Design Guide: TIDA-010279

Up to 1500V Stackable Battery Management Unit Reference Design for Energy Storage Systems

Description

This reference design is a full cell-temperature sensing and high cell-voltage accuracy Lithium-ion (Li-ion), lithium iron phosphate (LiFePO4) battery pack (52s). The design monitors each cell voltage, cell temperature, and protects the battery pack for safe use. This design supports both daisy-chain and controller area network (CAN) interfaces for a stackable communication up to 1500V battery energy storage systems. These features make this reference design applicable for high-capacity battery pack applications.

Resources

TIDA-010279	Design Folder
BQ78706, MSPM0G3519	Product Folder
TMUX1308, UCC33420	Product Folder
ISO7731, UCC33421-Q1	Product Folder
LMR51406, TCAN1044-Q1	Product Folder

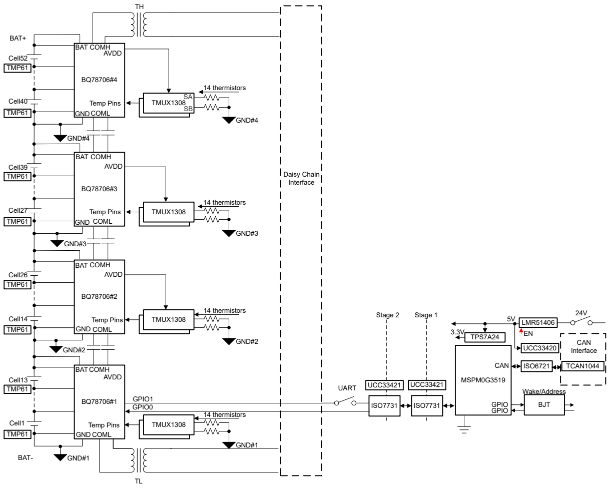
Ask our TI E2E™ support experts

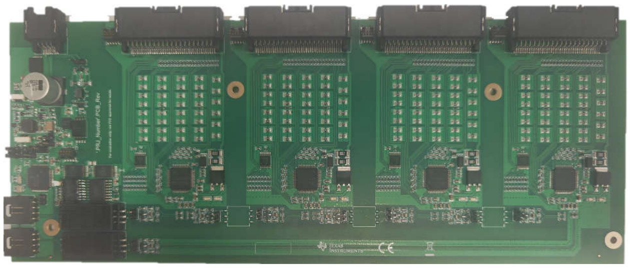
Features

- ±2.5mV voltage accuracy at –40°C to 85°C without calibration
- Full cell-temperature sensing with multiplexer (MUX)
- Robust and programmable battery cell and pack protection
- Robust daisy-chain communication with data reclocking and ring architecture
- 7µA in shutdown mode
- Supports stackable architecture through daisy chain and CAN interface up to 1500V
- Compatible with bus bar or no bus bar connection

Applications

- ESS – Battery management system (BMS)





1 System Description

Currently, the battery energy storage systems (BESS) play an important role in residential, commercial and industrial, grid energy storage, and management. A BESS has various high-voltage system structures. Commercial and industrial and grid BESS contain several racks that each contain packs in stack. Residential BESS only contains packs.

A *pack* is a basic module composing the BESS. A *pack* consists of battery cells in a matter of series and parallel connection. The number of cell channels varies from 12 to 64. Since the battery cells require a proper working and storage temperature, voltage range, current range for lifecycle and safety, the designer must monitor and protect the battery cell in the pack level.

A battery management unit (BMU) is a controller that monitors the voltage and temperature of each battery cell in the *pack* for a complete lifecycle. High measurement accuracy for voltage and temperature monitoring is required for the BMU. The information collected by the BMU is transmitted to the rack-level controller battery control unit (BCU) for safety and charging management. A robust and fast-speed communication is also required between the BMU and the BCU.

Safety, regulations, and cost concerns drive the need for a LiFePO4 battery in a BESS. The LiFePO4 battery charge or discharge curve remains fairly linear for the approximately 85% to 100% state of charge (SOC) range, but the curve abruptly changes in slope in the approximately 10% to approximately 85% SOC range. This becomes significant when choosing what voltage accuracy is acceptable in a BESS design. For most conditions, measuring accuracy in 3mV to 5mV is required to calculate a high SOC accuracy and a wide depth of discharge (DOD).

For a communication interface, a controller area network (CAN) is traditionally and widely used for robustness of communication. A CAN structure controller needs a microcontroller unit (MCU), a digital isolator, and an isolated power module to operate the CAN communication function.

A daisy chain can replace a CAN design. Compared with the CAN interface, only a couple of transformers are needed in the BMU. Thus, a daisy chain design shows an advantage in cost over a CAN especially in high-capacity battery pack applications since cost is a concern for a CAN structure in large-capacity BESS which consist of many BMU nodes and CAN interface devices. Insulation requirements also raise cost because the reinforced insulation required between the BMU and BCU communication interface necessitates a digital isolator and isolated power module.

This design focuses on large capacity battery-pack applications and applications that can also be applied in residential, commercial and industrial, grid BESS, and so forth. The design uses four BQ78706 devices (battery monitor, balancer, and integrated hardware protector) to monitor each cell voltage, the temperature of a 52s battery pack, and to protect the pack against situations that include cell overvoltage, cell undervoltage, and overtemperature. The design contains eight TMUX1308 devices for a general-purpose input/output (GPIO) expansion ratio of 8:1 to measure up to 52s cells. The design uses an internal cell balancing (CB) to get 100mA balancing current per cell channel.

The onboard communication between BQ78706 devices uses capacitor-isolated daisy chain. The offboard communication between the BMU and BMU or BCU uses transformer-isolated daisy chain. The design also combines a CAN interface and MCU for stackable communication.

2 System Overview

The design uses four BQ78706 devices to monitor each cell voltage, monitor the temperature of a 52-cell battery pack, and to protect the pack against all unusual situations, including cell overvoltage, cell undervoltage, and overtemperature. In Figure 2-1, the top BQ78706 device is the BQ78706#4 and the bottom BQ78706 device is the BQ78706#1. The forward daisy-chain communication direction is from the BQ78706#1 device to the BQ78706#2 device.

Each BQ78706 has 11 GPIO pins for temperature sensing and 14 VC pins for voltage sensing. To monitor the temperatures for all the VC channels with fewer GPIO pins, two TMUX1308 multiplexers are used. The multiplexers expand temperature-sensing capabilities of one BQ78706 from 11 channels to 20 channels, which includes14 MUX-related thermistors, 2 constant resistors and 6 independent thermistors.

To run diagnostics for the TMUX1308 to prevent the MUX from failure mode, one channel of each TMUX1308 is connected to a constant resistor. This constant resistor is out of the range of thermistors which enable a plausibility check. This diagnostic method can show if the MUX is stuck on a specific channel or reporting voltages corresponding to incorrect channels.

The AVDD pin on the BQ78706 is used to supply power to the TMUX1308. Since AVDD can be configured as off state by shorting RX to AVDD, AVDD can enable a low shutdown current with no leakage current to external MUX devices. When BQ78706 is waked, then AVDD supplies all the external loads with 20mA capacity which is enough for MUX or other devices.

The internal passive cell balancing resistors can support up to 100mA of balancing current per channel. An odd and even cell balancing can be used to achieve average 50mA balancing current.

To isolate communication, the design uses two capacitors for daisy chain communication between two BQ78706 and two 1500V reinforced transformers in daisy chain communication between the BMUs or the BCU. This daisy chain communication enables a ring communication structure which can reduce gap current caused by daisy chain communication.

Besides daisy chain, CAN interface and MCU is also designed into this board. MCU MSPM0G3519 is used to collect the data from four BQ78706 devices and transfer data to the CAN bus. BQ78706 supports the universal asynchronous receiver-transmitter (UART) interface or serial peripheral interface (SPI) to the MCU. This design uses UART. Two-stage reinforced isolation is used to achieve 1500V insulation standard required creepage by both UL1973 and IEC 62477. The reinforced isolated power module is UCC33421 and digital isolator is ISO7731 which converts RX, TX and FAULT signals between BQ78706 and MSPM0G3519. To enhance the stability of the CAN interface communication, ISO6721 and UCC33420 are used for a functional insulation.

