TI Designs
Power and Battery Management Reference Design for CC2530 ZigBee® Wireless MCU

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Design Resources

TIDA-00600	www.ti.com/tool/TIDA-00600
LP5907	www.ti.com/product/LP5907
BQ24230	www.ti.com/product/BQ24230
CC2530	www.ti.com/product/CC2530
TPD1E05U06	www.ti.com/product/TPD1E05U06
TPS3839K33	http://www.ti.com/product/TPS3839K33

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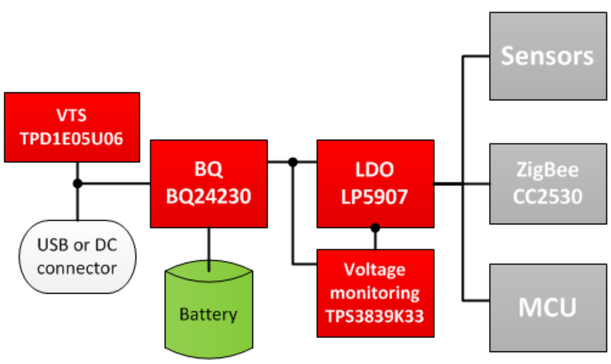
Block Diagram



Design Features

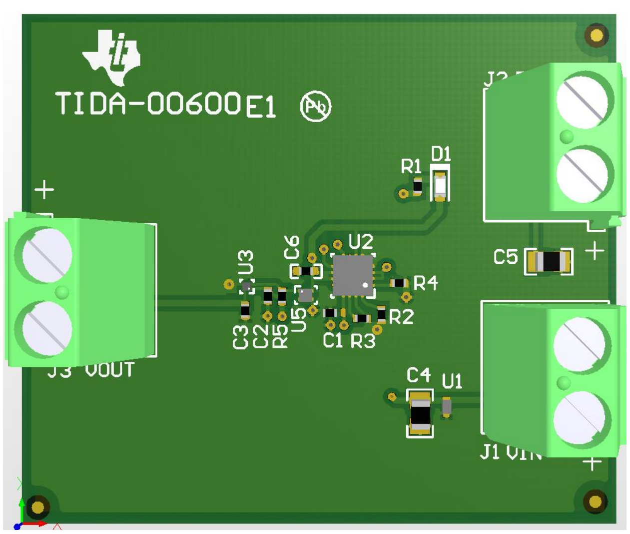
- Standalone battery charger capable of independently and simultaneously charge the battery.
- Autonomously switch from USB or DC connector to battery supply when the DC connector is removed.
- Low noise and high PSRR output voltage.
- Under voltage lockout feature to keep the battery from reaching critical low voltage levels.
- Small footprint and cost efficient components.

Featured Applications

TIDA-00600 features a power supply solution for ZigBee® Wireless MCU, some of the possible end equipment are:

- Home & Building Automation
- Wireless Sensor Networks
- Residential, commercial and industrial Lighting Systems
- Smart Meter
- Smart Plug

Board Image



1 Design Description

Many publications[1] have forecasted that ZigBee (IEEE 802.15.4) enabled devices in areas of energy monitoring, home automation, telecom and retail service will grow at a rate higher than 20% CAGR over the period of 2014-2019. Some contributors to ZigBee market growth are credited to the low power consumption and the ability to support various network topologies (Mesh, Star, and Tree)

Some ZigBee applications requires that the coordinator or master ZigBee device is powered at all times especially the topologies that depend on a central coordinator or master unit, Figure 1 shows examples of these topologies.

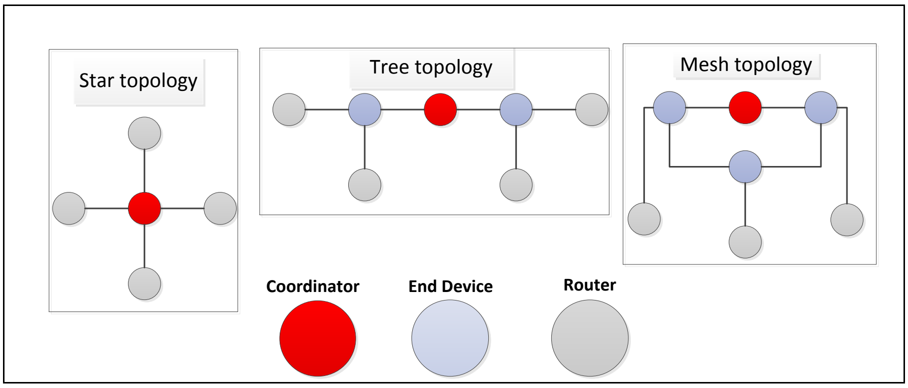


Figure 1: ZigBee Topologies

TIDA-00600 offers a solution to deliver a regulated and low transients power supply to the ZigBee system when is either connected to a DC connector or directly connected to a battery.
The main focus of TIDA-00600 design is to provide a small size and cost efficient battery charger and power management solution for ZigBee controllers, MCU and additional components in the system. Some of the benefits are:

- Low noise high PSRR power supply by implementing the LP5907UVE industry smallest (0.65mm x 0.65mm DSBGA package) low dropout regulator (LDO). The LP5907 provides a regulated 2.8 V voltage supply to power the CC2530 ZigBee controller and additional components in the system.
- Thanks to the dynamic power-path management (DPPM) feature of BQ24230 the battery can be charged at the same time that current is being supply to the load. The battery will begin to supply current to the load as soon as the DC connector is removed from the BQ24230 input.
- Safety features:
  - Under voltage lockout (UVLO) is provided by TPS3839K33. The UVLO keeps the battery from reaching critical low voltages levels.
  - TIDA-00600 also proposes the implementation of a unidirectional transient voltage suppressor (TVS). An electrostatic discharge protection diode like the TPD1E05U06 provides a path to ground to dissipate ESD events on signal lines between a human interface connector and the system.

The TIDA-00600 reference design provides test data, design guide and Gerber files for the power management segment, all the files can be obtain from the design folder at www.ti.com/tool/TIDA-00600.

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[1] Zigbee.org - *Global ZigBee Enabled Devices Market 2014-2018;* 01/19/2014
market watch - *Global ZigBee STB Market 2015-2019;* 04/16/2015
eecatalog.com - *Energy Demand and Standards Development Help Drive Investments;* 01/21/2011

Table 1 Design Parameters

DESIGN PARAMETERS	VALUES
DC connector Input Voltage range	4.35 to 6.4 V
Output Voltage (V_{OUT})	2.8 V
Output Current (I_{OUT})	250 mA
PSRR 1KHz	83 dB
Output noise voltage RMS at 250mA	6.5 μV_{RMS}
Battery type	Lithium Ion
Maximum input Current	500 mA
Fast current charging	300 mA
Battery discharge safety limit	2.93 V

2 Block Diagram

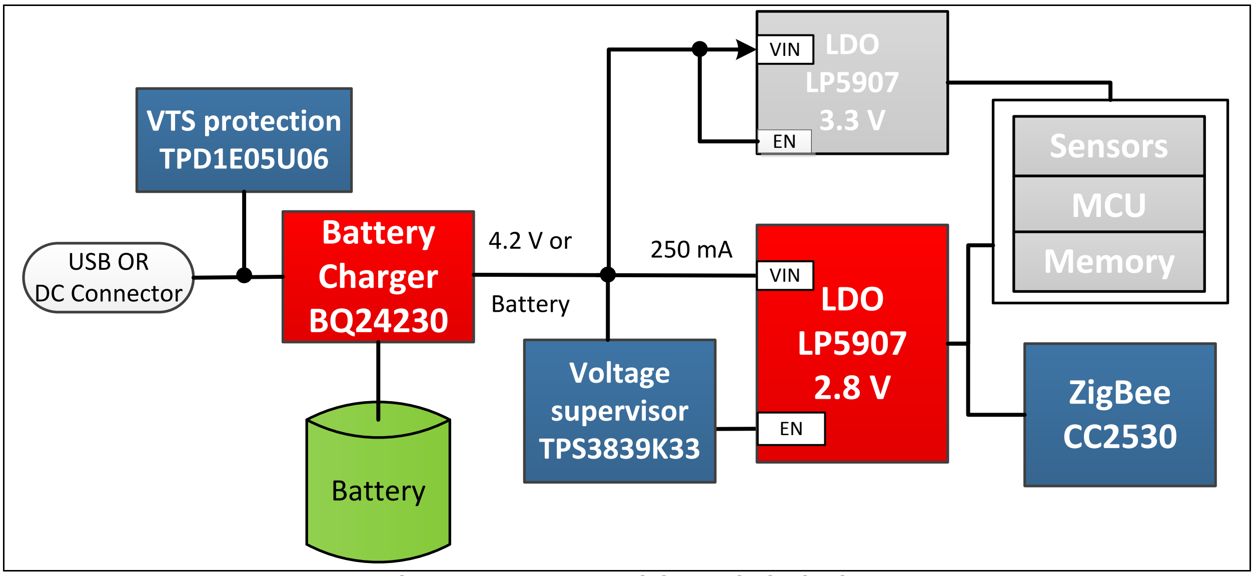

Figure 2 TIDA-00600 High Level Block Diagram

Figure 2 shows the comprehensive block diagram of the TIDA-00600 power management solution. The red blocks represents the focus components of this document. The blue blocks represent other TI devices that are recommended and described in this document. The CC2530 ZigBee SoC was not designed in the evaluation board, but its power requirements were taken into consideration to define the design parameters. The grey blocks show the scalability of the TIDA-00600 power management design.

