Test Report: PMP41062

100W Integrated USB Type-C® PD Bidirectional Charger 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 tool chargers with a USB Type-C port, vacuum cleaners, portable power stations, and more.

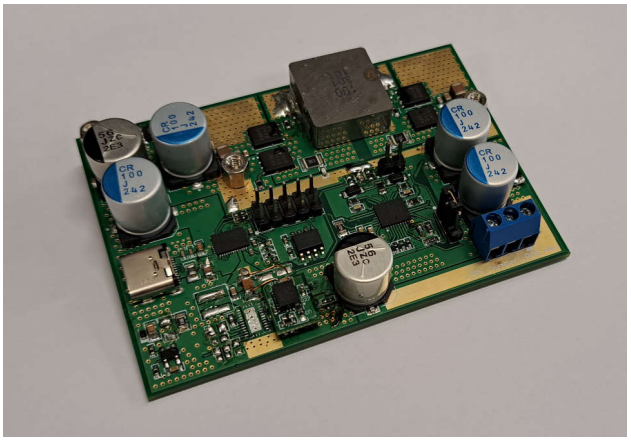
The design incorporates the TPS25751 highly-integrated USB Type-C PD controller, which integrates a fully-managed robust power path switch inside to reduce size and external component. Configuring the power specification is easy, depending on the user's application through a web-based GUI, thus reducing 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, reliable charger. In addition to charging, the BQ25756 also support USB On-the-Go (OTG) mode with 5V, 9V, 15V, and 20V which is compatible with USB PD 3.0. This reference design can support charging batteries with maximum of 100W through a USB PD 3.0 compliance input source and provide a maximum 20V at 5A output in OTG mode. The high integration and simple design leads to lower BOM cost, a smaller size, and reduces time to market.

Features

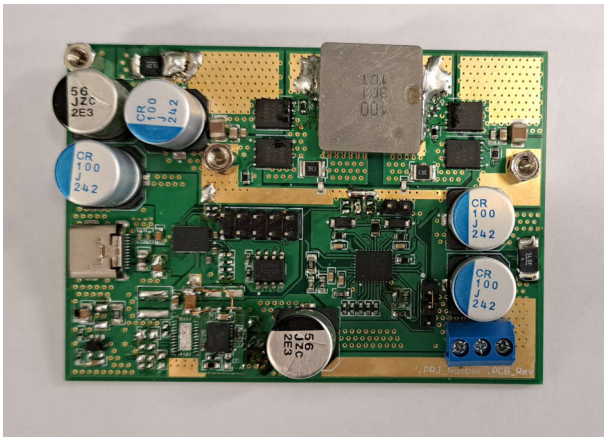
- Supports 4- to 10-cell battery charging with maximum 100W power
- Supports OTG mode (source mode)
- Compatible with USB PD 3.0 protocol
- High integration of power path switch
- Seamless transition among buck, buck-boost and boost to optimize efficiency across a wide input and output range
- High efficiency of 96.1% at full load

Applications

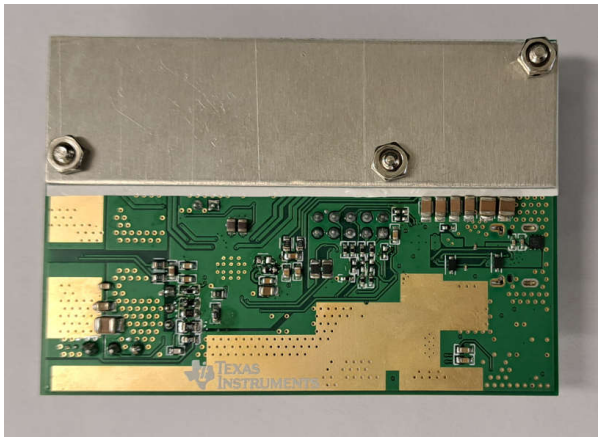
- Cordless power tool
- Vacuum robot
- Appliances: battery charger
- Cordless vacuum cleaner



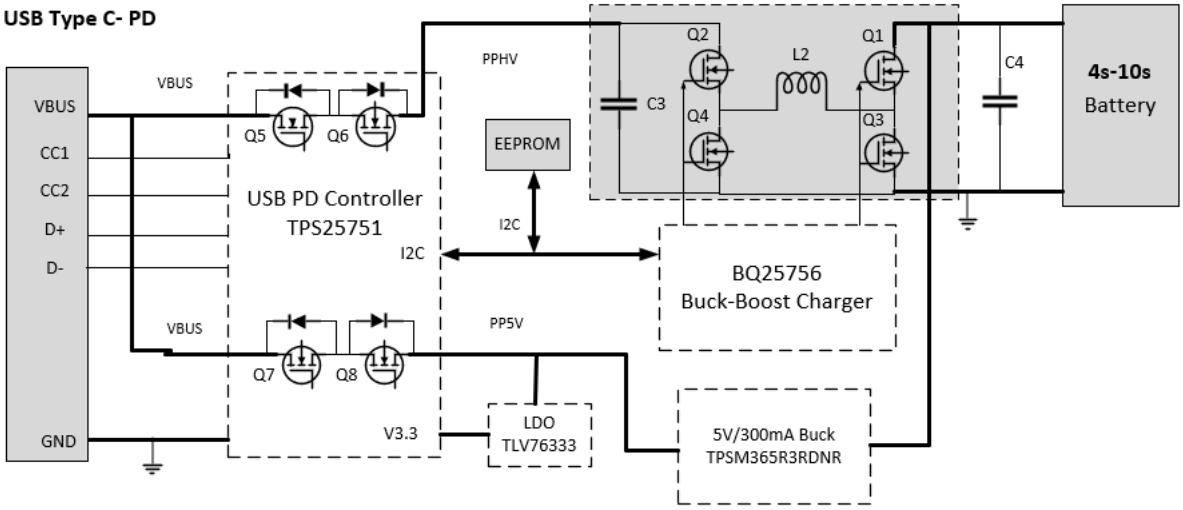
Top View



Angled View



Bottom View



PMP41062 Block Diagram

1 Test Prerequisites

Table 1-1 shows the USB Type-C PD bidirectional charger specification; the USB Type-C port can be either a source or sink depending on the equipment plug in. The battery side supports 4- to 10-cells, the maximum charge current is limited to 3A. While in reverse mode, the output voltage is configured to 5V, 9V, 15V at 3A and 20V at 5A. The maximum output power is limited to 100W.

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
Sink voltage range	5 to 20VDC
Source voltage range	5V, 9V, 15V, 20V
Battery cell configuration	4 to 10 Cells
Maximum output current	Charge mode: 3A, Reverse mode: 5A
Maximum power	100W
Switching frequency	300kHz
Efficiency	> 96% at full load

1.2 Required Equipment

1. DC source: GWinstek, GPS-3303C
2. Bidirectional power source: IT6010C-80-300
3. 140W USB Type-C PD adapter
4. 1m USB Type-C cable (supports 5A)
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 high current. This design can be used in power tool chargers, vacuum robot chargers, and portable power stations as well as various other personal electronic systems. This design assists with different functions, from the ability to charge a battery as well as providing power to the system or switching to OTG mode to source power to the connected device all through the USB Type-C connector.

1.4 Dimensions

Board size: 55.7mm × 79.5mm × 12.5mm (open frame).

1.5 Test Setup

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

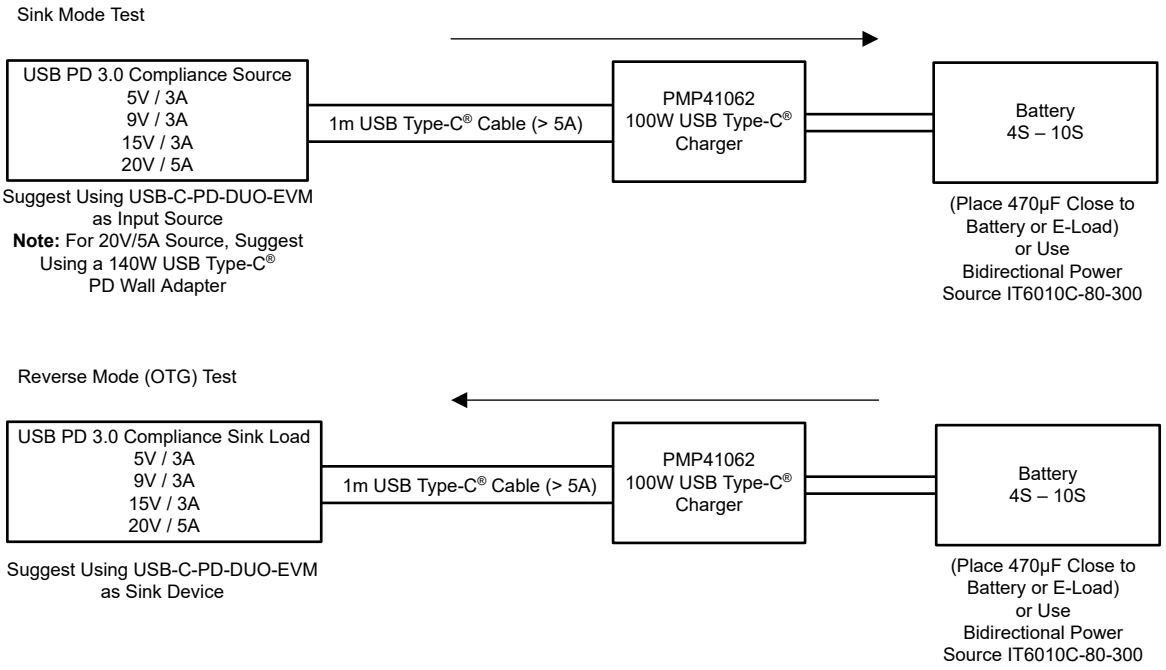


Figure 1-1. Test Setup

2 Testing and Results

2.1 Efficiency Graphs

Figure 2-1 shows the sink mode efficiency across different Vsys voltage and battery cell conditions. The fast charge current limit is set to 3A and input current limit is set to 3A for 5V, 9V, and 15V input source, and 5A for a 20V input source. At OTG mode, Figure 2-3 shows the efficiency test which was performed at the 10S battery setting.

