*TI Designs*

# *Non-Military Drone, Robot, or RC 2S1P Battery Management Solution Reference Design*

## Design Overview

- Subsystem Design for 2S1P BMS (Battery Management Solution) for Non-Military Drone, Robot, or RC (Radio Controlled) Projects and Designs
- Quickly Add Gauging, Protection, Balancing and Charging to Any Existing Design for Non-Military Drone, Robot or RC Product or Use Board to Add Advanced Features to Existing Design
- Test Advanced Battery Management Features Quickly and Easily

## Design Resources

| | |
|---|---|
| TIDA-00982 | Design Folder |
| BQ4050 | Product Folder |
| BQ24600 | Product Folder |
| TPS62175 | Product Folder |

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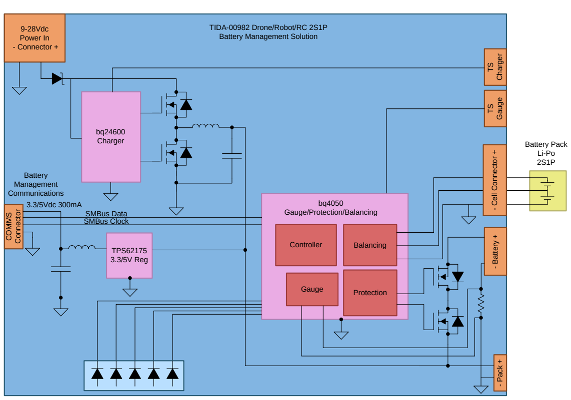
## Design Features

- 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

## Featured 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



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# 1 Key System Specifications

**Table 1. Collected Data and Set Parameters**

| PARAMETER | SPECIFICATION | VALUE | PREFIX |
|---|---|---|---|
| Idle current for the gauge with regulator | Gauge active, mosfets on, gauge current for each cell, with 3.3V Regulator | 350 | uA |
| Idle current for the gauge with no regulator | Gauge active, mosfets on, gauge current for each cell, without the regulator | 230 | uA |
| Charge voltage | Measured charge voltage | 8.390 | V |
| Charge current max | Measured charge voltage at max | 1.342 | A |
| Charger input minimum | Minimum voltage the charger would turn on | 9 | Vdc |
| Charger input maximum | Maximum voltage the charger preformed to spec | 28 | Vdc |
| Voltage regulator | Voltage of the 3.3V regulator | 3.32 | Vdc |
| Max current from regulator | Measured current limit of the 3.3V regulator | 510 | mA |
| Thermal test charger unit | (ambient 25.6C) 1.3A Charge Cycle | 25.7 | C |
| Thermal test under current for PCB | (ambient 25.6C) 4A Constant Current load | 33 | C |
| Pre-charge complete | Comes out of pre-charge | 3 | V |
| Pre-charge minimum voltage | Minimum pre-charge voltage | 2 | V |
| OCD1 Limit | Over Current limit during Discharge | 15,000 | mA |
| OCD1 Delay | Over Current delay during Discharge | 20 | S |
| OCD2 Limit | Over Current limit during Discharge | 2,0000 | mA |
| OCD2 Delay | Over Current delay during Discharge | 10 | S |
| AOLD Limit | Analog Front End Current Overload Limit | 25 | 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 | uS |
| ASCD2 Limit | Analog Front End Short Current Limit 2 | 44 | A |
| ASCD2 Delay | Analog Front End Short Current Delay 2 | 244 | uS |

## 2 System Description

The TIDA-00982 was designed using the best IC's and circuits available to provide a scalable BMS (Battery Management Solution) for non-military drone, robot or RC (Radio Controlled) 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 your 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 5 C more than the rated 1 C rate of the battery. The bq4050 use CEDV for the gauging algorithm and works excellent in designs well above the 1C rate up to 25-50C rates.

This drone board was developed to support most 200 mm and 250 mm non-military drones using 2S, 3S and 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 work very well in all of these designs.

All of the IC's on this board are capable of supporting 2S-4 S however this board was specifically designed for 2 S. With minor changes to the design most designers will be able to create a 3 S or 4 S design using the 2 S design as there template. See Section 4 for a better understanding of how to use this board, and understand what changes need to be made to this board to make it a 3 S or 4 S design.

This drone board has been designed to handle up to 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. Our battery was a 1.3-Ah rated capacity with a discharge rate of 25 C. The gauge parameter file was created to support 2S1P 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 4 Ah capacity. The charger may be adjusted to charge at 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 for pin compatible and may be changed on this board, or you may design the board in your 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 Vdc at 500 mA.

All of the connectors in this 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-00982 TI Design to get you up and testing advanced battery management quickly and easily. The TIDA-00982 design concept may be quickly inserted to add gauging, protection, balancing, and charging to any existing design without modifying your circuit. This design concept helps you test and qualify our BMS IC's with little effort.

You may also use this board to add advanced features to any existing drone, robot, or RC.

1. Unplug your battery from the drone.
2. Plug your battery power connector into the TIDA-00982 battery connector on the board.
3. Plug the cell connector into the TIDA-00982 2S1P connector.
4. Plug the drone into the pack connector on the board.
5. All of the features of the TIDA-00982 are now yours to test or use.

**NOTE:** You must verify that the designed operating specifications of the TIDA-00982 are within the proper operating range to work with your drone.

**NOTE:** If your battery is not the same battery that we are using, then you must collect data from your 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 your circuit. If your circuit draws more current than the settings that were used in our design, it may be possible for the protection circuit in the gauge to disconnect the battery from your 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.

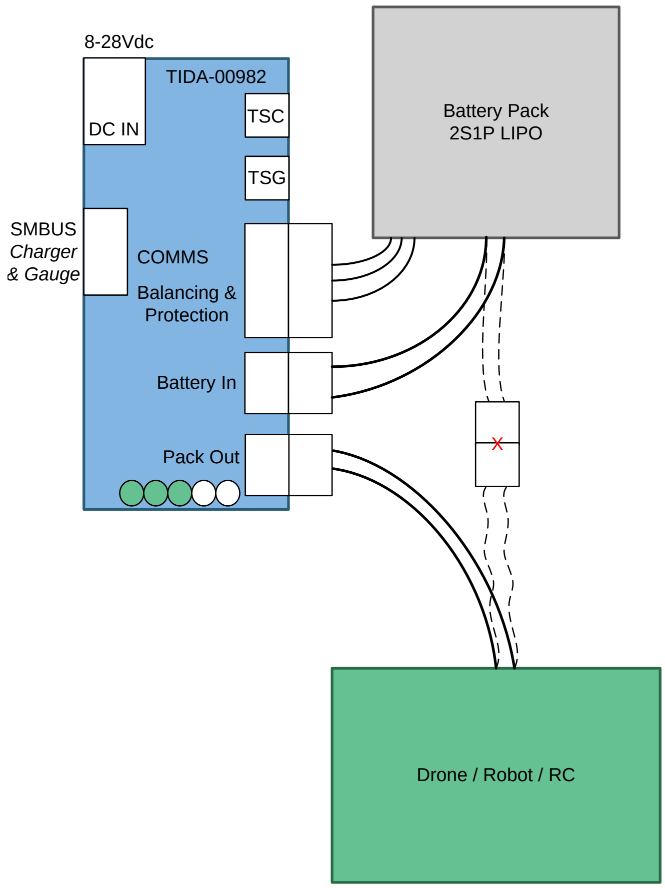




**Figure 1. Hook-Up Block Diagram**

# 3 Block Diagram

Figure 2 shows the TIDA-00982 block diagram.

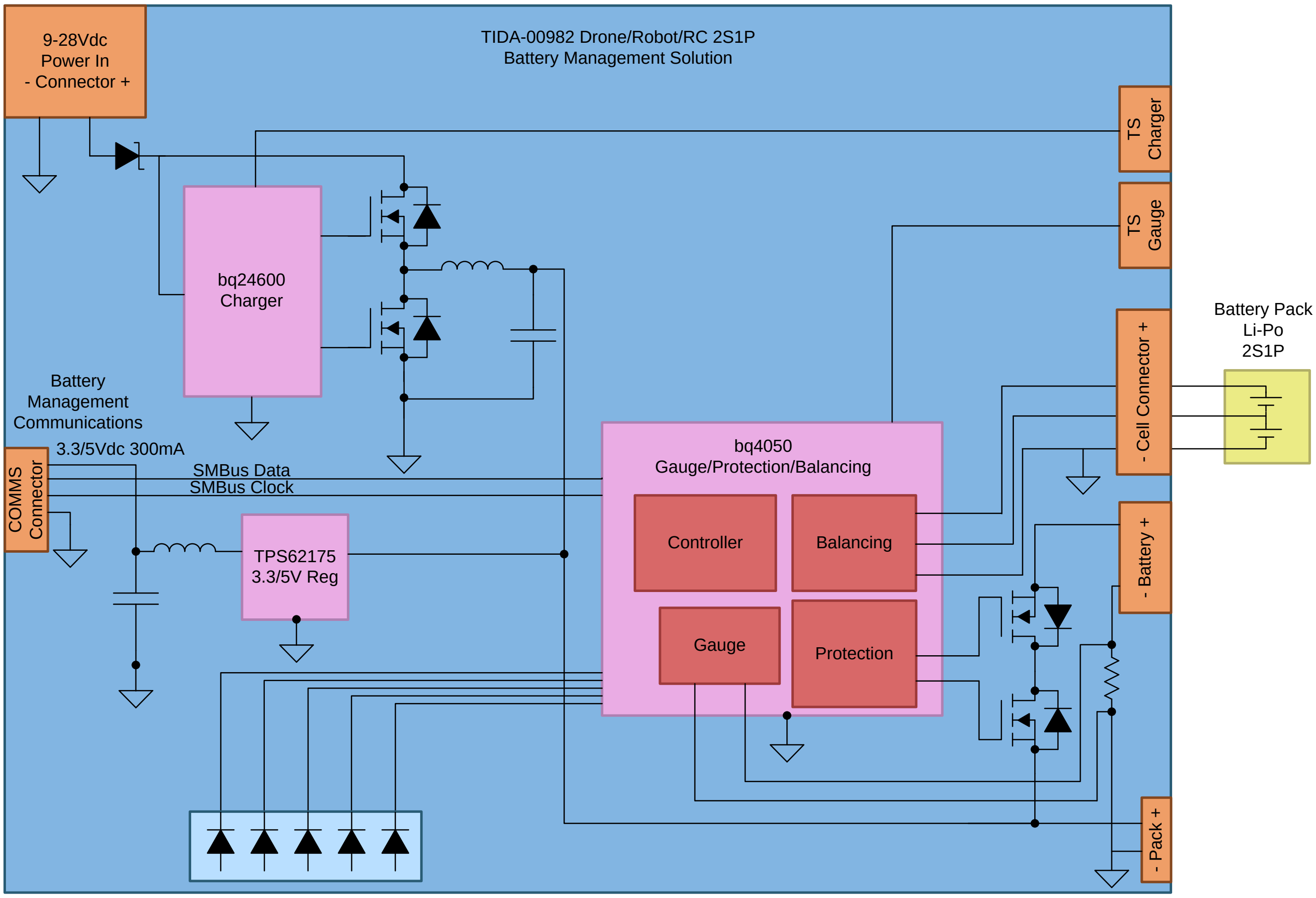




**Figure 2. TIDA-00982 Block Diagram**

### 3.1 BQ4050 Gauge

The TI bq4050 device, incorporating Compensated End-of-Discharge Voltage (CEDV) technology, is a highly integrated, accurate, 1-series to 4-series 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 via 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 a SHA-1 Authentication transform responder into a complete, high-performance battery management solution. 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 1-series, 2-series, 3-series, and 4-series 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 Compensated End-of-Discharge Voltage (CEDV).

