

TI Designs

TMS570 Active Cell-Balancing Battery-Management Design Guide



TI Designs

This TI Design shows a system example for an active cell-balancing battery management system. The TMS570LS0432 MCU commands EMB1402 EVM to monitor the battery cells and perform charge and discharge from one battery cell to an external 12-V supply. The user can view the cell status and control-cell balancing from a GUI running on the host PC.

Design Resources

- [TIDM-TMS570BMS](#)
- [TMS570LS0432](#)
- [BQ76PL455A-Q1](#)
- [EMB1428Q](#)
- [EMB1499Q](#)
- [LAUNCHXL-TMS57004](#)
- [BQ76PL455A-Q1 EVM GUI](#)

- TI Design Files
- Product Folder
- Product Folder
- Product Folder
- Product Folder
- Tools Folder
- Tools Folder



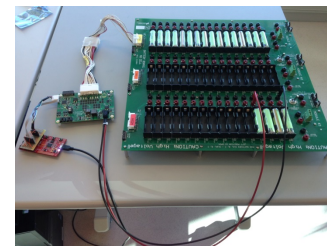
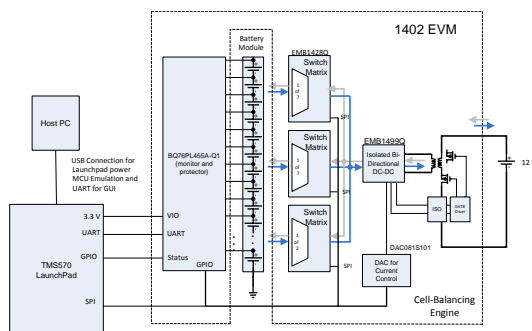
[ASK Our E2E Experts](#)

Design Features

- The Diagnostic Features of TMS570LS0432 microcontroller (MCU) Are Enabled to Monitor and Report TMS570LS0432 Status During Run Time.
- The TMS570LS0432 MCU Configures BQ76PL455A-Q1 for Monitoring Cell Voltages and Checking BQ76PL455A-Q1 Status During Run Time.
- The TMS570LS0432 MCU Analyzes the Data From All Cells and Generates Active Cell Balancing Commands.
- The TMS570LS0432 MCU Commands EMB1428Q for Cell Balancing and Monitors EMB1428Q and EMB1499Q Status During Run Time.
- The TMS570LS0432 MCU Communicates With Host PC Through a Universal Asynchronous Receiver and Transmitter (UART) Emulated by the Next Generation High-End Timer (N2HET) Module to Display the Status and Control the Balancing Operation During Run Time.

Featured Applications

- Electric and Hybrid Electric Vehicles (EVs, HEVs, PHEVs, and mild hybrids)
- Energy Storage Systems (ESS)
- Uninterruptible Power Supplies (UPSs)
- E-Bikes and E-Scooters



An IMPORTANT NOTICE at the end of this TI reference design addresses authorized use, intellectual property matters and other important disclaimers and information.

LaunchPad, Code Composer Studio are trademarks of Texas Instruments.
ARM, Cortex are registered trademarks of ARM Limited.
All other trademarks are the property of their respective owners.

1.2 BQ76PL455A-Q1

The BQ76PL455A-Q1 device is an integrated 16-cell battery-monitoring and protection device, designed for high-reliability automotive applications. The integrated high-speed, differential, capacitor-isolated communication interfaces allow up to 16 BQ76PL455A-Q1 devices to communicate with a host through a single high-speed UART interface. The BQ76PL455A-Q1 monitors and detects several fault conditions, including the following:

- Overvoltage
- Undervoltage
- Overtemperature
- Communication faults

Six GPIO ports and eight analog AUX analog-to-digital converter (ADC) inputs are included for additional monitoring and programmable functionality. A secondary thermal shutdown is included for further protection. For more information, see [Figure 2](#).

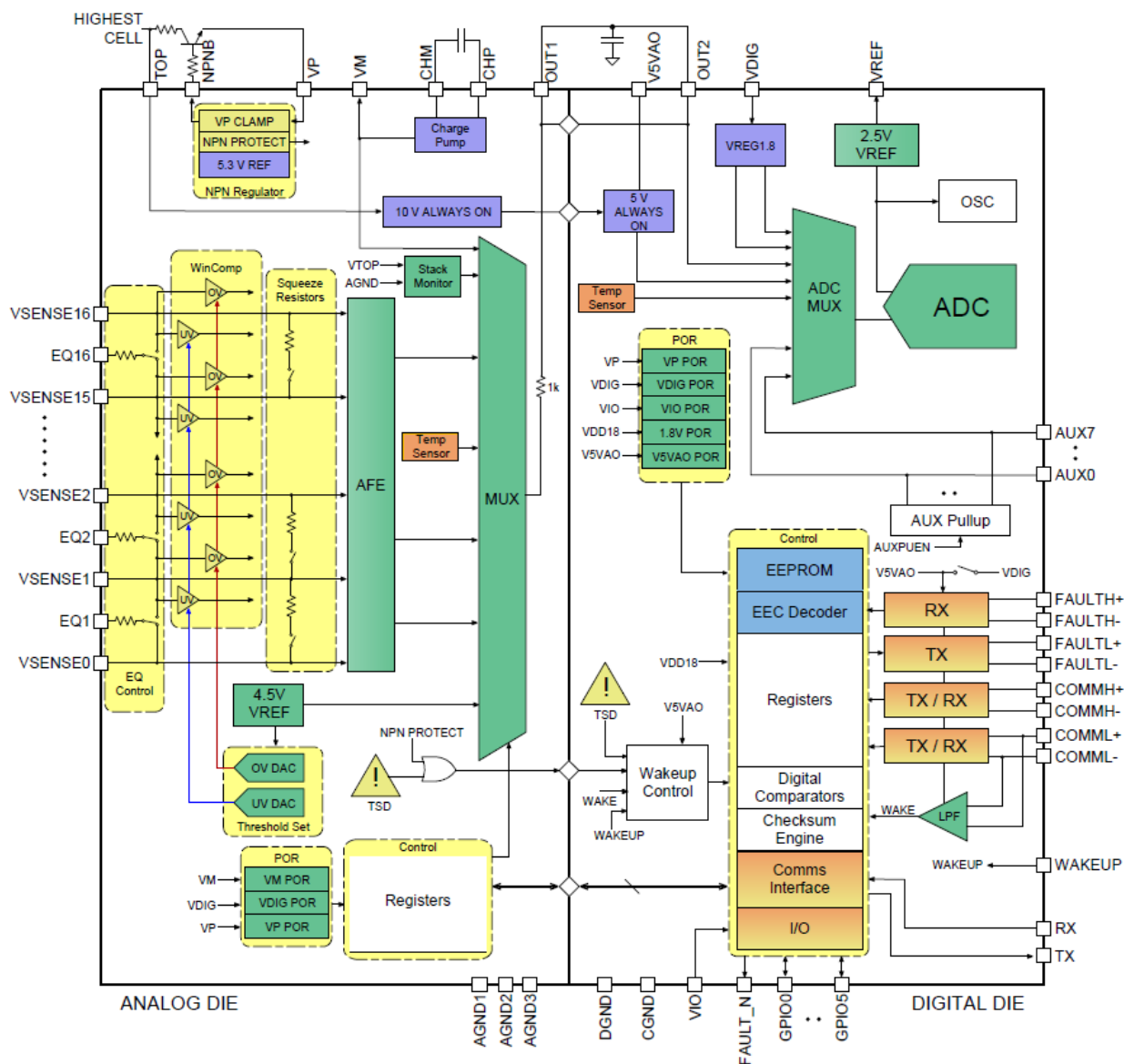


Figure 2. BQ76PL455A-Q1 Hardware Overview

1.3 EMB1428Q

The EMB1428Q switch matrix gate driver IC is designed to work with the EMB1499Q DC-DC controller IC to support TI's switch matrix-based active cell balancing scheme in a battery-management system. The EMB1428Q device provides 12 floating MOSFET gate drivers necessary for balancing up to seven battery cells connected in a series stack. The EMB1428Q ICs may be used together to balance a stack with more than 7 battery cells.

The EMB1428Q integrated circuit interfaces with the EMB1499Q DC-DC controller to control and enable charging and discharging modes. The EMB1428Q uses an SPI bus to accept commands from the main controller on which battery cell should be charged or discharged and to report any faults to the main controller. For more information, see [Figure 3](#).

