TI Designs: TIDA-01400

bq76PL455A-Q1 Communications Bridge Reference Design

Description

TIDA-01400 uses a dedicated bq76PL455A-Q1 device to act as the communications interface between a system microcontroller (MCU) and a daisy-chained stack of bq76PL455A-Q1 battery-monitoring devices. Using a dedicated bq76PL455A-Q1 allows the pack controller to take full advantage of the daisy-chain communication structure and simplifies the process of communicating to the battery pack, while isolating the pack controller from potentially high battery pack voltages. TIDA-01400 also incorporates two fully-isolated amplifiers, which allows for isolated pack current sensing and offers a separate isolated voltage measurement.

Resources

TIDA-01400	Design Folder
bq76PL455A-Q1	Product Folder
TPS61093	Product Folder
TPD4E05U06QDQARQ1	Product Folder
SN6501DBVR	Product Folder
TPS76350DBVR	Product Folder
TPS7A1650DGNR	Product Folder
AMC1200BDUBR	Product Folder
bq76PL455 EVM	Tools Folder

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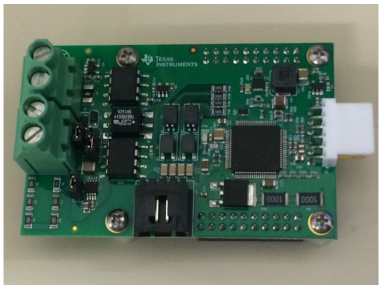
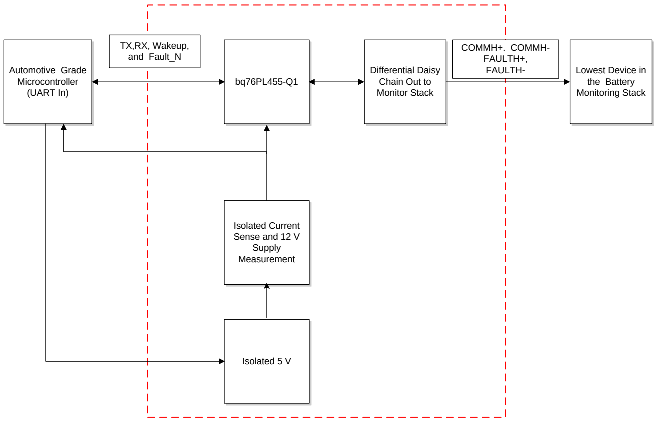
Features

- Compatible With TMS570 or C2000™ Automotive-Grade MCUs
- Fully-Isolated Pack Current and User-chosen Voltage Measurements Reported to MCU or bq76PL455A-Q1 AUX Pins
- 12-V Rail to Power the bq76PL455A-Q1 From Existing MCU Power Supply
- Isolated Daisy-Chain Communication Output to Communicate With Battery Pack

Applications

- Electric and Hybrid Vehicles
- E-Bikes and Electric Scooters
- Energy Storage and UPS





1 System Overview

1.1 System Description

The bq76PL455A-Q1 acts as a communication bridge between a system controller's or battery pack controller's UART commands into the differential daisy-chain protocol used by the bq76PL455A-Q1 stack used for battery pack monitoring. Universal asynchronous receiver and transmitter (UART) communication takes place on the TX and RX pins as well as an interrupt pin FAULT_N, which is used to alert the MCU of a device fault in the battery monitoring stack. A fourth pin, WAKEUP, transitions the device from its shutdown mode. The device acting as the bridge sends commands to the stack through the COMMH+, COMMH-, FAUTLTH+, and FAULTH- connections.

The bq76PL455A-Q1 requires a minimum of 12 V of power. In a typical application the bq76PL455A-Q1 derives power from the battery stack. When used as a communication bridge, the bq76PL455A-Q1 will typically be on the same board as the pack controller, which is isolated from the battery stack. TIDA-01400 implements a 12-V boost converter with the TPS61093, which allows the bq76PL455A-Q1 to be powered from the same source as the controller.

TIDA-01400 incorporates two AMC1200BDUBR isolated fully-differential amplifiers to sense current passing through the pack as well as an isolated-voltage measurement. These values are then reported back to the MCU and the AUX inputs of the bq76PL455A-Q1.

Using a dedicated bq76PL455A-Q1 allows the pack controller to take full advantage of the daisy-chain communication structure and simplifies the process of communicating to the battery pack, while isolating the pack controller from potentially high battery pack voltages

1.2 Block Diagram

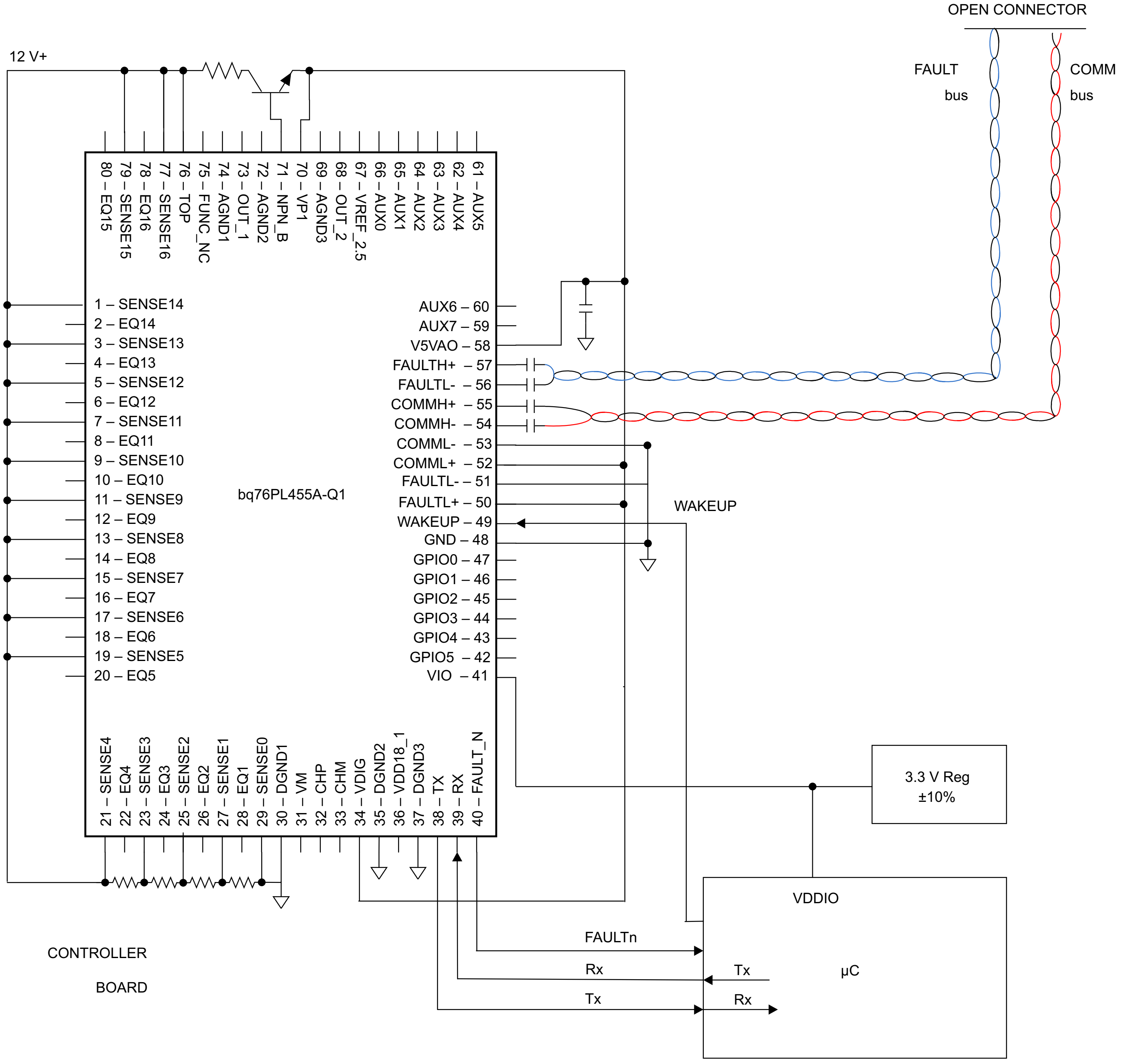


Figure 1. System Block Diagram

1.3 Highlighted Products

1.3.1 bq76PL455A-Q1

The bq76PL455A-Q1 device is an integrated 16-cell battery monitoring and protection device, which is designed for high-reliability automotive applications. The integrated high-speed, differential, capacitor-isolated communications interface allows 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 different fault conditions, which includes overvoltage, undervoltage, overtemperature, and 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.