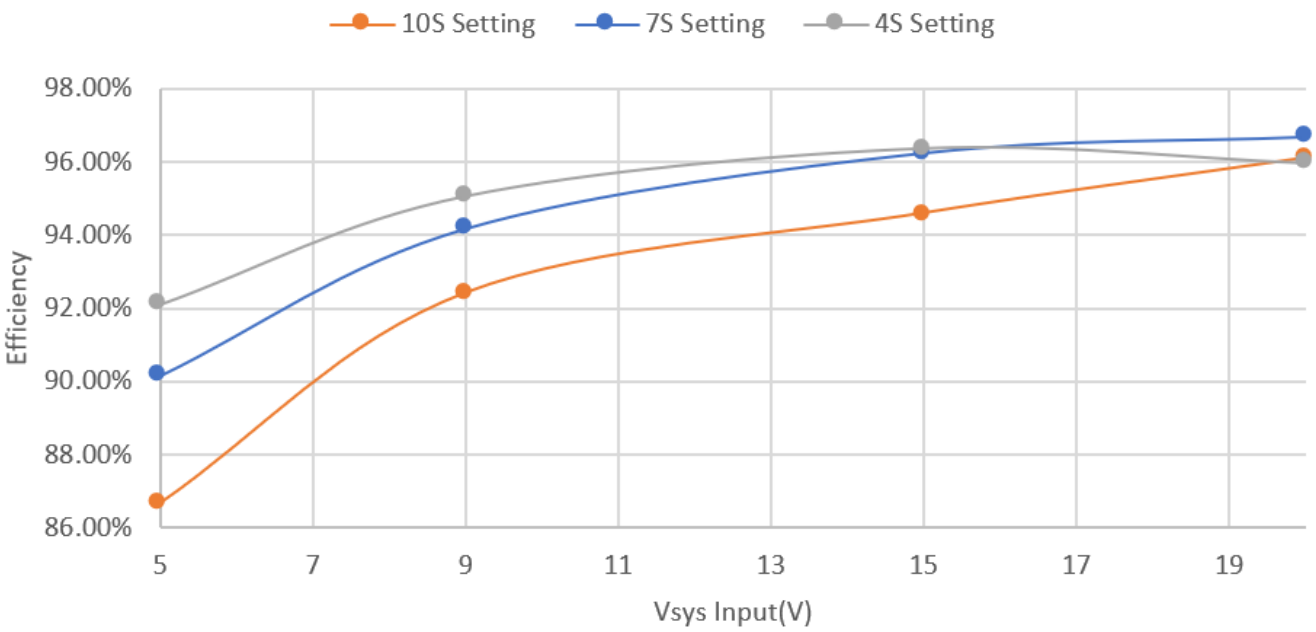


Figure 2-1. Charge Mode Efficiency Across Vsys and Vbat

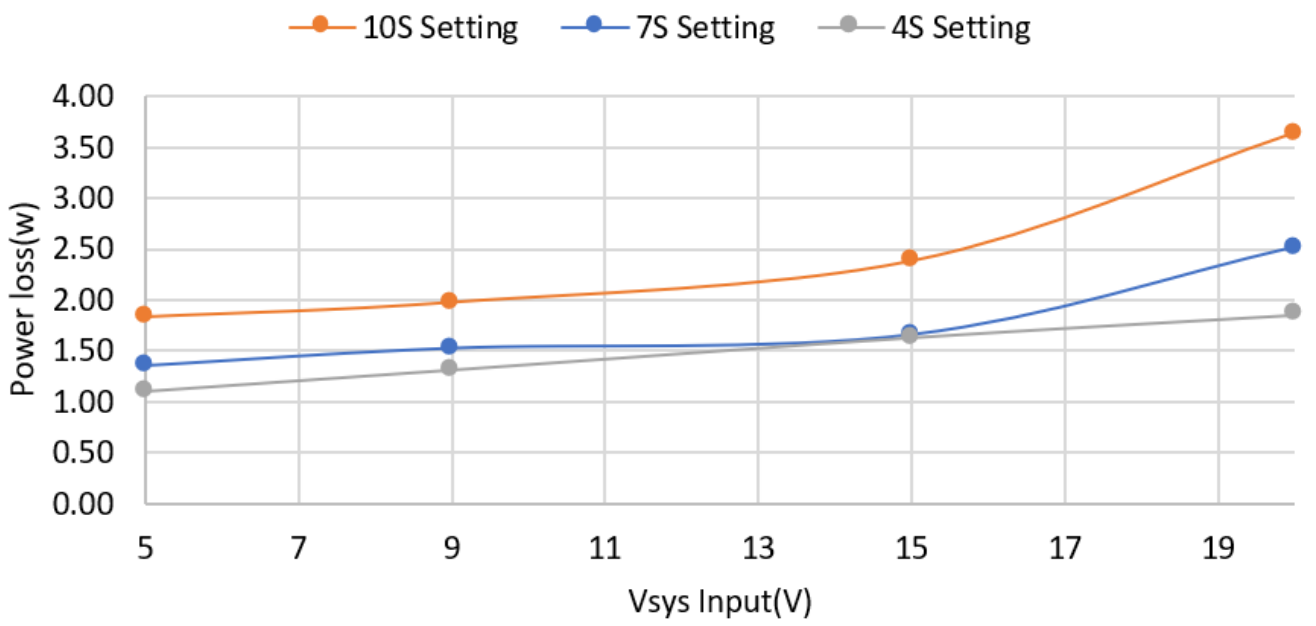


Figure 2-2. Power Loss vs Vsys and Vbat

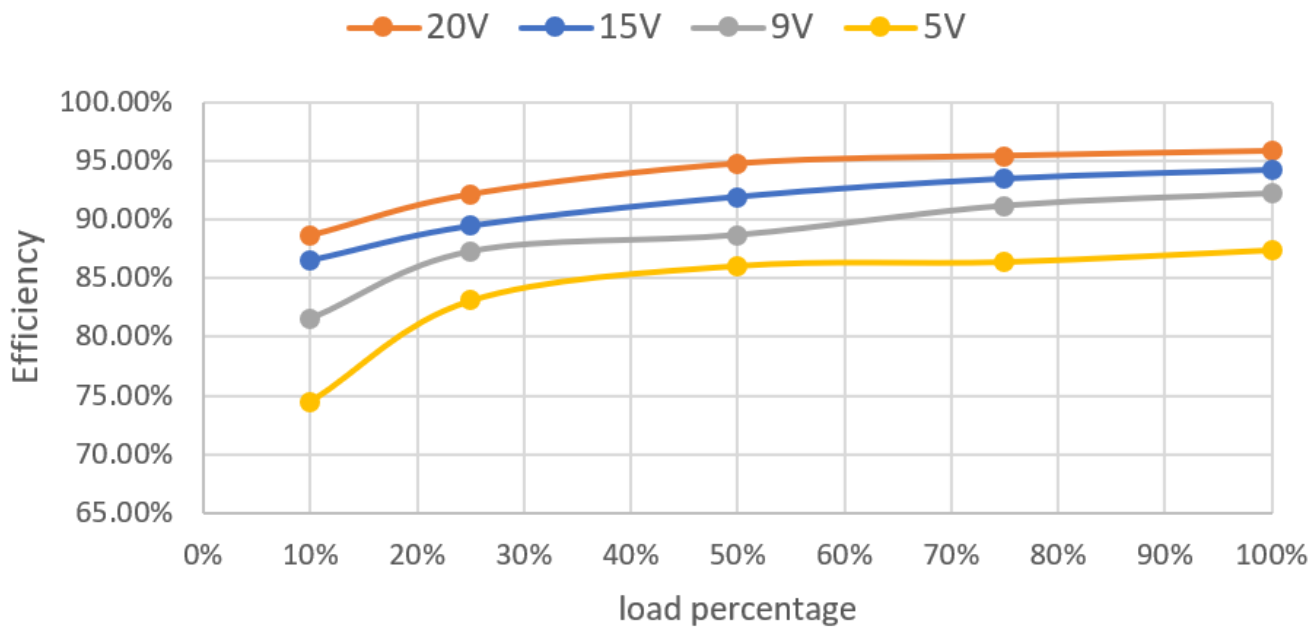


Figure 2-3. OTG Mode 20V at 5A Full-Load Efficiency Vbat = 40V

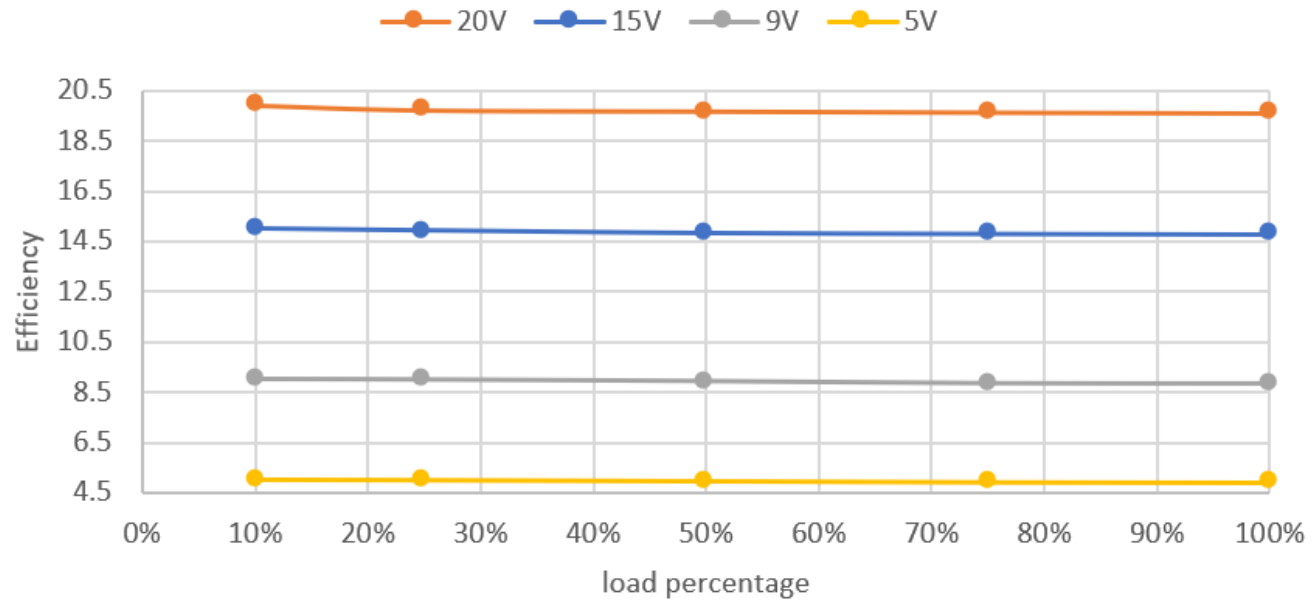


Figure 2-4. OTG Mode Output Voltage Regulation vs Load

2.2 Efficiency Data

Efficiency data is shown in the following tables.

Table 2-1. Charge Mode Efficiency Data

Vsys (V)	Iin (A)	Pin (W)	Vbat (V)	Ichg (A)	Pout (W)	Efficiency	Power Loss (W)
4.62	2.994	13.83	40.41	0.297	11.99	86.68%	1.84
8.83	2.969	26.22	40.52	0.598	24.23	92.43%	1.99
14.92	2.967	44.27	40.62	1.031	41.88	94.60%	2.39
19.04	4.92	93.68	40.87	2.203	90.04	96.11%	3.64
4.62	2.99	13.81	24.47	0.509	12.46	90.17%	1.36
8.85	2.969	26.28	24.6	1.006	24.75	94.18%	1.53
14.93	2.967	44.30	24.76	1.722	42.64	96.25%	1.66
19.24	3.952	76.04	24.99	2.942	73.52	96.69%	2.52
4.61	3.028	13.96	14.58	0.882	12.86	92.12%	1.10
8.85	3.002	26.57	14.77	1.71	25.26	95.07%	1.31
14.93	3.001	44.80	14.96	2.886	43.17	96.36%	1.63
19.52	2.352	45.91	14.97	2.943	44.06	95.96%	1.85

Table 2-2. OTG Mode Efficiency Data

Vbat (V)	Idisc (A)	Pin (W)	Vsys (V)	Iout (A)	Pout (W)	Efficiency	Power Loss (W)
39.5	2.596	102.54	19.62	5.009	98.28	95.84%	4.265
39.63	1.953	77.397	19.65	3.759	73.86	95.44%	3.533
39.73	1.313	52.165	19.69	2.511	49.44	94.78%	2.724
39.85	0.678	27.018	19.73	1.262	24.90	92.16%	2.119
39.91	0.287	11.454	19.91	0.51	10.15	88.65%	1.300
39.75	1.189	47.263	14.8	3.009	44.533	94.22%	2.729
39.81	0.9	35.829	14.82	2.26	33.493	93.48%	2.335
39.85	0.612	24.388	14.85	1.51	22.423	91.94%	1.964
39.91	0.318	12.691	14.94	0.76	11.354	89.47%	1.337
39.93	0.135	5.3906	15	0.311	4.665	86.54%	0.725
39.83	0.724	28.837	8.84	3.009	26.59	92.24%	2.237
39.86	0.55	21.923	8.85	2.259	19.99	91.19%	1.930
39.9	0.381	15.202	8.93	1.51	13.48	88.7%	1.717
39.93	0.196	7.826	8.99	0.76	6.832	87.3%	0.9938
39.95	0.086	3.4357	9.01	0.311	2.802	81.56%	0.6336
39.98	0.42	16.792	4.89	3.002	14.68	87..42%	2.111
40.01	0.3201	12.807	4.91	2.254	11.06	86.41%	1.741
40.02	0.2167	8.672	4.96	1.505	7.465	86.08%	1.211
40.03	0.1137	4.551	4.99	0.758	3.782	83.10%	0.771
40.05	0.0518	2.075	5	0.309	1.545	74.47%	0.530

Table 2-3. Standby Loss

Vbat (V)	Idisc (A)	Pin (mW)	Notes
40.5	0.00012	4.65	USB port is unplugged
28.3	0.00014	4.02	USB port is unplugged
16.2	0.00019	3.03	USB port is unplugged

2.3 Thermal Images

Table 2-4 shows the thermal images at full power charge mode and OTG mode. All images were captured at 25ºC ambient temperature, after a 30-minute warm up.