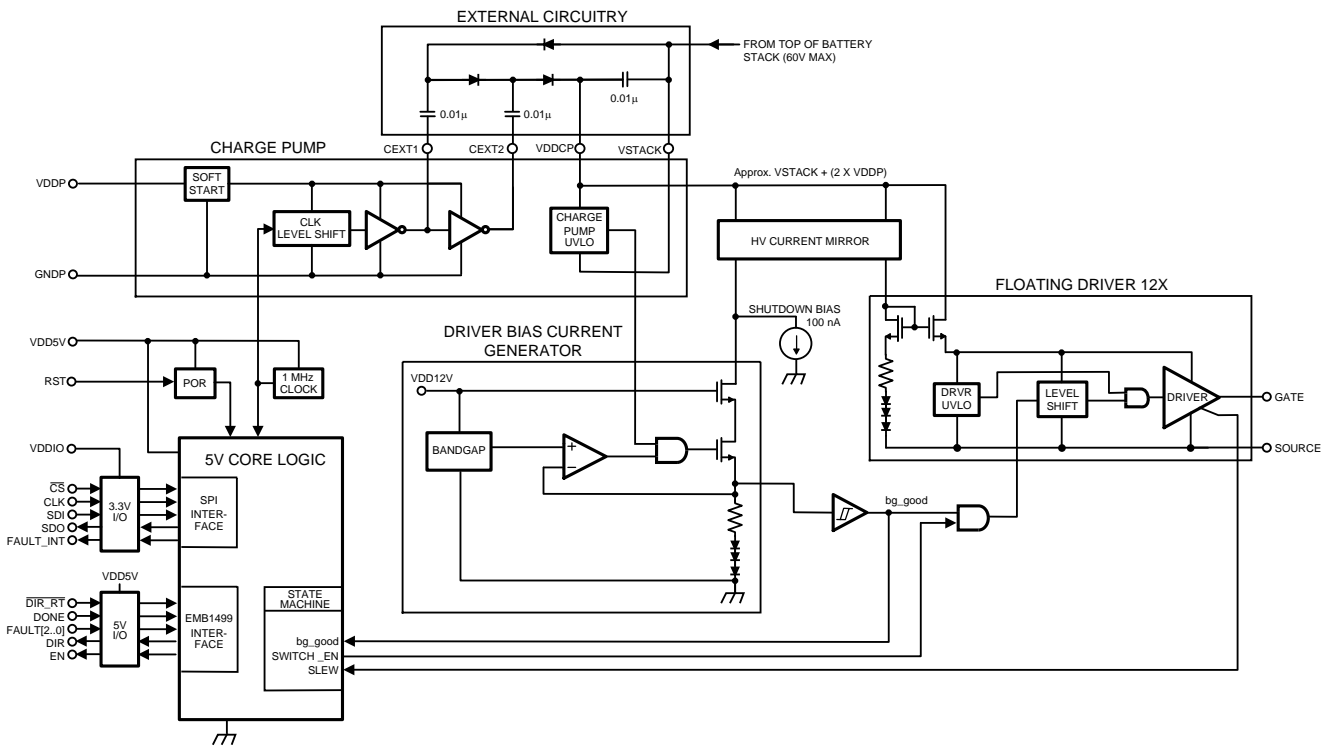


Figure 3. EMB1428Q Hardware Overview

1.4 EMB1499Q

The EMB1499Q bidirectional current DC-DC controller IC works with the EMB1428Q switch matrix gate driver IC to support TI's switch matrix-based active cell balancing scheme for a battery-management system. The EMB1499Q device provides three PWM MOSFET gate signals to a bidirectional forward converter so that its output current, either positive or negative, is regulated around a user-defined magnitude. This inductor current is channeled by the EMB1428Q device through the switch matrix to the cell that must be charged or discharged. In a typical scheme, the EMB1499Q-based forward converter exchanges energy between a single cell and the battery stack to which it belongs, with a maximum stack voltage of up to 60 V. The switching frequency is fixed at 250 kHz. The EMB1499Q device senses cell voltage, inductor current, stack current, and provides protection from abnormal conditions during balancing.

The EMB1499Q device also provides an active clamp timing signal to control an external FET driver for the primary-side active clamp FET. The EMB1499Q device is enabled and disabled by the EMB1428Q device. Fault conditions detected by the EMB1499Q device are communicated to the EMB1428Q device through the DONE and FAULT pins. For more information, see [Figure 4](#).

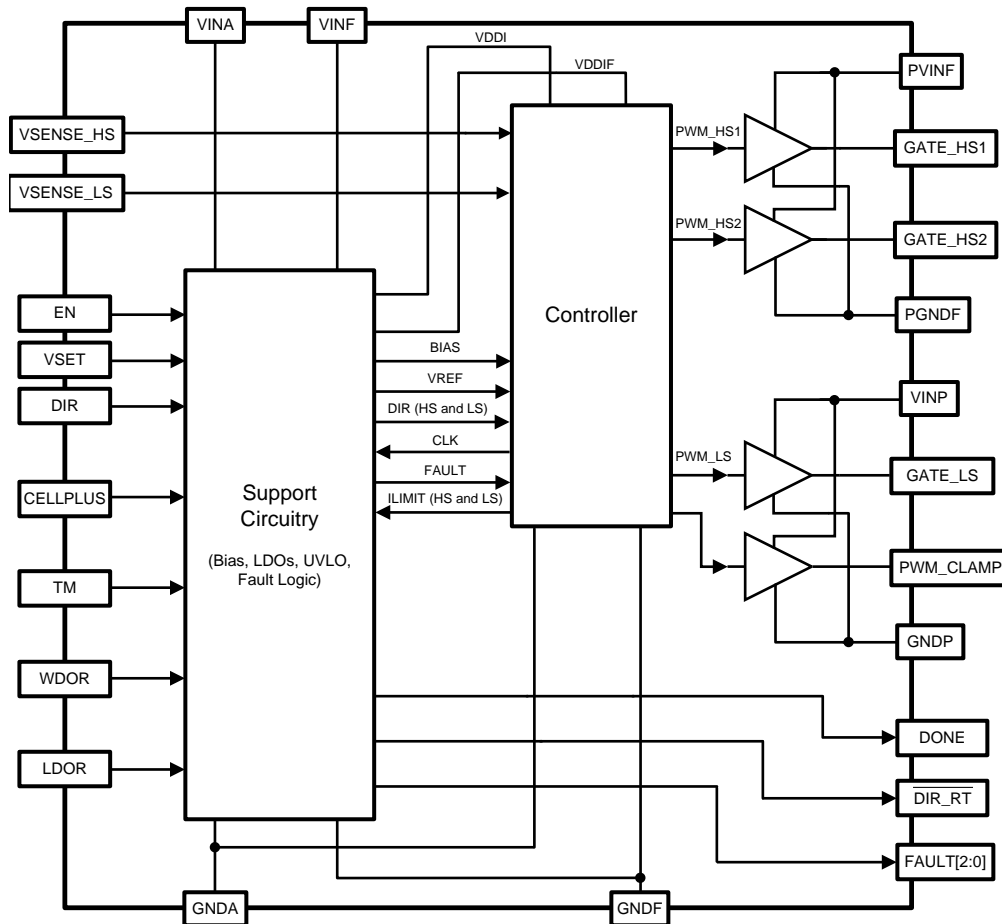


Figure 4. EMB1499Q Hardware Overview

2 Getting Started Hardware

Figure 5 shows the block diagram of active cell balancing hardware.