The power rail uses LM51406 to supply from a maximum 36VDC to 5VDC, which converts 5V to isolated power module.

2.1 Block Diagram

Figure 2-1 shows the system block diagram.

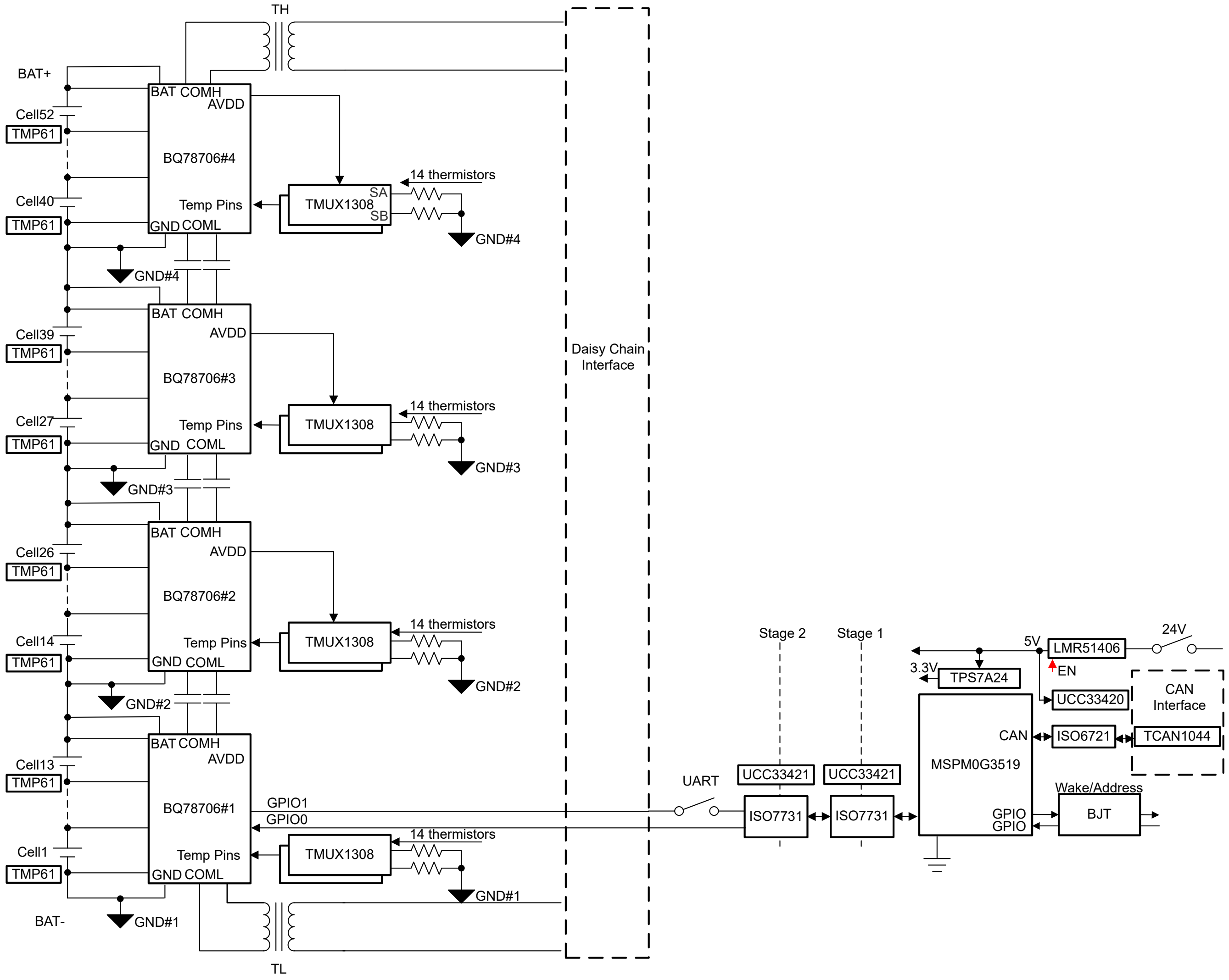


Figure 2-1. TIDA-010279 BMU Block Diagram

2.2 Design Considerations

2.2.1 Multiplexer Network and Switch Strategy

Figure 2-2 shows the strategy of reading all thermistors and cell voltages. Two TMUX1308 devices are used to multiplex 14 thermistors and 2 constant resistors TS_R1 and TS_R2 to one BQ78706. The BQ78706 uses three GPIOs (GPIO9, GPIO10, and GPIO11) to address the 8 thermistor channels of the TMUX1308 and 2 GPIOs (GPIO7 and GPIO8) to read the common output pin from 2 TMUX1308 devices. This means 5 GPIOs can switch 16 thermistors.

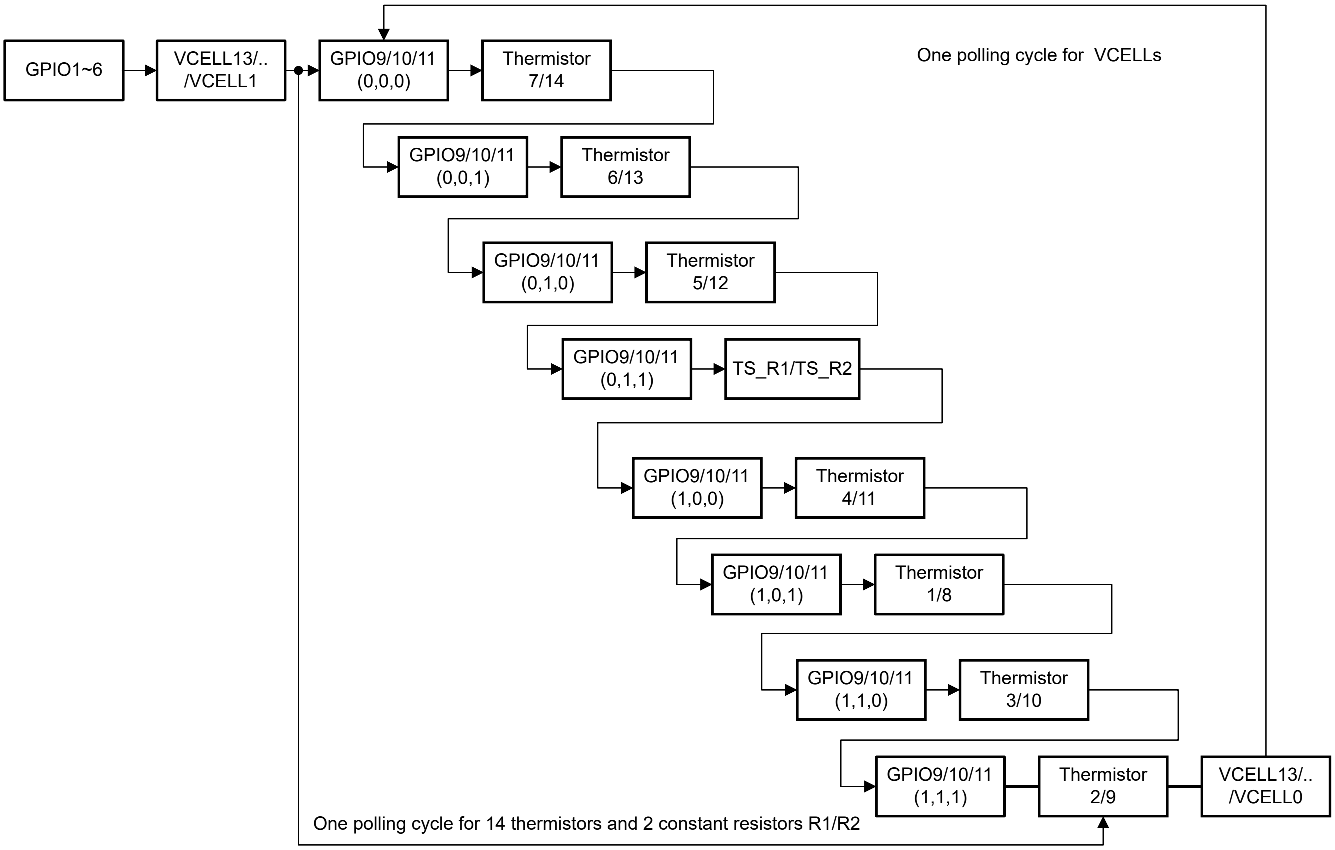


Figure 2-2. Strategy of Reading all Thermistors and Cell Voltages

Although the number of thermistors can easily be increased using the TMUX1308 or a different multiplexer, the system still needs an efficient switching strategy to connect all thermistors in a safe time defined by regulation.