2.1 Highlighted Components

2.1.1 LP5907

The LP5907 provides low noise, high PSRR, low quiescent current and low line or load transient response. The device offers excellent noise performance without the need for a noise bypass capacitor and is stable with input and output ceramic capacitors with a value of 1 µF.

The LP5907 delivers this performance in industry standard packages such as DSBGA, X2SON, and SOT-23 which, for this device, are specified with an operating junction temperature (T_J) of –40°C to 125°C.

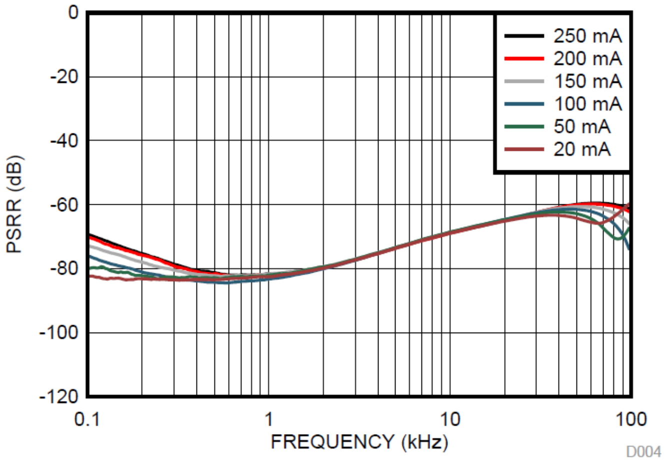

Figure 3: PSRR 100 Hz to 100 KHz

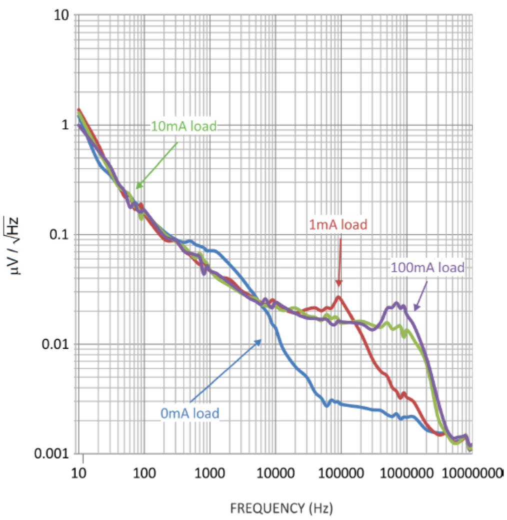

Figure 4: Noise Density

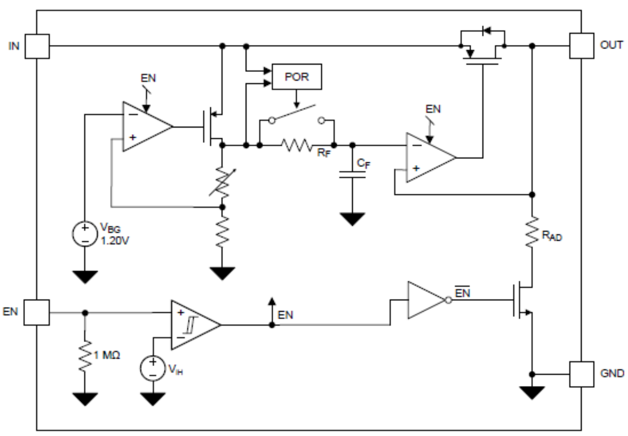

Figure 5: LP5907 Functional Block Diagram

2.1.2 BQ24230

The BQ2423x powers the system while simultaneously and independently charging the battery. This feature reduces the number of charge and discharge cycles on the battery, allows for proper charge termination, and enables the system to run with a defective or absent battery pack. It also allows instant system turn-on even with a totally discharged battery. The input power source for charging the battery and running the system can be an AC adapter or a USB port.

The devices feature dynamic power-path management (DPPM), which shares the source current between the system and battery charging and automatically reduces the charging current if the system load increases. When charging from a USB port, the input dynamic power management (VIN-DPM) circuit reduces the input current limit if the input voltage falls below a threshold, preventing the USB port from crashing. The power-path architecture also permits the battery to supplement the system current requirements when the adapter cannot deliver the peak system currents.

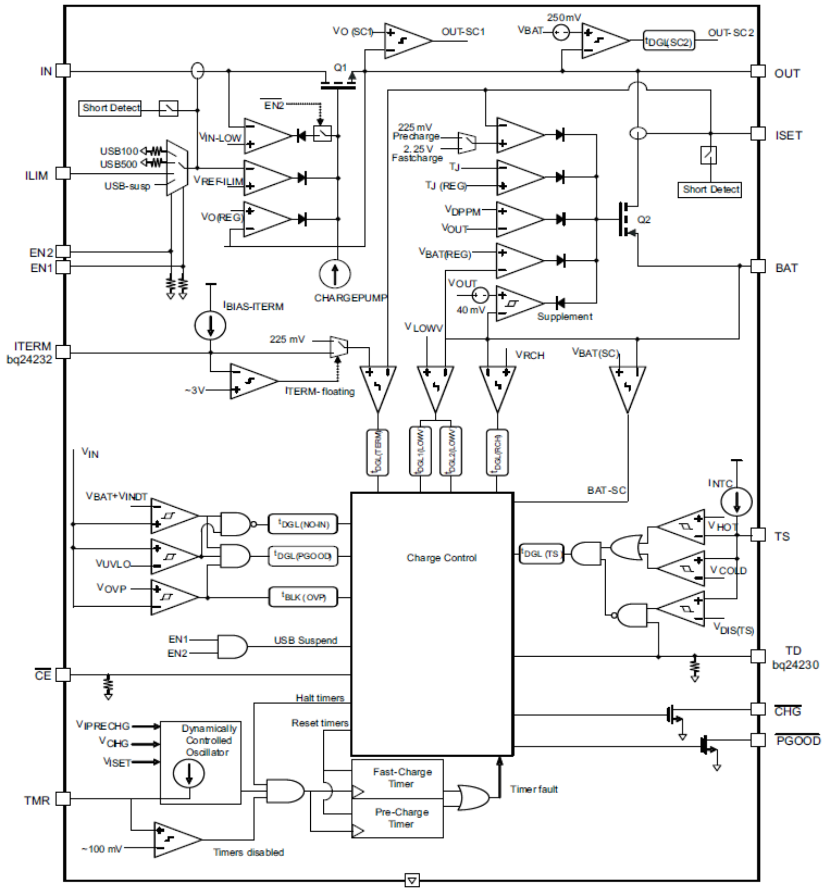

Figure 6: BQ24230 Functional Block Diagram

Alternative Devices

BQ24232: Similar functionality but higher maximum input voltage of 10.2V

2.2 Other TI parts:

Note:

The power requirements of these parts were taken into consideration to define TIDA-00600 parameters but they were not populated in the evaluation board or tested as a whole system.

2.2.1 CC2530 System-on-Chip

The CC2530 is a true system-on-chip (SoC) solution for IEEE 802.15.4, ZigBee and RF4CE applications. It enables robust network nodes to be built with very low total bill-of-material costs. The CC2530 combines the excellent performance of a leading RF transceiver with an industry-standard enhanced 8051 MCU, in-system programmable flash memory, 8-KB RAM, and many other powerful features. The CC2530 comes in four different flash versions: CC2530F32/64/128/256, with 32/64/128/256 KB of flash memory, respectively. The CC2530 has various operating modes, making it highly suited for systems where ultralow power consumption is required. Short transition times between operating modes further ensure low energy consumption.

