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Multiplexers and Protection Devices

ABSTRACT

The Universal Serial Bus (USB) industry standard specifies connection, communication, and power supply between computers and peripherals. There are several different variations of USB hardware with the most common currently being USB 2.0 and USB 3.2. USB Type-C® has a 24-pin connector that can support USB 3.2, DisplayPort, HDMI, and other alternative modes. It also supports the USB Power Delivery (USB-PD) standard that allows for increased power transmission over USB.

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1 USB 2.0 Circuit Protection

1.1 Description

The USB 2.0 connector has 4 pins: V_{BUS} for power, D+ and D– for differential data signals, and a ground pin. The V_{BUS} line carries 5-V DC power supply and the data lines transfer 480Mbps differential signal.

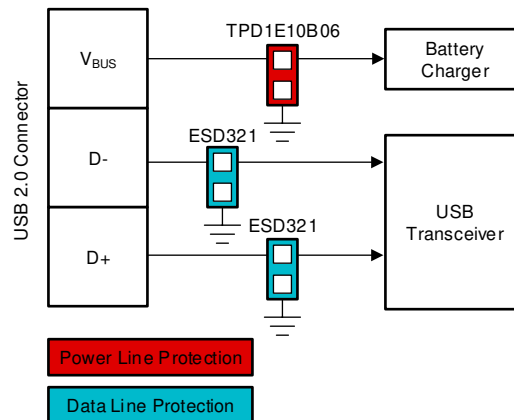


Figure 1-1. USB 2.0 Data and Power Line Protection

1.2 Data Line Protection

The D+ and D– lines require low-capacitance ESD protection to support a 480Mbps signal. The protection on the data lines should be at a working voltage of at least 3.6 V. If there is a chance for the power and data lines to cross, consider a 5.5-V working voltage device.

1.3 Power Line Protection

The V_{BUS} line requires at least a 5-V working voltage to maintain that breakdown does not occur during normal operation. The [TVS0500](#) surge protection device in a 2-mm × 2-mm SON package provides precise flat clamping during a fault, keeping the system exposure below 10 V. The [TPD1E10B06](#) is another surge protection diode which is much smaller than the TVS0500 in a 0402 footprint (1 × 0.6 mm) and is also cost effective.

Table 1-1 and Table 1-2 detail the USB 2.0 data-line and power-line protection recommendations, respectively.

Table 1-1. USB 2.0 Data Line Protection Recommendations

	Device	# of Channels	IEC 61000-4-2 Rating Contact Air Gap	Description
Data Line Protection Diodes	TPD1E05U06 TPD1E05U06-Q1	1	12 kV 15 kV	0.4-pF, 5.5-V, ± 12 -kV ESD protection diode in 0402 package for high-speed interfaces
	ESD321	1	30 kV 30 kV	0.8-pF, 3.3-V, ± 30 -kV ESD protection diode with 6.8-V, 16-A TLP clamping in 0402 package for USB 2.0
	TPD1E1B04	1	30 kV 30 kV	1-pF, ± 3.6 -V, ± 30 -kV ESD protection diode with 6-A, 8- to 20- μ s surge and low clamping in 0402 package
	ESD341	1	30 kV 30 kV	0.66-pF, ± 3.6 -V, ± 30 -kV ESD protection diode with 5.4-A surge rating in 0201 package
	ESDS312	2	30 kV 30 kV	Dual 4.5-pF, 3.6-V, ± 30 -kV ESD protection diode with 25-A, 8- to 20- μ s surge rating for USB and Ethernet
	ESD122	2	18 kV 18 kV	Dual 0.2-pF, ± 3.6 -V, ± 18 -kV ESD protection diode

Table 1-2. USB 2.0 Power Line Protection Recommendations

	Device	# of Channels	IEC 61000-4-5 Surge Rating	Description
Power Line Protection Diodes	TVS0500	1	43 A	5-V surge protection diode with 43-A, 8- to 20- μ s surge rating
	TPD1E10B06 TPD1E10B06-Q1	1	6 A	± 5.5 -V, ± 30 -kV ESD protection diode in 0402 and SOD-523 package