The loop of thermistor switching consists of a broadcast write to all the stacked BQ78706 GPIO9 to GPIO11 and a broadcast read of the GPIO7 and GPIO8 configured as ADC and OTUT inputs (ratiometric). The design needs 8 loops to read the temperature data from 14 thermistors and 2 constant resistors.

If the BESS rack voltage is 1500V, and one rack consists of 416 pieces of battery cells in series, then use 8 BMUs (32 BQ78706 devices) to monitor all the battery cells. Performing one loop to read temperature data from the stacked BQ78706 devices takes a longer time, which is likely to meet GBT34131-2023 standards (1s duty cycle for all the thermistors).

2.2.2 Cell Balancing

Figure 2-3 shows the cell balancing circuit.

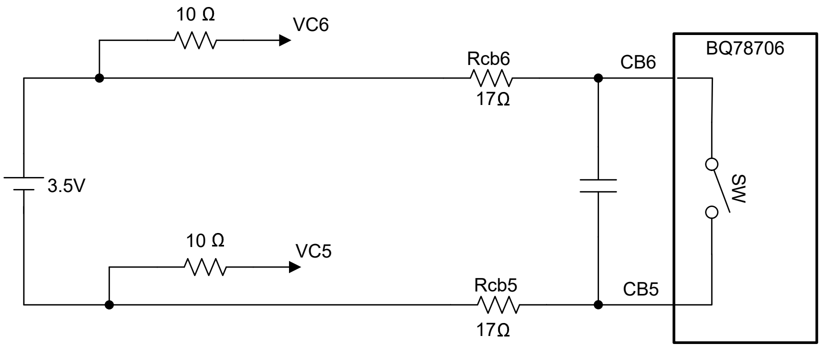


Figure 2-3. Cell Balancing Circuit

The design uses an internal field-effect transistor (FET) to achieve a 100mA balancing current. Assuming the given condition: an initial CB voltage of 3.5V, the final CB voltage is 3.3V. To achieve 100mA balancing current while the CB voltage is 3.5V; Rcb6 = Rcb5 = 17Ω is used.

2.2.3 Stacked AFE Communication

For very high cell count systems, BQ78706 devices can be stacked in series to monitor battery cells. This design uses four BQ78706 devices to monitor up to 52s battery cells. The BQ78706 monitors the 13 battery cells in series and references 13s top-of-stack voltage as ground. Isolation is required to communicate between each BQ78706 device. This design uses a capacitor-isolated daisy chain between two BQ78706 devices and a transformer-isolated daisy chain to the offboard BMU or BCU. The BMU is designed to support both the forward and reverse communication directions. The communication direction from the bottom BQ78706 to the top BQ78706 is North (Forward). The communication direction from the top BQ78706 to the bottom BQ78706 is South (Reverse). Figure 2-4 shows the ring communication of the BMUs.

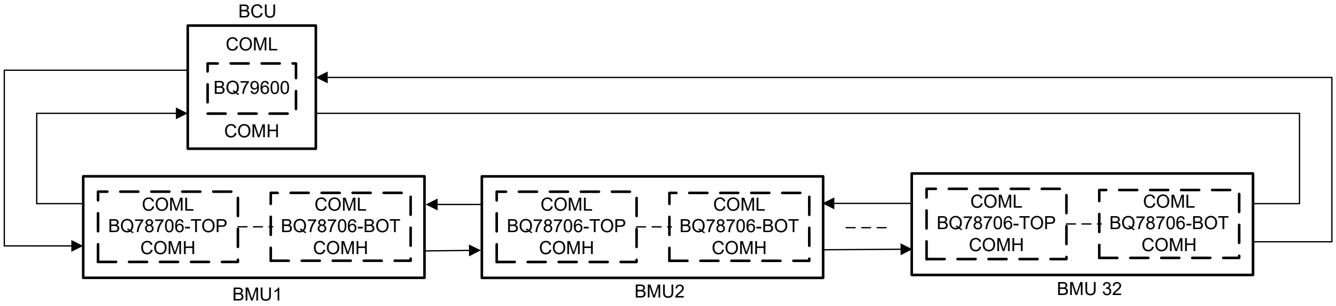


Figure 2-4. BMU Ring Communication

The BCU issues pings to the BQ79600 using UART. Pings are non-comm signals for simple actions, such as WAKE and SHUTDOWN. Commands are used to transmit data. The BQ79600 can send and receive tones to and from the stacked BQ78706 in the North and South in a duty cycle. Considering the GBT34131-2023 standards, the voltage cycle needs to be less than 100ms, and the temperature cycle needs to be less than 1 second.

2.2.4 MCU and CAN Interface

MCU and CAN interface is an optional choice to replace daisy chain. CAN interface is a widely-used standard interface. MCU MSPM0G3519 transfers the data from AFE1, AFE2, AFE3, and AFE4 to CAN interface. AFE1 works as a bridge device. The ISO7731 is used to connect the UART interface of the AFE1 and the MCU. A reinforced insulation is required since MCU is in low-voltage ground and AFE1 is in high-voltage ground. Two isolated stages are built with UCC33421 and ISO7731. Each stage has a 1500V working voltage and two stages are connected in series to meet 15mm creepage.

Since the TX pin of the BQ78706 supplies a constant voltage in both SHUTDOWN and ACTIVE modes, the ISO7731 is powered from the input (TX) when the BQ78706 SHUTDOWN mode of the ISO7731 is directly connected to BQ78706. A switch is added between BQ78706 and ISO7731 to prevent a leakage current. The switch can be a FET.

Figure 2-5 shows the MCU and CAN interface.

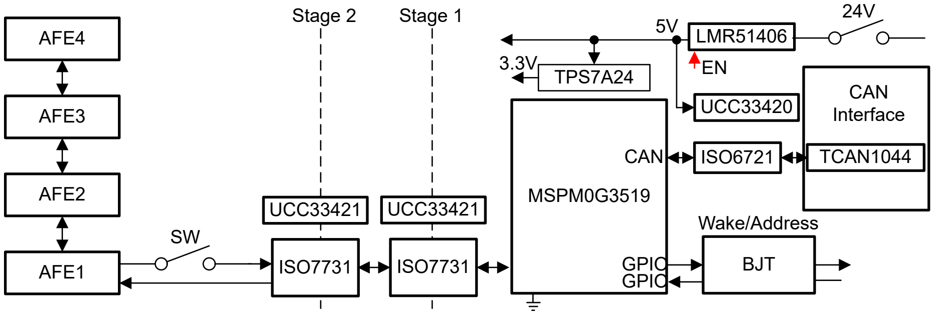


Figure 2-5. MCU and CAN interface

UCC33420 and ISO6721 provide a functional isolation for CAN interface. This CAN interface is usually connected to the CAN bus of BCU. The working current of the CAN transceiver, such as TCAN1044, is quite small. A functional isolation is set for the CAN transceiver not the MCU for a higher efficiency.

