Test Report: PMP41083

100-W Integrated USB Type-C® PD Charging Reference Design for 4- to 10-Cell Batteries

Description

This reference design is an integrated USB Type-C® power delivery (PD) and charging reference design for 4- to 10-cell batteries for applications such as power tools charger with USB Type-C port, vacuum cleaner, portable power station, and more.

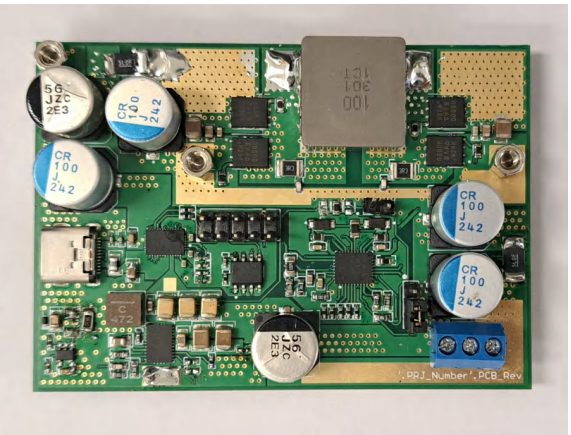
The design incorporates the TPS25751, a USB Type-C and PD controller, which integrates a fully-managed robust power path switch inside to reduce size and external components. The design is easy to configure the power specification depending on the user's application through a web-based GUI, thus reducing the design complexity. The PD controller works with the external battery charger controller BQ25756 through I2C communication. The BQ25756 supports a wide-range input with four-switch, buck-boost configuration, and supports seamless transition from buck, boost, and buck-boost operation mode to provide a highly-efficient, highly-accurate and reliable charger design. This reference design supports charging batteries with a maximum of 100 W through a USB PD3.0-compatible input source. The high integration and simple design lowers BOM cost, provides a smaller size, and reduces time to market.

Features

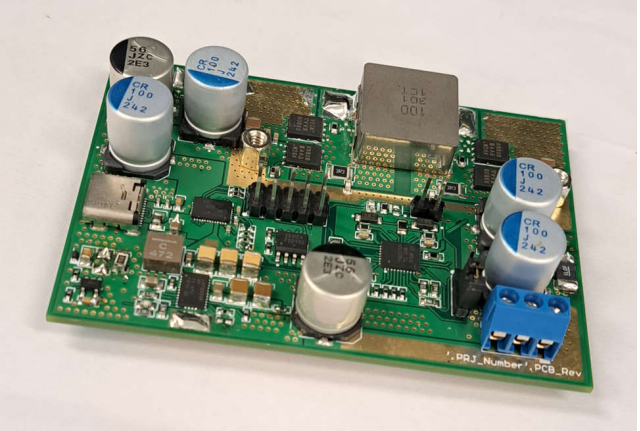
- Compatible with USB PD 3.0 protocol
- Supports 4- to 10-cell battery charging with maximum 100-W power
- High integration with integrated power path switch
- Seamless transition among buck, buck-boost, and boost to optimize efficiency across a wide input and output voltage range
- High efficiency of > 95.8% at full load

Applications

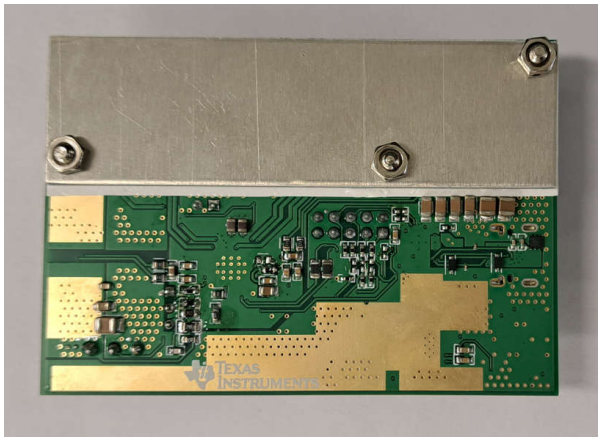
- Cordless power tool
- Vacuum robot
- Appliances: battery charger
- Cordless vacuum cleaner