2 USB 3.2 Circuit Protection

2.1 Description

USB 3.2 uses the TX and RX lines to handle speeds up to 5Gbps–20Gbps depending on the generation. To maintain the signal integrity at these speeds, the capacitance of the protection device must be minimized for the TX and RX SuperSpeed data lines. Similar to USB 2.0, the V_{BUS} line carries a 5-V DC supply

2.2 Data Line Protection

USB 3.2 Gen 1 interfaces are able to handle speeds up to 5Gbps and 10Gbps for **USB 3.2 Gen 1x2**. The capacitance of ESD solutions must be 0.5 pF, or lower. **Figure 2-1** illustrates a low-capacitance (0.5 pF) 6-channel ESD solution for the data lines paired with a 5-V protection device for V_{BUS} lines.

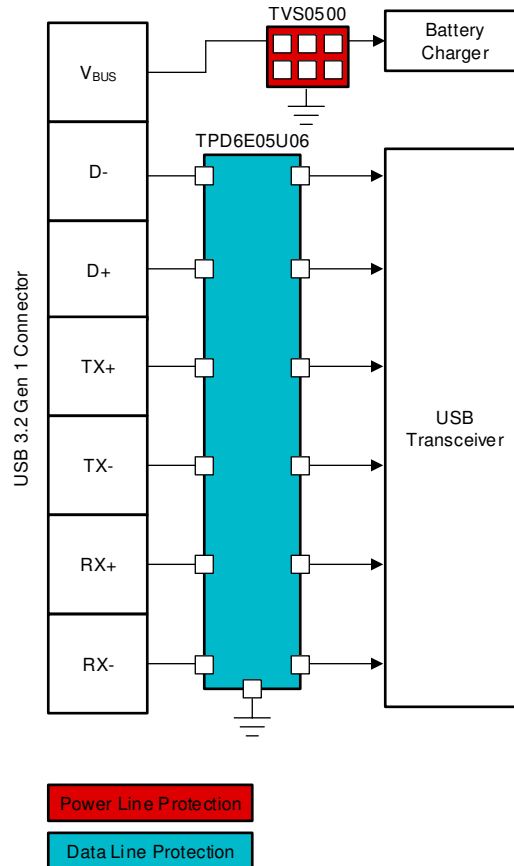


Figure 2-1. USB 3.2 Gen 1 Data and Power Line Protection

USB 3.2 Gen 2 interfaces are able to handle speeds up to 10Gbps while **USB 3.2 Gen 2x2** interfaces can handle speeds up to 20Gbps. The capacitance of ESD solutions must be 0.3 pF, or lower. [Figure 2-2](#) illustrates a 4-channel ESD device for the TX and RX data lines combined with a 2-channel ESD device for the D+, D– and a single-channel ESD device for the V_{BUS} line.