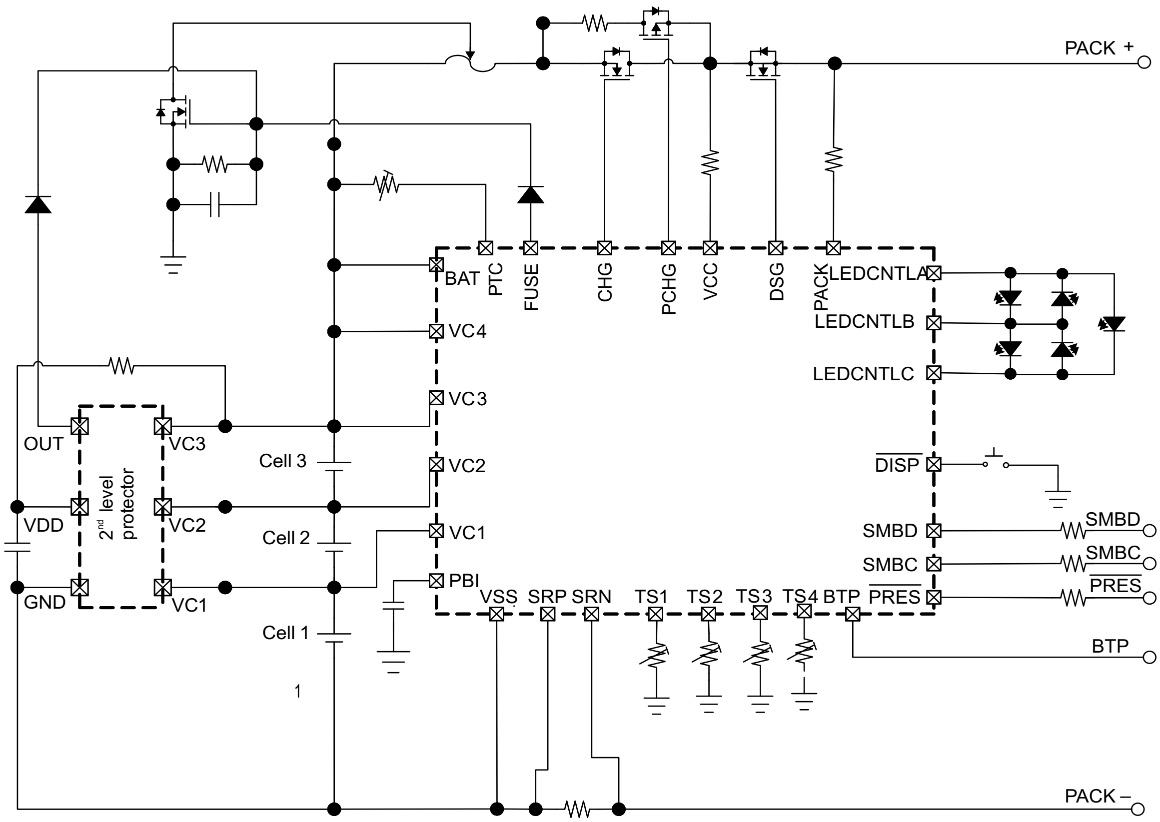


**Figure 3. BQ4050 Device, Incorporating Compensated End-of-Discharge Voltage (CEDV)**

### 3.2 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.

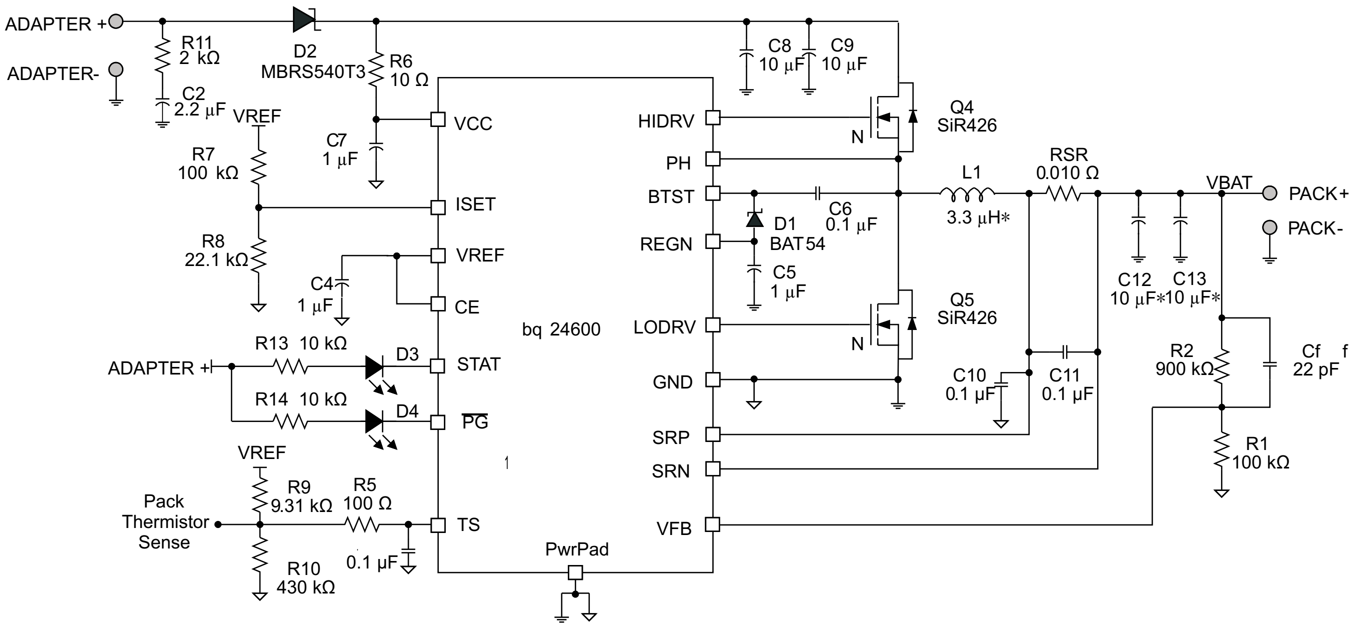


**Figure 4. BQ24600 Integrated Li-Ion or Li-Polymer Switch-Mode-Battery-Change Controller.**

### 3.3 TPS62175 Regulator

The TPS6217x 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 V 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 500-mA output current.

The TPS6217x automatically enters power save mode at light loads, to maintain high efficiency across the whole load range. As well, it features a sleep mode to supply applications with advanced power save modes like ultra-low power micro controllers. The power good output may be used for power sequencing and/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 TPS6217x high efficiency synchronous step-down Dc/DC converter.

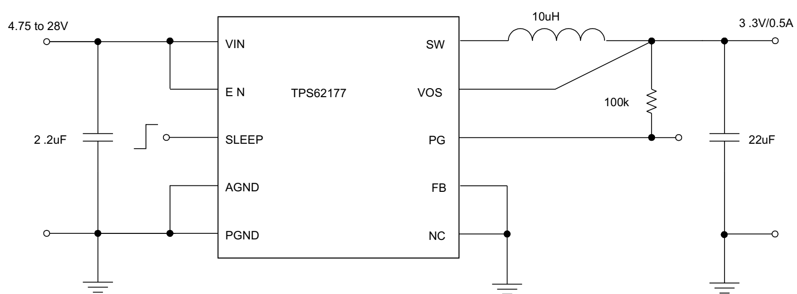




**Figure 5. TPS6217x High Efficiency Synchronous Step-Down Dc/DC Converter**

# 4 System Design Theory

The TIDA-00982 design concept was created to be able to be quickly inserted into an existing design. This design adds gauging, protection, balancing, and charging to any existing design without modifying your circuit. You may also use this board to add advanced features to any existing drone, robot or RC. Simply unplug your battery from the drone, plug your battery power connector into the TIDA-00982 battery connector on our board, then plug the battery cell connector into the TIDA-00982 2S1P cell connector. **You 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-00982. All of the features of the TIDA-00982 are now yours to test and or use.

Use this board as a pack side gauge. Once this board is connected to a battery, they 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 you are using this board as a systems side gauge then there are a few details that you must be aware of. First you should 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 can't 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 you connect a battery that is not fully charged the gauge may not be able to report the state of charge accurately however the gauge will become more accurate, the longer you leave the battery connected and go through several charge and discharge cycles.

## *4.1 Communications*

The TIDA-00982 has a connector on the left side of the board labeled COMMS. Any micro controller 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.

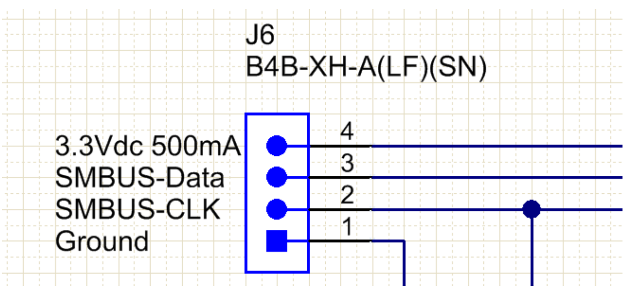


**Figure 6. COMMS Connector**

COMMS:

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

On the bench, you may use TI's bqStudio and the EV2300 or EV2400 interface. The bqStudio program may be downloaded from the TI website. See Section 5.2, bqStudio, and EV2300 for more information.

