Texas Instruments

Application Report
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How to Design a Simple and Highly Integrated Battery Testing System

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ABSTRACT

The battery must be tested strictly before it comes out of the factory, and the battery test equipment is used to verify battery pack functionality and performance. For the most commonly used battery testing system in the market is the separation solution, which is a mature solution. This application report introduces an integration battery testing solution which is simpler than the separation solution in the design.

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1 Introduction

The use of rechargeable batteries in testing systems is becoming increasingly extensive. In order to initialize the rechargeable batteries, the multiple charging and discharging cycles are demanded. In this process, the current and voltage of the battery must be controlled accurately. It is usually required that the precision can reach 0.1%. Therefore, battery formation and test systems require high precision analog front ends and controllers.

There are two modes of battery charging and discharging: constant current mode and constant voltage mode. In a typical battery charging system, the batteries are charged or discharged at a constant current until the preset voltage is reached. After reaching the preset voltage, the system switches to the constant voltage mode.

Right now, most battery testing manufacturers use separation solutions to design battery charging and discharging systems. This application report describes how to design an integration solution using the TPS54821 and TPS61178 devices.

The TPS61178 is a synchronous boost converter designed for delivering switch peak current up to 10 A and output voltage reaching to 20 V. The TPS61178 operates at a fixed-frequency pulse-width modulation at moderate-to-heavy load currents. At the light-load current, the TPS61178 operates in PFM mode. PFM mode brings the high-efficiency crossing the entire load range.

The TPS54821 is a 17-V, 8-A, synchronous buck converter with two integrated n-channel MOSFETs to improve performance during line and load transients. The TPS54821 implements a constant frequency and peak current mode control which simplifies external frequency compensation. The wide switching frequency of 200 kHz to 1600 kHz allows for efficiency and size optimization when selecting the output filter components. The switching frequency is adjusted using a resistor to ground on the RT/CLK pin.

2 Separation Solution and Integration Solution

2.1 Separation Solution

Figure 1 shows the separation solution block diagram. The charge and discharge circuit is composed of separation devices that consist of two MOSFETs, an inductor, PWM generators, and MOS drivers. This solution can achieve high efficiency because it is possible to select the MOSFETs with small equivalent conduction impedance. As a result, the conduction loss of the MOSFET is relatively small, but there are many devices used in a separation solution, so the design is complex and the area of the layout is large. See the *Bi-Directional Battery Initialization System Power Board Reference Design* for more details on this design.

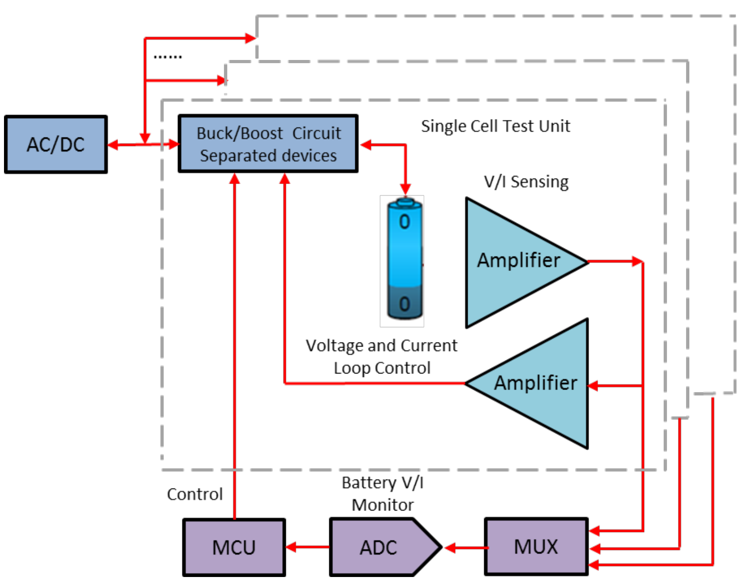

Figure 1. Separation Solution Block Diagram

2.2 Integration Solution

Figure 2 shows the integration solution block diagram. The integration solution replaces two MOSFETs, PWM generators, and MOS drivers in the separation solution with buck and boost converters. The efficiency of the integration solution is lower than the separation solution because the MOSFETs are integrated in the converts, but the integration solution has the following advantages compared to the separation solution:

- The area of the PCB is smaller. It is a highly integrated system, so few components are used. In addition, many of the protection circuits are integrated into the IC, so the design is more simple.
- The stability is better. Many protection circuits are integrated inside the device and have greater reliability.
- The maintenance cost is less. If the product breaks, the cause is simpler to determine in the integration solution. The integration solution has more convenient maintenance with lower costs and higher efficiency.

