Test Report: PMP41013

Integrated USB Type-C® PD and Bidirectional Charging Reference Design for 1–5 Cell Batteries

Description

This reference design is an integrated USB Type-C® power delivery (PD) and charging reference design for 1-5 cell batteries for applications such as power tool chargers, vacuum cleaners, portable power stations, so on and so forth.

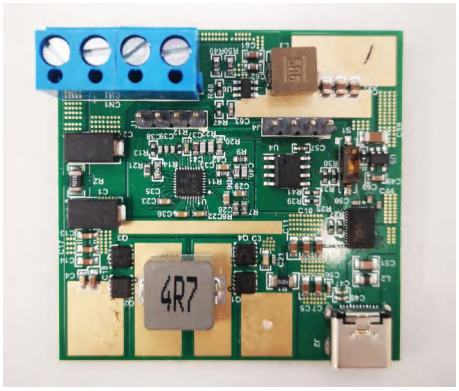
The design incorporates a highly-integrated standalone TPS25750 USB Type-C and PD controller with a build-in fully-managed robust power path switch inside to reduce the size and number of external components. The power specification can easily be configured to the user's application through a web-based GUI, thus reducing the design complexity. The PD controller works with an external battery charger controller (BQ25731) through I2C communication. The BQ25731 supports a wide range input with a four-switch buck-boost configuration. The controller also supports a seamless transition from buck, boost, and buck-boost operation mode, thus providing a highly-efficient, highly-accurate and reliable charger. In addition to charging capabilities, the BQ25731 also supports USB OTG(On The Go) mode which adds benefits to the end-user experience. In general, this reference design can support charging batteries through a USB Type-C port and provide a maximum 60W output at OTG mode, the high integration and simple design will benefit low BOM(Bill of Material) cost, smaller size as well as accelerating time to market.

Features

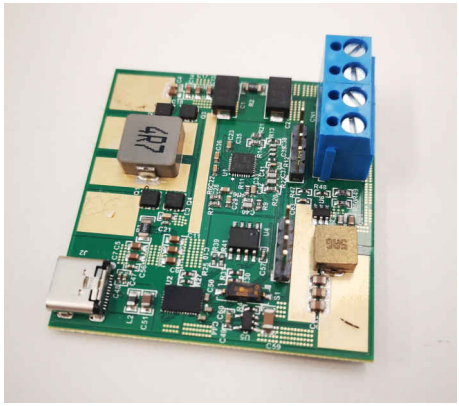
- Supports 1–5 cell battery charging
- High integration with an integrated power path switch and USB PD control
- Seamless transition among buck, buck-boost, and boost mode to optimize efficiency across a wide I/O range
- Supports OTG mode in source mode
- High efficiency > 97.3% at full load

Applications

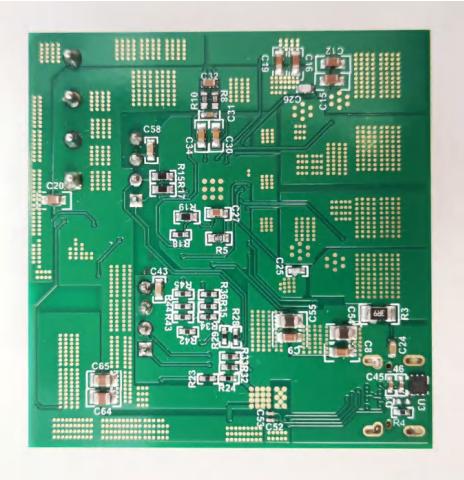
- Cordless power tool
- Vacuum robot
- Appliances: Battery charger
- Cordless vacuum cleaner



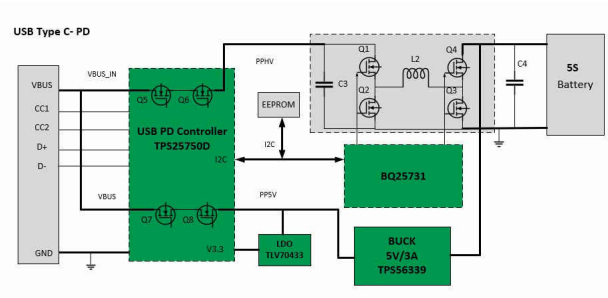
Board Top View



Board Angle View



Board Bottom View



System Block Diagram

1 Test Prerequisites

1.1 Voltage and Current Requirements

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 connected to the USB Type-C port. The maximum output power is limited to 60 W.

Table 1-1. Voltage and Current requirement

Parameter	Specifications
Sink voltage range	5–20 VDC
Source voltage range	5–20 VDC
Cell Configurations	1–5 cells
Maximum output current	Up to 3 A
Maximum output power	60 W
Switching frequency	400 kHz
Efficiency	> 97% at full load

1.2 Required Equipment

1. DC source: GW Instek, GPS-3303C
2. Electronic load: Chroma, 6314A
3. Oscilloscope: Tektronix, DPO 3054
4. Frequency response analyzer: AP instruments, Model 300
5. Infrared thermal camera: Fluke, TiS55
6. True RMS multimeter: Fluke, 287C
7. Digital power meter: Yokogawa WT310
8. TPS65987 EVM board

1.3 Considerations

The reference design illustrates 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 as well as various other personal electronic systems.