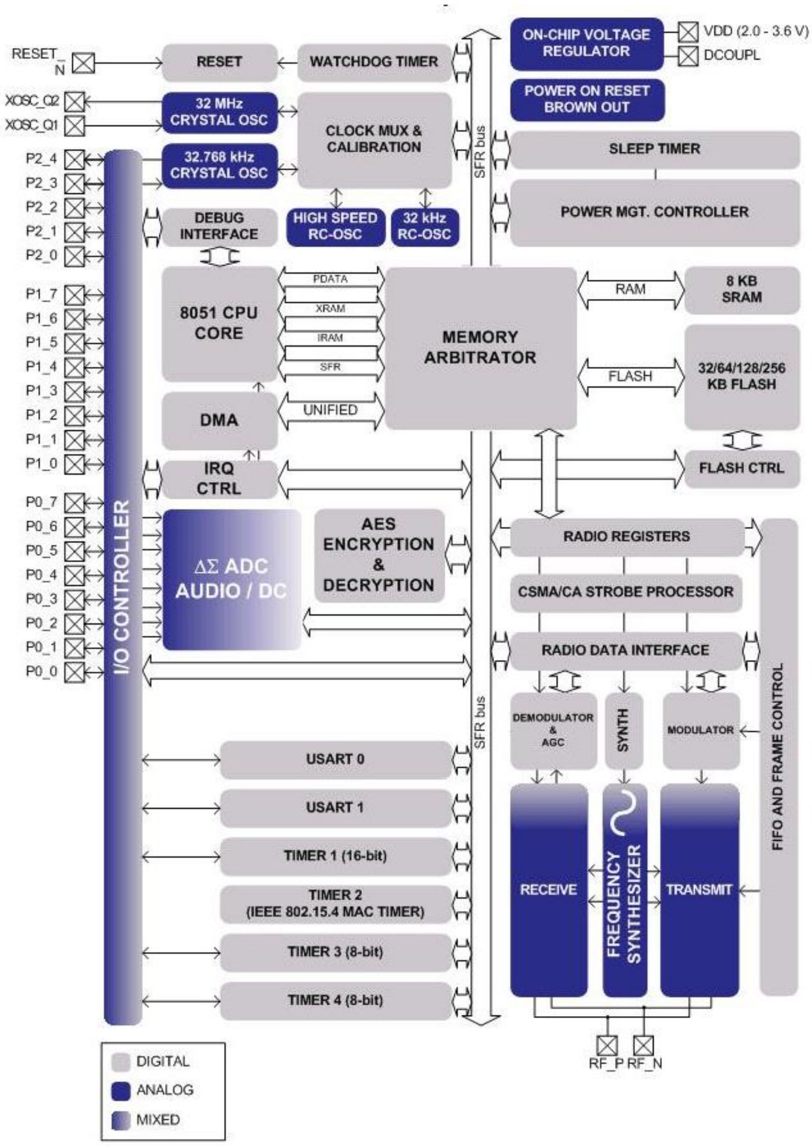

Figure 7: CC2530 Functional Block Diagram

- Low Power
    - Active-Mode RX (CPU Idle): 24 mA
    - Active Mode TX at 1 dBm (CPU Idle): 29 mA
    - Power Mode 1 (4 ms Wake-Up): 0.2 mA
    - Power Mode 2 (Sleep Timer Running): 1 mA
    - Power Mode 3 (External Interrupts): 0.4 mA
    - Wide Supply-Voltage Range (2 V–3.6 V)
- Microcontroller
    - High-Performance and Low-Power 8051 Microcontroller Core With Code Prefetch
    - 32-, 64-, 128-, or 256-KB In-System-Programmable Flash
    - 8-KB RAM With Retention in All Power Modes
    - Hardware Debug Support
- Peripherals
- Powerful Five-Channel DMA
- IEEE 802.15.4 MAC Timer, General-Purpose Timers (One 16-Bit, Two 8-Bit)
- IR Generation Circuitry
- 32-kHz Sleep Timer With Capture
- CSMA/CA Hardware Support
- Accurate Digital RSSI/LQI Support
- Battery Monitor and Temperature Sensor

- 12-Bit ADC With Eight Channels and Configurable Resolution
- AES Security Coprocessor
- Two Powerful USARTs With Support for Several Serial Protocols
- 21 General-Purpose I/O Pins (19× 4 mA, 2×20 mA)
- Watchdog Timer
- Development Tools
    - CC2530 Development Kit
    - CC2530 ZigBee Development Kit
- Software Development Tools
    - SmartRF Software
    - Packet Sniffer
    - IAR Embedded Workbench Available

2.2.2 TPS3839K33

TPS3839K33 assert an active-low reset whenever the VDD supply voltage drops below the negative threshold voltage (VIT), the VIT is 2.93 V. The output, RESET, remains asserted for approximately 200 ms after the VDD voltage rises above the positive-going threshold voltage (VIT– + Vhys) Vhys is typically 29mV. These devices are designed to ignore fast transients on the VDD pin.

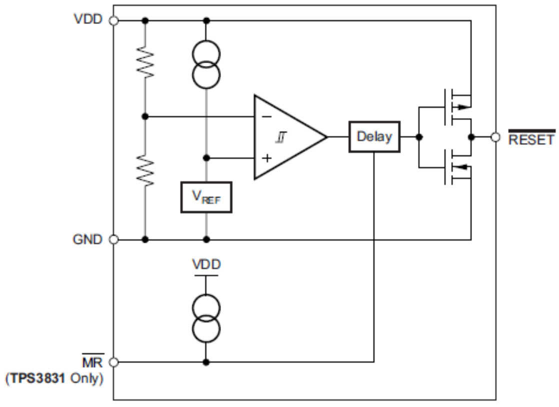

Figure 8: Functional Block Diagram

2.2.3 TPD1E05U06

TPDxE05U06 is transient voltage suppressor (TVS) which is typically used to provide a path to ground for dissipating ESD events on signal lines between a human interface connector and a system. As the current from ESD passes through the TVS, only a small voltage drop is present across the diode. This is the voltage presented to the protected IC. The low RDYN of the triggered TVS holds this voltage, VCLAMP, to a safe level for the protected IC.

- IEC 61000-4-2 Level 4 ESD Protection
  - ±12-kV Contact Discharge
  - ±15-kV Air Gap Discharge
- IO Capacitance 0.42 pF to 0.5 pF (Typ)
- DC Breakdown Voltage 6.5 V (Min)
- Ultra low Leakage Current 10 nA (Max)

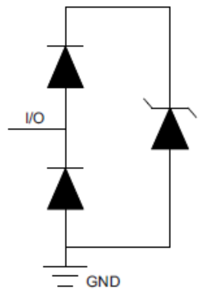

Figure 9 TPD6E05U06 Block Diagram

This ESD clamp is good for the protection of end equipment typical applications of ESD protection products are keypad or other buttons, VBUS pin and ID pin of USB ports, and general-purpose I/O ports.

Alternative parts
TPD1E10B06: bidirectional TPD1E10B06 Single-Channel ESD Protection Diode in 0402 Package

3 Design Considerations

3.1 Power requirements for CC2530

This section shows the power requirements for CC2530. Please refer to CC2530 datasheet for functionality and applications information. For additional references see section 8 of this document.

3.1.1 Voltage requirements

The CC2530 has an on-chip voltage regulator allowing a wide input supply-voltage in the range of 2 V to 3.6 V. **Figure 10** and **Figure 11** shows the correlation between input supply voltage and current consumption.