1.3.2 TPS61093

The TPS61093 is a 1.2-MHz, fixed-frequency boost converter designed for high integration and high reliability. The IC integrates a 20-V power switch, input-output isolation switch, and power diode. When the output current exceeds the overload limit, the isolation switch of the IC opens up to disconnect the output from the input, thus protecting the IC and the input supply. The isolation switch also disconnects the output from the input during shutdown to minimize leakage current. When the IC is shut down, the output capacitor is discharged to a low-voltage level by internal diodes. Other protection features include 1.1-A peak overcurrent protection (OCP) at each cycle, output overvoltage protection (OVP), thermal shutdown, and undervoltage lockout (UVLO).

1.3.3 TPD4E05U06QARQ1

The TPDxE05U06-Q1 is a family of unidirectional transient voltage suppressor (TVS) electrostatic discharge (ESD) protection diodes with ultra-low capacitance. The devices are rated to dissipate ESD strikes above the maximum level specified in the IEC 61000- 4-2 level four international standard. The ultra-low-loading capacitance makes these devices ideal for protecting any high-speed signal applications up to 6 Gbps.

1.3.4 SN6501DBVR

The SN6501 is a monolithic oscillator and power-driver, specifically designed for small form factor, isolated power supplies in isolated interface applications. The device drives a low-profile, center-tapped transformer primary from a 3.3-V or 5-V DC power supply. The secondary can be wound to provide any isolated voltage based on transformer turns ratio. The SN6501 consists of an oscillator followed by a gate drive circuit that provides the complementary output signals to drive the ground referenced N-channel power switches. The internal logic ensures break-before-make action between the two switches.

1.3.5 TPS76350DBVR

The TPS763xx family of low-dropout (LDO) voltage regulators offers the benefits of LDO voltage, low-power operation, and miniaturized packaging. These regulators feature LDO voltages and quiescent currents compared to conventional LDO regulators. Offered in a 5-pin, small outline integrated-circuit SOT-23 package, the TPS763xx series devices are ideal for cost-sensitive designs and for applications where board space is at a premium. A combination of new circuit design and process innovation has enabled the usual pnp pass transistor to be replaced by a P-channel MOS (PMOS) pass element. Because the PMOS pass element behaves as a low-value resistor, the dropout voltage is low—typically 300 mV at 150 mA of load current (TPS76333)—and is directly proportional to the load current. Because the PMOS pass element is a voltage-driven device, the quiescent current is low (140-µA maximum) and is stable over the entire range of output load current (0 mA to 150 mA). Intended for use in portable systems such as laptops and cellular phones, the LDO voltage feature and low-power operation results in a significant increase in system battery operating life. The TPS763xx also features a logic-enabled sleep mode to shut down the regulator, which reduces quiescent current to 1-µA maximum at TJ = 25°C. The TPS763xx is offered in 1.6-V ,1.8-V, 2.5-V, 2.7-V, 2.8-V, 3-V, 3.3-V, 3.8-V, and 5-V fixed-voltage versions.

1.3.6 TPS7A1650DGNR

The TPS7A16 family of ultra-low-power, lLDO voltage regulators offers the benefits of ultra-low quiescent current, high-input voltage, and miniaturized, high thermal-performance packaging. The TPS7A16 family is designed for continuous or sporadic (power backup) battery-powered applications where ultra-low quiescent current is critical to extending system battery life. The TPS7A16 family offers an enable pin (EN) compatible with standard CMOS logic and an integrated open drain active-high power good output (PG) with a user-programmable delay. These pins are intended for use in MCU-based, battery-powered applications where power-rail sequencing is required.

1.3.7 AMC1200BDUBR

The AMC1200 and AMC1200B are precision-isolation amplifiers with an output separated from the input circuitry by a silicon dioxide (SiO2) barrier that is highly resistant to magnetic interference. This barrier has been certified to provide galvanic isolation of up to 4250 VPEAK (AMC1200B) or 4000 VPEAK (AMC1200) according to UL1577 and VDE V 0884-10. Used in conjunction with isolated power supplies, these devices prevent noise currents on a high common-mode voltage line from entering the local ground and interfering with or damaging sensitive circuitry. The input of the AMC1200 or AMC1200B is optimized for direct connection to shunt resistors or other low-voltage level signal sources. The excellent performance of the device supports accurate current control resulting in system-level power saving and, especially in motor-control applications, lower torque ripple. The common-mode voltage of the output signal is automatically adjusted to either the 3-V or the 5-V low-side supply.

1.4 Design Considerations

1.4.1 bq76PL455A-Q1

For bq76PL455A detailed design considerations, see the *bq76PL455A-Q1 Design Recommendations*[6] application report.

When using the AUX pins to monitor a voltage, such as the output of the AMC1200B isolated amplifier, Equation 1 can be used to convert between the voltage at the AUX pin and the ADC reading.

$$V_{Aux} = \frac{2\,V_{ref}}{65535} \times ADC\_Read\_Value \tag{1}$$

1.4.2 12-V Boost Converter

For a detailed design procedure of the boost converter, see Section 9.2.1.2 of the *TPS61093 Low-Input Boost Converter With Integrated Power Diode and Input/Output Isolation*[4] datasheet..

1.4.3 Isolated-Current Sense and Voltage Measurements

For a detailed procedure of generating the isolated 5-V power supply, see the *SN6501 Transformer Drive for Isolated Supplies* datasheet[3].

When using the ACM1200B isolated op-amp, a differential-input voltage of no more than 250 mV should be applied to the VINP and VIN- pins to prevent the output from clipping. The output voltage should also be considered as it is possible for the op-amp to generate more than 3.3 V at the output when using an isolated 5-V supply. If an MCU is used to monitor the voltages, the voltage can exceed the maximum voltage rating of the pins and damage the part. The bq76PL455A-Q1 AUX pins are rated to 5 V, so no damage should occur.

When designing the input-resistor networks, note that the op-amp will have a gain of four if using the op-amp in a single-ended mode of operation, and there will be a 2.55-V offset at the output. Using the 100-mΩ shunt resistor on the board means that largest current that can be sensed without damaging the 3.3-V pin on the MCU is 1.875 A. This current can be found using Equation 2.

$$\text{Max Sense Current} = \frac{3.3 - 2.5}{4 \times R_{SHUNT}} \tag{2}$$

In general, the pack current can always be determined by replacing 3.3 V with the sampled ADC value and R_{shunt} with the desired shunt resistance.

A second AMC1200B is provided to allow for an isolated-voltage measurement. A simple voltage divider can be used to sample the desired voltage, but the user must scale the resistor divider according to the voltage to be measured. For example, TIDA-01400 is currently set up to measure an external 12-V supply using 50 kΩ of series resistance, and 499 Ω of shunt resistance across the input terminals of the op-amp. The voltage detected by the MCU or bq76PL455A-Q1 can be calculated by Equation 3.

$$V_{sense} = 2.55 + 4 \frac{R_{shunt}}{R_{shunt} + R_{stack}} \tag{3}$$

If measuring a larger voltage such as the pack voltage, the resistor divider must be scaled so that the 250-mV maximum input-voltage requirement is satisfied.

WARNING

TIDA-01400 was designed with intentions to measure a separate 12-V battery to be used in active cell balancing. If modifying the design to measure high voltages, use proper safety precautions.

By default, two 0Ω resistors are present on the isolated side of the board. Resistor R32 connects the two ground planes at a single point, while resistor R33 connects the ISO_SUP net to the PISO_5V net, powering the op-amp U8. These resistors should be left on when measuring voltage and current of the same battery or pack. If measuring current from one battery, a separate 12V battery for active cell balancing for example, and pack voltage then resistors R32/R33 should be removed, and jumpers J5/J6 should be placed. In this configuration, both measurement circuits will be fully isolated from each other, as well as the MCU/455 bridge circuitry. Table 1 summarizes the jumper and resistor configurations required for having both amplifiers isolated together or separately. A situation with both the resistors and jumpers on should be avoided as a precaution.

Table 1. Isolation Jumper Configurations

ISOLATION CONFIGURATION	J5	J6	R32/R33	COMMENT
Voltage and current from same battery	OFF	OFF	ON	Default
Current and voltage of separate batteries	ON	ON	REMOVE	Both measurement circuits isolated from each other.
—	ON	ON	ON	Avoid this situation.