1.4 Dimensions

Board size: 51 mm × 50.5 mm × 6 mm (open frame)

1.5 Test Setup

- The TPS65987 EVM works as PD compliance source or sink to simulate the battery charge and OTG function
- Place a 47-µF bus capacitor physically close to the output terminal to avoid a long cable connection to the battery side when performing the test

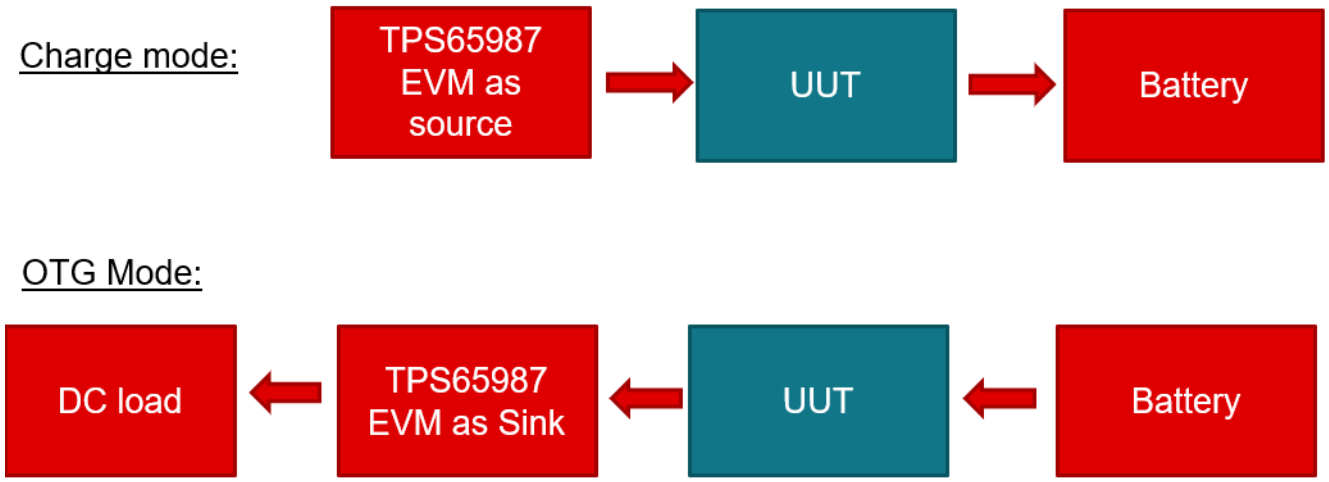


Figure 1-1. System Test Setup

2 Testing and Results

2.1 Efficiency Graphs