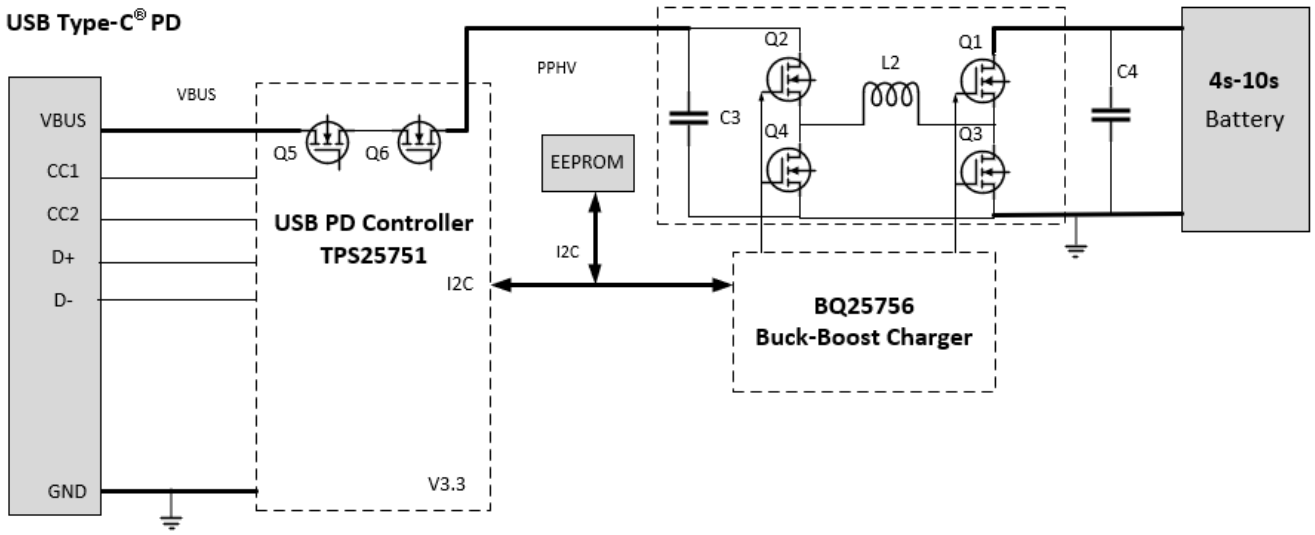
PMP41083 Top View



PMP41083 Angle View



PMP41083 Bottom View



PMP41083 Sink Only Charger Block Diagram

1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1 shows the USB Type-C PD charger specification. The PD controller negotiates a specific voltage depending on the input source. This input source is set to 5 V at 3 A, 9 V at 3 A, 15 V at 3 A, or 20 V at 5 A. Because of this variety of conditions, different profiles and charge current settings can be flashed based on the user scenario.

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
Sink voltage	5 to 20 VDC
V_{BAT} voltage range	12 V to 42 V
Cell Configurations	4 to 10 Cells
Maximum charge current	Charge current limit 3 A
Maximum power	100 W
Switching frequency	300 kHz
Efficiency	> 95% at full load

1.2 Required Equipment

The following equipment is required:

1. DC source: GWinstek, GPS-3303C
2. Bidirectional power source: IT6010C-80-300
3. 140-W USB Type-C PD adapter
4. 1-m USB Type-C cable (supports 5 A)
5. Electronic load: Chroma, 6314A
6. Oscilloscope: Tektronix, DPO 3054
7. Infrared Thermal Camera: Fluke, TiS55
8. Ture-RMS-Multimeter: Fluke, 287C
9. Digital Power Meter: Yokogawa WT310
10. TPS65987 EVM board
11. USB Type-C DUO EVM board (Sink and Source Emulator)

1.3 Considerations

The reference design shows an example of how to implement a USB Type-C PD alongside a switching battery charger that is capable of handling high power and current. This design can be used in power tool chargers, vacuum robot chargers, and portable power stations.

1.4 Dimensions

The board size of this design is 55.7 mm × 79.5 mm × 12.5 mm (open frame).

1.5 Test Setup

When performing the test, place a 470-µF, 100-V bus capacitor physically close to the output terminal to avoid long cable connections to the battery side.

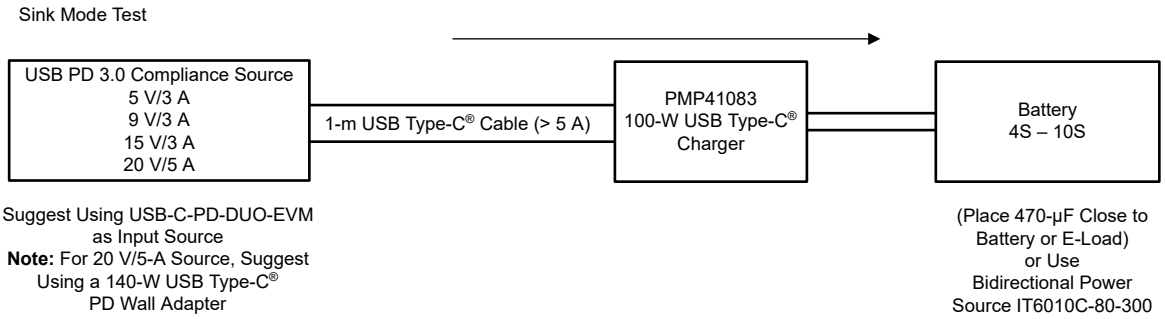


Figure 1-1. Test Setup

2 Testing and Results

2.1 Efficiency Data

Table 2-1 shows the sink mode only efficiency test across different Vsys voltages from input source as well as different battery cell conditions. The fast charge current limit is set to 3 A and input current limit is set to 3 A for 5-V, 9-V, and 15-V input source, and 5 A for 20-V input source.

Table 2-1. Sink Mode Only Efficiency Test

Battery Cell Setting	Vsys Input Voltage (V)	Vsys (V)	I_{IN} (A)	P_{IN} (W)	Vbat (V)	Ichg (A)	P_{OUT} (W)	Efficiency	Power Loss (W)
10S	5	4.65	3.033	14.10	40.41	0.302	12.20	86.53%	1.90
10S	9	8.87	3.008	26.68	40.52	0.605	24.51	91.88%	2.17
10S	15	14.95	3.006	44.94	40.62	1.037	42.12	93.73%	2.82
10S	20	19.17	4.95	94.89	40.88	2.224	90.92	95.81%	3.97
7S	5	4.65	3.031	14.09	24.49	0.518	12.69	90.01%	1.41
7S	9	8.88	3.008	26.71	24.62	1.016	25.01	93.65%	1.70
7S	15	14.96	3.005	44.95	24.78	1.73	42.87	95.36%	2.09
7S	20	19.33	3.943	76.22	25.02	2.937	73.48	96.41%	2.73
4S	5	4.66	3.032	14.13	14.6	0.889	12.98	91.86%	1.15
4S	9	8.89	3.008	26.74	14.8	1.711	25.32	94.70%	1.42
4S	15	14.96	3.006	44.97	15.02	2.88	43.26	96.19%	1.71
4S	20	19.58	2.344	45.90	14.98	2.938	44.01	95.89%	1.88

2.2 Efficiency Graphs

Efficiency data is shown in the following graphs.