2 Getting Started Hardware and Software

2.1 Hardware

- GW INSTEK SPD-3606 dual-range DC-power supply
- KIKUSUI PLZ1004W electronic load
- bq76PL455A-Q1 communication bridge board
- bq76PL455A EVM
- Resistor ladder board
- USB-serial cable

2.2 Software

- bq76PL455A EVM GUI

3 Testing and Results

3.1 Communications Bridge

To set up the communications bridge board, several connections must be made:

- Connect the communication bridge board to the PC with a USB-serial cable.
- Connect the bridge board high-side differential communication head to the bq76PL455A EVM low-side differential communication header.
- Connect the GW INSTEK power supply to a resistive load board, emulating a 16-S battery connection. Set the voltage to 61.2 V.

Figure 2 summarizes these connections

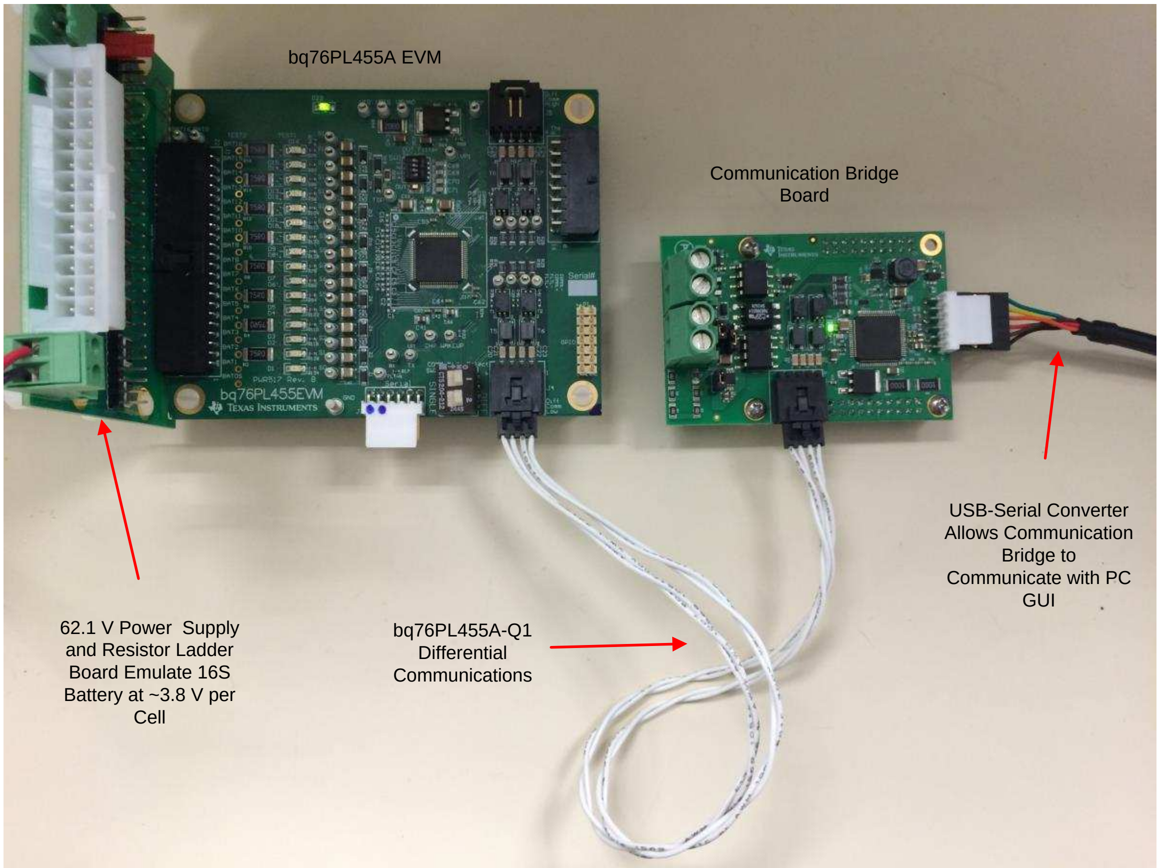
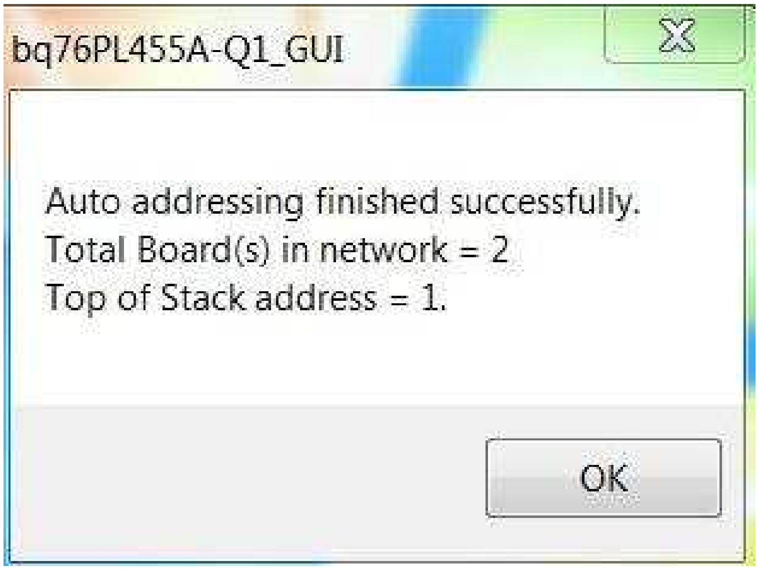


Figure 2. Communication Bridge Board Setup

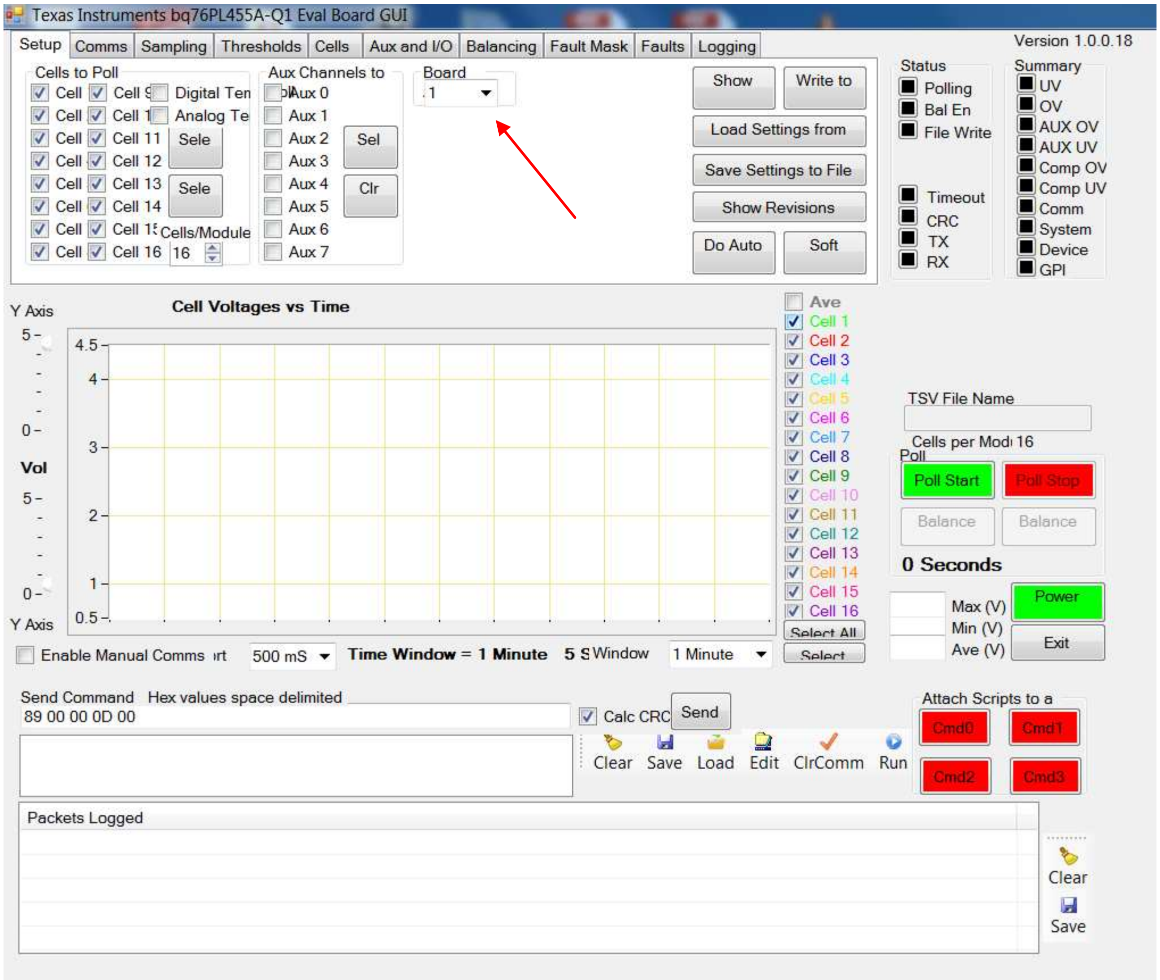
After setting up the boards, open the bq76PL455A EVM GUI. After selecting the appropriate COM port, a dialog box confirming that two bq76PL455A devices were detected will appear. Figure 3 shows this dialog box.