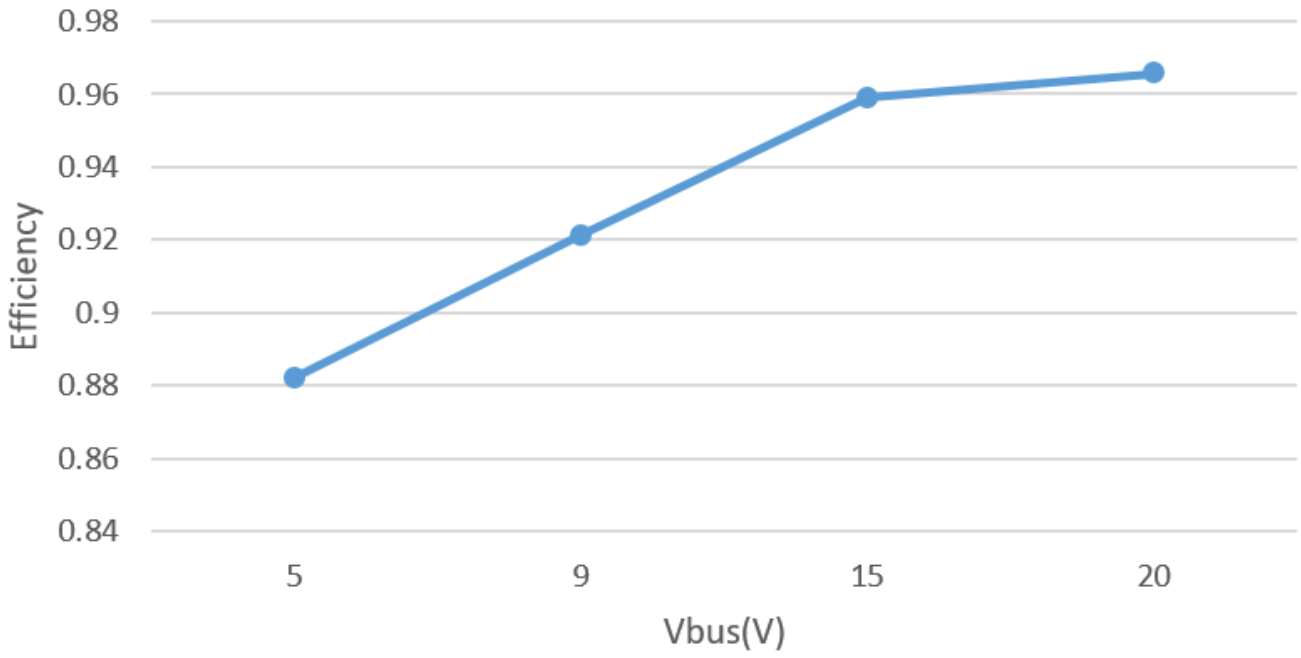


Figure 2-1. Efficiency at Charge Mode

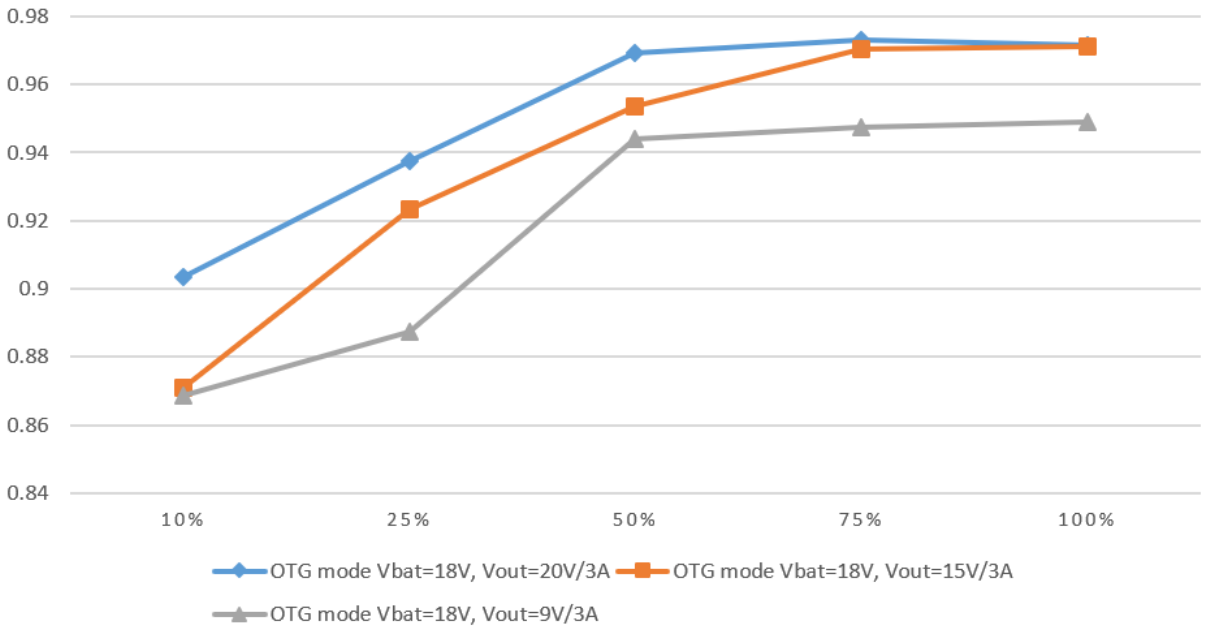


Figure 2-2. Efficiency at OTG Mode

2.2 V_{OUT} Regulation

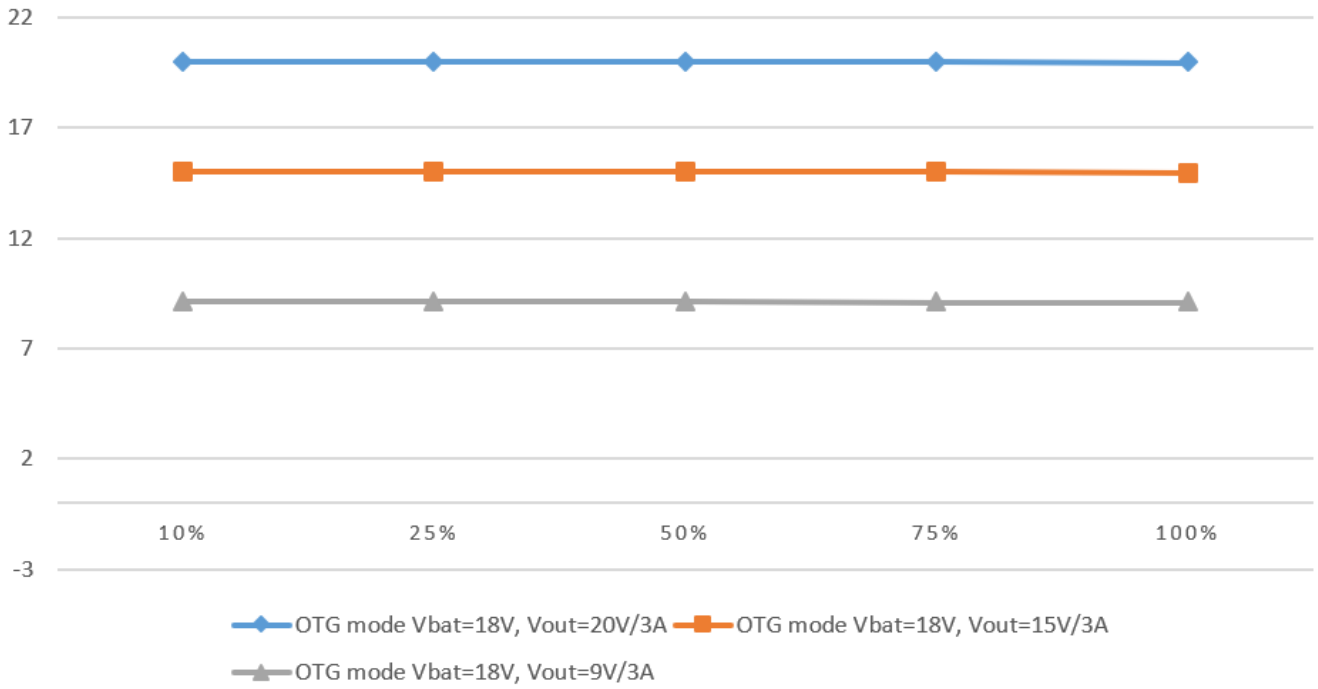


Figure 2-3. V_{OUT} Regulation of 5 V, 9 V, 15 V, and 20 V at OTG Mode

2.3 Thermal Images

All images were captured with the unit under test (UUT) enclosed in a 30 cm × 45 cm × 20 cm plexiglass box, 25ºC ambient, after a 30-minute warm up.