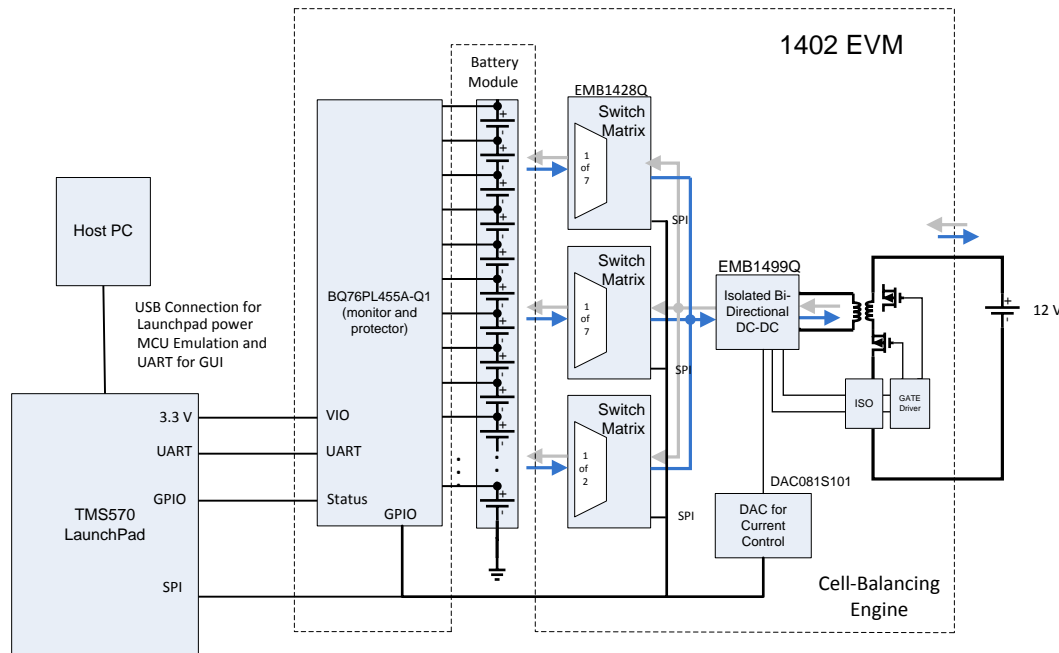


Figure 5. Hardware

Cell balancing is a method for extending battery run time and battery life. The active cell balancing is based on the active energy transfer at the cell that must be charged or discharged. In this BMS example, the energy is transferred between one cell in a 16-cell battery module and an external 12-V battery for the simulation of an EV application.

The EM1402 EVM is designed as the battery monitor and cell balancing engine. The cell-monitoring architecture is based on the BQ76PL455A-Q1 IC. The TMS570LS0432 MCU configures and commands the BQ76PL455A-Q1 IC to measure the voltages of all cells and read the error status through the UART port. In this BMS example, the average of the cell voltage is calculated and the cell with the most voltage deviation for the average is selected for charge or discharge. The TMS570LS0432 MCU commands the EMB1428Q IC to charge or discharge through the SPI port.

The EMB1428Q IC is designed to control charging or discharging up to seven battery cells. Three EMB1428Q ICs are used in EM1402 EVM to charge or discharge sixteen battery cells. The EM1402 EVM is designed with one EMB1499Q IC to allow charge or discharge of one battery cell at a time. The user can control the operation of the system from a GUI running on the host PC. This GUI is developed for the released BQ76PL455A-Q1 EVM and requires a UART interface. On the TMS570LS0432 MCU, there is only one UART port that is used for the communication with the BQ76PL455A-Q1 device. A second UART is created by the N2HET timer module on the TMS570LS0432 MCU. This emulated UART runs at a baud rate of 250 kHz and does not incur any CPU overhead.

Figure 6 shows the hardware connection between TMS570LS0432 LaunchPad and EM1402 EVM. The SPI port controls four ICs on EM1402 EVM: three EMB1428Q ICs for charging or discharging to the battery cells and digital-to-analog converter (DAC) DAC081S101CIMK/NOPB for controlling the charge or discharge current. On the EM1402 EVM, the SPI chip select signals are generated by a shift register IC. The output of the shift register IC is controlled by the SPI data and two TMS570LS0432 GPIO signals: GIOA4 for strobe and GIOA7 for output enable.

EM1402 EVM / TMS570LS0432 Launchpad Connection				
EM1402 EVM			TMS570LS0432 Launchpad	
Connector	Pin	Pin Function	Coonector	Pin Function
	J3-1	GND	J2-1	GND
	J3-2	FLT_N	J2-3	GIOA0
	J3-3	VCC	J1-1	3.3V
	J3-4	RX	J1-4	SCI_TX
	J3-5	TX	J1-3	SCI_RX
	J3-6	/WAKE	J1-10	SPI1CS3 (use as GIO)
	J6-1	GND	J2-1	GND
	J6-2	GPIO3/MOSI_1	J2-6	SPI1SIMO
	J6-3	GPIO4/MISO_1	J2-7	SPI1SOMI
	J6-4	GPIO2/SCLK_1	J1-7	SPI1CLK
	J6-5	GPIO5/RS_EMB1428	J2-8	GIOA6
	J6-6	GIPO1/CS_OE	J2-9	GIOA7
	J6-7	FAULT_INT	J2-4	GIOA1
	J6-8	GPIO0/CS_STORE	J2-10	GIOA4

Figure 6. TMS570LS0432 LaunchPad and EM1402 EVM Connection

On the TMS570LS0432 LaunchPad, the TMS570LS0432 UART is connected to the XDS100V2 FT232HL IC for user to communicate with the TMS570LS0432 device through a USB UART port on the host PC. This connection must be replaced by the UART emulated by the N2HET module. Figure 7 shows the required modification of the TMS570LS0432 LaunchPad.

TMS570LS0432 Launchpad Modification	
Remove R8 and R9	
Connect J4-1 (NHET00, emulated UART TX) to U2(FT2322HL) pin 39	
Connect J4-2 (NHET02,emulated UART RX) to U2(FT2322HL) pin 38	

Figure 7. TMS570LS0432 LaunchPad Modification

3 Getting Started Software

This software is developed to work with the existing BQ76PL455A-Q1 EVM GUI. With the GUI, the user is able to view the cell voltage graphically in run time, select the cells to be balanced, and enable or disable the balancing. The software can also log the data of ACB history in a file.

Figure 8 shows the main flow of the TMS570LS0432 software. At start up, the TMS570LS0432 diagnostic functions such as LBIST and PBIST are executed. Flash and RAM ECC and the ESM module are enabled to monitor and report the TMS570LS0432 error status during run time. The TMS570LS0432 device also configures the BQ76PL455A-Q1 IC to monitor the battery cells. After initialization, the TMS570LS0432 device waits for the instruction message from the host PC.

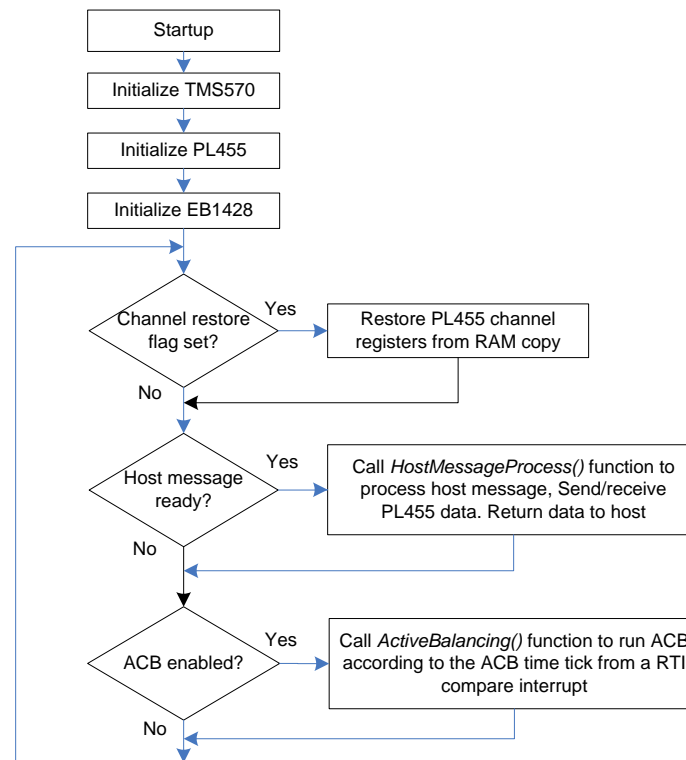


Figure 8. TMS570LS0432 Mainloop Flow

When TMS570LS0432 receives a complete message from the host, a *host message ready* flag is set in the N2HET interrupt service routine for the emulated UART port. The function `HostMessageProcess()` is called from the mainloop to process the host message. The configuration command is sent to the BQ76PL455A-Q1 device. If host requests any cell data, the `HostMessageProcess()` function commands the BQ76PL455A-Q1 device to sample the cells and read the data when available. The `HostMessageProcess()` function waits for the data to be ready and returns the data to the host. If the host message is a cell balancing enable command, the `HostMessageProcess()` function sets the ACB enable flag. When the ACB is enabled, the BQ76PL455A-Q1 registers are not updated when the host message is received. The new configuration data is saved to a RAM copy of the BQ76PL455A-Q1 registers and loaded to the BQ76PL455A-Q1 during the sampling of the cell voltages. To ensure the synchronization between the RAM content and the values in BQ76PL455A-Q1 IC, a channel restore flag is set when ACB is disabled for saving the RAM copy to the BQ76PL455A-Q1 IC.