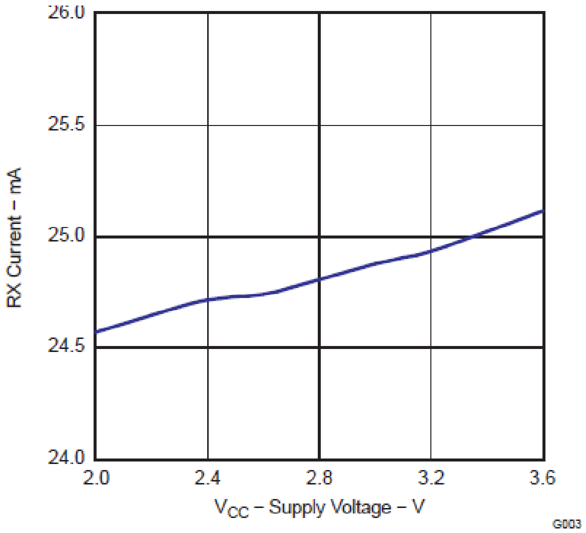

Figure 10: Comparison Between RX Current (-100 dBm Input) and Supply Voltage

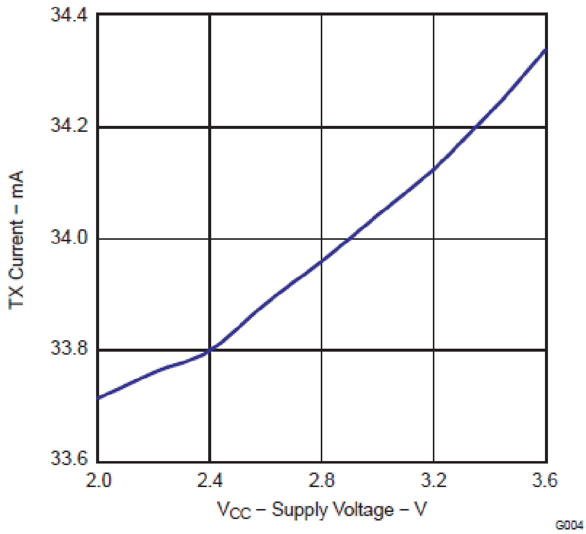

Figure 11: Comparison Between TX Current (4.5 dBm) and Supply Voltage

3.1.2 Current requirements

From AN079 (SWRA292)application note we can obtain an estimate of the peak and average current consumption in a generic battery-powered ZED running Z-stack on the CC2530; in this generic application the device is receiving messages and sending replies.

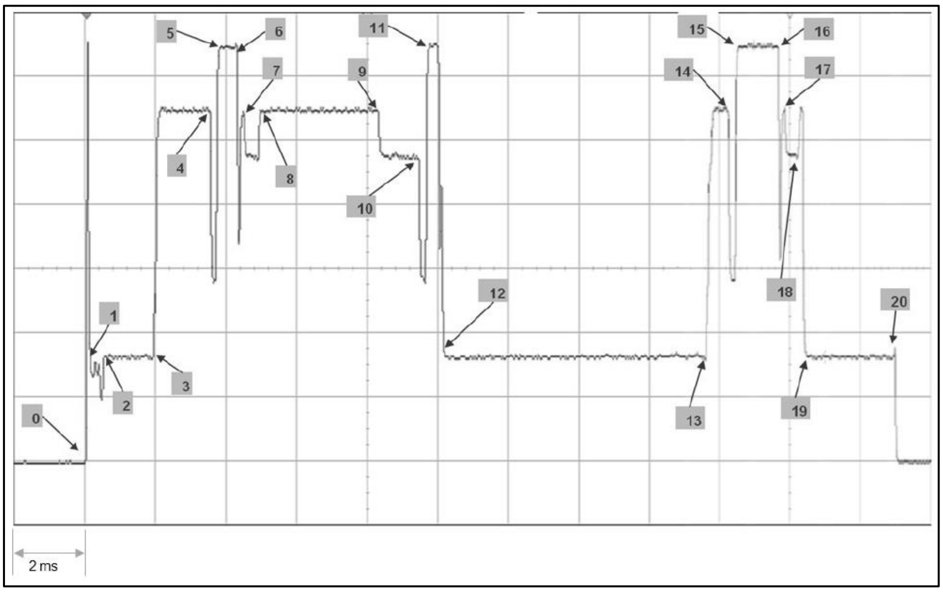

Figure 12: Current Consumption Measurement (App-note SWRA292)

Table 2 Current Consumption Measurement (App-note SWRA292)

Section	Unit Operation Description	Current (mA)	Time (ms)	Consumption (mA*ms)
Before 0	Power Mode 2	0.001		
Point 0 to 1	Power mode start-up sequence.	12	0.2	2.4
Point 1 to 2	MCU in active mode running on 16-MHz clock	6	0.25	1.5
Point 2 to 3	MCU running on 32-MHz clock	7.5	1.7	12.75
Point 3 to 4	CMSA/CA algorithm. Radio in RX mode	27	1.068	28.836
Point 4 to 5	Switch from RX to TX	14	0.2	2.8
Point 5 to 6	Transmitting MAC data request. Radio in TX mode	32	0.58	18.56
Point 6 to 7	Switch from TX to RX	25	0.2	5
Point 7 to 8	Receiving MAC ACK from coordinator	23.5	0.35	8.225
Point 8 to 9	Radio in RX mode (processing MAC ACK and then waiting for the packet)	25	4.1915	104.7875
Point 9 to 10	Receiving Toggle command	23	1.2	27.6
Point 10 to 11	Switch from RX to TX	14	0.2	2.8
Point 11 to 12	Transmitting MAC Acknowledgement. Radio in TX mode	32	0.35	11.2
Point 12 to 13	Processing incoming Toggle command (for example, toggling the light)	7.5	7.8	58.5
Point 13 to 14	CMSA/CA algorithm. Radio in RX mode	27	0.955	25.785
Point 14 to 15	Switch from RX to TX	14	0.2	2.8
Point 15 to 16	Transmitting Default Response command. Radio in TX mode	32	1.22	39.04
Point 16 to 17	Switch from TX to RX	25	0.2	5
Point 17 to 18	Receiving MAC ACK from coordinator	23	0.35	8.05
Point 18 to 19	Radio remaining in RX mode and processing the MAC ACK	27	0.15	4.05
Point 19 to 20	Processing and shut down	7.5	2.5	18.75
After 20	Power Mode 2	0.001		
			23.865	**388.4335**

Figure 12 and **Table 2** show that the peak current occurs during the transmitting (TX) periods. In this example the peak current is 32 mA, this correlates with CC2530 data sheet which mentions that the maximum TX current is 39 mA without peripherals. From this information it can be concluded that the power supply must be able to handle at least 40mA in addition to the current required by the peripherals.

3.2 LP5907- 2.8V Low Dropout Linear Regulator

When the battery charger is connected to a DC connector the output of the charger is internally regulated to 4.2 V which exceed the CC2530 maximum input voltage of 3.6 V. The LDO regulates the output of BQ24230 to 2.8 V which is low enough to utilize most of the energy stored in a lithium battery and is a typical voltage for other possible components in the system.

The LP5907 was chosen for its high PSRR, low cost and tiny DSBGA package. The LP5907 does not have minimum load requirements and can operate with very small ceramic capacitors. The output capacitor is 1µF since the maximum load step of CC2530 is expected to be less than 50 mA. The maximum and minimum transient peaks at 250 mA load step are ±40 mV. An additional feature of the LP5907 is the line transient response, which is beneficial to filter the line voltage steps and transients created by the BQ24230 when it swaps from USB or connector to battery supply.

3.3 Voltage Supervisor

The voltage supervisor is implemented as an under voltage lock out (UVLO) which protects the battery from reaching critical low voltage levels. The TPS3839K33 monitors the output voltage of the BQ24230 when the voltage goes lower than 2.93 V it disables the LP5907 output by pulling the LP5907 EN pin low.

The **Figure 13** is a representation for a typical discharge curve of a Li-Ion battery the MPV stands for midpoint voltage when the battery has discharged 50% of its total capacity and the EOL stands for End of Life voltage which means that the battery has reached the end of its operating life at this point the battery is going to rapidly discharge to a critical low voltage level.

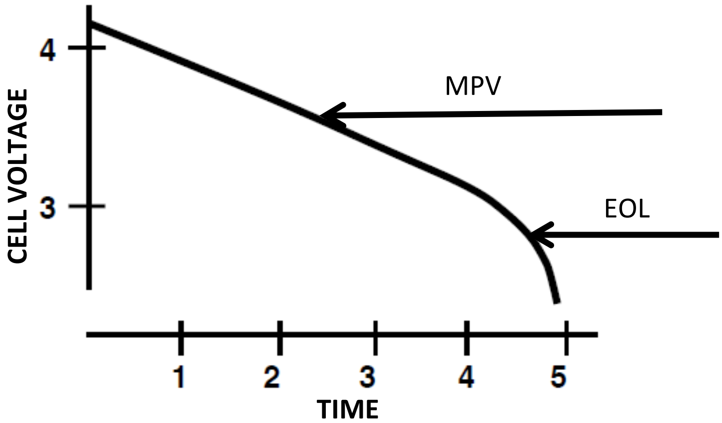

Figure 13: Lithium Ion Battery Charge Discharge Curve

An important parameter to select the threshold of the voltage supervisor is the dropout voltage (V_{DO}) of the LDO; the V_{DO} is the lowest input and output voltage difference required by the LDO to maintain output voltage regulation. An alternative LDO and voltage supervisor combination for a 2.2V output voltage is LP5907_2.2V paired with TPS3839G25_2.35.