Figure 2-4 through Figure 2-7 illustrate the *charge mode* thermal images.

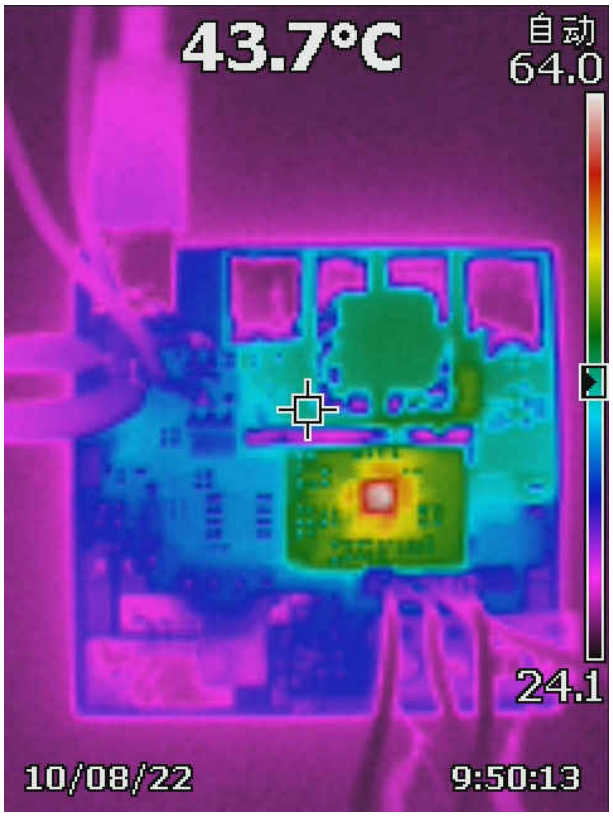


Figure 2-4. 20 V_{BUS} and 20 V_{BAT} Full Charging Mode

Figure 2-5. 15 V_{BUS} and 20 V_{BAT} Full Charging Mode

Figure 2-6. 9 V_{BUS} and 20 V_{BAT} Full Charging Mode

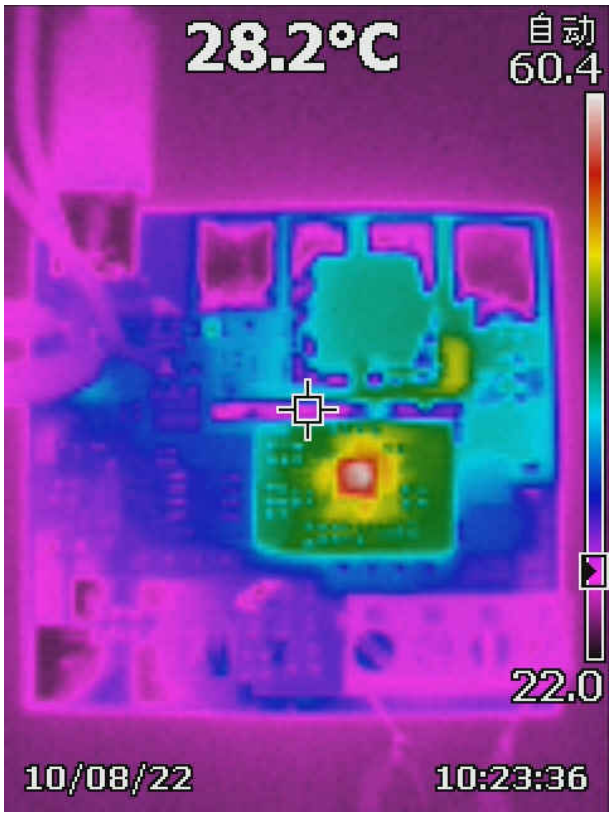


Figure 2-7. 5 V_{BUS} and 20 V_{BAT} Full Charging Mode

Figure 2-8 through Figure 2-10 illustrate the OTG mode thermal images.