Three interrupts are enabled for the BMS demonstration. The first interrupt is a RTI timer interrupt occurring every 100 ms. The RTI interrupt service routine(ISR) maintains an ACB timer tick. When the ACB is enabled, the ACB timer tick controls the sampling of the cell voltages, charge, and discharge. The second interrupt is the UART interrupt for the communication with the BQ76PL455A-Q1 device. This interrupt occurs at every byte transfer. The third interrupt is the N2HET interrupt for the emulated UART port. This interrupt occurs when each data byte is transmitted and received. A data table is defined in TMS570LS0432 system RAM for saving all BQ76PI455A-Q1 registers, cell voltages, and other statuses. The BQ76PI455A-Q1 register RAM copy is updated when the register is updated. For more information, see [Figure 9](#) shows the processing flow of the TMS570LS0432 NHET (emulated UART) ISR.

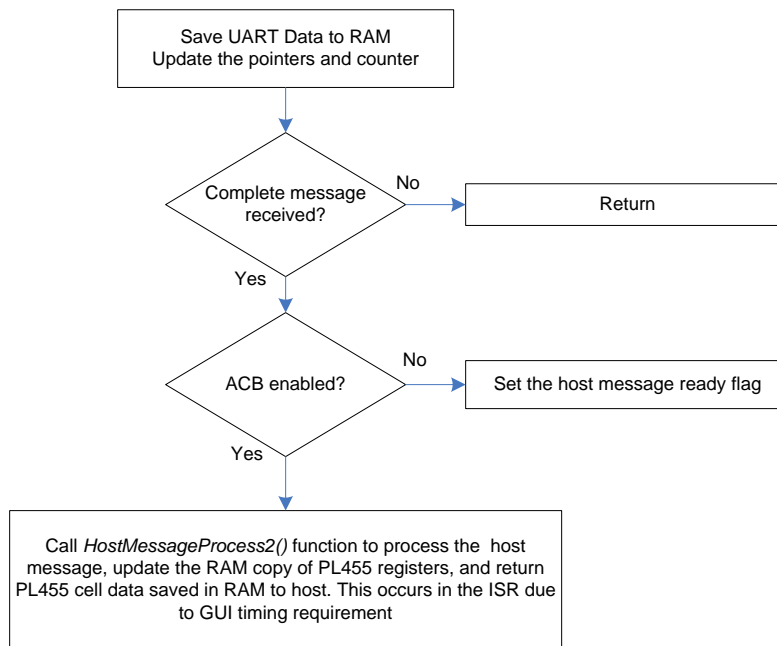


Figure 9. TMS570LS0432 N2HET (Emulated UART) ISR

When a complete host message is received, the interrupt service routine checks if the active cell balancing (cell charge or discharge) is enabled. If active cell balancing (ACB) is not enabled, the host message ready flag is set. The HostMessageProcess() function is called in the mainloop to process the message. [Figure 10](#) shows the processing in HostMessageProcess().

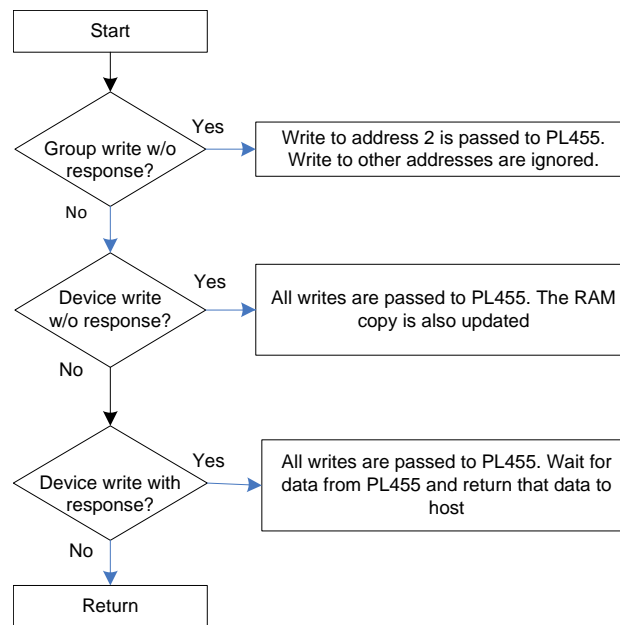


Figure 10. Processing in the HostMessageProcess() Function

When ACB is enabled, the return of the requested data is delayed to the host due to the time for transmitting the ACB command (sampling the cells and commanding charge or discharge). This delay results in a timing error in the GUI running on the host PC. To ensure the timing in producing an response to the host, HostMessageProcess2() function is called in the interrupt service routine and content in the system RAM copy of the BQ76PL455A registers and cell voltages are returned to the host. For more information, see [Figure 11](#).

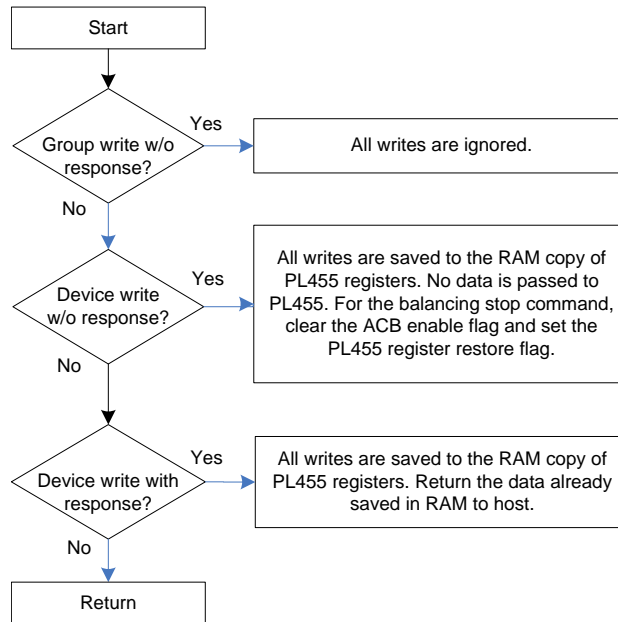


Figure 11. Processing in the HostMessageProcess2() Function

The active cell charge or discharge is handled by the ActiveBalancing() function, which is called in the processing mainloop. The ACB charge time and period are constants defined in the source code file acb.c. Figure 12 shows the processing in ActiveBalancing(). In Figure 12, the cell voltages are sampled at the end of the ACB period to avoid the transient caused by charging or discharging. During development, the user may want to sample the cell voltages often to see how the voltages change during charge or discharge time. Due to the transient caused by charging or discharging, the measurement during charging or discharging can cause overvoltage or undervoltage errors in the measurement data. For more information, see Figure 13.

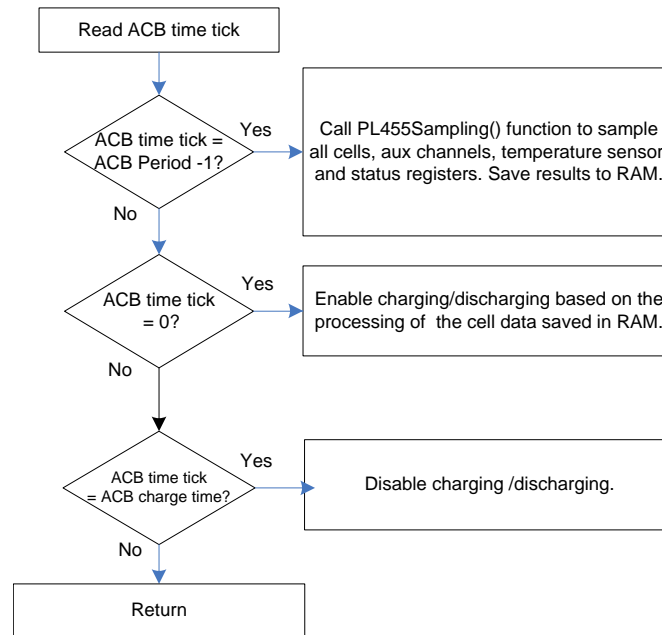


Figure 12. The ActiveBalancing() Function

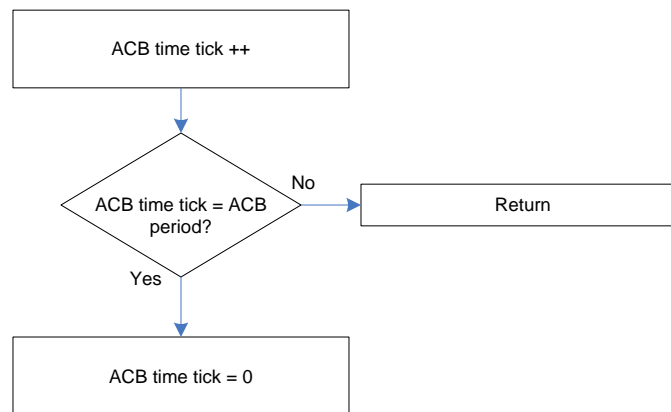


Figure 13. The RTI Compare ISR

4 Install the Demonstration

To install the demonstration, the following TI development tools and software packages are required:

