Design Guide: TIDA-050047

Integrated USB Type-C®, USB Power Delivery and Charging Reference Design for 2–4 Cell Batteries

Description

The integrated USB Type-C®, USB Power Delivery (PD) and charging reference design for 2- to 4-cell batteries is a 2-in-1, USB Type-C and USB PD controller along with a battery charging system. This reference design can support charging 2S to 4S batteries through a USB Type-C port, in addition to the standard USB Type-C communication, power delivery negotiations, power role swaps, and data role swaps. This board features charging current up to 5A, without the need for any external FETs enabling a much smaller design size, reducing total BOM cost, and so on. In addition, an external microprocessor is not necessary as the USB-PD controller can handle the I^2C communication to the battery charger integrated circuit (IC). As a result, there is no need for any firmware development work and the design greatly reduces the total time needed to market.

Resources

TIDA-050047	Design Folder
TPS25751, BQ25798	Product Folder
TPS54531, TLV755P	Product Folder
TVS2200	Product Folder

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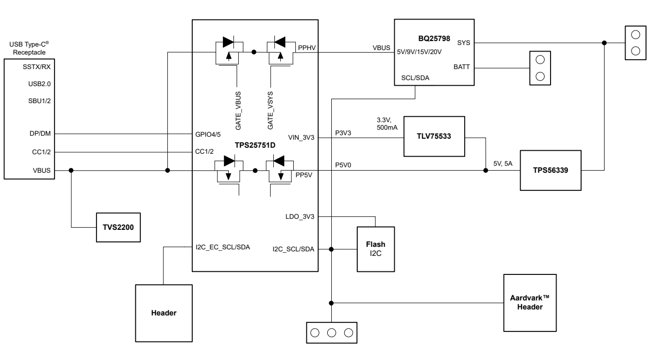
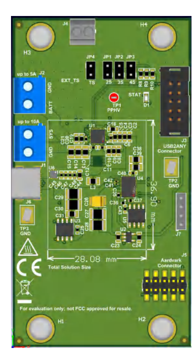
Features

- Configurable as Source-Sink or Sink-Only power roles
- Configuration Options Selected through Binary Vending Machine GUI
- Comprehensive Power Path Management and Protection
- Supports Charging of a 2S-4S Battery
- Seamless Transition Among Buck, Buck-boost and Boost Functionality
- OTG Mode Support in Source Mode

Applications

- Battery pack: cordless power tool
- Retail automation and payment
- Wireless speaker
- Headsets, headphones, and earbuds
- Portable electronics
- Industrial





1 System Description

The integrated USB Type-C and USB PD and charging reference design is a USB Type-C and PD controller system along with a battery charging system capable of 66W sinking and up to 45W sourcing. This reference design can support charging 2S to 4S batteries through a USB Type-C port, in addition to the USB Type-C communication and power delivery negotiations.

This board features charging up to 18.8V or 5A, without the need for any external FETs. An external microprocessor is not necessary as the USB-PD controller handles the I^2C communications to the battery charger IC to configure the appropriate functionality. Some examples of what the USB-PD controller handles includes setting the charging voltage and current, and configuring the battery charger for OTG or charge mode based off of the active USB Type-C power role.

1.1 Key System Specifications

Table 1-1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Sink Capabilities	5V–20V	VBUS from USB Type-C input
Source Capabilities	5V–20V	Output from BQ25798
Cell Configurations	2 cell–4 cell	Battery Cell Number
Charge Current	Up to 5A	Battery Charging Current
OTG Capability	Up to 45W	Sourcing Power From Battery

2 System Overview

2.1 Block Diagram

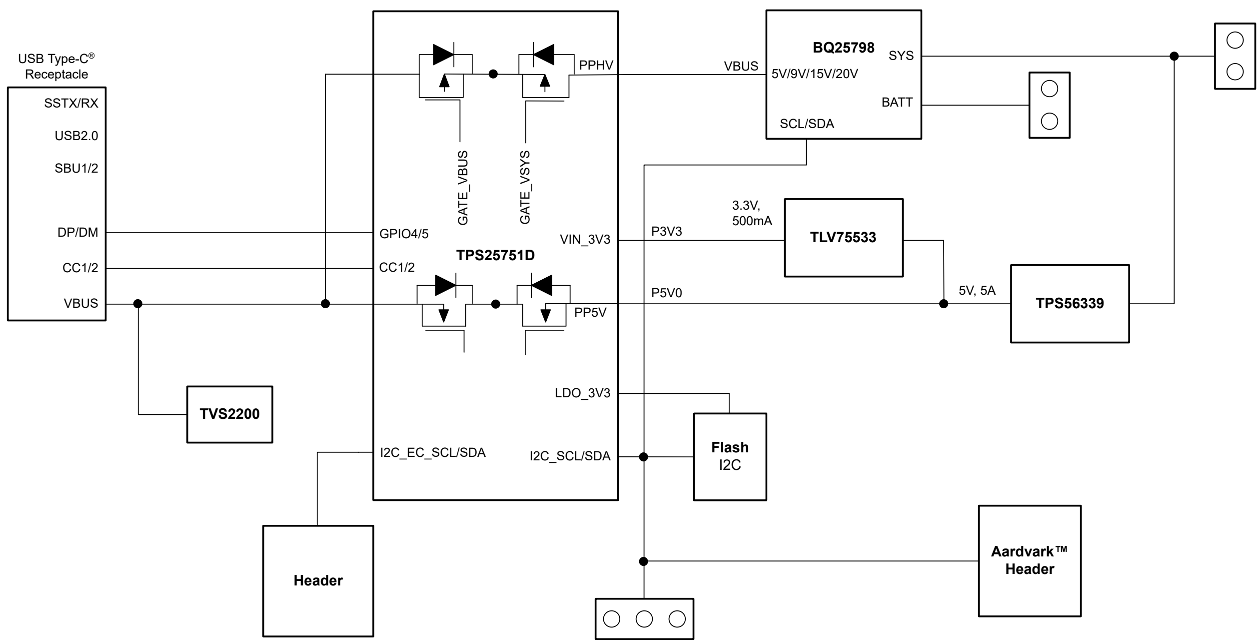


Figure 2-1. TIDA-050047 Block Diagram

2.2 Design Considerations

TIDA-050047 shows an example of how to implement a USB Type-C PD system alongside a switching battery charger that is capable of handling high power and current. This design can be used in power tools, power banks, and any various other personal electronic systems. This design can assist 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.

2.3 Highlighted Products

2.3.1 TPS25751D

The TPS25751D is a USB Type-C and Power Delivery (PD) controller providing cable plug and orientation detection for a single USB Type-C connector. Upon cable detection, the TPS25751D communicates on the CC wire using the USB PD protocol. When cable detection and USB PD negotiation are complete, the TPS25751D enables the appropriate power path for sourcing or sinking power depending on the contract negotiation and configuration.