Auto addressing finished successfully.
Total Board(s) in network = 2
Top of Stack address = 1.

Figure 3. bq76PL455A GUI Detecting Two Board Stack

To communicate with the bq76PL455A that is monitoring the cells, board one should be selected. This selection will tell the GUI to communicate to the second board in the stack by translating the UART commands into the proprietary daisy-chain protocol. Figure 4 demonstrates selecting board address one.



Board 1

Cells/Module 16

Cells per Modi 16

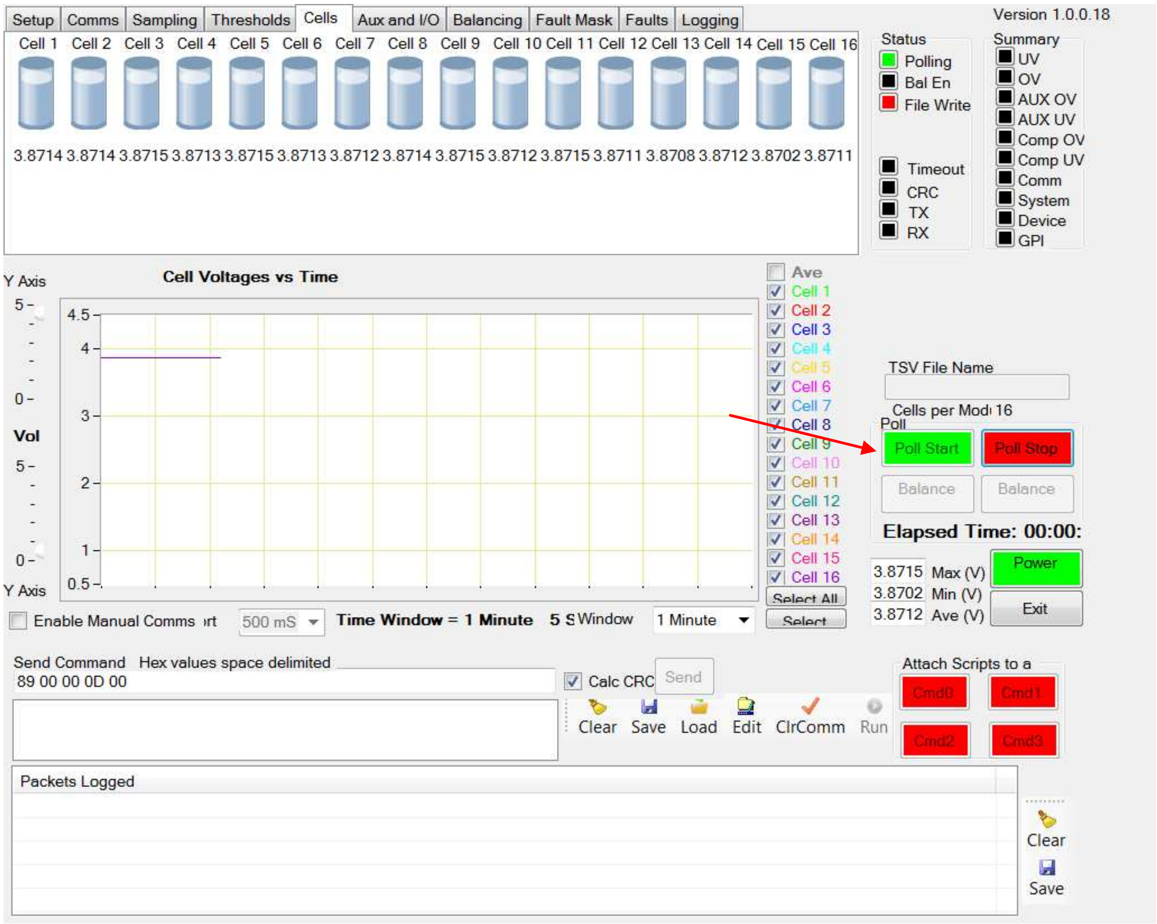
☐ Enable Manual Comms 500 mS Time Window = 1 Minute 5 S Window 1 Minute

Send Command Hex values space delimited: 89 00 00 0D 00

☑ Calc CRC

Figure 4. Addressing Top of the Stack Through the Bridge

Next move to the *Cell* tab, and click the *Poll Start* button, which is demonstrated in Figure 5. If the correct board is addressed and the resistor ladder is set up so 1/16th of the voltage is detected at each branch, the board should report those cell voltages back to the GUI through the communication bridge .



Version 1.0.0.18

Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8	Cell 9	Cell 10	Cell 11	Cell 12	Cell 13	Cell 14	Cell 15	Cell 16
3.8714	3.8714	3.8715	3.8713	3.8715	3.8713	3.8712	3.8714	3.8715	3.8712	3.8715	3.8711	3.8708	3.8712	3.8702	3.8711

TSV File Name

Cells per Modı 16

Elapsed Time: 00:00:

3.8715 Max (V)
3.8702 Min (V)
3.8712 Ave (V)

☐ Enable Manual Comms ırt 500 mS

Time Window = 1 Minute 5 S Window 1 Minute

Send Command Hex values space delimited
89 00 00 0D 00

☑ Calc CRC

Figure 5. Reporting Cell Voltage to GUI Through Bridge

The bq76PL455A-Q1 communication bridge was developed to be a BoosterPack™, so firmware can be developed on an automotive-grade MCU, such as the TMS570 or C2000, once a project is mature enough.

3.2 Isolated-Voltage Measurement

To set up the isolated-voltage measurement, the bq76PL455A-Q1 communication bridge board must be connected to the GUI through a USB-serial connection. The voltage to be measured must also be connected to header J3, as seen in Figure 6.