2.3 Highlighted Products

2.3.1 BQ78706

The BQ78706 provides high-accuracy cell voltage measurements for up to 14s battery modules in high-voltage battery management systems in energy storage systems (ESS) and portable power stations (PPS). This device has a state-of-the-art ADC architecture - measurement system meeting stringent safety requirements. With the daisy-chain isolated by transformer (or capacitor), the device is designed for centralized or distributed architectures in residential, commercial, or grid-scale energy storage systems.

2.3.2 TMUX1308

The TMUX1308-Q1 and TMUX1309-Q1 devices are general purpose complementary metal-oxide semiconductor (CMOS) multiplexers (MUX). The TMUX1308-Q1 is an 8:1, 1-channel (single-ended) MUX, while the TMUX1309-Q1 is a 4:1, 2-channel (differential) MUX. The devices support bidirectional analog and digital signals on the source (Sx) and drain (Dx) pins ranging from GND to VDD.

The TMUX13xx-Q1 devices have an internal injection current control feature which eliminates the need for external diode and resistor networks typically used to protect the switch and keep the input signals within the supply voltage. The internal injection current control circuitry allows signals on disabled signal paths to exceed the supply voltage without affecting the signal of the enabled signal path. Additionally, the TMUX13xx-Q1 devices do not have an internal diode path to the supply pin, which eliminates the risk of damaging components connected to the supply pin or providing unintended power to the supply rail.

All logic inputs have 1.8V logic compatible thresholds, providing both transistor-transistor logic (TTL) and CMOS logic compatibility when operating with a valid supply voltage. Fail-safe logic circuitry allows voltages on the control pins to be applied before the supply pin, protecting the device from potential damage.

2.3.3 TCAN1044-Q1

The TCAN1044-Q1 is a high-speed controller area network (CAN) transceiver that meets the physical layer requirements of the ISO 11898-2:2016 high-speed CAN specification.

The TCAN1044-Q1 transceiver supports both classical CAN and CAN FD networks up to 8 megabits per second (Mbps). The TCAN1044-Q1 includes internal logic level translation through the VIO terminal to allow for interfacing the transceiver I/Os directly to 1.8V, 2.5V, 3.3V, or 5V logic I/Os. The transceiver supports a low-power standby mode and wake-over CAN compliant to the ISO 11898-2:2016 defined wake-up pattern (WUP).

The TCAN1044-Q1 transceiver also includes protection and diagnostic features supporting thermal-shutdown (TSD), TXD-dominant time-out (DTO), supply undervoltage detection, and bus fault protection up to ±58V.

2.3.4 MSPM0G3519

MSPM0Gx51x microcontrollers (MCUs) are part of the MSP highly integrated, ultra-low-power 32-bit MCU family based on the enhanced Arm Cortex-M0+ 32-bit core platform, operating at up to 80MHz frequency. These MCUs offer a blend of cost optimization and design flexibility for applications requiring 256KB to 512KB of flash memory in small packages (down to 5mm × 5mm) or high pin count packages (up to 100 pins). These devices include dual CAN-FD controllers, cybersecurity enablers, high-performance integrated analog, and provide excellent low-power performance across the operating temperature range.

Up to 512KB of embedded flash program memory with built-in error correction code (ECC) and up to 128KB SRAM (with ECC and parity protection for the first 64KB). The flash memory is organized into two main banks to support field firmware updates, with address swap support provided between the two main banks.

Flexible cybersecurity enablers can be used to support secure boot, secure in-field firmware updates, IP protection (execute-only memory), key storage, and more. Hardware acceleration is provided for a variety of AES symmetric cipher modes, as well as a TRNG entropy source. The cybersecurity architecture is pending Arm® PSA Level 1 certification.

A set of high-performance analog modules is provided, such as two simultaneously sampling 12-bit 4Msps ADCs supporting up to 27 external channels, on-chip voltage reference (1.4V or 2.5V), one 12-bit 1Msps DAC, and three high-speed comparators with built-in 8-bit reference DACs operable in low-power and high-speed modes.

The TI MSPM0 family of low-power MCUs consists of devices with varying degrees of analog and digital integration allowing for customers to find the MCU that meets the needs of the project. The MSPM0 MCU platform combines the Arm® Cortex®-M0+ platform with a holistic ultra-low-power system architecture, allowing system designers to increase performance while reducing energy consumption.

2.3.5 LMR51406

The LMR514xx is a wide-V_{IN}, easy-to-use synchronous buck converter capable of driving up to 0.6A and 1A load current. With a wide input range of 4V to 42V, the device is designed for a wide range of industrial applications for power conditioning from an unregulated source.

The LMR514xx operates at 400kHz and 1.1MHz switching frequency to support use of relatively small inductors for an optimized design size. The LMR514xx has a PFM version to realize high efficiency at light load and a FPWM version to achieve constant frequency and small output voltage ripple over the full load range. Soft-start and compensation circuits are implemented internally, which allow the device to be used with minimal external components.

The device has built-in protection features, such as cycle-by-cycle current limit, hiccup mode short-circuit protection, and thermal shutdown in case of excessive power dissipation.

2.3.6 ISO7731

The ISO773x devices are high-performance, triple-channel digital isolators with $5000V_{RMS}$ (DW package) and $3000V_{RMS}$ (DBQ package) isolation ratings per UL 1577.

This family includes devices with reinforced insulation ratings according to VDE, CSA, TUV, and CQC. The ISO7731B device is designed for applications that require basic insulation ratings only.

The ISO773x family of devices provides high electromagnetic immunity and low emissions at low power consumption, while isolating CMOS or LVCMOS digital I/Os. Each isolation channel has a logic input and output buffer separated by a double capacitive silicon dioxide (SiO2) insulation barrier. This device comes with enable pins which can be used to put the respective outputs in high impedance for multi-controller driving applications and to reduce power consumption.

The ISO7730 device has all three channels in the same direction and the ISO7731 device has two forward and one reverse-direction channel. If the input power or signal is lost, the default output is high for devices without suffix F and low for devices with suffix F.

Used in conjunction with isolated power supplies, this family of devices helps prevent noise currents on data buses, such as RS-485, RS-232, and CAN , or other circuits from entering the local ground and interfering with or damaging sensitive circuitry. Through remarkable chip design and layout techniques, electromagnetic compatibility of the ISO773x device is significantly enhanced to ease system-level ESD, EFT, surge, and emissions compliance. The ISO773x family of devices is available in 16-pin wide-SOIC and QSOP packages.

2.3.7 UCC33420

UCC33420 is an industrial DC/DC power module with integrated transformer technology designed to provide 1.5W of isolated output power. The devices support an input voltage operation range of 4.5V to 5.5V and regulates 5.0V output voltage with a selectable headroom of 5.5V.

UCC33420 features a proprietary transformer architecture that achieves a 3kV_{RMS} isolation rating, while simultaneously supporting low EMI and excellent load regulation.

The UCC33420 integrates protection features for increased system robustness such as an enable pin with a fault-reporting mechanism, short-circuit protection and thermal shutdown.

The UCC33420 comes in a miniaturized, low-profile design VSON (4.00mm × 5.00mm) package with 1.00mm height and > 4.1mm creepage and clearance.

2.3.8 UCC33421

UCC33421-Q1 is an automotive qualified DC/DC power module with integrated transformer technology designed to provide 1.5W of isolated output power. The device supports an input voltage operation range of 4.5V to 5.5V and regulates 5.0V output voltage with a selectable headroom of 5.5V.

UCC33421-Q1 features a proprietary transformer architecture that achieves a 5kV_{RMS} isolation rating, while simultaneously supporting low EMI and excellent load regulation.

The UCC33421-Q1 integrates protection features for increased system robustness such as an enable pin with a fault-reporting mechanism, short-circuit protection and thermal shutdown.

The UCC33421-Q1 comes in a miniaturized, low-profile design SOIC (5.85mm × 7.50mm) package with 2.65mm height and > 8.2mm creepage and clearance.

2.3.9 TMP61

The Thermistor Design Tool offers the complete resistance versus temperature table (R-T table) computation and other helpful methods to derive temperature and example C-code.