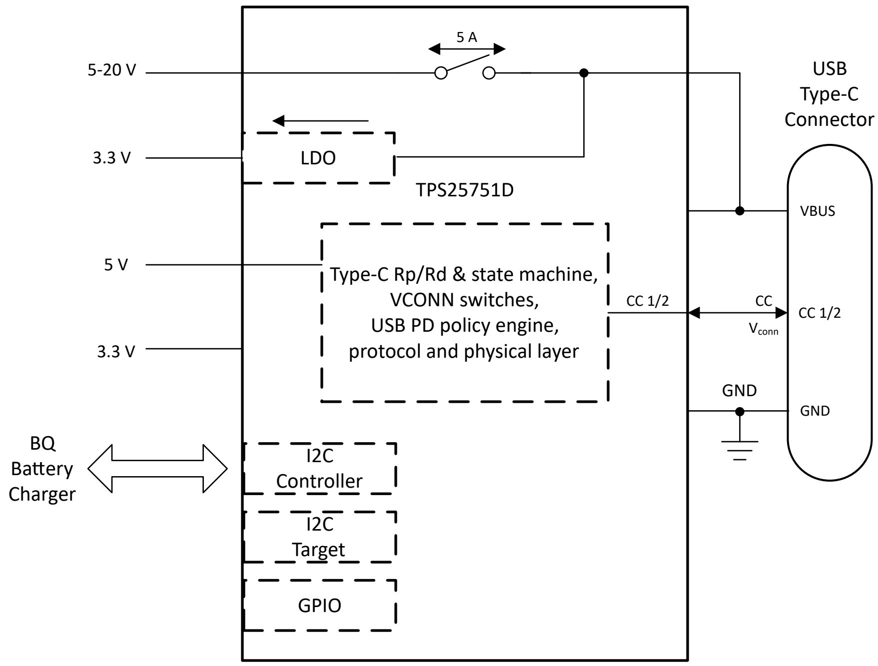


Figure 2-2. TPS25751D Typical Application Circuit

2.3.2 BQ25798

The BQ25798 is a highly integrated switched-mode buck-boost battery charge management device intended for 1- to 4-series cell Li-ion and Li-polymer batteries. The charger features a narrow VDC architecture (NVDC) which allows the system to be regulated to a minimum value even if the battery is completely discharged. With dual-input source selection, USB OTG support, and an integrated 16-bit multichannel analog-to-digital converter (ADC), the BQ25798 is a complete charging design.

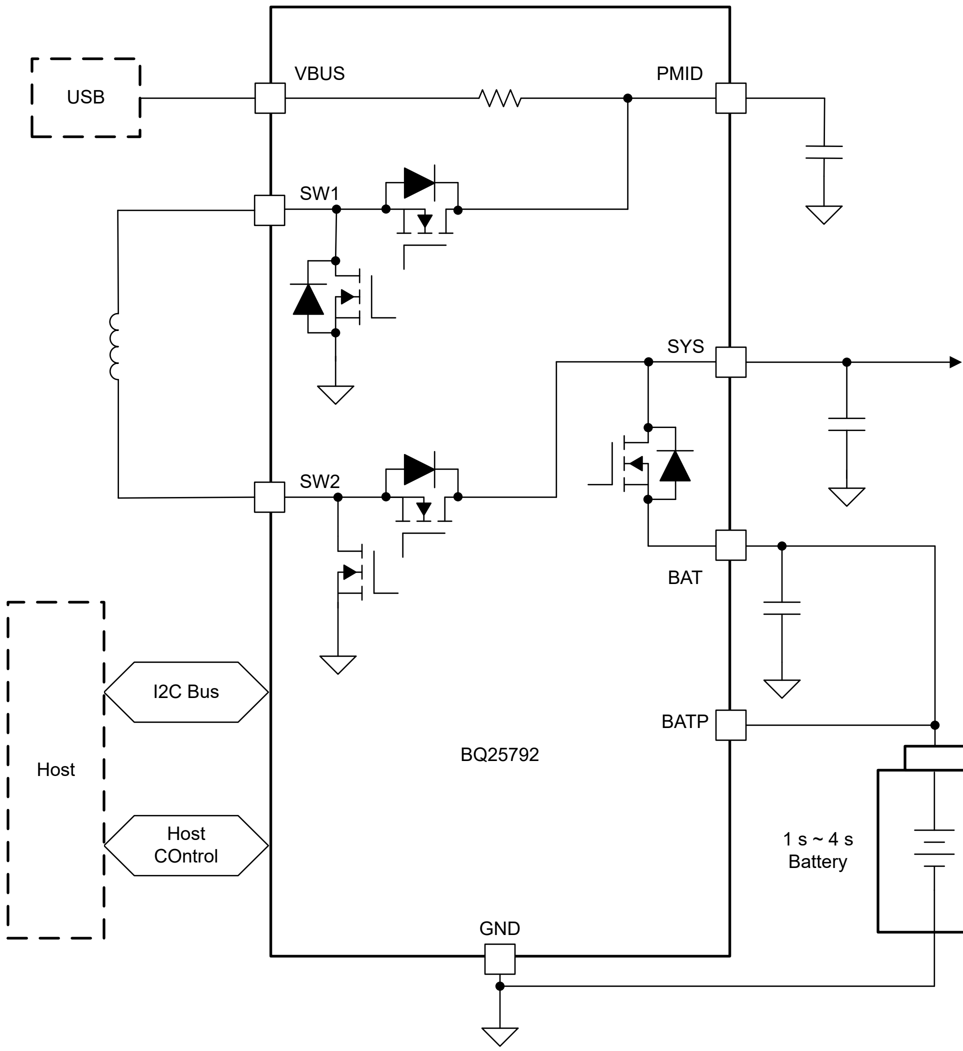


Figure 2-3. BQ25798 Typical Application Circuit

2.4 System Design Theory

The following sections highlight subsystems of the TIDA-050047 design, discuss the features, and how the features are implemented. This section illustrates how the TPS25751D PD Controller is interfaced with the BQ25798 through I^2C enabling a simpler design that does not require any external FETs or any FW development.

2.4.1 TPS25751D PD Controller

The TPS25751D features two I^2C ports: one as a controller port that connects directly to the battery charger. The latter communicates proper configurations for charging mode, charging current, OTG mode, and so forth. The controller port also connects to the I2C EEPROM that contains a patch and configuration bundle which the TPS25751 loads from on boot. The controller port can be used with header J7 to communicate to the BQ25798. The second I2C port, or the target port, can be used to directly program the TPS25751, and program the BQ25798 through the host microcontroller (MCU), or program both, and is available on J3.