- LAUNCHXL-TMS57004 LaunchPad
- EM1402 EVM
- BQ76PL455A-Q1 EVM GUI
- Code Composer Studio™ (CCS) v6.0.1 or greater
- Hercules HALCoGen tool v04.05.01 or greater
- Battery module with 16 3.6-V cells
- 12-V battery

Make the changes to TMS570LS0432 LaunchPad as described in [Section 2](#). Connect the TMS570LS0432 LaunchPad and EM1402 EVM correctly.

The released software can be saved anywhere in the PC from the zip file. To enable the user to control the execution from CCS, the LBIST and CCM self-tests are not enabled in the HALCoGen INIT tab for the following reasons:

- LBIST removes all breakpoints. If LBIST is executed at start-up, the CPU does not stop at main() after the program loading is complete. CPU keeps running and can confuse a user.
- CCM self-test works only when the debugger is not connected to the target.

The user can enable those two tests in the final version. The executable and user guide of BQ76PL455A-Q1 EVM GUI can be downloaded from [TI BQ76PL455A-Q1 EVM tool page](#). When the GUI is installed, an icon appears on the desktop of the PC.

5 Run the Demonstration

Before running the demonstration, do as follows:

1. Modify the TMS570LS0432 LaunchPad.
2. Program the demonstration software into the TMS570LS0432 device.
3. Check the connections between boards and batteries.
4. Ensure the battery voltages are in the correct range.

To start the demonstration, do as follows:

1. Run the demonstration on the TMS570LS0432 LaunchPad.
2. Start the GUI on the host PC.

NOTE: A window pops up as shown in [Figure 14](#).

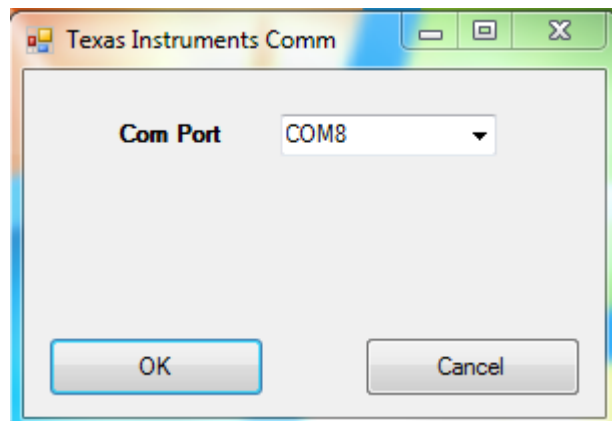


Figure 14. Pop-up Window After the GUI is Started

3. Select the COM port assigned to the USB UART port for TMS570LS0432 LaunchPad.

If the host PC has successfully established the communication with TMS570LS0432, a status message window should appear as shown in [Figure 15](#).

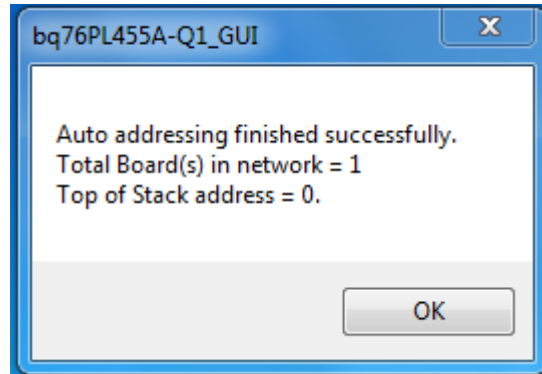


Figure 15. Status Window After the GUI Successfully Communicates With the TMS570LS0432 Device

The setup window of the GUI displays as shown in [Figure 16](#) after clicking OK in the status window.

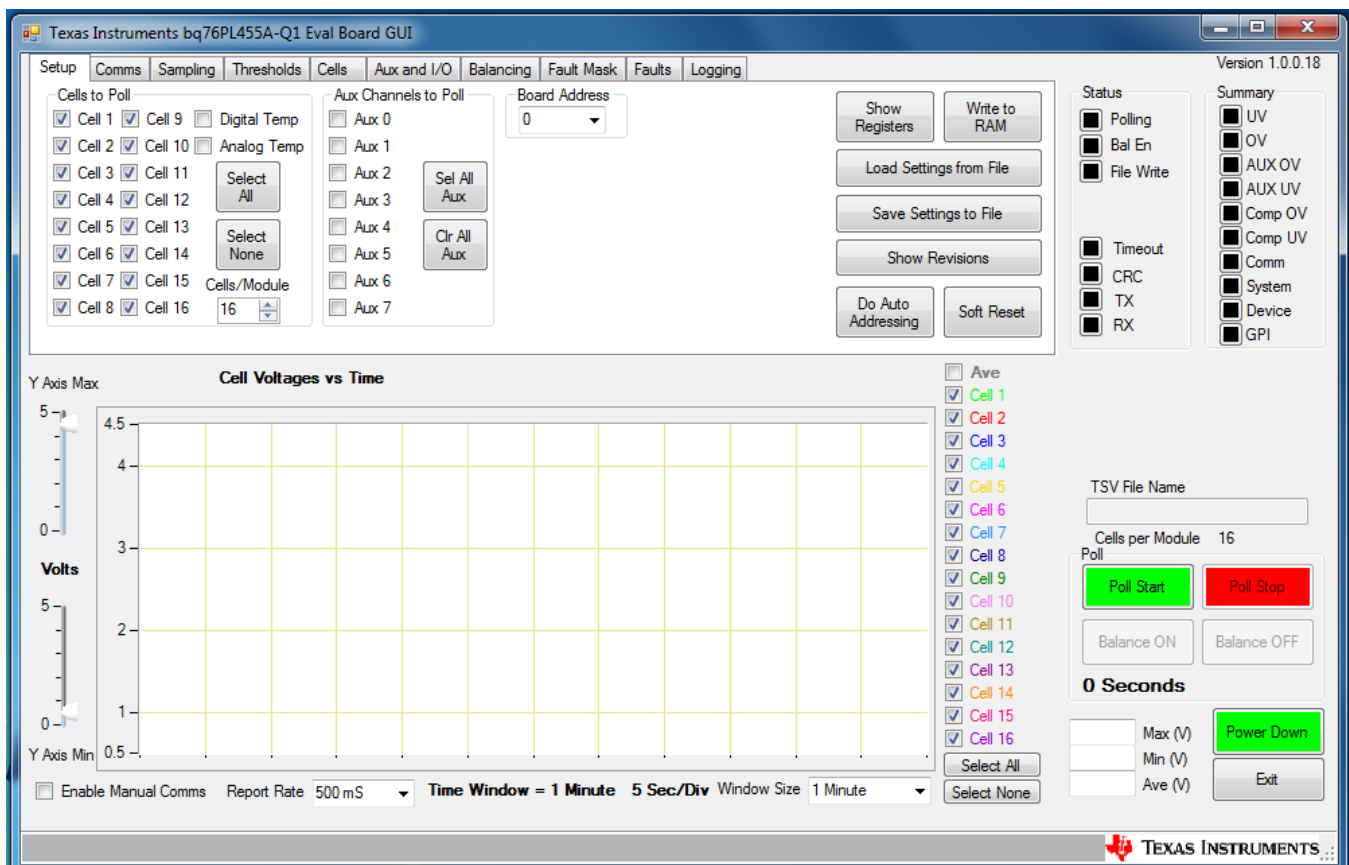


Figure 16. GUI Setup Window

The user can select the desired data from the setup window and click *Poll Start* to view the data in run time as shown in [Figure 17](#).

