Test Report: PMP41100

27W Integrated USB Type-C® PD Sink-Only Charger Reference Design for 4- to 7-Cell Batteries

Description

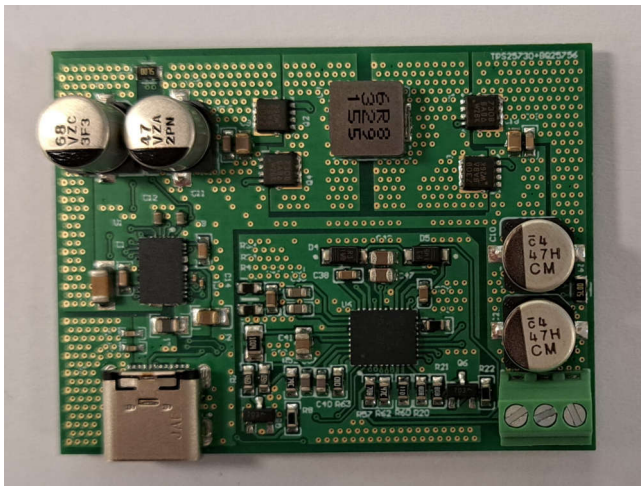
This reference design is a low cost and highly-integrated stand-alone USB Type-C® power delivery (PD) charger reference design for 4- to 7-cell, 900mA battery chargers for applications such as power tool chargers, vacuum cleaners with USB Type-C port input, and so forth. The design incorporates the TPS25730D, a highly-integrated USB Type C PD controller, which includes a fully-managed robust power path switch inside and removes the external E^2PROM without firmware effort, using a simple resistor string to configure the power profile. The BQ25756E 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 high efficiency, reliable charger design and achieve 96% peak efficiency.

Features

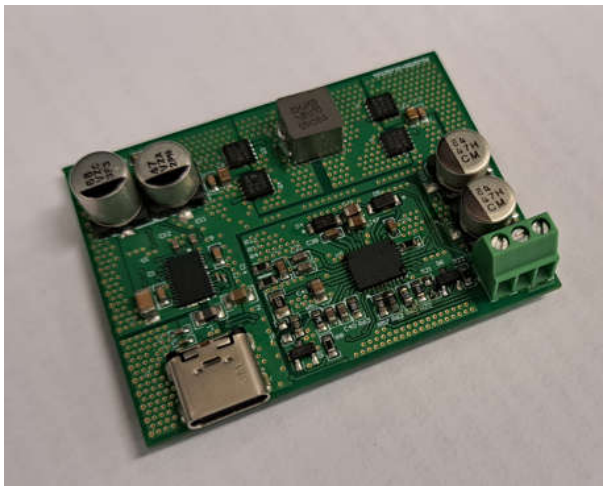
- Supports 4- to 7-cell battery charging with 900mA charger current
- Simple power profile configuration with resistor string without firmware
- Compatible with USB-C PD 3.0 Power Protocol
- High integration of power path switch
- Seamless mode transition to optimize efficiency across a wide input and output range
- 96% Peak efficiency

Applications

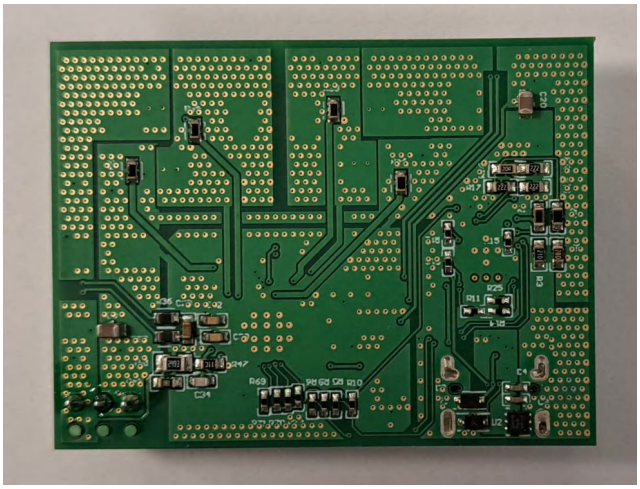
- Cordless power tool
- Vacuum robot
- Battery charger
- Cordless vacuum cleaner