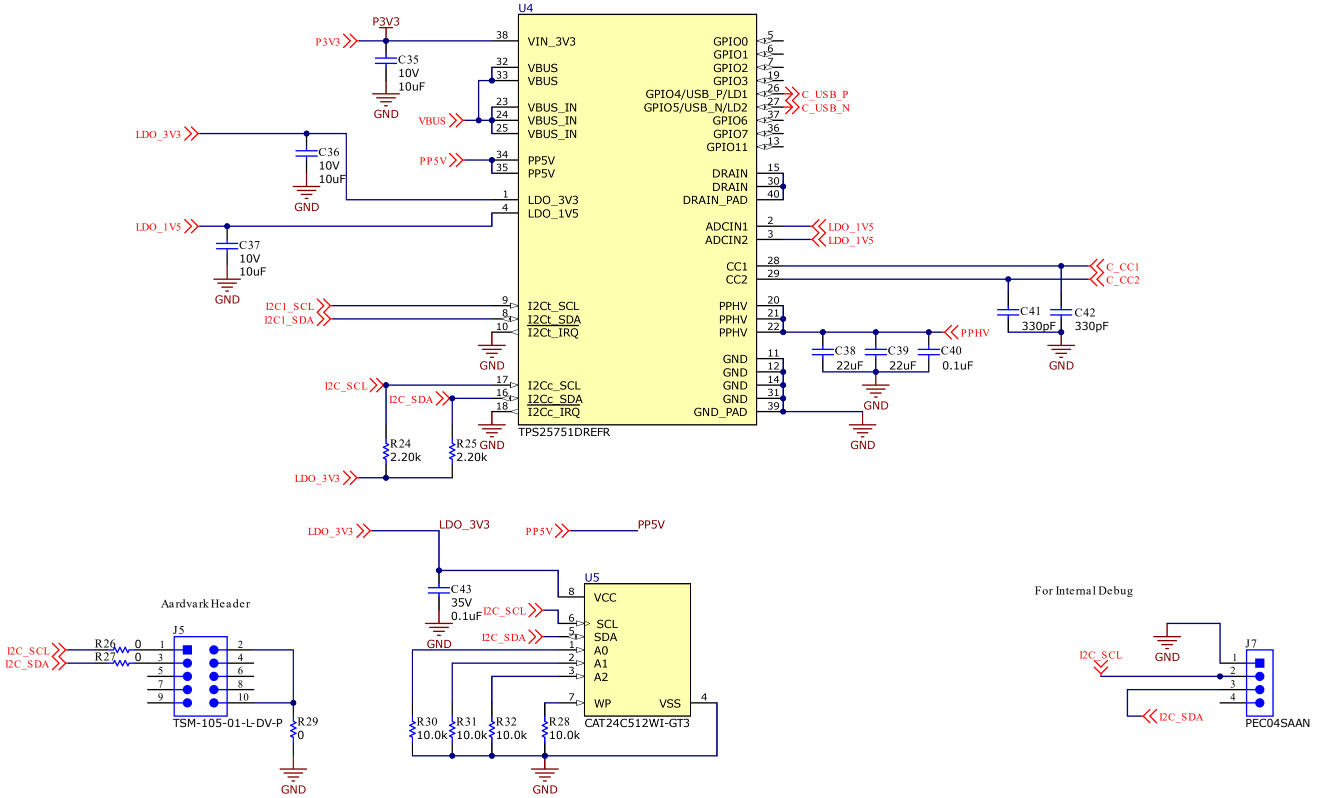


Figure 2-4. TPS25751D Schematic

2.4.2 BQ25798 Battery Charger

The BQ25798 is a highly integrated switch-mode buck-boost charger for a 1- to 4-cell Li-ion battery and a Li-polymer battery. The integration includes four switching MOSFETs (Q1, Q2, Q3, and Q4), input and charging current sensing circuits, battery FET (QBAT), and all the loop compensation of the buck-boost converter. This battery charger receives I^{2}C commands from the PD controller to configure the registers appropriately for the desired application. There are sockets to connect the charger to a system as well as a battery.

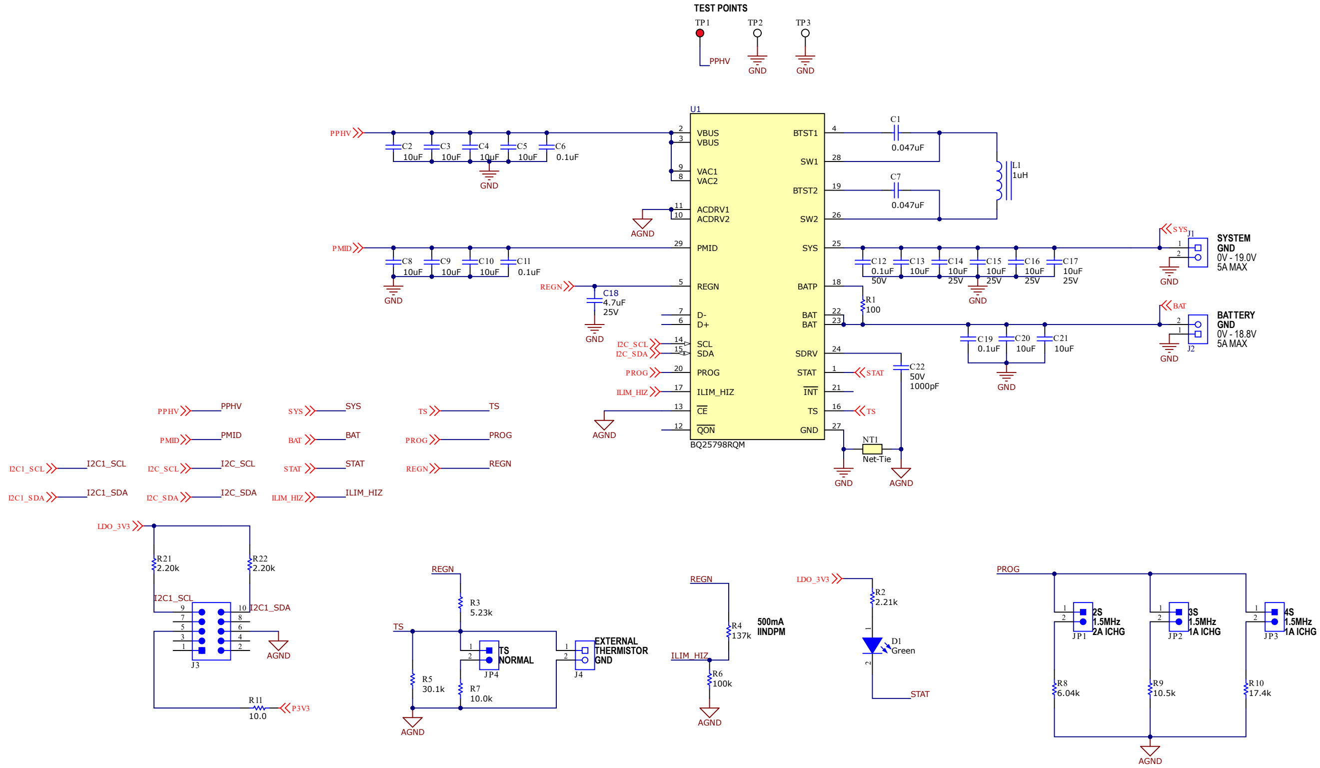


Figure 2-5. BQ25798 Schematic

2.4.3 TPS54531 Buck Converter

For sourcing capabilities, this design uses the PP5V power path to supply a 5V source and the PPHV power path to source higher voltages. Therefore to keep a constant 5V system source readily available on VBUS for the PD controller and for VCONN support, a buck converter is needed. Due to the buck topology selection, a 2S-4S battery is needed to work with the TPS54531 to achieve a 5V output operation using the battery as the input. For this design, the TPS54531 is a good choice, the device features integrated FETs and a wide input voltage range. Since this converter is connected to the system rail of the battery charger, the converter can handle any input voltage in the range of 3.5V to 28V and provide a 5V output capable of delivering up to 5A. For a sink-only application, this device is not needed and a 5V rail can be omitted.

