

## Design Guide: TIDA-01042

# Modular Battery Tester Reference Design for 50-A, 100-A, and 200-A Applications



### Description

This reference design provides a modular battery test solution allowing users to have the flexibility to test batteries at different current levels with one design. This design leverages the TIDA-01041 reference design by providing two 100-A battery testers that can work independently or be connected in parallel to increase the maximum current output from 100 A to 200 A. This design guide describes the design theory, part selection, and optimization of this solution.

### Resources

<a href="#">TIDA-01042</a>	Design Folder
<a href="#">LM5170-Q1</a>	Product Folder
<a href="#">INA828</a>	Product Folder
<a href="#">DAC80004</a>	Product Folder
<a href="#">ADS131A04</a>	Product Folder
<a href="#">TIDA-01041</a>	Design Folder

### Features

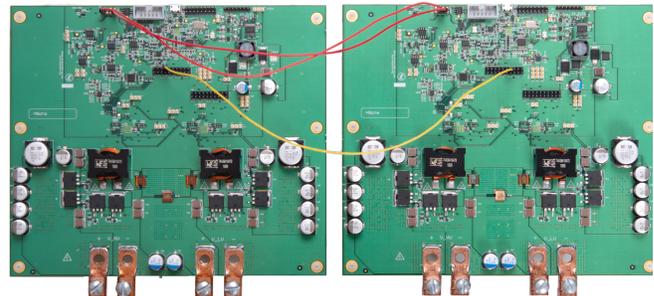
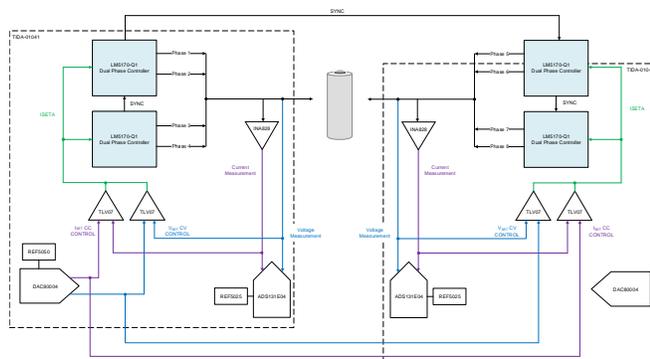
- Modular design capable of 200 A maximum charge and discharge
- High-precision calibration control achieving 0.02% full-scale current control accuracy and 0.02% voltage control accuracy
- Input voltage (bus) from 8 V–16 V and output load (battery) from 0 V–4.2 V (5 V maximum)
- Up to four LM51700-Q1 multiphase bidirectional buck, boost integrated controllers and drivers for charging and discharging

### Applications

- [Battery test equipment](#)



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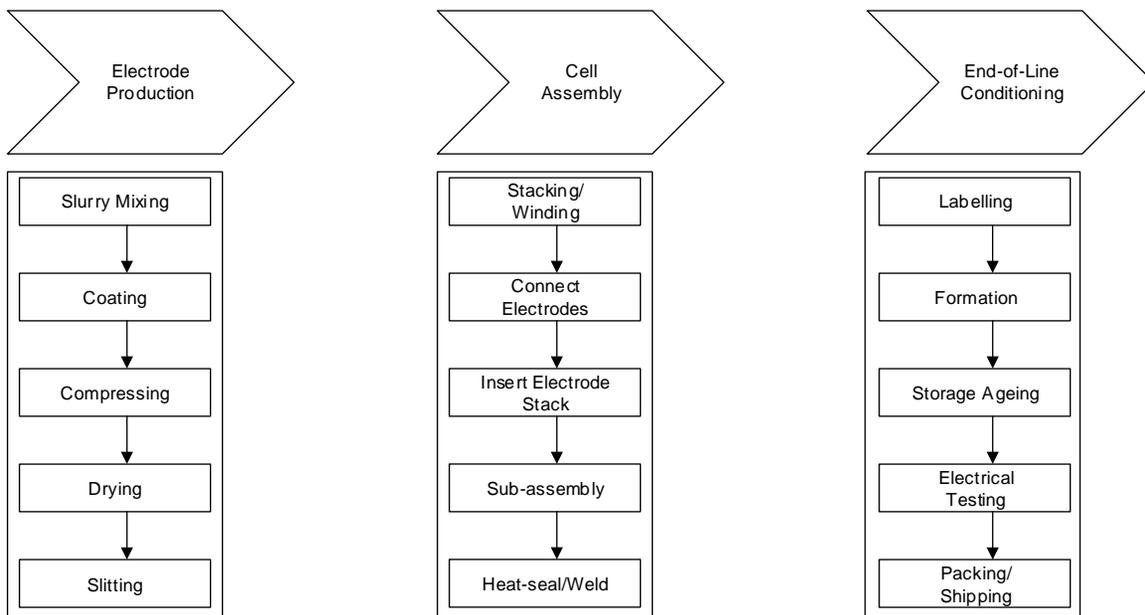
## 1 System Description

The battery tester equipment contains a wide variety of battery test and formation equipment including high-performance battery manufacturing equipment and laboratory test instruments. The battery tester features circuit control, data acquisition, battery simulation, and manufacturing automation tools that are appropriate for all battery chemistries and applications.

### 1.1 Li-Ion Formation

Figure 1 shows the manufacturing process for the Li-Ion battery, which is a popular, rechargeable battery chemistry. Battery test falls into the final step in the manufacturing process.

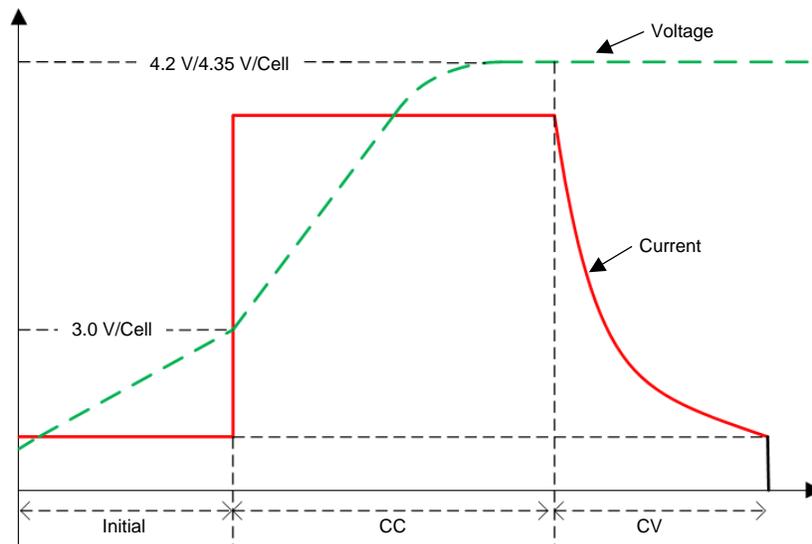
Figure 1. Simplified Li-Ion Battery Manufacturing Process



### 1.2 Li-Ion Battery Formation Profile

Figure 2 shows the typical Li-Ion battery formation profile, detailing the phases of the initial charging and formation of a battery which directly affects its quality and capacity for the entirety of the life span of the battery. In the first phase, labeled "Initial," a small initial charge of around 10% of the full-charge current is applied. This is done to prevent the cell from overheating and is done until the battery is able to accept the full current of the constant-current phase. During the constant-current, or "CC" phase, the battery is typically charged at 1 A or less until the battery voltage reaches 4.1 V or 4.2 V (depending on electrochemistry) where it then transitions to the constant voltage, or "CV" phase. For detailed test results on the transformation between CC and CV, see [Section 3.1.4.3](#).

Figure 2. Regular Li-Ion Battery Formation Profile



For more information on Li-Ion battery formation, see the [TIDA-01040 Battery Tester Reference Design for High Current Applications](#) design guide.

### 1.3 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
$V_{\text{battery\_min}}$	0 V	Battery-port minimum operating voltage
$V_{\text{battery\_nominal}}$	4.2 V	Battery-port normal operating voltage
$V_{\text{battery\_max}}$	5 V	Battery-port maximum operating voltage
$V_{\text{bus\_min}}$	8 V	Bus-port minimum operating voltage
$V_{\text{bus\_nominal}}$	12 V	Bus-port normal operating voltage
$V_{\text{bus\_max}}$	16 V	Bus-port normal operating voltage
$F_{\text{SW}}$	100 kHz	Switching frequency
$I_{\text{ph\_max}}$	25 A	Maximum DC current per phase, bidirectional
$I_{\text{Total\_max}}$	200 A	Total maximum DC current at battery-port
Current control accuracy	0.02%	Full-scale current control accuracy for charge and discharge
Voltage control accuracy	0.02%	Full-scale current control accuracy for charge and discharge

For detailed test results on current control accuracy, see [Section 3.1.4.1](#).

For detailed test results on voltage control accuracy, see [Section 3.1.4.2](#).

## 2 System Overview

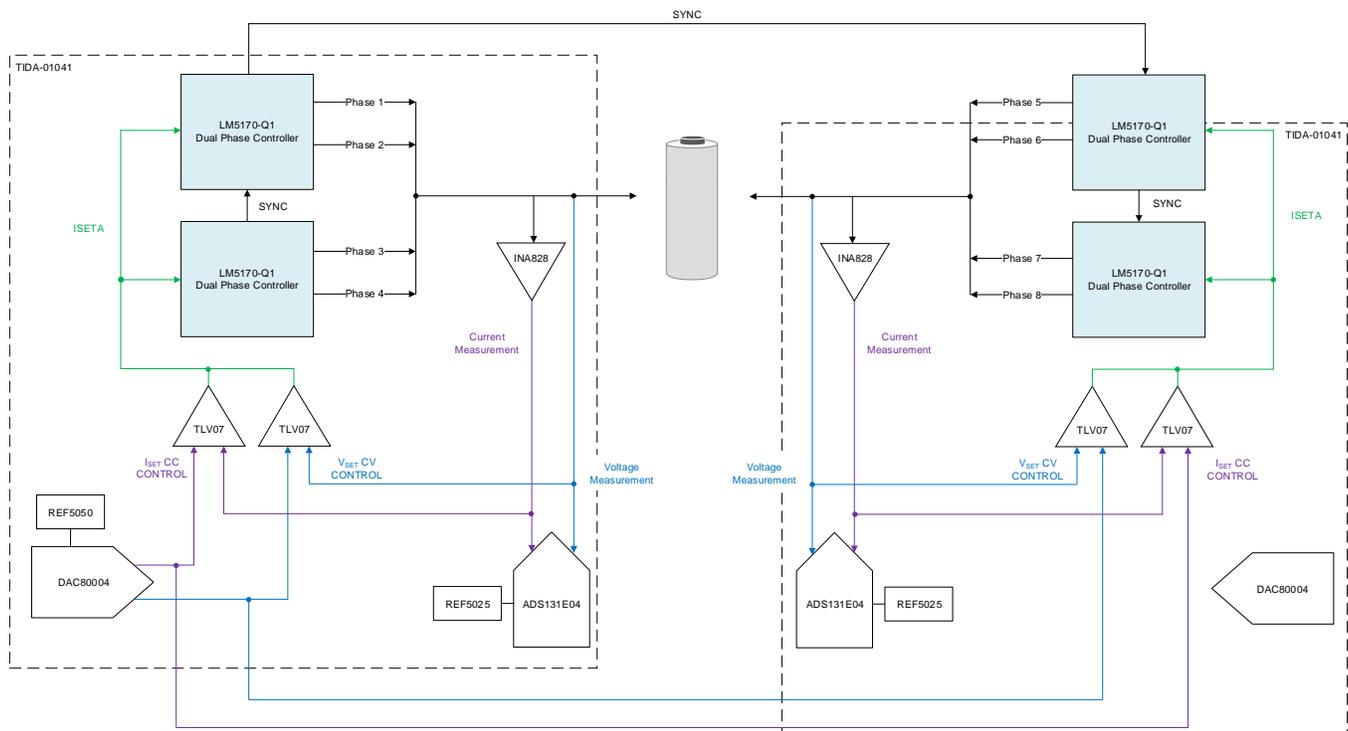
This design encompasses the battery test cell unit as well as the analog front end of the battery test and formation equipment. In the following subsections, the system and its design theory are detailed.