**NOTE:** TI recommends that you do not connect your drone until the parameters have been adjusted to meet your requirements for the battery and drone that you are using.

### 4.2 Gauging

The bq4050 is a CEDV gauge IC. CEDV is our choice of gauging for motor control applications with high current surges up to 25C the batteries amp hour rating. The bq40Z50 uses IT (Impedance Tracking) and is more accurate over all, 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 your application does not have high discharge rates then you may want to switch to the bq40Z50 with IT technology.

The bq4050 is a fully integrated 1-Series, 2-Series, 3-Series, and 4-Series Li-Ion or Li-Polymer cell battery pack manager and protection IC. It uses 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 Compensated End of Discharge Voltage (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 3 pairs of log files that can be created with various user equipment or by using TI's Battery Management Studio (bqStudio) software with a CEDV evaluation board connected through USB. Refer to TI's *Simple Guide to CEDV Data Collection for Gauging Parameter Calculator (GPC)* (SLUUB45) for more information on creating your CEDV coefficients for your battery. The TIDA-00982 was designed as a 2S solution, but can be changed to a 3S very easily using the 2S schematic as a template. Change the 3 pin JST cell connector to a 4 pin version. Add the series resistor and filter capacitor to the design exactly like the input for the other 2 cells and move the VBAT diode connection to the top of cell 3 instead of cell number 2. The 4S change is very similar to the changes for a 3S except the 4 pin JST will become a 5 pin JST connector, add another series resistor and filter capacitor and move the VBAT diode connection from the number 3 cell input to the number 4 cell input. Remember to change the charge voltage to the appropriate voltage for your design. The only other change required is to update the parameters in the gauge for your new setup.

### 4.3 Protection

The TIDA-00982 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
- Overtemperature in Charge Protection
- Overtemperature in Discharge Protection
- Undertemperature in Charge Protection
- Undertemperature in in Discharge Protection
- Overtemperature 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 Overtemperature Permanent Failure
- Safety FET Overtemperature 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 will need to be set to the correct value for your design. Once you have a default file with the battery profile information, the protection settings, your standard operating settings and the AFE protection settings in place you will be able to setup and test your battery management solution in your design.

Pay close attention to the AFE settings. This will prevent your drone from triggering a false failure mode and falling from the sky. The AFE detects over current and cell shorts in the system and can disconnect the protection mosfets without the influence of the controller.

### 4.4 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 cell(s) to be balanced based on the cell voltage until all cell voltages are within a programmable voltage range.

### 4.5 Charging

The output for the charger is set at 8.4 V for a 2 S battery solution. The input voltage range for our charger is 1 V above the output voltage or 9.4V up to 28V. This charger tested well to 9.0V at the 1.3A setting. If the charge current was set to 4 A the drop out voltage would have been higher at 9.4 V. If this were a 3 S solution, the output voltage would be set to 12.6 V. The input voltage would be 13.6 V to 28 V.

The current limit was set to a 1 C rate of 1.3 Ah for the battery that we are using. While it is true that the battery can charge at a 5 C rate, there are many reasons that we are not charging 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 monitoring.

The charger feedback circuit uses a resistor divider to set the output voltage. A third resistor was added to the resistor divider as a zero Ohm 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-0098 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. If you want to test charging at a higher rate then use the charger thermistor port. If you want to test discharging at a higher constant current or higher surge current rate then 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 you connect an external thermistor to the connector without removing the default 10k resistor, the temperature will always read about 25 degrees C. If you remove the default 10k resistor and not add the external leaded thermistor then you will read very high or max temperatures all of the time and the system will not operate.

### 4.6 Mosfets

The PSMN013-30YLC mosfet for this design was picked for its high power rating low RDS, low parasitic inductance and capacitance. The low gate drive voltage and the ultralow 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 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.

Figure 7 shows the mosfet parameters.

| Symbol | Parameter | Conditions | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| $V_{DS}$ | drain-source voltage | 25 °C ≤ $T_j$ ≤ 175 °C | - | - | 30 | V |
| $I_D$ | drain current | $T_{mb}$ = 25 °C; $V_{GS}$ = 10 V; see Figure 1 | - | - | 32 | A |
| $P_{tot}$ | total power dissipation | $T_{mb}$ = 25 °C; see Figure 2 | - | - | 26 | W |
| $T_j$ | junction temperature | | -55 | - | 175 | °C |
| **Static characteristics** | | | | | | |
| $R_{DSon}$ | drain-source on-state resistance | $V_{GS}$ = 4.5 V; $I_D$ = 10 A; $T_j$ = 25 °C; see Figure 12 | - | 14.4 | 16.9 | mΩ |
| | | $V_{GS}$ = 10 V; $I_D$ = 10 A; $T_j$ = 25 °C; see Figure 12 | - | 11.6 | 13.6 | mΩ |

**Figure 7. Mosfet Parameters**

## 4.7 Battery

TURNIGY nano-tech Li-Poly batteries utilize 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 8 shows the li-poly battery used in this design.

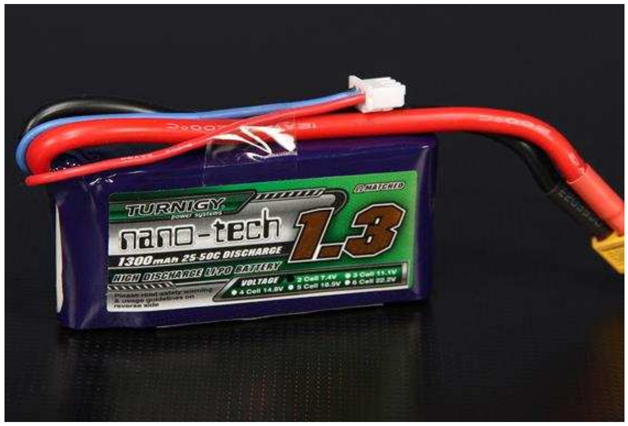


**Figure 8. Li-Poly Battery**

**Specifications:**

- Capacity:
- Voltage: 2S1P, 2 cell, 7.4 V (8.4 V dc max)
- Discharge: 25 C constant and 50 C burst
- Weight: 86 g (including wire, plug, and case)
- Dimensions: 85 mm × 34 mm × 16 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 1.2m0hms compared to that of 3m0hms of a standard Li-Poly.
- Greater thermal control, pack usually doesn't exceed 60degC
- 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.

# 5 Getting Started Hardware

In this section it is assumed that you are familiar with bqStudio and have a basic understanding of how it works. If you are not familiar with bqStudio please see the user's guide or operations manual before continuing.

## 5.1 Setup

Figure 9 shows the connector layout.

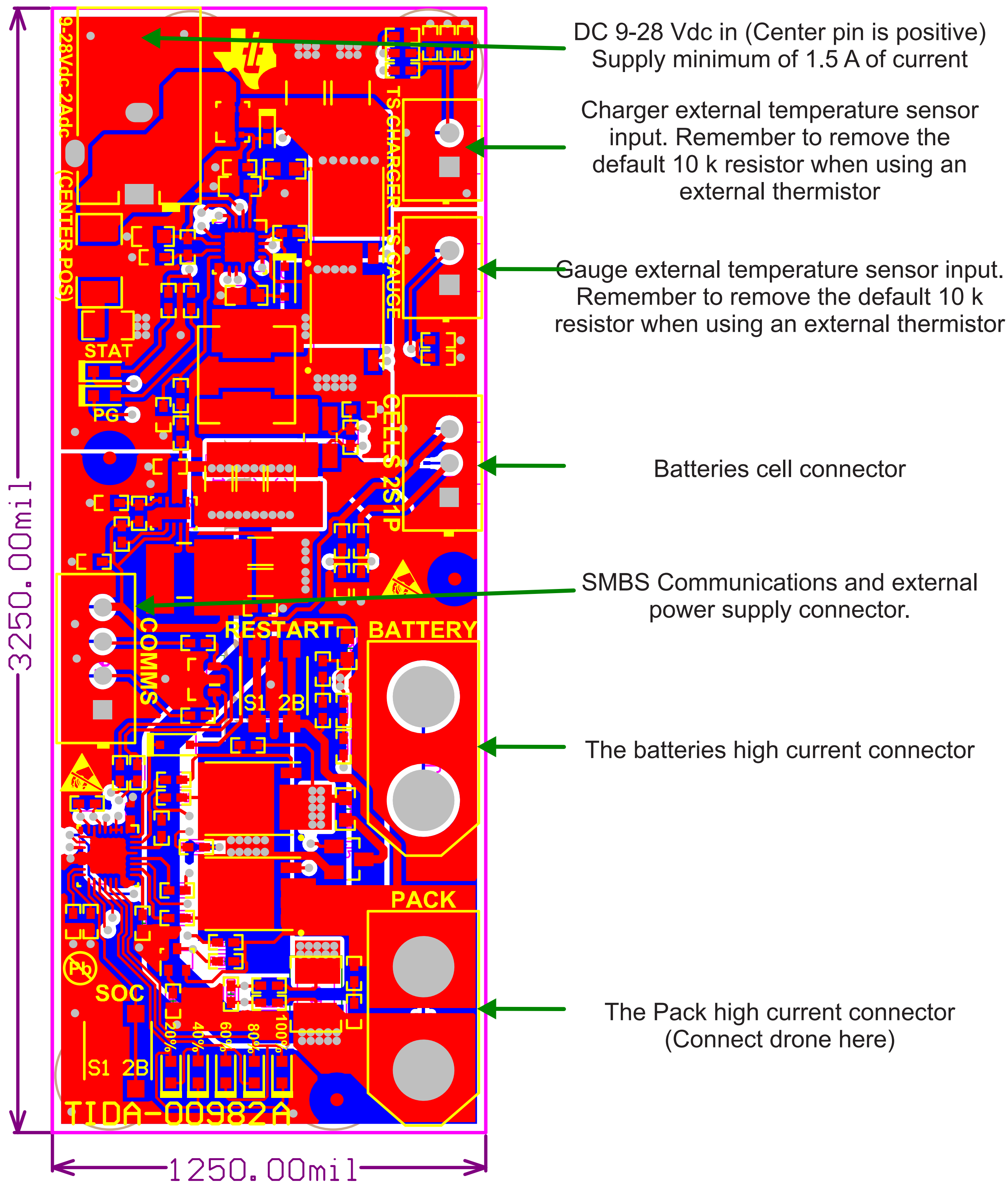




**Figure 9. Connector Layout**

See Figure 9 for the placement of the following connectors:

1. Battery connections
2. Communications
3. Thermistors
4. Charger input
5. Pack connection

### 5.2 bqStudio and EV2300

Battery Management Studio (bqStudio) offers a full suite of robust tools to assist with the process of evaluating, designing with, configuring, testing, or otherwise utilizing TI Battery management products. The EV2300 provide the hardware interface to communicate with the TIDA-00982 reference design.