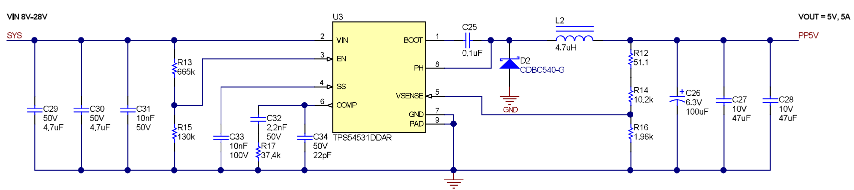


Figure 2-6. TPS54531 Buck Converter Schematic

2.4.4 TLV75533 LDO

To power on the TPS25751D device when the system needs to source power, the VIN_3V3 input pin must also be supplied. The TLV75533 is chosen to provide the 3.3V needed to power the PD controller. The input is connected to the TPS54531 output of 5V, which drops down to 3.3V. However, this input supply is not needed for sink-only applications and so the 3.3V rail can be omitted as well if that is the case.

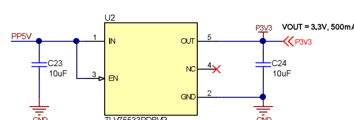


Figure 2-7. TLV75533 Schematic

2.4.5 USB Type-C® Receptacle

Figure 2-8 shows the schematic of the USB Type-C receptacle that this design uses. From this receptacle, the communication (CC1 and CC2) and VBUS pins are mapped appropriately to the TPS25751D PD controller. In addition, the TVS2200 diode, which is a 22V precision surge protection clamp, is also added to the design at the USB Type-C port for added protection.

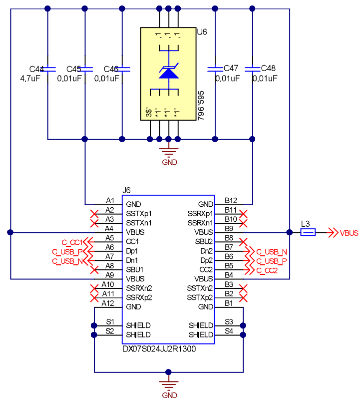


Figure 2-8. USB Type-C® Receptacle Circuit With TVS2200

2.4.6 Supporting Components for Programming

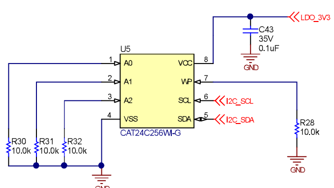


Figure 2-9. Flash IC

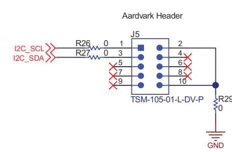


Figure 2-10. Aardvark™ Connector

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Hardware and Software Requirements

To fully test TIDA-050047, the following components are required:

1. Microsoft® Windows® PC running the web-based TPS25751 application customization tool GUI
2. TIDA-050047 board
3. Bidirectional power supply for battery connection testing
4. High-current USB Type-C cable
5. E-load or resistive Load for system connection testing
6. I2C Flash Programming Tool (Total Phase® Aardvark™ or similar device)

3.2 Application Customization Tool

This section guides users through the configuration of the GUI and generation of the EEPROM binary file needed to reprogram TIDA-050047. The reference design EEPROM comes programmed with a similar image.

1. First, open the TPS25751 application customization tool.

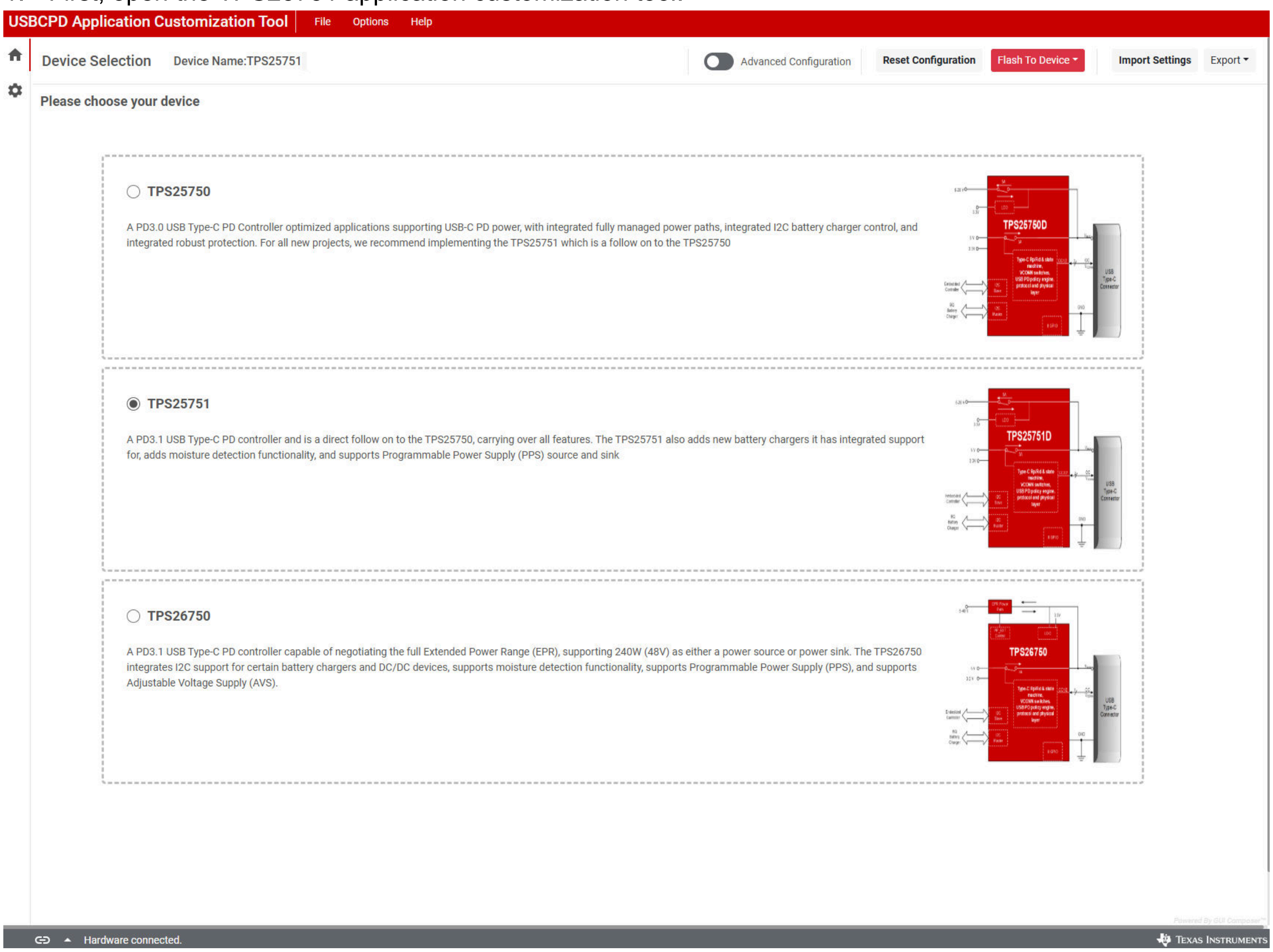


Figure 3-1. Device Selection

2. Select TPS25751 as the device.
3. Next, select the configuration. For this reference design, choose the first option, which is selected by default as shown in Figure 3-2.

