Application Note

ESD and Surge Protection for USB Interfaces

Obi Oji

Multiplexers and Protection Devices

ABSTRACT

Universal Serial Bus, more commonly known as USB, is an industry standard that defines communication, power supply, and connectors between computers and peripherals. There are many variations of USB standards that range from 1.5Mbps all the way up to 40Gbps with the more common standards being USB 2.0 and USB 3.x. There are also numerous connector types such as USB Type-A and USB Type-C®. With the recent European Union regulations, USB Type-C® is soon to be the single charging design for electronic devices in the EU, increasing the popularity of the connector. USB Type-C® is able to support alternate modes like DisplayPort, HMDI, and others as well as supporting USB Power Delivery (USB-PD) that allows for increased power transmission over USB.

Table of Contents

Trademarks

USB Type-C® is a registered trademark of USB Implementers Forum.
All trademarks are the property of their respective owners.

1 Overview

The Universal Serial Bus (USB) is an industry standard that specifies connection, communication, and power supply between host systems and peripherals. USB has evolved over the years through a series of standards focusing on increased data rates. The following table breaks down the standards including naming convention, data lines, nominal rates, and connector types.

There are two types of data pairs: half-duplex (HDx) and full-duplex (FDx). USB 2.0 and earlier standards use a single half-duplex which provides communication in both directions but only one direction at a time. A half-duplex translates to the D+ and D- data lines. USB 3.0 and later implement a single half-duplex (D+, D-) for USB 2.0 compatibility and two or four pairs in full-duplex with the full-duplex allowing for bidirectional communication simultaneously. A pair is considered to be either the transmit lines (TX+, TX-) or the receive lines (RX+, RX-). USB 3.0 and later include at least two pairs (TX+, TX-, RX+, RX-), also known as a lane.

Since there are many USB standards, determining the data rates can be confusing specifically for USB 3.2 and USB 4. The general consensus is that if the format is *AxB* then the last digit determines the number of lanes. For example, USB 3.2 Gen 2x2 has a nominal rate of 20Gbps, but since there is a *2* as the last digit, this means there are 2 data lanes each with 10Gbps totaling 20Gbps.

The following sections go into detail on ESD protection based on the nominal rate for USB interfaces.

Table 1-1. USB Standards

Standards	Data Pairs	Nominal Rate	USB-IF Name	Connector Types
USB 1.1	1 HDx	12Mbps	Basic-Speed USB	Type-A, Type-B
USB 2.0	1 HDx	480Mbps	Hi-Speed USB	Type-A, Type-B, Type-C, Micro, Mini
USB 3.0/USB 3.1 Gen 1/ USB 3.2 Gen 1x1	2 FDx + 1 HDx	5Gbps	USB 5Gbps	Type-A, Type-B, Type-C, Micro
USB 3.1 Gen 2/ USB 3.2 Gen 2x1	2 FDx + 1 HDx	10Gbps	USB 10Gbps	Type-A, Type-C
USB 3.2 Gen 1x2	4 FDx + 1 HDx	10Gbps	USB 10Gbps	Type-C
USB 3.2 Gen 2x2	4 FDx + 1 HDx	20Gbps	USB 20Gbps	Type-C
USB 4 Gen 2x1	2 FDx + 1 HDx	10Gbps	USB 10Gbps	Type-C
USB 4 Gen 2x2	4 FDx + 1 HDx	20Gbps	USB 20Gbps	Type-C
USB 4 Gen 3x1	2 FDx + 1 HDx	20Gbps	USB 20Gbps	Type-C

2 USB 1.1

2.1 Overview

USB 1.0 was the first USB standard released with a revision, USB 1.1, shortly after. USB 1.0/1.1 has a 4-wire interface: V_{BUS} for power, D+ and D- for differential data signals, and a ground pin. USB 1.0/1.1 is able to support Low Speed (1.5Mbps) and Full Speed (12Mbps). Figure 2-1 details the pin configuration in a Type-A connector for USB 1.0/1.1.

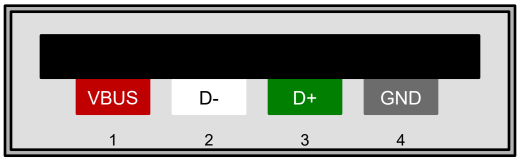

Figure 2-1. USB 1.0/1.1 Pin Configuration

USB 1.0/1.1 is a fairly uncommon standard used today in new systems but still at risk of high voltage strikes due to the external connector. An ESD strike can enter through the connector and can cause damage to the downstream components in the system. The following sections discuss the ESD protection requirements and the system-level design for USB 1.0/1.1.

2.2 ESD Protection Requirements

For protecting UBS 1.0/1.1, follow the list of parameters related to each pin:

- **D+ and D-**
  - Working Voltage: The reverse working voltage (V_{RWM}) of the protection diode is recommended to be greater than or equal to the operating voltage of the system being protected. For USB 1.0/1.1 data lines, the typical operating voltage is 3.3V. A working voltage greater than or equal to 3.3V is recommended.
  - Clamping Voltage: There can be many systems utilizing USB. This results in the clamping voltage of the ESD diode being dependent on the circuity downstream from the USB connector. The clamping voltage is recommended to be below the absolute maximum rating of the downstream component.
  - Capacitance: For USB 1.0/1/1, the signal speeds can reach up to 12Mbps. A capacitance less than 20pF is recommended to support the signal speed.
  - IEC 61000-4-2 Rating: Real-world ESD strikes are defined by the IEC 61000-4-2 testing standard. This standard consists of two measurements: contact and air-gap discharge. The higher the contact and air-gap rating, the higher the voltage a device can withstand. For USB 1.0/1.1, a minimum IEC 61000-4-2 rating of 8kV for contact and 15kV for air-gap is recommended.
- **V_{BUS}**
  - Working Voltage: For V_{BUS}, the operating voltage is 5V. An ESD diode with a working voltage greater than or equal to 5V is recommended.