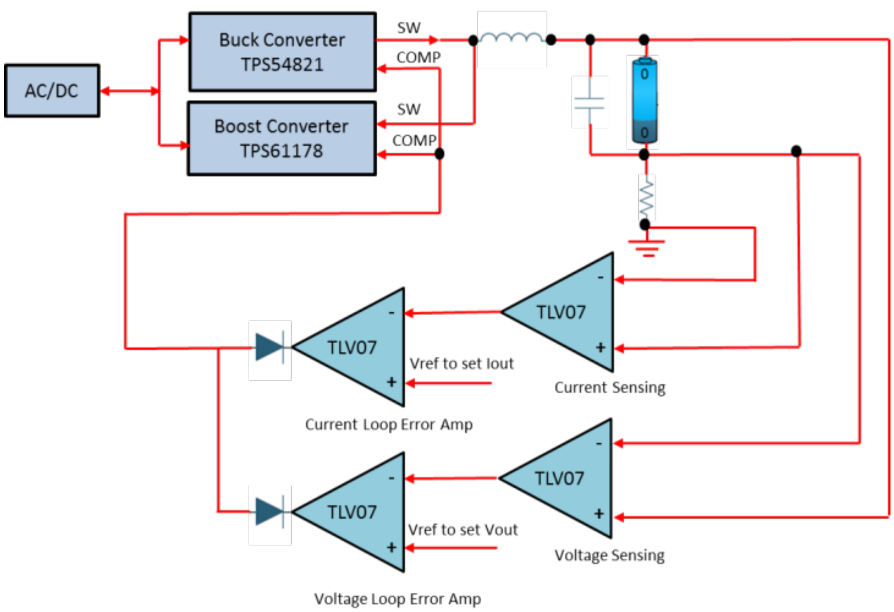

Figure 2. Integration Solution Block Diagram

3 Design of Integration Solution

Table 1 lists the design specifications. Figure 3 and Figure 4 show the schematics of integration solution. A buck converter charges the circuit and a boost discharges the circuit.

Table 1. Design Parameters

DESIGN PARAMETER	VALUE
Input voltage (VBUS)	12 V
Voltage resolution	1 mV
Voltage detection accuracy	0.1%
Minimum discharge voltage	2 V
Charge and discharge current range	0 A to 6 A
Minimum detection current	10 mA
Current resolution	1 mA
Current detection accuracy	0.1%
Output voltage ripple	< 50 mV