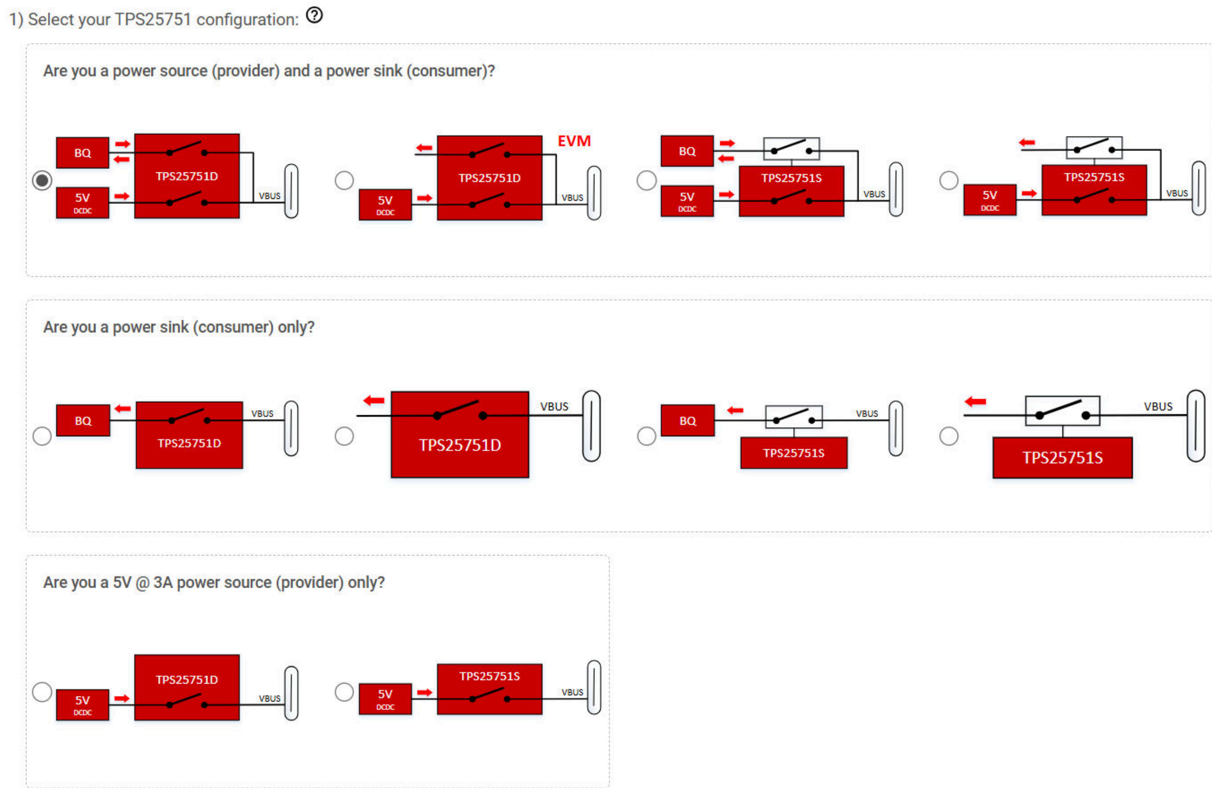
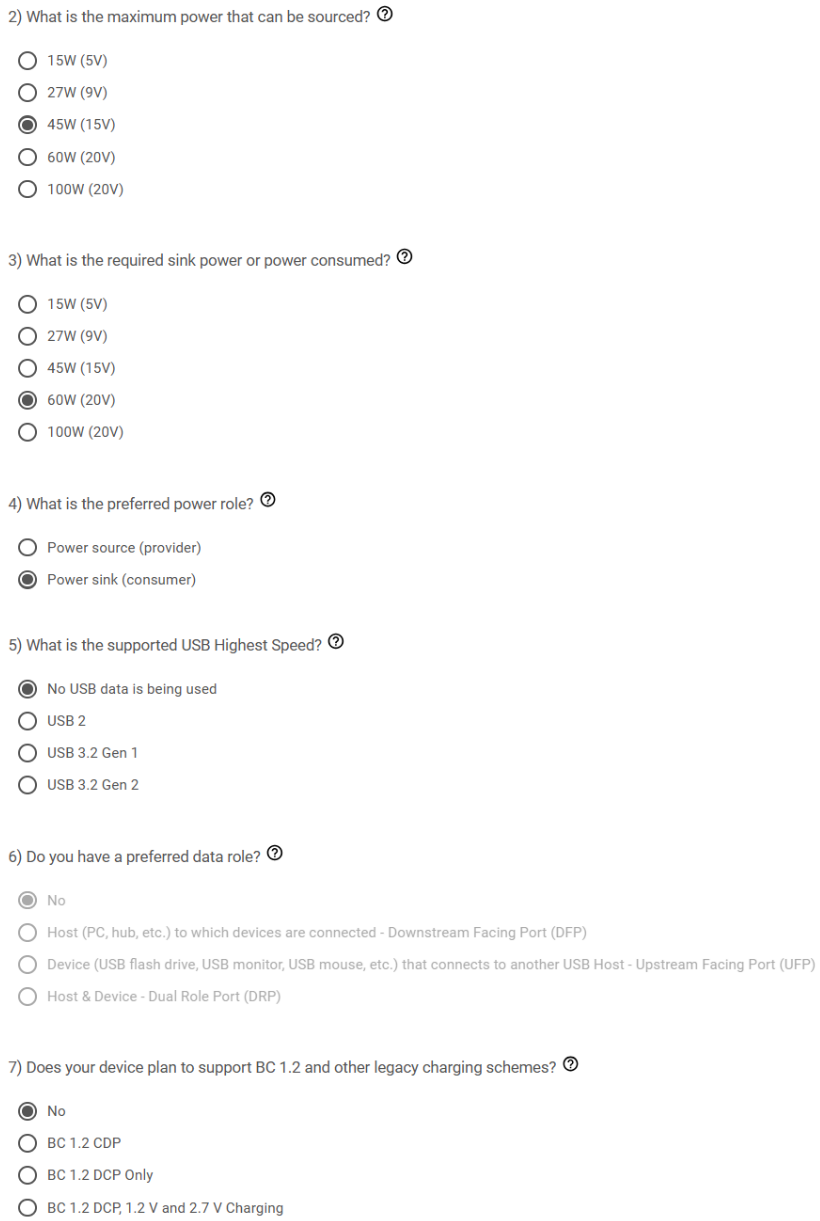


Figure 3-2. TPS25751 Application Selection

4. Questions 2 through 7 configure the power and data configurations as needed for this reference design. TIDA-050047 is capable of sourcing up to 45W (15V, 3A or 20V, 2.25A) and sinking up to 66W. Depending on preference, select the settings for testing. For this reference design, follow the settings shown in Figure 3-3.



2) What is the maximum power that can be sourced?

○ 15W (5V)
○ 27W (9V)
◉ 45W (15V)
○ 60W (20V)
○ 100W (20V)

3) What is the required sink power or power consumed?

○ 15W (5V)
○ 27W (9V)
○ 45W (15V)
◉ 60W (20V)
○ 100W (20V)

4) What is the preferred power role?