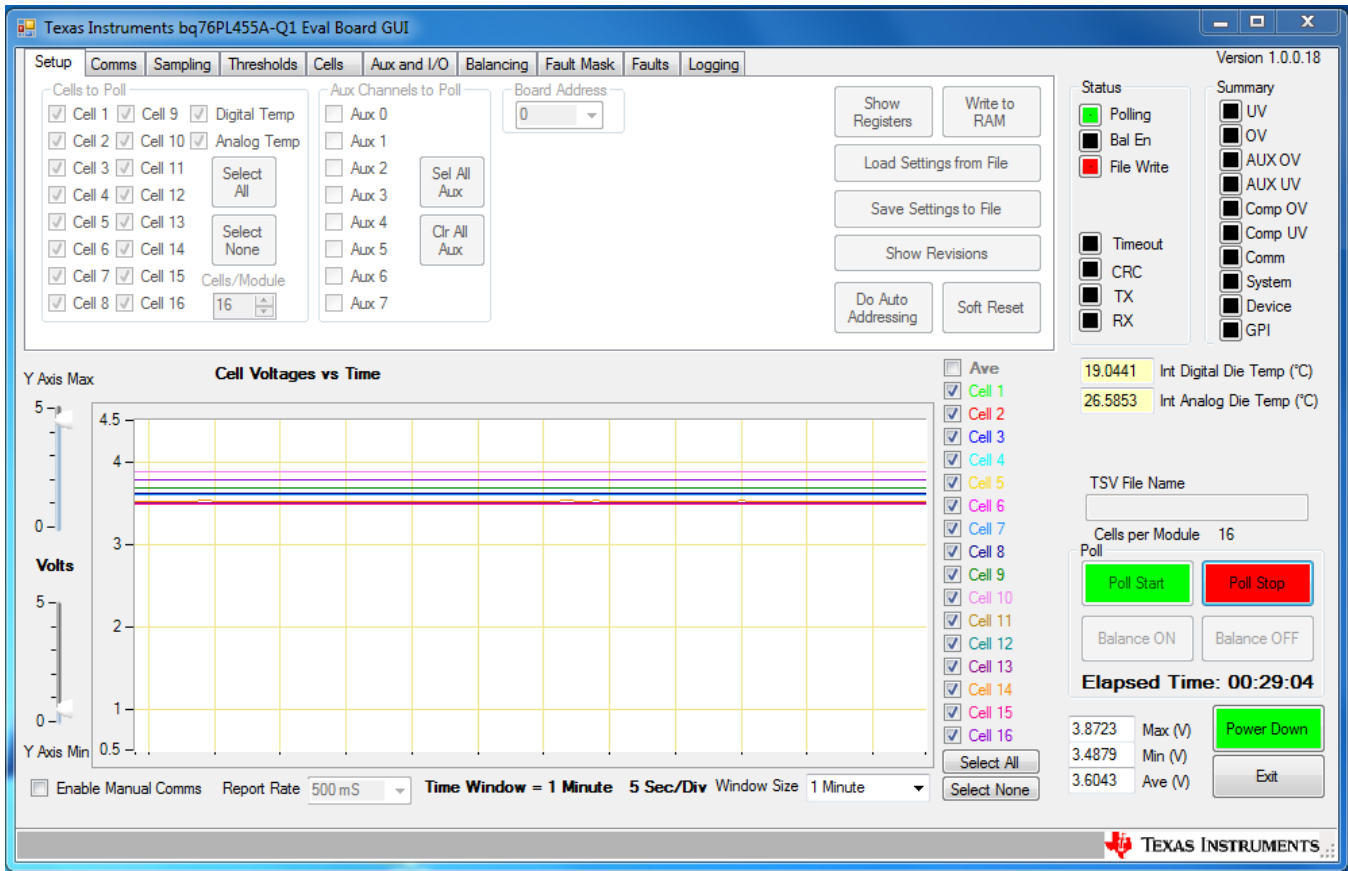


Figure 17. Display of Cell Voltage Waveform

To enable balancing, do as follows:

1. Select the *Balancing* window.
2. Choose the cells to be balanced.
3. Click *Balance ON*.

The balancing time and period are constants defined in the TMS570LS0432 software. For the waveform in Figure 18 and Figure 19, the balancing time (for charge and discharge) is 1 second. The balancing period is 4 seconds. The cell voltages are sampled every 500 ms.

Figure 18 and Figure 19 show the cell voltage waveforms during charge and discharge of the battery cell 14.