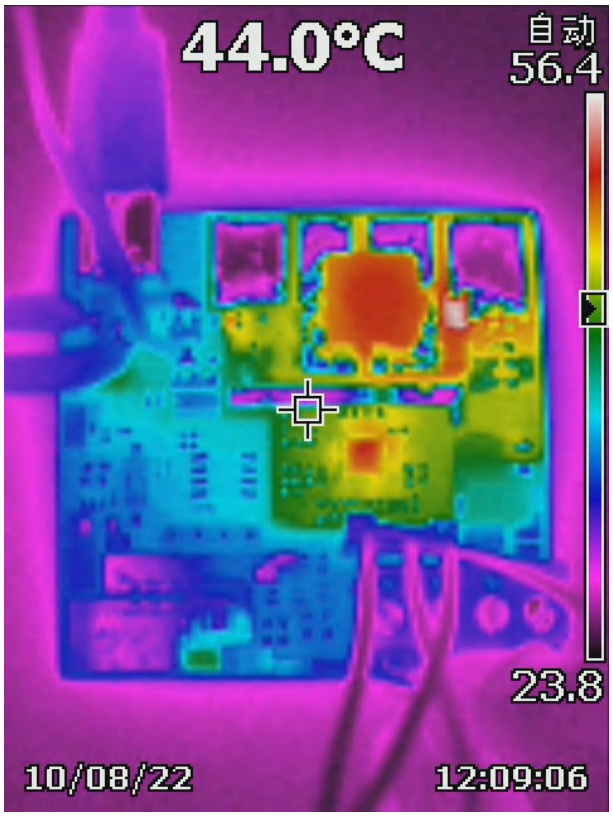


Figure 2-8. 18 V_{BAT} to 9 V, 3 A OTG Full Load

Figure 2-9. 18 V_{BAT} to 15 V, 3 A OTG Full Load

Figure 2-10. 18 V_{BAT} to 20 V, 3 A OTG Full Load

3 Waveforms

3.1 Start-up Waveforms

Switching behavior is shown in the following figures. The waveform channel key is as follows: Light Blue: V_{BUS}, Pink: V_{BAT}, Green: Iout.

Figure 3-1 through Figure 3-4 illustrate the charge mode start up.

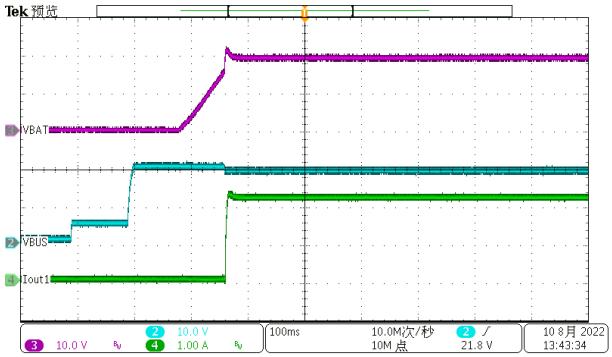


Figure 3-1. V_{BUS} 20 V to V_{BAT} 20-V Charge Mode

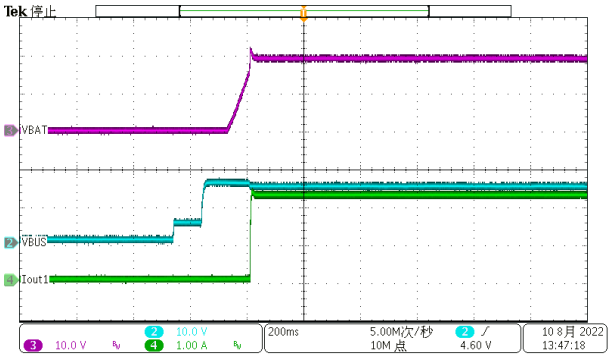


Figure 3-2. V_{BUS} 15 V to V_{BAT} 20-V Charge Mode

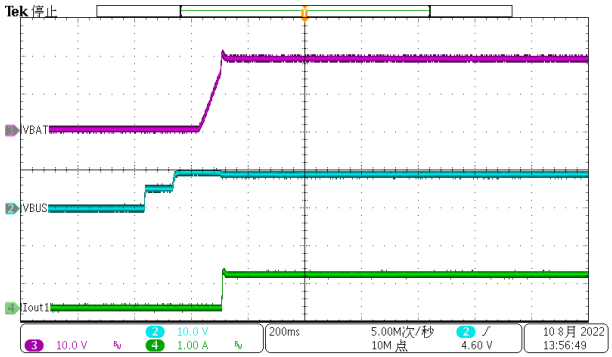


Figure 3-3. V_{BUS} 9 V to V_{BAT} 20-V Charge Mode

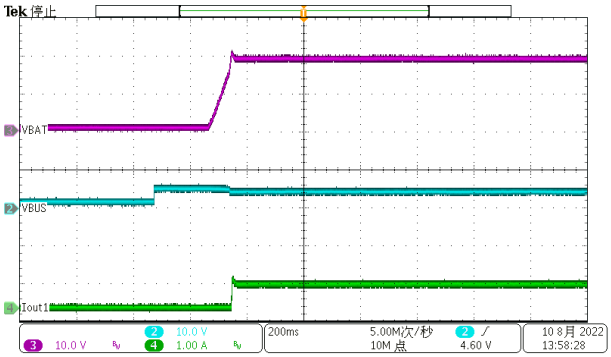


Figure 3-4. V_{BUS} 5 V to V_{BAT} 20-V Charge Mode

Figure 3-5 through Figure 3-8 illustrate OTG mode start up.