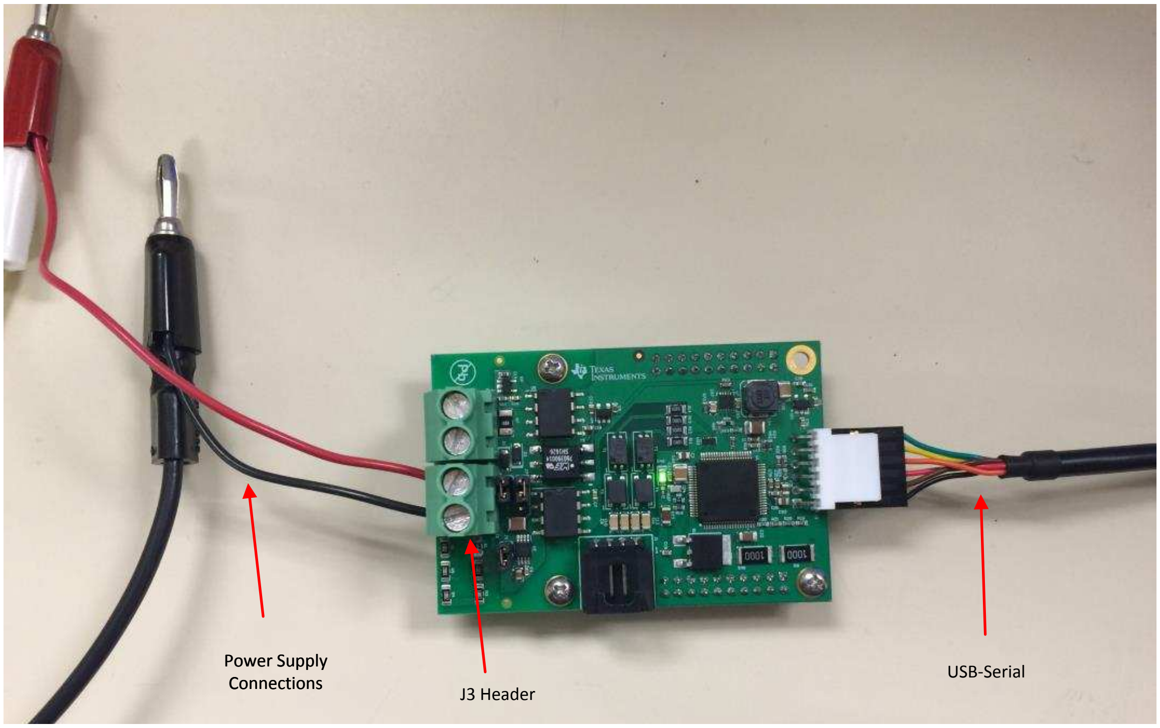
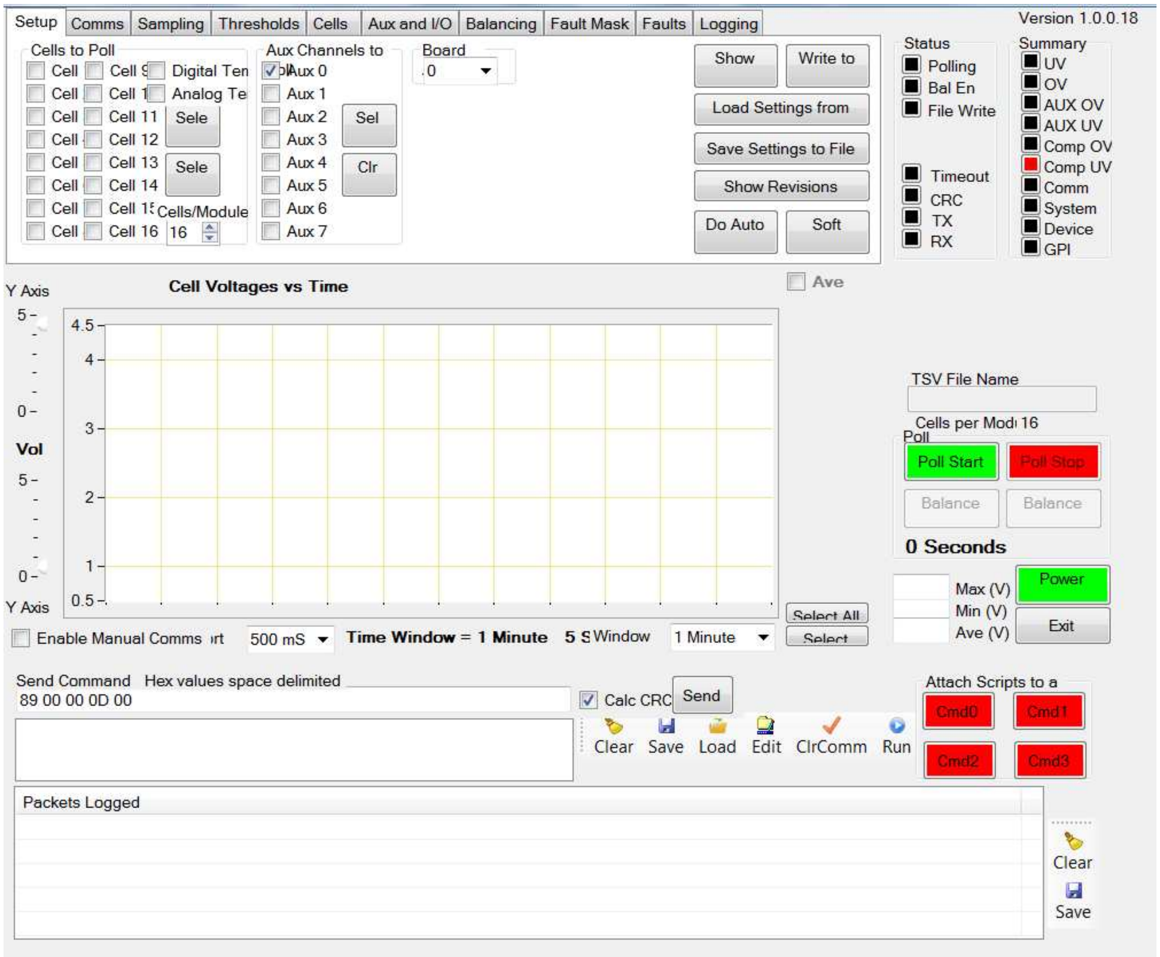


Figure 6. Isolated-Voltage Measurement Setup

Once the board has been set up, the bq76PL455A GUI must be set up to read the voltage reported by the AMC1200B isolated op-amp. To do so, the GUI must be opened and *Board 0* selected if there are more boards than just the communication bridge in the stack. Because the communication bridge is isolated from the cells and powered by a 12-V boost converter, all cell measurements can be deselected, and AUX0 should be enabled. Figure 7 shows the proper setup of the GUI.



☑ Aux 0

Board 0

Cells/Module 16

500 mS

Window 1 Minute

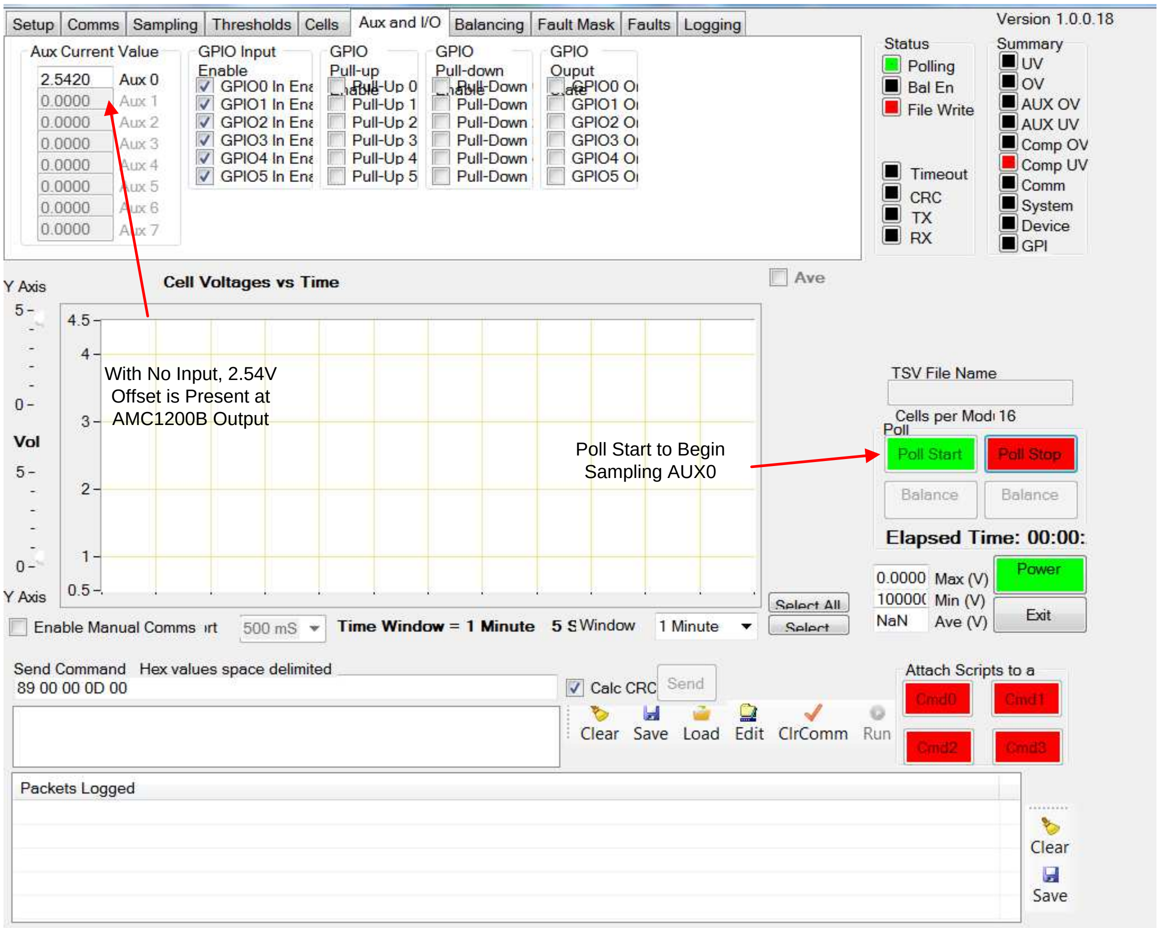
☐ Enable Manual Comms

Send Command: 89 00 00 0D 00

☑ Calc CRC

Figure 7. GUI Setup for Isolated Voltage Measurement

Moving to the *Aux and I/O* tab and then clicking the *Poll Start* button will cause the bq76PL455A-Q1 to begin sampling the AUX0 pin, which is connected to the output of an AMC1200B isolated op-amp. The AMC1200B has a 2.54-V offset at the output, which AUX0 should measure with no input attached to J3, as shown in Figure 8.