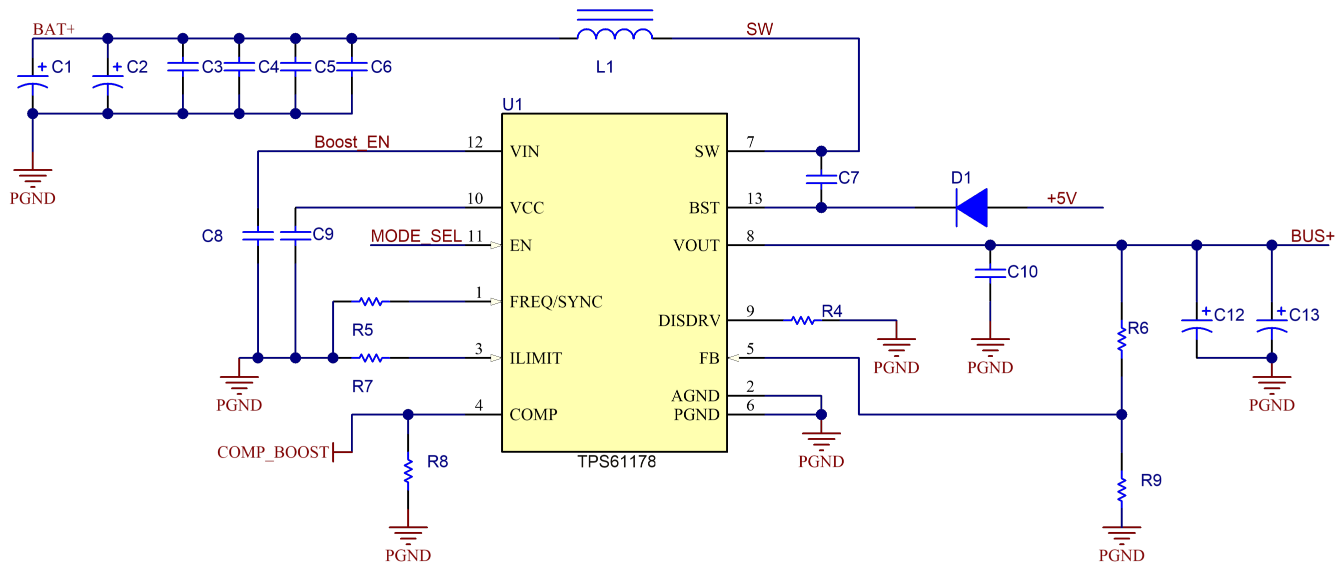

Figure 3. Charging Circuit

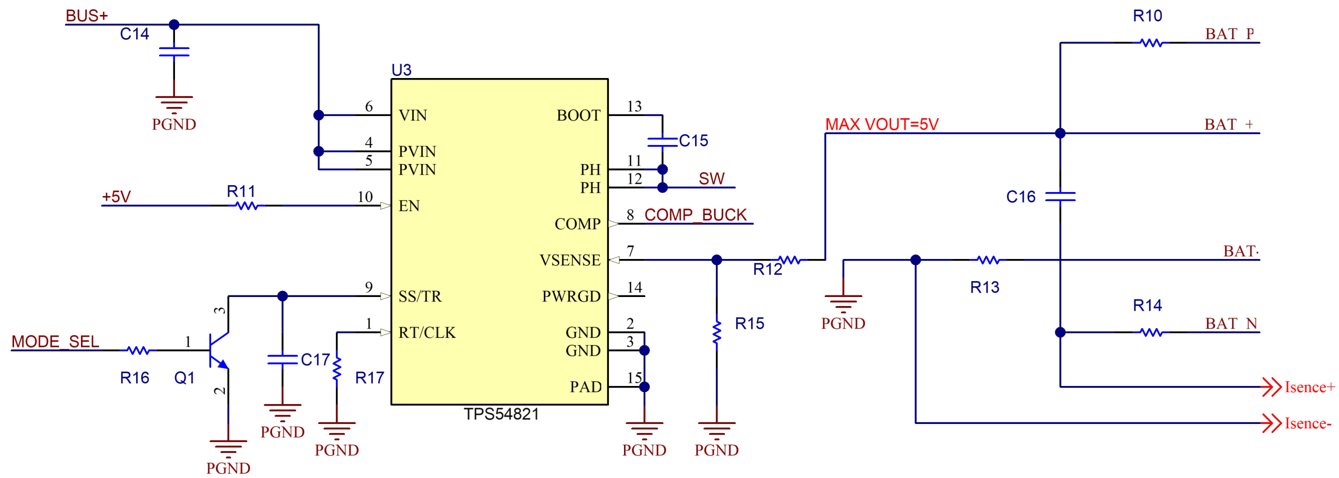

Figure 4. Discharging Circuit

3.1 Control Circuits

3.1.1 Analog Switch Circuit

When the battery discharges, the value of current sensing is negative. Figure 5 shows the analog switch circuit used for ensuring that the current sense value is positive if the battery is charging or discharging.

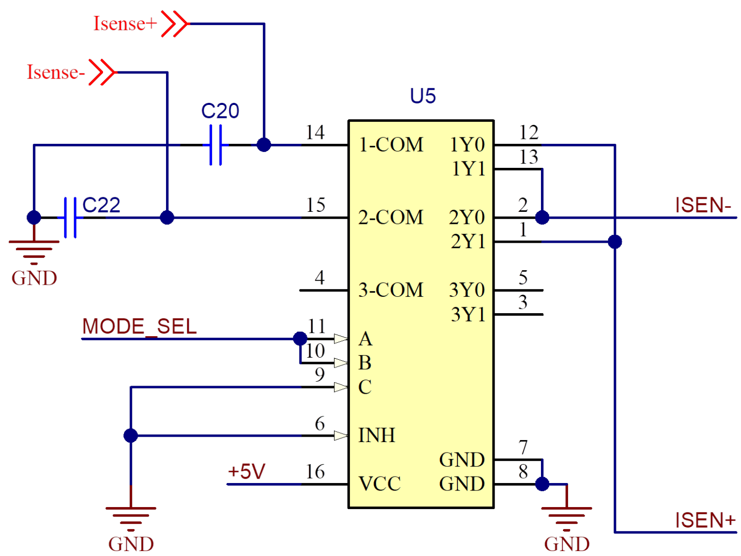

Figure 5. Analog Switch Circuit

3.1.2 Voltage Conditioning Circuit

Figure 6 shows the voltage conditioning circuit that is composed of three operational amplifiers. U4, U6, and U8. U4 and U8 consist of a buffer circuit that reduces the output impedance and improves the accuracy of current sampling. U6 and the peripheral circuits adjust the current sensing value.

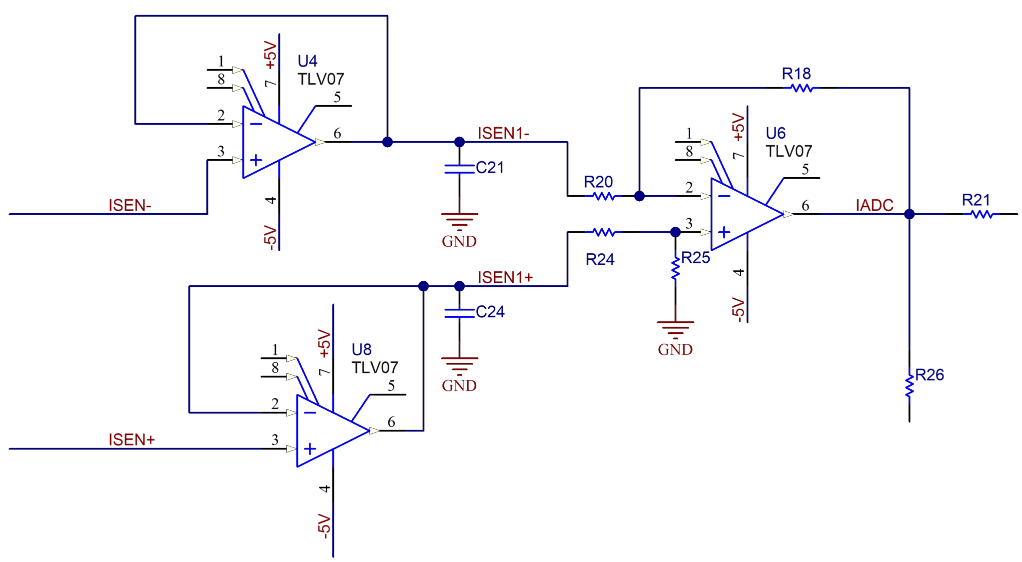

Figure 6. Voltage Conditioning Circuit

3.1.3 Compensation Circuit

Figure 7 shows the compensation circuit. Because the accuracy of the error amplifier and reference voltage inside the device are low, it is difficult to achieve 0.1% sampling precision. It is necessary to rebuild the compensation loop outside the device. IDAC is the reference voltage from MCU. Adjust the IDAC to regulate the discharge current of the battery.