Table 2-1 lists devices that support these specifications.

Table 2-1. USB 1.0/1.1 Device Recommendations

Device	V_{RWM} (V)	IEC 61000-4-2 (kV) (Contact/Air-gap)	Capacitance (pF)	Channel Count	Package Size (mm)	Recommended For
ESD321	3.6	30/30	0.9	1	DFN1006 (1.00 x 0.60), SOD523 (1.60 x 0.80)	D+, D-
ESD441	5.5	30/30	1	1	DFN0603 (0.60 x 0.30)	VBUS
TPD4E05U06	5.5	12/15	0.5	4	USON (2.50 x 1.00)	D+, D-, VBUS

2.3 System Level Design

TI offers ESD protection diodes with options to protect USB 1.0/1.1. Figure 2-2 shows a block diagram implementing three ESD protection diodes. The diodes are connected to each data and power line between the connector and either the battery charger or USB controller. To properly protect the system, place the diodes as close to the source of ESD, in this case the connector, as design rules allow.

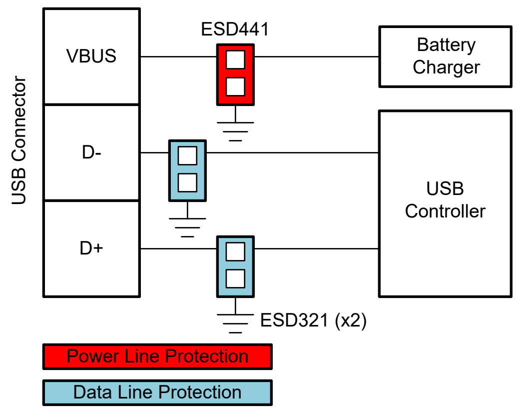

Figure 2-2. USB 1.0/1.1 ESD Protection

For Figure 2-2, ESD321 is used to the protect the D+ and D- lines and ESD441 is used to protect the VBUS line. There is also an option to use one ESD diode that protects both the data and power lines. For this to work, the diode is recommended to have a working voltage greater than or equal to 5V. A device that can handle both data and power lines is TPD4E05U06.

3 USB 2.0 Circuit Protection

3.1 Overview

USB 2.0, also known as hi-speed USB, is an updated version of USB 1.0/1.1 with improved functionality and increased data speeds. USB 2.0 has a 4-wire interface: V_{BUS} for power, D+ and D- for differential data signals, and a ground pin. The pin configuration for USB 2.0 is shown in Figure 3-1 for a Type-A connector. USB 2.0 is able to support Low Speed (1.5Mbps), Full Speed (12Mbps), and High Speed (480Mbps).

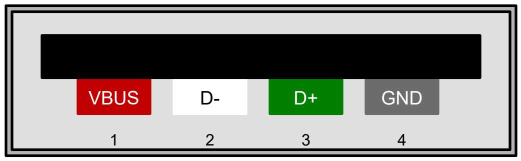

Figure 3-1. USB 2.0 Pin Configuration

USB 2.0 is a common interface still used today across a range of devices and applications. Since the connector is exposed to the outside world, the system is at risk of a high voltage strike. This transient event can cause damage to the downstream components in the system. The following sections discuss the ESD protection requirements and the system-level design for USB 2.0.

3.2 ESD Protection Requirements

For protecting UBS 2.0, follow the list of parameters related to each pin:

- **D+ and D-**
  - Working Voltage: The reverse working voltage (V_{RWM}) of the protection diode is recommended to be greater than or equal to the operating voltage of the system being protected. For USB 2.0 data lines, the typical operating voltage 3.3V. This translates to a working voltage of greater than or equal to 3.3V.
  - Clamping Voltage: There can be many systems utilizing USB. This results in the clamping voltage of the ESD diode being dependent on the circuity downstream from the USB connector. The clamping voltage is recommended to be below the absolute maximum rating of the downstream component.
  - Capacitance: Since the signal speeds for USB 2.0 can reach up to 480Mbps, a low-capacitance ESD diode with less than 4pF is recommended to support the signal speed.
  - IEC 61000-4-2 Rating: Real-world ESD strikes are defined by the IEC 61000-4-2 testing standard. This standard consists of two measurements: contact and air-gap discharge. The higher the contact and air-gap rating, the higher the voltage a device can withstand. For USB 2.0, a minimum IEC 61000-4-2 rating of 8kV for contact and 15kV for air-gap is recommended.
- **V_{BUS}**
  - Working Voltage: For V_{BUS}, the operating voltage is 5V. An ESD diode with a working voltage greater than or equal to 5V is recommended.

Table 3-1 lists devices that support these specifications.

Table 3-1. USB 2.0 Device Recommendations

Device	V_{RWM} (V)	IEC 61000-4-2 (kV) (Contact/Air-gap)	Capacitance (pF)	Channel Count	Package Size (mm)	Recommended For
ESD321	3.6	30/30	0.9	1	DFN1006 (1.00 x 0.60), SOD523(1.60 x 0.80)	D+, D-
ESD122	3.6	17/17	0.2	2	DFN1006, 3 pins (1.00 x 0.60)	D+, D-
ESD441	5.5	30/30	1	1	DFN0603 (0.60 x 0.30)	VBUS
TPD4E05U06	5.5	12/15	0.5	4	USON (2.50 x 1.00)	D+, D-, VBUS

3.3 System Level Designs

TI offers a multitude of ESD diodes with options to protect USB 2.0. Figure 3-2 shows a block diagram implementing three ESD protection diodes. The diodes are connected to each data and power line between the connector and either the battery charger or USB controller. To properly protect the system, place the diodes as close to the source of ESD, in this case the connector, as design rules allow.