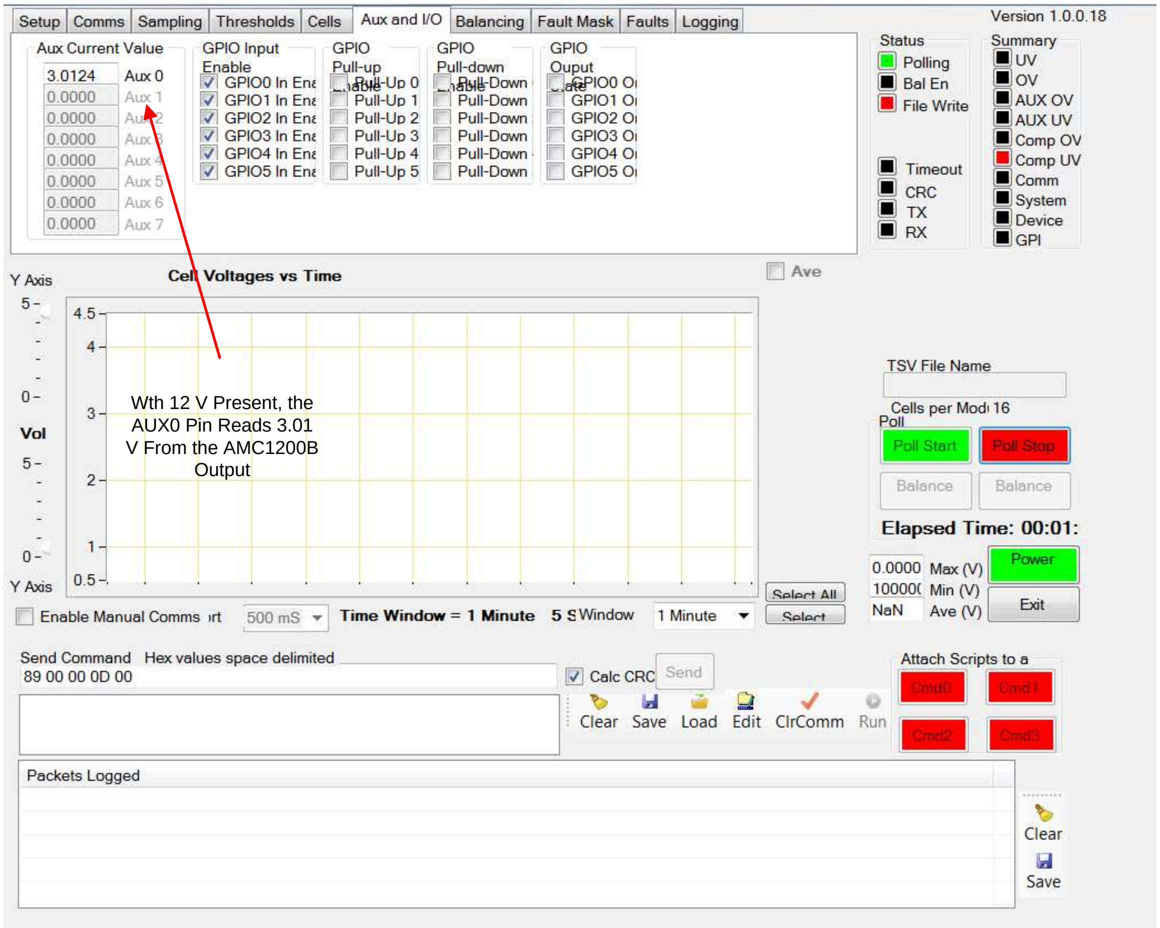


With No Input, 2.54V Offset is Present at AMC1200B Output

Poll Start to Begin Sampling AUX0

Figure 8. AUX0 Reading With No Input Voltage

Connecting the GW INSTEK DC power supply to J3 will allow the user to apply a voltage to the voltage divider present at the input of the AMC1200B. TIDA-01400 has been set up to measure a separate 12-V battery used for active cell balancing. To ensure that the 250-mV input voltage limit of the AMC1200B is not violated, the input resistor network has been set up with 50-kΩ of series resistance and a 499-Ω shunt resistance. Figure 9 shows that AUX0 measures roughly 3 V with 12 V present.



Version 1.0.0.18

Aux Current Value

3.0124	Aux 0
0.0000	Aux 1
0.0000	Aux 2
0.0000	Aux 3
0.0000	Aux 4
0.0000	Aux 5
0.0000	Aux 6
0.0000	Aux 7

☑ GPIO0 In Ena ☐ Pull-Up 0 ☐ Pull-Down ☐ GPIO0 O
☑ GPIO1 In Ena ☐ Pull-Up 1 ☐ Pull-Down ☐ GPIO1 O
☑ GPIO2 In Ena ☐ Pull-Up 2 ☐ Pull-Down ☐ GPIO2 O
☑ GPIO3 In Ena ☐ Pull-Up 3 ☐ Pull-Down ☐ GPIO3 O
☑ GPIO4 In Ena ☐ Pull-Up 4 ☐ Pull-Down ☐ GPIO4 O
☑ GPIO5 In Ena ☐ Pull-Up 5 ☐ Pull-Down ☐ GPIO5 O

Wth 12 V Present, the AUX0 Pin Reads 3.01 V From the AMC1200B Output

Cells per Modı 16

Elapsed Time: 00:01:

0.0000 Max (V)
10000(Min (V)
NaN Ave (V)

☐ Enable Manual Comms ɪrt 500 mS

Time Window = 1 Minute 5 S Window 1 Minute

Send Command Hex values space delimited

89 00 00 0D 00

☑ Calc CRC

Figure 9. AUX0 Reading With 12-V Input

If a larger voltage, such as the pack voltage, is going to be measured the resistor divider should be scaled accordingly. Failure to scale the resistor divider can result in a voltage larger than 3.3 V at the output of the AMC1200B, which can result in damage to some MCUs.

3.3 Isolated Current-Sense Measurement

TIDA-01400 also offers a second AMC1200B for dedicated current-sense measurements. To test the current-sense measurement, an electronic load was used to draw current from the GW INSTEK DC power supply with an onboard 10-mΩ shunt resistor connected in series with the load. Figure 10 shows the board connections.