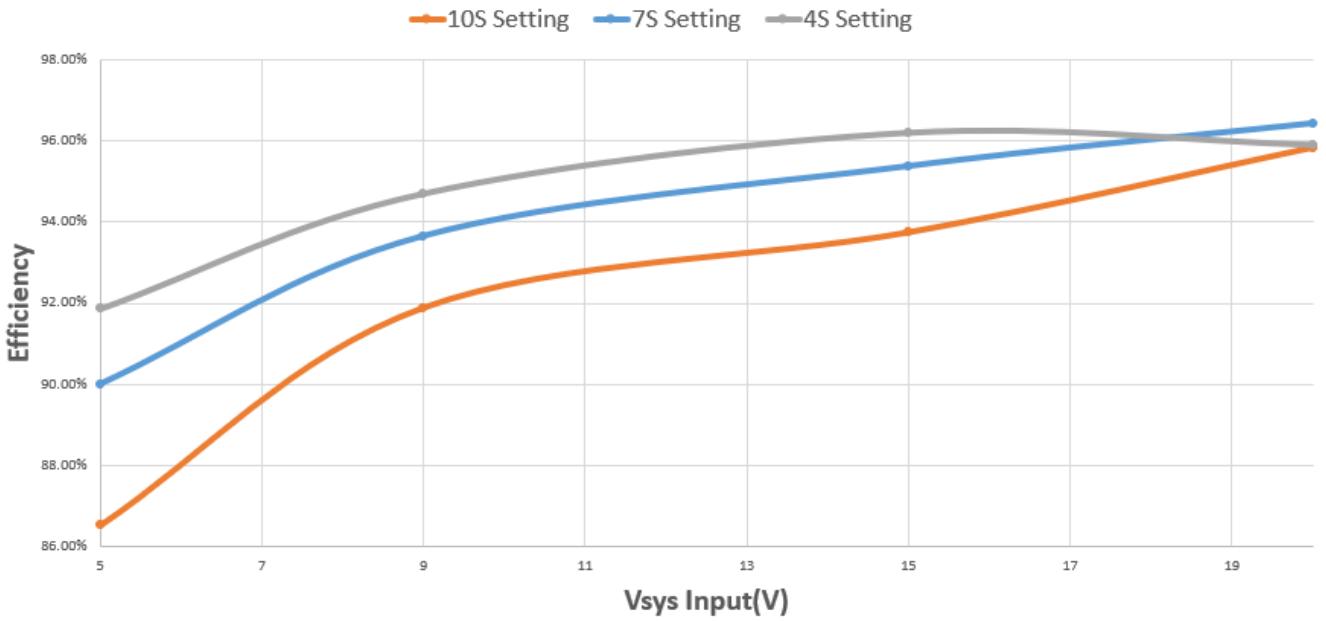


Figure 2-1. Efficiency Across Vsys and Vbat

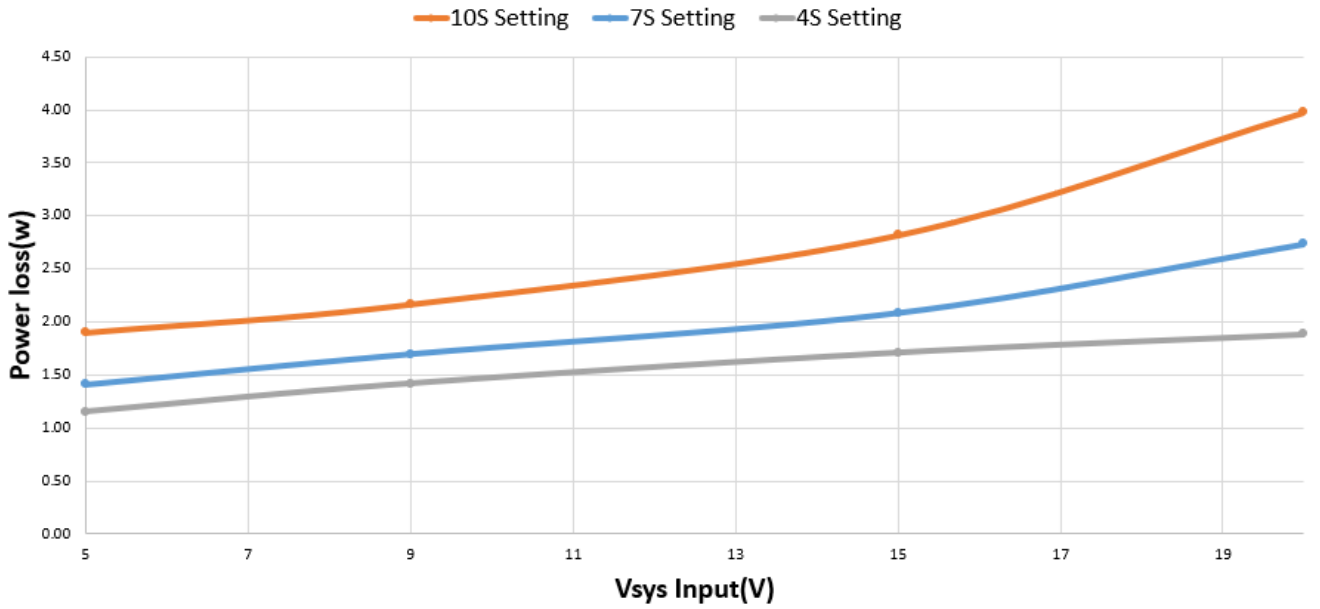


Figure 2-2. Power Loss Across Different Vsys and Vbat Condition

2.3 Thermal Images

Table 2-2 shows the thermal images at fast charge mode at maximum power condition for each battery cell condition. All image were captured with 25ºC ambient, after a 30-minute warm up.