### 2.1 Block Diagram

In this reference design, the LM5170-Q1 device is a multiphase, buck-boost bidirectional controller that is able to charge or discharge the load at up to 25 A per channel depending on the "DIR" setting. Four LM5170-Q1 devices can charge and discharge up to 200 A using eight 25-A phases. The DAC80004 device is a 16-bit DAC that sets the reference current and reference voltage for either CC or CV mode using the USB2ANY interface. The high-precision INA828 current sense amplifier measures the current charging or discharging the load. That measurement is compared with the reference control signal using the TLV07 device. The same is done with the load voltage. The ADS131A04 device is a 24-bit delta-sigma ADC used to monitor the current and voltage of the load. A TIVA processor is used to allow communication between the ADS131A04 and the PC for this reference design. When the system is set to CC or CV mode, the multiphase controllers output the signified voltage or current to the load. The system monitors and controls the output at the load to ensure precision while the user can monitor the results through the acquired data.

This reference design uses two TIDA-01041 boards. Both boards can work independently if the desired battery test application is for a maximum 100 A. For 200-A applications, the TIDA-01042 uses both TIDA-01041 boards to achieve that level of current. To accomplish this, the TIDA-01041 boards are connected in two ways: The synchronization pins on the LM5170-Q1 devices and the voltage and current references from the DAC80004. The board acting as the master will set the voltage and current reference for both boards by shorting the reference lines of each board together.

**Figure 3. TIDA-01042 Block Diagram**

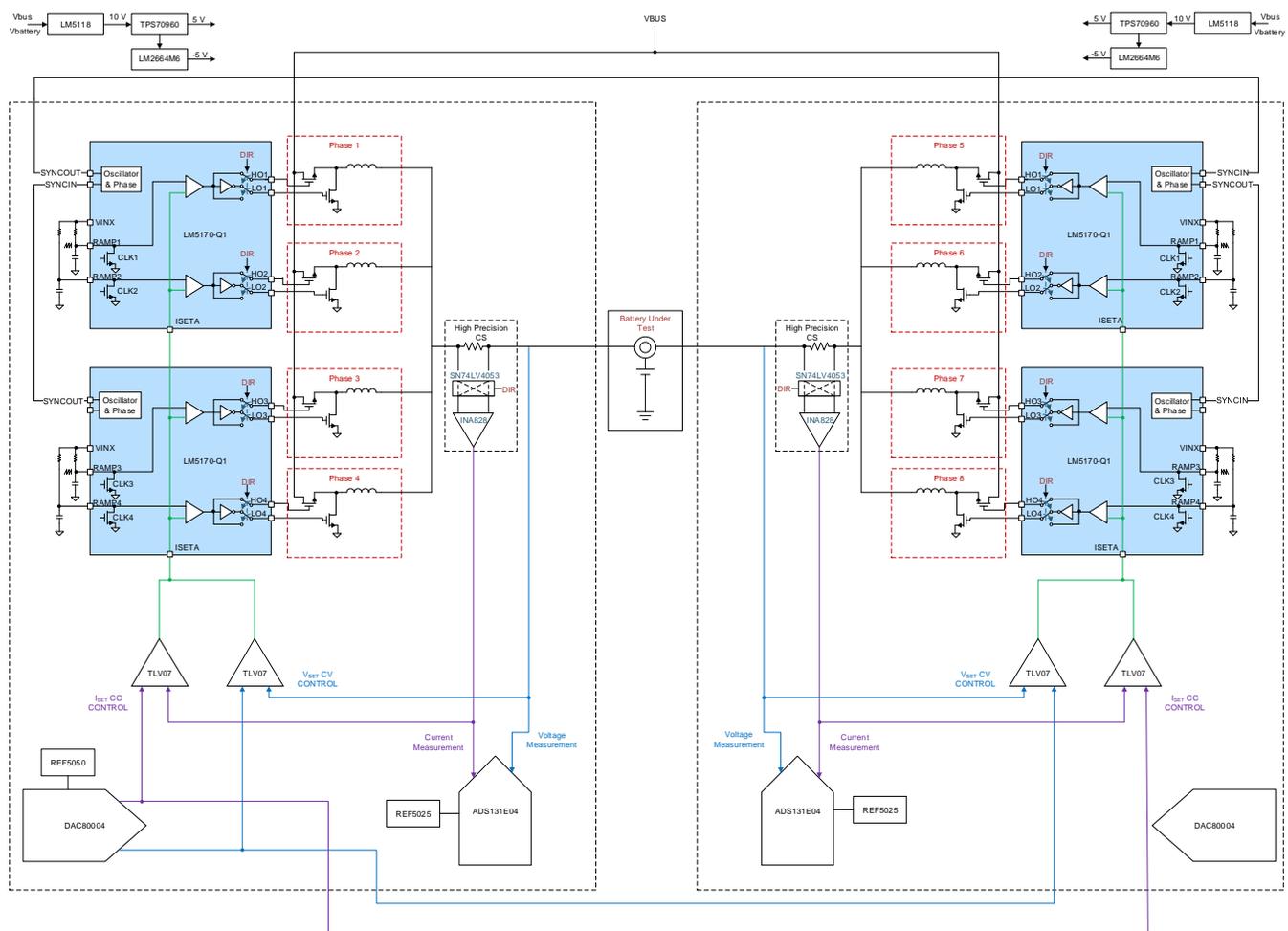


## 2.2 Design Considerations

This reference design aims to solve two design challenges for battery test equipment. First, this design must show its modular capability. This will demonstrate the ability to use one design for different and multiple battery test applications. Second, this design must test at charge and discharge rates of up to 200-A continuous for larger capacity batteries.

To solve these design challenges, this reference design uses two TIDA-01041 boards to demonstrate both the modular and current capabilities. The TIDA-01041 is a 100-A battery test reference design. This design solves both design challenges by synchronizing the multiphase configuration on each board for eight total phases to achieve 200 A, and by two TIDA-01041 boards that can operate independently or together to achieve a modular design.

**Figure 4. Modular TIDA-01042 Design**

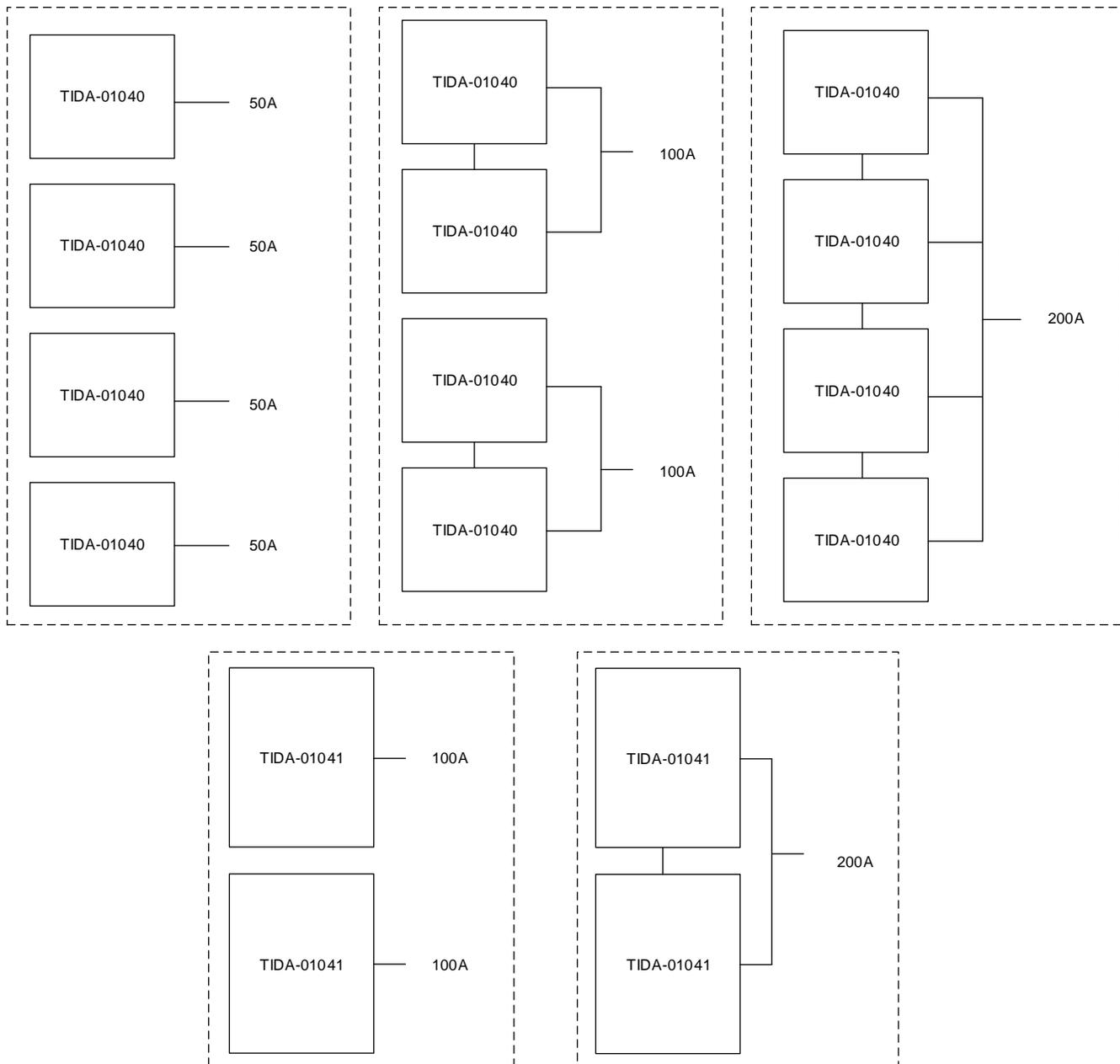


### 2.2.1 Modular Design

Battery testers are currently designed based on their current level application. Low current battery testers use converters to drive the battery current, usually up to 6 A. Medium current battery testers use a single-phase controller to achieve currents up to 20 A. High current applications use multiphase controllers to achieve currents higher than 20 A. With the increase in current, especially in the high-current applications, the equipment becomes more expensive. Higher current levels means larger and more expensive components that can handle high currents.