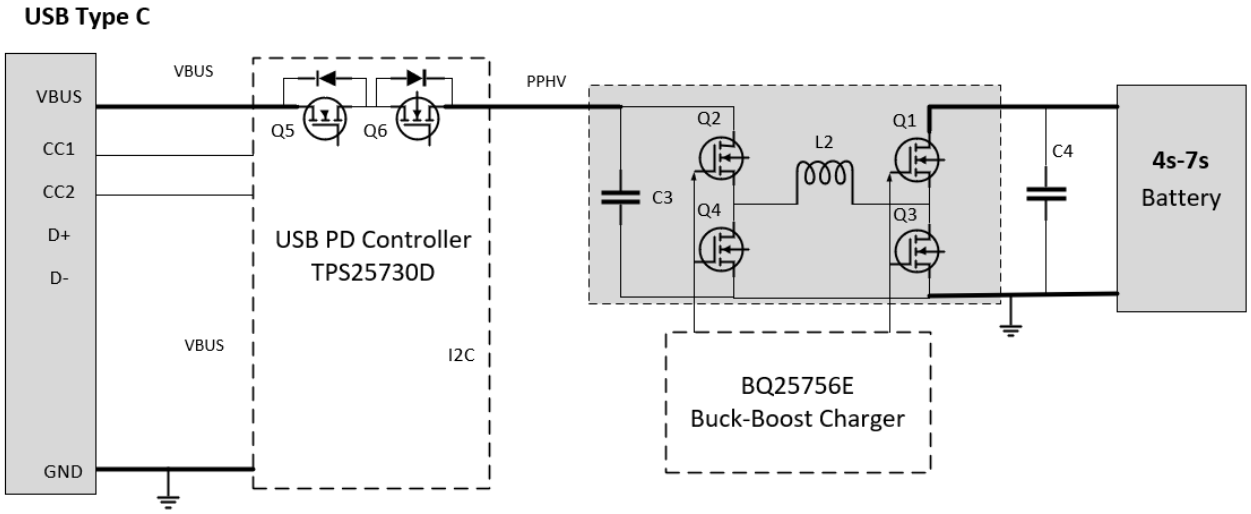
Top of Board



Top Angled View



Bottom of Board



Block Diagram

1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
Sink voltage range	5V–20V
Source voltage and current range	For USB PD source: 5V, 3A,9V, 3A, 15V, 3A, 20V, 3A For Non-USB PD source such as legacy AC-DC 5V, 2A charger
Battery Cell Configuration	4–7 cells
Battery voltage	16V–31.5V
Maximum charge current	900mA
Maximum power	27W
Switching frequency	300kHz
Efficiency	96% peak

1.2 Required Equipment

The following equipment is required:

- DC source: GWinstek, GPS-3303C
- Bidirectional Power Source: IT6010C-80-300
- USB Type-C DUO EVM board (Sink and Source Emulator)
- 5V, 2A AC-DC Charger (Non-USB PD Source)
- 45cm USB Type-C Cable
- Electronic load: Chroma, 6314A
- Oscilloscope: Tektronix, DPO 3054
- Infrared Thermal Camera: Fluke, TiS55
- True-RMS-Multimeter: Fluke, 287C
- Digital Power Meter: Yokogawa WT310
- USB Type C DUO EVM board (Sink and Source Emulator)

1.3 Dimensions

The PCB board size is 37.4mm × 49.7mm × 6.1mm.

1.4 Test Setup

Place a 470µF, 100V bus capacitor physically close to the output terminal to avoid long cable connection to the battery side when performing the test.

