Design Guide: TIDA-010248

USB Type-C Power Delivery and Redriver Reference Design

Description

This USB Type-C® power delivery (PD) and USB Type-C® redriver reference design outputs from 5 V to 20 V with a maximum of 3 A for a total output power of 60 W. The redrivers support USB 3.2 (10Gbps), USB 3.2 ×2 (20Gbps) and DisplayPort 1.4 (8.1Gbps). This reference design is used in industrial PC and HMI applications.

Resources

TIDA-010248	Design Folder
TPS65994	Product Folder
TUSB1104	Product Folder
TUSB1044	Product Folder
TPS55288	Product Folder

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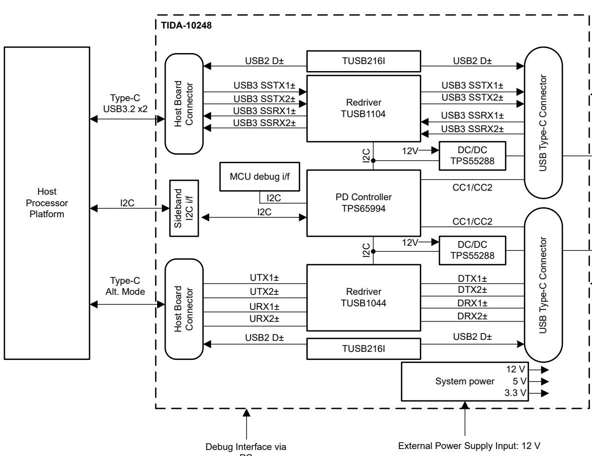
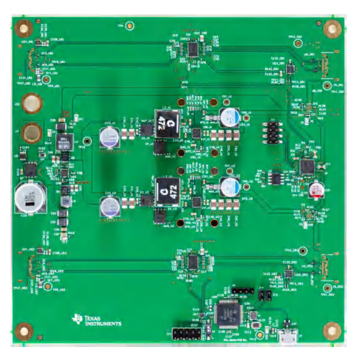
Features

- Complete USB Type-C power delivery (PD) and redriver reference design
- 5-V to 20-V PD over USB Type-C with 60 W of output power
- Fully-configurable dual-port USB 4 and Thunderbolt 4 (TBT4) PD 3.0 controller
- USB Type-C 10Gbps, USB 3.2 ×2 adaptive linear redriver
- USB Type-C 10Gbps multiprotocol bidirectional linear redriver
- 5-V to 20-V, 5-A buck-boost converter with I2C control interface

Applications

- Factory automation and control
- Single board computer
- Industrial monitor





1 System Description

This reference design with a USB Type-C power delivery controller, a USB 3.2 ×2 adaptive linear redriver and a multiprotocol bidirectional linear redriver provides up to 60 W of total power at a range of 5 V to 20 V with a maximum of 3 A. The redrivers support USB 3.2 (10Gbps), USB 3.2 ×2 (20Gbps) and DisplayPort 1.4 (8.1Gbps). This reference design can be used in industrial PC and HMI applications.

The redriver corrects signal integrity issues between the host and device resulting in a more robust system. The PD subsystem consists of a USB-PD controller and adjustable buck-boost DC/DC converter. The PD controller communicates with the redrivers to enable the USB or DP switching path and also controls the DC/DC converter and the redrivers via I2C protocol. The PD controller interacts with the USB Type-C devices plugged into the USB Type-C connectors over the configuration channel (CC) lines which enable the corresponding paths in the redriver and set the desired voltage and current in the DC/DC converters.

The USB Type-C PD and redriver reference design can be integrated with an Intel CPU (Elkhart Lake, Alder Lake, Tiger Lake) with TI's Sitara™ MPU, and other CPU or MPU designs that have USB 3 or DP capabilities, or both.

2 System Overview

2.1 Block Diagram

Figure 2-1 shows the USB Type-C PD and redriver reference design. The design consists of various subsystems which are described in the highlighted products section. The PCB subsection overview is shown in Figure 2-2, with each box indicating a specific subsection, such as the redriver path, input power, DC/DC converters, PD controller block, and so on.