The TMP61 linear thermistor offers linearity and consistent sensitivity across temperature to enable simple and accurate methods for temperature conversion. The low power consumption and a small thermal mass of the device minimize self-heating.

With built-in fail-safe behaviors at high temperatures and powerful immunity to environmental variation, these devices are designed for a long lifetime of high performance. The small size of the TMP6 series also allows for close placement to heat sources and quick response times.

Take advantage of benefits over NTC thermistors such as no extra linearization circuitry, minimized calibration, less resistance tolerance variation, larger sensitivity at high temperatures, and simplified conversion methods to save time and memory.

The TMP61 is currently available in a 0402 X1SON package, a 0603 SOT-5X3 package, and a 2-pin through-hole TO-92S package.

3 Hardware, Testing Requirements, and Test Results

The key performances of the TIDA-010279 were tested in a TI lab. This section describes the end equipment used and the test processes and results. Table 3-5 describes the hardware connections for the TIDA-010271 board.

Table 3-1. Battery Connector J2 – *n* (*n* = 1, 2, 3, 4)

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J2-A*n* – 1	RTN_MUX2	Negative terminal of thermistor
J2-A*n* – 21	TS1	Positive terminal of thermistor1
J2-A*n* – 2	TS2	Positive terminal of thermistor2
J2-A*n* – 22	TS3	Positive terminal of thermistor3
J2-A*n* – 3	TS4	Positive terminal of thermistor4
J2-A*n* – 23	TS5	Positive terminal of thermistor5
J2-A*n* – 4	TS6	Positive terminal of thermistor6
J2-A*n* – 24	TS7	Positive terminal of thermistor7
J2-A*n* – 5	TS8	Positive terminal of thermistor8
J2-A*n* – 25	RTN_MUX1	Negative terminal of thermistor
J2-A*n* – 26	TS9	Positive terminal of thermistor9
J2-A*n* – 6	TS10	Positive terminal of thermistor10
J2-A*n* – 27	TS11	Positive terminal of thermistor11
J2-A*n* – 7	TS12	Positive terminal of thermistor12
J2-A*n* – 28	TS13	Positive terminal of thermistor13
J2-A*n* – 8	TS14	Positive terminal of thermistor14
J2-A*n* – 10	Module_N	BQ78706 Ground
J2-A*n* – 31	CELL0	Negative terminal of CELL1
J2-A*n* – 11	CELL1	Positive terminal of CELL1
J2-A*n* – 32	CELL2	Positive terminal of CELL2
J2-A*n* – 12	CELL3	Positive terminal of CELL3
J2-A*n* – 33	CELL4	Positive terminal of CELL4
J2-A*n* – 13	CELL5	Positive terminal of CELL5
J2-A*n* – 34	CELL6	Positive terminal of CELL6
J2-A*n* – 14	CELL7	Positive terminal of CELL7
J2-A*n* – 35	CELL8	Positive terminal of CELL8
J2-A*n* – 15	CELL9	Positive terminal of CELL9
J2-A*n* – 36	CELL10	Positive terminal of CELL10
J2-A*n* – 16	CELL11	Positive terminal of CELL11
J2-A*n* – 37	CELL12	Positive terminal of CELL12
J2-A*n* – 17	CELL13	Positive terminal of CELL13
J2-A*n* – 38	CELL14	Positive terminal of CELL14
J2-A*n* – 18	CELL15	Positive terminal of CELL15
J2-A*n* – 39	CELL16	Positive terminal of CELL16
J2-A*n* – 19	CELL17	Positive terminal of CELL17
J2-A*n* – 40	CELL18	Positive terminal of CELL18
J2-A*n* – 20	Module_P	BQ78706 power

Table 3-2 lists the daisy-chain (COMH) connector information.

Table 3-2. Daisy-Chain (COMH) Connector

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J8-3	BMU_COMMH_P	COM high-side positive
J8–4	BMU_COMMH_P	COM high-side negative

Table 3-3 shows the daisy-chain (COML) connector information.

Table 3-3. Daisy-Chain (COML) Connector

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J7–1	BMU_COMML_N	COM low-side negative
J7–2	BMU_COMML_P	COM low-side positive

Table 3-4 details the CAN and power interface functions.

Table 3-4. CAN and Power Interface

CONNECTOR AND PIN ASSIGNMENTS	FUNCTION OR SCHEMATIC NET	NOTES
J5–1	PGND	GND of CAN interface
J5–2	BMU_WAKEOUT_C	BMU wake up output
J5–3	CAN0_CANH	CAN high
J5–4	CAN0_CANL	CAN low
J5–5	LV24V	Power supply of CAN interface
J5–6	BMU_WAKEIN_C	BMU wake up input
J5–7	CAN0_CANL	CAN high
J5–8	CAN0_CANH	CAN high

3.1 Hardware Requirements

Table 3-5 summarizes the equipment used for testing.

Table 3-5. Test Equipment Summary

EQUIPMENT	MODEL OR DESCRIPTION
Multimeter	Agilent® 34401A
Battery simulator	TZ1104
USB2ANY	TI HAP655
Logic Analyzer	Kingst® LA5016

The *Battery Management Studio (bqStudio) Software* is recommended when debugging the board for the first time.

3.2 Test Setup

Use the following procedures before running this design board. The design was constructed as 52s pack configurations. The board was tested using 24s-battery simulator to simulate the total pack. Thirteen channels of battery simulator are used and each channel is separated with four cables to the cell voltage input terminal in the BQ78706#1, BQ78706#2, BQ78706#3, and BQ78706#4 connectors .

Figure 3-1 shows the BMU test setup for daisy chain and accuracy.