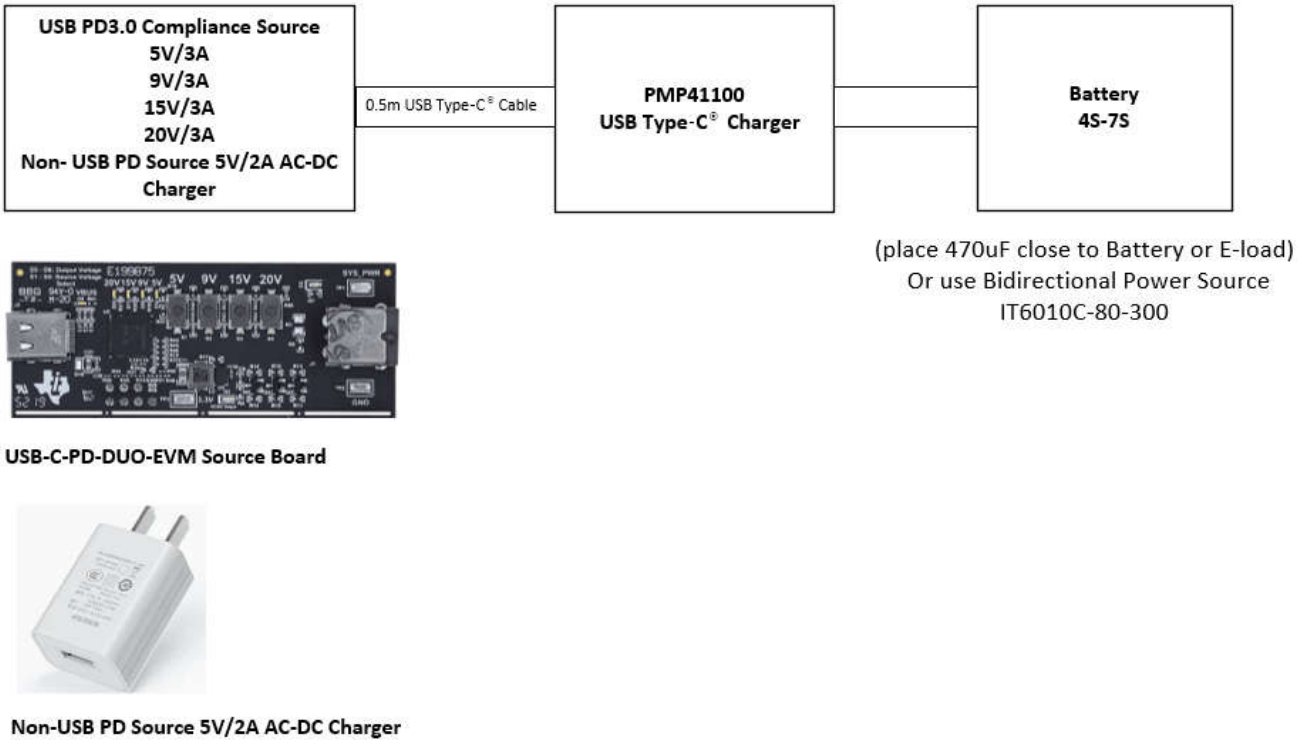


Figure 1-1. Test Setup

2 Testing and Results

2.1 Efficiency Graphs

Figure 2-1 through Figure 2-3 show the efficiency across different input voltage and battery cell conditions.