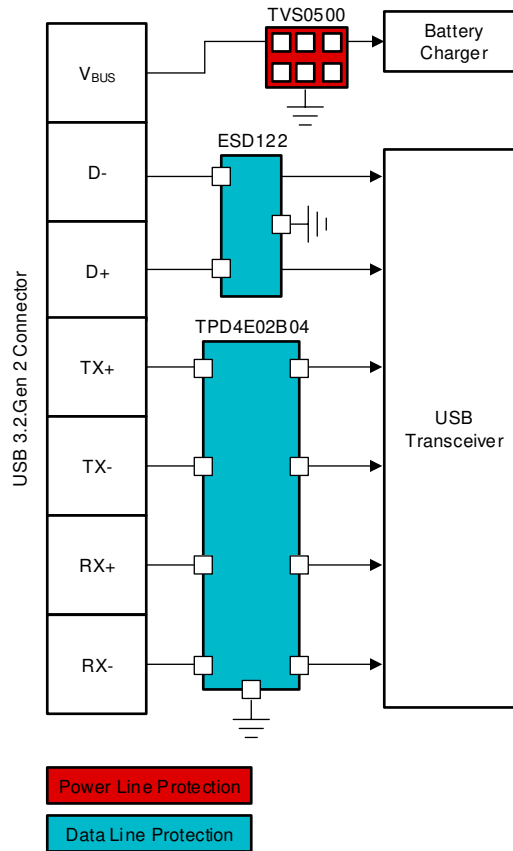


Figure 2-2. USB 3.2 Gen 2 Data and Power Line Protection

Table 2-1. USB 3.2 Data Line Protection Recommendations

	Device	# of Channels	Capacitance	Description
Data Line Protection Diodes	TPD4E02B04 TPD4E02B04-Q1	4	0.25 pF	Quad 0.25-pF, ±3.6-V, ±12-kV ESD protection diode for USB 3.2, HDMI 2.0 and high-speed signals
	ESD122	2	0.2 pF	Dual 0.2-pF, ±3.6-V, ±18-kV ESD protection diode for USB 3.2 and HDMI 2.0
	TPD1E01B04 TPD1E01B04-Q1	1	0.18 pF	0.18-pF, ±3.6-V, ±15-kV ESD protection diode in 0402 and 0201 packages for USB 3.2
	TPD1E0B04	1	0.13 pF	0.13-pF, ±3.6-V, ±8-kV ESD protection diode in 0402 and 0201 packages for USB-C and Antenna

Table 2-2. USB 3.2 VBUS Power Line Protection Recommendations

	Device	# of Channels	IEC 61000-4-5 Surge Rating	Description
Power Line Protection Diodes	TVS0500	1	43 A	5-V surge protection diode with 43-A, 8- to 20-μs surge rating
	TPD1E10B06 TPD1E10B06-Q1	1	6 A	±5.5V, ±30-kV ESD protection diode in 0402 and SOD-523 package

3 USB Power Delivery (USB-PD) Surge Protection

3.1 Introduction

Over the years the USB standard has become an interface that not only allows data to be transferred but one that allows for transfer of power. In USB 2.0 and USB 3.2, the maximum power that can be delivered is 15 W, with a maximum of 5 V on VBUS. The USB-PD standard allows for more power (up to 240 W) to be supplied to systems over a compliant USB cable. The voltage on the VBUS pin can vary depending on the power that needs to be supplied. Common voltages are 5 V, 9 V, 15 V, and 20 V and more recently 28 V, 36 V, and 48 V.

3.2 VBUS Protection

As with all power lines, consideration must be taken about how to protect against transient overvoltage events. For example, when there is a plug or unplug event while there is current flowing through the cable, inductive ringing could cause a 20-V line to temporarily go up to 50 V which could damage downstream circuitry. A solution to protect the system is to use a protection diode and a key specification to consider is the clamping voltage, ensuring that the voltage experience by the system is below the maximum voltage of the system. The [TVS2200](#) is a device that protects a 20-V line with a very low clamping voltage, ensuring the maximum voltage on the system is 28 V during a transient event. The plots in [Figure 3-1](#) and [Figure 3-2](#) show the result and benefits of using a TVS device. Also, [Table 3-1](#) shows recommended TVS diodes for USB-PD voltage levels.

Table 3-1. USB-PD VBUS Surge Protection Recommendations

USB-PD Voltage	Recommended TVS	Surge Clamping Voltage	Package Size
5 V	TVS0500	9 V	DRV 2 × 2 mm
9 V	TVS1400	18 V	DRV 2 × 2 mm
15 V	TVS1800	23 V	DRV 2 × 2 mm
20 V	TVS2200	28 V	DRV 2 × 2 mm
28 V	TVS3300	38 V	DRV 2 × 2 mm YZF 1.1 × 1.1 mm