○ Power source (provider)
◉ Power sink (consumer)

5) What is the supported USB Highest Speed?

◉ No USB data is being used
○ USB 2
○ USB 3.2 Gen 1
○ USB 3.2 Gen 2

6) Do you have a preferred data role?

◉ No
○ Host (PC, hub, etc.) to which devices are connected - Downstream Facing Port (DFP)
○ Device (USB flash drive, USB monitor, USB mouse, etc.) that connects to another USB Host - Upstream Facing Port (UFP)
○ Host & Device - Dual Role Port (DRP)

7) Does your device plan to support BC 1.2 and other legacy charging schemes?

◉ No
○ BC 1.2 CDP
○ BC 1.2 DCP Only
○ BC 1.2 DCP, 1.2 V and 2.7 V Charging

Figure 3-3. Supported Power Questions

5. Question 8 enables the *Liquid Detection* feature of the TPS25751. TIDA-050047 does not support the hardware for *Liquid Detection*, set this question to *No*.

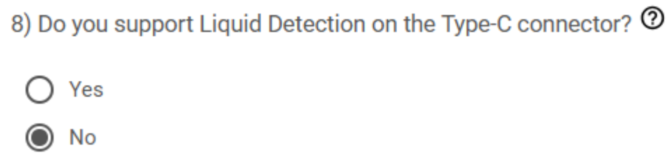


Figure 3-4. Liquid Detection

6. Questions 9 and 10 pertain to the Vendor ID and Product ID, which are not necessary to fill out. Exclusive IDs can be entered here, if desired. For this project, the second option can be selected for both questions.

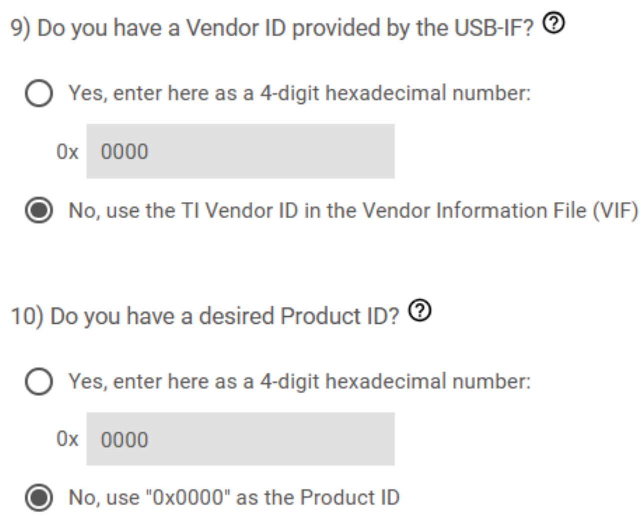


Figure 3-5. Vendor or Product ID Information

7. The last section asks questions regarding the battery charger configuration. For this design, the battery charger used is the BQ25798, so the first option can be selected here.

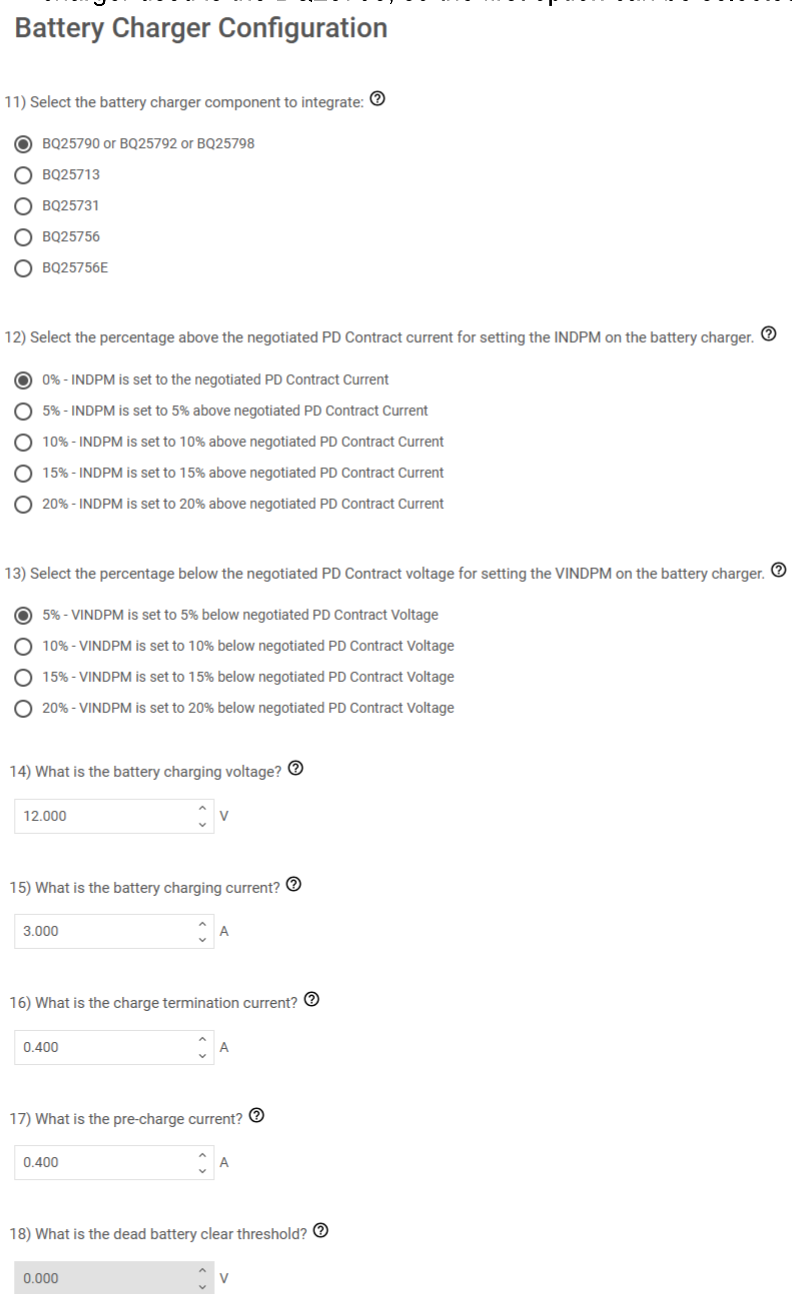


Figure 3-6. Battery Charger Questions

Questions 12 through 18 can be filled out according to the desired use case. For example, responses can be set to the following:

- INDPM percentage can be set to 0%
- VINDPM percentage can be set to 5%
- Battery charging voltage: input 12V for a 3s battery
- Battery charging current can be set to 3A
- Charge termination current is set to a low 400mA, this is the current that the battery charges once the battery has reached almost full capacity
- Pre-charge current depends on the selected battery charger, select 400mA for the BQ25798 device

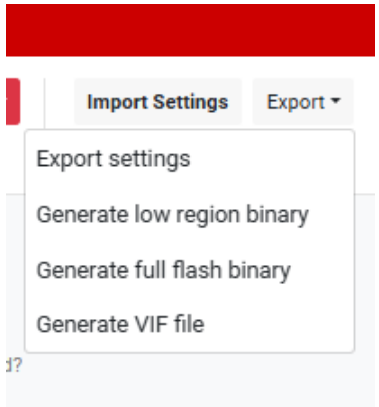


Figure 3-7. Exporting the Selected Settings

When all of the questions are answered, the EEPROM binary file is ready to be generated and programmed. Generate the binary using the *Export -> Generate Full Flash Binary* option. Next, use the I2C Flash programming tool of your choice to flash the binary to the TPS25751 EEPROM (U5) through one of the exposed I2C headers (J5, J7).