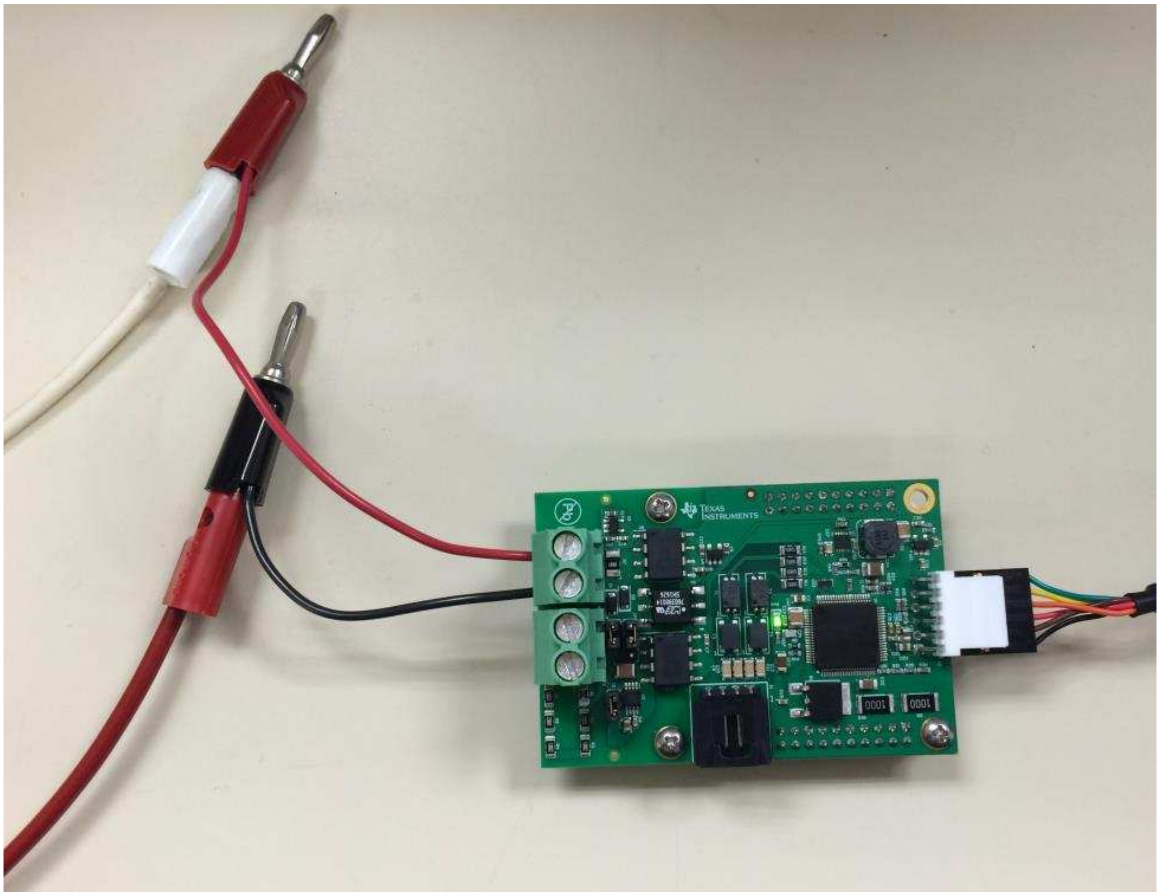
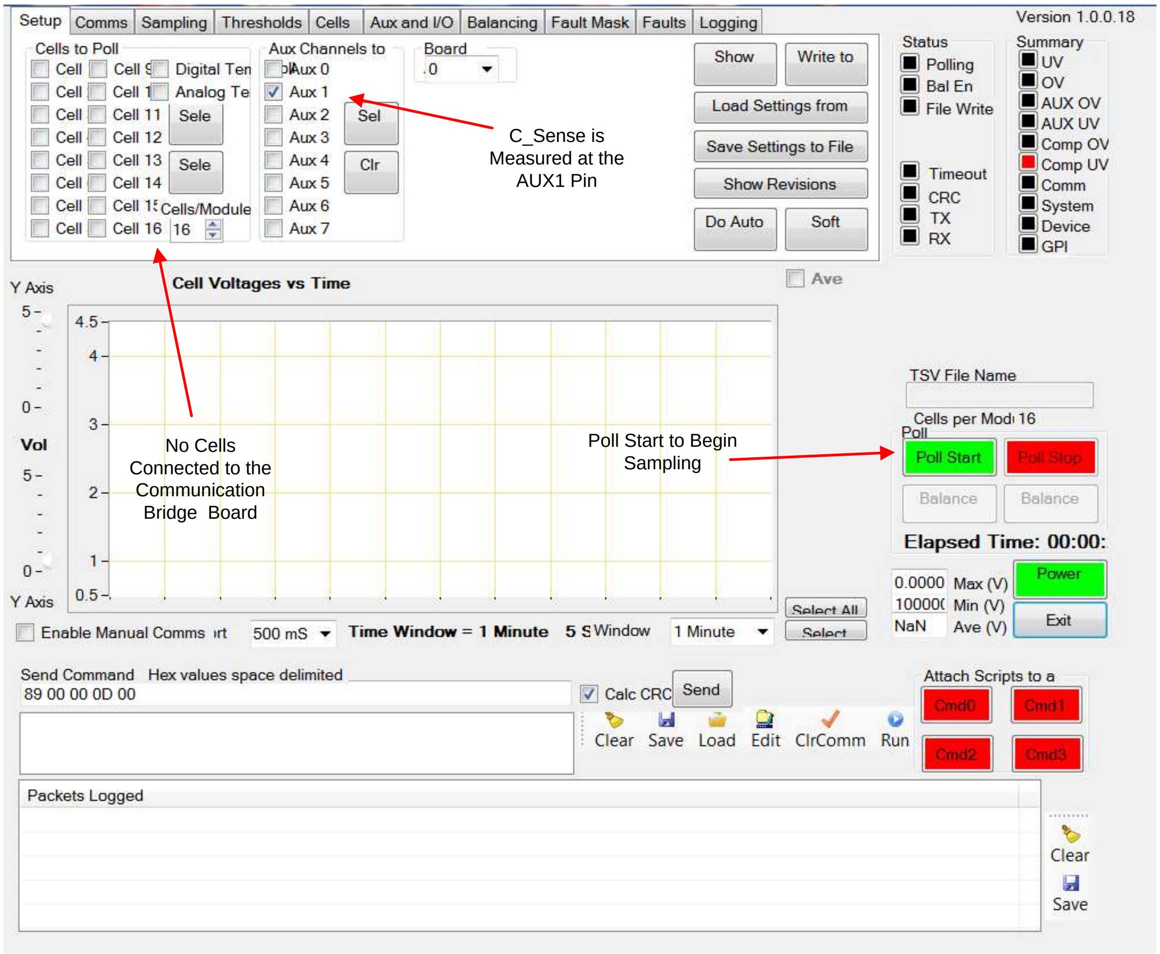


Figure 10. Isolated Current-Sense Measurement Setup

To configure the GUI, deselect all of the cell measurements and enable the AUX1 measurement. Move to the *Aux and I/O* tab, and click the *Poll Start* button to enable sampling of the AUX1 pin. With no current passing through the sense resistor, 2.54 V should be present at the AUX1 pin.