Table 2-2. Thermal Results: Fast Charge Mode at Maximum Power Conditions for Each Battery Cell Condition

Temperature (°C)	Test Condition		
Component	**20 Vsys and 10S Full-Load Charging**	**20 Vsys and 7S Full-Load Charging**	**20 Vsys and 4S Full-Load Charging**
Q2 (Vsys high side)	63.2°C	50.4°C	46.2°C
Q4 (Vsys low side)	61.4°C	49.3°C	44.2°C
Q1(Vbat high side)	67.3°C	53.4°C	42.3°C
Q3 (Vbat low side)	75.6°C	57.2°C	40.4°C
Buck-Boost Inductor	66.5°C	51.2°C	42.1°C
TPS25751	74.5°C	64.5°C	57.2°C
BQ25756	56.2°C	50.3°C	45.2°C
Rsense (Input)	61.5°C	47.8°C	43.2°C
Rsense (CHG)	52.6°C	42.3°C	40.2°C

Figure 2-3 through Figure 2-5 illustrate the thermal images at three different conditions.

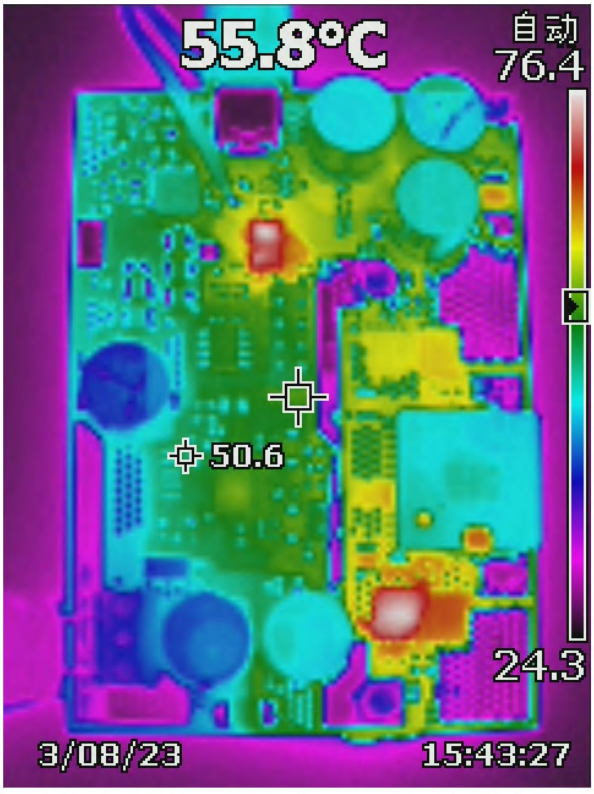


Figure 2-3. Charge Mode Thermal 20 Vsys to 10S Vbat

Figure 2-4. Charge Mode Thermal 20 Vsys to 7S Vbat

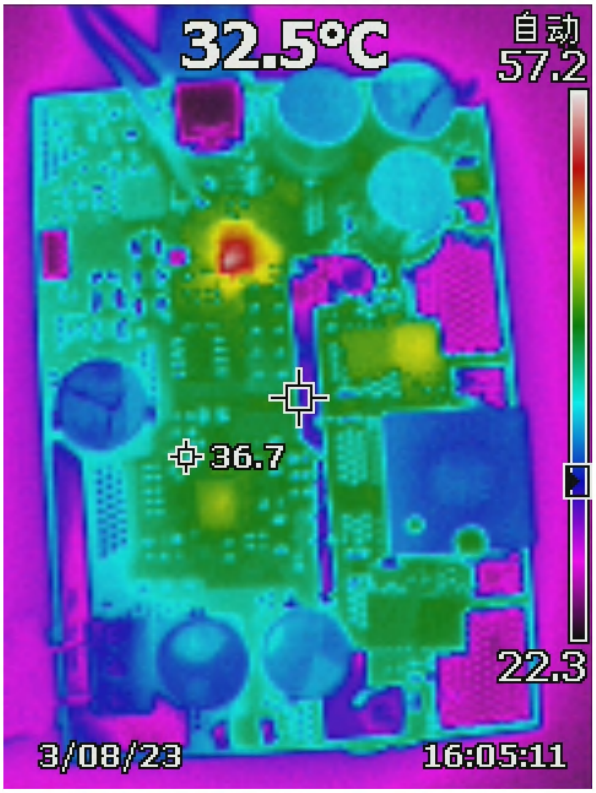


Figure 2-5. Charge Mode Thermal 20 Vsys to 4S Vbat

3 Waveforms

3.1 Charging Waveform

Below shows the charging waveform with different Input source voltage negotiated on USB Type C port. Input source voltage, battery voltage as well as charge current were captured during the test.