Table 2-4. Thermal Results: Full Power Charge Mode and OTG Mode

Temperature(°C)	Test Condition	
Component	**Charge Mode (20Vsys to 10S BAT Full Load)**	**OTG Mode (42V BAT to 20V at 5A, 100W)**
Q2 (Vsys high side)	59.4	63.1
Q4 (Vsys low side)	58.6	60.2
Q1(Vbat high side)	64	76.8
Q3 (Vbat low side)	73.6	66.8
Buck-Boost inductor	64.2	66.3
TPS25751	68.6	72.2
BQ25756	53.2	57.3
Rsense (Input)	61.5	62.1
Rsense (CHG)	52.6	53.2

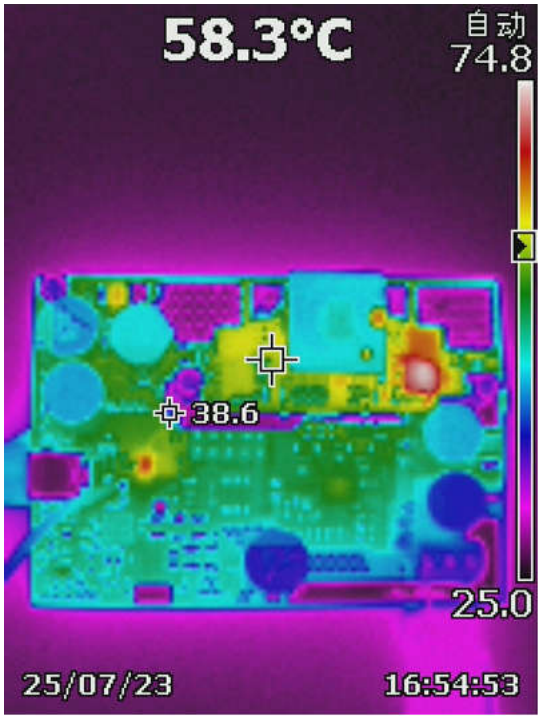


Figure 2-5. Charge Mode From 20Vsys to 42V Vbat Full Load

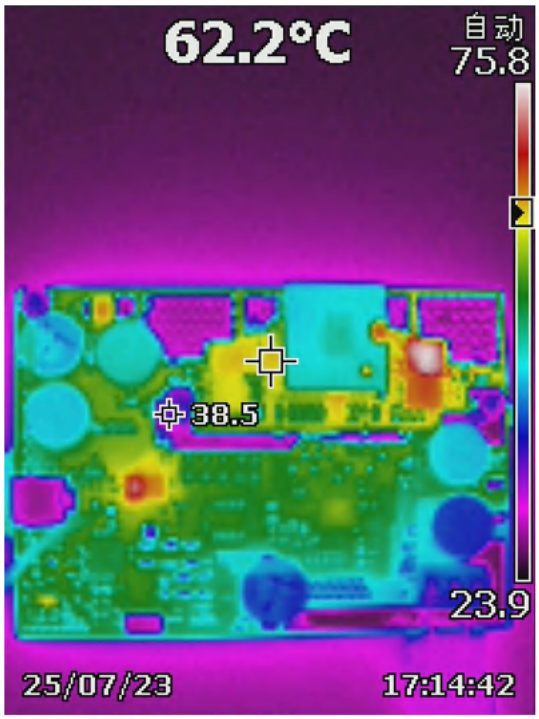


Figure 2-6. OTG Mode From Vbat = 42V to 20V at 5A

3 Waveforms

3.1 Charge Mode Start-Up Waveform

Figure 3-1 through Figure 3-4 show the charging waveforms with different input source voltage negotiated on the USB Type-C port. Input source voltage, battery voltage, as well as charge current were captured during the test.

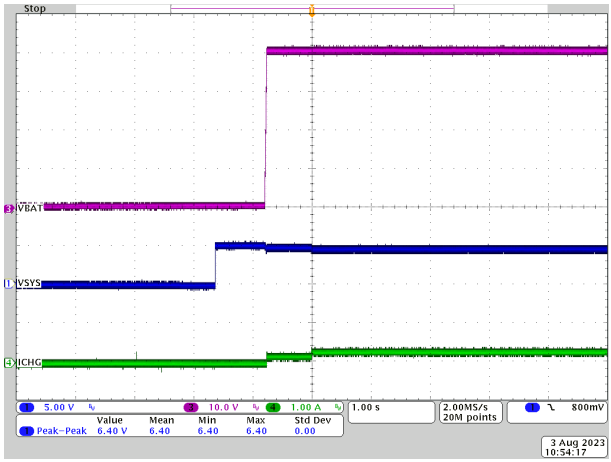


Figure 3-1. 5Vsys to 10S BAT = 40V Charge Mode

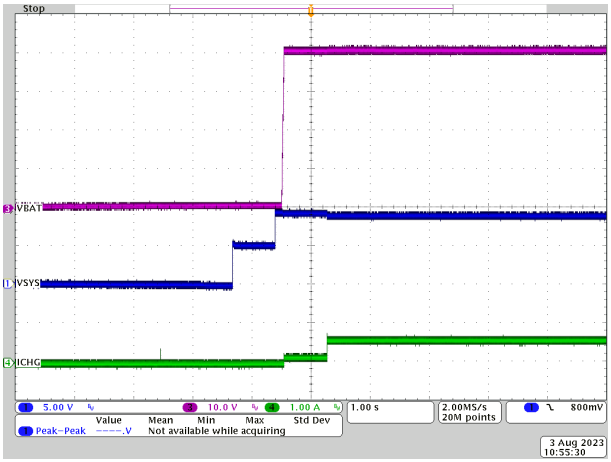


Figure 3-2. 9Vsys to 10S BAT = 40V Charge Mode

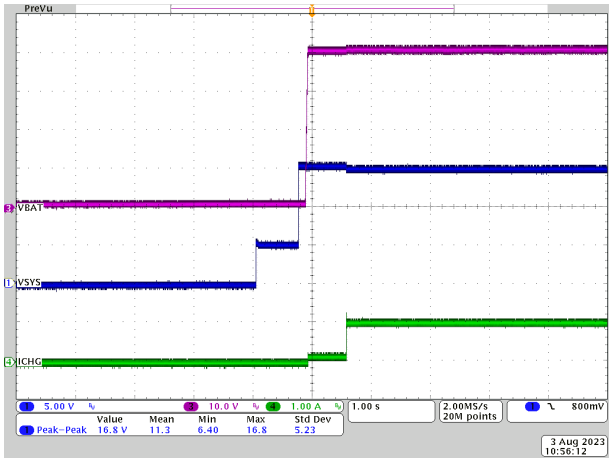


Figure 3-3. 15Vsys to 10S BAT = 40V Charge Mode

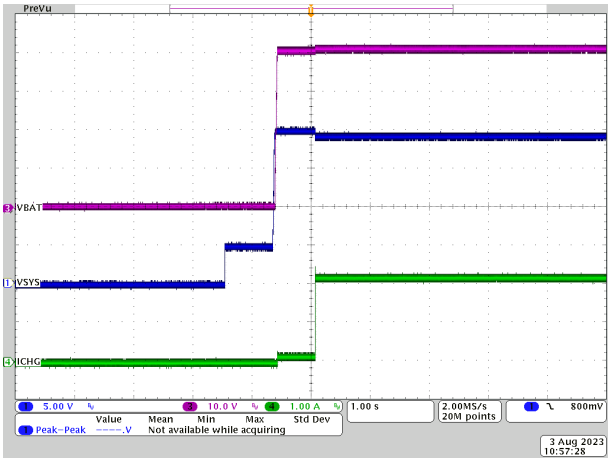


Figure 3-4. 20Vsys to 10S BAT = 40V Charge Mode

3.2 OTG Mode Start-Up Waveform

Figure 3-5 through Figure 3-8 show the OTG mode start-up waveforms at different input source voltages.