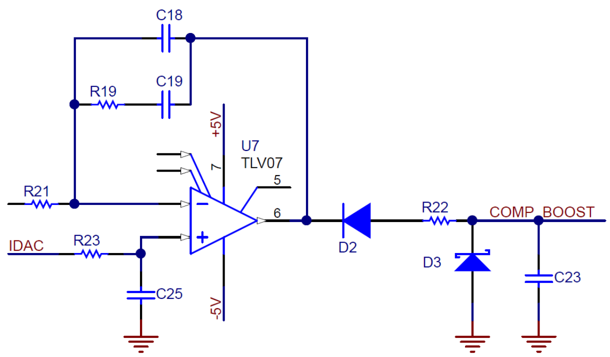

Figure 7. Compensation Circuit

3.1.4 Charging Mode Transition Circuit

Figure 8 shows the charging mode transition circuit. U8 and the peripheral circuits consist of a current loop compensation circuit. The voltage loop is composed of U10 and U11. U10 adjusts the sensing voltage and U11 is the error amplifier. IDAC and VDAC are the reference voltage.

D4 and D6 switches the charging mode. When the output voltage of U8 is lower than the output voltage of U11, D4 turns on and D6 turns off in reverse. The current loop works and the voltage loop does not work and enters the constant current charging mode. When the output voltage of U8 is higher than the output voltage of U11, D4 turns off, and D6 turns on. The voltage loop works and enters the constant voltage charging mode.

The COMP pin of the TPS54821 has an input voltage range of –0.3 V to 3 V. The input voltage range of the COMP pin of the TPS61178 is 0.3 V to 7 V. D5 turns on so that the comp voltage is limited to greater than –0.3 V to protect the devices when the output voltage of U8 or U11 is negative.

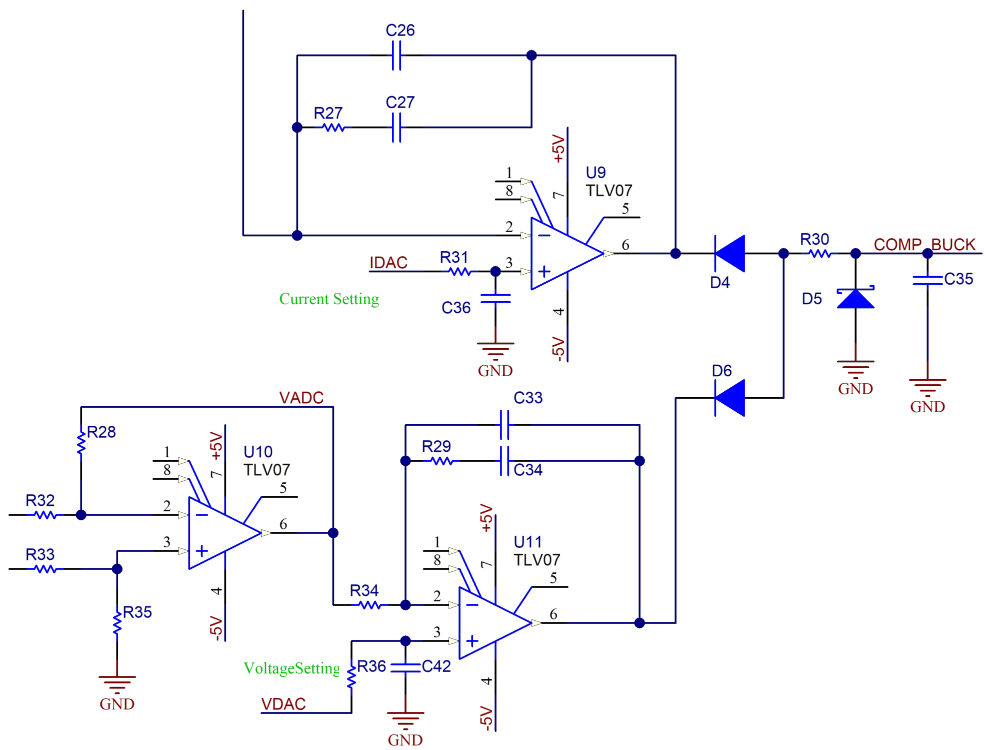

Figure 8. Charging Mode Transition Circuit

3.2 Protection Circuit

3.2.1 Battery Over-Discharge Protection

shows the over-discharge protection circuit. The protection circuit prevents the voltage of battery from decreasing below 2 V. When the voltage of the battery is less than 2 V, the output voltage of the comparator is low. The TPS61178 stops. Select a value of R20 to be approximately 100 kΩ. Equation 1 shows the relationship of the resistor divider.

$$R_7 = (R_5 \times 2\ V) / (5\ V - 2\ V) = 66.8\ k\Omega \quad (1)$$

Select R_7 = 68 kΩ.

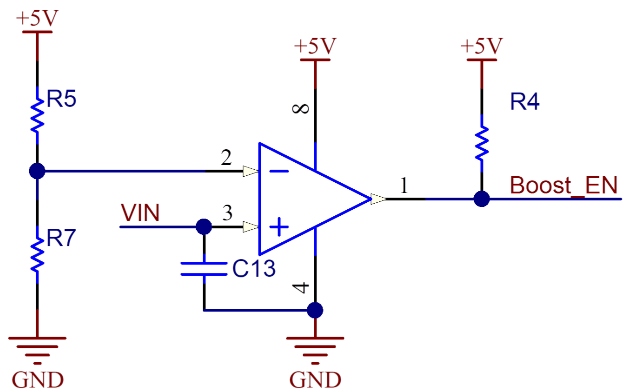

Figure 9. Battery Over-Discharge Protection

3.2.2 Overvoltage Protection

The maximum output voltage of the TPS54821 is set to 5 V, and V_{FB} = 0.596 V (typical), V_{OUT} is calculated to be:

$$V_{OUT} = V_{FB} \times (1 + R_{12} / R_{15}) \quad (2)$$

Start with a value of 10 kΩ for R_{15}.

$$R_{12} = (R_{15} \times (V_{OUT} - V_{FB})) / V_{FB} = 73.89\ k\Omega \quad (3)$$

Select R_{12} = 73.2 kΩ.