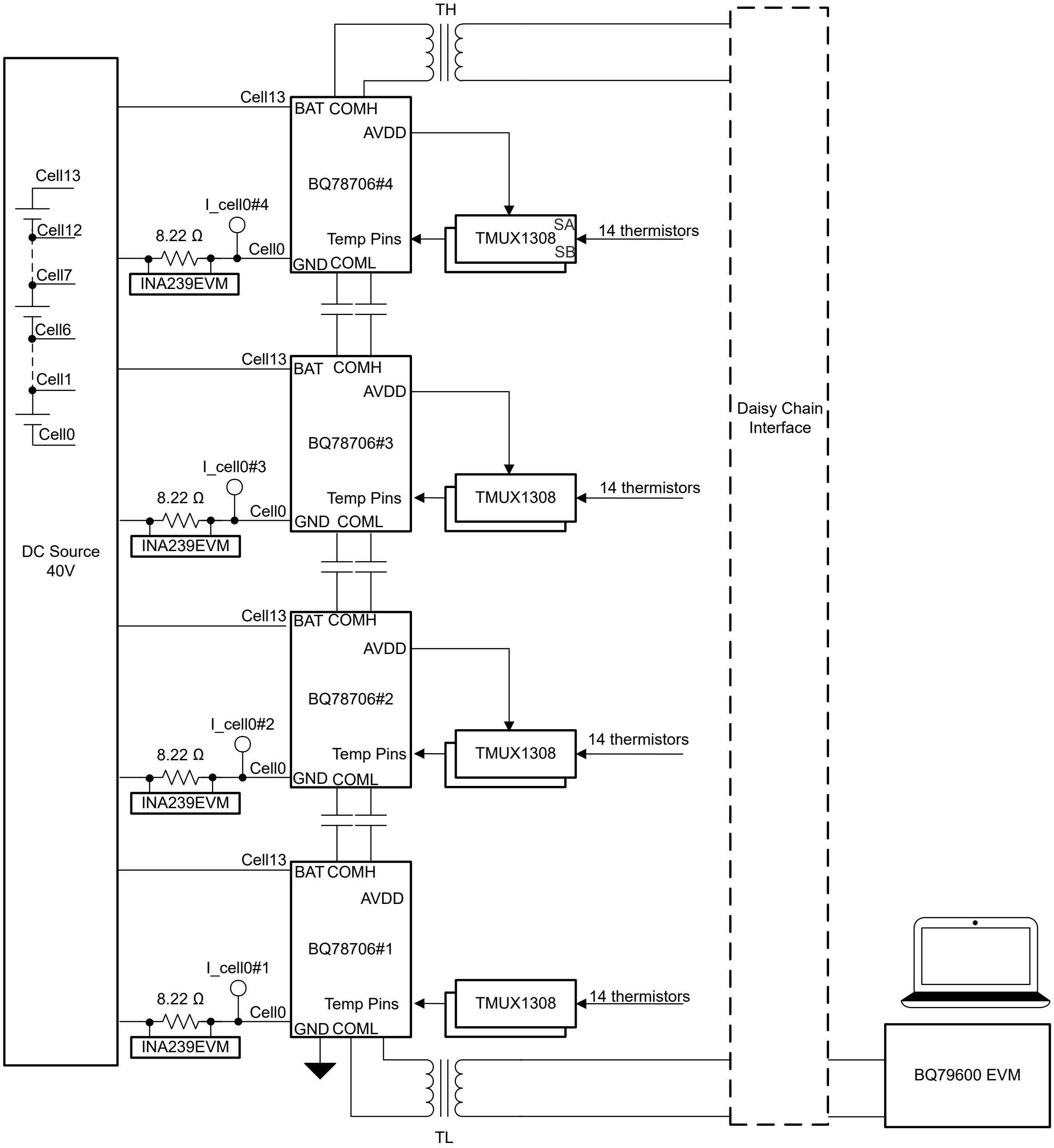


Figure 3-1. BMU Test Setup for Daisy Chain and Accuracy

3.3 Test Results

3.3.1 Daisy Chain

This design tests the BQ76900-Q1 COMHP-COMHN and BQ78706#1 COMLP-COMLN response frame daisy chain waveforms.

Table 3-6 shows the BQ76900-Q1 test result. Table 3-7 shows the BQ78706#1 test result. The MIN and MAX parameters in the table is the measurement criteria. Table 3-6 shows the positive pulse width, negative pulse width, rise slew rate, fall slew rate meet the criteria well.

Table 3-6. BQ76900-Q1 COMHP-COMHN Test Results

PARAMETER	CONDITION	MIN CRITERIA	TEST RESULT	MAX CRITERIA
Positive pulse width	Measure COMP-COMN from +1.8V of rising edge to –1.8V of next falling edge	230ns	252ns	270ns
Negative pulse width	Measure COMP-COMN from –1.8V of falling edge to +1.8V of next rising edge	230ns	260ns	270ns
Rise slew rate	Measure COMP-COMN from –1.8V to +1.8V of rising edge		12ns	90ns
Fall slew rate	Measure COMP-COMN from +1.8V to –1.8V of falling edge		12ns	90ns

Table 3-7. BQ78706 COMLP-COMLN Test Result

PARAMETER	CONDITION	MIN CRITERIA	TEST RESULT	MAX CRITERIA
Positive pulse width	Measure COMP-COMN from +1.2V of rising edge to –1.2V of next falling edge	230ns	252ns	270ns
Negative pulse width	Measure COMP-COMN from –1.2V of falling edge to +1.2V of next rising edge	230ns	253ns	270ns
Rise slew rate	Measure COMP-COMN from –1.2V to +1.2V of rising edge		19ns	60ns
Fall slew rate	Measure COMP-COMN from +1.2V to –1.2V of falling edge		20ns	60ns

3.3.2 Cell Voltage Accuracy

This design does not perform any calibrations to further improve the cell voltage accuracy since the BQ78706 already achieves ±2.4mV accuracy at –40°C to 125°C. The typical voltage range of a LiFePO4 cell is from 2.5V (0% SOC) to 3.6V (100% SOC), so the design uses a battery simulator to provide cell voltages from 2.5V to 3.6V to verify the VCELL accuracy of the BMU.

The maximum error of all cell channels for the BQ78706#1 is 0.7mV at a room temperature of 22.7°C. Figure 3-2 shows the cell voltage accuracy.

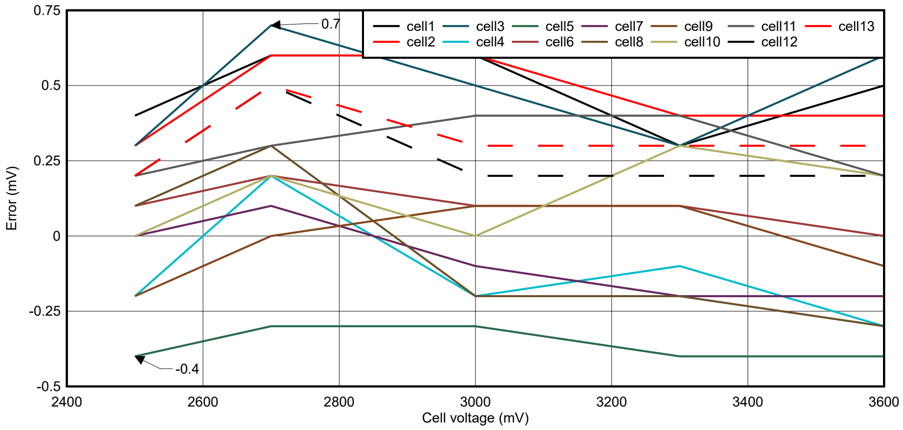


Figure 3-2. Cell Voltage Accuracy

3.3.3 Temperature Sensing Using TMP61

Four TMP61 thermistors are used to verify the BMU temperature sensing function. This section focuses on how to use TMP61 to measuring the temperature with BQ78706.

In this design, GPIO1 to GPIO8 are configured as ADC and OTUT inputs (ratiometric). GPIO3 to GPIO6 are connected to TMP61 with 10kΩ pullup resistors. Using GPIO3 as an example, RT3 is the resistance of the TMP61 connected to GPIO3, RATIO3 is the GPIO3_RATIO reading data, R_{pull} is the 10kΩ pullup resistor, T3 is the temperature sensing by TMP61. Calculate RT3 using Equation 1.

$$\mathrm{RT3} = \frac{\mathrm{RATIO3}}{1 - \mathrm{RATIO3}} \times \mathrm{R_{pull}} \tag{1}$$

TMP61 provides the fourth order polynomial TMP. Calculate T3 using Equation 2.

$$\mathrm{T3} = \mathrm{A4} \times \mathrm{RT3}^4 + \mathrm{A3} \times \mathrm{RT3}^3 + \mathrm{A2} \times \mathrm{RT3}^2 + \mathrm{A1} \times \mathrm{RT3} + \mathrm{A0} \tag{2}$$

where

- A0 = –2.720252E+02, A1 = 5.256220E–02, A2 = –3.442327E–06,
  A3 = 1.370186E–10, A4 = –2.227207E-15

In the test, the BQ78706 GPIO3 reading data is 47.79%. The corresponding RT3 is 9916.35Ω. The temperature T3 is 22.8°C. The accuracy of the TMP61 measurement can be referred from the TMP61 Thermistor Design Tool.

3.3.4 Temperature Sensing Timings

This test uses one BMU and the BQ79600 EVM. The test points for BQ78706#1 are found in Figure 3-3 including GPIO7, GPIO9, GPIO10, GPIO11, and COMLP. The temperature sensing test software follows the steps in Figure 2-2.