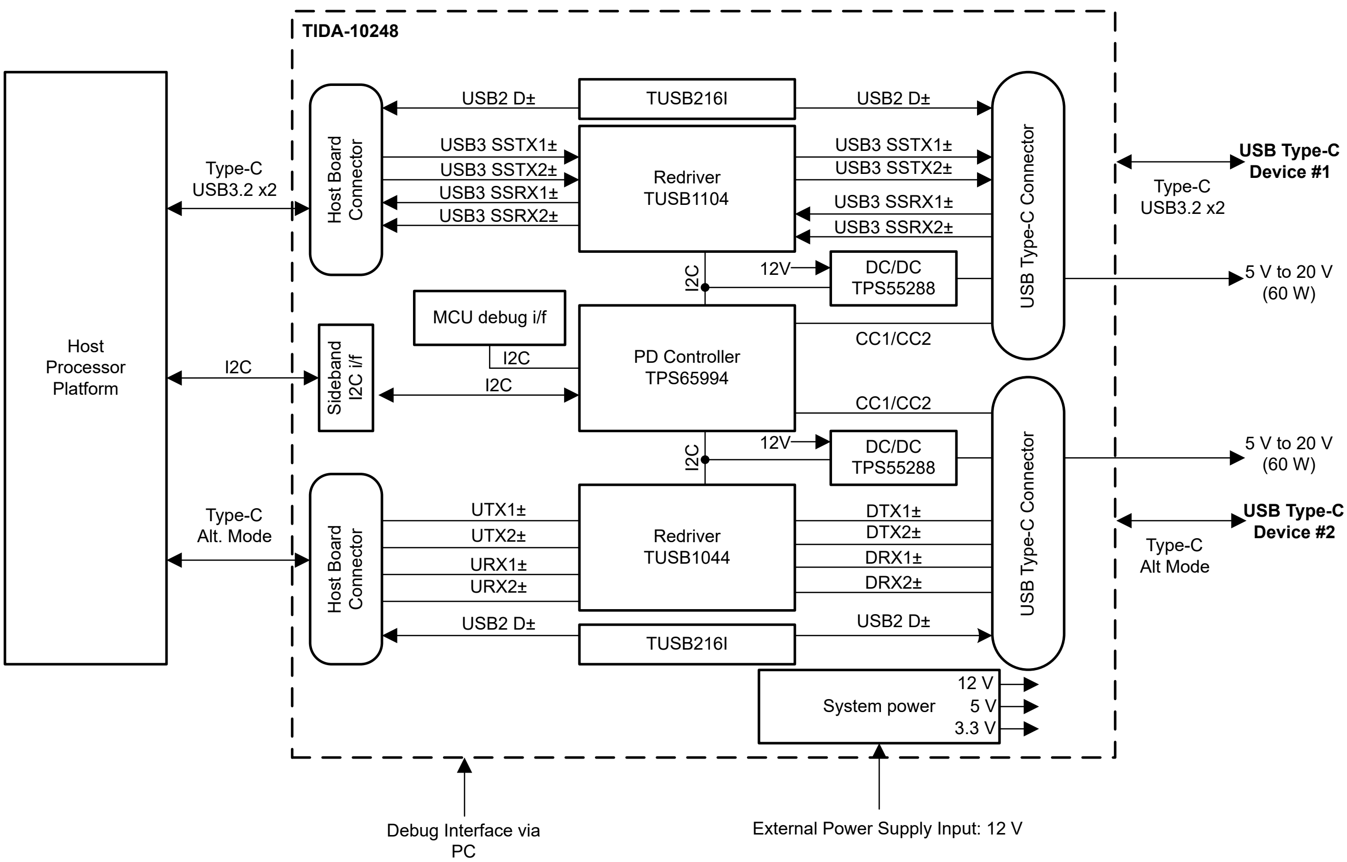


Figure 2-1. Block Diagram

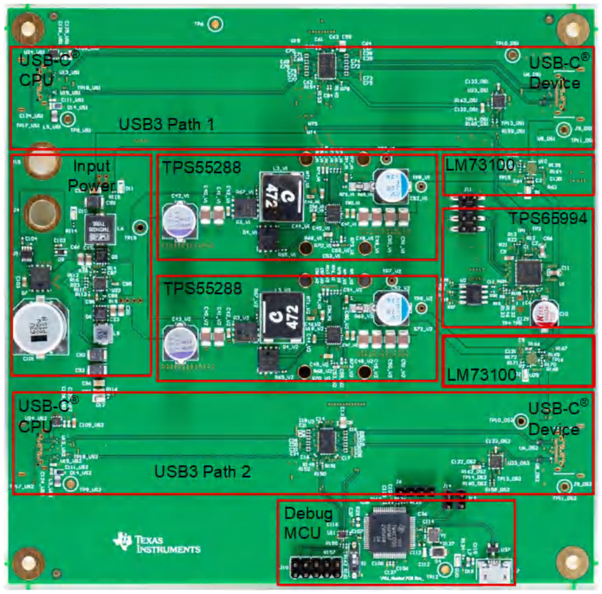


Figure 2-2. PCB Subsection Overview

2.2 Highlighted Products

2.2.1 PD Controller - TPS65994BF

The PD controller communicates with the USB Type-C device to negotiate the voltage, current, and the alternate mode configuration. The controller then configures the DC/DC buck-boost converter and redrivers via the I2C interface. Additionally, the PD controller notifies the independent processing platform of the selected configuration by using the I2C protocol.