The maximum output voltage of the TPS61178 device is set to 16 V and V_{FB} = 1.198 V (typical). Start with a value of 1 MΩ for R_6. R_9 is calculated to be:

$$R_9 = (R_6 \times V_{FB}) / (V_{OUT} - V_{FB}) = 80.9\ k\Omega \quad (4)$$

Select R_9 = 80.6 kΩ

3.2.3 Charging and Discharging Interlock Protection Circuit

From the schematic, if the MODE_SEL voltage is high, the circuit is in discharge mode. If the MODE_SEL voltage is low, the circuit is in charge mode.

To prevent the MOSFET of the TPS54821 from turning on in discharge mode, use the SS pin to disable the device. When the boost circuit works, the input and output voltages are not zero, so Vds of the MOSFET is not zero. If the voltage of SS pin is pulled down to GND, the ability to pull down the driving voltage of MOSFET is stronger. Figure 10 shows the buck enable circuit.

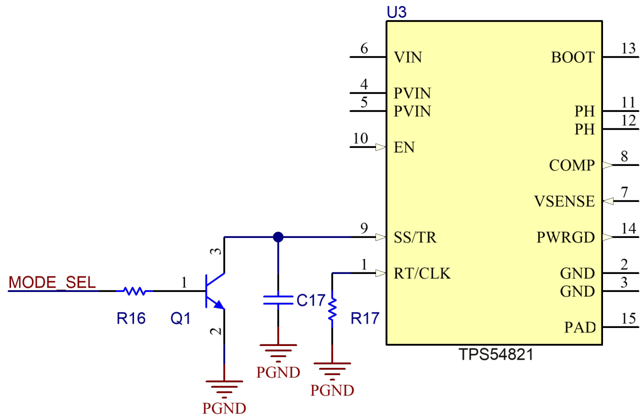

Figure 10. Enable Buck Circuit

In charge mode, it is better to use a diode connect BST pin to 5 V. This pin can make MOSFET turn off more efficiently .

3.3 Voltage and Current Detection Accuracy

The voltage and current detection accuracy are the most important parameters for battery testing system. There are three main factors that affect accuracy:

- The precision and temperature drift of sampling resistor
- The precision of the circuit resistor, which adjusts the current and voltage loop gains
- The precision of operational amplifier, including the offset and temperature drift

Take care when selecting an operational amplifier and resistors. TI recommends selecting 0.1% resistors and operational amplifiers with low offset.

Typically, a DAC corrects accuracy. There are two ways to use a DAC to correct accuracy. For this design, select the second option.

- Correct each channel. Each channel uses a DAC. This method is expensive.
- Correct eight channels with one DAC. This is a less expensive option. Take care to ensure consistency.

3.4 Layout

For the application of 3 A, TI recommends using two board layers and selecting TPS54521 as a buck converter.

For the application of 6 A, because of the factors such as board size and power, the temperature of board and IC is higher if the two layers board is used. So the four layers board is a good choice for better performance. Choose the TPS54821 as buck converter, because the load capacity of TPS54521 is not enough.

4 Experimental Results

4.1 Steady State

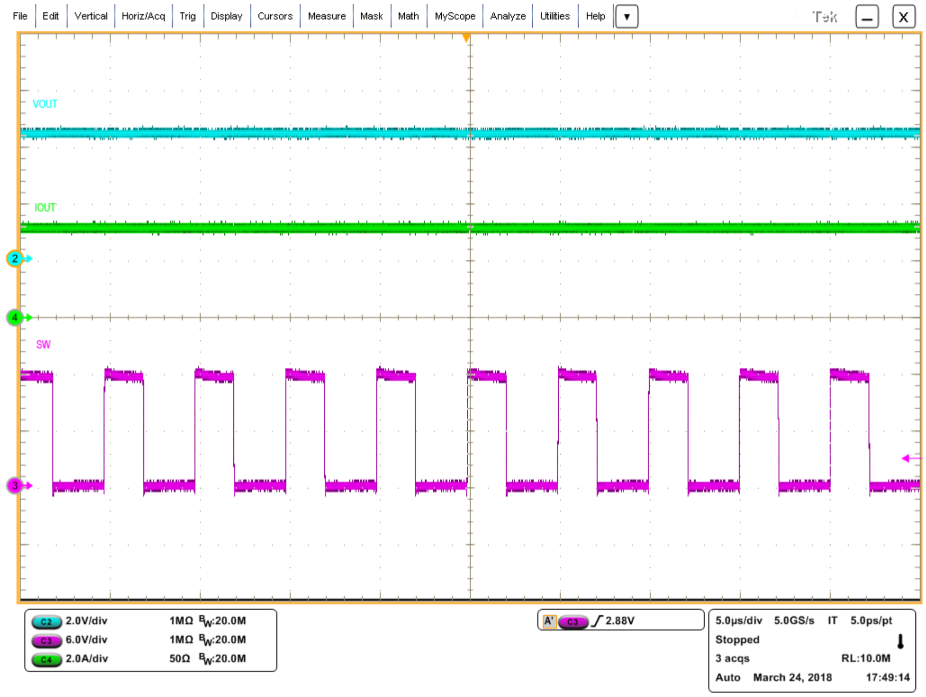

Figure 11. Steady State Waveform / Constant Current Charging (V_{IN} = 12 V, V_{OUT} = 4.2 V, I_{OUT} = 3 A)