Figure 18. Cell Voltage Waveform When Cell 14 is Being Charged With 3.5 A

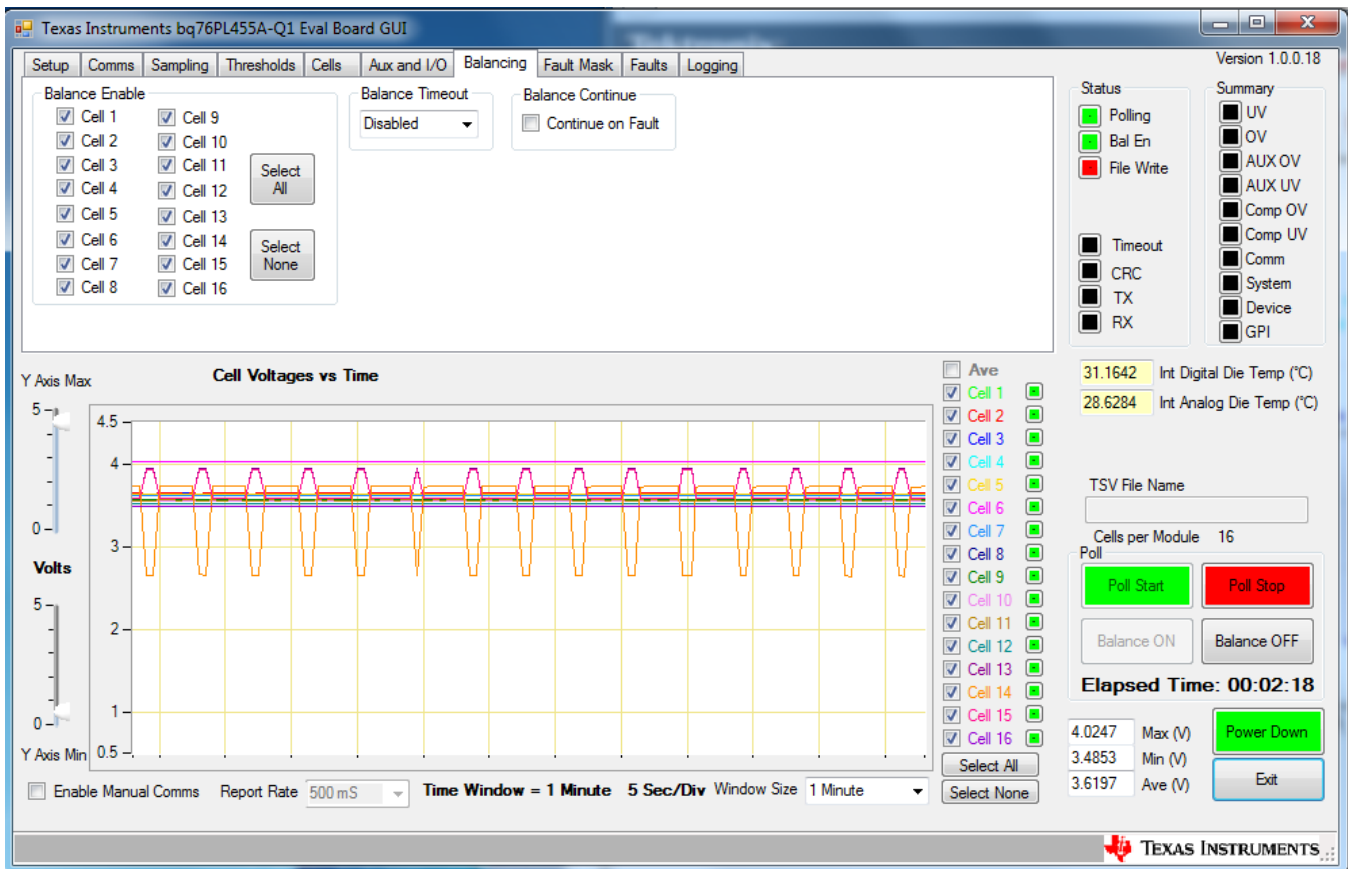
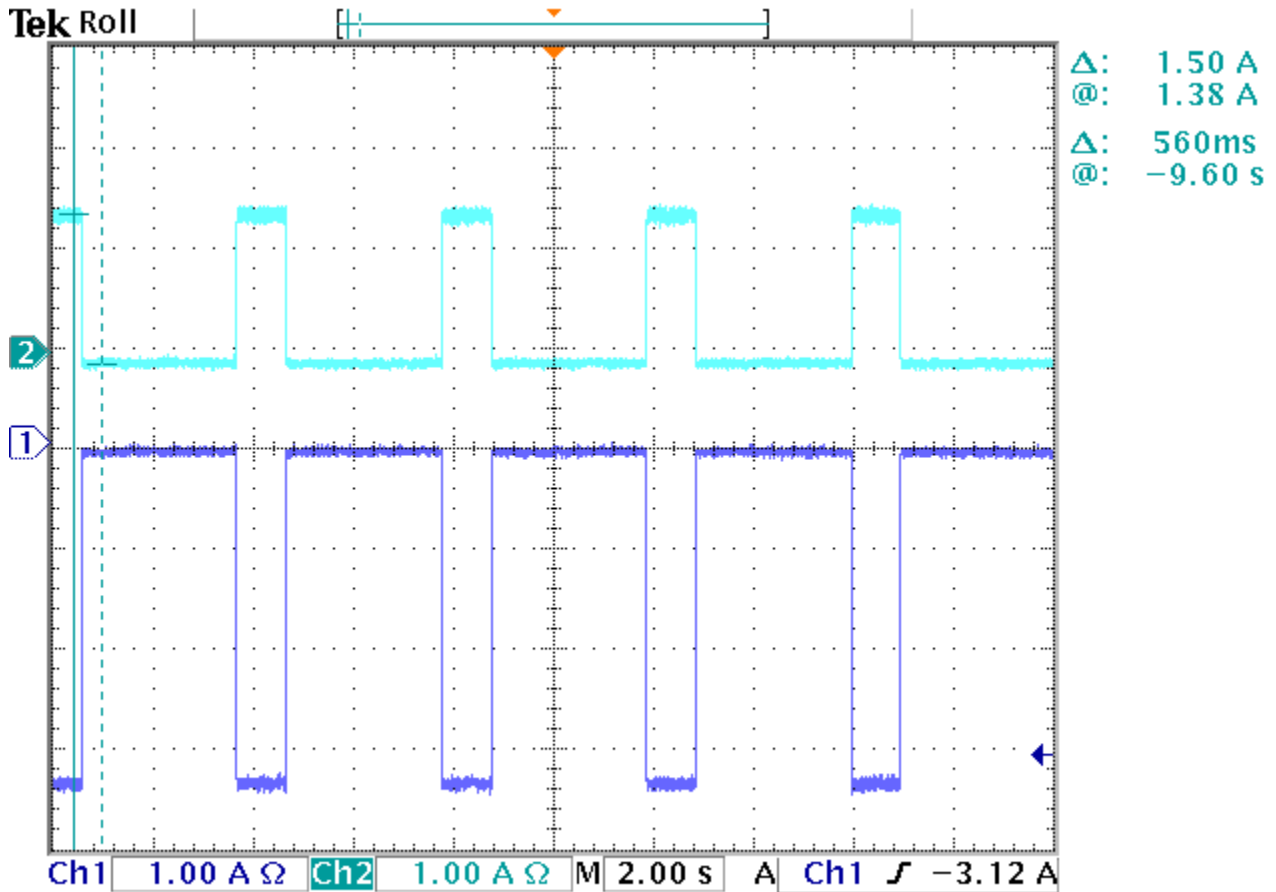


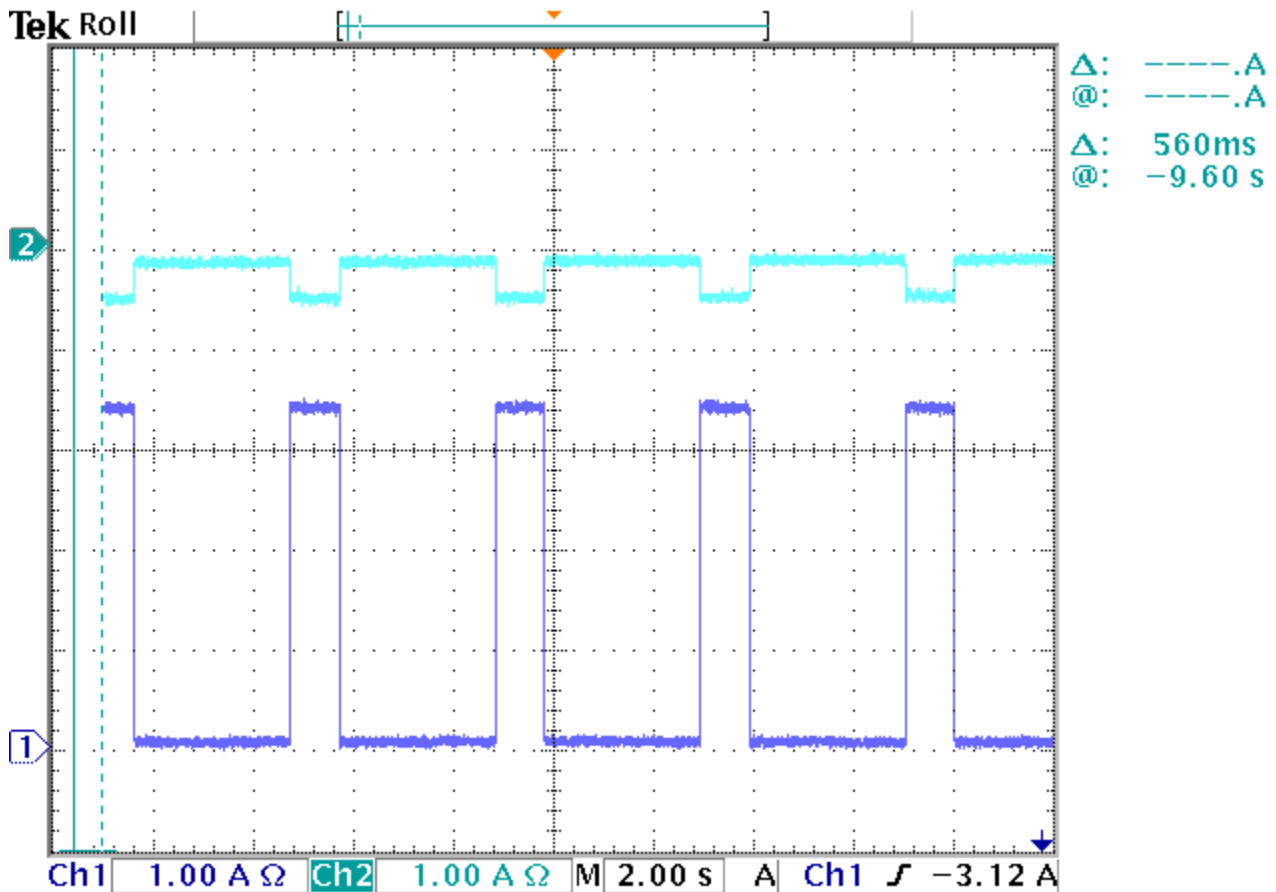
Figure 19. Cell Voltage Waveform When Cell 14 is Being Discharged With 3.5 A

Figure 20 and Figure 21 show the charge and discharge currents. In these figures, channel 1 is the current flowing out of the battery cell 14 and channel 2 is the current flowing out of the 12-V supply. The data in Figure 20 and Figure 21 indicates that the current at the cell is controlled accurately at 3.5 A.



1 Mar 2016
10:41:12

Figure 20. Current Waveform When Cell 14 is Being Charged With 3.5 A



1 Mar 2016
10:51:38

Figure 21. Current Waveform When Cell 14 is Being Discharged With 3.5 A

The voltage variation on the cell being charged and discharged and adjacent cells can be explained by the equivalent circuit in Figure 22. In Figure 22, R1, R2, and R3 are the equivalent internal resistance of the battery cells. This resistance provides information about the health of the battery cells. R4, R5, R6, and R7 are the resistance of the wiring connecting the battery to the measurement terminals. Because the charge and discharge current is a known value, those resistance can be calculated from cell voltage measurements.