2.2.2 LM73100

The LM73100 device is a power switch to enable 5 V to 20 V from the TPS55288 subsystem to the connected USB device.

2.2.3 Redriver TUSB1104

The redrivers used in this reference design correct the signal integrity issues between an USB Type-C host and the device resulting in a more robust system. TUSB1104 is a 10Gbps USB 3.2 ×2 linear redriver for USB Type-C applications.

2.2.4 Redriver TUSB1044

The TUSB1044 is a linear redriver that supports USB Type-C port signal conditioning at a data rate up to 10Gbps for USB 3.2 and DisplayPort™ MUX integrated for USB Type-C applications.

2.2.5 TUSB216I

The TUSB216I is the USB 2.0 high-speed signal conditioner that supports communication at up to 5-m cable length. Two TUSB216I components are connected to both the redrivers to compensate both AC loss (due to capacitive load) and DC loss (due to resistive load) in the transmission channel.

2.2.6 Buck-Boost DC/DC Converter - TPS55288

The TPS55288 is a synchronous four-switch buck-boost DC/DC converter capable of regulating the output voltage at, above, or below the input voltage which in this case is 12 V. Two such DC/DC converters are connected between the PD controller and USB Type-C connectors with each serving one USB Type-C channel. The TPS55288 provides output voltages between 5 V to 20 V, depending upon the voltage negotiated by the PD controller with the connected USB Type-C device. The PD controller communicates with TPS55288 via I2C interface.

2.2.7 System Power

The nominal input voltage provided for this application is 12 V which can range up to 23 V. Figure 2-3 shows the components used for the system power.

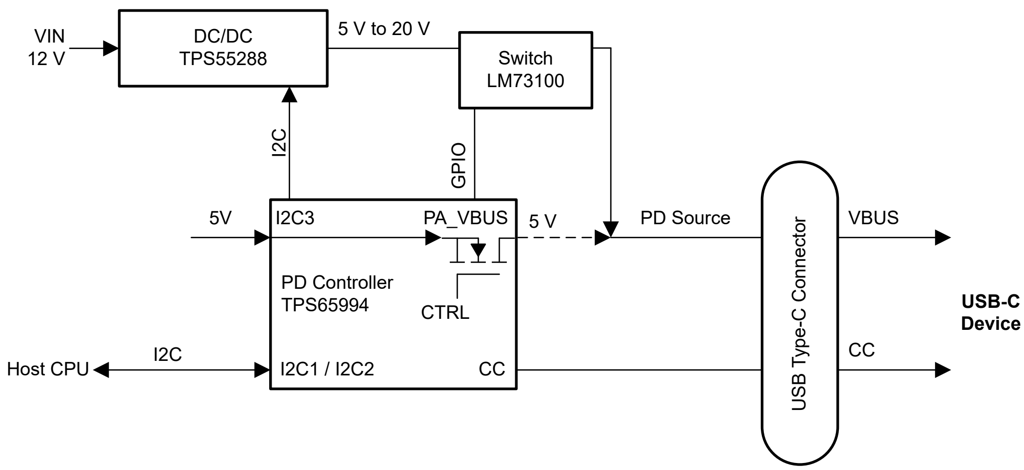


Figure 2-3. System Power Tree

2.2.7.1 Reverse Polarity Protection Diode - LM74500-Q1

The LM74500-Q1 is a controller that operates as a low-loss reverse polarity protection diode in conjunction with an external N-channel MOSFET.

2.2.7.2 TPS51225

The TPS51225 is a dual-synchronous buck controller with 5-V and 3.3-V output voltage and is used to control an external MOSFET. The device supports high efficiency, fast transient response, and provides an internal 0.8-ms voltage servo soft-start combined power-good signal.