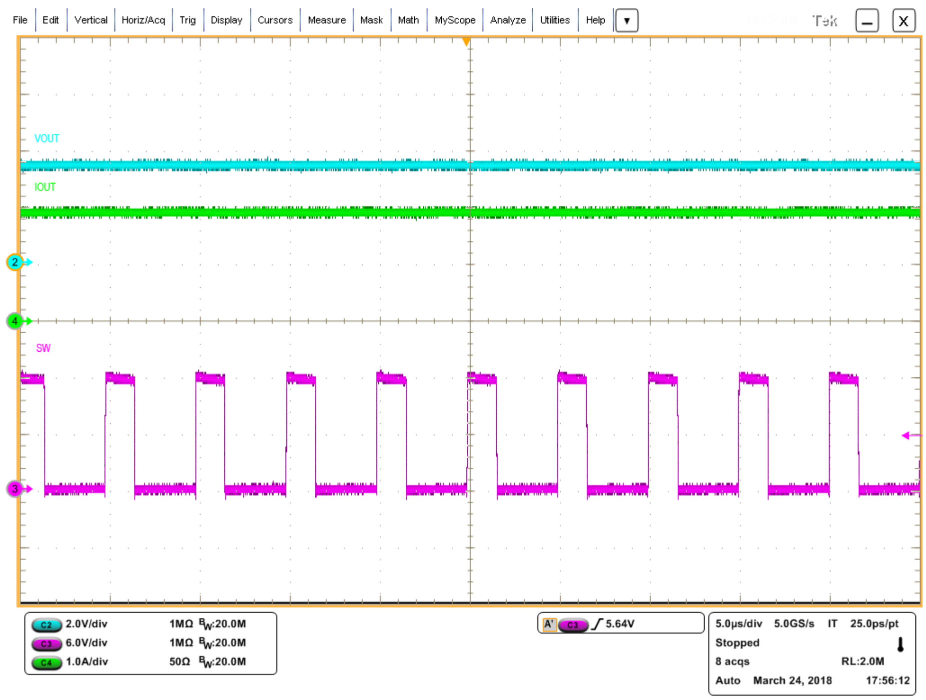

Figure 12. Steady State Waveform / Constant Voltage Charging (V_{IN} = 12 V, V_{OUT} = 3.5 V, I_{OUT} = 2 A)

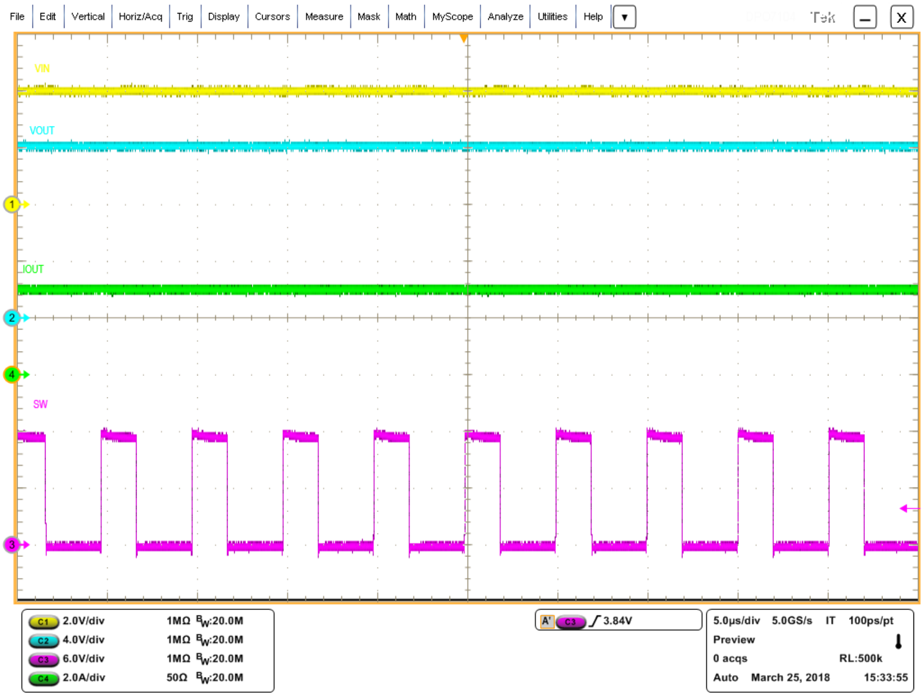

Figure 13. Steady State Waveform / Constant Current Discharging (V_{IN} = 4 V, V_{OUT} = 12 V, I_{OUT} = 3 A)