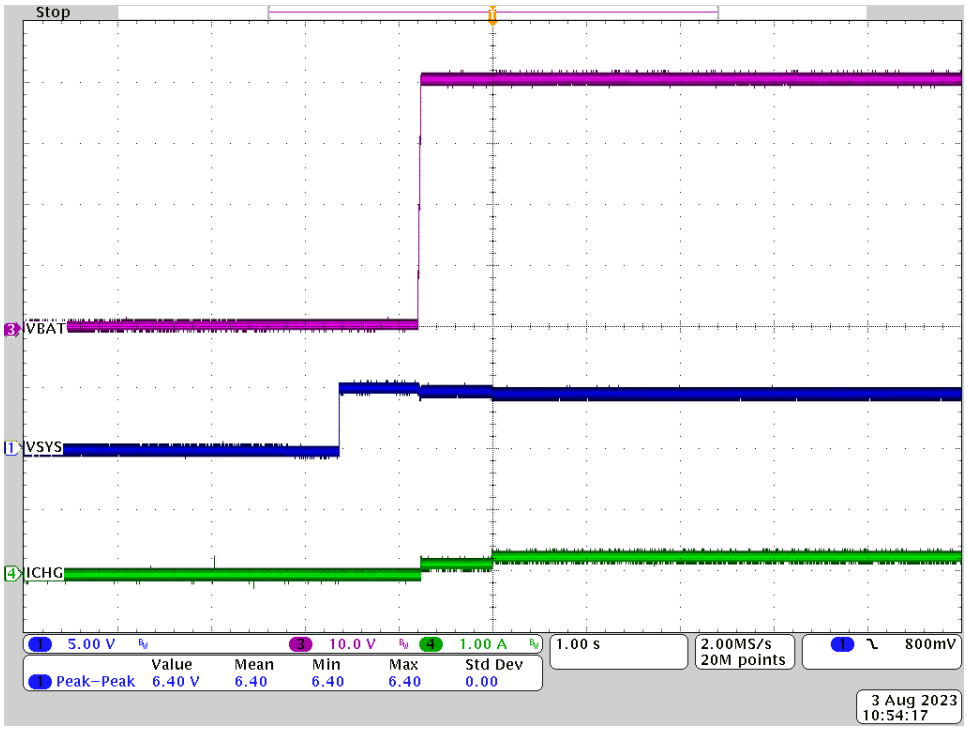


Figure 3-1. 5 Vsys to 10S BAT = 40-V Charge Mode 3.75

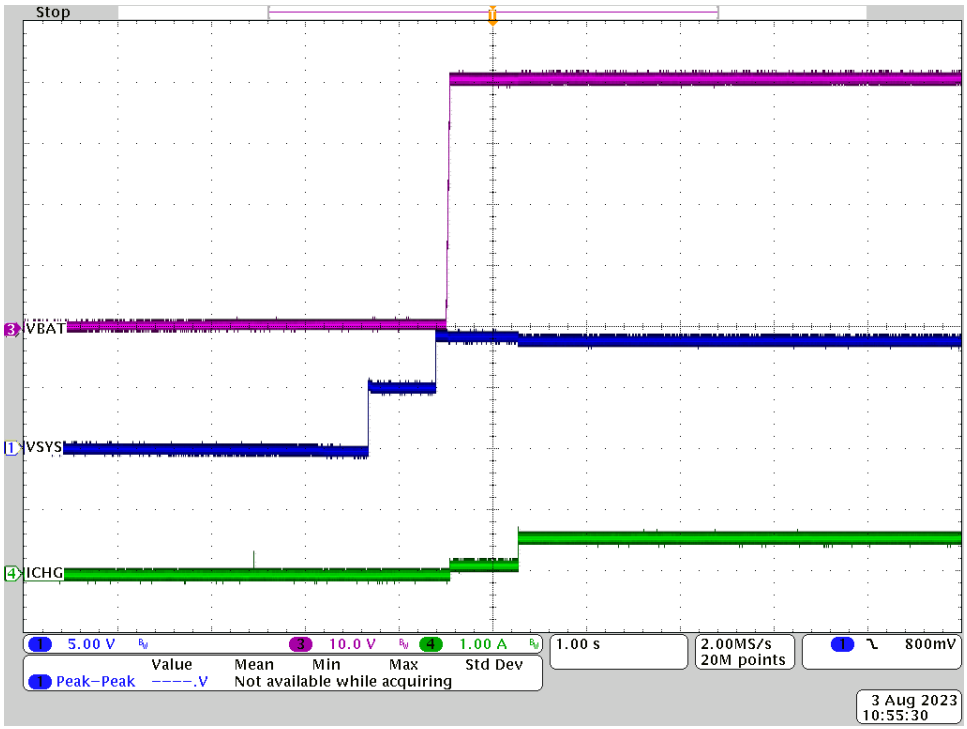


Figure 3-2. 9 Vsys to 10S BAT = 40-V Charge Mode