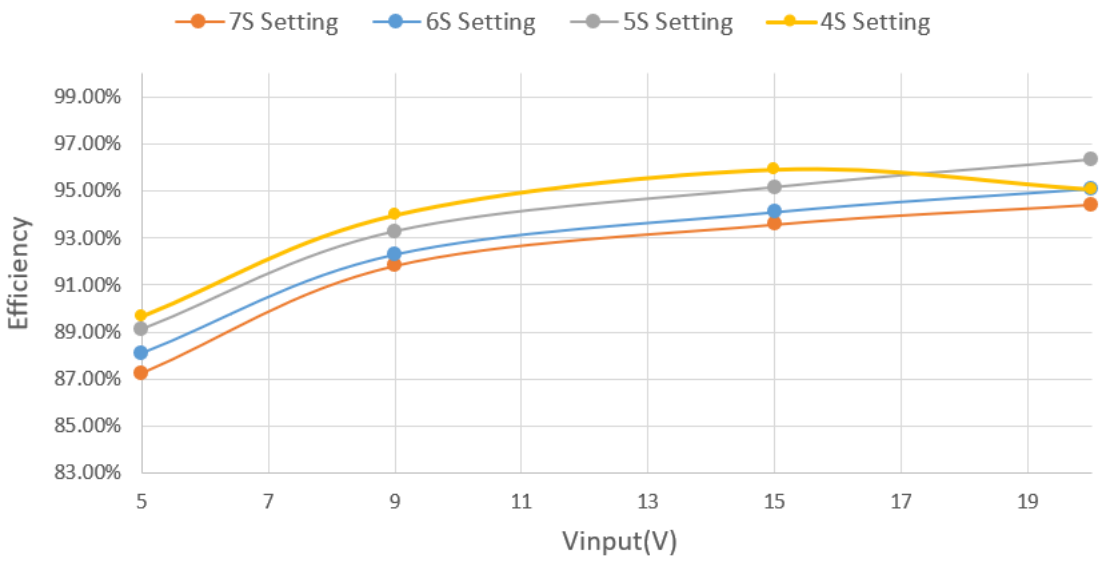


Figure 2-1. Efficiency Across Input Voltage and Battery Voltage

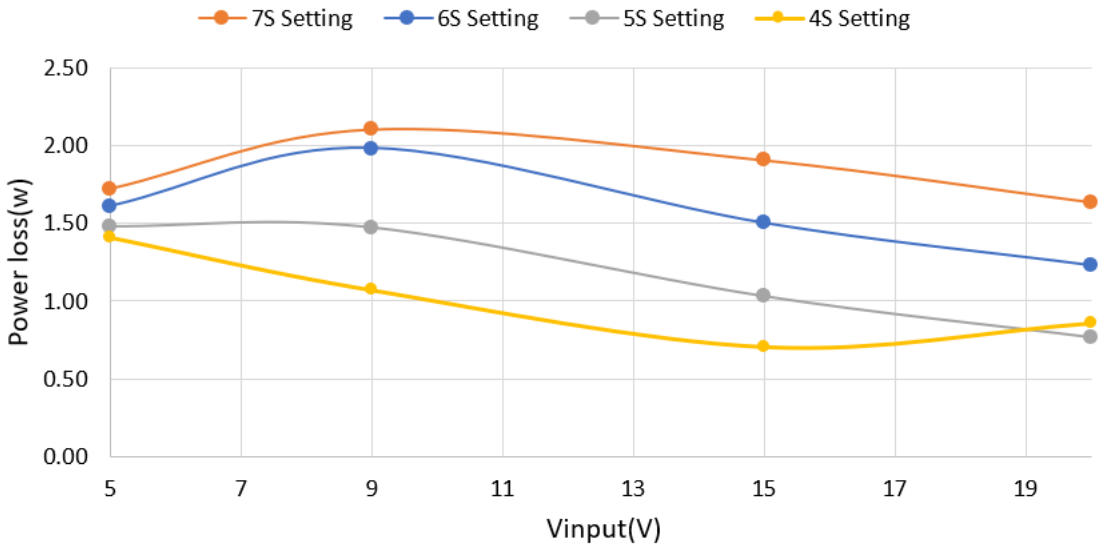


Figure 2-2. Power Loss Across V_{IN} and Battery Voltage

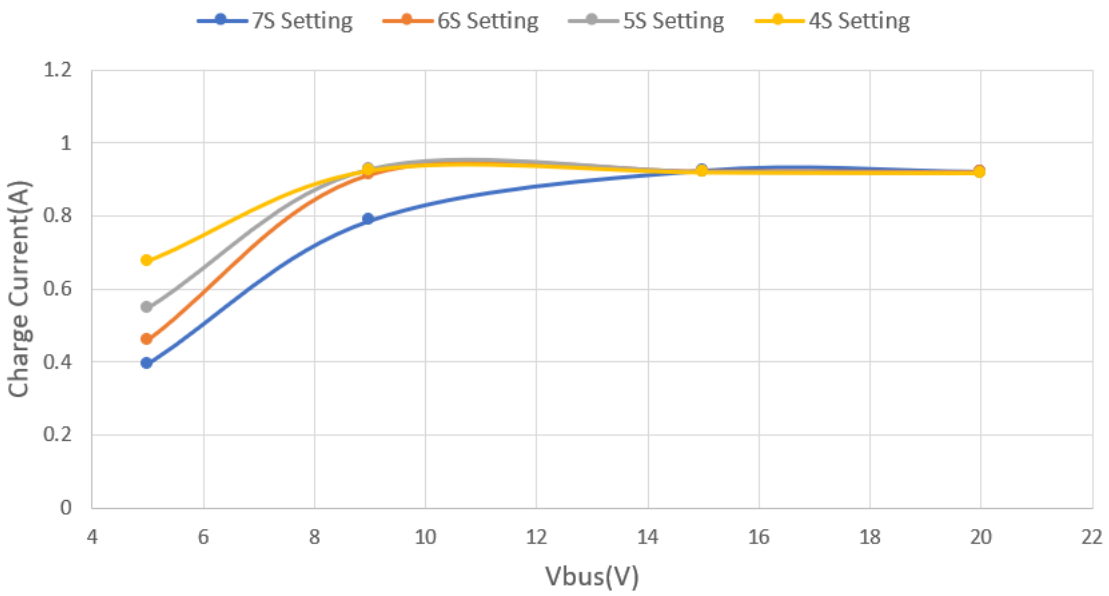


Figure 2-3. Charge Current Across V_{IN} and Battery Voltage

2.2 Efficiency Data

Table 2-1 shows the efficiency data.

Table 2-1. Test With USB PD Input Source

Input Source	Battery Setting	V_{IN} (V)	I_{IN} (A)	P_{IN} (W)	V_{OUT} (V)	I_{CHARGE} (A)	P_{OUT} (W)	Efficiency (%)	P_{LOSS} (W)
5V, 3A	7S	4.60	2.9403	13.53	30.03	0.393	11.80	87.26	1.72
9V, 3A	7S	8.84	2.9152	25.77	30.03	0.788	23.66	91.82	2.11
15V, 3A	7S	15.09	1.9692	29.72	30.03	0.926	27.81	93.58	1.91
20V, 3A	7S	19.92	1.4736	29.35	30.03	0.923	27.72	94.43	1.64
5V, 3A	6S	4.61	2.9411	13.53	26.02	0.458	11.92	88.09	1.61
9V, 3A	6S	8.83	2.9181	25.77	26.02	0.914	23.78	92.30	1.98
15V, 3A	6S	15.11	1.689	25.52	26.02	0.923	24.02	94.11	1.50
20V, 3A	6S	19.99	1.2605	25.20	26.02	0.921	23.96	95.11	1.23
5V, 3A	5S	4.61	2.9435	13.57	22.02	0.549	12.09	89.09	1.48
9V, 3A	5S	8.93	2.4558	21.93	22.02	0.929	20.46	93.28	1.47
15V, 3A	5S	15.18	1.4054	21.33	22.02	0.922	20.30	95.16	1.03
20V, 3A	5S	20.07	1.0465	21.00	22.02	0.919	20.24	96.35	0.77
5V, 3A	4S	4.61	2.9473	13.59	18.02	0.676	12.18	89.66	1.41
9V, 3A	4S	9.01	1.9687	17.74	18.02	0.925	16.67	93.97	1.07
15V, 3A	4S	15.22	1.1357	17.29	18.02	0.920	16.58	95.91	0.71
20V, 3A	4S	20.14	0.864	17.40	18.02	0.918	16.54	95.07	0.86