4.2 Output Voltage Ripple

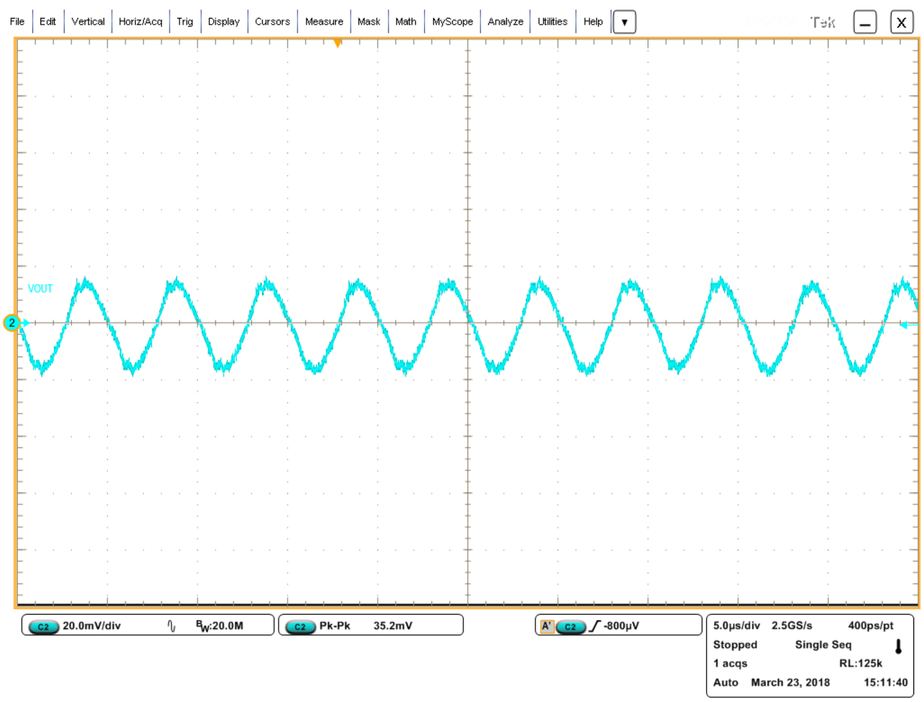

Figure 14. Output Voltage Ripple / Constant Voltage Charging (V_{IN} = 12 V, V_{OUT} = 4.2 V, I_{OUT} = 6 A)

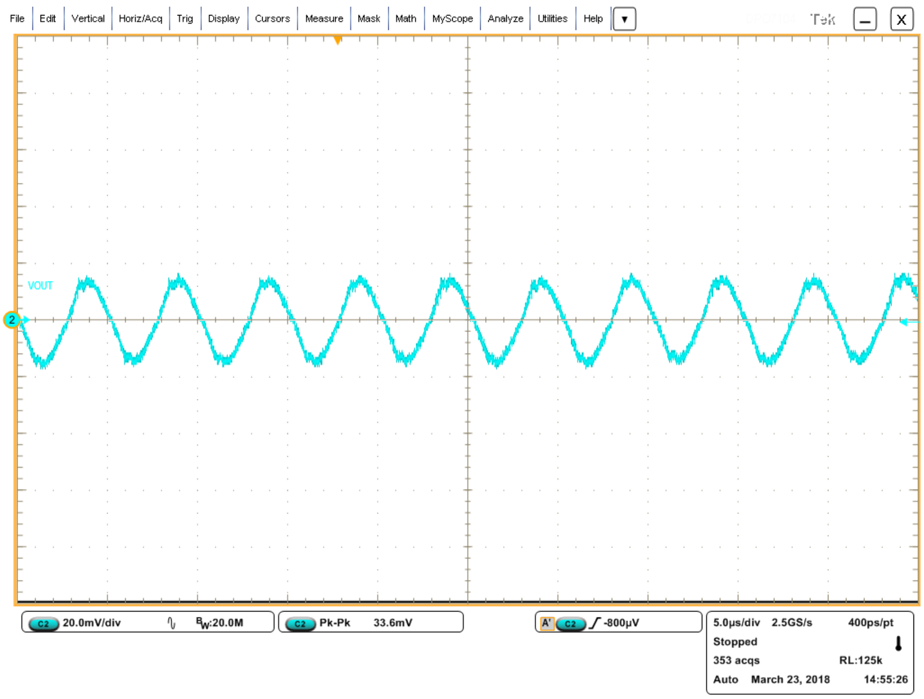

Figure 15. Output Voltage Ripple / Constant Current Charging (V_{IN} = 12 V, V_{OUT} = 4.2 V, I_{OUT} = 6 A)

4.3 *Charging Mode Transition*

Figure 16 and Figure 17 are the constant current and voltage charging transition waveforms. These waveforms have a test condition where voltage loop and charging voltage is set to 4 V. VDAC is the setting value to adjust charging current, and the range of VADC is 0 V to 2.4 V, so the charging current increases from 0 A to 6 A. Load resistance is 1 Ω.

From Figure 16, after the VADC increases to 1.6 V, the charging current is 4 A, and output voltage is 4 V, which is equal to the setting value of charging voltage. The output voltage no longer changes with the increase of VADC, the effective loop is changed from current loop to voltage loop, and the charging mode is changed from constant current charging to constant voltage charging. Figure 17 shows the transition from a constant voltage charging to a constant current charging.

Figure 17 also shows the waveform from a constant voltage charging to a constant current charging. When the VDAC is reduced to about 1.56 V, the output voltage then begins to fall starting at 4 V. The charging current is equal to the set value, while the effective feedback loop switches from the voltage loop to the current loop, and the charging mode changes from a constant voltage to a constant current changing.