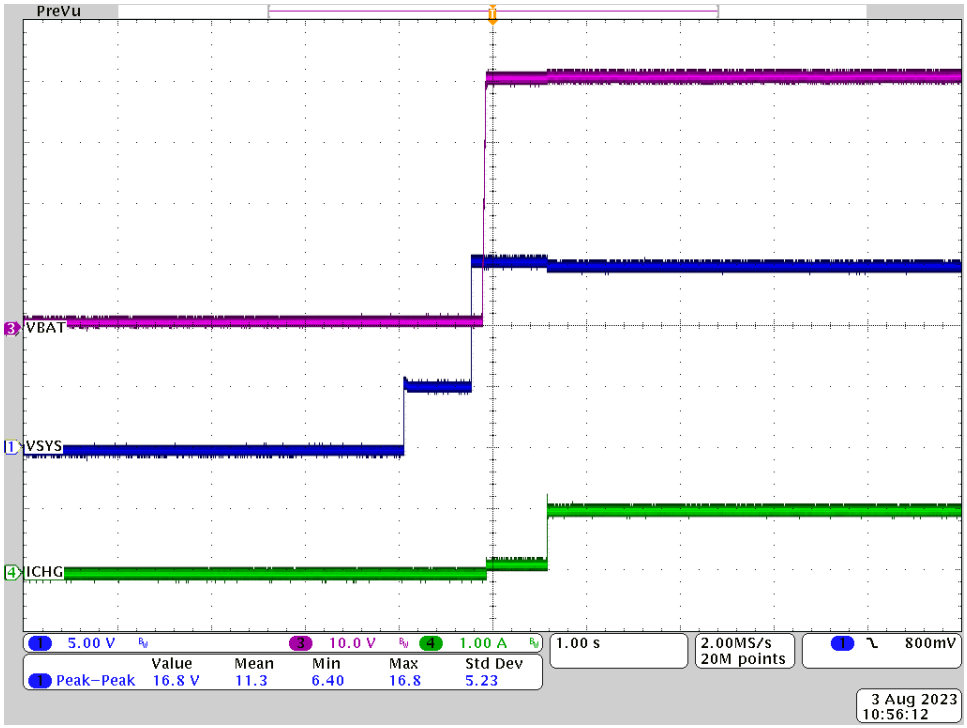


Figure 3-3. 15 Vsys to 10S BAT = 40-V Charge Mode

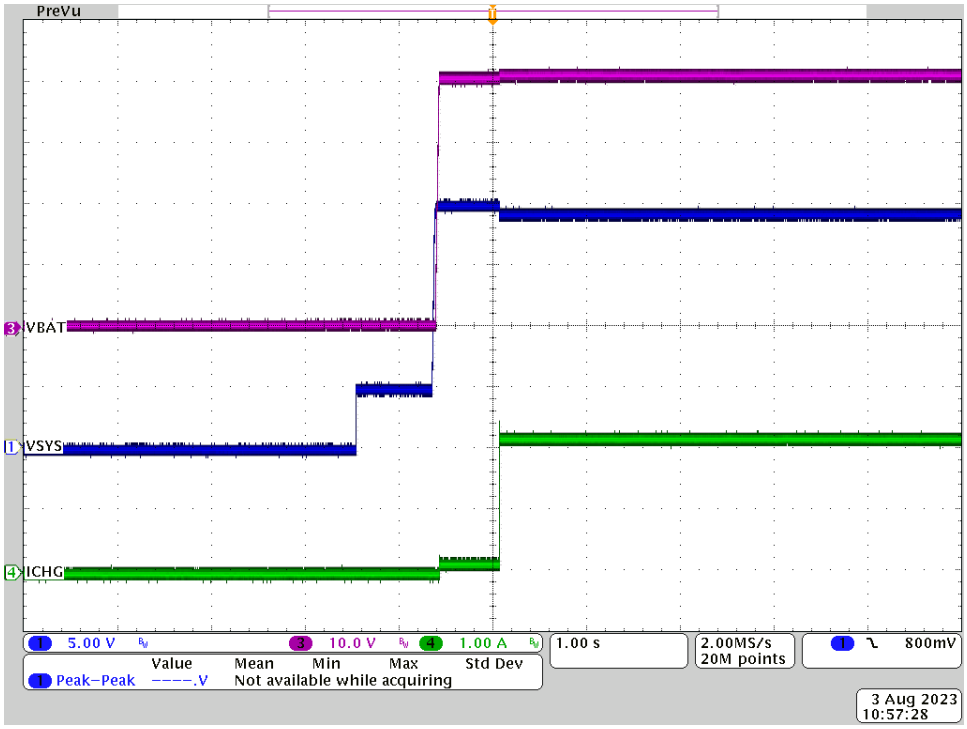
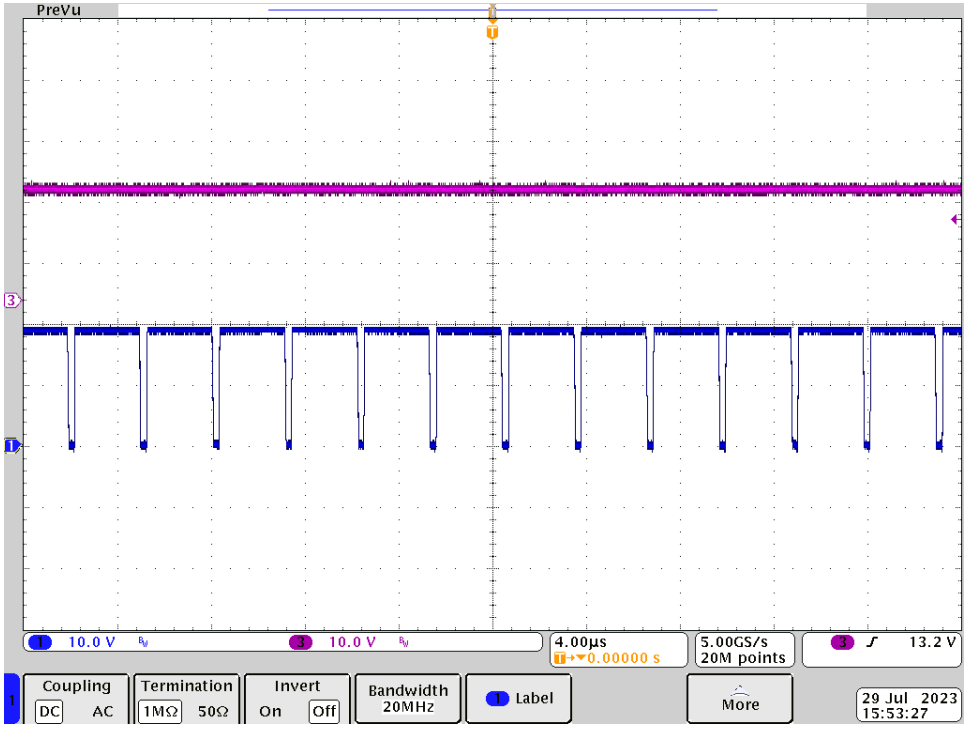


