of C as *capacity*, so if the battery label says *capacity: 1000 mAh* and someone says to charge at a C/2 rate, that means to charge with a current of 1,000 / 2 = 500 mA. If the discharge is specified at C/5, that means a current of 200 mA. Sometimes these are also called *hour rates*, because they refer to the current that would nominally discharge a full battery to empty in that number of hours. C/5 means to use a current that would discharge the battery from full to empty in about five hours. Again, these are *nominal* because discharging at C/2 might actually result in hitting empty in less than one hour, depending on the temperature, cell characteristics and other factors.

The following three-letter acronyms are also common: SOC, DOD, and SOH. State of charge (SOC) is the percentage seen on a phone or computer. This is actually a relative measure because it depends on the system characteristics as well as load and temperature, but it gives a rough idea of where the device's battery is between full (100%) and empty (0%).

Depth of discharge (DOD) can be thought of as the inverse of SOC. A DOD of 100% means that a battery is fully discharged and has no more energy at all, while a device reporting SOC = 0% could still have juice in the battery—just not enough to operate.

State of health (SOH) is another percentage measure, but instead of how much remaining energy is in the battery now, it tells roughly how old your battery is compared to a new one. Like SOC, it is also a relative term that depends on system characteristics. When SOH = 80%, it means that the battery, when fully charged, will give the device about 80% of the run time as it did when it was new. Instead of just going on a gut feeling that the battery is not lasting as long as before, SOH can give a more solid number to quantify it. Not all products report SOH (or they do not report it accurately), because it requires a fuel gauge that can track a battery's characteristics as it ages. TI's IT algorithm is the only one on the market that can track aging battery impedance. Thus, gauges like the bq2721, bq27532, or bq40z50 are some of the only gauges that can accurately report SOH.

8 About the Author

GORDON VARNEY is a Senior Systems and Applications Designer at TI, where he is responsible for developing reference design solutions and demos for the BMS Group. Gordon brings to this role his extensive experience in battery management, power, analog, digital, microcontroller, and energy harvesting. Gordon is an expert in circuit design and board layout as well as programming in several languages. Gordon earned his bachelor of science in electrical engineering (BSEE) from KWU in 1989 and is a member of the Institute of Electrical and Electronics Engineers (IEEE) and the Society of Automotive Engineers (SAE). Gordon is on the Board of Advisors for UTA's Electrical Engineering Department and has lectured many times at several Colleges and Universities in his 27 years as an electrical engineer.

Revision A History

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

Changes from Original (January 2017) to A Revision	**Page**
• Changed language to fit current style guide	1