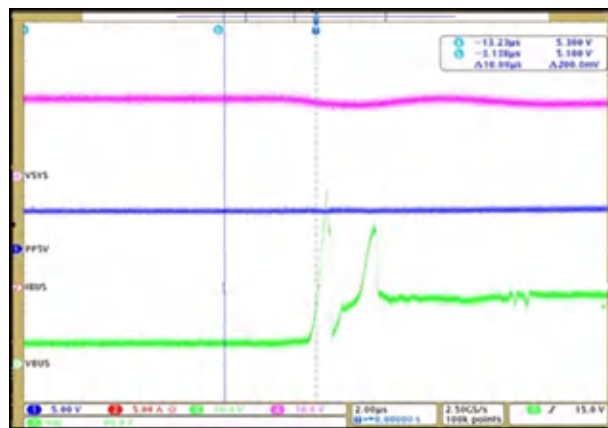


Figure 3-1. USB-PD VBUS Overvoltage Event Without TVS

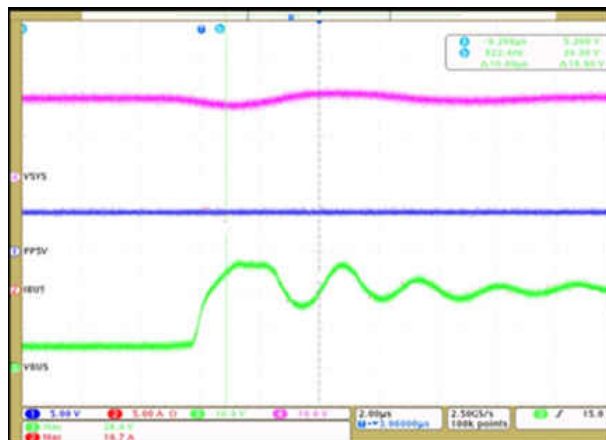


Figure 3-2. USB-PD VBUS Overvoltage Clamped by TVS2200

4 USB Type-C® Protection

4.1 Introduction

The USB Type-C standard with a 24-pin connector allows for transmission of large amounts of power and data on a single cable, supporting USB 3.2, HDMI, DisplayPort and other standards in alternate modes. The standard also supports the USB-PD standard which is primarily implemented on the USB Type-C connector. The USB Type-C connector also has the benefit of being much smaller than previous generation connectors while also being reversible. Due to the small size of the connector, a key consideration in selecting ESD devices is minimizing package size.

Figure 4-1 illustrates the USB Type-C® data and power line protection.