2.2.7.3 External MOSFET - CSD87330Q3D

This external MOSFET offers high-current, high-efficiency, and high-frequency capabilities. This MOSFET offers a flexible design capable of offering a high-density power supply when paired with any 5-V gate drive from an external controller or driver.

2.2.8 Upstream and Downstream USB Type-C® Ports

2.2.8.1 Downstream Ports

The PD controller in this reference design supports two channels, each having one downstream port (DS1 for first channel and DS2 for the second channel). This port acts as a device interface to connect the USB Type-C devices that negotiate the power and data from the PD controller. Both the ports are protected by the following ESD components.

2.2.8.1.1 ESD Protection - TPD6S300A

The TPD6S300A is a single-chip USB Type-C port protection device that provides 20-V short-to-VBUS overvoltage and IEC ESD protection. The device enables the CC and SideBand Use (SBU) pins to be 20-V tolerant without interfering with normal operation by providing overvoltage protection on the CC and SBU pins.

2.2.8.1.2 ESD Protection - ESD122

The ESD122 is a bidirectional ESD protection diode array for USB Type-C and HDMI 2.0 circuit protection. The device features a low I/O capacitance per channel and pinout to suit symmetric differential high-speed signal routing making the device an excellent choice for protecting high-speed interfaces up to 10Gbps.

2.2.8.2 Upstream Ports

Upstream USB Type-C ports are the host interfaces used only for the evaluation purposes in this reference design. As part of evaluation, the ports are used to connect the USB Type-C signals to an independent processor platform like an Intel CPU, Sitara™, and so forth. In a typical industrial PC application this reference design is incorporated on the Single Board Computer (SBC) or carrier board. Furthermore, the USB Type-C redriver signals are directly connected to the USB Type-C port of the CPU or MPU.

2.2.8.3 Sideband Signal Interface

The sideband signal interface is an I2C interface between the USB PD controller and the host CPU. The host CPU can program and get status information from the USB PD controller over this interface.

2.2.9 MCU Debug Interface

The Arm® Cortex® M4F-based MCU - TM4C123GH6PMTR, is only used as a debug interface. The device is not mandatory for the hardware developers to integrate it into their design. The MCU hosts a USB 2.0 to I2C interface. The USB 2.0 interface is connected to a Microsoft® Windows® PC which runs a debug software for the TPS65994 to access and program the PD controller register.

3 System Design Theory

3.1 PD Controller and I2C Communication

3.1.1 I2C Interfaces of PD Controller - TPS65994

There are three I2C interfaces, the first of which connects the MCU debug interface to the PD controller and functions as an I2C device. The independent host platform interface is connected via the second I2C interface, which likewise functions as an I2C device. By using this interface, the host CPU (in this case, Intel) instructs the PD controller to provide status information on the connected USB Type-C devices. The third I2C interface controls the redrivers (TUSB1104 and TUSB1044) and the DC/DC converter (TPS55288) as an I2C controller. Through this I2C interface, the PD controller programs the output voltage of DC/DC converters and controls the redrivers for various configurations summarized in Table 3-2 and Table 3-3.

3.1.2 I2C Commands to Control the DC/DC Converter - TPS55288

The commands listed in Table 3-1 control the register settings of the DC/DC converters.

Table 3-1. I2C Commands Controlling the Register Settings of the DC/DC Converters

REGISTER	PD CONTROLLER TRIGGER EVENT	REGISTER NAME	DATA	COMMENTS
0x00h - 01h	POWER_ON_RESET	REF	0xD200h	TPS55288 regulates the output voltage to 5 V at device power on reset
0x02h	POWER_ON_RESET	IOUT_LIMIT	0xE4h	Sets the current limit of the TPS55288 at device power on reset
0x06h	POWER_ON_RESET	MODE	0xB0h	Enables the TPS55288 output at device power on reset.
0x00h - 01h	SRC_PDO2_NEGOTIATED	REF	0x9A01h	TPS55288 regulates the output to the voltage specified by the 2nd PDO when the 2nd PDO is negotiated
0x00h - 01h	SRC_PDO3_NEGOTIATED	REF	0xC602h	TPS55288 regulates the output to the voltage specified by the 3rd PDO when the 3rd PDO is negotiated
0x00h - 01h	SRC_PDO4_NEGOTIATED	REF	0xC003h	TPS55288 regulates the output to the voltage specified by the 4th PDO when the 4th PDO is negotiated
0x00h - 01h	DETACH	REF	0xD200h	TPS55288 regulates the output to 5 V at device detach to prepare itself for the next device attachment

3.1.3 I2C Commands to Control the Redriver - TUSB1104

The commands in Table 3-2 control the register settings of the redriver TUSB1104.