Figure 3-4. 20 Vsys to 10S BAT = 40-V Charge Mode

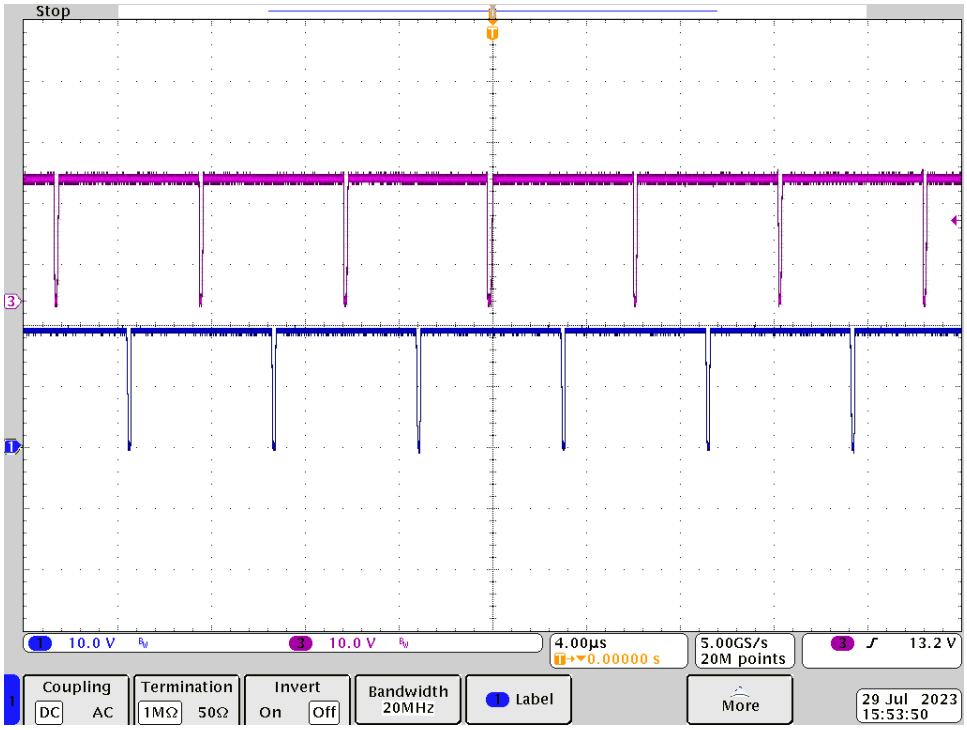
3.2 Switching Waveform

Figure 3-5 through Figure 3-8 show the power stage waveform at different working modes in the BQ25756 device among buck mode, buck-boost mode, and boost mode with seamless transition. The switching frequency is set to 300 kHz.



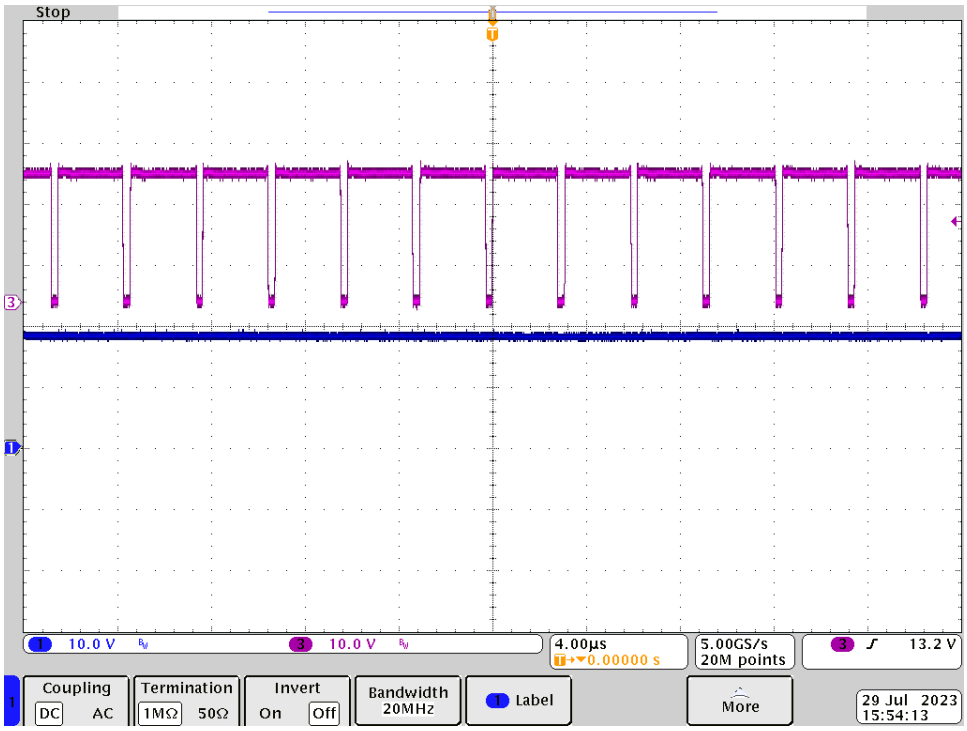
Blue: buck leg SW point, Purple: boost leg SW point

Figure 3-5. Buck Mode



Blue: Buck Leg SW point, Purple: Boost leg SW Point

Figure 3-6. Buck-Boost Mode



Blue: buck leg SW point, Purple: boost leg SW point

Figure 3-7. Boost Mode

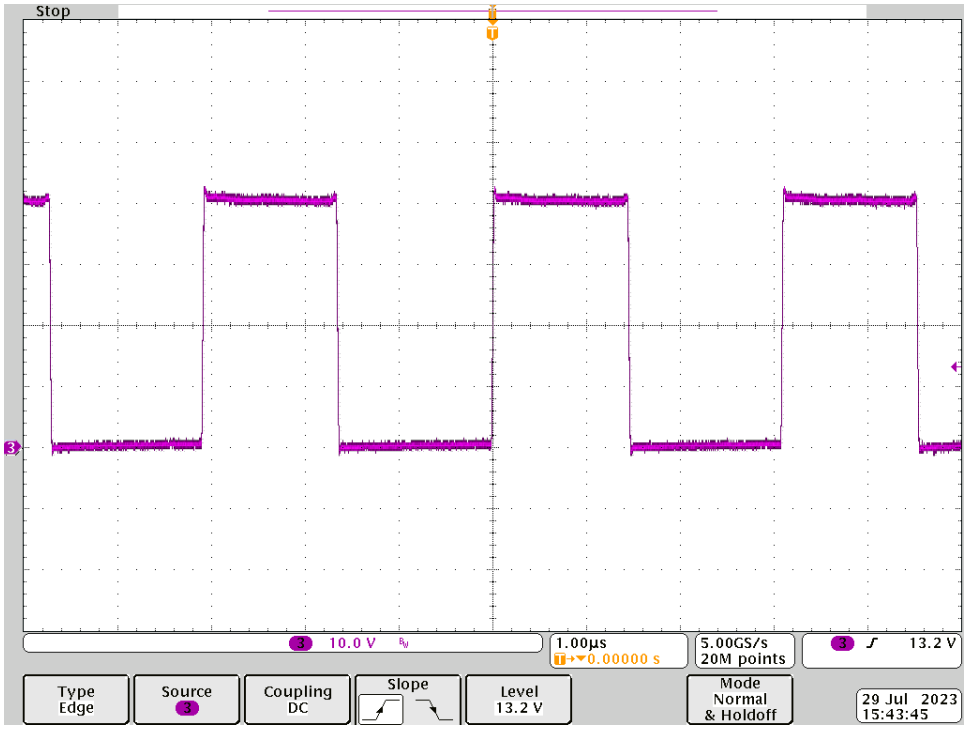


Figure 3-8. Switching Leg Waveform at Vsys = 20 V, Vbat = 40-V Fast Charging Mode, f_{SW} = 300 kHz