Table 2-2. Test With Non-USB PD Source Such as 5V, 2A Legacy AC/DC Wall Charger

Input Source	Battery Setting	V_{IN} (V)	I_{IN} (A)	P_{IN} (W)	V_{OUT} (V)	I_{CHARGE} (A)	P_{OUT} (W)	Efficiency (%)	P_{LOSS} (W)
5V, 2A Non-USB PD Source	7S	4.263	2.406	10.26	30.03	0.295	8.86	86.37	1.40
5V, 2A Non USB PD Source	6S	4.262	2.405	10.25	26.02	0.345	8.98	87.58	1.27
5V, 2A Non USB PD Source	5S	4.259	2.404	10.24	22.02	0.413	9.09	88.82	1.14
5V, 2A Non-USB PD Source	4S	4.260	2.404	10.24	18.02	0.509	9.17	89.55	1.07

2.3 Thermal Images

Table 2-3 shows the thermal images at full power charge. All images were captured with 25ºC ambient, after a 30-minute warm up.

Table 2-3.

Temperature(°C)	Test Condition				
	$5V_{IN}$ to 30V Battery Charge	$9V_{IN}$ to 30V Battery Charge	$15V_{IN}$ to 30V Battery Charge	$20V_{IN}$ to 30V Battery Charge	Short Circuit Test Temperature Rise at $20V_{IN}$
Q2 (Buck High side MOS)	58.1	69.2	66.2	60.2	51.5
Q4 (Buck Low side MOS)	56.2	66.3	64.2	58.3	54.5
Q1 (Boost High side MOS)	65.2	75.3	72.7	66.2	42.4
Q3 (Boost Low side MOS)	77.2	83.4	78.3	73.4	42.3
Buck Boost Inductor	55.4	66.2	69.2	58.3	44.6
TPS25730D	40.2	45.2	47.5	46.1	42.1
BQ25756E	45.2	51.2	56.2	57.3	45.6