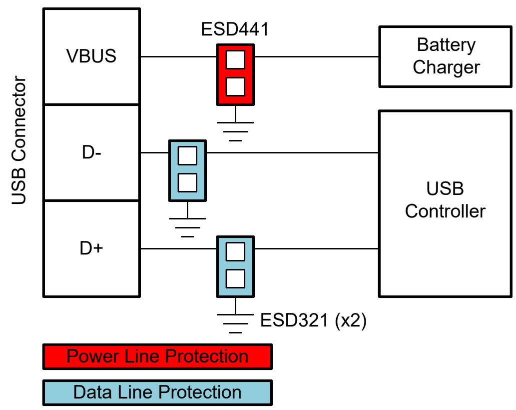

Figure 3-2. USB 2.0 ESD Protection

For the above diagram, ESD321 is used to the protect the D+ and D- lines and ESD441 is used to protect the VBUS line. There is also an option to use one ESD diode that protects both the data and power lines. For this to work, the diode is recommended to have a working voltage greater than or equal to 5V. A device that can handle both data and power lines is TPD4E05U06.

4 USB 5Gbps

4.1 Overview

USB standards that reach a nominal rate of 5Gbps include: USB 3.0, USB 3.1 Gen 1, and USB 3.2 Gen 1x1. These standards use the following pins: V_{BUS} for power, D+ and D- for differential data signals, TX+, TX-, RX+, and RX- for transmitting and receiving signals, and ground.

USB 5Gbps is used in various devices and applications. There is an external connector which puts the system at risk of a high voltage strike. This transient event can cause damage to the downstream components in the system if the system is not protected properly. The following sections discuss the ESD protection requirements and the system-level design for protecting speeds up to 5Gbps.

4.2 ESD Protection Requirements

For protecting USB 5Gbps, follow the list of parameters related to each pin:

- **D+, D-, TX+, TX-, RX+, RX-**
  - Working Voltage: The reverse working voltage (V_{RWM}) of the protection diode is recommended to be greater than or equal to the operating voltage of the system being protected. For USB 5Gbps data lines, the typical operating voltage is 3.3V. A protection diode with a working voltage greater than or equal to 3.3V is recommended.
  - Clamping Voltage: There can be many systems utilizing USB. This results in the clamping voltage of the ESD diode being dependent on the circuity downstream from the USB connector. The clamping voltage is recommended to be below the absolute maximum rating of the downstream component.
  - Capacitance (D+, D-): Since D+ and D- are specific to USB 2.0 data transfer, the signal speeds can reach up to 480Mbps. An ESD diode with a capacitance less than 4pF is recommended.
  - Capacitance (TX+, TX-, RX+, RX-): The signal speeds can reach up to 5Gbps, a low-capacitance ESD diode with less than 0.5pF is recommended to support the signal speed.
  - IEC 61000-4-2 Rating: Real-world ESD strikes are defined by the IEC 61000-4-2 testing standard. This standard consists of two measurements: contact and air-gap discharge. The higher the contact and air-gap rating, the higher the voltage a device can withstand. For USB 5Gbps, a minimum IEC 61000-4-2 rating of 8kV for contact and 15kV for air-gap is recommended.
- **V_{BUS}**
  - Working Voltage: For V_{BUS}, the operating voltage is 5V. An ESD diode with a working voltage greater than or equal to 5V is recommended.

Table 4-1 lists devices that support these specifications.

Table 4-1. USB 5Gbps Device Recommendations

Device	V_{RWM} (V)	IEC 61000-4-2 (kV) (Contact/Air-gap)	Capacitance (pF)	Channel Count	Package Size (mm)	Recommended For
ESD321	3.6	30/30	0.9	1	DFN1006 (1.00 x 0.60), SOD523(1.60 x 0.80)	D+, D-
ESD122	3.6	17/17	0.2	2	DFN1006, 3 pins (1.00 x 0.60)	D+, D-, TX+, TX-, RX+, RX-
TPD4E02B04	3.6	12/15	0.25	4	USON (2.50 x 1.00)	D+, D-, TX+, TX-, RX+, RX-
TPD6E05U06	5.5	12/15	0.47	6	USON (3.50 x 1.35)	D+, D-, TX+, TX-, RX+, RX-
ESD441	5.5	30/30	1	1	DFN0603 (0.60 x 0.30)	VBUS

4.3 System Level Designs

TI has a range of ESD diodes with options to protect USB 5Gbps. Figure 4-1 shows a block diagram implementing four ESD protection diodes. The diodes are connected to each data and power line between the connector and either the battery charger or USB controller. To properly protect the system, place the diodes as close to the source of ESD, in this case the connector, as design rules allow.

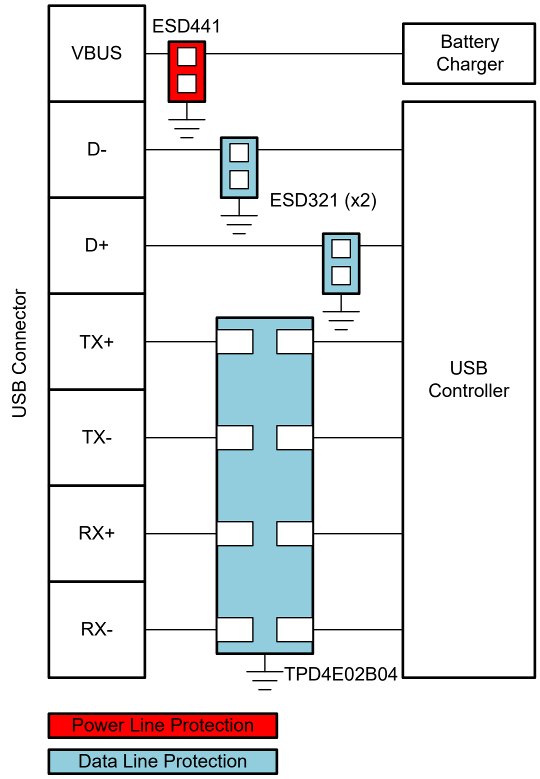

Figure 4-1. USB 5Gbps ESD Protection

For Figure 4-1, ESD321 is used to the protect D+ and D-. TPD4E02B04 is used for the TX/RX lines. There are a few other options for protecting the D/TX/RX lines such as using a 6-channel device, using multiple 2-channel devices, or even using 1-channel devices. ESD441 is used to protect the VBUS line.