Standard battery test equipment for high-current applications is designed for their specific current level. This reference design provides the user with the ability to use a modular level design to satisfy the multiple levels of high current battery tester needs. This design creates the option of using multiple, lower current battery tester channels connected in parallel for higher current applications allowing the user to be more flexible and save on cost. Using multiple TIDA-01040 or TIDA-01041 reference designs in parallel, the user is able to achieve up to 200-A maximum current and have the option of having multiple 100-A or 50-A outputs if the 200 A maximum is not desired. [Figure 5](#) demonstrates the flexibility of the TIDA-01042 reference design.

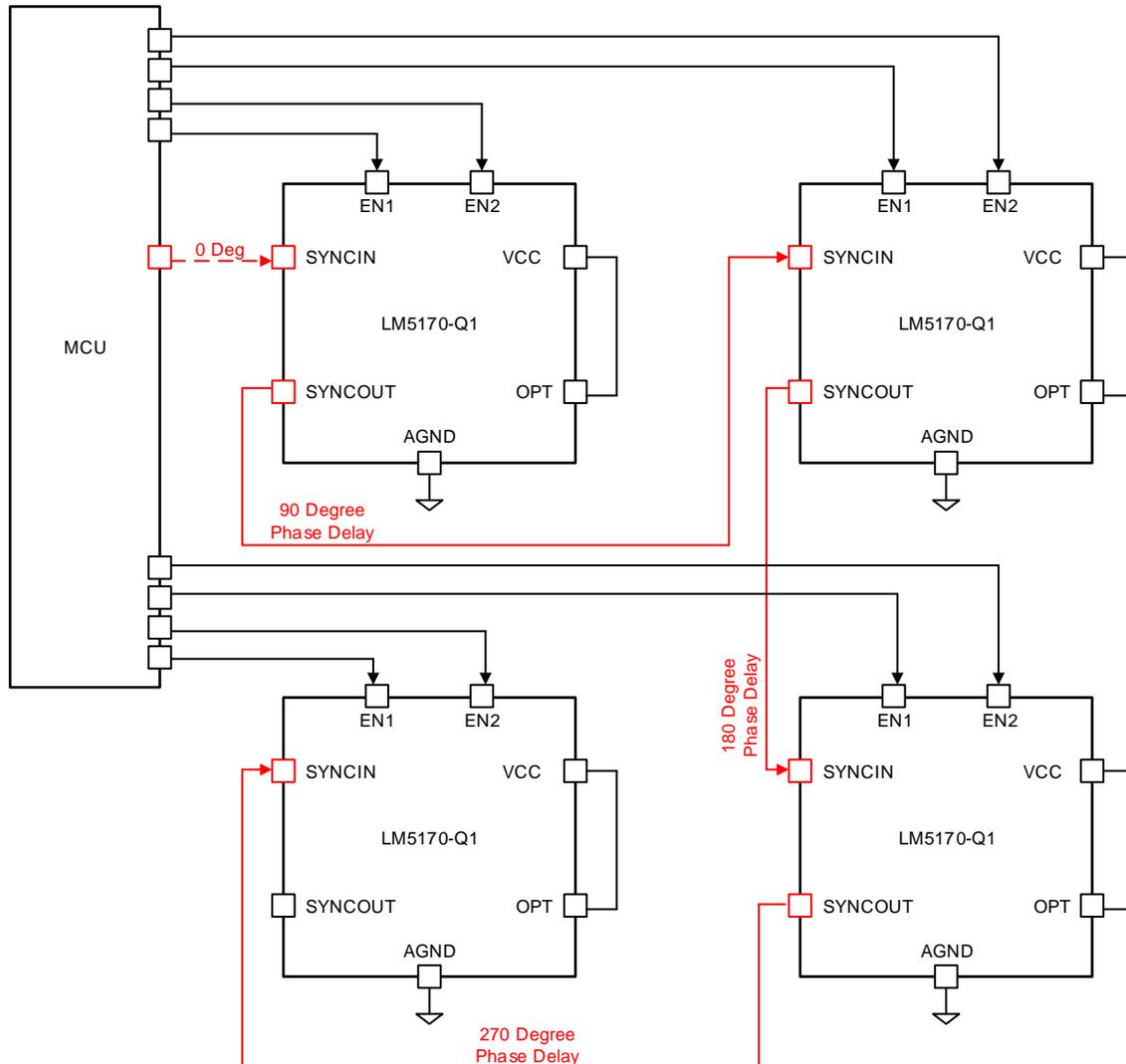
**Figure 5. TIDA-01042 Current Application Flexibility**



This design has benefits for different applications. Although the maximum current is 200 A, it is able to provide the current for four different 50-A applications or two different 100-A applications, providing the user the ability to apply this design to more and different current levels.

To accomplish the modular, 200-A design, this reference design relies on the use on the LM5170-Q1 device, which is a bidirectional, two channel, multiphase buck-boost controller. Each chip is able to output two 25-A phases. Each TIDA-01041 board uses two LM5170-Q1 devices to produce four phases and 100 A. Figure 6 shows the configuration for the LM5170-Q1 at eight phases. The four LM5170-Q1 devices are connected through the SYNCIN and SYNCOUT pins. This connection can be made through the jumper pins from board to board, allowing for the modular and flexible design. It is important the OPT pin is set to high on both boards so that the SYNC pins allow for 90 degrees phase shift.

Figure 6. Eight Phases 90° Interleaving Configuration



The multiphase design is what enables this reference design to be flexible while reaching 200 A. Multiphase controllers have many benefits when working with high currents. The ability to separate the 200 A into eight phases allows for lower cost inductors, power and heat distribution within the system, load transient performance, and lower output current and voltage ripple. To learn more about the benefits of the multiphase configuration for battery test and formation, see the [Battery Tester Reference Design for Multi-phase High-Precision 0.5- to 100-A Battery Formation Design Guide](#) (TIDA-01041).

## 2.2.2 Constant Current Control Design

This section details the process for designing the control system that handles constant current flow for battery charging and discharging. For the modular TIDA-01042 design, it is important to control and calibrate each board separately to ensure the high precision. The reference for both boards is set by the master board, but each control system operates independently from each other. See [Section 3.1.4.1](#) for more information on accuracy test results for this system. For information on part selection and the simulation tool used for this design, see the [Battery Tester Reference Design for High Current Applications Design Guide](#) (TIDA-01040).

The INA828 device, a precision instrumentation amplifier, provides a low-noise differential signal that dictates current regulation. The TIDA-01040 reference design uses the INA188 device as its instrumentation amplifier. There are two gain settings for the instrumentation amplifier: low current (0–50 A) and high current (50–100 A) as [Figure 7](#) shows.

Figure 7. INA828 Gain Settings

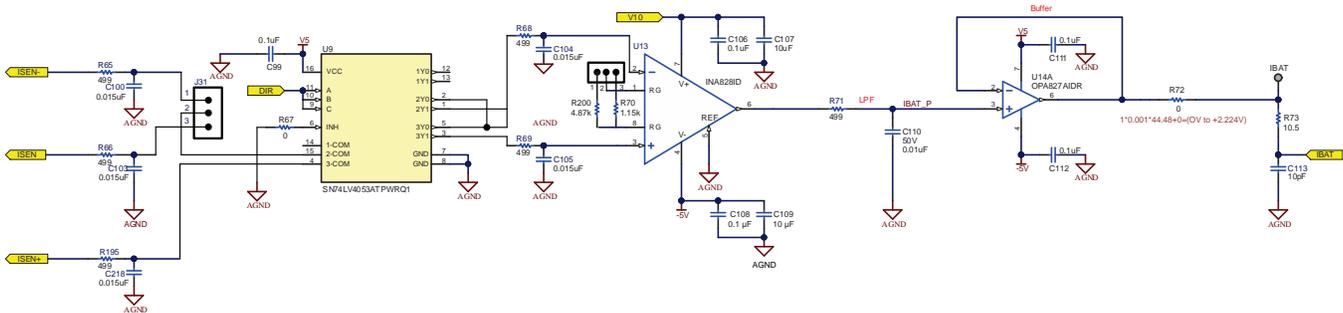
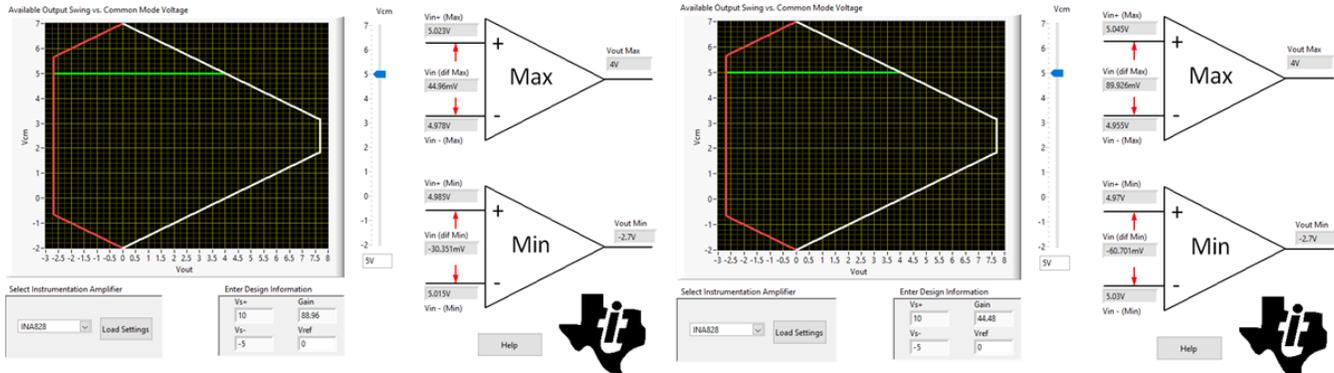


Figure 8. Vcm vs Vout Calculator for INA828 at Gain = 44.48 and 88.96



[Figure 8](#) highlights the calculation results of the INA828 input and output ranges for this reference design. In this case, the maximum common-mode voltage is the same as the maximum voltage on the battery side, so its maximum value is 5 V. For low current gain at 44.48, the input range for an INA828 device with power rails at 10 V and -5 V is -60.701 mV to 89.926 mV. For high current gain at 88.96, the calculation results show the input range from -30.351 mV to 44.96 mV. These ranges both fit within the current signal range ( $\pm 100 \text{ A} \times 0.5 \text{ m}\Omega = \pm 50 \text{ mV}$ ).