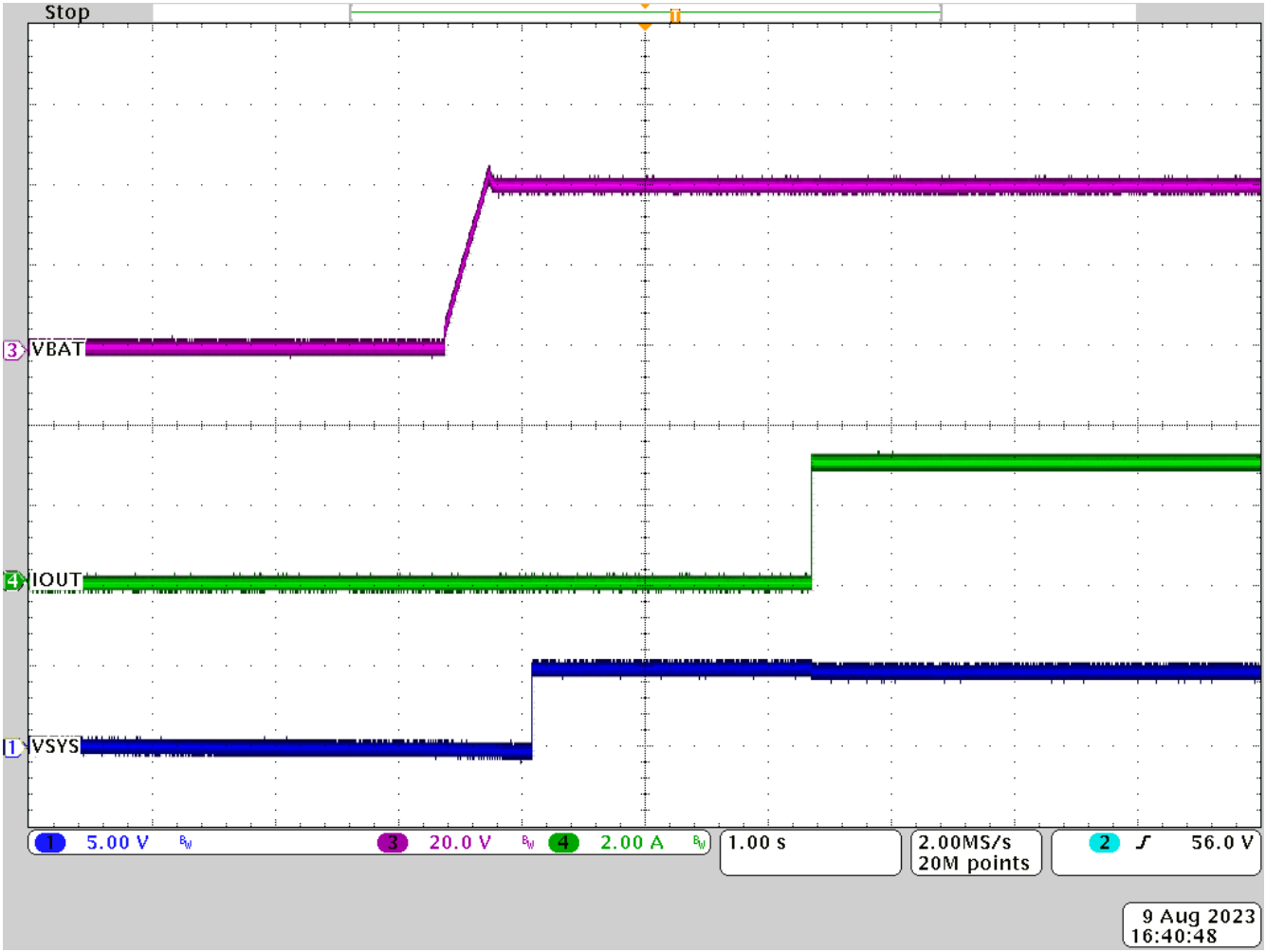


Figure 3-5. 40Vbat, Start-Up at 5V Input Source

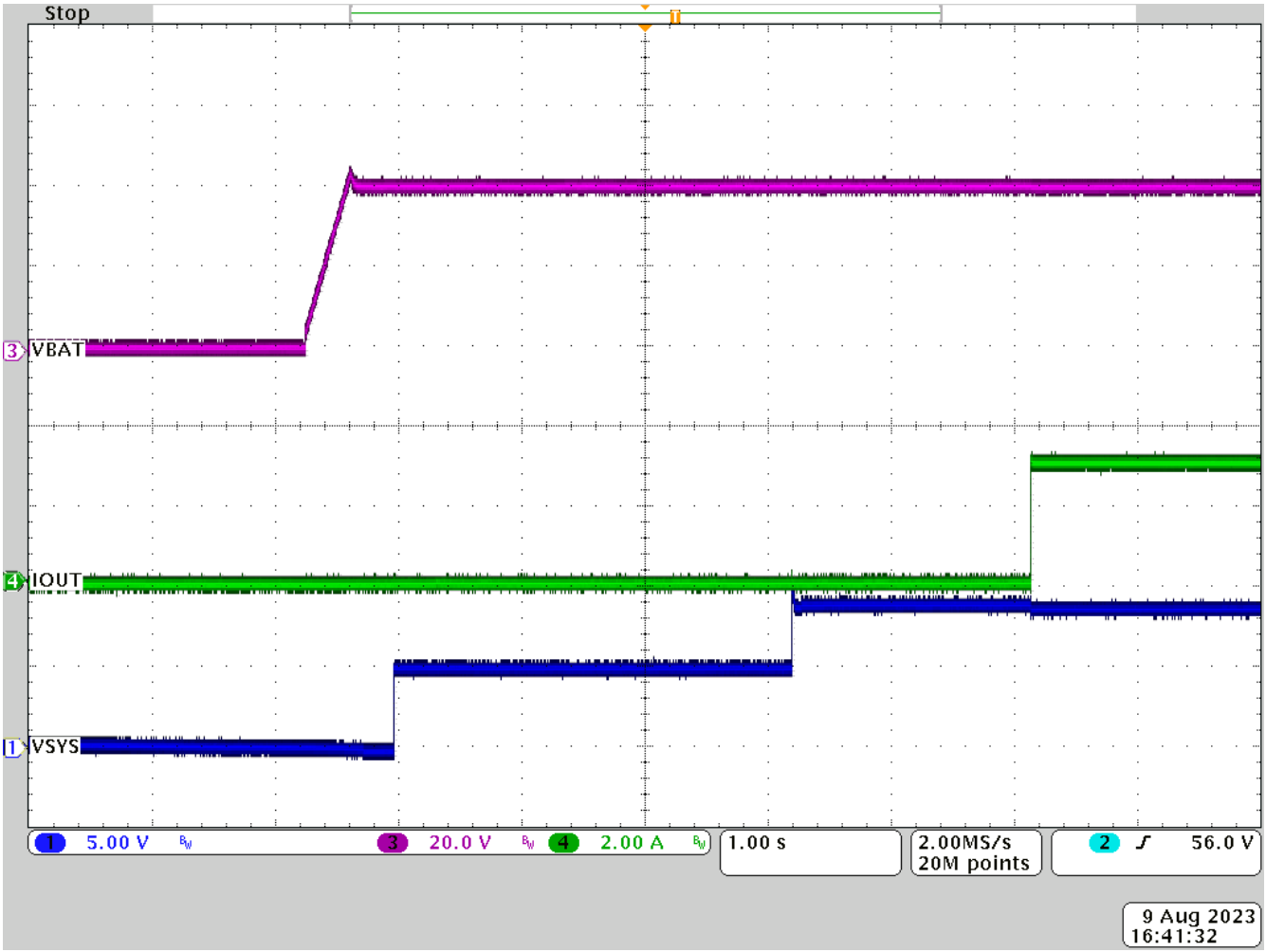


Figure 3-6. OTG, 40Vbat, Start-Up at 9V Input Source

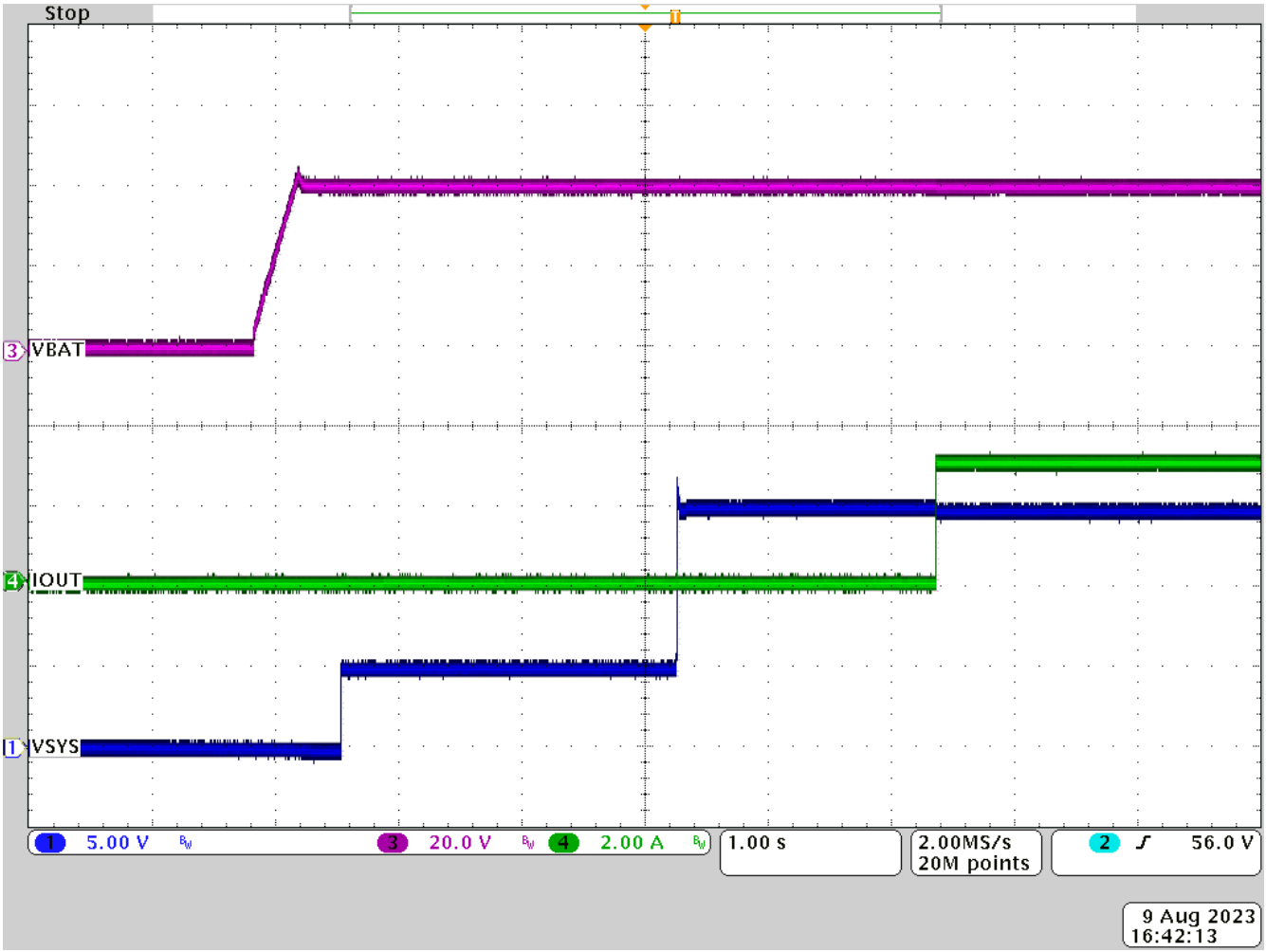


Figure 3-7. OTG, 40Vbat, Start-Up at 15V Input Source

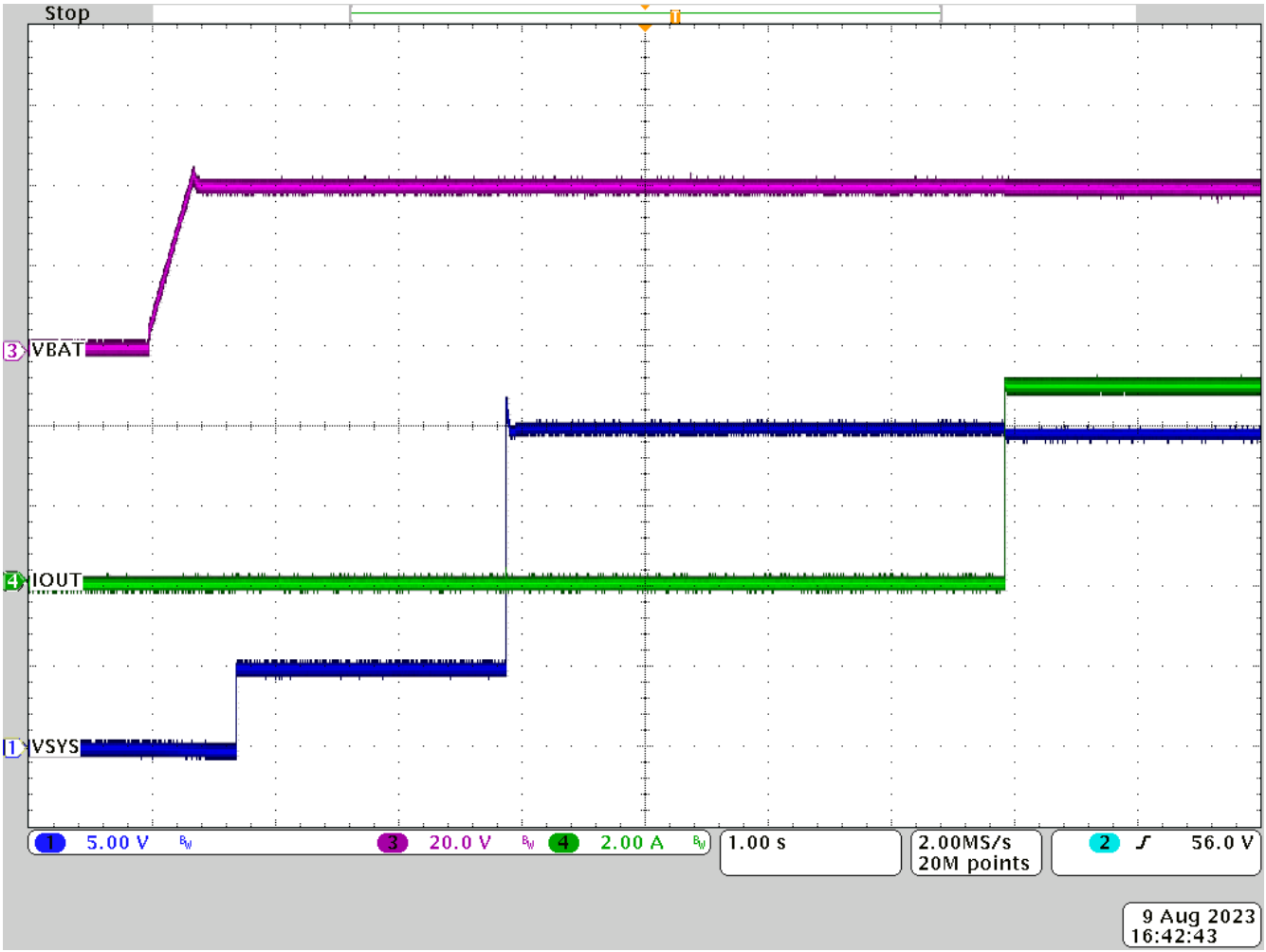


Figure 3-8. OTG, 40Vbat, Start-Up at 20V Input Source

3.3 Voltage Transition at OTG Mode

Figure 3-9 through Figure 3-11 show a voltage transition from 5V to 20V at OTG mode, and then back to 5V.