5 USB 10Gbps

5.1 Overview

USB standards that reach up to a nominal rate of 10Gbps are: USB 3.1 Gen 2, USB 3.2 Gen 2x1, USB 3.2 Gen 1x2, and USB 4 Gen 2x1. These standards use the following pins: V_{BUS} for power, D+ and D- for differential data signals, one lane (USB 3.1 Gen 2, USB 3.2 Gen 2x1, and USB 4 Gen 2x1) or two lanes (USB 3.2 Gen 1x2) for transmitting and receiving signals (TX1/RX1, TX2/RX2), and ground.

USB 10Gbps is commonly used today, and since there is an external connection, the system is at risk of a high voltage strike. An ESD strike can enter through the connector and cause damage to the downstream components if the system is not protected properly. The following sections discuss the ESD protection requirements and the system-level design for protecting USB 10Gbps signals.

5.2 ESD Protection Requirements

For protecting USB 10Gbps, follow the list of parameters related to each pin:

- **D+, D-, TX1+, TX1-, RX1+, RX1-, TX2+, TX2-, RX2+, RX2-**
  - Working Voltage: The reverse working voltage (V_{RWM}) of the protection diode is recommended to be greater than or equal to the operating voltage of the system being protected. For USB 10Gbps data lines, the typical operating voltage range is 3.3V. This translates to a working voltage of greater than or equal to 3.3V.
  - Clamping Voltage: There can be many systems utilizing USB. This results in the clamping voltage of the ESD diode being dependent on the circuity downstream from the USB connector. The clamping voltage is recommended to be below the absolute maximum rating of the downstream component.
  - Capacitance (D+, D-): Since D+ and D- are specific to USB 2.0 data transfer, the signal speeds can reach up to 480Mbps. An ESD diode with a capacitance less than 4pF is recommended.
  - Capacitance (TX+, TX-, RX+, RX-): Since the signal speeds can reach up to 10Gbps, a low-capacitance ESD diode with less than 0.3pF is recommended to support the signal speed. For USB 3.2 Gen 1x2, there are two lanes each with 5Gbps, a capacitance less than 0.5pF is recommended to support each lane.
  - IEC 61000-4-2 Rating: Real-world ESD strikes are defined by the IEC 61000-4-2 testing standard. This standard consists of two measurements: contact and air-gap discharge. The higher the contact and air-gap rating, the higher the voltage a device can withstand. For USB 10Gbps, a minimum IEC 61000-4-2 rating of 8kV for contact and 15kV for air-gap is recommended.
- **V_{BUS}**
  - Working Voltage: For V_{BUS}, the operating voltage is 5V. An ESD diode with a working voltage greater than or equal to 5V is recommended.

Table 5-1 lists devices that support these specifications.

Table 5-1. USB 10Gbps Device Recommendations

Device	V_{RWM} (V)	IEC 61000-4-2 (kV) (Contact/Air-gap)	Capacitance (pF)	Channel Count	Package Size (mm)	Recommended For
ESD321	3.6	30/30	0.9	1	DFN1006 (1.00 x 0.60), SOD523(1.60 x 0.80)	D+, D-
TPD1E01B04	3.6	15/17	0.18	1	DFN0603 (0.60 x 0.30), DFN1006 (1.00 x 0.60)	D+, D-, TX+, TX-, RX+, RX-
ESD122	3.6	17/17	0.2	2	DFN1006, 3 pins (1.00 x 0.60)	D+, D-, TX+, TX-, RX+, RX-
TPD4E02B04	3.6	12/15	0.25	4	USON (2.5 x 1.0)	D+, D-, TX+, TX-, RX+, RX-
ESD441	5.5	30/30	1	1	DFN0603 (0.60 x 0.30)	VBUS

5.3 System Level Designs

TI has a variety of ESD diodes that are able to protect USB 10Gbps. Figure 5-1 shows a block diagram implementing four ESD protection diodes. The diodes are connected to each data and power line between the connector and either the battery charger or USB controller. To properly protect the system, place the diodes as close to the source of ESD, in this case the connector, as design rules allow.

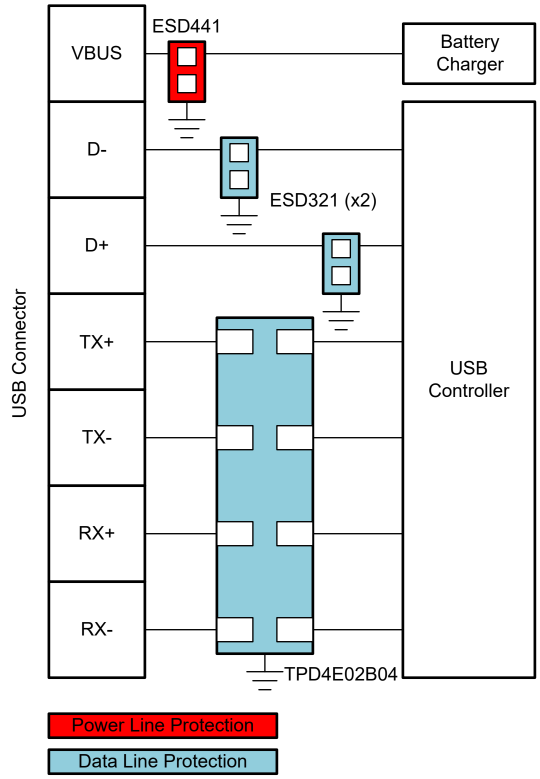

Figure 5-1. USB 10Gbps ESD Protection

For Figure 5-1, ESD321 is used to the protect D+ and D-. TPD4E02B04 is used for the TX/RX lines. There are a few other options for protecting the D/TX/RX lines such as using a 6-channel device, using multiple 2-channel devices, or even using 1-channel devices. ESD441 is used to protect the VBUS line.