The CC control amplifier to which the INA828 provides feedback needs to meet high accuracy requirements or it will bottleneck the design. In this design, the CC control amplifier is the TLV07 device due to its input offset voltage. In the 200-A high-current application, worst-case, the input offset voltage on each board causes an error of  $112.5 \mu\text{V} / (100 \text{ A} \times 0.001 \times 21.57) \times 100\% = 0.005216\%$  on the control loop. The error is less than the 0.01% demanded accuracy, making the TLV07 device a suitable amplifier.

Further information on the TLV07 device and its control stability is found in the [Battery Tester Reference Design for High Current Applications Design Guide](#).

Figure 9 shows the CC control simulation schematic. To keep the system working in CC control mode, ISETA provides a DC voltage for D4 to conduct continuously. ISET1 and ISET2 capture the differential voltage across the current sense resistor, E1 is an ideal differential amplifier to output a single-ended signal, R16 and C19 create a low-pass filter, and X6 is the error amplifier used to calibrate the current signal to the reference signal.

Figure 9. Constant Current Control Simulation Schematic

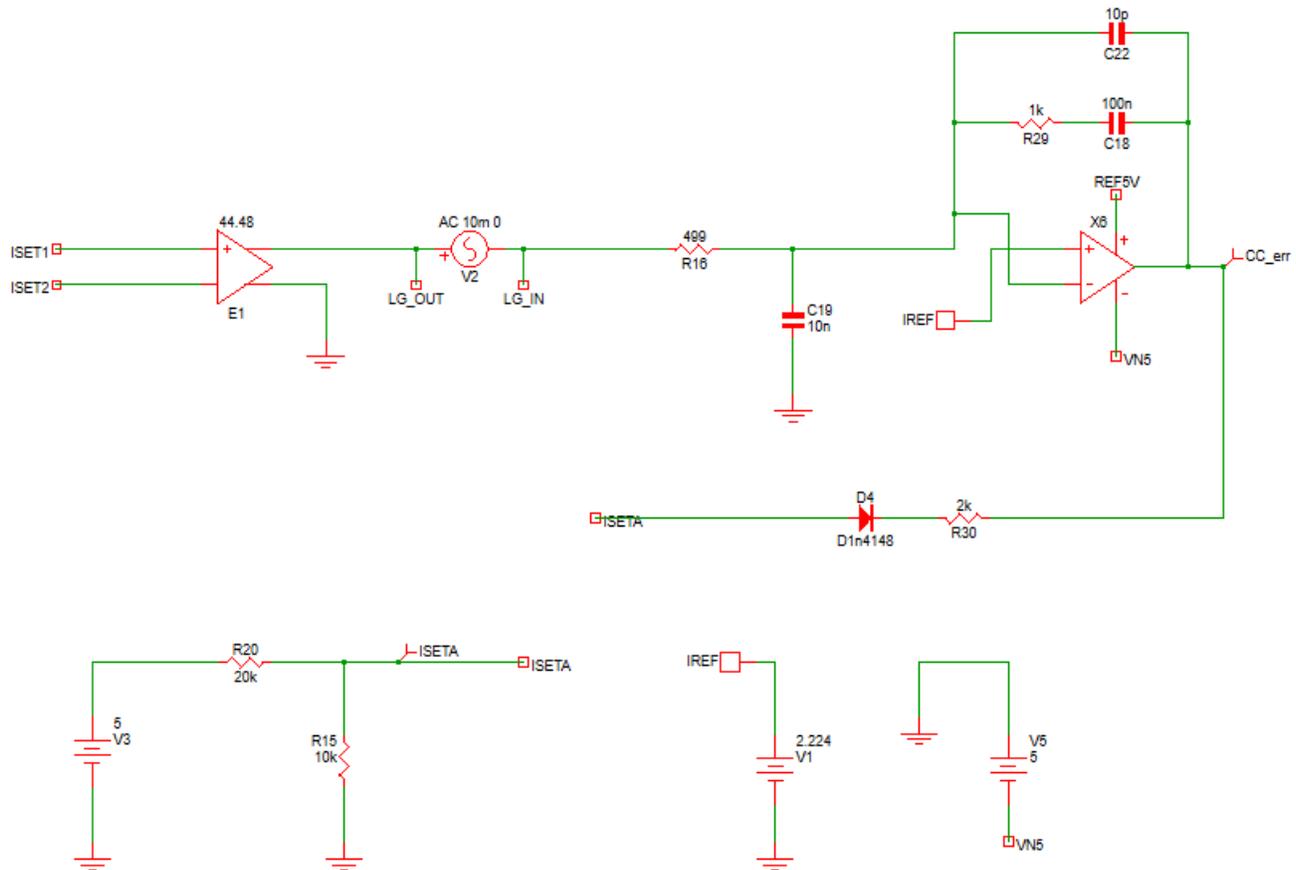
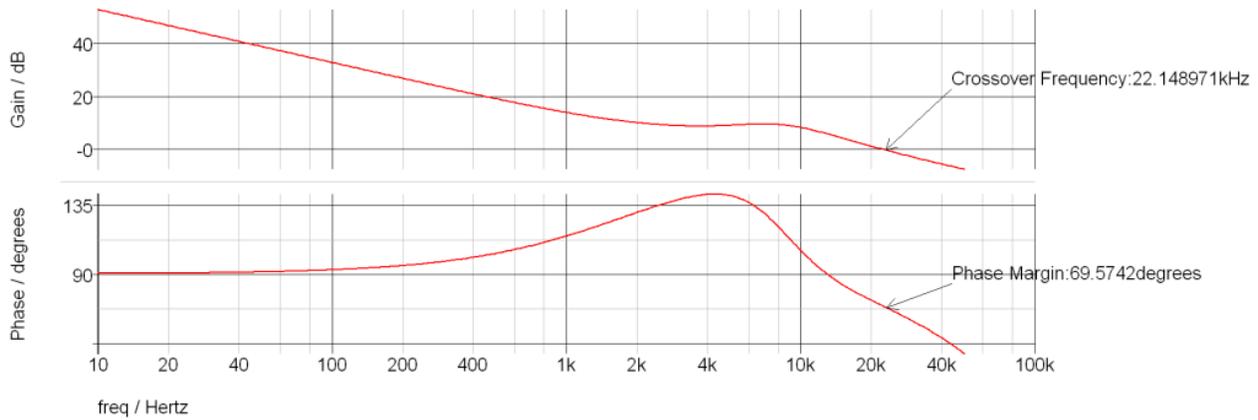


Figure 10 shows the small signal performance of this CC control subsystem. The gain crossover frequency is 22.15 kHz, and the phase margin is 69.57° which means this control circuit is stable and can provide enough bandwidth.

**Figure 10. CC Small Signal Simulation Results**



To generate a reference signal for current (DAC Channel D) control, commands are written to the 32-bit wide SPI shift register.

**Figure 11. DAC SPI Shift Register**

D31	D30	D29	D28	D27-D24	D23-D20	D19-D04	D03-D00
Don't Cares		R/W	Command Bits	Channel Address Bits	16/14/12-Bit DAC Data left aligned/Power Down Bits/Device Ready bit		Mode Bits

The bits that are altered for this design are the 'Channel Address bits' and the 'Data bits'. For example, inputting '03 31 C7 70' generates a reference voltage that causes the CC amplifier to regulate the charge and discharge rate of the battery to 25 A. D23–D20 is set to '03 3', selecting DAC output channel D and D19–D04 is set to '1 C7 7', which generates a decimal value that is converted into an analog signal based off the bit rate of the DAC and its voltage reference, calculated with Equation 1 and Equation 2.

$$D_{IN} = \frac{INAGAIN}{REFIN} \times R_{CS} \times \text{Ideal Current} \times 65536 \tag{1}$$

$$V_{OUT} = \frac{D_{IN}}{2^N} \times REFIN \tag{2}$$

More information on DAC80004 commands are found in the [DACx0004, Quad 16-, 14-, 12-bit, 1 LSB INL, Buffered, Voltage-Output Digital-to-Analog Converters Data Sheet](#).

### 2.2.3 Constant Voltage Control Design

For information on part selection and the simulation tool used for this design, see the [Battery Tester Reference Design for High Current Applications Design Guide](#) (TIDA-01040). There is no difference in constant voltage control design between the TIDA-01042, the TIDA-01041, and the TIDA-01040 designs. This is because the output voltage at the battery is still regulated to the same range (0 V to 4.2 V).

See [Section 3.1.4.2](#) for more information on accuracy test results for this system.

To generate a reference signal for voltage (DAC Channel A) control, commands are written to the 32-bit wide SPI shift register.

The bits that are altered for this design are the 'Channel Address bits' and the 'Data bits'. For example, inputting '03 0B 87 F0' generates a reference voltage that causes the CV amplifier to regulate the voltage of the battery to 4.2 V. D23–D20 is set to '03 0', selecting DAC output channel A and D19–D04 is set to 'B 87 F' which generates a decimal value that is converted into an analog signal based off the bit rate of the DAC and its voltage reference.

$$V_{\text{OUT}} = \frac{D_{\text{IN}}}{2^N} \times \text{REFIN} \quad (3)$$

$$D_{\text{IN}} = \frac{\text{INAGAIN}}{\text{REFIN}} \times \text{Ideal Voltage} \times 65536 \quad (4)$$

More information on DAC80004 commands is found in the [DACx0004, Quad 16-, 14-, 12-bit, 1 LSB INL, Buffered, Voltage-Output Digital-to-Analog Converters Data Sheet](#).

## 2.3 Highlighted Products

This section provides more detail on some of the core products that make up this design, explaining why they were selected and their potential alternatives.

### 2.3.1 LM5170-Q1 Multiphase Bidirectional Current Controller

The LM5170-Q1 is a dual-channel, bidirectional, multiphase controller that can support high current battery test applications up to 200 A using eight phases. It can regulate the average current flowing between the high and low voltage ports in the direction designated by the DIR input signal.

Other important features include:

- 5-A peak half-bridge gate drivers which enables the ability to drive high currents
- Programmable oscillator frequency which allows the user to choose the FET switching frequency
- MOSFET failure detect at start-up and circuit breaker control which provides security to the system

### 2.3.2 INA828 Precision Instrumentation Amplifier

The INA828 is a precision instrumentation amplifier with integrated resistor networks for sensing and data acquisition systems. This device measures and amplifies a differential voltage that represents output current which acts as feedback to regulate current. The INA828 device uses super-beta input transistors which allows for lower input bias current and current noise while also improving input offset voltage and offset drift.