1. Make sure the bqStudio software is installed.
2. Connect your EV2300 communications USB interface cable to your computer.
3. Connect the EV2300's SMBUS communications cable to the TIDA-00982 communications connector.
4. Connect your 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 that you do not connect your drone until the parameters have been adjusted to meet your requirements for the battery drone that you are using.

### 5.3 Gauge Initialization

The first time the TIDA-00982 is powered up the bq4050 must be initialized. Some of the default parameters must be changed before you may load the default parameter file. You may use the provided default parameter file as a starting point.

You must hold down the RESTART button until the necessary default registers have been changed and the main FETS turned on.

**NOTE:** The bq4050 is initialize for a 3 S from the factory and must be changed to 2 S for this board.

### 5.4 Restart Button

You must use the restart button when swapping the battery or when first initializing the TIDA-00982 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.

### 5.5 SOC Button

Press the SOC button to show the State of Charge any time without needing a micro controller or computer with bqStudio to communicate with the gauge. The bq4050 can drive a 3-, 4-, or 5- segment LED display for remaining capacity indication or a permanent fail (PF) error code indication.

### 5.6 Loading the Default Setup File

To load the default setup file:

1. Download and save the default setup file to your computer.
2. Start the bqStudio software and establish a connection with your 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 your requirements.
5. Write the new setup to the TIDA00982 when the previous steps are completed.
6. Save the parameters to a file using a new name to represent your new default setup configurations.

### 5.7 Understanding the AFE

The AFE is the Analog Front End for the gauge. The AFE does not rely on the controller in the gauge. It's 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 over current protection is not set correctly then the protection could kick in while the drone is in flight. This 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-00982 protection circuit or it could cause the battery to become shorted and that could be much worse as Lithium cell can catch on fire if shorted. Measure and verify the currents that will be supplied to the motors in your drone. Capture these currents with a scope and make sure the AFE is set appropriately to protect your drone.

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

## 6 Test Setup

Figure 10 shows the TIDA-00982 test bench.

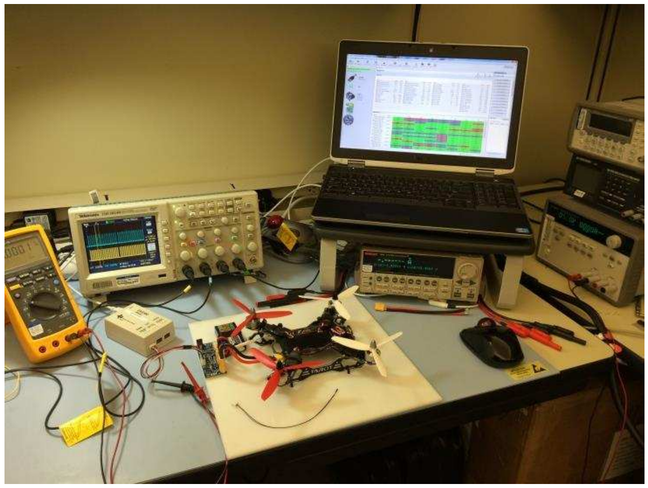

**Figure 10. TIDA-00982 Test Bench**

**Test equipment used:**

- Dell® laptop running bqStudio
- EV2300 USB interface
- Modified SMBUS 4 pin connector (One end of the standard cable was removed and the JST 4 pin connector was added. See the schematic for the correct pin out configuration)
- Tektronix® TDS 2024B Oscilloscope
- Fluke™ 189 Multi-Meter
- Keithley™ 2812 Sourcemeter
- BK precision 8502 electronic load
- Agilent™ E3649A Power Supply
- Flir™ i7 Thermography Camera
- TIDA-00982 Drone, Robot, RC 2S1P BMS
- Turnigy™ 1300mAh 2S1P battery 50C
- TAROT™ Mini 200 drone

**Setup:**

Figure 11 shows the TIDA-00982 drone setup.

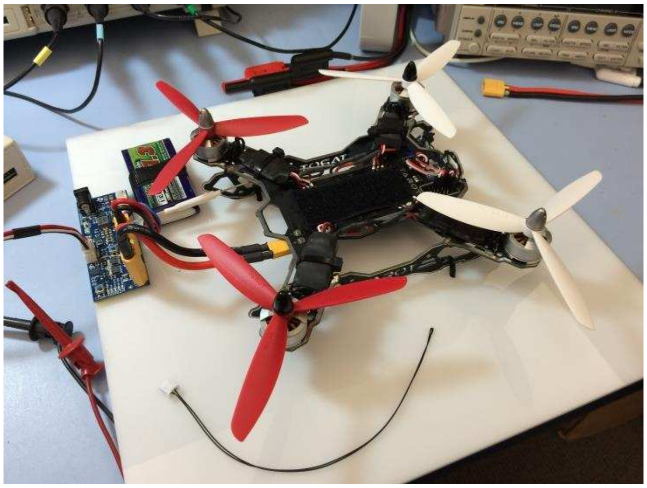

**Figure 11. TIDA-00982 Drone Setup**

The drone was mounted to a 12” × 12” sheet of white acrylic using zip ties. The battery was mounted to the sheet using Velcro®. The board was mounted to the sheet using double stick tape. The reason for mounting the drone is to allow the rotors to spin at maximum, but the drone would stay in place allowing the EV2300 to stay connected to collect data. The TIDA-00982 board was mounted in a way that allowed access to the board for testing but was clear of the propellers from the drone.

The initial testing on the TIDA-00982 board was completed using test equipment to supply power and load the board. Once the board was determined to operate correctly the bulk of the testing was completed on a working drone.

The plots shown in Figure 12 through Figure 16 were first captured using the bqStudio software by communicating with the gauge on the TIDA-00982 board. The plots were created after the bqStudio captured the data. All of this data and more is available to the user not just form the bqStudio but by using a micro controller on the drone to capture in real time. This data can then be relayed back to the operator with the use of an on-board transmitter and a receiver at the operator.

## 6.1 Charging

The bq24600 is set to a max charge voltage of 8.4V and charges at 1.3A.

Connect a 2S1P 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 12V current limited to 1.5 A) charge to full while logging the voltage, current, capacity and SOC from the gauge.

Figure 12 shows the TIDA-00982 1.3 A charge cycle.

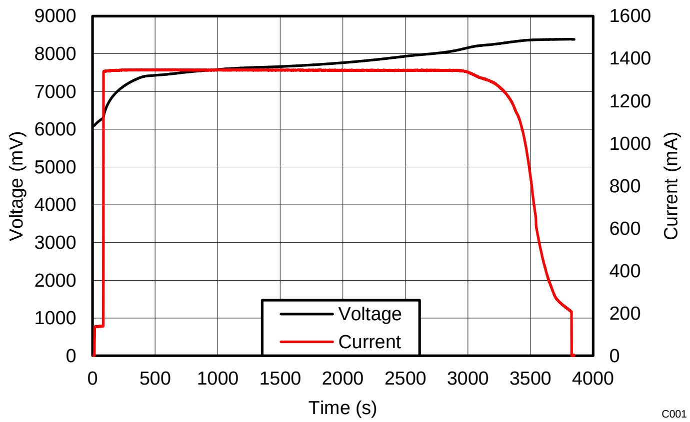


**Figure 12. TIDA-00982 1.3 A Charge Cycle**

Figure 13 shows the TIDA-00982 1.3 A charge capcity vs SOC.

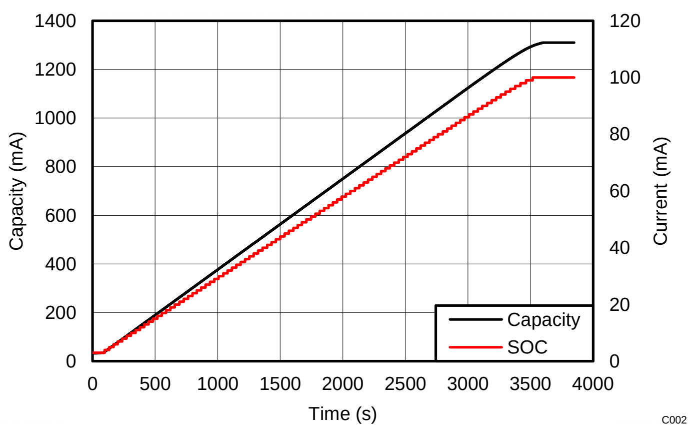


**Figure 13. TIDA-00982 1.3 A Charge Capacity vs SOC**

## 6.2 Discharging

The discharge cycle consisted of using an electronic load that was set to 10A constant current and discharge the battery.

Connect a 2S1P 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 10A. Discharge to 0% SOC while logging the voltage, current, capacity, temperature and SOC from the gauge.

Figure 14 shows the TIDA-00982 10 A discharge cycle.

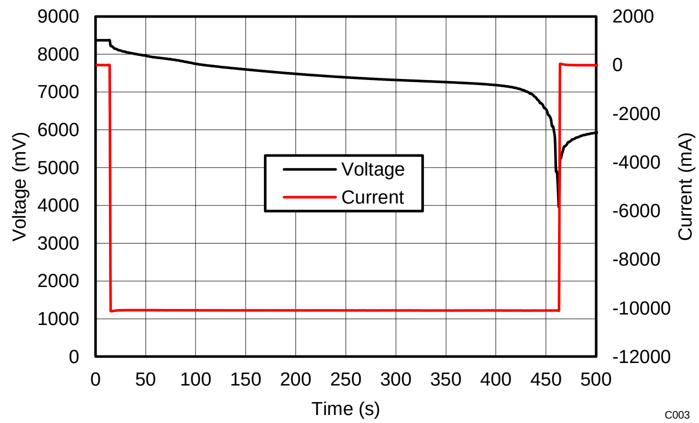


**Figure 14. TIDA-00982 10 A Discharge Cycle**

Figure 15 shows the TIDA-00982 10 A discharge capacity vs SOC.