3.3 Short-Circuit Protection

Figure 3-9 and Figure 3-10 show the short-circuit protection and recovery waveform, once the battery voltage falls below Vbat_short (2.5 V), the device is forced into PFM mode, and current is reduced to around 200 mA. Once the battery short is removed, it recovers to normal operation.

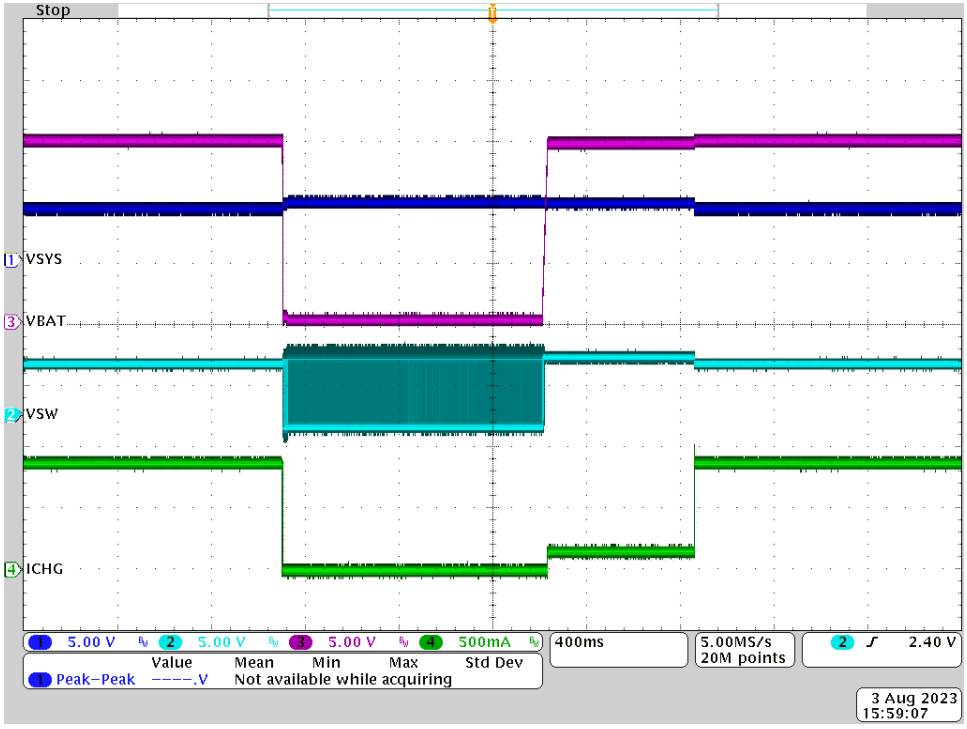


Figure 3-9. Short-Circuit Protection and Recovery

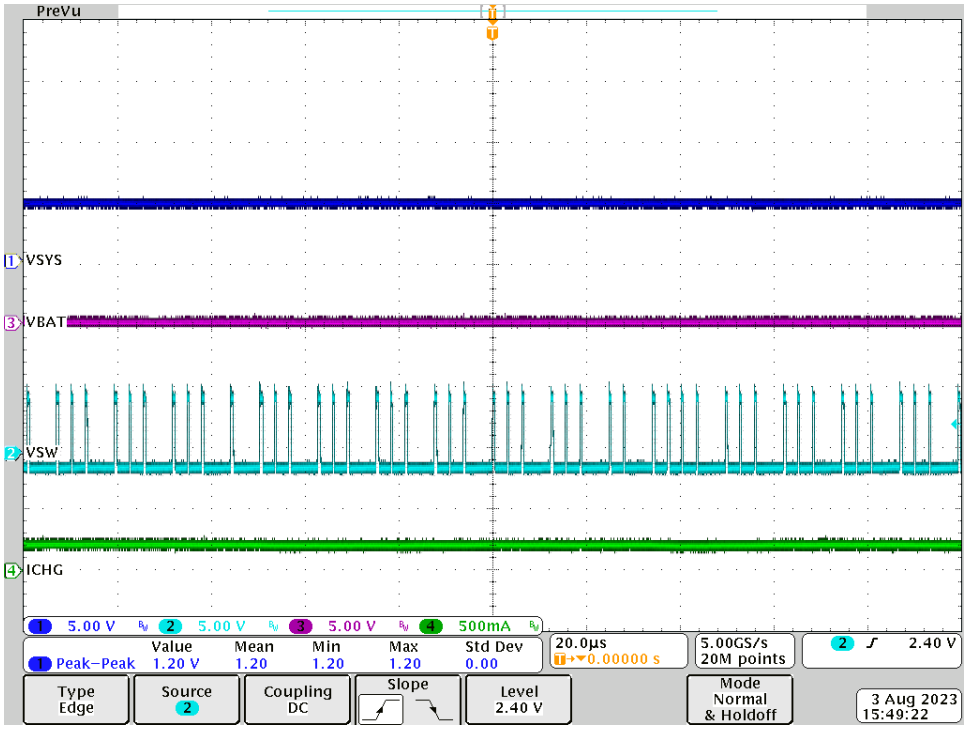


Figure 3-10. Zoom Waveform During SCP

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