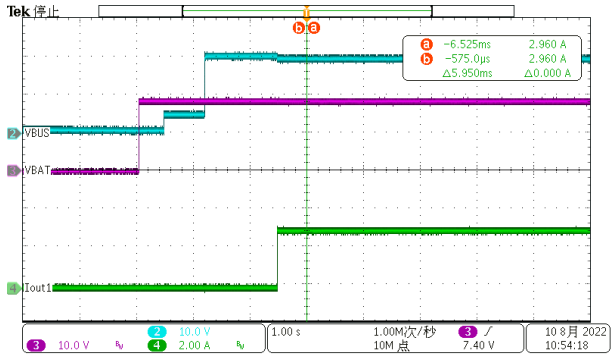


Figure 3-5. 18 V_{BAT} to 20 V, 3 A Out OTG Mode

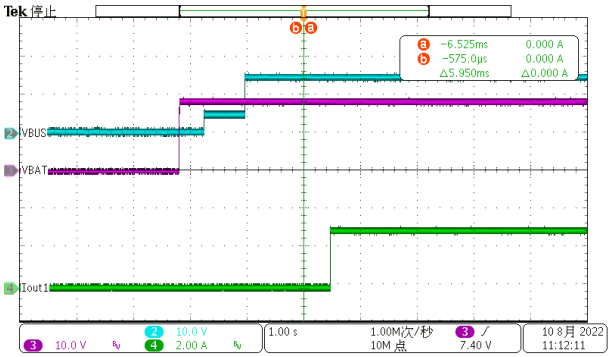


Figure 3-6. 18 V_{BAT} to 15 V, 3 A Out OTG Mode

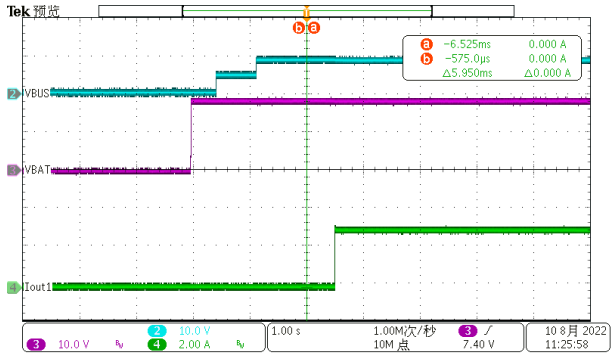


Figure 3-7. 18 V_{BAT} to 9 V, 3 A Out OTG Mode

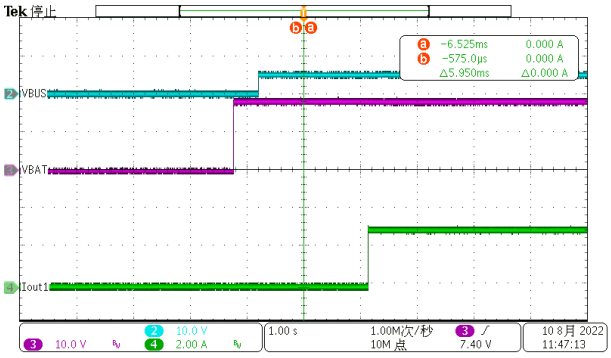


Figure 3-8. 18 V_{BAT} to 5 V, 3 A Out OTG Mode

3.2 Output Voltage Ripple and Noise

Output voltage ripple is shown in the following figures.

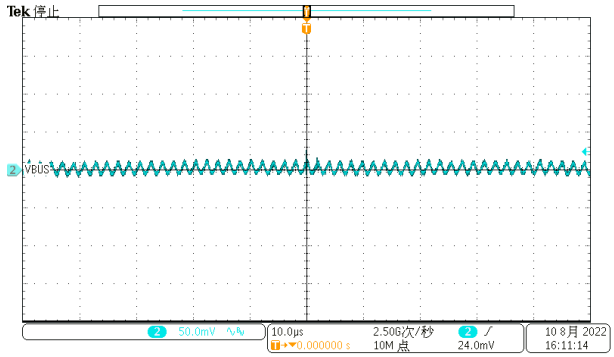


Figure 3-9. V_{BAT} 18 V to 5 V, 3 A Full-Load Ripple at OTG Mode

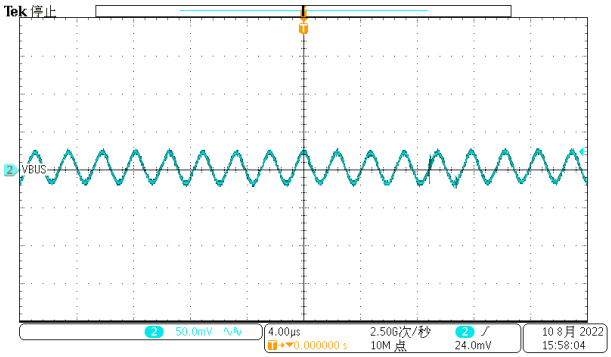


Figure 3-10. V_{BAT} 18 V to 9 V, 3 A Full-Load Ripple at OTG Mode

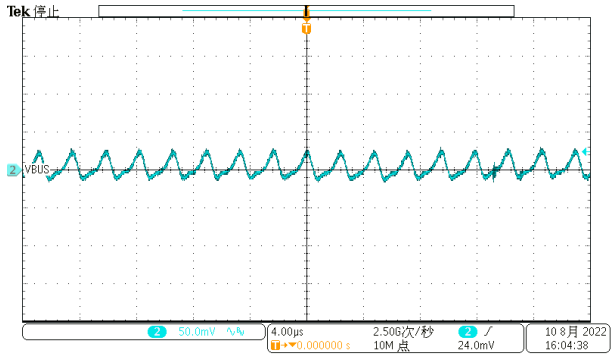


Figure 3-11. V_{BAT} 18 V to 15 V, 3 A Full-Load Ripple at OTG Mode

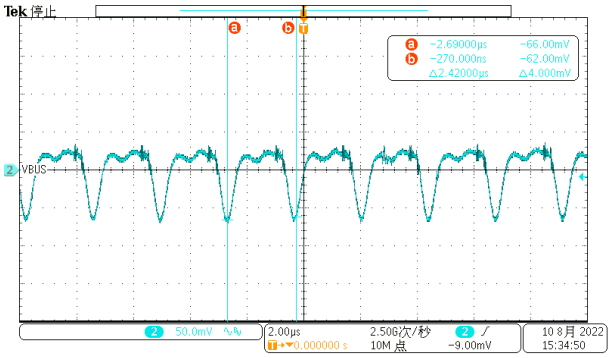


Figure 3-12. V_{BAT} 18 V to 20 V, 3 A Full-Load Ripple at OTG Mode

3.3 Load Dynamic

Load dynamic is performed with load dynamic from 0.1 A to 3 A with 2 A/µs slew rate. The output voltage at the PCB board end is recorded for reference.