3.3 Test Setup

To test TIDA-050047 after the configuration has been programmed, a few connections need to be made before powering on.

A bidirectional power supply can be connected to the BATT socket(J2) to emulate a battery. Depending on the cell configuration jumper settings for JP1–JP3, set the voltage on the power supply accordingly. 1A is sufficient for testing, but can be modified as needed. The JP4 jumper also needs to be populated for the default thermistor settings.

Once the connections are properly made, the power supply can be turned on. The power supply on BATT, powers on the BQ25798 and the necessary 5V and 3.3V buck converter and LDO that connects to the TPS25751D. Once the PD controller is powered on, the controller loads the project configurations that are programmed on the Flash IC to operate based on the selected options in the Application Customization Tool.

The TIDA-050047 is now ready to be connected to a port partner via a USB Type-C cable to either source power or the sink power as negotiated.

Power is supplied on the BATT pin only for sink-only testing modes like dead battery simulation. The connection setup remains the same. Therefore, once the correct jumpers are set, when the USB Type-C cable connects to a port partner that offers source capabilities, the TPS25751D powers on using VBUS and loads the proper configurations from the flash to program the BQ25798 for charging the battery.

3.4 Test Results

On power-up, the TPS25751D configures the BQ25798 over I2C, configuring the charge current, pre-charge current, termination current, charge voltage, and control settings. These initial writes are based on the answers provided in the Web-based Application Customization Tool. When a 5V sink PDO Contract is negotiated, the PD controller sets up the buck-boost battery charger BQ25798 for a V_{IN} of 5V and charging the battery at1A based on this particular configuration.

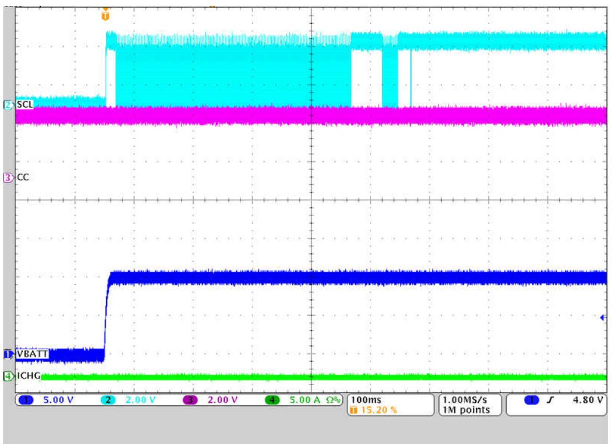


Figure 3-8. Power On Reset (POR) Commands

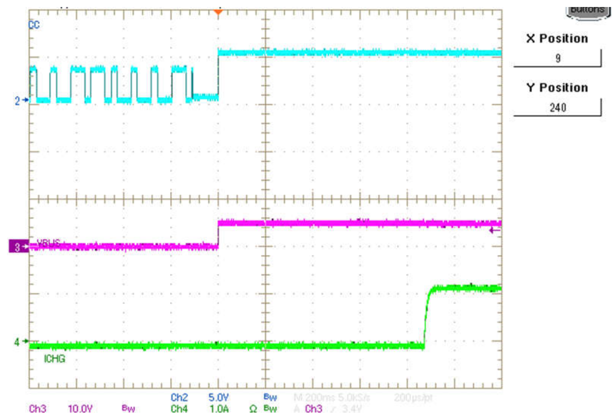


Figure 3-9. Example of a 5V Sink Contract Charging a Battery

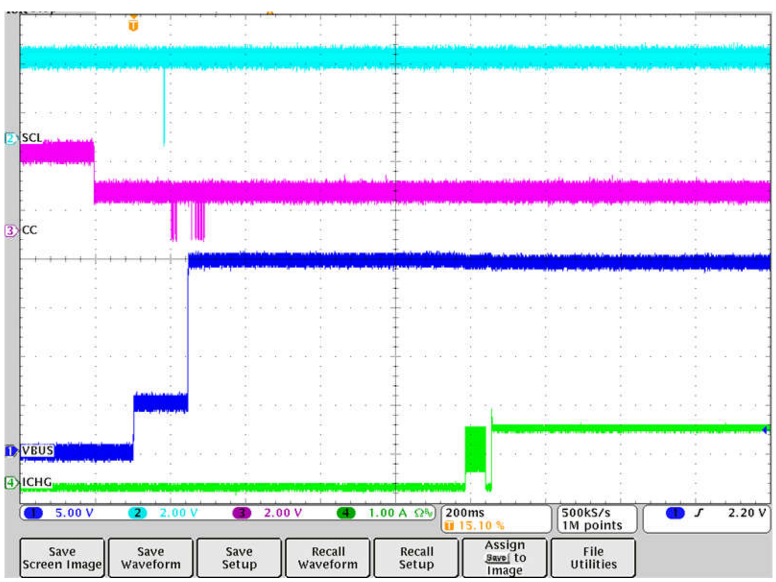


Figure 3-10. 20V Sink Charging at 1A

Similarly, when a 20V sink PDO contract is negotiated, the same behavior can be seen where the PD controller sets up V_{IN} at 20V this time, while maintaining charging at 1A.

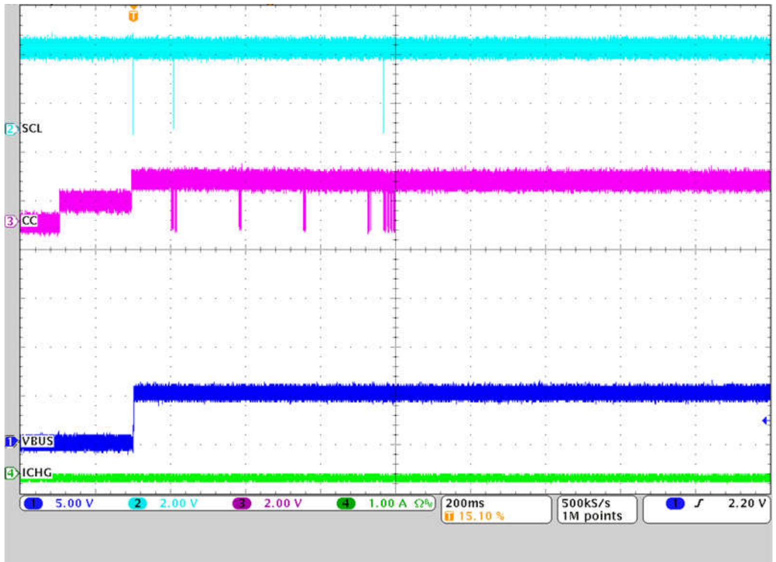


Figure 3-11. Sourcing 5V With BQ25798 in OTG Mode

When the TPS25751D negotiates a source PDO contract, the device configures the BQ25798 to operate in OTG mode so that the battery can source the power needed for the port partner. In this case, the BQ25798 needs to boost up the battery voltage up to 5V to source power to the other device.