3.4 Battery Management

This section mentions the key parameters of BQ24230 for this application. For additional information about additional functionality and additional features of the BQ24230 charger please review the datasheet (SLUS821H) and EVM user guide (SLVU274C)

BQ24230 Input

The BQ24230 is used as a standalone charger with the capability of simultaneously and independently charging the battery. The operating voltage range is between 4.35 V and 6.4 V. The input capacitor should be a ceramic capacitors tested for 2x their rated values so a 10-V capacitor can support 20-V transients.

BQ24230 Output

When a power supply higher than 4.35 V is connected to the IN pin the output voltage is regulated to 4.2V and the current is shared between the output load and the battery.

In case that the source at the IN pin is disconnected or is lower than the internal UVLO (3.3V typical) the control inputs ($\overline{CE}$, EN1 and EN2) are ignored and the Q1 FET connected between IN and OUT pins is off preventing reverse current to flow from OUT to IN pin, the status output CHG and PGOOD are high impedance, and the Q2 FET that connects BAT to OUT is ON allowing the battery to directly source current to the load.

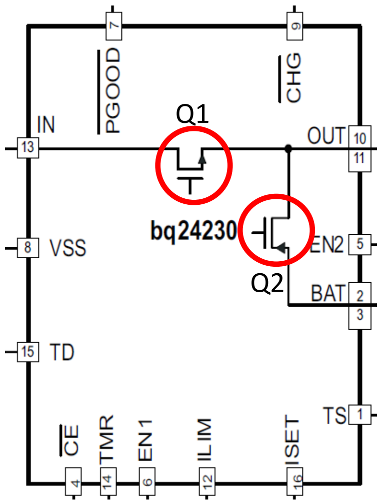

Figure 14 Simplify Block configuration of Internal FETs

3.4.1 Battery Charging Profile

To initiate battery charging sequence $\overline{\text{CE}}$ Pin has to be pulled low. To prevent over temperature conditions the temperature monitoring feature of the BQ24230 can be used.
Figure 15 illustrates a typical Li-ion charge cycle

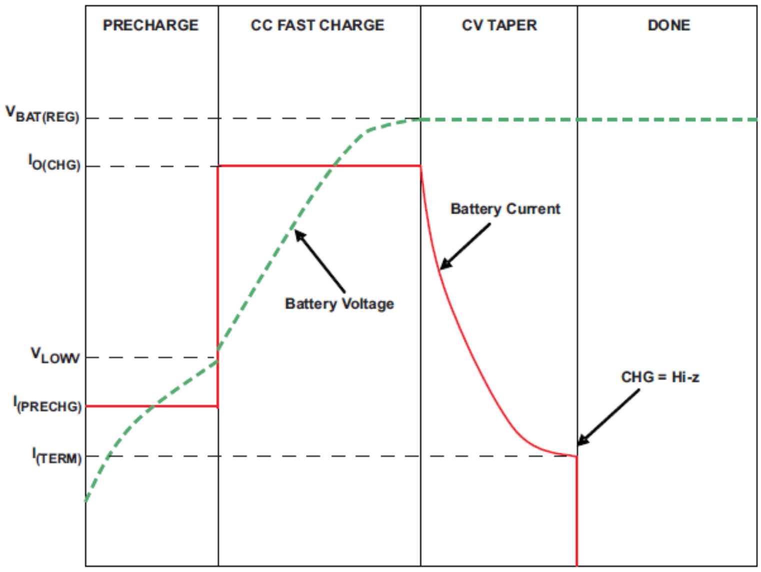

Figure 15: Normal Li-Ion Charge Cycles

3.4.2 BQ24230 Features and Compensation Components

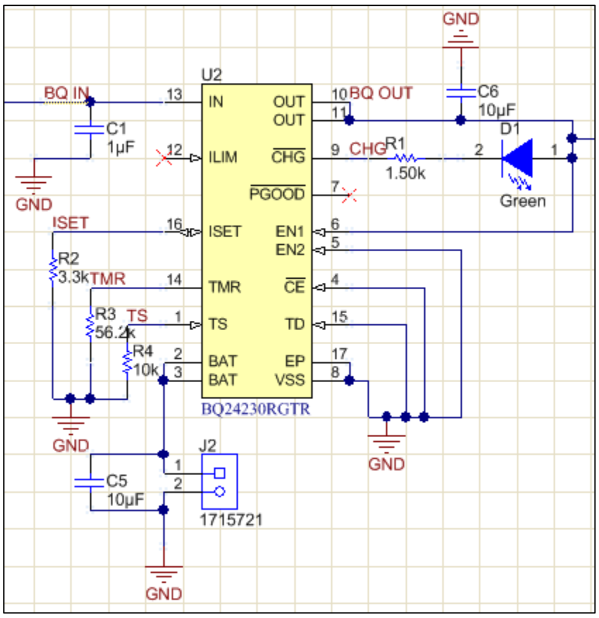

Figure 16: BQ24230 Compensation Components

Fast current

Fast-charge current was set to approximately 300 mA by connecting resistor R2 (3.3KΩ) from ISET (pin 16) to VSS (GND)
The value of R2 can be calculated with Equation 1

$R_{SET} = K_{ISET} / I_{CHG}$ **Equation 1**

K_{ISET} = 870 AΩ from the electrical characteristics table of BQ24230 datasheet.

Input Current Limit

Current limit is set by the EN2 and EN1 pin, Table 3 shows the current mode based in the EN pins configuration. The USB500 mode was selected which means that the input current is limited to 500 mA. When Mode USB500 is selected the ILIM (pin 12) can be left floating.
The input current is shared between the load and the battery during the charging periods.

Table 3: EN Pins Configuration and Maximum Current Mode

EN2	EN1	Maximum Input Current Into IN Pin
0	0	100 mA. USB100 mode
0	1	500 mA. USB500 mode
1	0	Set by an external resistor from ILIM to VSS
1	1	Standby (USB suspend mode)

Fast Charge Safety Timer (TMR)

Safety timer duration was set to 6.25 hours; by resistor R3 connected between TMR (pin 14) and ground. Equation 2 can be used to calculate the value of R3

RTMR = tMAXCHG / (10 × KTMR) **Equation 2**

KTMR = 40 s/kΩ from the electrical characteristics table of BQ24230 datasheet.
RTMR = (6.25 hr × 3600 s/hr) / (10 × 40 s/kΩ) = 56.25 kΩ

Temperature Sense

This feature is disabled in this design by connecting a by connecting R4 a 10 kΩ resistor from TS pin 1 to ground. To enable this feature connect a 10-kΩ NTC thermistor in the battery pack (103AT) and TS pin. Pay close attention to the linearity of the chosen NTC so that it provides the desired hot and cold turnoff thresholds.

4 Other Methods

This section shows an alternative method to automatically swap the power supply from a DC connector to battery supply.

Figure 17 shows a simple method to automatically connect the battery to the load when the main connector is removed. This approach does not have a battery recharging capability or a battery supervisor to keep the battery from discharging to a critical level.