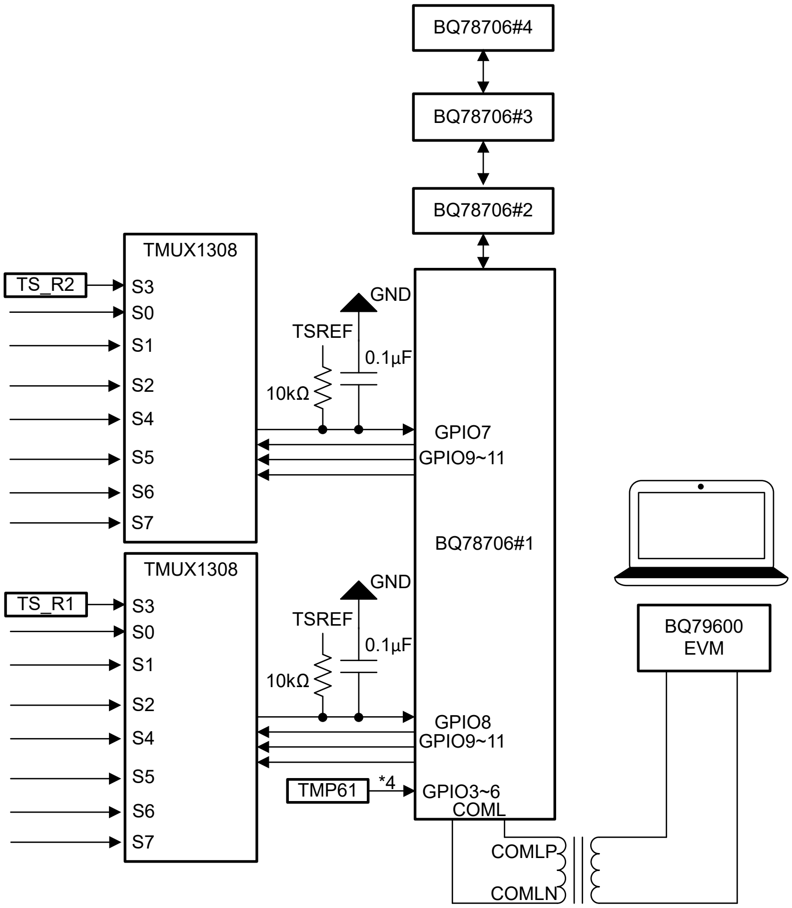


Figure 3-3. Test Setup for Temperature Sensing

Figure 3-4 shows the temperature sensing timings with MUX.

|A1 - A2|=3.08938ms
A1 @ 51.98601ms
A2 @ 55.07539ms
|B1 - B2|=27.03956ms
B1 @ 46.03477ms
B2 @ 73.07433ms

Figure 3-4. Temperature Sensing Timings With MUX

The test needs eight steps to read all the thermistor and voltages. Each step contains a broadcast write to set TMUX1308 and a broadcast read of GPIO7 and GPIO8 from all the BQ78706 devices in the stacked BMUs. To clearly show the process of each step, the reading command is not used. Only the write command is used to select TMUX1308 channels from S0 to S8. The RS_R2 is connected in channel S3 and has a small resistance of 1kΩ that a logic analyzer can recognize as a signal *0*. In Figure 3-5, eight steps transfer one by one and the duration from step 0 to step 7 is 27.07ms. This process demonstrates that eight TMUX1308 status transfers work correctly.

When the MUX channel is switched, a settling time must be considered. In this design, the filter capacitor is 0.1µF and the pullup resistor is 10kΩ. When channel S3 switches to S4, the voltage of GPIO7 changes from 0.455V to 5V. The constant time of circuit is 1ms and at least 9ms is needed for the GPIO7 voltage to be stable within 1mV of change. Figure 3-3 shows the GPIO7 MUX voltage settling waveform.

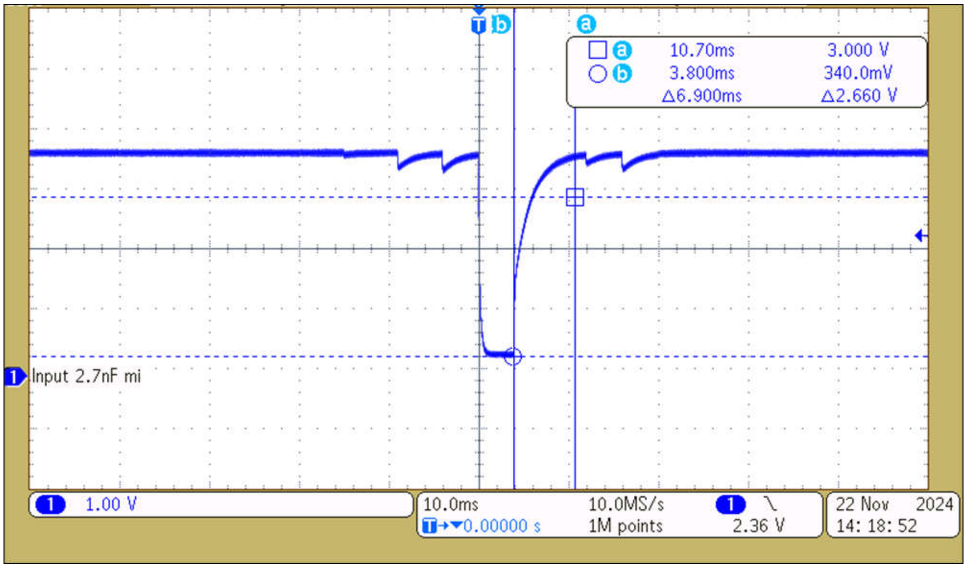


Figure 3-5. MUX Voltage Settling Waveform

3.3.5 Cell Balancing and Thermal Performance

The test uses a battery simulator to test the bottom BQ78706 device of the BMU at room temperature (22.7°C) and 3.5V cell voltage. Auto-balancing control is used and the CB FET of channel 1 is enabled with a duty cycle of 30 minutes. After 30 minutes of cell balancing, the temperature is stable.

Table 3-8 shows the BQ78706#1 cell 1 balancing current from a DC source. The cell balancing current is 98.23mA.

Table 3-8. Cell Balancing Current From DC Source

CELL	CELL VOLTAGE DC SOURCE OUTPUT (V)	CELL VOLTAGE BMU INPUT (V)	VOLTAGE ACROSS Rcb (V)	BALANCING CURRENT (mA)	TEMPERATURE INCREASE (°C)
1	3.509	3.448	1.674	98.23	7.4

Figure 3-6 shows the cell balancing temperature of cell1. The maximum temperature rise is 7.4°C.