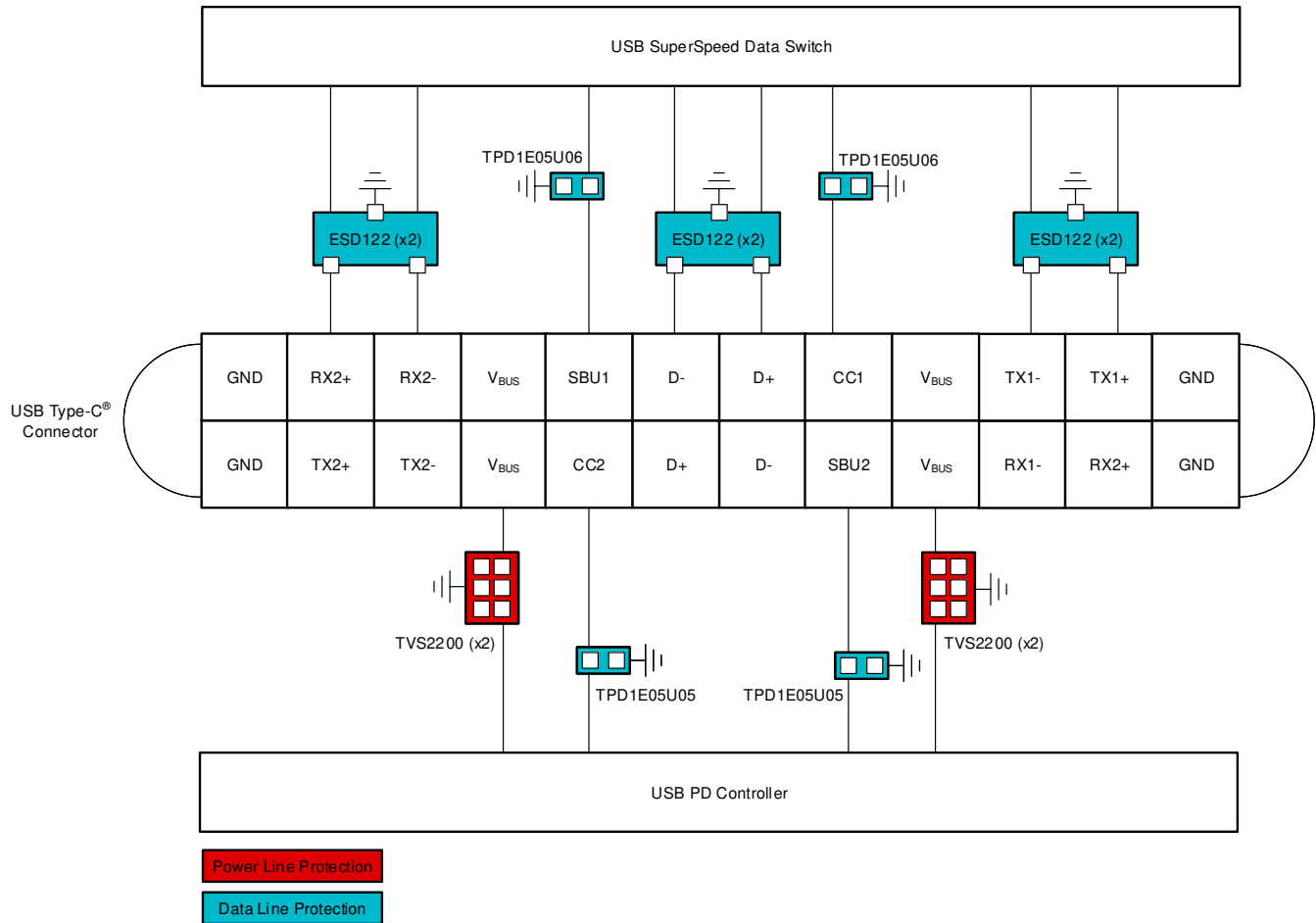


Figure 4-1. USB Type-C® Data and Power Line Protection

4.2 CC and SBU Line ESD Protection

While it incorporates the same pins as the USB 3.2 such as D+ and D– and the 4 RX and TX lines, for the flexibility of data transmission, there are other configuration pins such as CC and SBU. The protection needed on this connector is similar to the USB 3.2 on the data lines; however, the additional data lines, CC and SBU lines, also require ESD protection. Since these lines could experience voltages up to 5 V in normal operation, ESD diodes with at least 5-V working voltage are required for these lines. The [TPD1E6B06](#) and [TPD1E05U06](#) devices in the space-saving 0201 and 0402 packages are recommended devices for these lines.

[Table 4-1](#) details the CC and SBU ESD protection recommendations.

Table 4-1. CC and SBU ESD Protection Recommendations

Device	# of Channels	IEC 61000-4-2 ESD Rating	Description
TPD1E05U06 TPD1E05U06-Q1	1	12 kV 15 kV	0.4-pF, 5.5-V, ±12-kV ESD protection diode in 0402 package
TPD1E6B06	1	15 kV 15 kV	6-pF, ±5.5V, ±15-kV ESD protection diode in 0201 package
ESD401	1	24 kV 30 kV	0.77-pF, ±5.5V, ±24-kV ESD protection diode in 0402 package
ESD341	1	30 kV 30- kV	0.66-pF, ±3.6-V, ±30-kV ESD protection diode with 5.4-A surge rating in 0201 package

5 References

- Texas Instruments, [A primer on USB Type-C® and USB Power Delivery Applications and Requirements Marketing White Paper](#)

6 Revision History

Changes from Revision * (November 2021) to Revision A (August 2022)	Page
• Updated the numbering format for tables, figures, and cross-references throughout the document.....	1
• Added <i>ESD341</i> to the <i>USB 2.0 Data Line Protection Recommendations</i> table.....	2

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