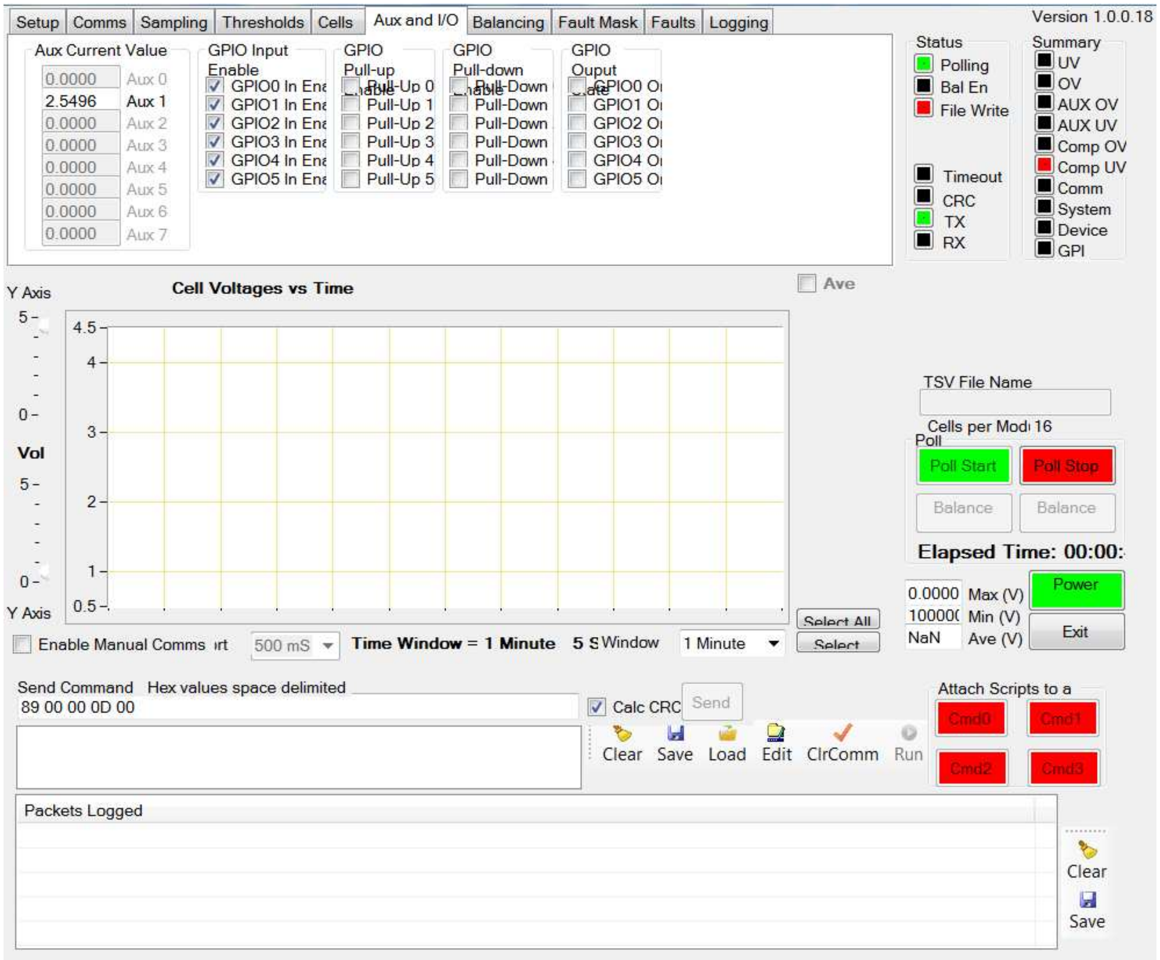
C_Sense is Measured at the AUX1 Pin

No Cells Connected to the Communication Bridge Board

Poll Start to Begin Sampling

Figure 11. AUX1 Reading With No Current Passing Through a 10-mΩ Sense Resistor

Increasing the current drawn by the electronic load will increase the output voltage of the AMC1200B. Increasing the current to 2 A resulted in the AUX1 voltage to increase to 2.62 V with a 10-mΩ resistor, as seen in Figure 12.



Version 1.0.0.18

Aux Current Value	
0.0000	Aux 0
2.5496	Aux 1
0.0000	Aux 2
0.0000	Aux 3
0.0000	Aux 4
0.0000	Aux 5
0.0000	Aux 6
0.0000	Aux 7

Cells per Modı 16

Elapsed Time: 00:00:

0.0000 Max (V)
100000(Min (V)
NaN Ave (V)

500 mS
Time Window = 1 Minute
1 Minute

Send Command Hex values space delimited
89 00 00 0D 00
☑ Calc CRC

Figure 12. AUX1 Reading With 2 A Passing Through a 10-mΩ Resistor

The TIDA-01400 PCB was not laid out with high currents in mind, so there is insufficient copper to measure true pack voltages. It is recommended that the current being measured be less than 3 A if using the onboard shunt resistor. If larger currents are desired, it is suggested to remove the shunt resistor R7 and use an external shunt with parallel connections to header J4. When using the isolated current-sense measurement, it is important to size the shunt resistor so that the output of the AMC1200B remains less than 3.3 V; otherwise, damage to the MCU can occur.

Table 2 summarizes some common shunt-resistor values and maximum currents without damaging a 3.3-V MCU.

Table 2. Common Shunt Resisters and Maximum Current

EXTERNAL/ONBOARD	RESISTANCE	MAXIMUM CURRENT
Onboard	10 mΩ	18.75 A
Onboard	50 mΩ	3.75 A
Onboard'	100 mΩ	1.875 A
Onboard	500 mΩ	0.375 A
External	100 µΩ	1875 A
External	200 µΩ	937.5 A
External	500 µΩ	375 A
External	1 mΩ	187.5 A

4 Design Files

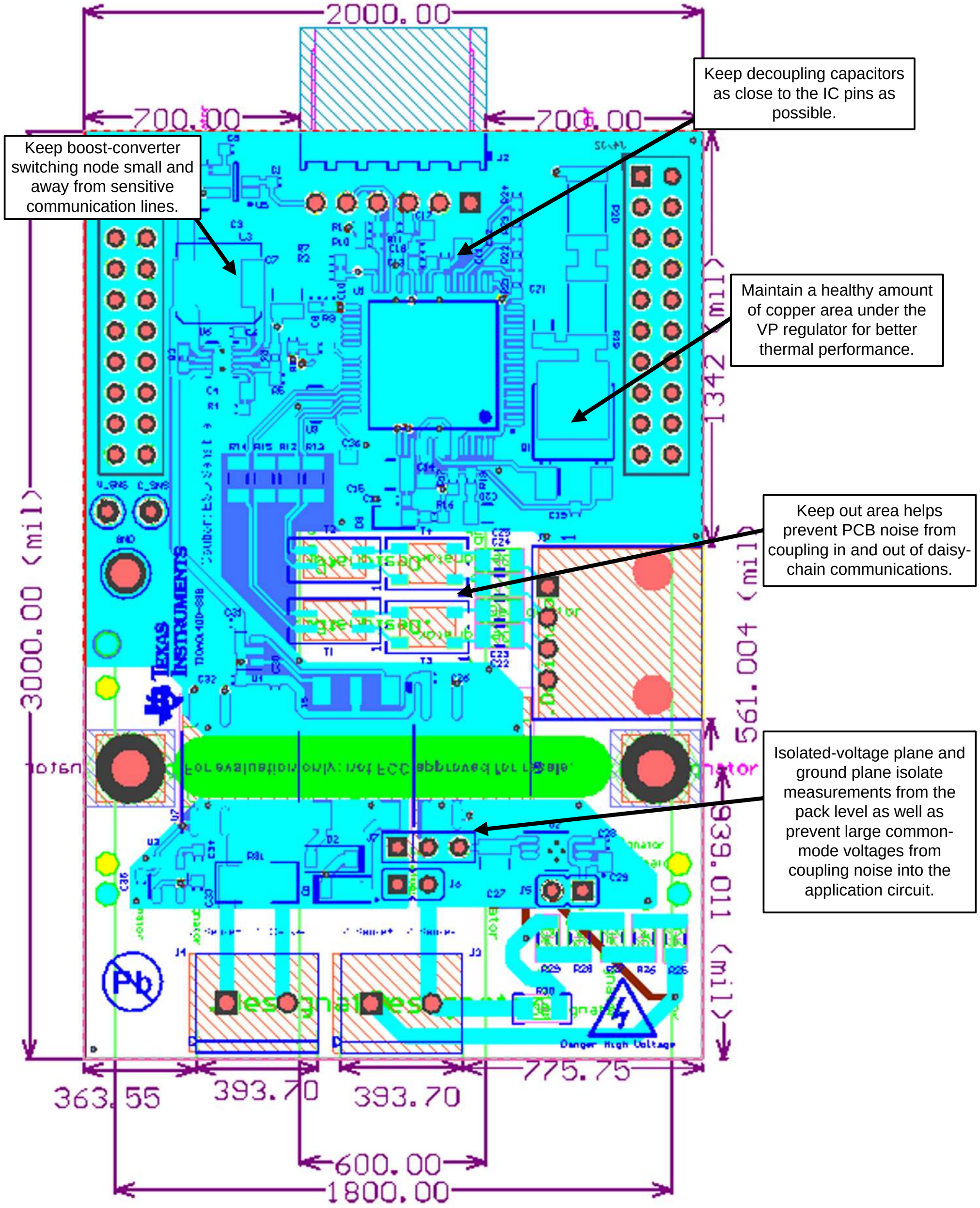
4.1 Schematics

To download the schematics, see the design files at TIDA-01400.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01400.

4.3 PCB Layout Recommendations



Keep boost-converter switching node small and away from sensitive communication lines.

Keep decoupling capacitors as close to the IC pins as possible.

Maintain a healthy amount of copper area under the VP regulator for better thermal performance.

Keep out area helps prevent PCB noise from coupling in and out of daisy-chain communications.

Isolated-voltage plane and ground plane isolate measurements from the pack level as well as prevent large common-mode voltages from coupling noise into the application circuit.

Figure 13. TIDA-01400 Layout Recommendations

4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01400.

4.4 Altium Project

To download the Altium project files, see the design files at TIDA-01400.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01400.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01400.

5 Related Documentation

1. Texas Instruments, *bq76PL455A 16-Cell Industrial Integrated Battery Monitor with Passive Cell Balancing*, bq76PL455A Datasheet (SLUSCL0)
2. Texas Instruments, *bq76PL455EVM and GUI User Guide*, bq76PL455A User's Guide (SLUUBA7)
3. Texas Instruments, *SN6501 Transformer Drive for Isolated Supplies*, SN6501 Datasheet (SLLSEA0)
4. Texas Instruments, *TPS61093 Low-Input Boost Converter With Integrated Power Diode and Input/Output Isolation*, TPS61093 Datasheet (SLVS992)
5. Texas Instruments, *AMC1200/B Fully-Differential Isolation Amplifier*, AMC1200, AMC1200B Datasheet (SBAS542)
6. Texas Instruments, *bq76PL455A-Q1 Design Recommendations*, Application Report (SLUA791)

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