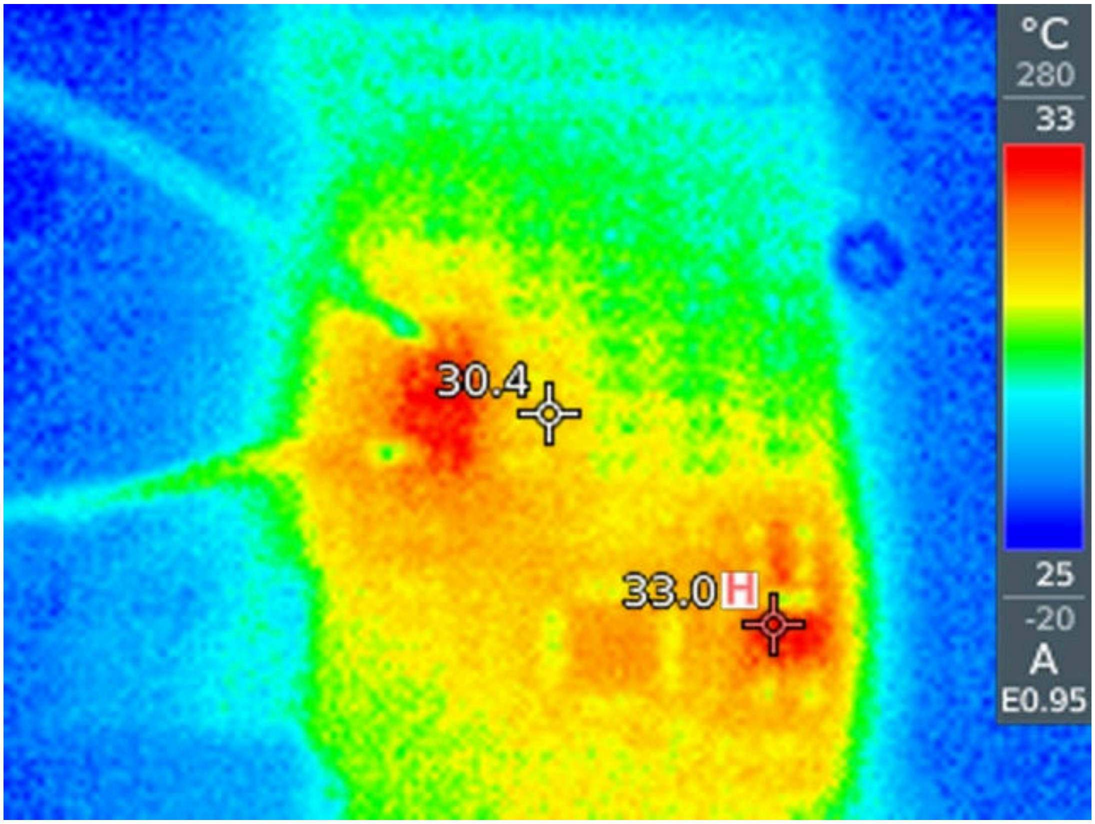


Figure 3-6. Cell Balancing Temperature of Cell1

3.3.6 Current Consumption

Figure 3-7 shows the test setup for consumption. Two working modes are tested including shutdown mode and active mode. Cell0 of each BQ78706 was selected as a test point for current measurement because Cell0 is the location where the power supply cable directly connects to the GND pin of the BQ78706. In both modes, the DC source sets 40V voltage between cell0 and cell13. Additionally, an 8.22Ω current sensing resistor is added between negative terminal of DC source and GND of each BQ78706 device. An INA239 EVM board is used to measure the voltage across the current sensing resistor. The sample rate is 2ms and 60000 points of data are collected for average calculation.

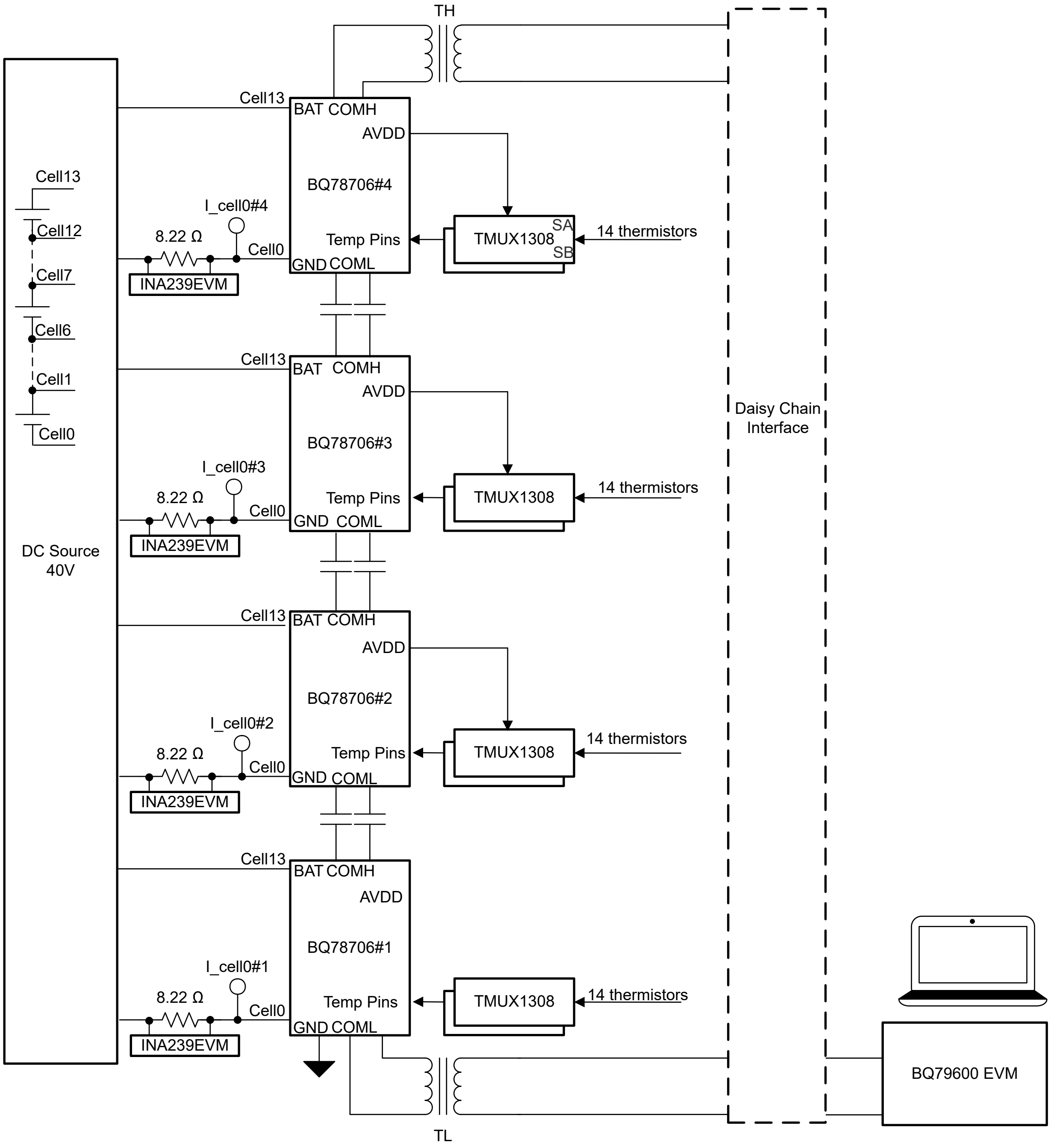


Figure 3-7. Test Setup for Consumption

In active mode, the BQ79600 EVM runs the cell voltage polling loop. In shutdown mode, the leakage current to the BQ78706 pin is 3.416µA, 3,65µA,3.65µA, and 4.258µA. In active mode, the working current is 10.693mA, 10.673mA, 10.544mA, and 10.717mA. The maximum AFE gap current in active mode is 134µA.

Table 3-9 shows the BMU current consumption.

Table 3-9. BMU Current Consumption

DESCRIPTION		$I_{cell0\#1}$	$I_{cell0\#2}$	$I_{cell0\#3}$	$I_{cell0\#4}$
Shutdown Mode	Current (µA)	3.416	3.65	3.65	4.258
Active Mode	Current (mA)	10.400	10.430	10.296	10.426

4 Design and Documentation Support

4.1 Design Files

4.1.1 Schematics

To download the schematics, see the design files at TIDA-010279.

4.1.2 BOM

To download the schematics, see the design files at TIDA-010279.

4.2 Tools and Software

Tools

USB2ANY	USB2ANY interface adapter

Software

BQSTUDIO	Battery Management Studio (bqStudio) Software
CCSTUDIO	Code Composer Studio™ integrated development environment (IDE)

4.3 Documentation Support

1. Texas Instruments, *LiFePO4 Design Considerations Application Note*
2. Texas Instruments, *BQ78706 Functional Safety-Compliant 14S Battery Monitor Data Sheet*
3. Texas Instruments, *How to Stack Battery Monitors for High-cell-count Industrial Applications* E2E™ forum
4. Texas Instruments, *Expanding Functionality of Cell Supervision Unit in Battery Management Systems Application Brief*

4.4 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

Linked content is provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

4.5 Trademarks

TI E2E™, Code Composer Studio™, and E2E™ are trademarks of Texas Instruments.
Arm® and Cortex® are registered trademarks of Arm Limited.
Agilent® is a registered trademark of Agilent Technologies Inc.
Kingst® is a registered trademark of Qingdao Kingst Electronics Co., Ltd.
All trademarks are the property of their respective owners.

5 About the Author

JUNHUA YAN, is a TI system engineer from the SEM *Energy Infrastructure* team. Junhua focuses on battery pack and energy storage system applications and has created several designs to address industrial battery pack design challenges.

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2024, Texas Instruments Incorporated