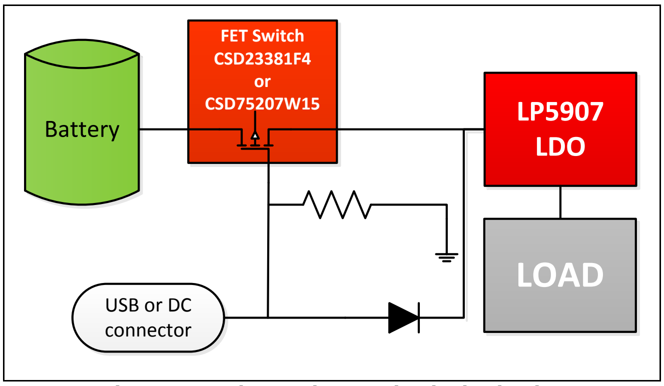

Figure 17: Alternative Method Block Diagram

The Q1 FET is open (battery disconnected from load) when the DC connector is connected. When the DC connector is removed Q1 is closed which means that the battery will be directly connected to the LDO input. Q1 must have a low drain to source resistance (R_{DSON}) to avoid a big voltage drop during battery operation. Possible Q1 selections are CSD23381F4 and CSD75207W15

5 Test Setup and Results

Note

The TIDA-00600 EVM is not available for purchase; however, reference design files can be downloaded at http://www.ti.com/tool/tida-00600

Before applying power to the TIDA-00600 board, all external connections should be verified. The external power supply must be turned off before being connected. Confirm proper polarity to the J1, J2 and J3 terminals before turning the external power supply on.

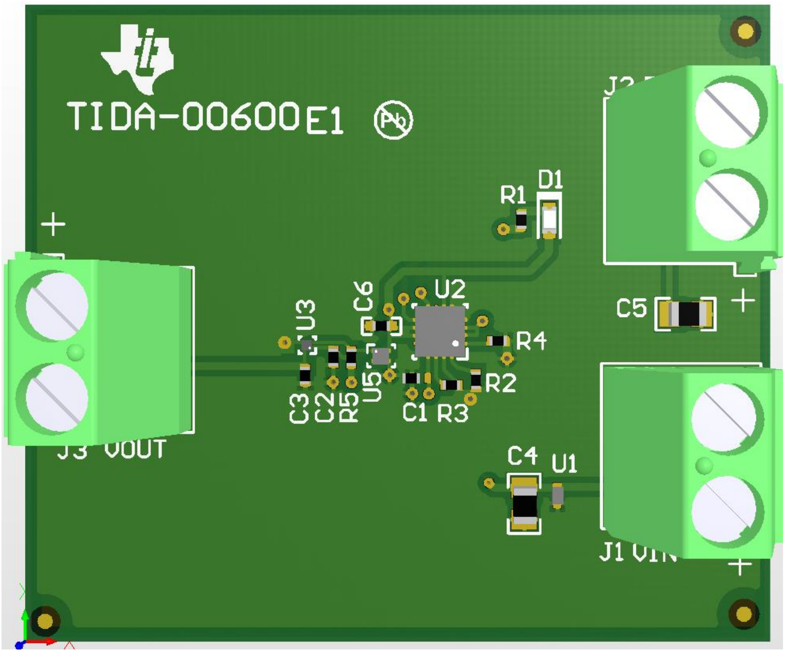

Figure 18: TIDA-00600 Board

5.1 Test Equipment

The following table shows the test equipment used to collect the test data.

Table 4 Test Equipment

Test equipment	Part number
Oscilloscope	Agilent DPO4014B
DC voltage supply	Agilent E3631A
Multimeter	Agilent E34401A
Network Analyzer	Agilent E5061B ENA

6 Test Data

6.1 LP5907 Power Supply Ripple Rejection

The output voltage ripple rejection ratio ()is calculated by comparing the regulated output voltage of the device under test (DUT) with the input voltage ripple over a frequency range of 10Hz to 10MHz.

Test parameters:
$C_{IN} = C_{OUT} = 1\mu F$
V_{IN_AC} = Sweep from 10Hz to 10MHz
Room Temperature = 23^{o} C
EN pin tied to V_{IN}

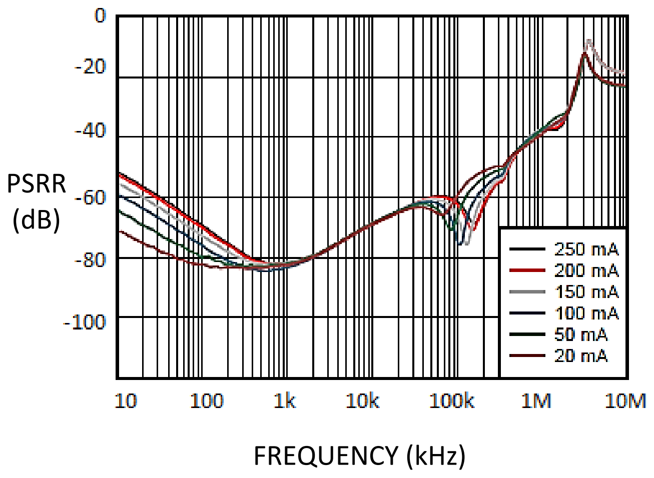

Figure 19 LP5907 PSRR

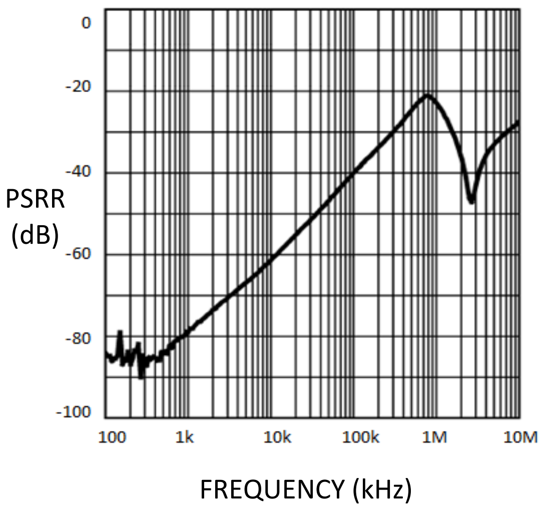

Figure 20 LP907 PSRR

6.2 LP5907 Start-UP

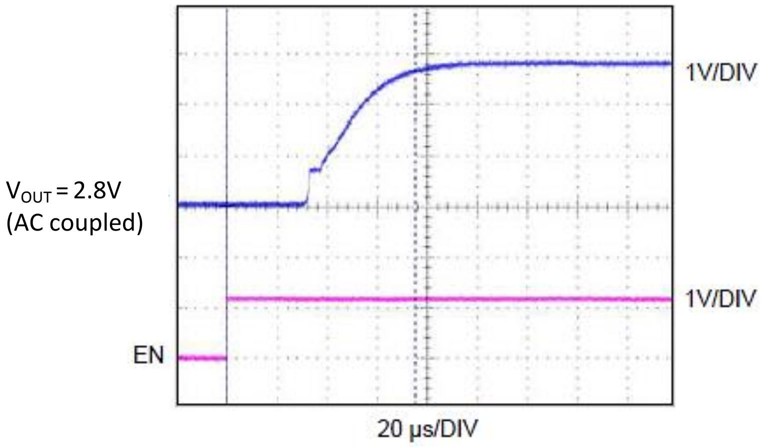

Figure 21: Start-Up (1mA load)

6.3 LP5907 Load Transient and Regulation

The LP5907 line regulation test is defined as the change in output voltage from nominal value resulting from a change in load current.

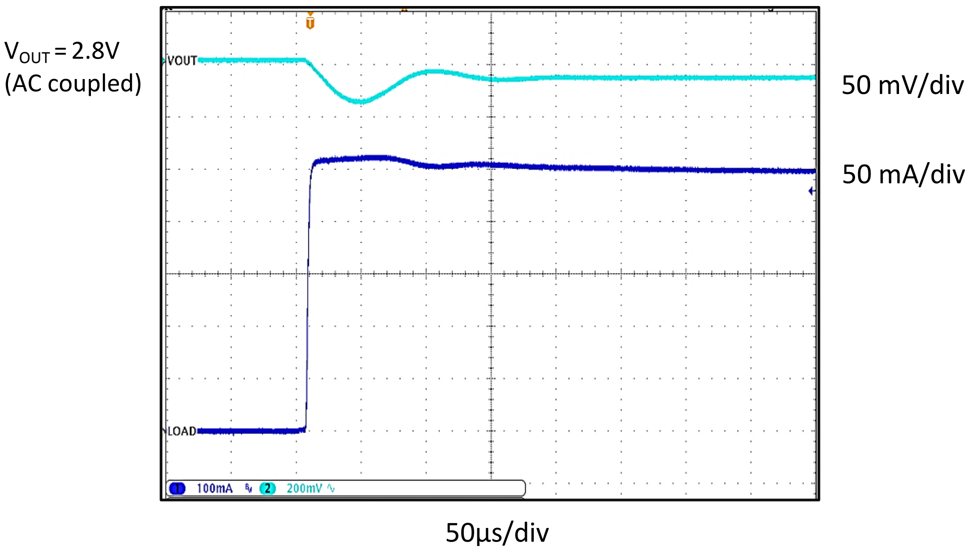

Figure 22 Load Transient

6.4 BQ24230 Adapter Plug-In With Battery Connected

Figure 23 shows the behavior of the BQ24230 when a DC adapter is suddenly plug-in when the battery is connected.