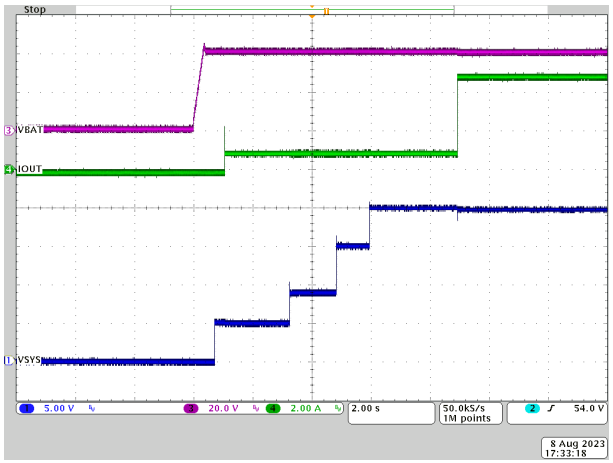


Figure 3-9. OTG, 40Vbat, 5V to 20V Voltage Transition

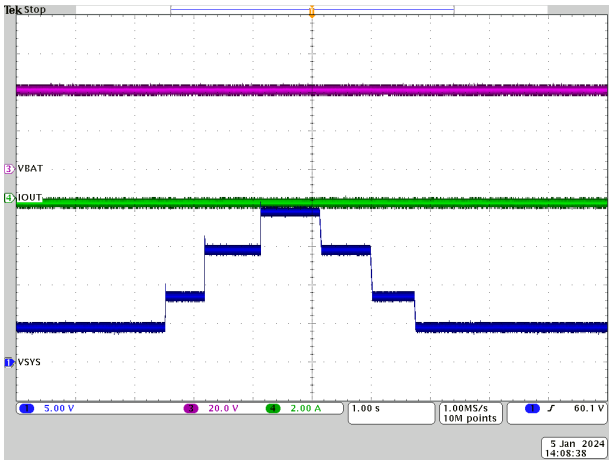


Figure 3-10. OTG, 40Vbat, 5V to 20V Full Cycle Transition at Open Load

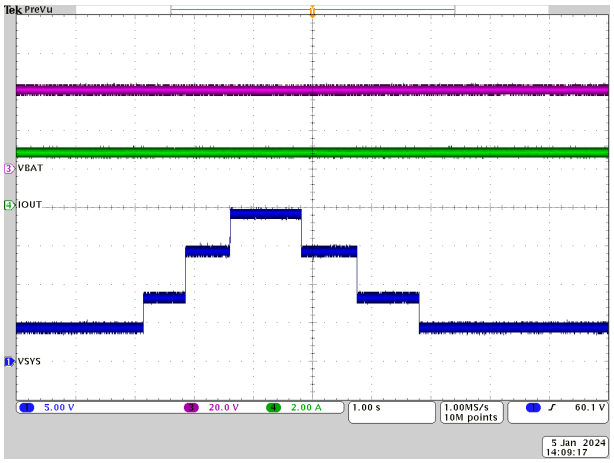


Figure 3-11. OTG, 40Vbat, 5V to 20V Full Cycle Transition at 3A Load

3.4 Ripple and Noise at OTG Mode

The following images show the ripple and noise at full load , 50%, 25%, and open load at 5V, 9V, 15V, and 20V conditions.

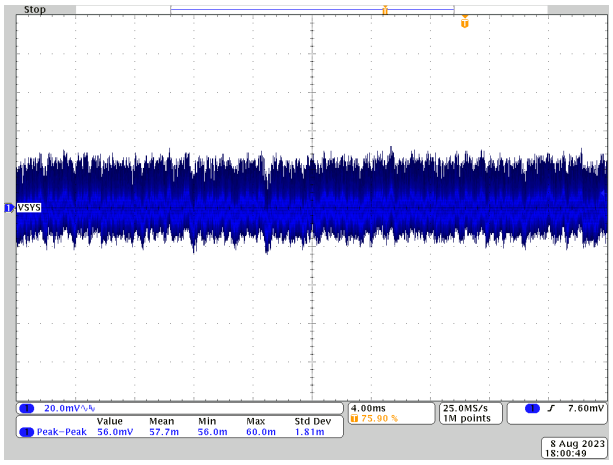


Figure 3-12. OTG Mode, 20V, 100% Load Ripple

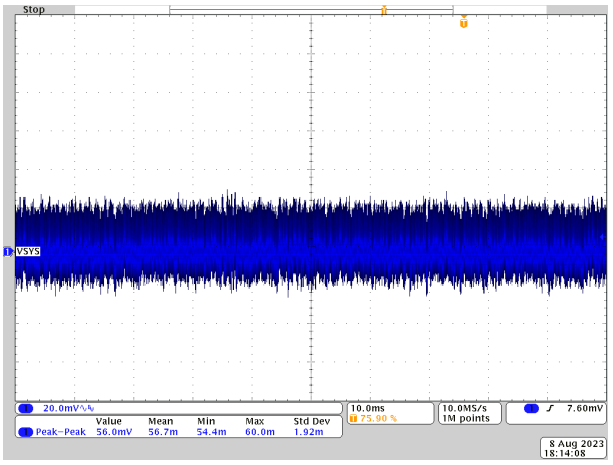


Figure 3-13. OTG Mode, 20V, 75% Load Ripple

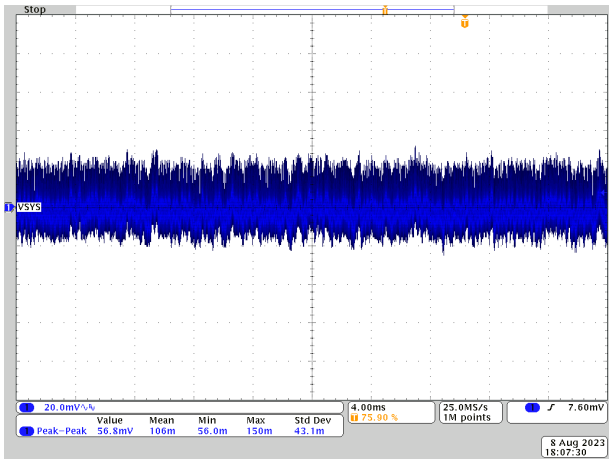


Figure 3-14. OTG Mode, 20V, 50% Load Ripple

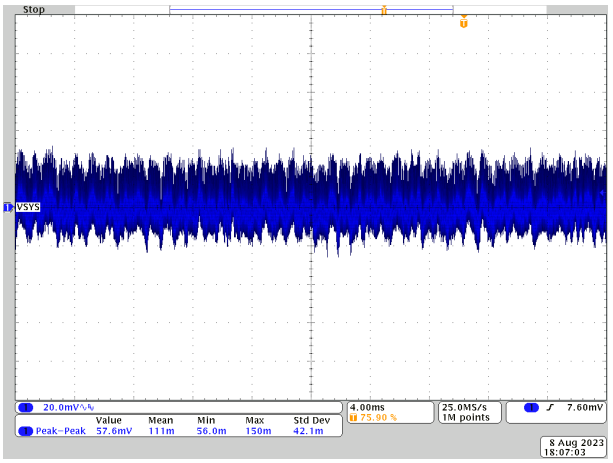


Figure 3-15. OTG Mode, 20V, 25% Load Ripple

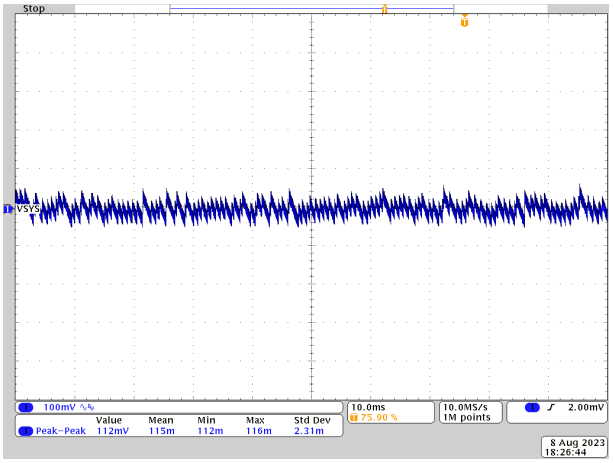


Figure 3-16. OTG Mode, 20V, Open Load Ripple

3.5 Load Transients at OTG Mode

The load dynamic test was performed from 10% to full load for 5V, 9V, 15V, and 20V individually, the slew rate is set to 0.5A / µs, output voltage was measured at the PCB end of the USB Type-C receptacle.