Table 3-2. I2C Commands Controlling the Register Settings of the Redriver TUSB1104

REGISTER	PD CONTROLLER TRIGGER EVENT	REGISTER NAME	DATA	COMMENTS
0x0Ah	POWER_ON_RESET	General_1	0x10h	Allows software to use EQ settings from registers instead of value sampled from pins
0x1Ch	POWER_ON_RESET	AEQ_CONTROL 1	0x84h	Disables the adaptive EQ feature because this feature is not a focus in this design
0x21h	POWER_ON_RESET	SS_EQ	0x77h	Selects EQ Index 7 for USB3 SSTX1 and SSTX2 receivers which face the USB host. The value written can be changed based on the result of signal integrity test
0x0Ah	ATTACH_UU	General_1	0x11h	Enables the redriver and selects the orientation for USB 3.2 ×2 mode when a connection with normal orientation is made
0x0Ah	ATTACH_UD	General_1	0x15h	Enables the redriver and selects the orientation for USB 3.2 ×2 mode when a connection with flip orientation is made
0x0Ah	DETACH	General_1	0x10h	Disables the redriver when detecting a device detach

3.1.4 I2C Commands to Control the Redriver - TUSB1044

The commands listed in Table 3-3 control the register settings of the redriver TUSB1044.

Table 3-3. I2C Commands Controlling the Register Settings of the Redriver TUSB1044

REGISTER	PD CONTROLLER TRIGGER EVENT	REGISTER NAME	DATA	COMMENTS
0x0Ah	POWER_ON_RESET	General_1	0x10h	Allows software to use EQ settings from registers instead of value sampled from pins and disables the redriver
0x0Ch	POWER_ON_RESET	General_3	0x48h	1. Allows software to use VOD linearity range and DC gain settings from registers instead of value sampled from pins 2. Selects Setting #2 for VOD linearity range and DC gain 3. Sets the operation mode to USB + DP Alt Mode source
0x10h	POWER_ON_RESET	UFP2_EQ	0x77h	Selects EQ Index 7 for UTX2P, UTX2N and URX2P, URX2N pins. The value written can be changed based on the result of signal integrity test.
0x11h	POWER_ON_RESET	UFP1_EQ	0x77h	Selects EQ Index 7 for UTX1P, UTX1N and URX1P, URX1N pins. The value written can be changed based on the result of the signal integrity test.
0x20h	POWER_ON_RESET	DFP2_EQ	0x33h	Selects EQ Index 3 for DTX2P, DTX2N and DRX2P, DRX2N pins. The value written can be changed based on the result of the signal integrity test.
0x21h	POWER_ON_RESET	DFP1_EQ	0x33h	Selects EQ Index 3 for DTX1P, DTX1N and DRX1P, DRX1N pins. The value written can be changed based on the result of the signal integrity test.
0x0Ah	ATTACH_UU	General_1	0x11h	When a connection with normal orientation is made: 1. Enables the redriver and sets the redriver to USB3.1-only mode 2. Selects normal orientation
0x0Ah	ATTACH_UD	General_1	0x15h	When a connection with flip orientation is made: 1. Enables the redriver and sets the redriver to USB3.1-only mode 2. Selects flip orientation
0x0Ah	DP_CONFIG_ACE_UU	General_1	0x1Ah	When a connection with pin assignment A, C, or E and normal orientation is made: 1. Enables the redriver and sets the redriver to Four Lanes of the DisplayPort mode 2. Selects normal orientation
0x0Ah	DP_CONFIG_ACE_UD	General_1	0x1Eh	When a connection with pin assignment A, C, or E and flip orientation is made: 1. Enables the redriver and sets the redriver to Four Lanes of DisplayPort mode 2. Selects flip orientation
0x0Ah	DP_CONFIG_BDF_UU	General_1	0x1Bh	When a connection with pin assignment B, D, or F and normal orientation is made: 1. Enables the redriver and sets the redriver to USB3.1 and Two DisplayPort Lanes mode 2. Selects normal orientation
0x0Ah	DP_CONFIG_BDF_UD	General_1	0x1Fh	When a connection with pin assignment B, D, or F and flip orientation is made: 1. Enables the redriver and sets the redriver to USB3.1 and Two DisplayPort Lanes mode 2. Selects flip orientation
0x0Ah	DETACH	General_1	0x10h	Disables the redriver when detecting a device detach

3.1.5 I2C MCU Debug Interface

The TIVA MCU debug interface has a USB-to-I2C interface. The Application Customization Tool can be used to interface the TPS65994 using the Read/Write registers via TIVA MCU. J10 is an Aardvark™ interface which can optionally be used with the third party USB-to-I2C interface hardware box. Additionally, the U11 switch is used to enable the MCU or Aardvark interface to write to the DC/DC converter or the USB-C redriver by accessing either the PD controller or via I2C3 communication.