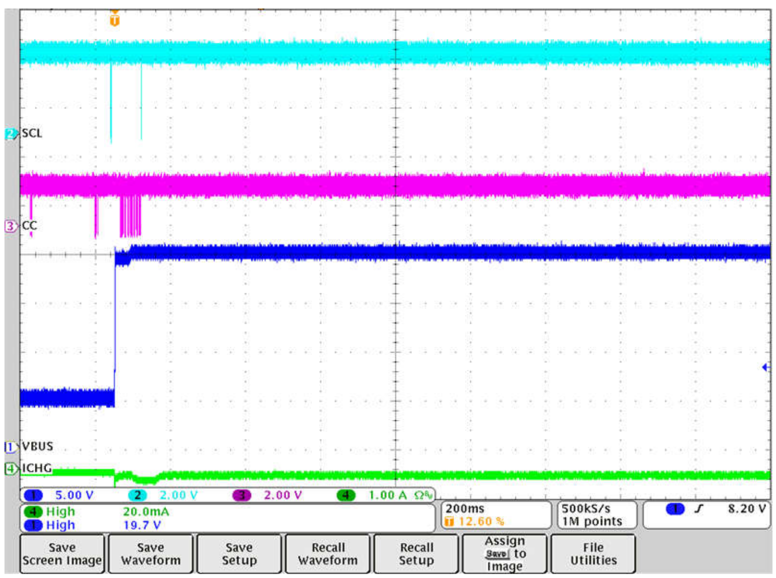


Figure 3-12. Sourcing 20V With BQ25798 in OTG Mode

The same behavior can be observed when the port partner and the TPS25751D negotiate a 20V contract using the TPS25751D as a source.

One feature of USB Type-C PD is the ability to perform power role swaps. Figure 3-13 shows a power role swap from source to sink.

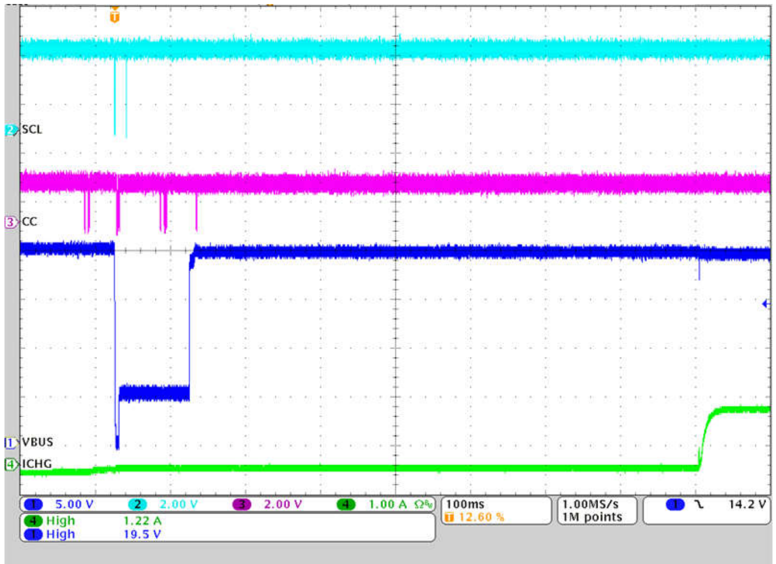


Figure 3-13. Power Role Swap from 20V Source to 20V Sink

TIDA-050047 is initially sourcing 20V on VBUS. A power role swap is initiated, and VBUS transitions to 0V as the port stops sourcing. The far-end USB-C port becomes the new power source, and a 20V PD contract is negotiated, with TIDA-050047 now acting as the power sink. Once the power role swap has successfully completed, the TPS25751D configures the BQ25798 for charging mode.

Similarly, Figure 3-14 shows a power role swap from sink to source can occur.

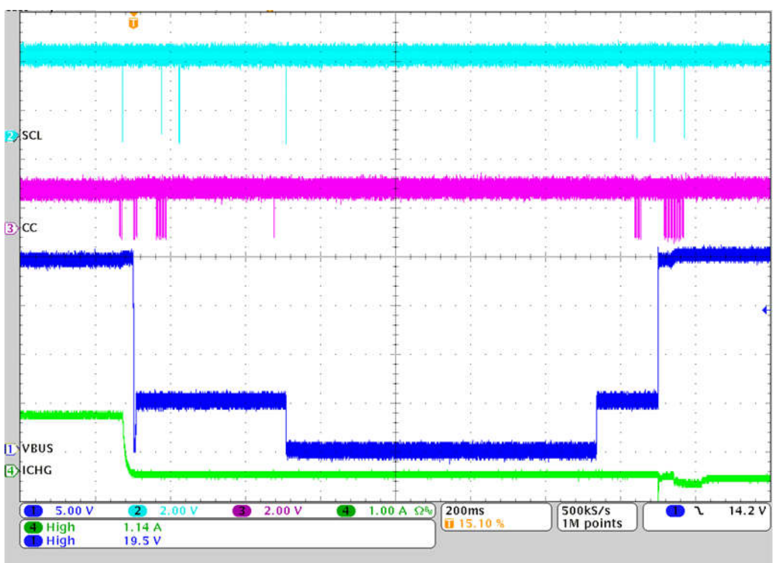


Figure 3-14. Power Role Swap from 20V Sink to 20V Source

4 Design and Documentation Support

4.1 Design Files

4.1.1 Schematics

To download the schematics, see the design files at TIDA-050047.

4.1.2 BOM

To download the bill of materials (BOM), see the design files at TIDA-050047.

4.1.3 Altium Project

To download the Altium Designer® project files, see the design files at TIDA-050047.

4.2 Software

To download the software binary file needed to configure the TPS25751D for this reference design, see the design files at TIDA-050047.

4.3 Documentation Support

1. Texas Instruments, TPS25751 USB Type-C® and USB PD Controller with Integrated Power Switches Optimized for Power Applications data sheet
2. Texas Instruments, BQ25798 I^2C Controlled, 1- to 4-Cell, 5A Buck-Boost Battery Charger with Dual-Input Selector, MPPT for Solar Panels and Fast Backup Mode data sheet
3. Texas Instruments, Web-Based Application Customization Tool Guide for TPS25751

4.4 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

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5 About the Author

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6 Revision History

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

Changes from Revision B (November 2020) to Revision C (June 2025) **Page**

- Updated document title to match AP style....1
- Updated mentions of TPS25750 to TPS25751 including updates to text, pictures, and diagrams. Updated the *GUI* section to reflect the new TPS25751 GUI. Deleted any mention of the USB2ANY because TIDUEY1 does not support the USB2ANY through the connector. Updated I2C "Master" and "Slave" to "Controller" and "Target" in the *TPS25751D PD Controller* section....1
- Deleted "0" µF marking on the PMID cap. Deleted comment about D+/D– because D+/D– is not used in this design and is handled by TPS25751....4
- Updated wording and updated BQ25798 schematic to BQ25798 (previously 792)....6
- Updated flashing process for EEPROM. Deleted mentions of TIVA because TI does not support non-EVM TIva usage. Updated GUI images to reflect the latest GUI....9