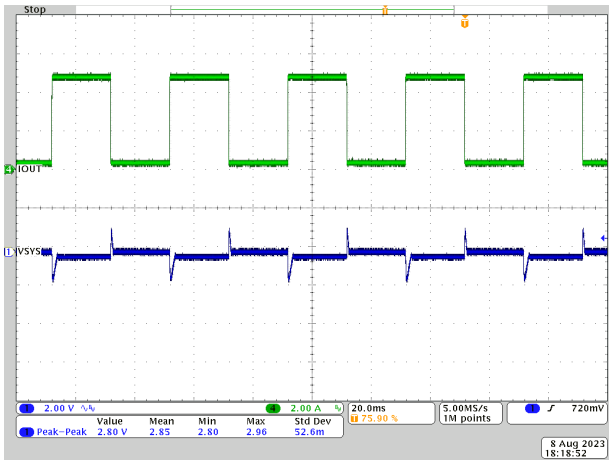


Figure 3-17. OTG Mode, 20V, 10% to 100% Load Dynamic

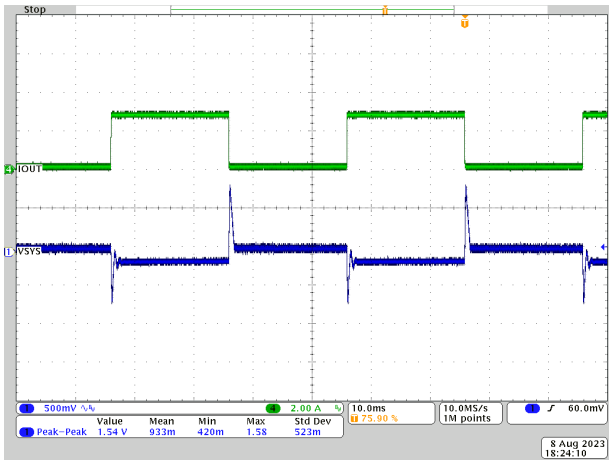


Figure 3-18. OTG Mode, 15V, 10% to 100% Load Dynamic

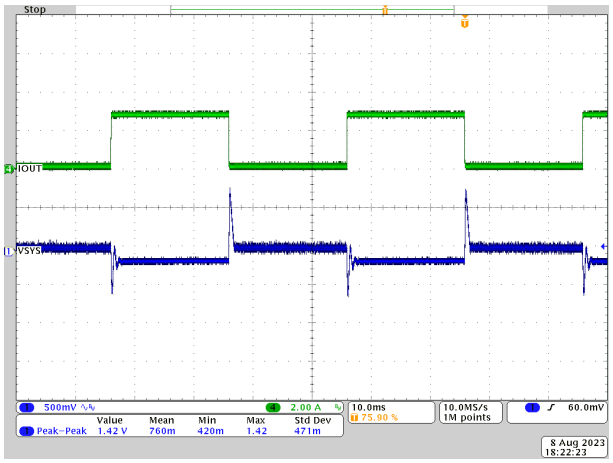


Figure 3-19. OTG Mode, 9V, 10% to 100% Load Dynamic

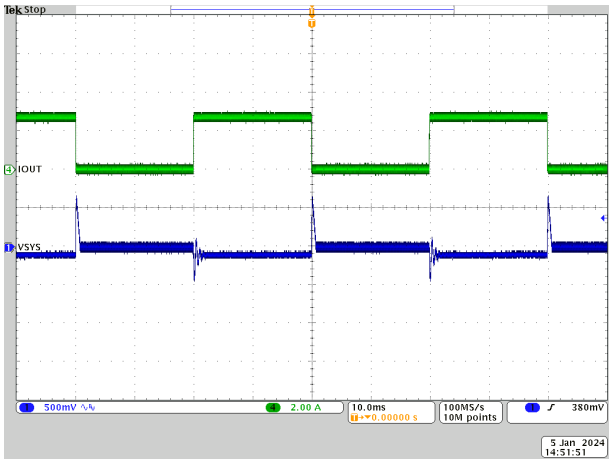
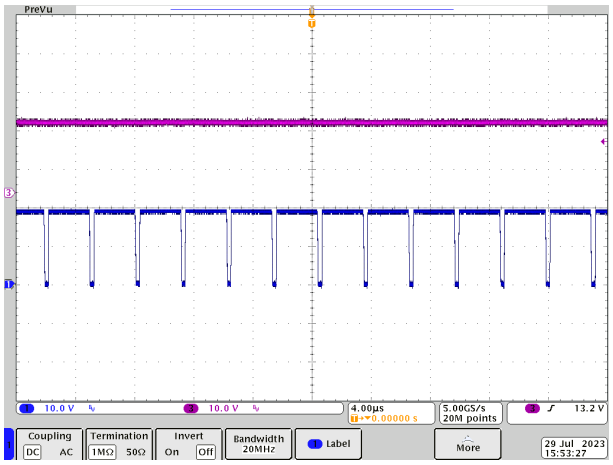


Figure 3-20. OTG Mode, 5V, 10% to 100% Load Dynamic

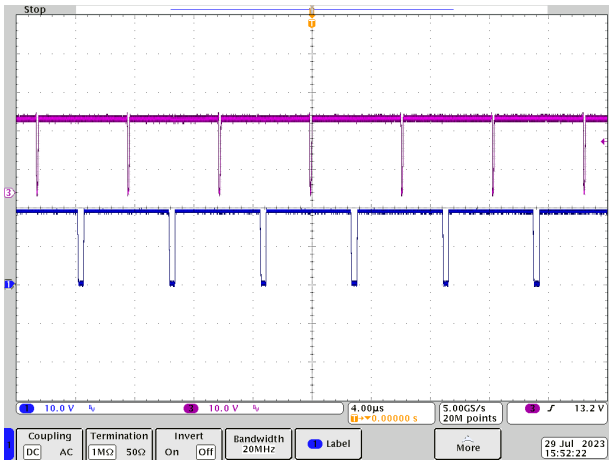
3.6 Switching Waveform

The following images show the power stage waveform at different working modes in BQ25756 among buck mode, buck-boost mode, and boost mode with seamless transition. The switching frequency is set to 300kHz.



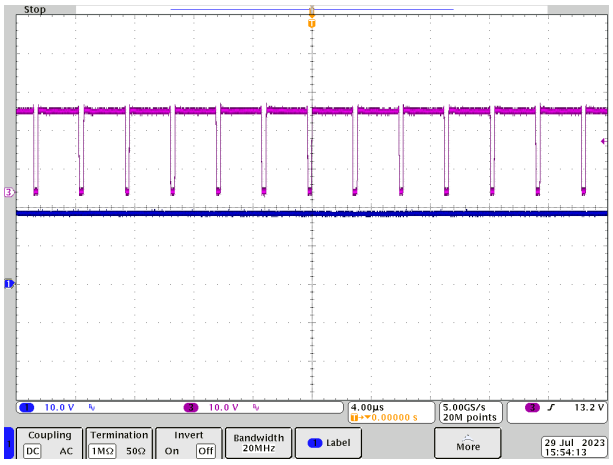
Blue: buck leg switching point, Purple: boost leg switching point

Figure 3-21. Buck Mode



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

Figure 3-22. Buck-Boost Mode



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

Figure 3-23. Boost Mode

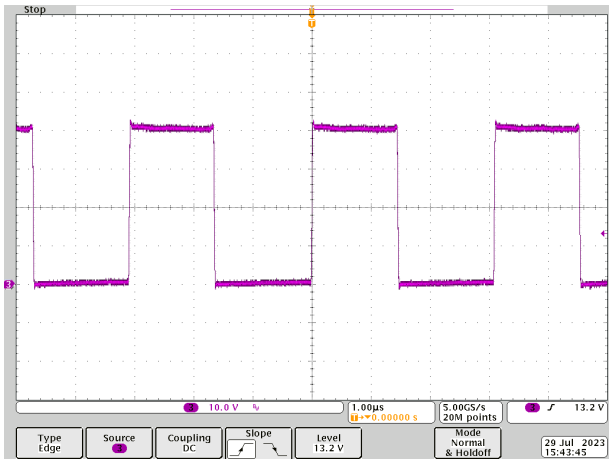


Figure 3-24. Switching Leg Waveform at Vsys = 20V, Vbat = 40V Full-Load Charging Mode, f_{SW} = 300kHz

3.7 Overcurrent Protection at OTG Mode

Overcurrent protection was performed at the USB Type-C cable end and the test gradually increased the current of E-load at constant current (CC) mode for 5V, 9V, 15V, and 20V individually, see Figure 3-25 through Figure 3-28. At OTG mode, BQ25756 regulates the output with a CC and constant voltage (CV) profile, once the output current triggers the current limit, the output voltage drops and goes to auto restart if the voltage hits 80% of Vsys.

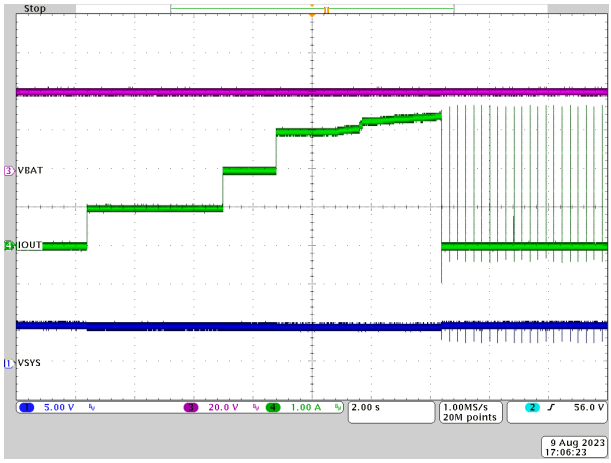


Figure 3-25. OTG Mode, 40Vbat, 5Vsys, OCP = 3.3A

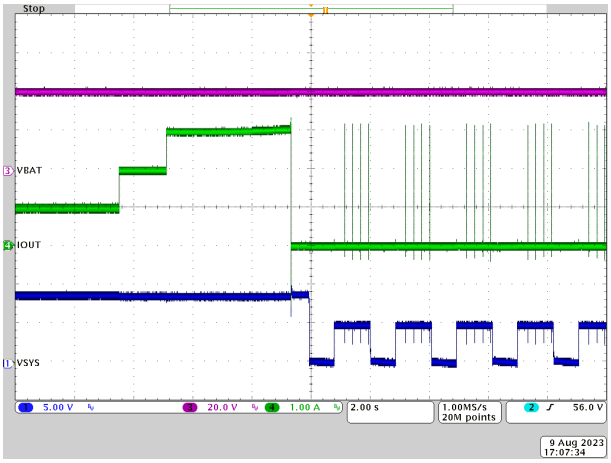


Figure 3-26. OTG Mode, 40Vbat, 9Vsys OCP = 3.1A

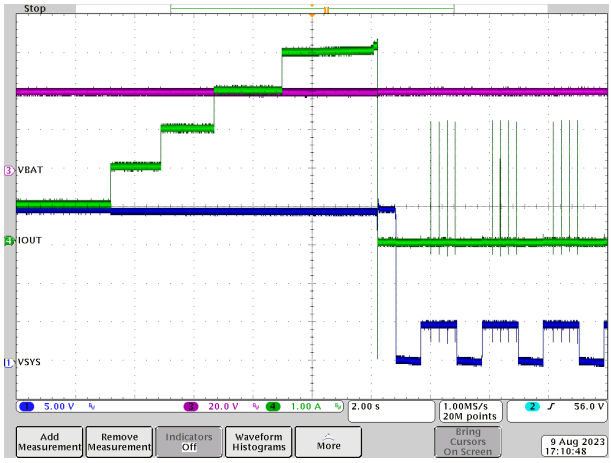


Figure 3-27. OTG Mode, 40Vbat, 15Vsys OCP = 3.1A

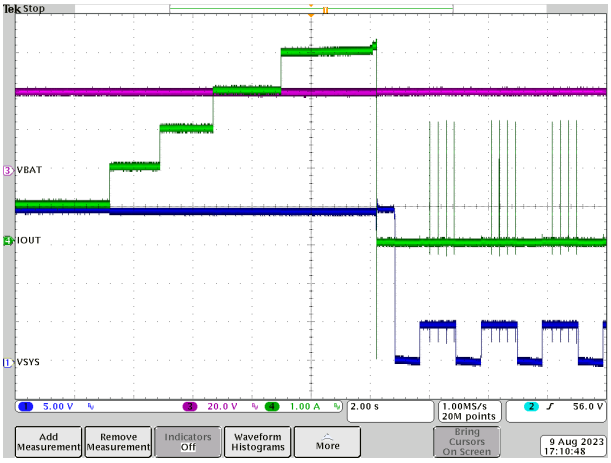


Figure 3-28. OTG Mode, 40Vbat, 20Vsys OCP = 5.1A

3.8 Short-Circuit Protection at OTG Mode

Short-circuit testing was performed at the USB Type-C cable end. Figure 3-29 through Figure 3-32 show the short-circuit test and recovery at 5V, 9V, 15V, and 20V individually.