3.1.6 USB Type-C® VBUS Power Generation

The TPS55288 provides 5 V, 9 V, 15 V and 20 V. The external FET switch LM73100 switches the power path of TPS55288 to USB Type-C VBUS. Note that the TPS65994 can also source 5 V, only to the USB Type-C VBUS. The internal power path of TPS65994 must be disabled when the voltage is provided by TPS55288. The configuration file generated from the Application Customization Tool can be used to disable the internal power path. Additionally, the TPS65994 manages the GPIOs to activate the power path of the TPS55288. GPIO7 activates port 1 of the power source, while GPIO8 activates port 2 of the power source.

4 Hardware, Software, Testing Requirements, and Test Results

4.1 Hardware Requirements

The following hardware components are required to validate the USB Type-C PD and redriver reference design.

- TIDA-010248 evaluation board
- Power supply with 12 V, 5 A
- Two banana cables to power up the board
- Two USB Type-C cables
- TPS65994AD (QFN package) dual-port USB Type-C PD evaluation module
- Passive USB Type-C cables
- USB Type-A to USB Micro-B cable
- USB Type-A to USB Type-B cable
- Notebook with USB 2.0, USB 3.2, and DP capabilities
- Multimeter
- Power DUO source and sink evaluation module (USB-C-PD-DUO-EVM)

4.2 Software Requirements

The following software components are required to validate the USB Type-C PD and redriver reference design:

- TPS65994 Application Customization Tool (reach out to your TI representatives for this tool).
- Binary configuration file for TPS65994, generated from Application Customization Tool.
- I2C interface for PC if the Application Customization Tool is not used - Optional:
  - Aardvark interface
  - USB2ANY interface (USB to I2C debug interface) user software

4.3 Test Setup

The following steps provide a description of the test setup:

1. Power on the TIDA-010248 evaluation board by supplying 12 V.
2. Use the Application Customization Tool to program the EEPROM with binary configuration file.
3. Do a power cycle.

4.3.1 Test Procedure to Validate Power Delivery

The test procedure to validate power delivery is described in the following steps:

1. Plug in USB-C-PD-DUO-EVM to the DS1 port of the TIDA-010248 evaluation board. USB-C-PD-DUO-EVM is a power DUO source and sink evaluation module used to source or sink the power from the TIDA-010248 evaluation board..
2. USB-C-PD-DUO-EVM is powered on when connected to the USB Type-C PD EVM via the USB Type-C port. Observe the LED that turns *on* when the EVM is powered on.
3. Press the buttons 5V, 9V, 15V and 20V on the USB-C-PD-DUO-EVM sink board to request the output voltages to be delivered and measure the corresponding output voltages 5V, 9V, 15V and 20V at USB Type-C VBUS channel of DS1 port.
4. Repeat step 1 to step 3 by connecting the USB-C-PD-DUO-EVM to the DS2 port of the TIDA-010248 evaluation board to measure the power delivery on second channel and also observe if the LED of the requested voltage lights up.

5 Design and Documentation Support

5.1 Design Files

5.1.1 Schematics

To download the schematics, see the design files at TIDA-010248.

5.1.2 BOM

To download the bill of materials (BOM), see the design files at TIDA-010248.

5.2 Documentation Support

1. Texas Instruments, *TPS65994AD Dual Port USB Type-C® and USB PD Controller with Integrated Source Power Switches Supporting USB4 and Alternate Mode* data sheet
2. Texas Instruments, *TPS65994AE Dual Port USB Type-C® and USB PD Controller with Integrated Source Power Switches* data sheet
3. Texas Instruments, *TUSB1104 USB Type-C® 10Gbps USB 3.2 x2 Adaptive Linear Redriver* data sheet
4. Texas Instruments, *TUSB1044 USB TYPE-C™ 10Gbps Multi-Protocol Bidirectional Linear Redriver* data sheet
5. Texas Instruments, *TPS55288 36-V, 16-A Buck-boost Converter with I^2C Interface* data sheet

5.3 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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