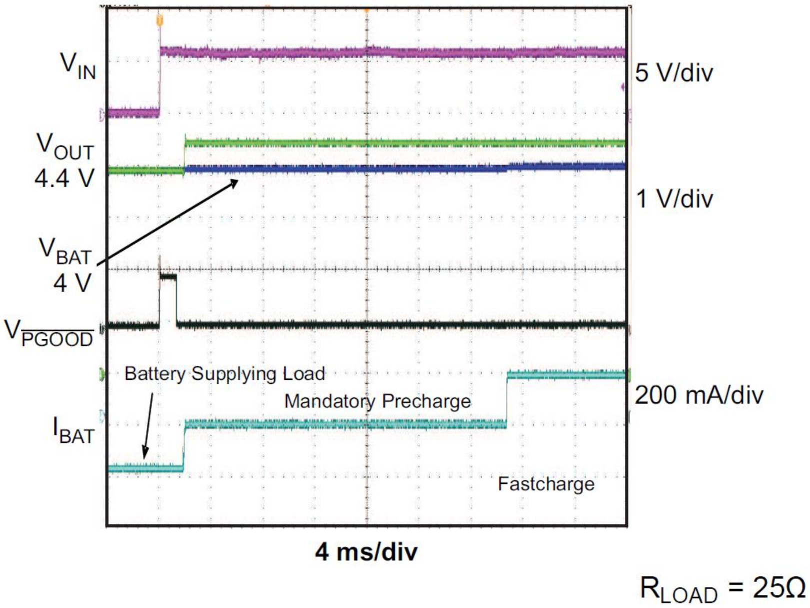

Figure 23 Adapter Plug-In With Battery Connected

6.4.1 LP5907 Line Transients

This section evaluates the line transient response of the LP5907. The green line in **Figure** 24 is the input power of the BQ24230; the yellow trace is the output of the BQ24230 changing from DC power supply to only battery and the purple trace is the output of the LP5907 which stays steady under these conditions.

Figure 25 shows a more extreme case in which the LP5907 input voltage changes by 1V and yet the output voltage does not have any significant transients

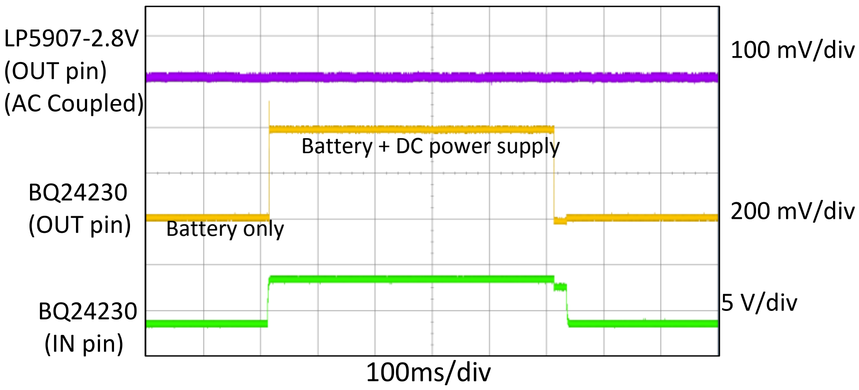

Figure 24: LP5907 Line Transient (1 mA load)

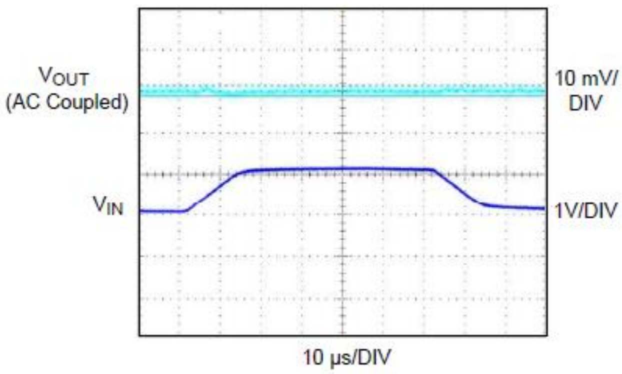

Figure 25 LP5907 Line Transient (1V step)

6.5 BQ24230 Current vs Battery Voltage

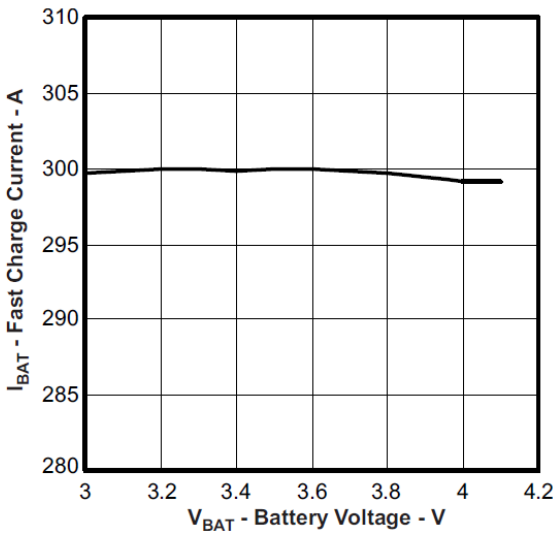

Figure 26: Fast charge current vs Battery voltage

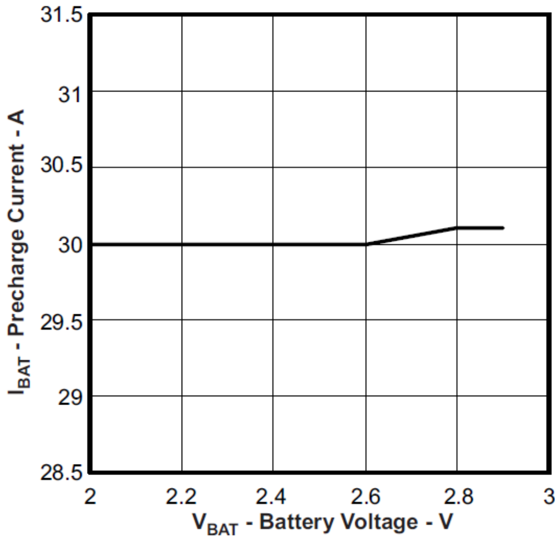

Figure 27: Precharge Current vs Battery Voltage

7 Design Files

7.1 Schematics

To download the Schematics for each board, see the design files at http://www.ti.com/tool/TIDA-00600
The DNP devices were populated in the evaluation board or tested with the whole system