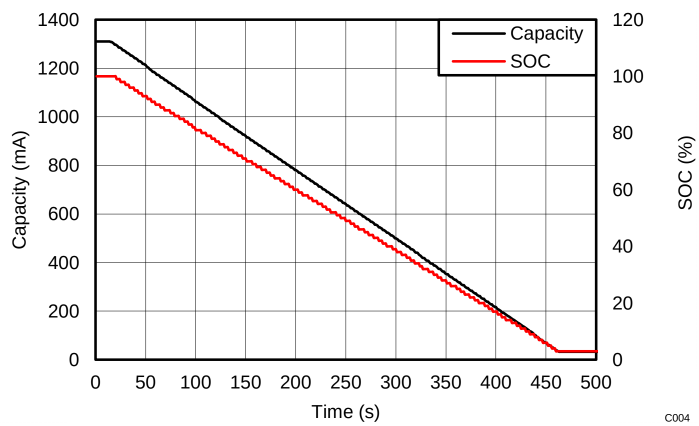


**Figure 15. TIDA-00982 10 A Discharge Capacity vs SOC**

Figure 16 shows the TIDA-00982 10 A discharge mosfet current vs temperature.

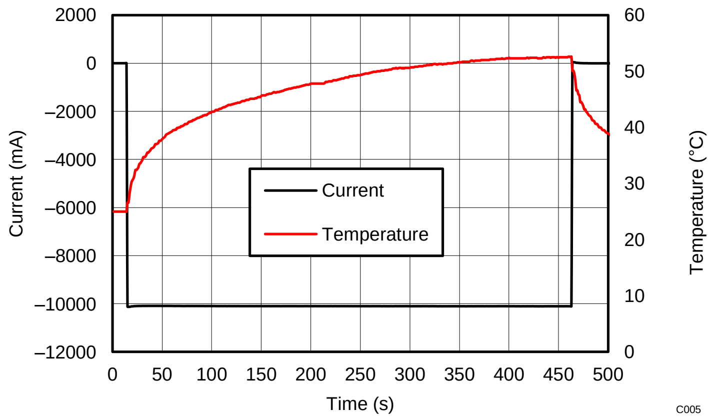


**Figure 16. TIDA-00982 10 A Discharge Mosfet Current vs Temperature**

### 6.3 Non-Military Drone

The test from this point was completed while connected to an actual drone. The bqStudio was used to log the data while testing.

#### 6.3.1 Drone Startup

To start up the drone:

1. Connect the TIDA-00982 board and battery to the drone.
2. Log the voltage and current during power up.
3. Connect a 2S1P fully charged battery to the battery connector and cell connector.
4. Connect the drone board to the drone. (The drone must be fixed to a test board to prevent take off).
5. Use a bqStudio to measure and capture the battery voltage and current during power up.

Figure 17 shows the TIDA-00982 initial power up of the drone.

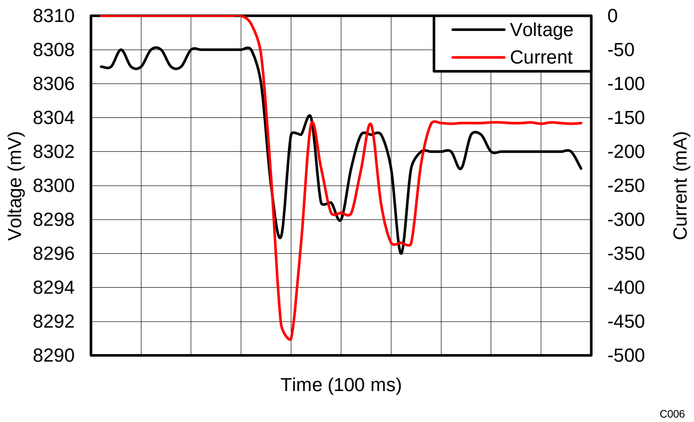


**Figure 17. TIDA-00982 Initial Power Up of the Drone**

#### 6.3.2 Drone Rotor Startup

The drone rotor startup test measures the current and voltage during the rotor startup process.

1. Connect the TIDA-00982 board and battery to drone and test motor startup current and voltage.
2. Connect a 2S1P fully charged battery to the battery connector and cell connector.
3. Connect the drone board to the drone. (The drone must be fixed to a test board to prevent take off).
4. Use a bqStudio to measure and capture the battery voltage and current during rotor startup.

Figure 18 shows the TIDA-00982 drone rotor start up.

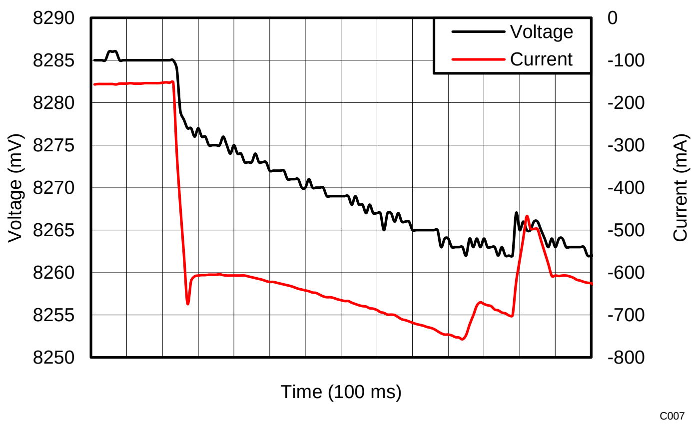


**Figure 18. TIDA-00982 Drone Rotor Start Up**

### 6.3.3 Drone Low-Speed Run

The low speed rotor test captures the current and voltage of the rotor for several seconds to show the idle state of current and voltage on the battery.

1. Connect the TIDA-00982 board and battery to drone and test rotor low-speed run.
2. Connect a 2S1P fully charged battery to the battery connector and cell connector.
3. Connect the drone board to the drone. (The drone must be fixed to a test board to prevent take off).
4. Use bqStudio to measure and capture the battery voltage and current while running the rotors at low speed (about 25%) for several seconds.

Figure 19 shows the TIDA-00982 drone low speed run.

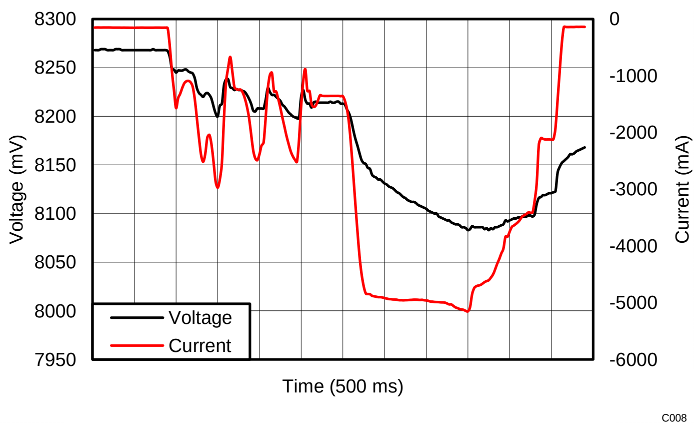


**Figure 19. TIDA-00982 Drone Low Speed Run**

### 6.3.4 Drone Surge Testing

The surge test provides the data necessary to set maximum current draw and peak current draw in the gauge for the best protection settings.

1. Connect board and battery to drone and log voltage and current while performing multiple motor surges.
2. Look current, voltage drop and verify that communications continue to work.
3. Connect a 2S1P fully charged battery to the battery connector and cell connector.
4. Connect the drone board to the drone. (The drone must be fixed to a test board to prevent take off).
5. Use bqStudio to measure and log the data for voltage and current.
6. Quickly ramp up the drone rotors multiple times to create rotor surges, and test for proper operations, Mosfet temperature and communications to the gauge board.

Figure 20 shows the TIDA-00982 drone surge testing for current and comms.

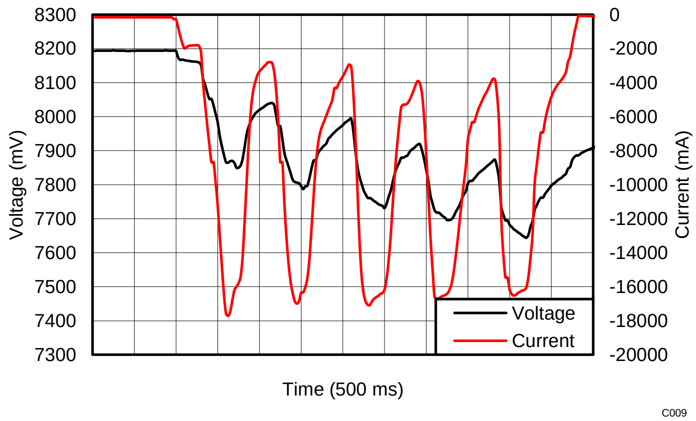


**Figure 20. TIDA-00982 Drone Surge Testing for Current and Comms**

Figure 21 shows the scope shot of a 4 rotor current surge.

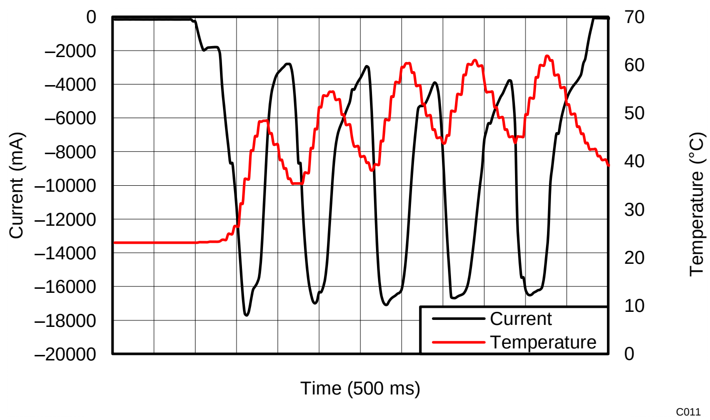


**Figure 21. Scope Shot of a 4 Rotor Current Surge**

Figure 22 shows the TIDA-00982 drone surge current vs chg_dschg mosfet temperature.

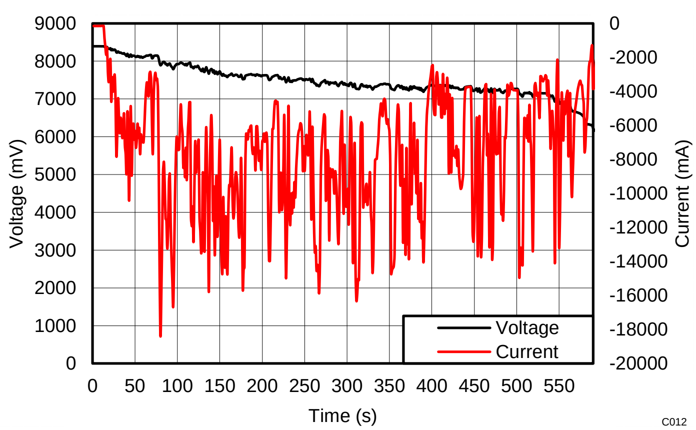


**Figure 22. TIDA-00982 Drone Surge Current vs Chg_Dschg Mosfet Temperature**

### 6.3.5 Drone Full in Flight Discharge

This is a simulated flight process that provides necessary flight data for the gauge, and verifies that the protection settings are valid for your drone.