Other important features include:

- Gain drift: 50 ppm/°C ( $G > 1$ ) which limits the variation of calibration at high temperatures
- Bandwidth: 2 MHz ( $G = 1$ ), 260 kHz ( $G = 100$ ) which allows for fast transients
- Inputs protected up to  $\pm 40$  V which provides protection to the device
- Power-supply rejection: 100 dB, minimum ( $G = 1$ ) which limits the noise observed on the signal chain

Alternatives:

The INA828 device offers lower noise than its predecessor, the INA188 device, but has a narrower bandwidth than the INA821. The INA828 device is pin-to-pin compatible with the SOIC package of the INA188 device.

**Table 2. INA828 Alternatives**

	<b>INA828</b>	<b>INA821</b>	<b>INA188</b>
Quiescent current	0.6 mA	0.6 mA	1.4 mA
Noise density at 1 kHz	7 nV/ $\sqrt{\text{Hz}}$	7 nV/ $\sqrt{\text{Hz}}$	12 nV/ $\sqrt{\text{Hz}}$
Gain error ( $\pm$ )	0.15%	0.15%	0.50%
Bandwidth at $G = 1$	2 MHz	4.7 MHz	0.6 MHz

### 2.3.3 DAC80004 16-bit DAC With 1 LSB INL/DNL

The DAC80004 device is low-power, quad-channel, 16-bit digital-to-analog converter. Hexadecimal values are written to the DAC using a computer which produce voltages at two channels. These voltages set the battery voltage charge and discharge rate. The four channels of the DAC80004 are used for the generation of high accuracy, user-defined voltage references.

Other important features include:

- True 16-bit performance: 1 LSB INL/DNL (maximum) which ensures accurate references for current and voltage
- Output buffer with rail-to-rail operation which provides clean references for current and voltage
- 50 MHz, 4- or 3-wire SPI-compatible which allows for simplified user interface

Alternatives:

The DAC80508 device is an eight channel DAC from the same family as the DAC80004.

**Table 3. DAC80004 Alternatives**

	DAC80004	DAC80508
INL/DNL	1 LSB (maximum)	1 LSB (maximum)
# of channels	4	8
Glitch energy	1 nV-s	4 nV-s

### 2.3.4 ADS131A04 24-bit, 128-kSPS, 4-Channel, Simultaneous-Sampling Delta-Sigma ADC

The ADS131A04 device uses four channels to simultaneously and continuously sample voltage or current measurements. The ADC is the front-end of the battery tester and interface with a computer to display voltage and current values in TI's Evaluation software. The ADS131A04 device is well equipped for measuring current and voltage signals due to it being a simultaneous sampling 4-channel converter, with a flexible SPI and data integrity to check and correct single-bit errors during data transmission.

Other important features include:

- Single-channel accuracy: Better than 0.01% at 10,000:1 dynamic range which enables high accuracy data acquisition
- Effective resolution: 20.6 bits at 8 kSPS which allows for high accuracy data acquisition
- Low-drift internal voltage reference: 6 ppm/°C which limits the effects that temperature has on the data acquisition
- Multiple SPI data modes which allows for a simplified user interface

Alternatives:

The ADS131E08 and ADS131E04 devices, predecessors to the ADS131A04, have a lower data rate but implement integrated buffer amplifiers.

**Table 4. ADS131A04 Alternatives**

	ADS131A04	ADS131E08	ADS131E04
Data rates (maximum)	128 kSPS	64 kSPS	64 kSPS
# of Channels	4	8	4
SNR	115 dB	107 dB	107 dB

### 2.3.5 Other Highlighted Products

In addition to the key products highlighted in the previous sections this reference design also showcases the following Texas Instruments devices:

- OPA2277 precision op amp; DAC driver buffer
- OPA827 precision op amp; ADC current and voltage measurement buffers
- TPS709 LDO regulators; 5-V DAQ and control power rails
- TLV07 36-V precision, rail-to-rail output, op amp; CC control amplifier
- THS4561 low-power, 70-MHz, high-supply range, fully differential amplifier; differential signal input for ADC
- LM2664 switched capacitor voltage converter; -5-V power rail
- LM7705 low-noise negative bias generator; -0.2 power rail
- LM5118 non-synchronous buck-boost controller; 10-V power rail
- LM6142 rail-to-rail I/O op amp; CV control amplifier
- SN74LVC1G04 single inverter; boost control logic
- SN74LV1T32 2-input positive OR gate; boost control logic
- SN74LV1T00 2-input positive NAND gate; buck control logic

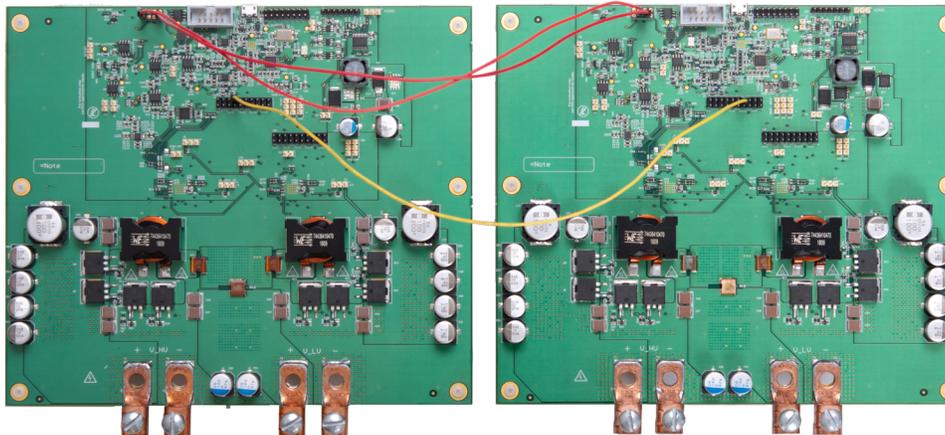
### 3 Hardware, Software, Testing Requirements, and Test Results

#### 3.1 Testing and Results

##### 3.1.1 Getting Started: Hardware

For general details on each hardware subsystem in this design, see the [Battery Tester Reference Design for High Current Applications Design Guide](#) (TIDA-01040).

**Figure 12. TIDA-01042 Hardware**



This section gives brief information to set up and run the board.

This system has some configuration options. [Table 5](#) highlights the purpose of each jumper on each board as well as the default configurations.

**Table 5. Jumper Configuration**

HEADER	SIGNAL	PINS	FUNCTION DESCRIPTION	DEFAULT
J1	UVLO	(1,2)	Enable from V_HV	Y
		(2,3)	Enable from V_LV	
J3	SYNCOUT	(1,2)	Clock output for multiphase configuration	Y
J4	V10-Aux	(1,2)	Auxiliary power	Y
J5	OPT	(1,2)	Multiphase configuration	Y
		(2,3)	No multiphase configuration	
J6	DIR	(1,2)	BUCK mode	Y
		(2,3)	BOOST mode	
J7	EN1	(1,2)	Onboard CH-1 enable	
		(2,3)	Onboard CH-1 disable	Y
J8	EN2	(1,2)	Onboard CH-2 enable	
		(2,3)	Onboard CH-2 disable	Y
J13	UVLO	(1,2)	Enable from V_HV	Y
		(2,3)	Enable from V_LV	
J14	V5	(1,2)	Enable power supply for CC control	Y
J16	V-5	(1,2)	Enable -5-V power supply	Y
J18	IREF/VREF	(1,2),(7,8)	Enable DAC output signal for CC/CV control loop	Y
J24	INA828 GAIN	(1,2)	High Current (50–100 A) Gain	
		(2,3)	Low Current (0–50 A) Gain	Y
J25	EN3	(1,2)	Onboard CH-3 enable	
		(2,3)	Onboard CH-3 disable	Y

**Table 5. Jumper Configuration (continued)**

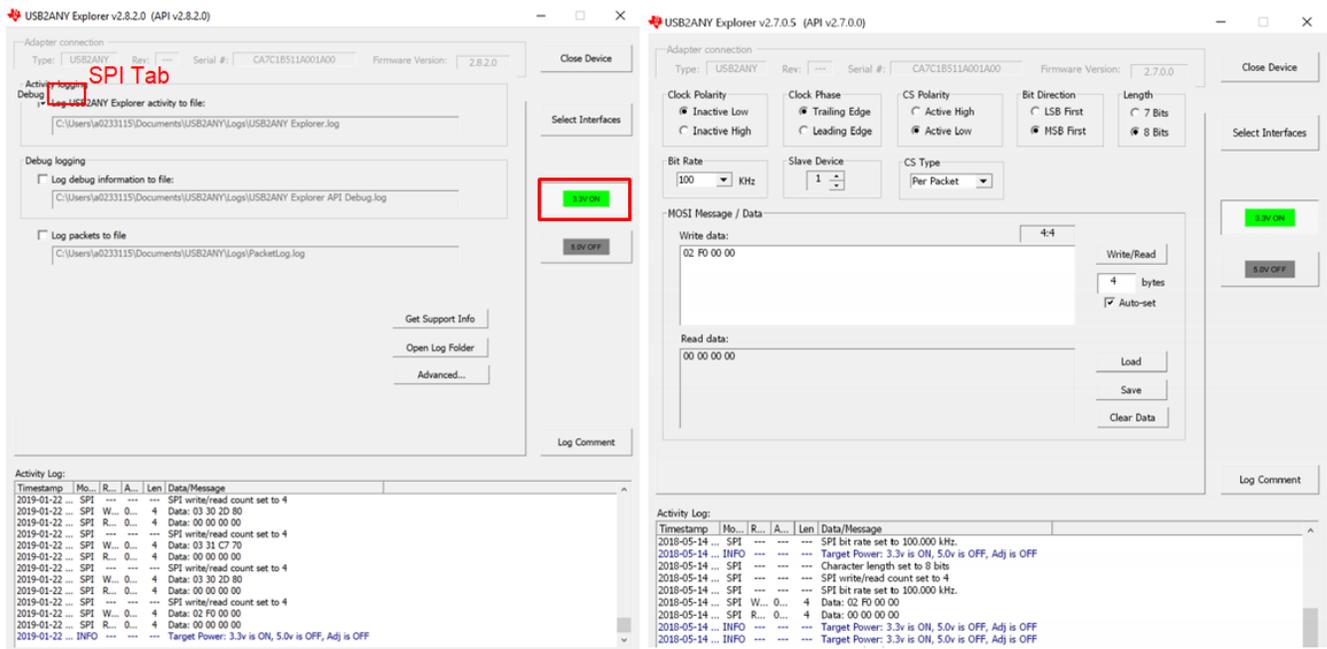
HEADER	SIGNAL	PINS	FUNCTION DESCRIPTION	DEFAULT
J26	EN4	(1,2)	Onboard CH-4 enable	
		(2,3)	Onboard CH-4 disable	Y
J27	SYNCOUT2	(1,2)	Clock output for multiphase configuration	N
		(2,3)	Multiphase Configuration	Y
J29	OPT2	(1,2)	Multiphase Configuration	Y
		(2,3)	No multiphase configuration	
J34	V_HV	(1,2)	Enable CV control for bus voltage(V_HV)	N
J35	V_LV	(1,2)	Enable CV control for battery voltage(V_LV)	Y
J37	V5A	(1,2)	Enable power supply for CV control	Y

### 3.1.2 Getting Started: Software

#### 3.1.2.1 DAC Setup

This reference design uses the USB2ANY interface adapter to communicate with the DAC80004 device to generate a reference signal for current and voltage control. First, open the *USB2ANY Explorer*, click *Select Interface* to choose the SPI, then click the 3.3V ON button. Click the *SPI* tab above the *Activity Logging* section. If the *SPI* tab does not appear, click around the words "Activity Logging" as sometimes the tabs are hidden. Configure the GUI parameters as [Figure 13](#) shows.