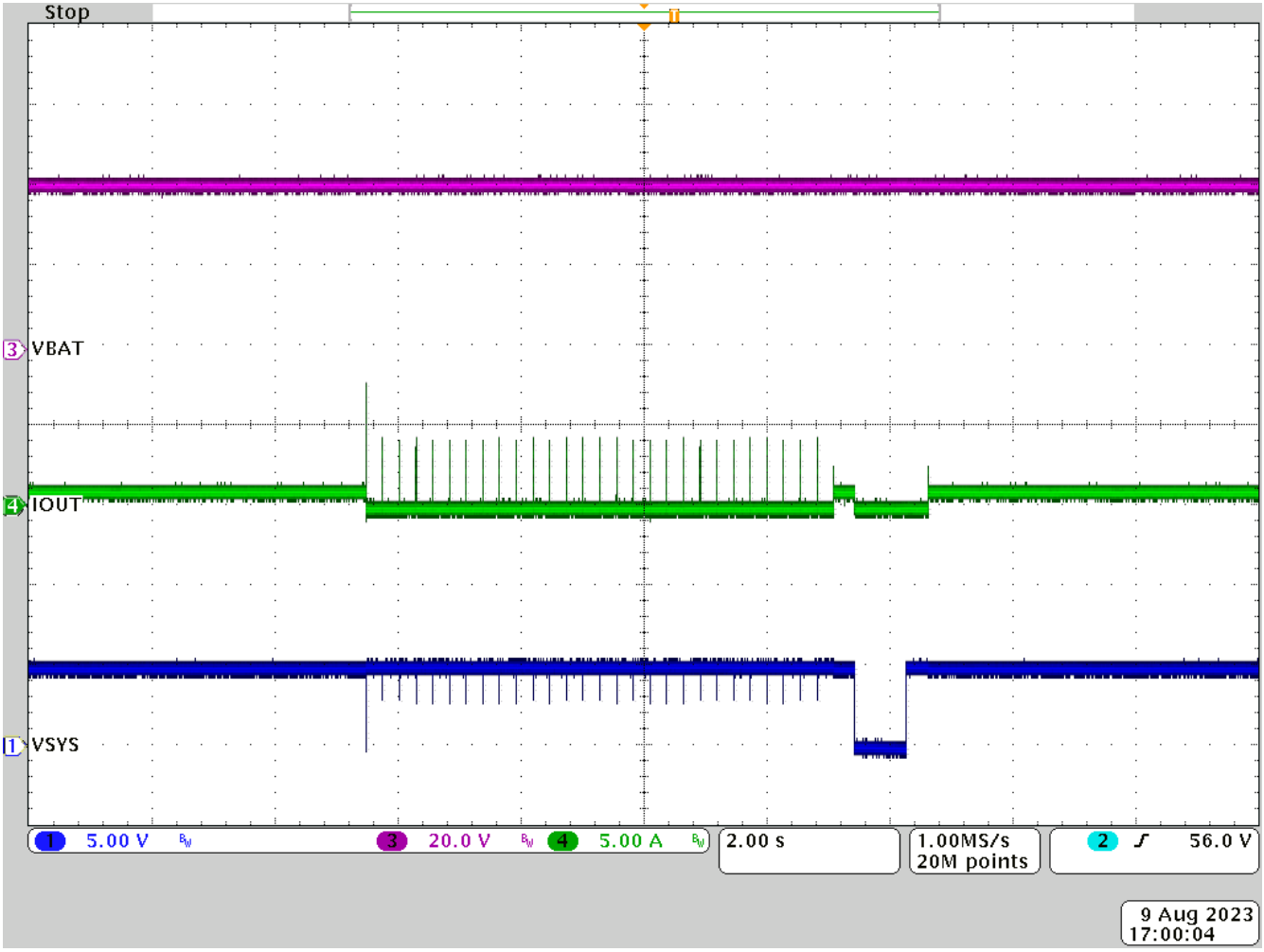


Figure 3-29. Short-Circuit Test at 5V

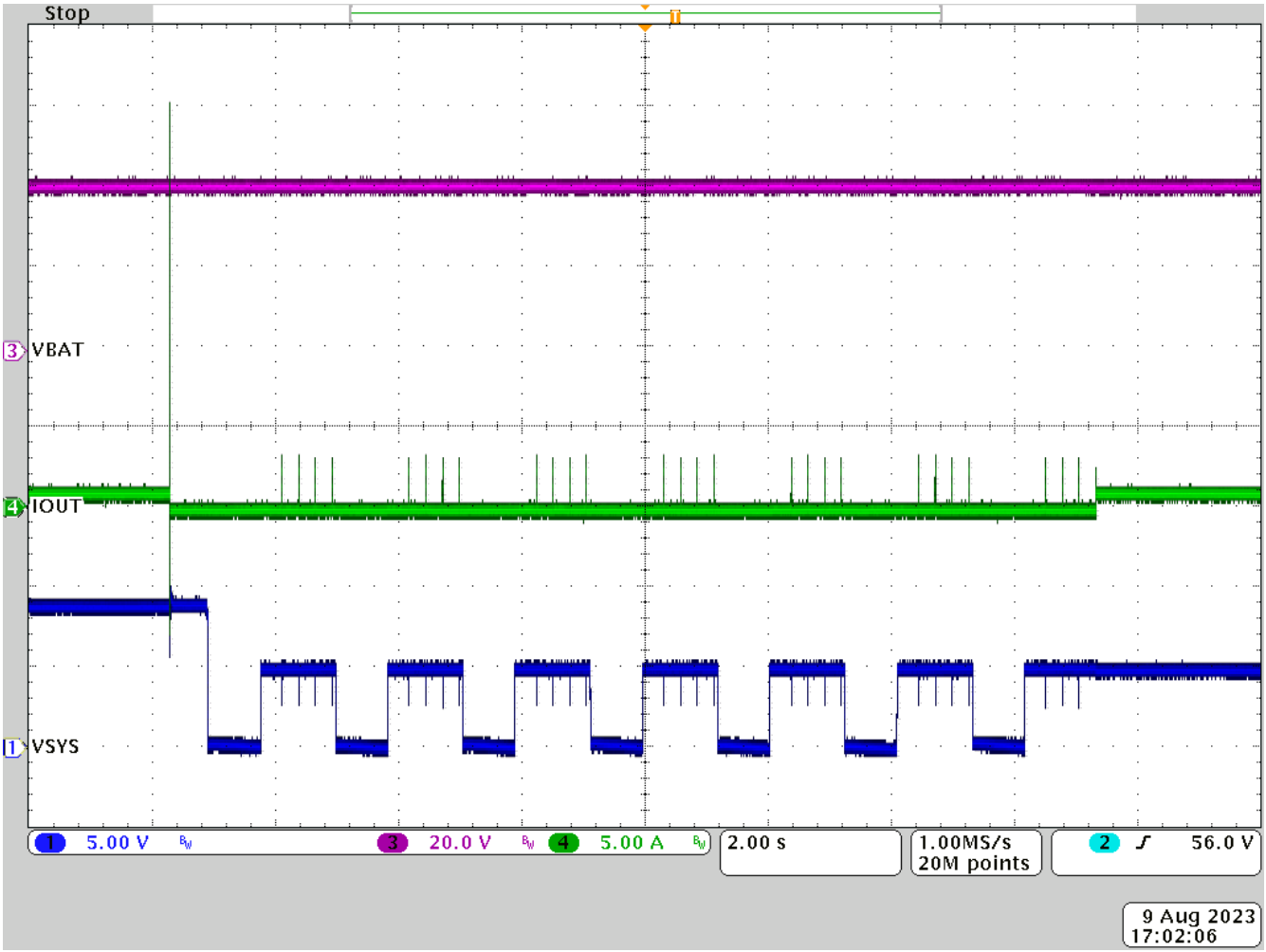


Figure 3-30. Short-Circuit Test at 9V

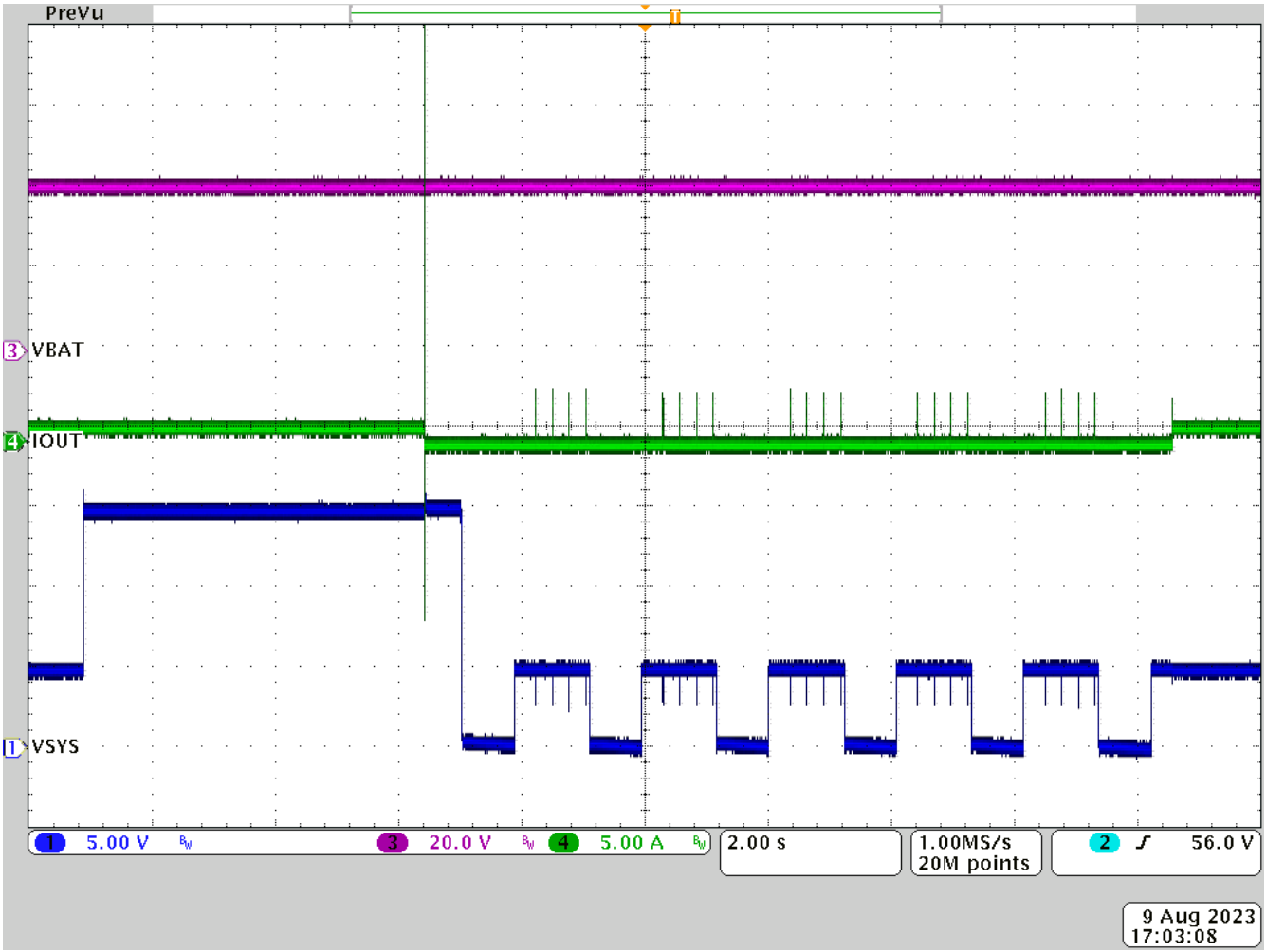


Figure 3-31. Short-Circuit Test at 15V

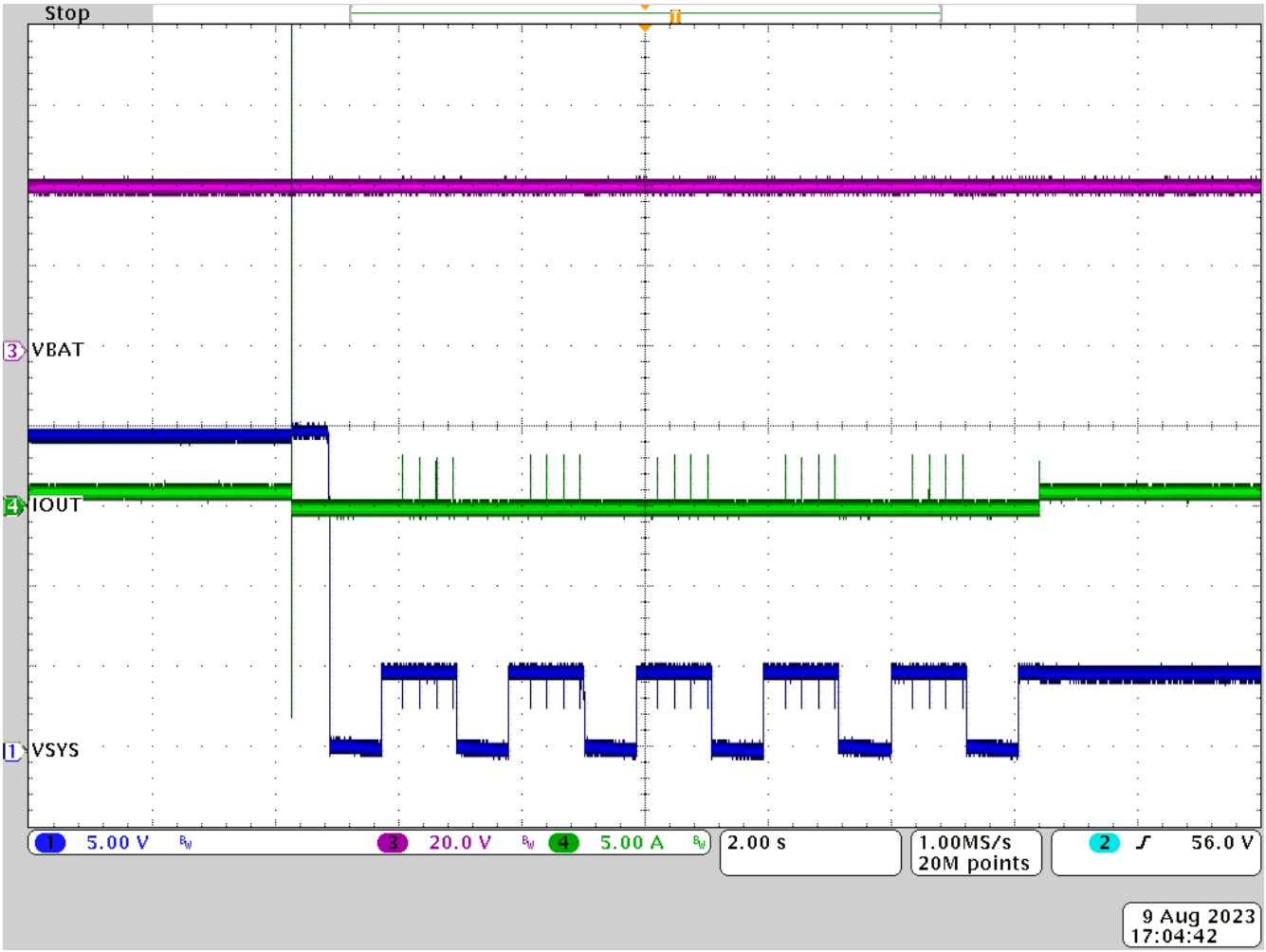


Figure 3-32. Short-Circuit Test at 20V

3.9 Short-Circuit Protection at Charge Mode

Figure 3-33 and Figure 3-34 show the short-circuit protection and recovery