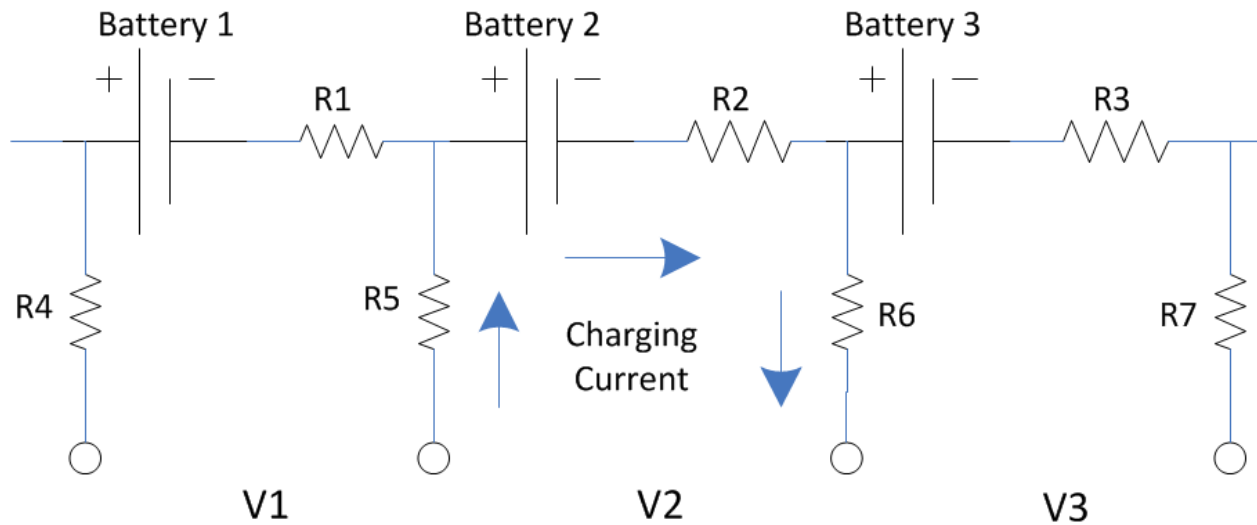


Figure 22. Equivalent Circuit for Battery Cell Voltage Measurement

Table 1 lists the performance data of the BMS system. All voltage data match theoretical expectations. From the measurement data, the energy transfer efficiency is 90% when cell 14 is charged from the 12-V supply. The energy transfer efficiency is 72% when cell 14 is discharging to the 12-V supply.

Table 1. BMS Performance Measurement

	All Cells Idle	Cell 14 Charge at 3.5 A	Cell 14 Discharge at 3.5 A
Cell 13 Voltage	3.5754 V	3.1597 V	4.0630 V
Cell 14 Voltage	3.6953 V	4.9930 V	2.2792 V
Cell 15 Voltage	3.577 V	3.0370 V	4.1078 V
12-V Voltage	14.0 V	13.0 V	14.3 V
12-V Current	0 A	1.5 A	0.4 A
Transfer Efficiency	N/A	90%	72%

6 Resources

To download the resource files for this reference design, see [TIDM-TMS570BMS](#).

7 References

1. *TMS570LS0432 MCU* product page, <http://www.ti.com/product/tms570ls0432>
2. *BQ76PL455A-Q1 battery monitor* product page, <http://www.ti.com/product/BQ76PL455A-Q1>
3. *EMB1428Q switch matrix gate driver* product page, <http://www.ti.com/product/EMB1428Q>
4. *EMB1499Q bidirectional DC-DC converter* product page, <http://www.ti.com/product/EMB1499Q>
5. *TMS570LS0432 LaunchPad* tool page, <http://www.ti.com/tool/launchxl-tms57004>

IMPORTANT NOTICE FOR TI REFERENCE DESIGNS

Texas Instruments Incorporated ("TI") reference designs are solely intended to assist designers ("Buyers") who are developing systems that incorporate TI semiconductor products (also referred to herein as "components"). Buyer understands and agrees that Buyer remains responsible for using its independent analysis, evaluation and judgment in designing Buyer's systems and products.

TI reference designs have been created using standard laboratory conditions and engineering practices. **TI has not conducted any testing other than that specifically described in the published documentation for a particular reference design.** TI may make corrections, enhancements, improvements and other changes to its reference designs.

Buyers are authorized to use TI reference designs with the TI component(s) identified in each particular reference design and to modify the reference design in the development of their end products. HOWEVER, NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY THIRD PARTY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT, IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI REFERENCE DESIGNS ARE PROVIDED "AS IS". TI MAKES NO WARRANTIES OR REPRESENTATIONS WITH REGARD TO THE REFERENCE DESIGNS OR USE OF THE REFERENCE DESIGNS, EXPRESS, IMPLIED OR STATUTORY, INCLUDING ACCURACY OR COMPLETENESS. TI DISCLAIMS ANY WARRANTY OF TITLE AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, QUIET ENJOYMENT, QUIET POSSESSION, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS WITH REGARD TO TI REFERENCE DESIGNS OR USE THEREOF. TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY BUYERS AGAINST ANY THIRD PARTY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON A COMBINATION OF COMPONENTS PROVIDED IN A TI REFERENCE DESIGN. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, SPECIAL, INCIDENTAL, CONSEQUENTIAL OR INDIRECT DAMAGES, HOWEVER CAUSED, ON ANY THEORY OF LIABILITY AND WHETHER OR NOT TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES, ARISING IN ANY WAY OUT OF TI REFERENCE DESIGNS OR BUYER'S USE OF TI REFERENCE DESIGNS.

TI reserves the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques for TI components are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

Reproduction of significant portions of TI information in TI data books, data sheets or reference designs is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards that anticipate dangerous failures, monitor failures and their consequences, lessen the likelihood of dangerous failures and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in Buyer's safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed an agreement specifically governing such use.

Only those TI components that TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components that have **not** been so designated is solely at Buyer's risk, and Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

IMPORTANT NOTICE FOR TI REFERENCE DESIGNS

Texas Instruments Incorporated ("TI") reference designs are solely intended to assist designers ("Buyers") who are developing systems that incorporate TI semiconductor products (also referred to herein as "components"). Buyer understands and agrees that Buyer remains responsible for using its independent analysis, evaluation and judgment in designing Buyer's systems and products.

TI reference designs have been created using standard laboratory conditions and engineering practices. **TI has not conducted any testing other than that specifically described in the published documentation for a particular reference design.** TI may make corrections, enhancements, improvements and other changes to its reference designs.

Buyers are authorized to use TI reference designs with the TI component(s) identified in each particular reference design and to modify the reference design in the development of their end products. HOWEVER, NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY THIRD PARTY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT, IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI REFERENCE DESIGNS ARE PROVIDED "AS IS". TI MAKES NO WARRANTIES OR REPRESENTATIONS WITH REGARD TO THE REFERENCE DESIGNS OR USE OF THE REFERENCE DESIGNS, EXPRESS, IMPLIED OR STATUTORY, INCLUDING ACCURACY OR COMPLETENESS. TI DISCLAIMS ANY WARRANTY OF TITLE AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, QUIET ENJOYMENT, QUIET POSSESSION, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS WITH REGARD TO TI REFERENCE DESIGNS OR USE THEREOF. TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY BUYERS AGAINST ANY THIRD PARTY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON A COMBINATION OF COMPONENTS PROVIDED IN A TI REFERENCE DESIGN. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, SPECIAL, INCIDENTAL, CONSEQUENTIAL OR INDIRECT DAMAGES, HOWEVER CAUSED, ON ANY THEORY OF LIABILITY AND WHETHER OR NOT TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES, ARISING IN ANY WAY OUT OF TI REFERENCE DESIGNS OR BUYER'S USE OF TI REFERENCE DESIGNS.

TI reserves the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques for TI components are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

Reproduction of significant portions of TI information in TI data books, data sheets or reference designs is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards that anticipate dangerous failures, monitor failures and their consequences, lessen the likelihood of dangerous failures and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in Buyer's safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed an agreement specifically governing such use.

Only those TI components that TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components that have **not** been so designated is solely at Buyer's risk, and Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.