**Figure 13. USB2ANY Configuration**

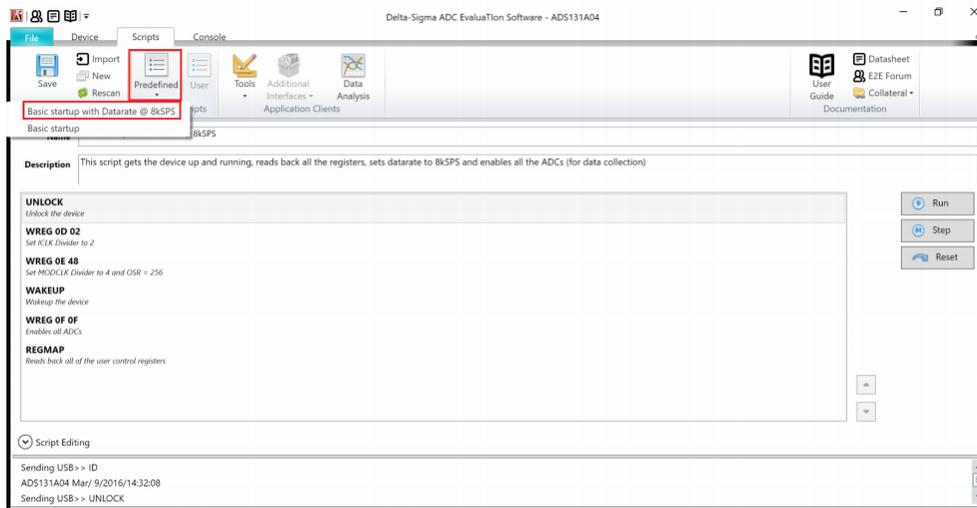


### 3.1.2.2 ADC Setup

Delta-Sigma ADC Evaluation Software is used to communicate with the ADS131A04 device. See the [Delta-Sigma ADC Evaluation Software User Manual](#) and [ADS131A04 Evaluation Module User's Guide](#) for detailed information.

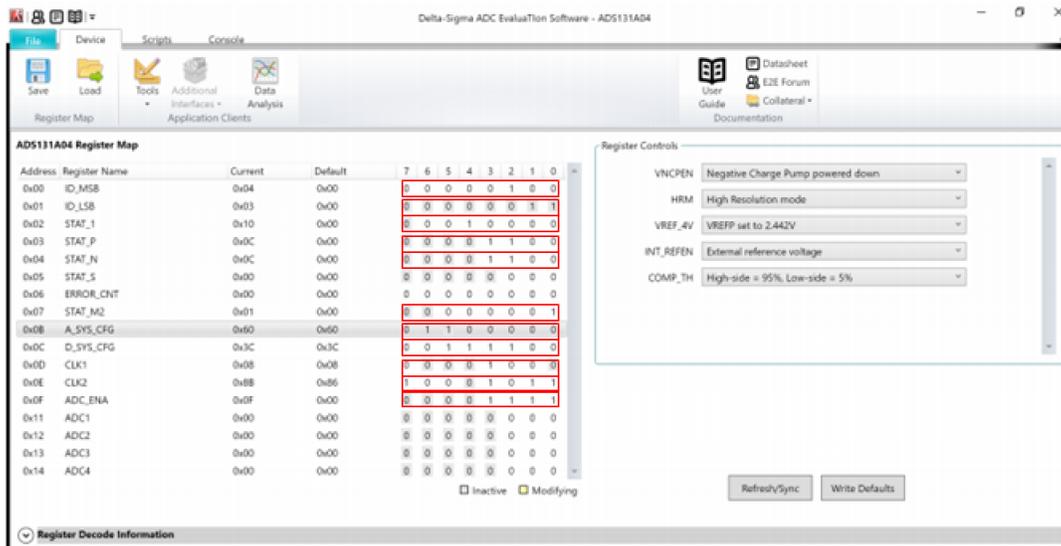
After launching this software, click the *Scripts* menu, then click *Predefined* and choose *Basic* startup with *Datarate at 8 kSPS* as [Figure 14](#) shows. Finally, click the *Run* button at the right side of the window.

Figure 14. ADC GUI Setting



The second step is to set the registers of the ADC. [Figure 15](#) highlights the registers that need to be changed and their correct values for this design. It can also modify clock and OSR settings.

Figure 15. ADC Register Setting

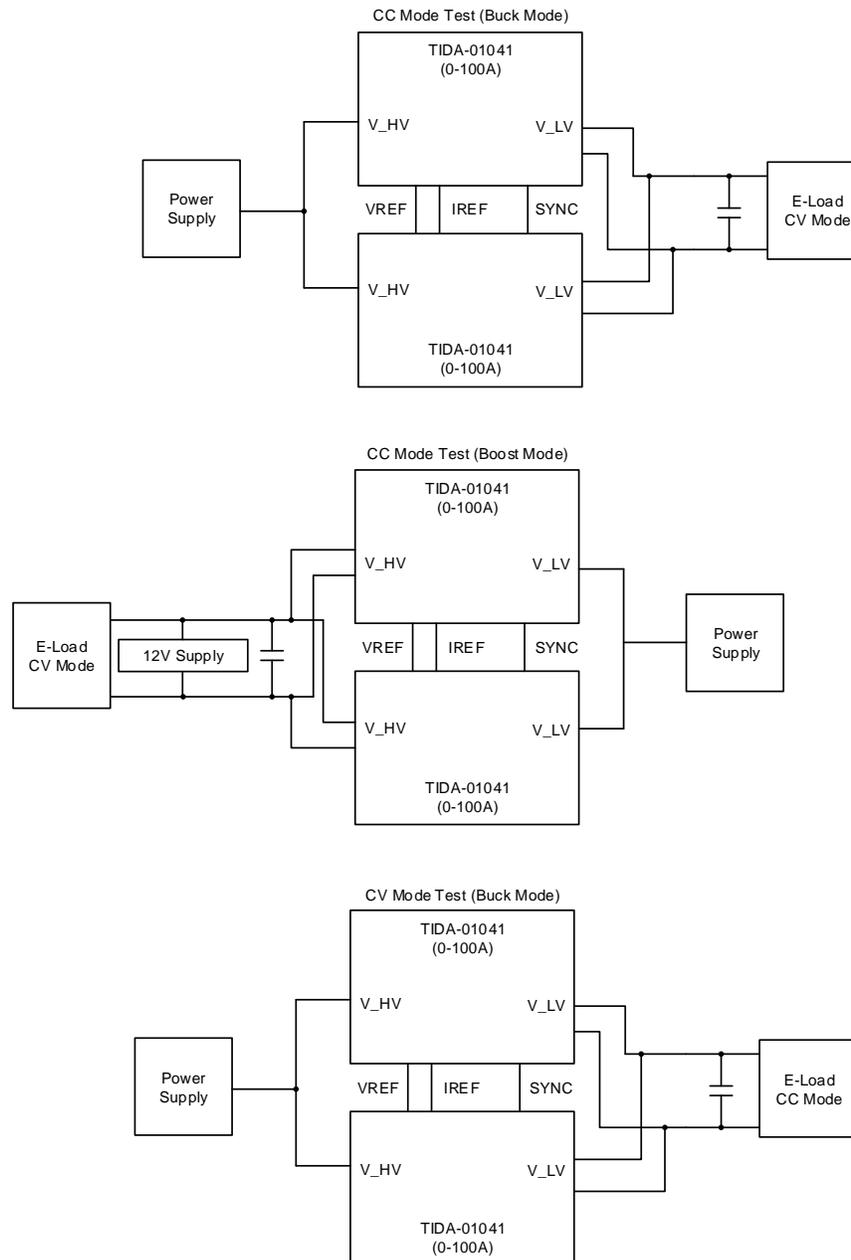


After setting the GUI and registers, the software can now capture data: click the *Data Analysis* menu, choose "ADC0" and "ADC1", change the Clock and VRef (V), and click the *Collect Data* button. For more on the acquisition results of the ADC software, see the [Battery Tester Reference Design for Multi-phase High-Precision 0.5- to 100-A Battery Formation Design Guide](#).

### 3.1.3 Test Setup

The test set up for the TIDA-01042 requires different set ups for buck and boost mode as well as for constant voltage and constant current mode. Figure 16 shows the test setups for constant current buck and boost as well as constant voltage.

**Figure 16. Test Setup for TIDA-01042 CC and CV Modes**



The power supplies must be able to provide enough power for the system. That means for buck mode, the power supply must be able to produce 10 V and high currents (about 60 A). In boost mode, the power supply on the LV side must be able to provide 200 A of discharge current. When switching between buck and boost mode, make sure to change the DIR jumper to reflect the intended mode of operation. The E-Load for constant current buck mode must be set to a lower voltage than the reference in CV mode allowing the control loop to give enough forward voltage for D3. The E-Load for constant voltage mode must be set to a lower current than the reference set by the DAC in CC mode.

### 3.1.4 Test Results

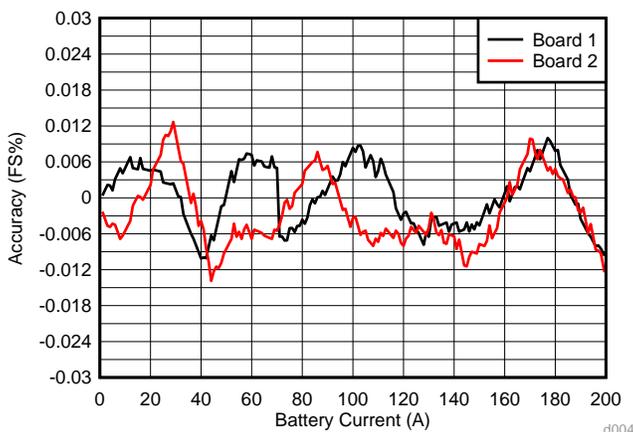
Battery test equipment must possess accurate voltage and current control, often better than  $\pm 0.05\%$ , as well as a smooth transition between the two to maximize capacity, battery life, quality, and performance. This section provides accuracy testing results for current and voltage control for this design as well as the performance of the system when transforming between CC and CV mode.