1. Run the drone in a simulated in flight test until the battery is dead.
2. Connect a 2S1P fully charged battery to the battery connector and cell connector.
3. Connect the drone board to the drone. (The drone must be fixed to a test board to prevent take off).
4. Use bqStudio to log voltage, current, capacity, SOC, and temperature.
5. Run the drone in a simulated fight pattern until the battery is at 0% SOC.

Figure 23 shows the TIDA-00982 drone in flight discharge.

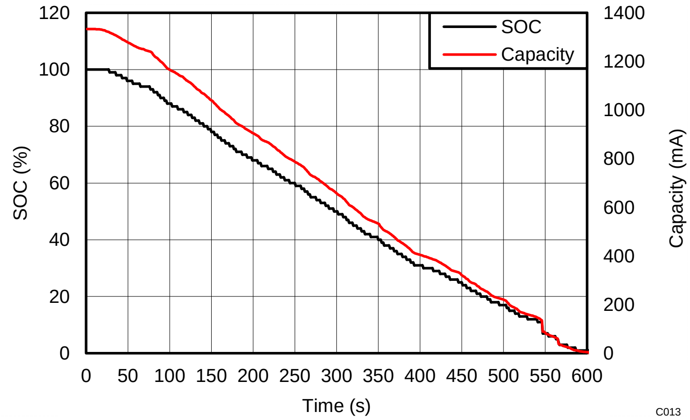


**Figure 23. TIDA-00982 Drone in Flight Discharge**

Figure 24 shows the TIDA-00982 drone in flight capactiy vs SOC.

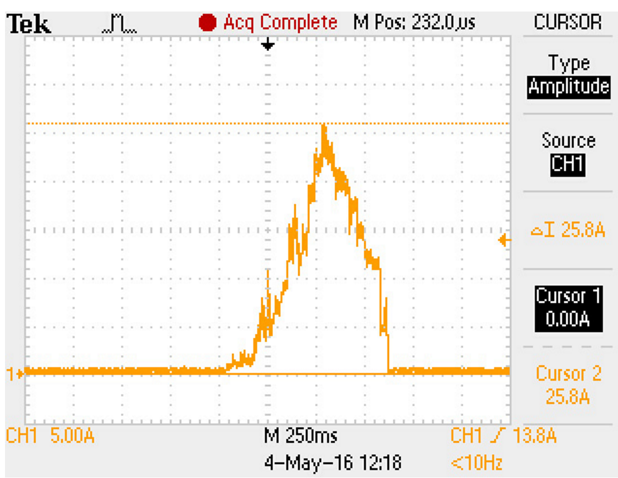


**Figure 24. TIDA-00982 Drone in Flight Capactiy vs SOC**

Figure 25 shows the TIDA-00982 drone current vs chg_dschg_mosfet temperature.

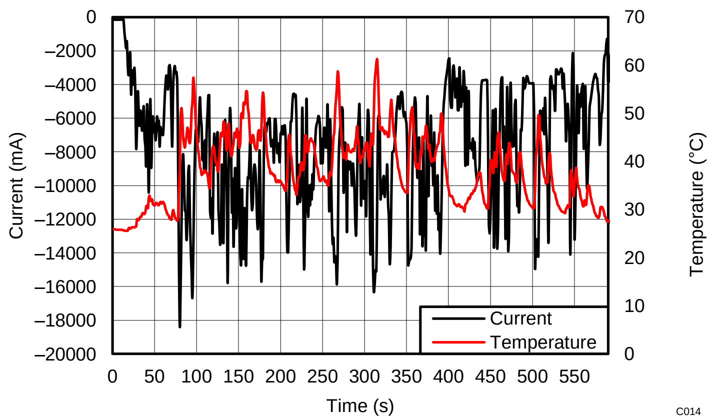


**Figure 25. TIDA-00982 Drone Current vs Chg_Dschg_Mosfet Temperature**

### 6.3.6 Drone Short Circuit

The short circuit test verifies that the protection settings in the gauge protect the battery and the protection switches in case of a short.

1. Short Pack connector and verify proper disconnect.
2. Connect a 2S1P fully charged battery to the battery connector and cell connector.
3. Initialize, and then apply a short to the pack connector.

Figure 26 shows the TIDA-00982 safety alert short circuit.

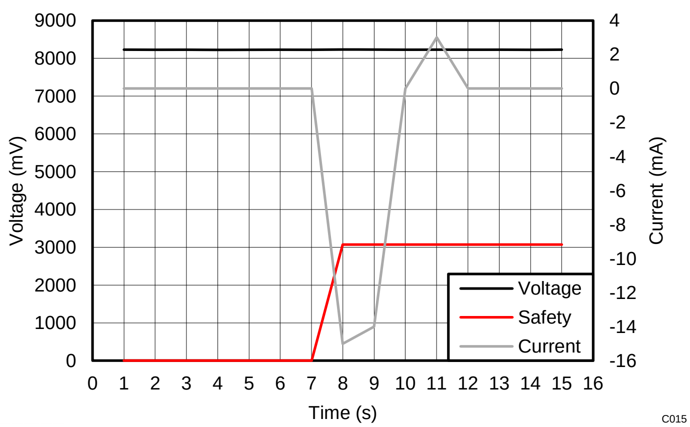


**Figure 26. TIDA-00982 Safety Alert Short Circuit**

Figure 27 shows the scope shot pack short.

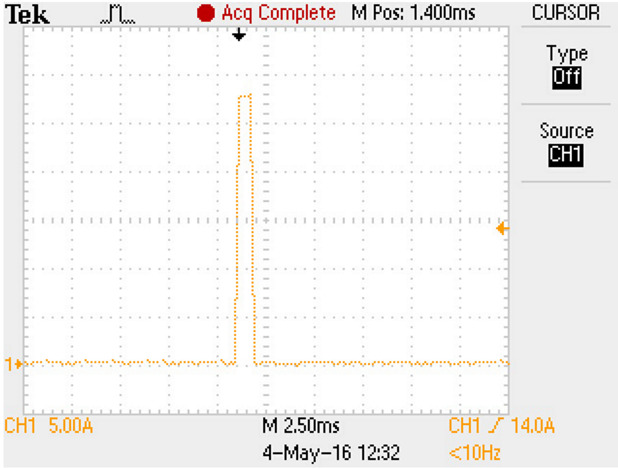


**Figure 27. Scope Shot Pack Short**

## 6.4 Thermal

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

### 6.4.1 Thermal Charge 1C

Test at a 1 C charge rate 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 2S1P discharged battery to the battery connector and cell connector.
4. Connect a DC 12-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 28 shows the TIDA-00982 temperature during a 1C charge.

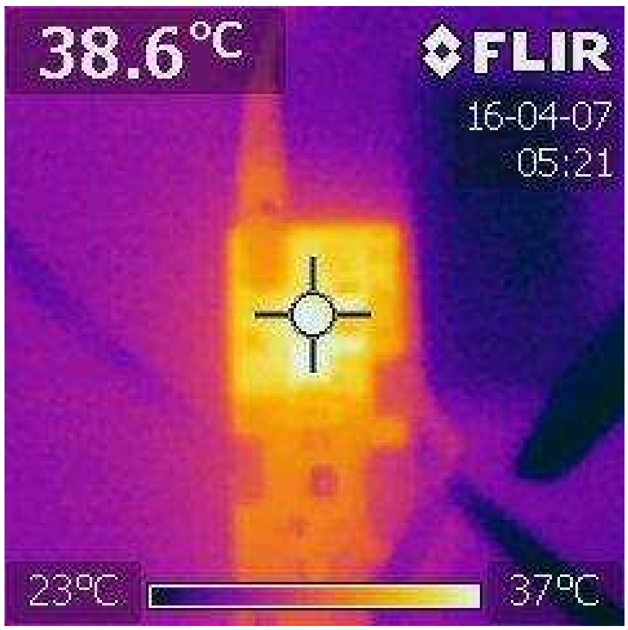


**Figure 28. TIDA-00982 Temperature During a 1C Charge**

### 6.4.2 Thermal Discharge 1C

Test at a 1 C discharge rate to verify that the protection switches are operating within normal thermal specifications.

1. Discharge at 1C current and measure the PCB circuitry and thermal conditions.
2. Connect a 2S1P charged battery to the battery connector and cell connector.
3. Connect an electronic load to the pack connector and set to 1.3 A.
4. Record the ambient temperature.
5. Turn on the load for 30 minutes and record the temperature of the protection mosfets and the battery pack.

Figure 29 shows the TIDA-00982 temperature during 1C discharge.

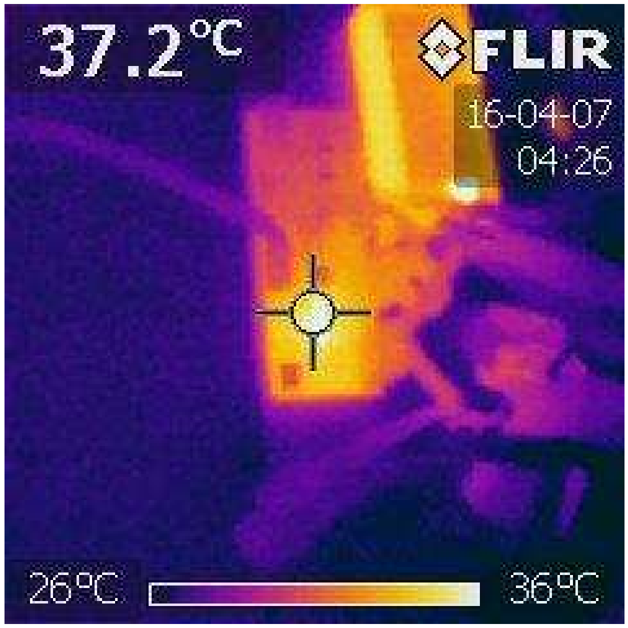


**Figure 29. TIDA-00982 Temperature During 1C Discharge**

Figure 30 shows the TIDA-00982 maximum temperature of pack during 1C discharge.