waveform, once the battery voltage falls below Vbat_short (2.5V), the device is forced into PFM mode, and current is reduced to around 200mA. Once the battery short is removed, it returns to normal operation.

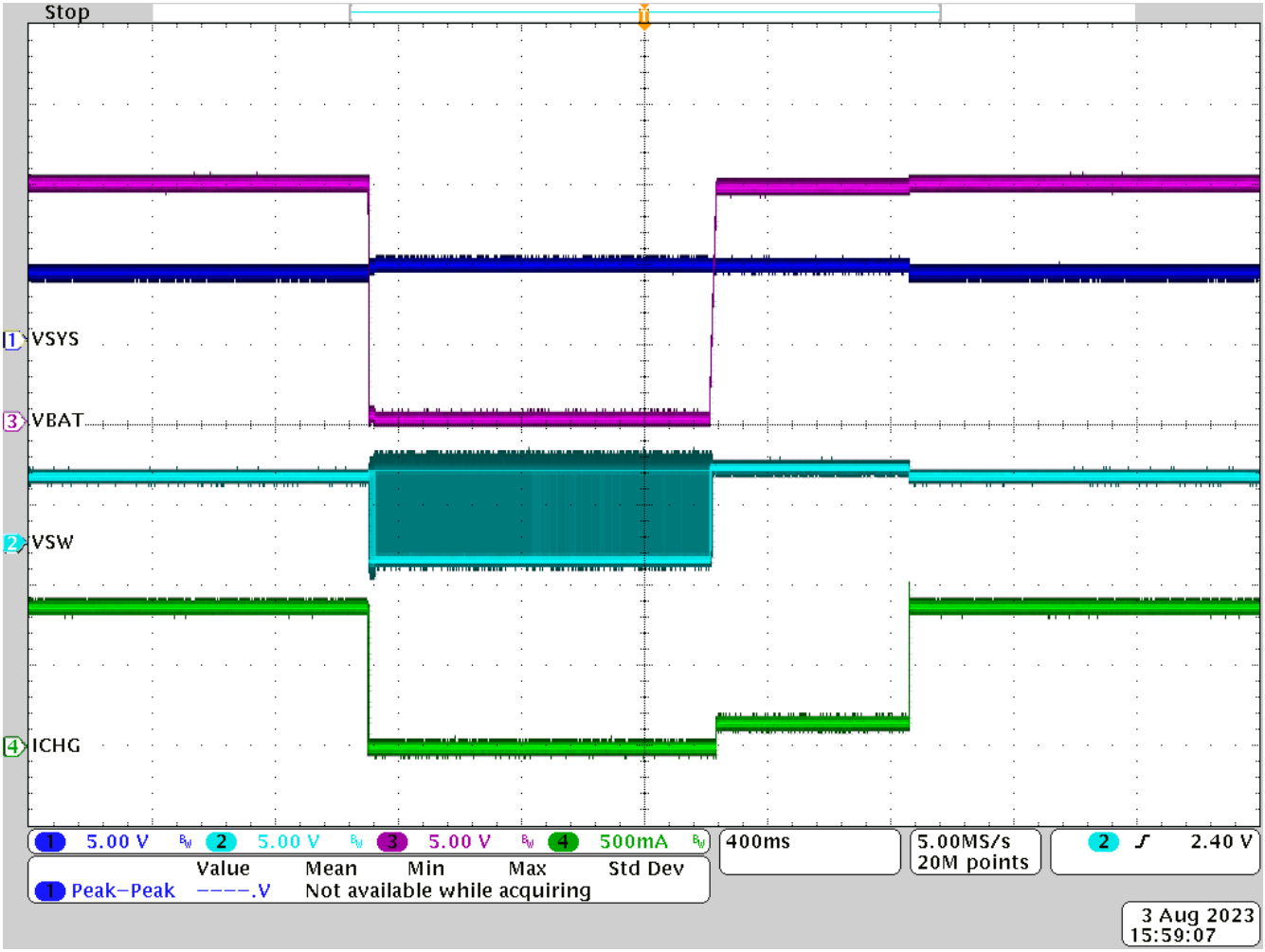


Figure 3-33. Short-Circuit Protection and Recovery at 40Vbat and 20Vsys

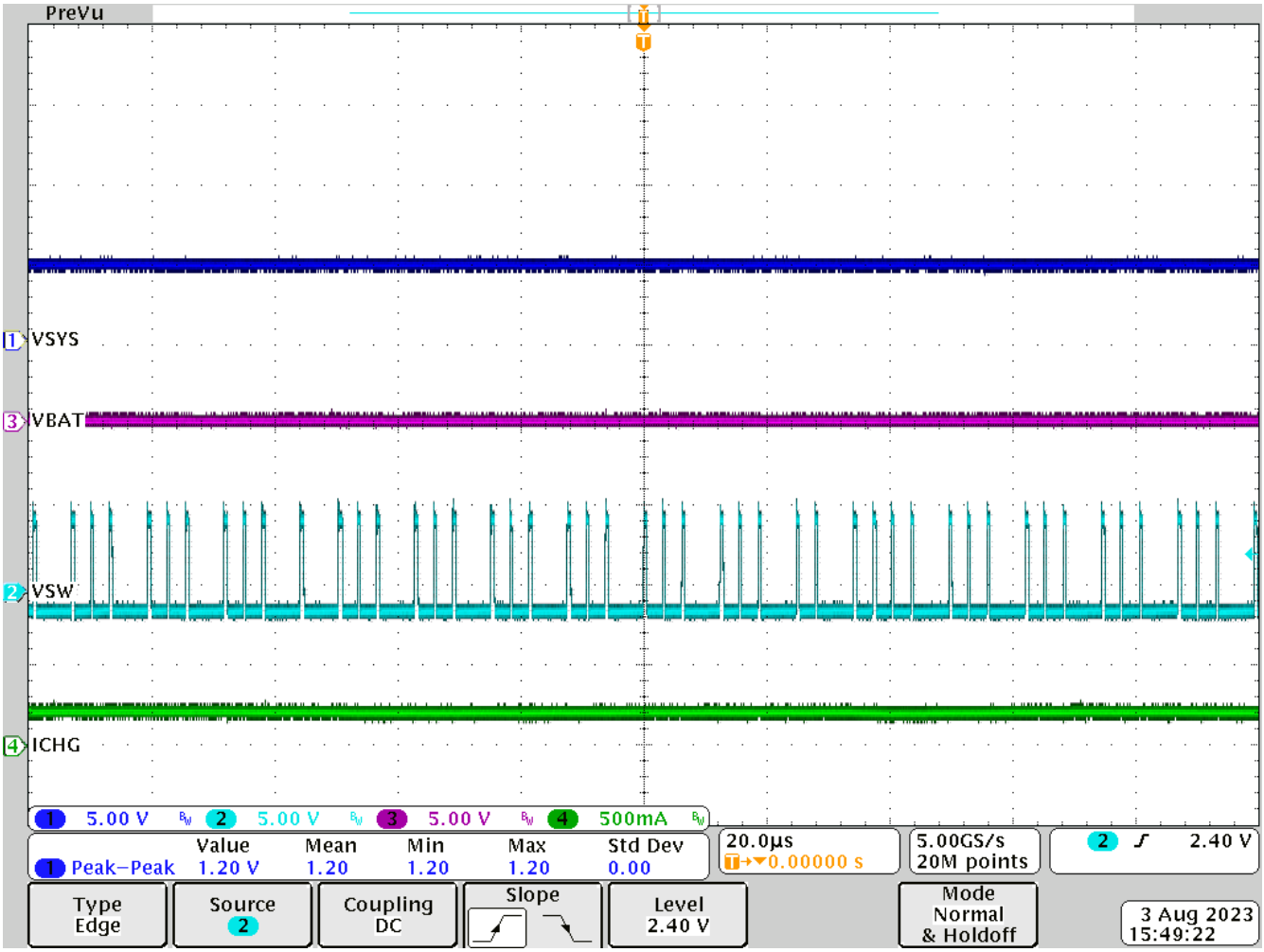


Figure 3-34. Zoom Waveform During SCP

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