#### 3.1.4.1 Current Control Accuracy

The current accuracy depends on the current sensing resistor, the gain, offset, and drift of the current amplifier, INA828, and TLV07 devices. For more information on current accuracy in this design as well as the calibration process for buck and boost mode operations, see the [TIDA-01040 Battery Tester Reference Design for High Current Applications Design Guide](#).

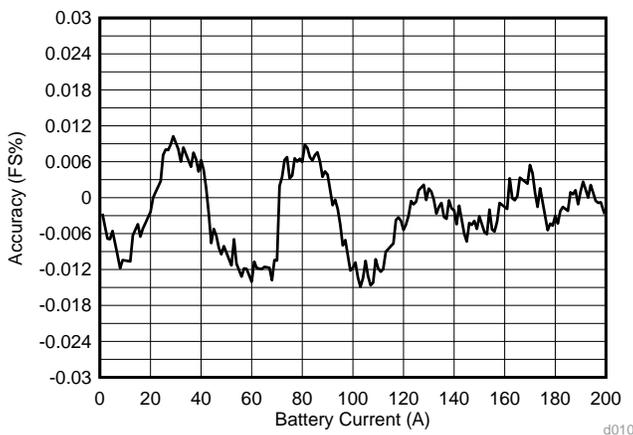
For the TIDA-01042, it is important to calibrate each board in the system separately to achieve maximum accuracy. Each board has its own control loop, so each board will require a unique calibration. [Figure 17](#) shows the results for the constant current control accuracy for buck mode for each board. The E-Load was set to 1 V CV.

**Figure 17. Independent Board Constant Current Buck Mode Accuracy**



As seen, both boards have different accuracy levels at different currents. A benefit to calibrating each board separately is that when you combine the boards into the system, their accuracies at each point are averaged. This means that the maximum level of error occurs at the high average of error, limiting the error of the overall system.

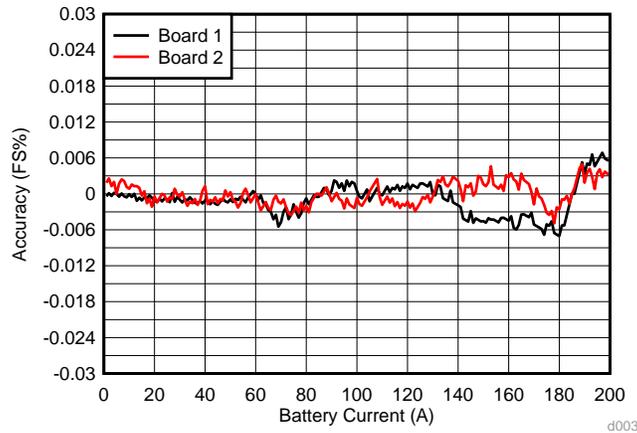
**Figure 18. System Constant Current Buck Mode Accuracy**



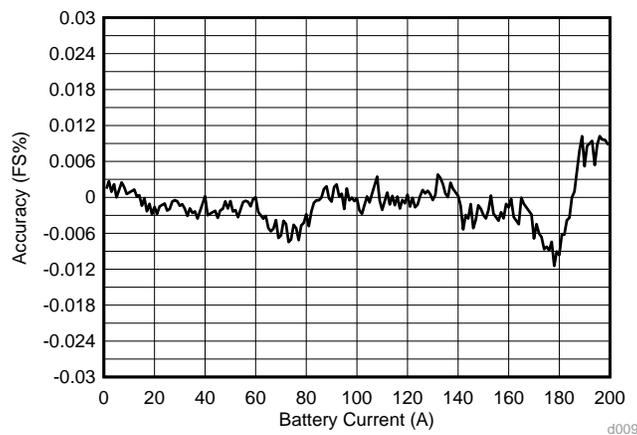
The results show that CC buck control for the entire system remains within 0.02% accuracy from 1 A to 200 A.

The same was done for the system in boost mode. A voltage of 1 V was on applied on the LV side. [Figure 19](#) shows the results that the system operates with accuracy within 0.02% in boost mode as well.

**Figure 19. Independent Board Constant Current Boost Mode Accuracy**



**Figure 20. System Constant Current Boost Mode Accuracy**



For different levels of current control, there are different values for battery current calibration. [Table 6](#) lists the suggested values of calibration for current at different voltage levels of each TIDA-01041 board.

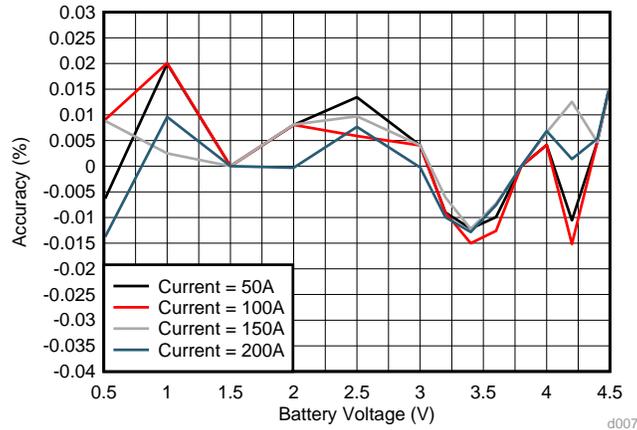
**Table 6. Current Calibration For Different Voltage Levels**

VOLTAGE	GAIN	OFFSET
1 V	0.003424289	0.016198132
2 V	0.003424078	0.016813532
3 V	0.003423972	0.01712133
4 V	0.00342355	0.018352035
4.5 V	0.003423444	0.018659735

### 3.1.4.2 Voltage Control Accuracy

The voltage accuracy also depends on the gain, offset, and drift of the system. See the [TIDA-01040 Battery Tester Reference Design for High Current Applications Design Guide](#) for more information on the calibration method for these test results.

**Figure 21. System Constant Voltage Accuracy**



The results in [Figure 21](#) show that the system is able to operate in CV mode with 0.01% accuracy. [Table 7](#) lists the suggested values of calibration for voltage at different current levels of the TIDA-01042 system.

**Table 7. Voltage Calibration For Different Current Levels**

CURRENT	GAIN	OFFSET
25 A	8.89155E-05	0.14167296
50 A	8.90044E-05	0.134773002
75 A	8.88266E-05	0.126572917
100 A	8.82969E-05	0.115707446

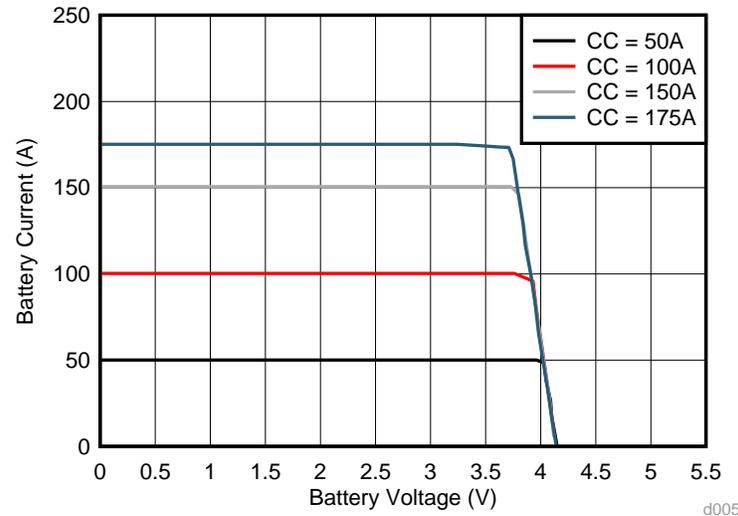
### 3.1.4.3 CC, CV Transformation

During the charging process, if the transition from constant current mode to constant voltage mode is not understood, the battery under test and formation could be overcharged. A smooth and rapid transition from constant current to constant voltage protects the battery from being overcharged.

It is critical to understand the performance of the system when transforming from CC to CV mode as this will affect its ability to eliminate overcharging in the battery.

Figure 22 and Figure 23 show the transition from constant current mode to constant voltage mode under different voltage and current settings.

**Figure 22. CC to CV Transformation Under Varying Current Settings**



In Figure 22, with the increase in current setting, the CC control starts transforming to CV control at lower voltage. The transformation remains linear throughout testing, indicating that the ability of the design to eliminate overcharging is not affected at higher currents.

**Figure 23. CC to CV Transformation Under Varying Voltage Settings**

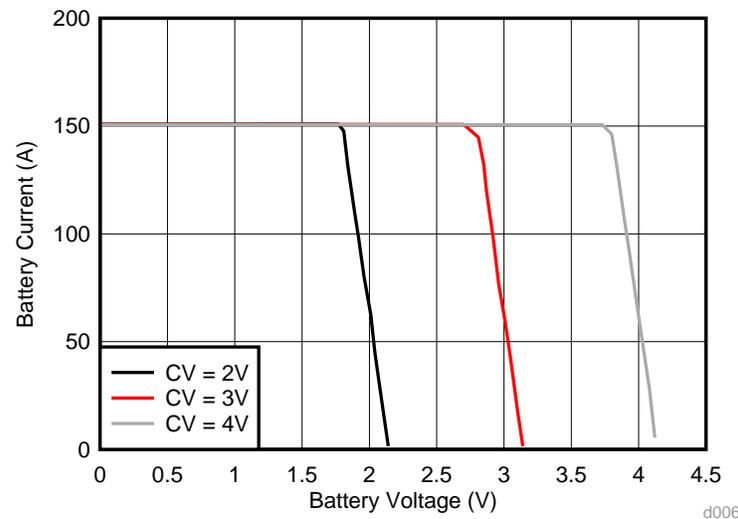
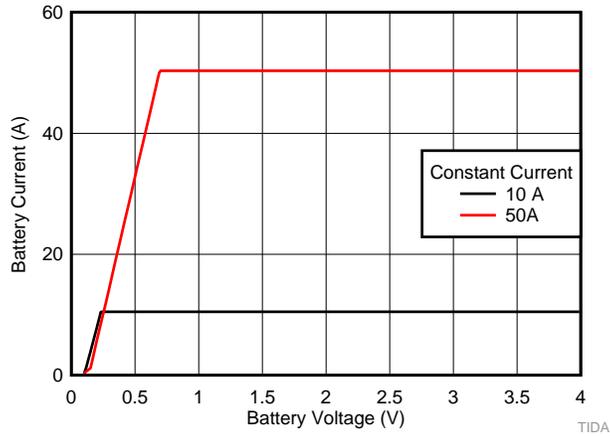


Figure 23 shows that voltage setting has less effect on the switch from CC control to CV control.