6 USB 20Gbps

6.1 Overview

USB standards that reach a nominal rate of 20Gbps are: USB 3.2 Gen 2x2, USB 4 Gen 2x2, and USB 4 Gen 3x1. These standards use the following pins: V_{BUS} for power, D+ and D- for differential data signals, one lane (USB 4 Gen 3x1) or two lanes (USB 3.2 Gen 2x2 and USB 4 Gen 2x2) for transmitting and receiving signals (TX1/RX1, TX2/RX2), and ground.

USB 20Gbps is used in a range of devices and applications. Since there is a connection exposed to the outside world, there is a risk of a high voltage strike occurring. An transient event can cause damage to the downstream components in the system. The following sections discuss the ESD protection requirements and the system-level design for protecting speeds up to 20Gbps.

6.2 ESD Protection Requirements

For protecting USB 20Gbps, follow the list of parameters related to each pin:

- **D+, D-, TX1+, TX1-, RX1+, RX1-, TX2+, TX2-, RX2+, RX2-**
  - Working Voltage: The reverse working voltage (V_{RWM}) of the protection diode is recommended to be greater than or equal to the operating voltage of the system being protected. For USB 20Gbps data lines, the typical operating voltage is 3.3V. This translates to a working voltage of greater than or equal to 3.3V.
  - Clamping Voltage: There can be many systems utilizing USB. This results in the clamping voltage of the ESD diode being dependent on the circuity downstream from the USB connector. The clamping voltage is recommended to be below the absolute maximum rating of the downstream component.
  - Capacitance (D+, D-): Since D+ and D- are specific to USB 2.0 data transfer, the signal speeds can reach up to 480Mbps. An ESD diode with a capacitance less than 4pF is recommended.
  - Capacitance (TX+, TX-, RX+, RX-): For USB 4 Gen 3x1, the signal speeds can reach up to 20Gbps meaning an ultra low capacitance ESD diode with less than 0.25pF is recommended. For the two lane standards that reach up to 10Gbps per lane, a very low capacitance ESD diode with less than 0.3-pF is recommended.
  - IEC 61000-4-2 Rating: Real-world ESD strikes are defined by the IEC 61000-4-2 testing standard. This standard consists of two measurements: contact and air-gap discharge. The higher the contact and air-gap rating, the higher the voltage a device can withstand. For USB 20Gbps, a minimum IEC 61000-4-2 rating of 8kV for contact and 15kV for air-gap is recommended.
- **V_{BUS}**
  - Working Voltage: For V_{BUS}, the operating voltage is 5V. An ESD diode with a working voltage greater than or equal to 5V is recommended.

Table 6-1 lists devices that support these specifications.

Table 6-1. USB 20Gbps Device Recommendations

Device	V_{RWM} (V)	IEC 61000-4-2 (kV) (Contact/Air-gap)	Capacitance (pF)	Channel Count	Package Size (mm)	Recommended For
ESD321	3.6	30/30	0.9	1	DFN1006 (1.00 x 0.60), SOD523(1.60 x 0.80)	D+, D-
TPD1E01B04	3.6	15/17	0.18	1	DFN0603 (0.60 x 0.30), DFN1006 (1.00 x 0.60)	D+, D-, TX+, TX-, RX+, RX-
ESD122	3.6	17/17	0.2	2	DFN1006, 3 pins (1.00 x 0.60)	D+, D-, TX+, TX-, RX+, RX-
TPD4E02B04	3.6	12/15	0.25	4	USON (2.5 x 1.0)	D+, D-, TX/RX for 10-Gbps per lane
ESD441	5.5	30/30	1	1	DFN0603 (0.60 x 0.30)	VBUS

6.3 System Level Designs

TI has an array of ESD diodes able to protect USB 20Gbps. Figure 6-1 shows a block diagram implementing multiple ESD protection diodes. The diodes are connected to each data and power line between the connector and either the battery charger or USB controller. To properly protect the system, place the diodes as close to the source of ESD, in this case the connector, as design rules allow.