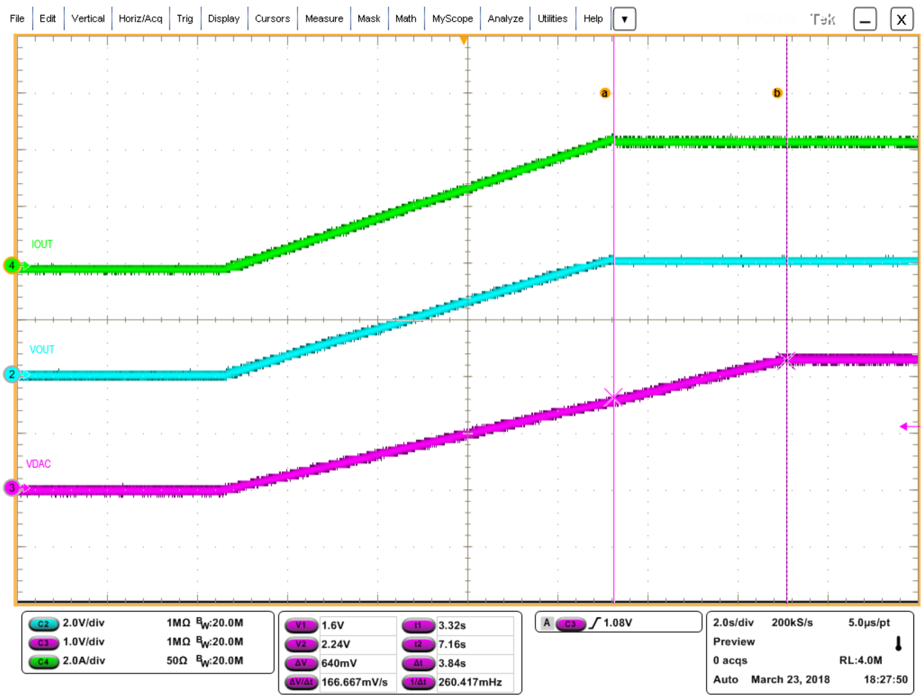

Figure 16. Transition from a Constant Current Charging to a Constant Voltage Charging

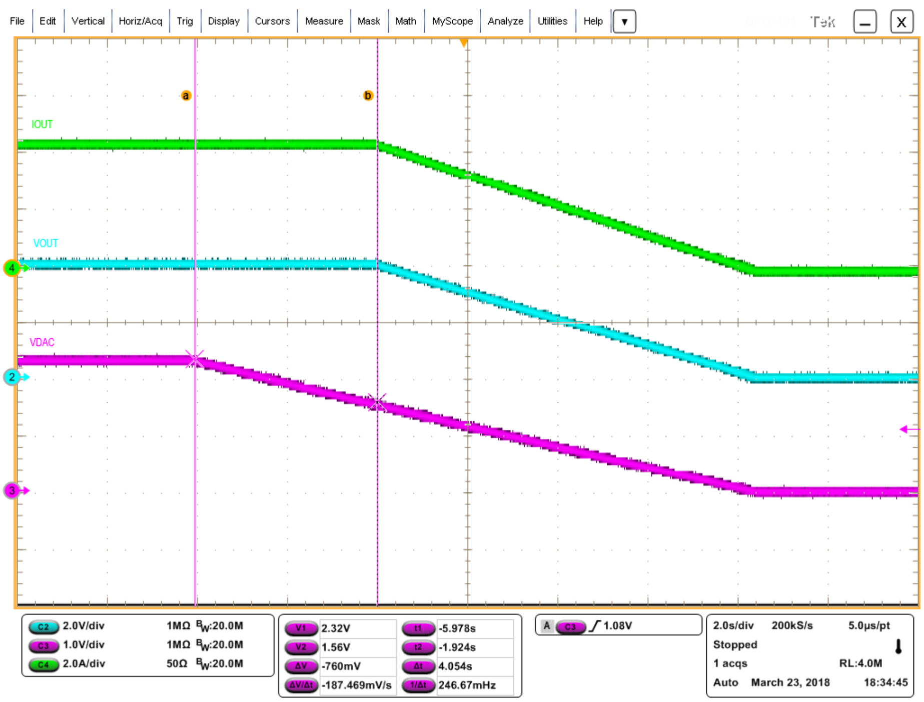

Figure 17. Transition from a Constant Voltage Charging to a Constant Current Charging

4.4 Detection Accuracy

During constant voltage charging mode, the voltage difference between the two boards is limited to 1 mV. Whereas when it is in a constant current charging mode, the current difference between the two boards is limited to 1 mA. So, this design has good consistency and meets the 1‰ accuracy requirement.

Table 2. Test Results for Voltage Loop

V_{VDAC}(V)	V_{BOARD1}(V)	V_{BOARD2}(V)	ΔV(mV)
1.4001	1.9916	1.9909	-0.7
2.2997	3.2729	3.2719	-1.0
3.0001	4.2701	4.2691	-1.0

Table 3. Test Results for Current Loop

V_{IDAC} (V)	I_{BOARD1}(A)	I_{BOARD2} (A)	ΔI (mA)
0.4008	0.9896	0.9896	0
0.8001	1.9761	1.9767	0.6
1.2001	2.9654	2.9661	0.7

5 Conclusion

This application report compares the separation solution to the integration solution, and describes how to design an integration solution using TPS54821 and TPS61178. The data and the waveforms show that this integration solution can meet the design requirements, especially the voltage and current detection accuracy.

6 References

1. Texas Instruments, *TPS54821 4.5 V to 17 V Input, 8 A Synchronous Step Down Converter with Hiccup Data Sheet*
2. Texas Instruments, *TPS61178 20-V, 10-A Fully-Integrated Synchronous Boost with Load Disconnect Control Data Sheet*
3. Texas Instruments, *Bi-Directional Battery Initialization System Power Board Reference Design*
4. Texas Instruments, *Bi-Directional Battery Initialization System Control Board Reference Design*

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from A Revision (#IMPLIED) to B Revision **Page**

- Edited application report for clarity. 2

Changes from Original (May 2018) to A Revision **Page**

- Added text updates. 1