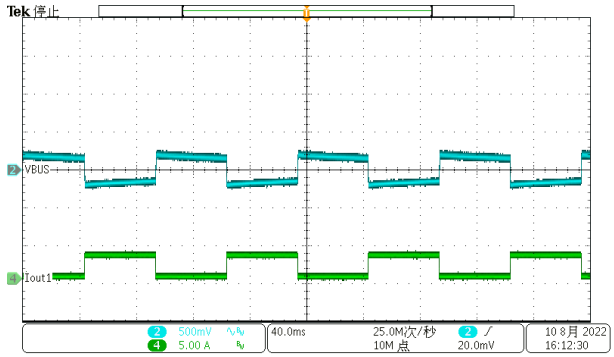


Figure 3-13. V_{BAT} 18 V to 5 V_{BUS} 0.1 A to 3 A Load Dynamic

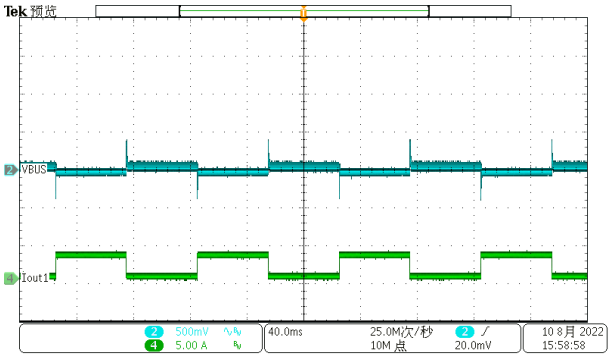


Figure 3-14. V_{BAT} 18 V to 9 V_{BUS} 0.1 A to 3 A Load Dynamic

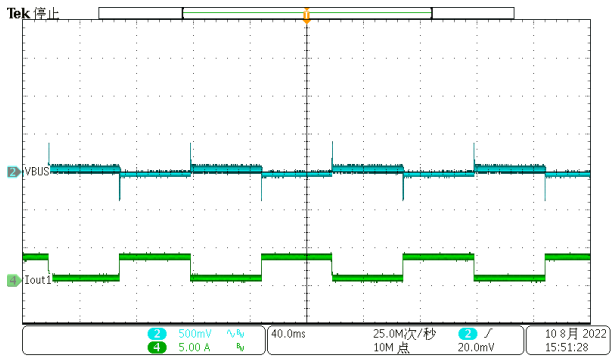


Figure 3-15. V_{BAT} 18 V to 15 V_{BUS} 0.1 A to 3 A Load Dynamic

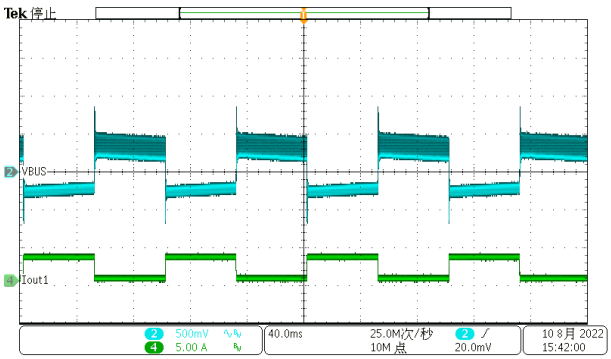


Figure 3-16. V_{BAT} 18 V to 20 V_{BUS} 0.1 A to 3 A Load Dynamic

3.4 Switching Node

Switching node on SW1 and SW2 is shown in the following figures. The waveform channel key is as follows: Pink: SW1-V_{BUS}, Light blue: SW2-V_{BAT}

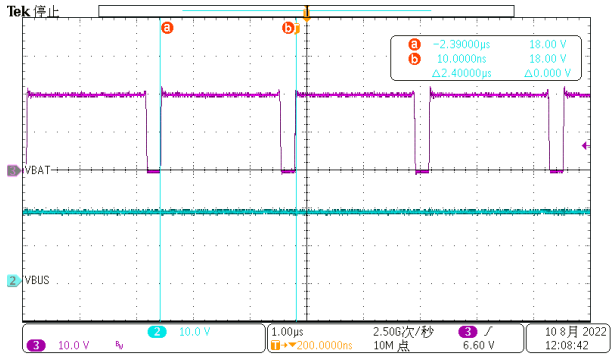


Figure 3-17. 19 V_{BAT} to 20 V, 3 A Full Load OTG Mode Working at Boost Mode

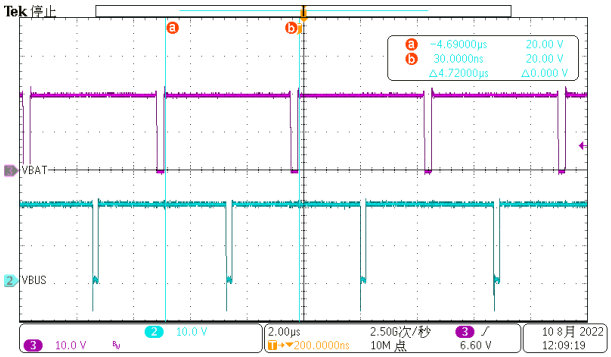


Figure 3-18. 20 V_{BAT} to 20 V, 3 A Full Load OTG Mode Working at Buck-Boost Mode