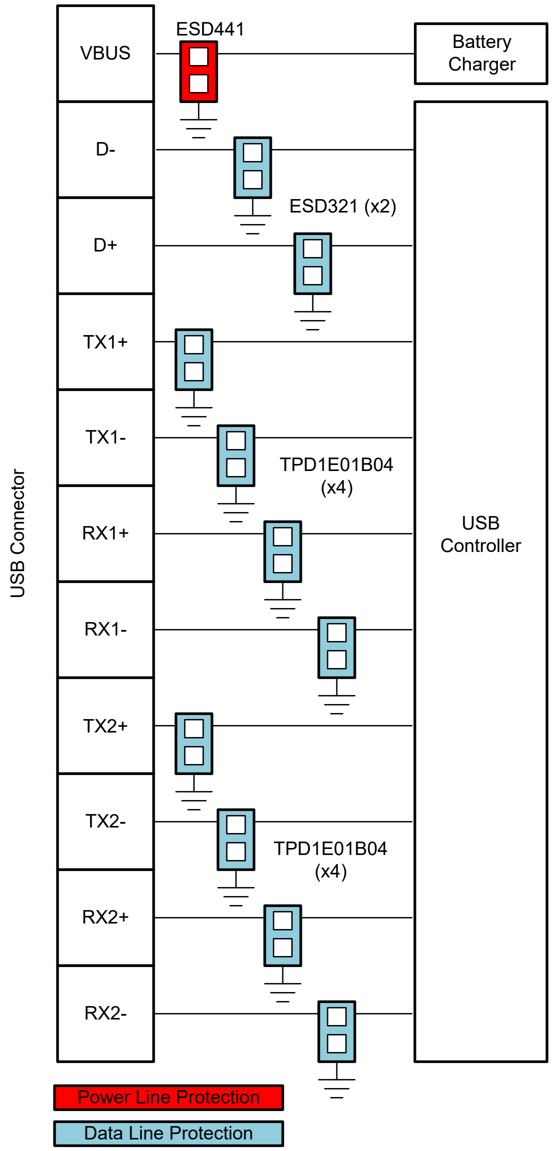

Figure 6-1. USB 20Gbps ESD Protection

For Figure 6-1, ESD321 is used to the protect the D+ and D- lines, eight TPD1E01B04's are used to protect the TX/RX lines, and ESD441 is used to protect the VBUS line. The possibilities are endless for protecting the USB lines and can use multi-channel or single-channel protection diodes.

7 USB Type-C® Protection

7.1 Overview

USB Type-C® is a 24-pin connector that allows for transmission of large amounts of power and data on a single cable. USB Type-C® is able to support USB 2.0 and all standards after as well as alternate modes like HDMI and DisplayPort. The standard also supports the USB-PD standard which is primarily implemented on the USB Type-C connector. Figure 7-1 details the pin configuration for the USB Type-C® connector.

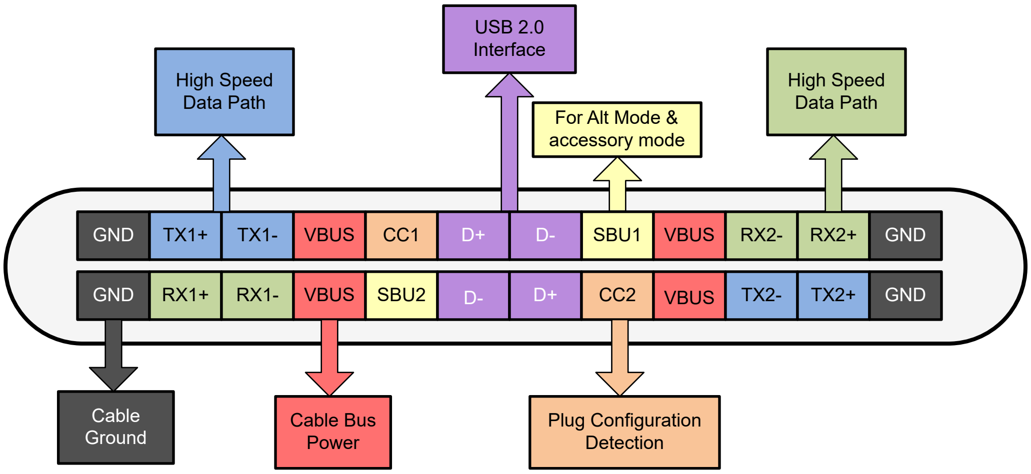

Figure 7-1. USB Type-C® Pin Configuration

While USB Type-C® incorporates the same pins mentioned throughout the application note such as D+ and D- and the TX/RX lines, there are additional pins specific to USB Type-C®: CC1/CC2 and SBU1/SBU2. The CC pins are the channel configuration pins. The pins are able to detect cable attachment, cable orientation, and current advertisement. The SBU pins are for sideband use. The pins are used in audio adapter accessory mode and alternate modes. The alternate modes include DisplayPort, HDMI, and Thunderbolt. The following section means the ESD protection requirements to properly protect a USB Type-C® connector.

7.2 ESD Protection Requirements

For protecting USB Type-C®, follow the list of parameters related to each pin:

- **D+, D-, TX1+, TX1-, RX1+, RX1-, TX2+, TX2-, RX2+, RX2-**
  - Working Voltage: The reverse working voltage (V_{RWM}) of the protection diode is recommended to be greater than or equal to the operating voltage of the system being protected. For data lines, the typical operating voltage range is 3.3V. This translates to a working voltage of greater than or equal to 3.3V.
  - Clamping Voltage: There can be many systems using USB. This results in the clamping voltage of the ESD diode being dependent on the circuity downstream from the USB connector. The clamping voltage is recommended to be below the absolute maximum rating of the downstream component.
  - Capacitance (D+, D-): Since D+ and D- are specific to USB 2.0 data transfer, the signal speeds can reach up to 480Mbps. An ESD diode with a capacitance less than 4pF is recommended.
  - Capacitance (TX+, TX-, RX+, RX-): For speeds up to 5Gbps per lane, the capacitance is recommended to be less than 0.5pF. For 10Gbps per lane, the capacitance is recommended to be less than 0.3pF, and 20Gbps per lane, the capacitance is recommended to be less than 0.25pF.
  - IEC 61000-4-2 Rating: Real-world ESD strikes are defined by the IEC 61000-4-2 testing standard. This standard consists of two measurements: contact and air-gap discharge. The higher the contact and air-gap rating, the higher the voltage a device can withstand. A minimum IEC 61000-4-2 rating of 8kV for contact and 15kV for air-gap is recommended.
- **CC**
  - Working Voltage: The reverse working voltage (V_{RWM}) of the protection diode is recommended to be greater than or equal to the operating voltage of the system being protected. The typical operating voltage for the CC pins can reach up to 5V. This translates to a working voltage of greater than or equal to 5V.
- **SBU**
  - Working Voltage: The reverse working voltage (V_{RWM}) of the protection diode is recommended to be greater than or equal to the operating voltage of the system being protected. The typical operating voltage for the SBU pins is up to 3.6V. This translates to a working voltage of greater than or equal to 3.6V.
  - Capacitance: Due to higher data speeds on the SBU lines, a low capacitance diode is needed. Depending on the signal speed, the capacitance can vary. For speeds up to 5Gbps, a capacitance less than 0.5pF is recommended.
- **VBUS**
  - Working Voltage: For V_{BUS}, the operating voltage is 5V. An ESD diode with a working voltage greater than or equal to 5V is recommended.