### 3.1.4.4 Low Voltage Discharge

Battery tester and formation equipment are designed to charge and discharge a battery. It is important to be able to discharge to a very low voltage to form the battery properly. Figure 24 shows the results of a single TIDA-01041 board discharging at different current levels.

**Figure 24. Battery Discharge at Low Voltage**

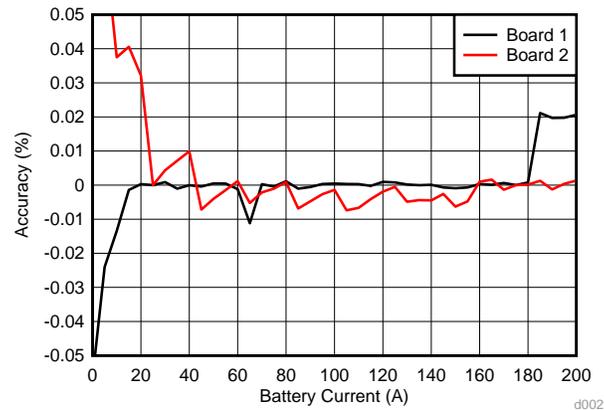


### 3.1.4.5 ADC Calibration

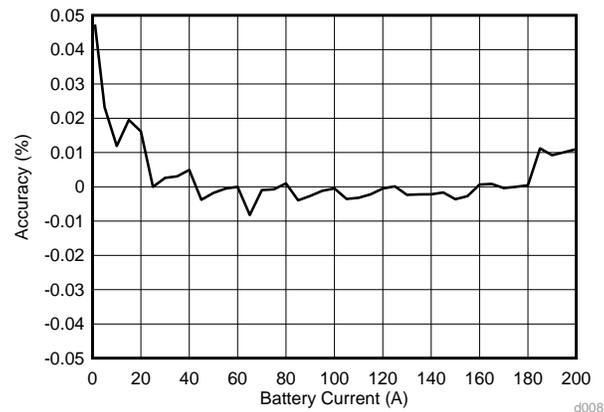
Two channels are used to monitor the battery current and voltage. The accuracy of this data acquisition depends on the gain and offset of the THS4561 device and other components, so the output of the ADC should be calibrated. Use a similar gain and offset method to calibrate those two channels as the previous current and voltage control loop.

Figure 25 through Figure 27 show the accuracy of this data acquisition after calibration.

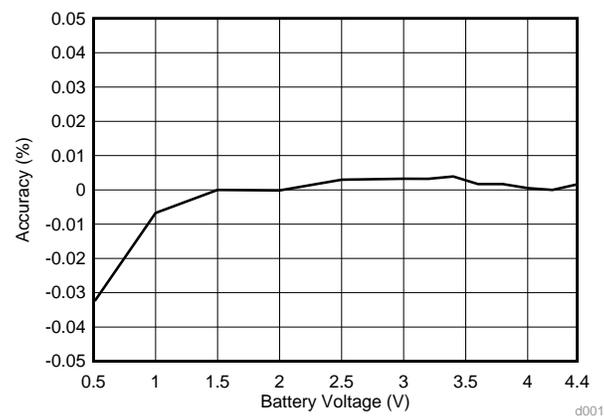
**Figure 25. Individual Board ADC Current Acquisition**



**Figure 26. System ADC Current Acquisition**



**Figure 27. ADC Voltage Acquisition**

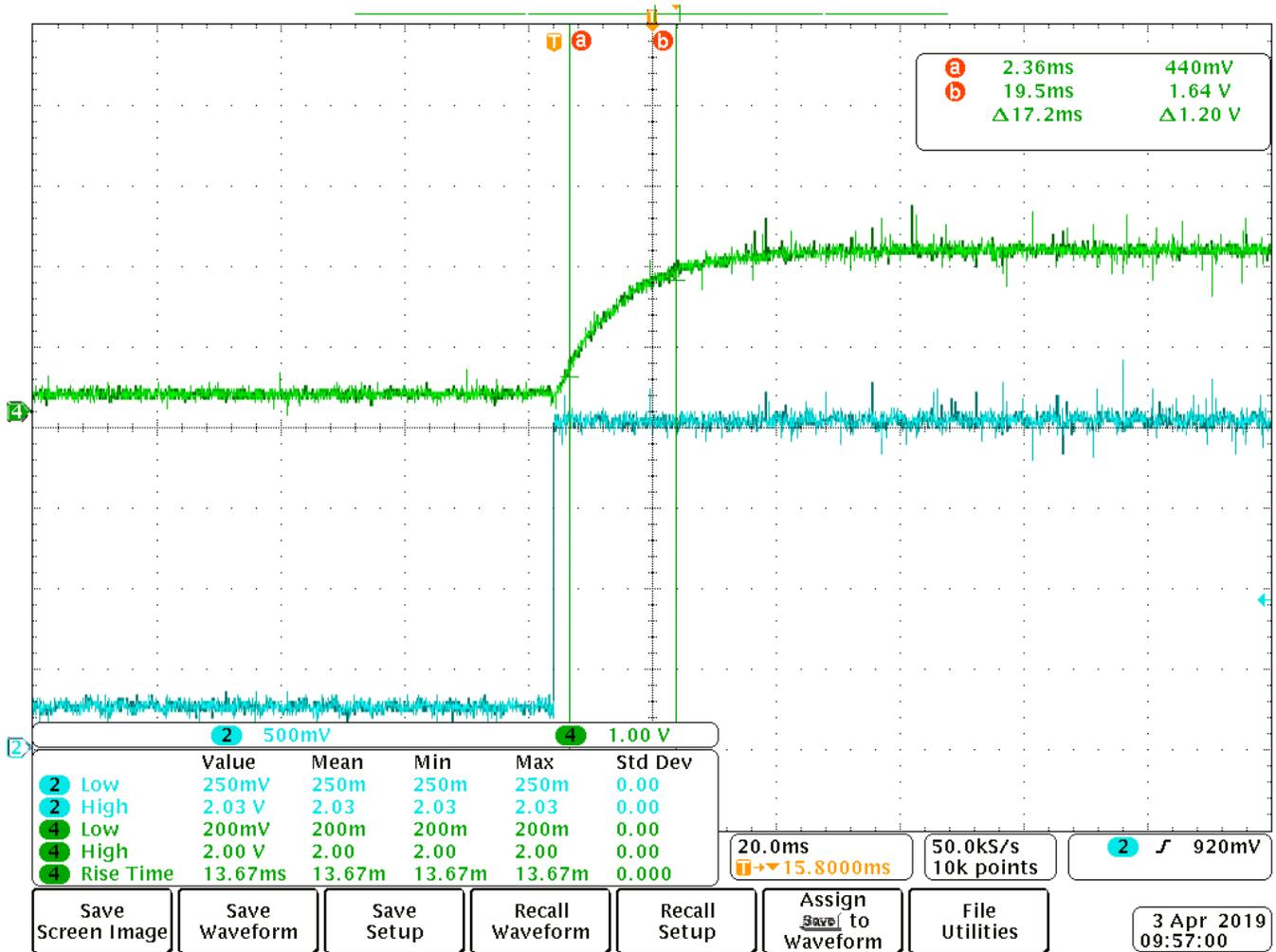


The results demonstrate that at high current levels, the ADC is able to capture current and voltage at accuracies lower than 0.01% error.

### 3.1.4.6 Transient Response

During the charging of batteries, it is important to be able to model the rise time of the current. Once the battery receives a current, it will start charging. A fast rise time allows the user to better predict the charge of the battery. Figure 28 shows the rise time of the TIDA-01042 reference design from 10 A to 180 A.

Figure 28. Rise Time of TIDA-01042



## 4 Design Files

### 4.1 Schematics

To download the schematics, see the design files at [TIDA-01042](#).

### 4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-01042](#).

### 4.3 PCB Layout Recommendations

#### 4.3.1 Layout Prints

To download the layer plots, see the design files at [TIDA-01042](#).

### 4.4 Altium Project

To download the Altium Designer® project files, see the design files at [TIDA-01042](#).

### 4.5 Gerber Files

To download the Gerber files, see the design files at [TIDA-01042](#).

### 4.6 Assembly Drawings

To download the assembly drawings, see the design files at [TIDA-01042](#).

### 4.7 Simulation Results

To download the simulation results, see the design files at [TIDA-01042](#).

## 5 Software Files

To download the software files, see the design files at [TIDA-01042](#).

## 6 Related Documentation

1. Texas Instruments, [Battery Tester Reference Design for High Current Applications Design Guide](#)
2. Texas Instruments, [Multiphase Buck Design From Start to Finish \(Part 1\) Application Report](#)
3. Texas Instruments, [Merits of multiphase buck DC/DC converters in small form factor applications White Paper](#)
4. Texas Instruments, [Benefits of a multiphase buck converter Technical Brief](#)
5. Texas Instruments, [LM5170-Q1 Multiphase Bidirectional Current Controller Data Sheet](#)
6. Texas Instruments, [LM2664 Switched Capacitor Voltage Converter Data Sheet](#)
7. Texas Instruments, [TPS709 150-mA, 30-V, 1- \$\mu\$ A  \$I\_Q\$  Voltage Regulators With Enable Data Sheet](#)
8. Texas Instruments, [LM5118 Wide Voltage Range Buck-boost Controller Data Sheet](#)
9. Texas Instruments, [INA188 Precision, Zero-Drift, Rail-to-Rail Out, High-Voltage Instrumentation Amplifier Data Sheet](#)
10. Texas Instruments, [DACx0004, Quad 16-, 14-, 12-bit, 1 LSB INL, Buffered, Voltage-Output Digital-to-Analog Converters Data Sheet](#)
11. Texas Instruments, [ADS131A0x 2- or 4-Channel, 24-Bit, 128-kSPS, Simultaneous-Sampling, Delta-Sigma ADC Data Sheet](#)
12. Texas Instruments, [TLV07 36-V Precision, Rail-to-Rail Output Operational Amplifier Data Sheet](#)
13. Texas Instruments, [OPAx22x High Precision, Low Noise Operational Amplifiers Data Sheet](#)
14. Texas Instruments, [OPA827 Low-Noise, High-Precision, JFET-Input Operational Amplifier Data Sheet](#)

15. Texas Instruments, [THS4561 Low-Power, High Supply Range, 70-MHz, Fully Differential Amplifier Data Sheet](#)
16. Texas Instruments, [LM6142/LM6144 17 MHz Rail-to-Rail Input-Output Operational Amplifiers Data Sheet](#)
17. Texas Instruments, [PMP15038 Test Results Technical Reference](#)

## 6.1 Trademarks

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## 7 About the Author

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## 8 Acknowledgment

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