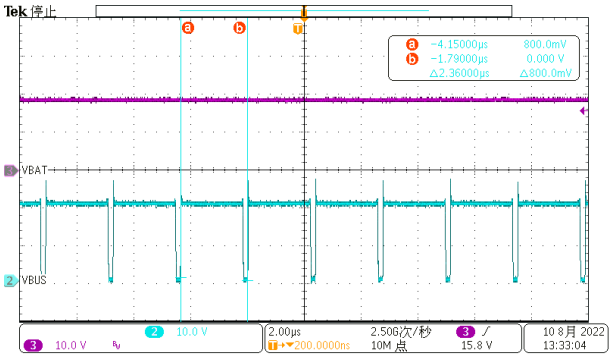


Figure 3-19. 21 V_{BAT} to 20 V, 3 A Full Load OTG Mode Working at Buck Mode

The following images illustrate charging mode switching node.

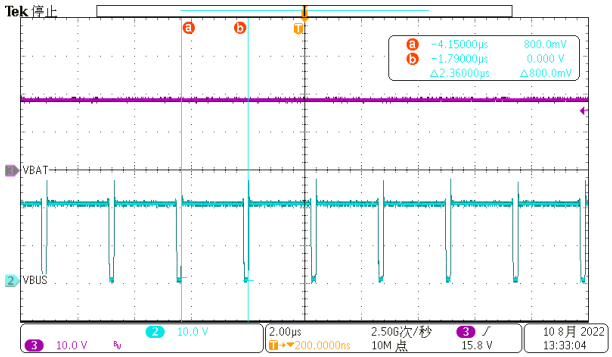


Figure 3-20. 20 V_{BUS} to V_{BAT} 21 V Charge Mode Working at Boost Mode

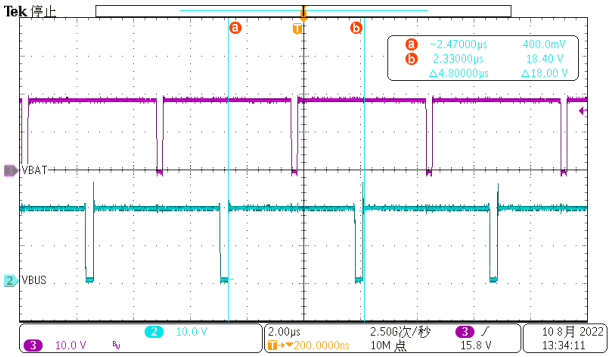


Figure 3-21. 20 V_{BUS} to V_{BAT} 20 V Charge Mode Working at Buck-Boost Mode

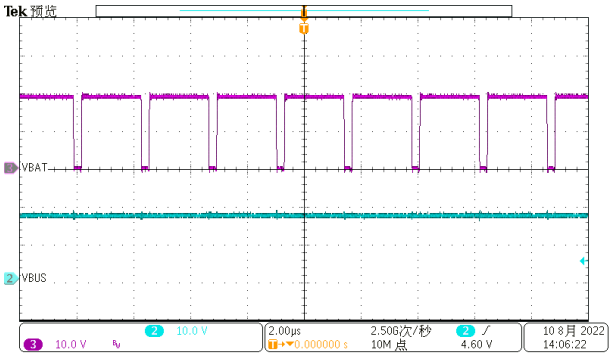


Figure 3-22. 20 V_{BUS} to V_{BAT} 19-V Charge Mode Working at Buck Mode

3.5 Short-Circuit Protection

Start-up behavior is shown in the following figures.

The waveform channel key is as follows: Pink: SW1-V_{BUS}, Light blue: SW2-V_{BAT}, Blue: V_{BAT}, Green: Iout

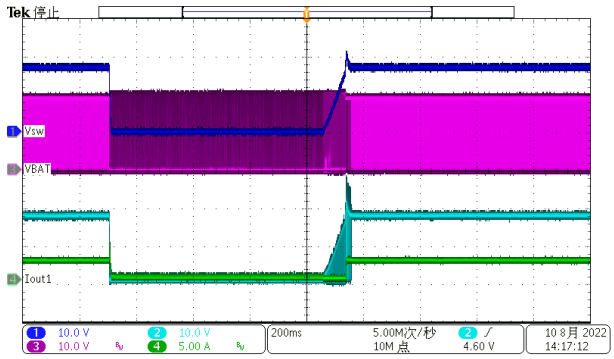


Figure 3-23. V_{BUS} = 20 V, V_{BAT} Short-Circuit Protection and Auto Recovery

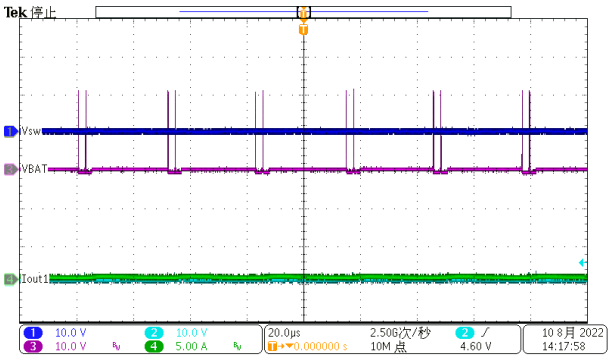


Figure 3-24. Switching Waveform During Short-Circuit Period

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