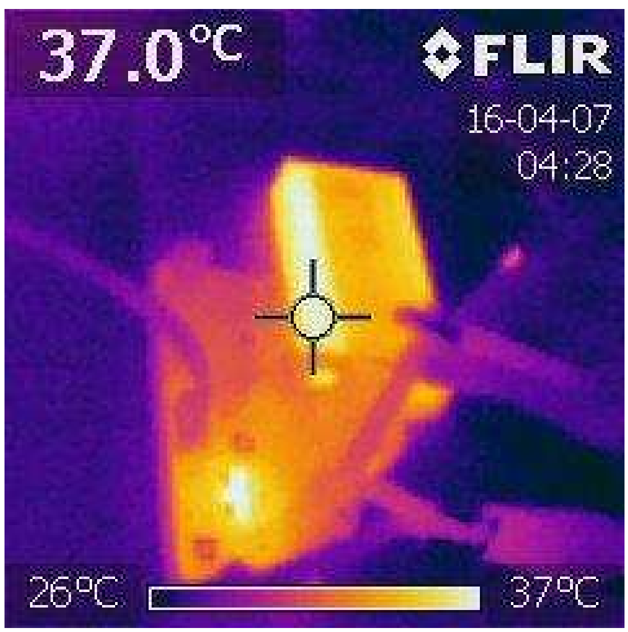


**Figure 30. TIDA-00982 Maximum Temperature of Pack During 1C Discharge**

### 6.4.3 Thermal All Rotors Full On

Testing with all rotors at full on verifies that under extreme conditions, the board operates within normal thermal spevcifications.

1. Run the board under load by running the rotors full on.
2. Measure the PCB and circuitry for thermal conditions.
3. Connect a 2S1P charged battery to the battery connector and cell connector.

4. Connect the drone board to the drone. (The drone must be fixed to a test board to prevent take off).
5. Record the ambient temperature.
6. Turn on the rotors to full on for 10 minutes.
7. Record the temperature of the protection mosfets.

Figure 31 shows the TIDA-00982 maximum temperature during all rotors full on.

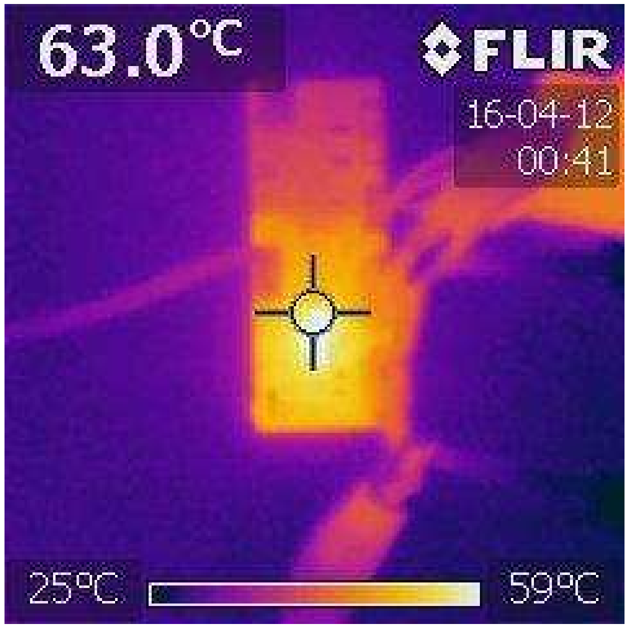


**Figure 31. TIDA-00982 Maximum Temperature During All Rotors Full On**

# 7 Design Files

## 7.1 Schematics

To download the schematics, see the design files at TIDA-00982.

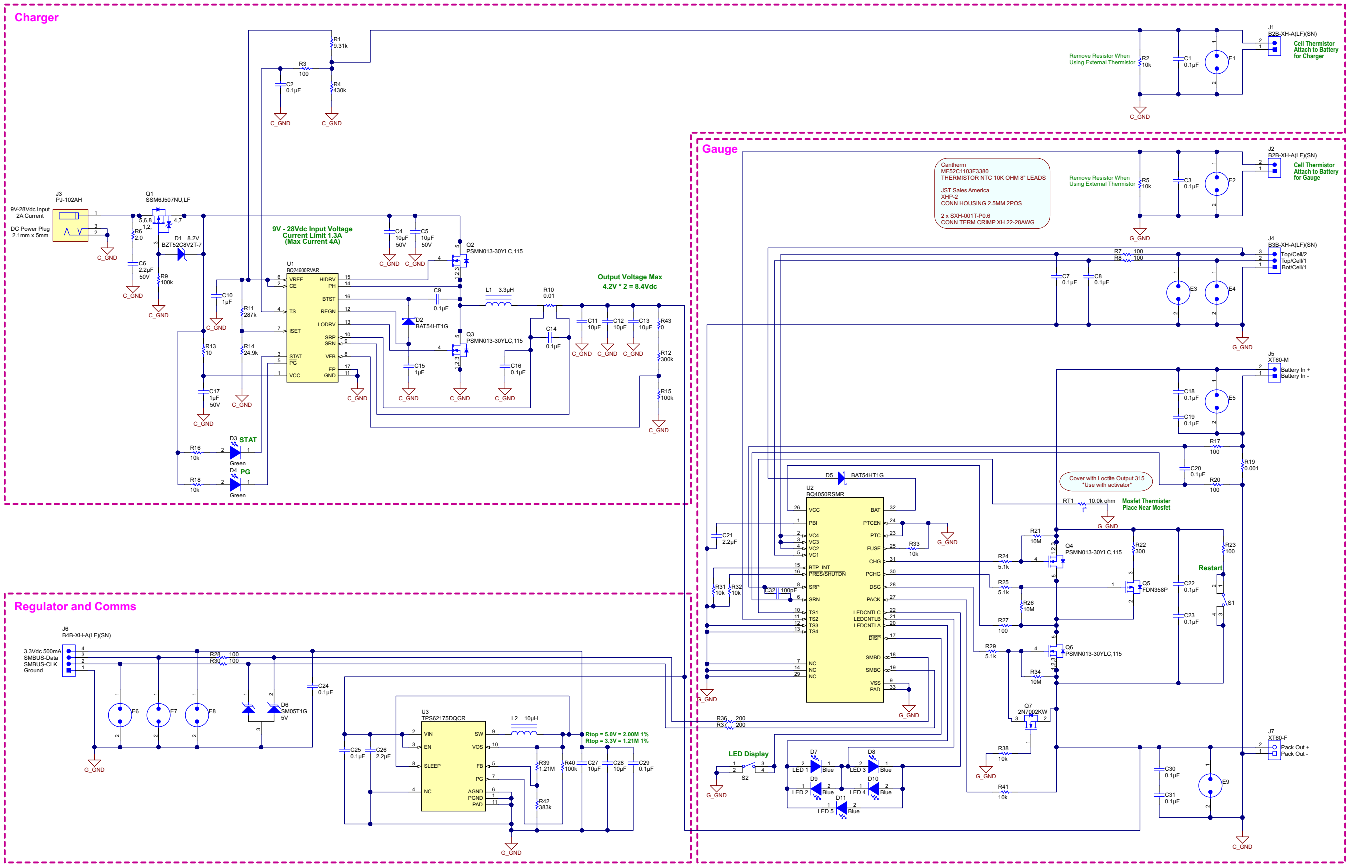

**Figure 32. TIDA-00982 Schematic**

## 7.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00xxX.

## 7.3 PCB Layout Recommendations

### 7.3.1 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 not carefully completed, the buck charger and 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-uF 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. The buck converter inductor should be placed 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, the external resistors must be placed 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 below 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 5 × below the measured ionic contamination.

### 7.3.2 Thermal Considerations

Implementation of integrated circuits 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. 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 please check 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).

## 7.4 Layout Prints

To download the layout prints for each board, see the design files at http://www.ti.com/tool/TIDA-00982.

### 7.5 Altium Project

To download the Altium project files, see the design files at TIDA-00982.

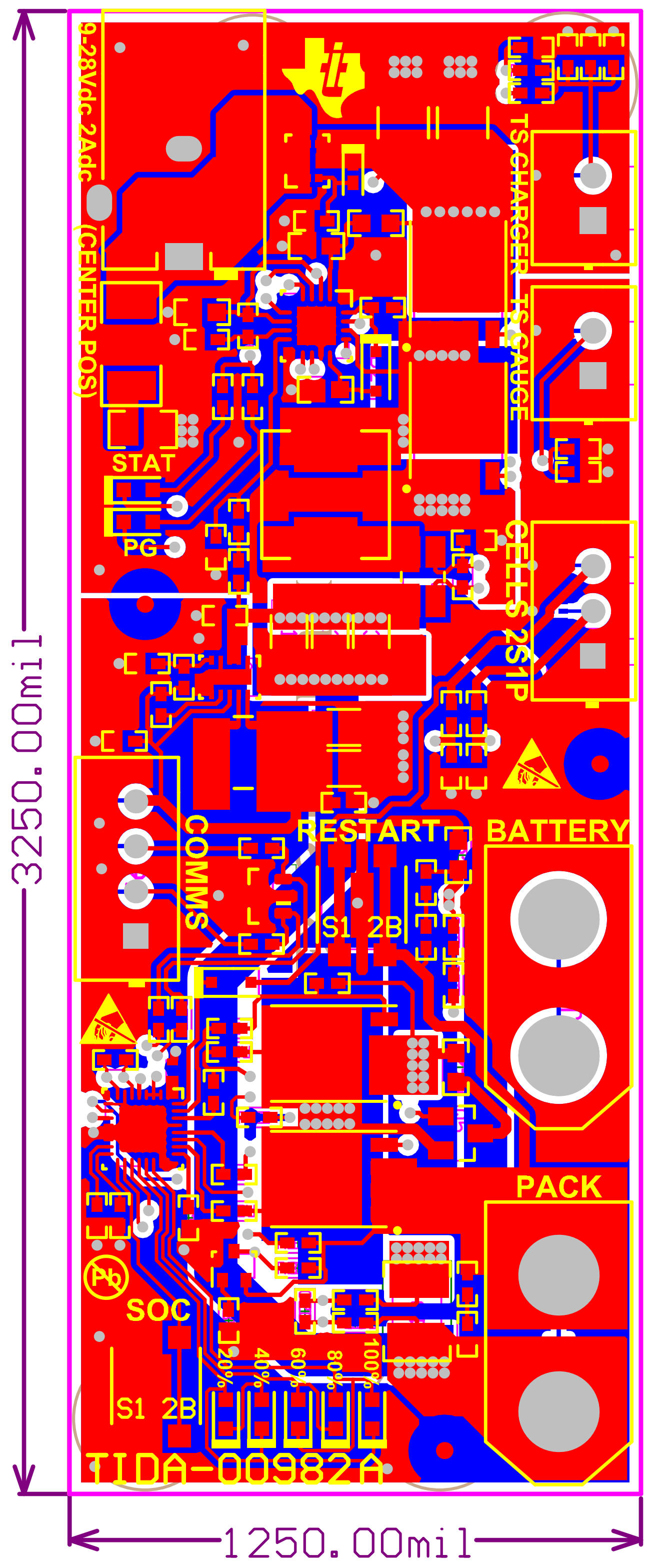




**Figure 33. Altium Project View**

### 7.6 Layout Guidelines

Figure 34 shows the layout guidelines.