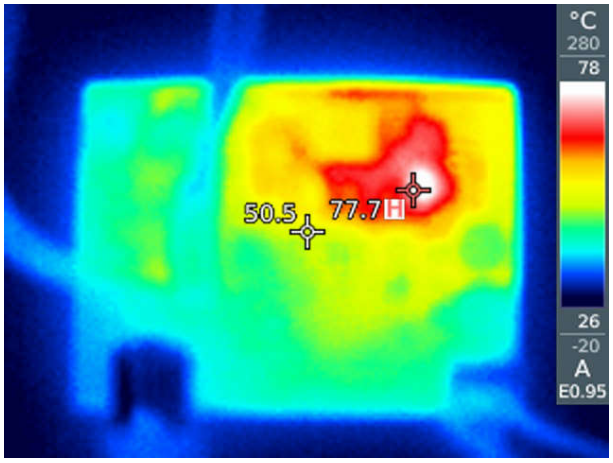


Figure 2-4. $5V_{IN}$ to 30V Battery Charge Thermal

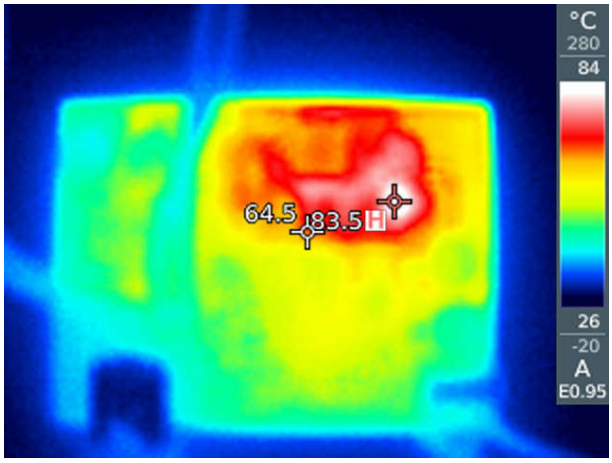


Figure 2-5. $9V_{IN}$ to 30V Battery Charge Thermal

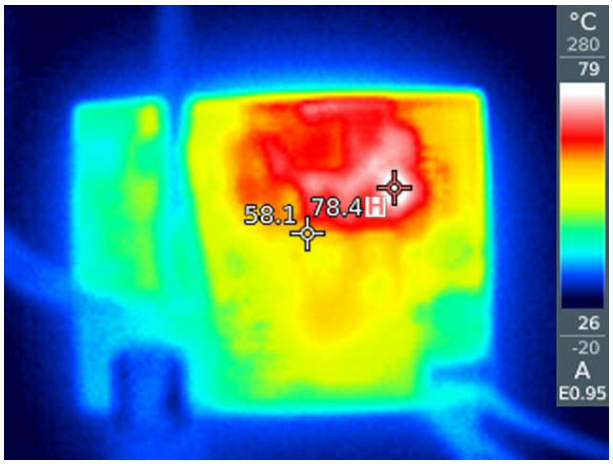


Figure 2-6. $15V_{IN}$ to 30V Battery Charge Thermal

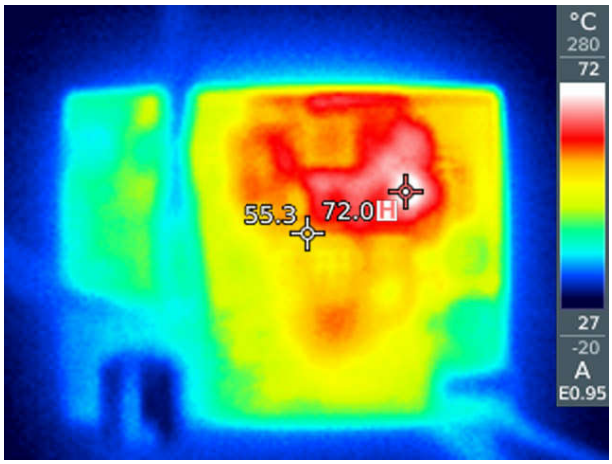


Figure 2-7. $20V_{IN}$ to 30V Battery Charge Thermal

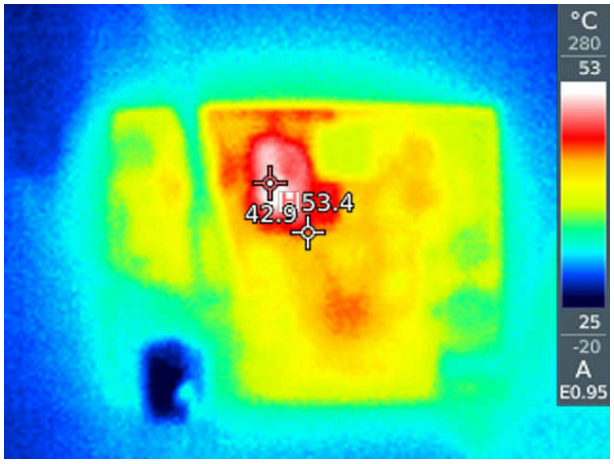


Figure 2-8. 20V_{IN} to 30V Battery Short Circuit Thermal Test

3 Waveforms

3.1 Start-Up Sequence

Figure 3-1 through Figure 3-4 show the charging waveform with input source voltage, battery voltage, and charge current in start-up and steady state.

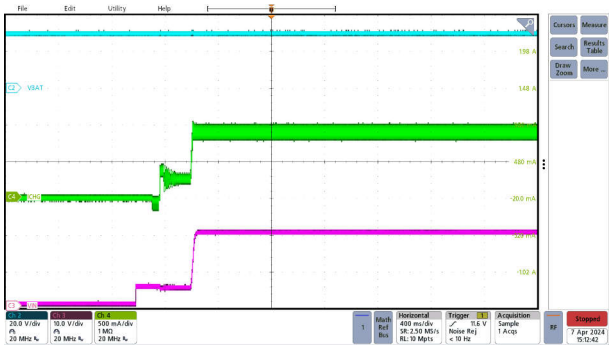


Figure 3-1. 20V, 3A Input Source to 7S Battery 30V, 900mA Charge

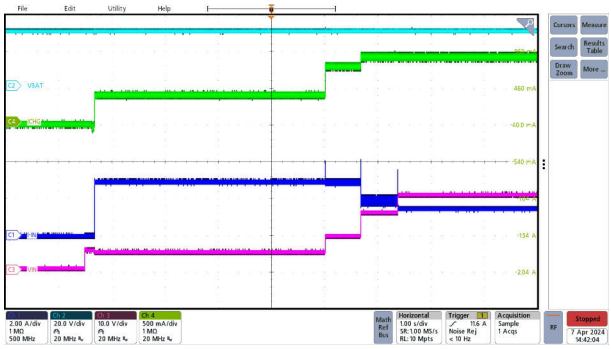


Figure 3-2. Input Source Voltage Transition up From 5V to 9V, 15V, 20V USB PD Source Charge 7S Battery 30V, 900mA

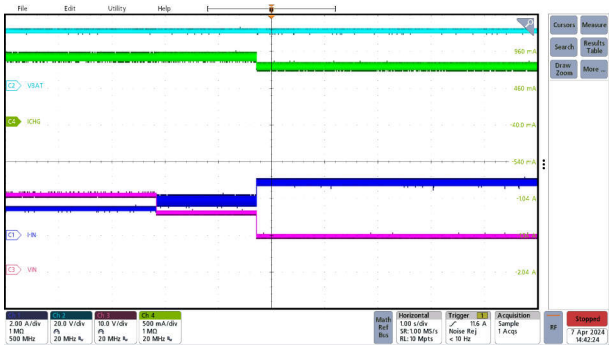


Figure 3-3. Input Source Voltage Transition Down From 20V to 15V, 9V Charge 7S Battery 30V, 900mA