Table 7-1. USB Type-C® Device Recommendations

Device	V_{RWM} (V)	IEC 61000-4-2 (kV) (Contact/Air-gap)	Capacitance (pF)	Channel Count	Package Size (mm)	Recommended For
ESD321	3.6	30/30	0.9	1	DFN1006 (1.00 x 0.60), SOD523(1.60 x 0.80)	D+, D-
TPD1E01B04	3.6	15/17	0.18	1	DFN0603 (0.60 x 0.30), DFN1006 (1.00 x 0.60)	D+, D-, TX+, TX-, RX+, RX-
TPD4E02B04	3.6	12/15	0.25	4	USON (2.5 x 1.0)	D+, D-, TX+, TX-, RX+, RX-
ESD341	3.6	30/30	0.66	1	DFN0603 (0.60 x 0.30)	SBU
ESD441	5.5	30/30	1	1	DFN0603 (0.60 x 0.30)	CC, VBUS

7.3 System Level Designs

TI has a variety of ESD protection diodes able to protect each pin of a USB Type-C® connector. Figure 7-2 shows a block diagram implementing single-channel ESD protection diodes. The diodes are connected to each data and power line between the connector and USB controller. To properly protect the system, place the diodes as close to the source of ESD, in this case the connector, as design rules allow.

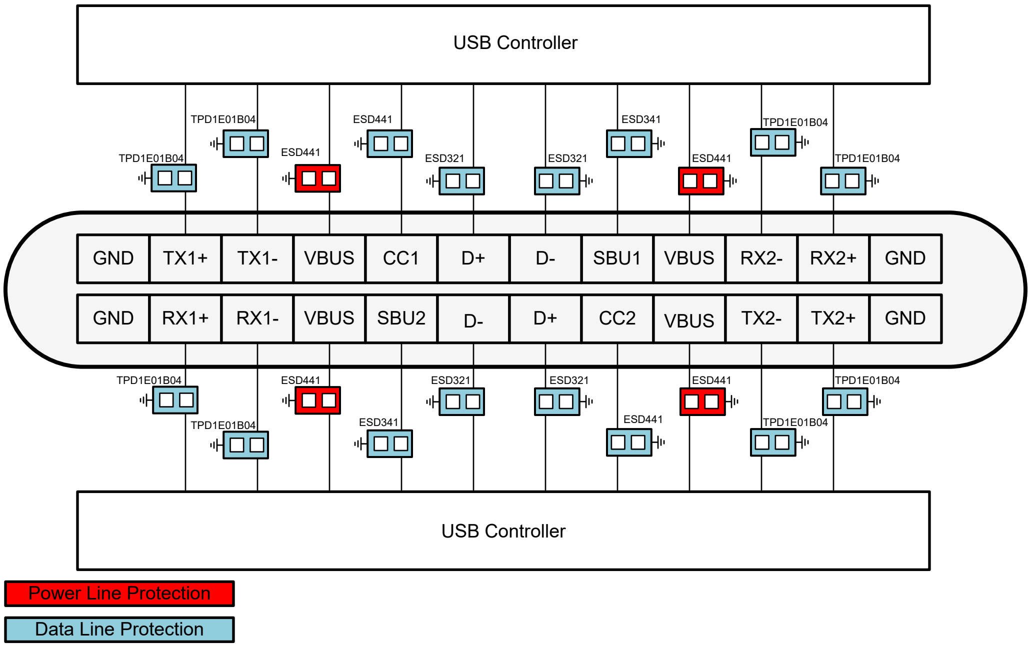

Figure 7-2. USB Type-C® ESD Protection

For Figure 7-2, TPD1E04B04 is used to protect the TX/RX lines, ESD321 is used for the D+ and D- lines, ESD441 is protecting the CC pins and VBUS, and ESD341 is used to protect the SBU pins. There are many options for protecting USB Type-C® including using multi-channel devices.

8 USB Power Delivery (USB-PD) Surge Protection

8.1 Overview

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.x standards, the maximum power that can be delivered is 15W, with a maximum of 5V on V_{BUS}. The USB-Power Delivery (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 V_{BUS} pin can vary depending on the power that needs to be supplied. Common voltages are 5V, 9V, 15V, and 20V and more recently 28V, 36V, and 48V.

8.2 VBUS Protection

As with all power lines, consideration must be taken about how to protect against transient over voltage events. For example, when there is a plug or unplug event while there is current flowing through the cable, inductive ringing can cause a 20V line to temporarily go up to 50V which can damage downstream circuitry. A recommendation to protect the system is to use a protection diode and a key specification to consider is the clamping voltage, confirming the voltage experienced by the system is below the maximum voltage of the system. The TVS2200 is a device that protects a 20V line with a very low clamping voltage. This results in the system seeing a maximum voltage of 28V during a transient event. The plots in Figure 8-1 and Figure 8-2 show the result and benefits of using a TVS device. Also, Table 8-1 shows recommended TVS diodes for USB-PD voltage levels.