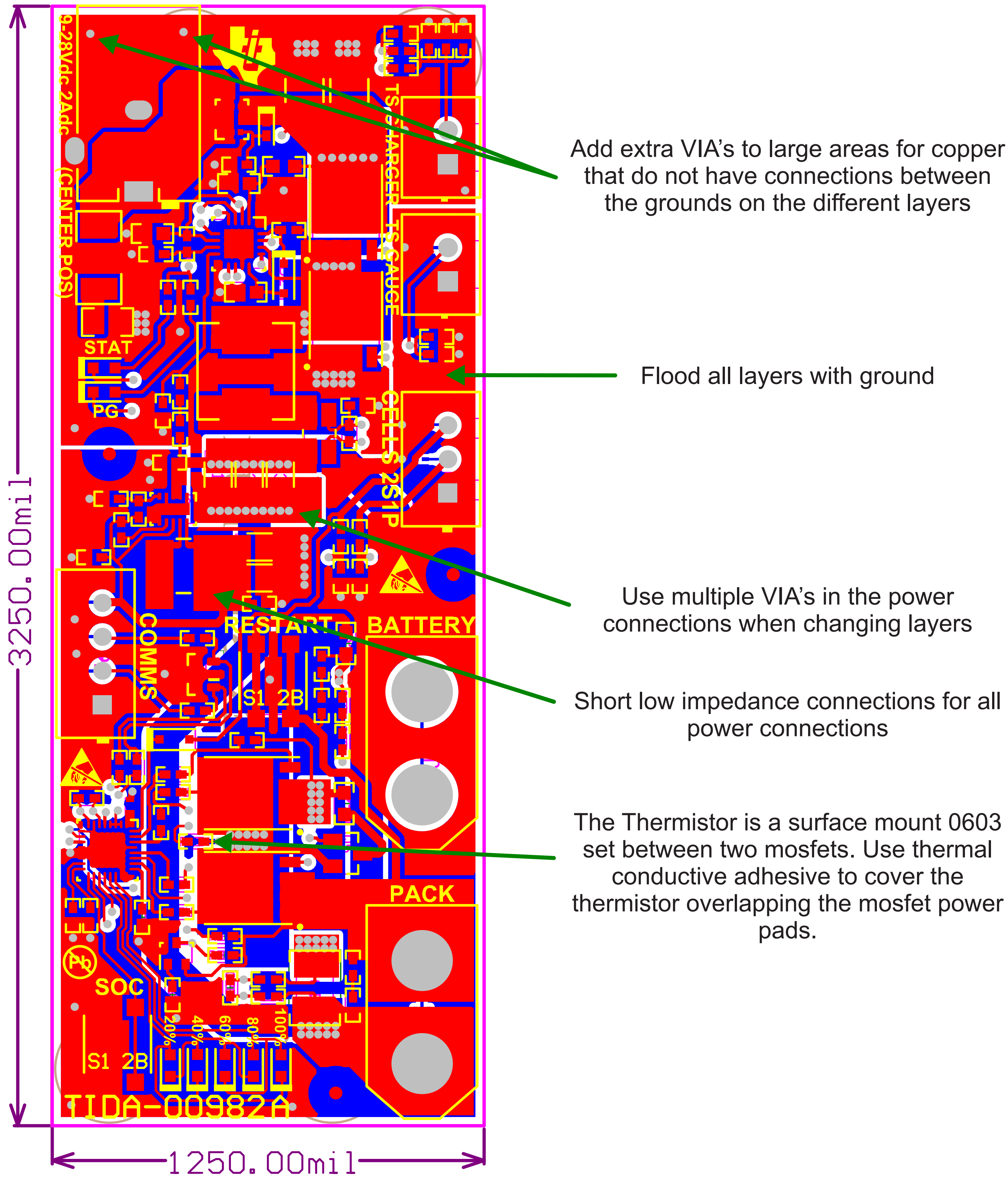




**Figure 34. Layout Guidelines**

Figure 35 shows the layout guidelines ground.

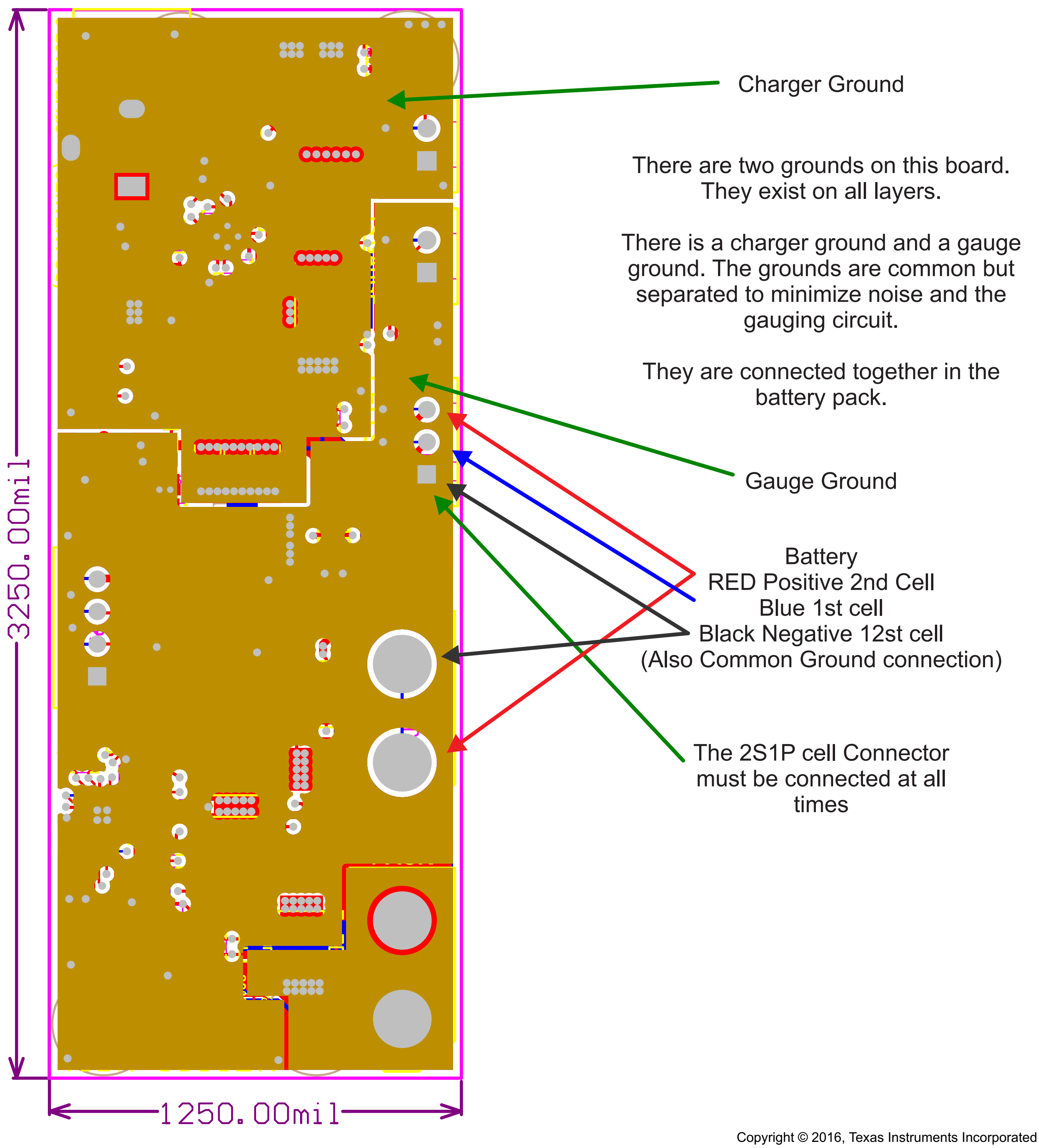


**Figure 35. Layout Guidelines Ground**

## 7.7 Gerber Files

To download the Gerber files, see the design files at TIDA-00982.

### *7.8 Assembly Drawings*

To download the assembly drawings, see the design files at TIDA-00982.

## 8 References

1. TI Gauging Parameter Calculator, GAUGEPARCAL
2. TI Gauging Parameter Calculator for CEDV gauges, GPCCEDV
3. *Simple Guide to CEDV Data Collecytion for Gauging Parameter Calculator (GPC)*, (SLUUB45)

## 9 Terminology

Let's get into a little bit of alphabet soup, starting with cell configuration. The nomenclature here 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, you can 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 you can 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 your battery or cell data sheet to get the full picture.

The next letter you will see thrown around is *C*, as in *C-rate*. It's a way to specify charging or discharging current as a ratio of the nominal battery capacity. Think of C as *capacity*, so if your 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*, since 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.

Let's close with a few three-letter acronyms: SOC, DOD and SOH. State of charge (SOC) is the percentage that you see on your phone or computer. This is actually a relative measure since it depends on the system characteristics as well as load and temperature, but it gives you a rough idea of where your 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 your battery now, it tells you 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 your battery, when fully charged, will give you about 80% of the run time as it did when it was new. Instead of just going on your gut feeling that your battery's not lasting as long as before, SOH can give you a more solid number to quantify it. Not all products report SOH (or they don't report it accurately), since it requires a fuel gauge that can track a battery's characteristics as it ages. TI's Impedance Track™ 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 may accurately report SOH.

# 10 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 (Battery Management Solutions) Group. Gordon brings to this role his extensive experience in Battery Management, Power, Analog, Digital, Micro Controller, 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 Engineering Department and has lectured more than a dozen times at several Colleges and Universities in his 27 years as an Engineer.

## Revision History

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

**Changes from Original (July 2016) to A Revision** **Page**

- Changed title from *Drone, Robot, or RC 2S1P Battery Management Solution Reference Design* to *Non-Military Drone, Robot, or RC 2S1P Battery Management Solution Reference Design* and updated applications to reflect that this design is intended for non-military drones ........ 1

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