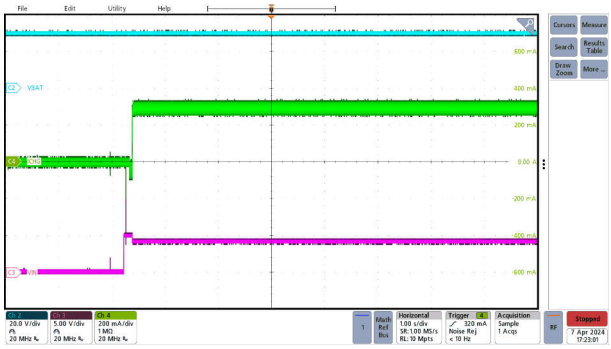


Figure 3-4. 5V, 2A Non-USB PD Input Source Charge 7S Battery 30V, Input Voltage Dynamic Power Management Works, Charge Current Reduced to 300mA

3.2 Switching

Figure 3-5 through Figure 3-10 show the power stage waveform at different working modes in BQ25756E among buck mode, buck-boost mode, and boost mode with seamless transition. The switching frequency is set to 300kHz.

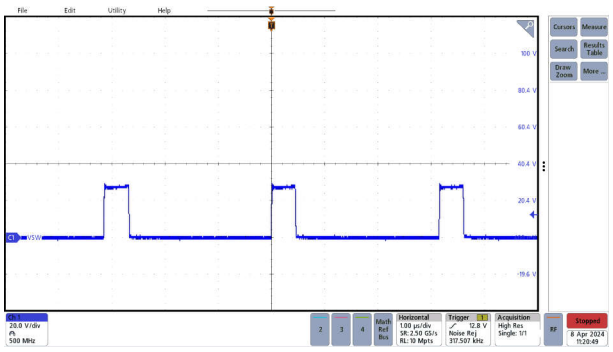


Figure 3-5. Boost Mode Switching Node Waveform V_{IN} = 5V, Battery Voltage = 30V

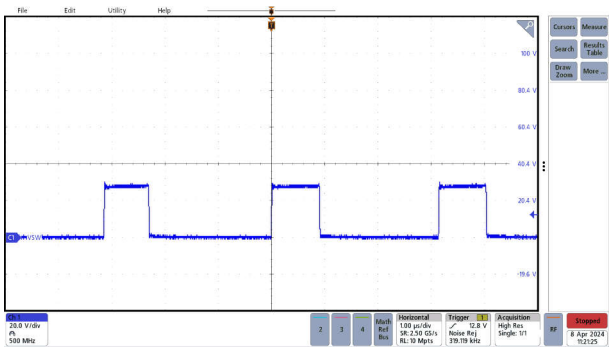


Figure 3-6. Boost Mode Switching Node Waveform V_{IN} = 9V, Battery Voltage = 30V

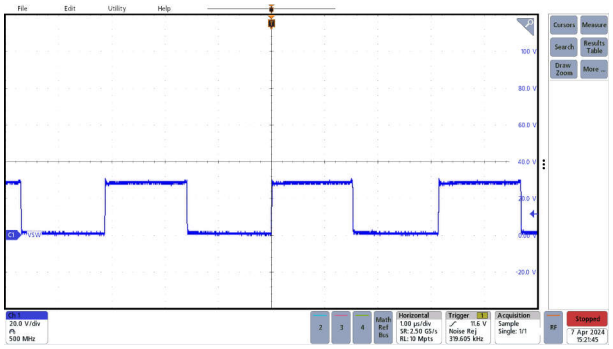


Figure 3-7. Boost Mode Switching Node Waveform V_{IN} = 15V, Battery Voltage = 30V

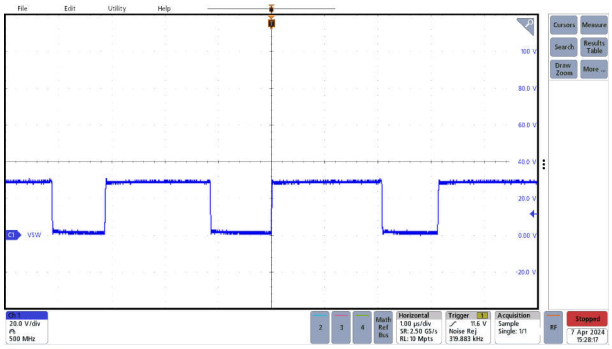


Figure 3-8. Boost Mode Switching Node Waveform V_{IN} = 20V, Battery Voltage = 30V