Table 8-1. USB-PD VBUS Surge Protection Recommendations

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

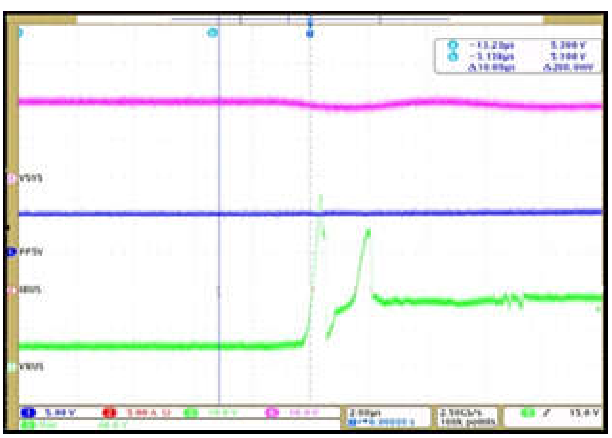

Figure 8-1. USB-PD VBUS Over Voltage Event Without TVS

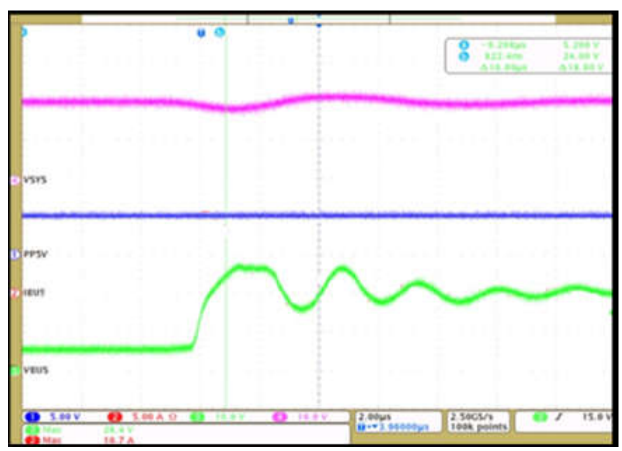

Figure 8-2. USB-PD VBUS Over Voltage Clamped by TVS2200

8.3 Short to VBUS

Protecting against a short to V_{BUS} is another care about. In the case of short to V_{BUS}, the CC and SBU pins can be exposed to the voltage on V_{BUS} due to the proximity to V_{BUS}. Figure 8-3 represents a cause of a short to VBUS event such as removing the connector improperly.

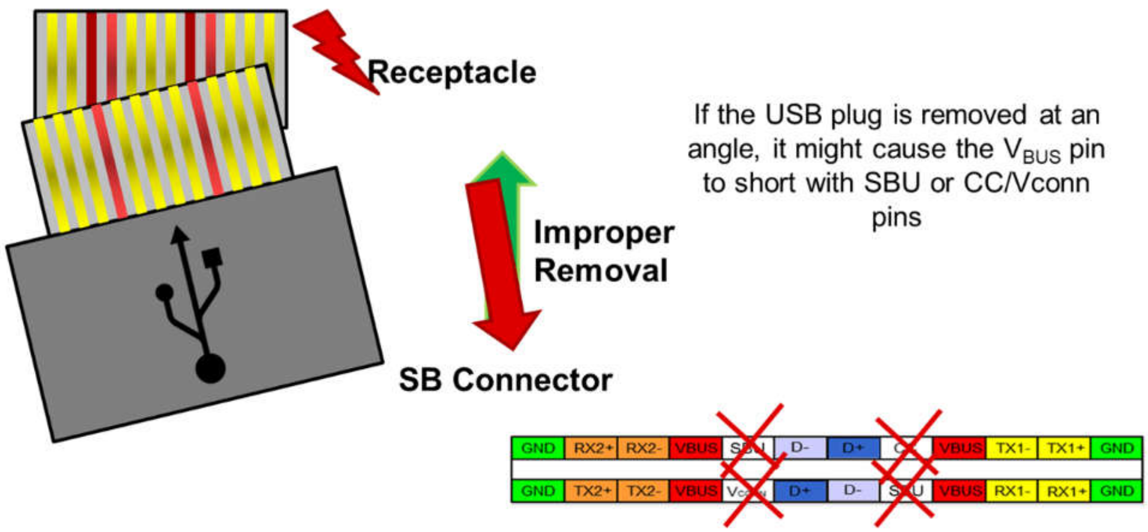

Figure 8-3. Short to VBUS

As mentioned, the voltages for USB-PD can be in the range of 5V all the way up to 48V. This requires the same working voltage of a protection diode across CC, SBU, and VBUS pins to verify the system is protected from ESD. Device recommendations for these conditions are shown in Table 8-2. For more devices on short to V_{BUS} protection, check out the USB-PD team at TI.

Table 8-2. Short to VBUS Device Recommendations

Device	V_{RWM} (V)	IEC 61000-4-2 (kV) (Contact/Air-gap)	Capacitance (pF)	Channel Count	Package Size (mm)	Recommended For
ESD2CAN24-Q1 / ESD752	24	30/30	3	2	SOT023 (2.92 x 2.37), SOT-SC70 (2.0 x 2.1)	VBUS, CC, SBU

9 References

- Texas Instruments, *A primer on USB Type-C® and USB Power Delivery Applications and Requirements*, marketing white paper.
- Texas Instruments, *System-Level ESD Protection Guide*.
- Texas Instruments, *Reading and Understanding an ESD Protection Data Sheet*, user's guide.
- Texas Instruments, *ESD Packaging and Layout Guide*, application note.

10 Revision History

Changes from Revision A (August 2022) to Revision B (January 2024)	Page
• Added and updated information on USB to include the majority of protocols as well as added device recommendations for each protocol	1

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 *ESD341* to the *USB 2.0 Data Line Protection Recommendations* table	6

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265