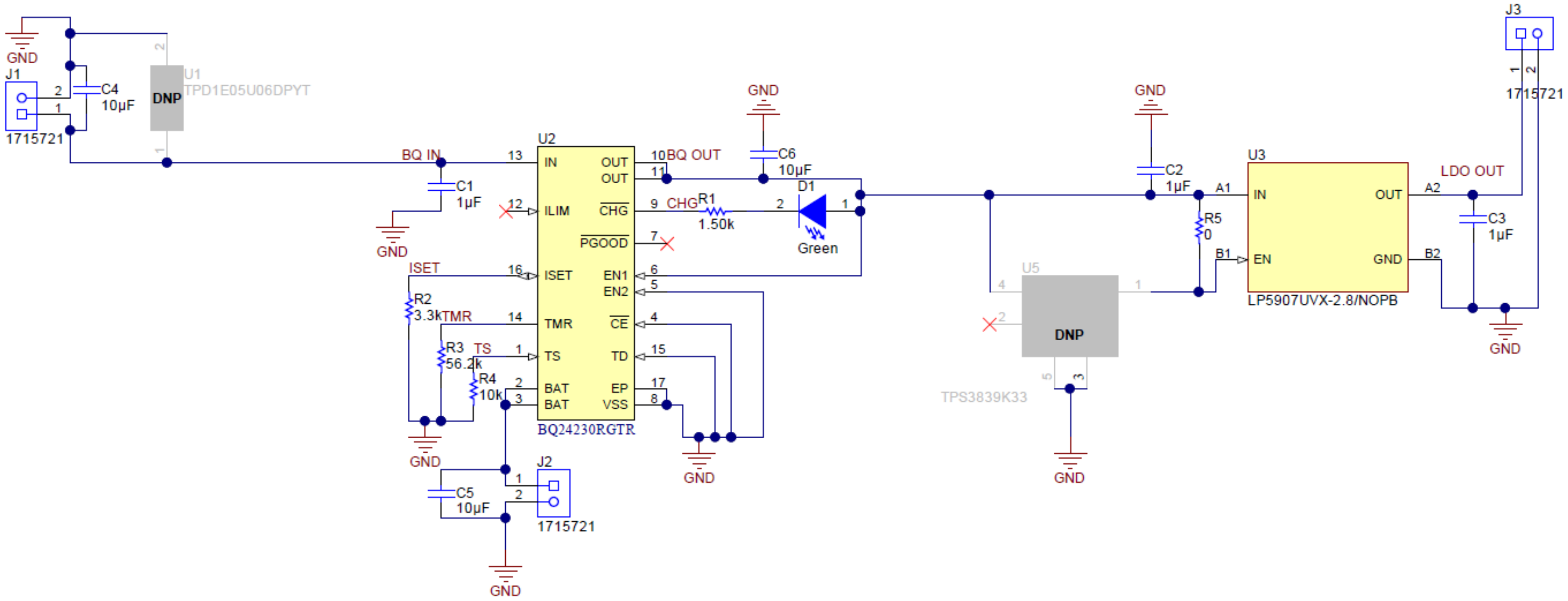

Figure 28: TIDA-00600 Schematic

7.1.1 Altium Project

To download the Altium project files, see the design files at http://www.ti.com/tool/TIDA-00600

- Gerber and NC-drills
- Bill of Materials (BOM)
- Schematic

7.2 PCB Layout Recommendations

- Best performance is achieved by placing input and output caps on the same side of the PCB and as close as is practical to the package. The ground connections for the caps should be back to the ground pin using as wide, and as short, of a copper trace as is practical.
- Connections using long trace lengths, narrow trace widths, and/or connections through vias should be avoided. These will add parasitic inductances and resistance that results in inferior performance especially during transient conditions
- Eliminate any sharp corners on the protected traces between the TVS and the connector by using rounded corners with the largest radii possible. Electric fields tend to build up on corners, increasing EMI coupling.

7.2.1 Recommendations for the For the BQ24230 QFN package

- TI recommends placing thermal vias in the solder mask defined thermal pad to transfer effectively the heat from the top copper layer of the PCB to the inner or bottom copper layers.
- TI provides the recommended layout of the thermal vias in most data sheets. The recommended via diameter is 0,3 mm or less, and the recommended via spacing is 1 mm
- Do not cover the vias with solder mask which causes excessive voiding.
- Do not use a thermal relief web or spoke connection which impedes the conduction path into the inner copper layer(s)
- All low-current GND connections must be kept separate from the high-current charge or discharge paths from the battery. Use a single-point ground technique incorporating both the small signal ground path and the power ground path.

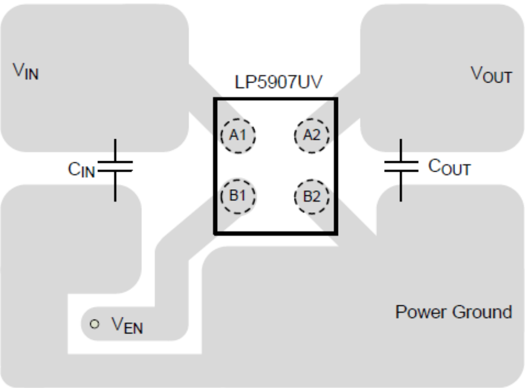

Figure 29 LP5907 Typical Layout

7.2.2 Layout Guidelines

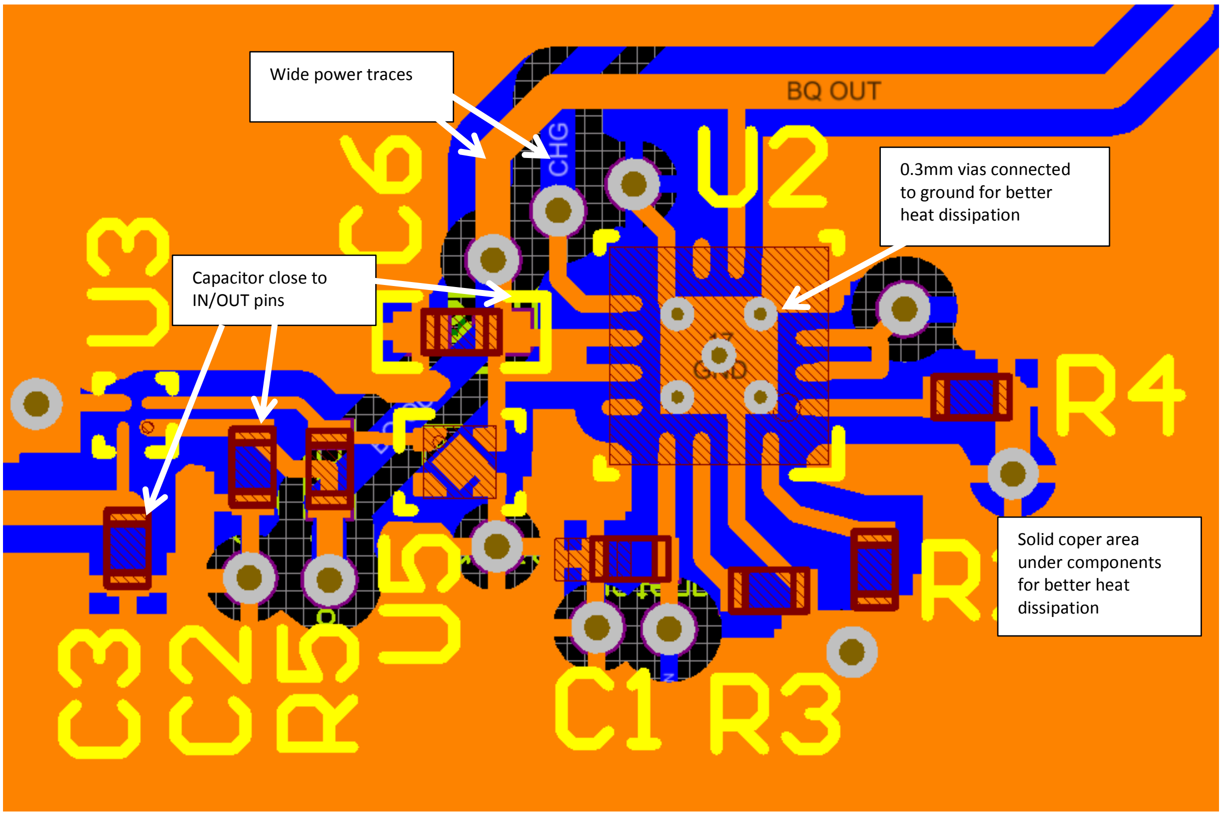

Figure 30: TIDA-00600 Layout Guidelines

8 References

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2. SWRA280Texas Instruments Application Report, CC2530 FAQ,
3. Texas Instruments CC2530 Wiki page: http://processors.wiki.ti.com/index.php/Category:Zigbee
4. SWRA292Texas Instruments Application Report, Measuring Power Consumption of CC2530 With Z-Stack,
5. Texas Instruments Overview for ZigBee® (IEEE 802.15.4): http://www.ti.com/lsds/ti/wireless_connectivity/zigbee/overview.page
6. Charging Lithium-Ion Batteries. – *Battery University*. N.p., n.d. Web. 02 Sept. 2015.
7. Elahi, Ata, and Adam Gschwender. *ZigBee Wireless Sensor and Control Network*. Upper Saddle River, NJ: Prentice Hall, 2010. Web.

9 Terminology

TI Glossary: SLYZ022 This glossary lists and explains terms, acronyms, and definitions.

10 About the Author

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Antony is an Applications Engineer at Texas Instruments Incorporated. Antony is responsible for developing reference design solutions for the mobile devices power RF (MDP-RF) power group. Antony brings to this role experience in system-level analog, mixed-signal, and power management design. Mr. Carvajales earned his bachelor of science (BS) in electrical engineering from the Florida International University in Miami, FL. Antony is a member of the Institute of Electrical and Electronics Engineers (IEEE) and the Society of Hispanic Professional Engineers (SHPE).

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