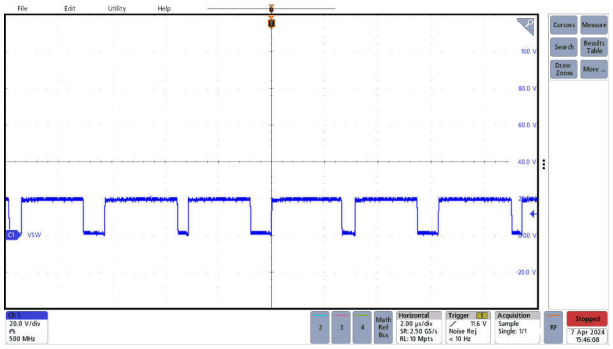


Figure 3-9. Buck Mode Switching Node Waveform V_{IN} = 20V, Battery Voltage = 16V

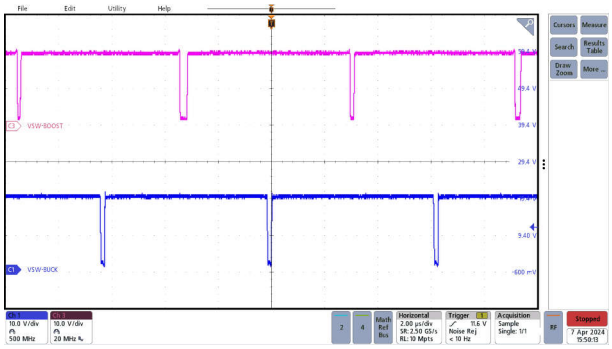


Figure 3-10. Buck-Boost Mode Switching Node Waveform V_{IN} = 20V, Battery Voltage = 20V

3.3 Short-Circuit Protection

Figure 3-11 shows the short-circuit protection waveform.

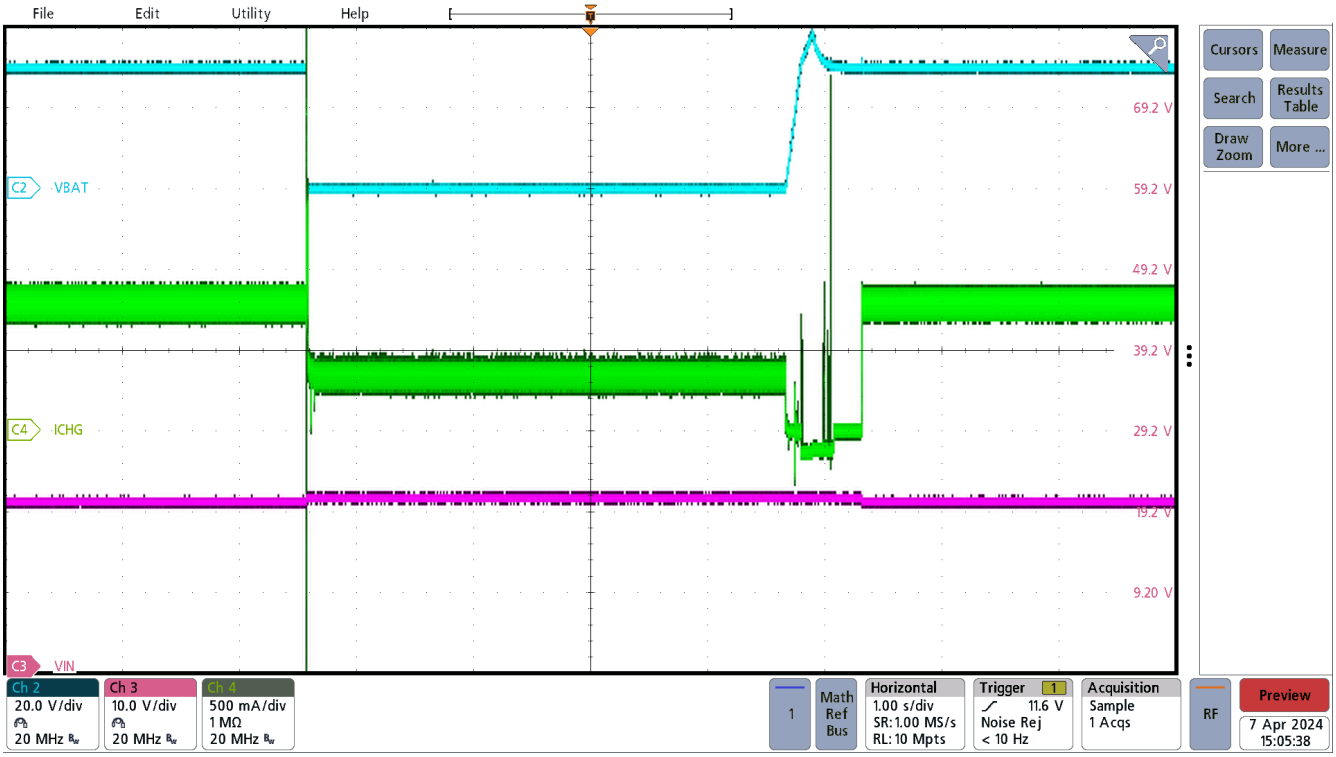


Figure 3-11. Short-Circuit Protection and Recovery at $20V_{IN}$ and 30V Battery Condition

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