Application Note

System-Level ESD Protection Guide

ABSTRACT

Electrostatic discharge (ESD) poses a risk to many electronic devices and can cause unexpected and catastrophic damage. While many ICs have device level ESD protection, ICs are still at risk of damage from system-level ESD events. To provide adequate system-level ESD protection, ESD and surge devices are used to guard against these higher power transient events. This guide discusses diode selection and parameters, explains the importance of system-level ESD protection, and provides device recommendations for a number of applications.

To learn more about ESD protection and TI's ESD devices, visit ti.com.

Table of Contents

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1 Overview of System Level ESD Protection

1.1 What is ESD Protection?

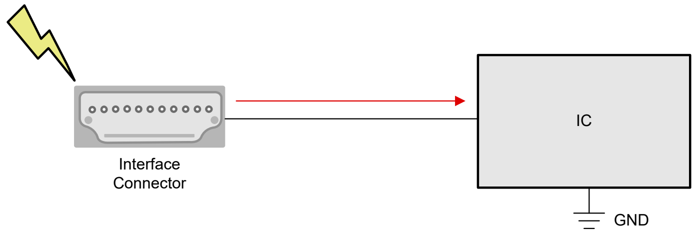


Figure 1-1. ESD Strike Without Protection

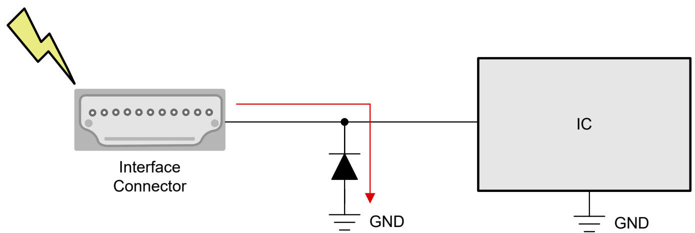


Figure 1-2. ESD Strike With Protection

Electrostatic discharge (ESD) is the sudden release of electricity from one charged object to another when the two objects come into contact. While we've all experienced ESD when we've been shocked by a metal doorknob or car door, most ESD strikes are quite harmless to humans. However, for sensitive integrated circuits (ICs), the high peak voltage and current of these ESD strikes can cause catastrophic failures.

If ESD protection is not present in a system, the high voltage of an ESD strike through an interface connection causes a large current spike to flow directly into the IC, causing damage. To protect sensitive circuitry from electrical overstress failures, ESD protection diodes are connected to each signal line between the interface connector and the IC.

In the event of an ESD strike, the ESD diode breaks down and creates a low impedance path that limits the peak voltage and current by diverting the current flow to ground, thereby protecting the IC.

Figure 1-3 compares the peak voltage of a typical ESD strike without protection to the same ESD strike on a signal line with ESD diode protection.

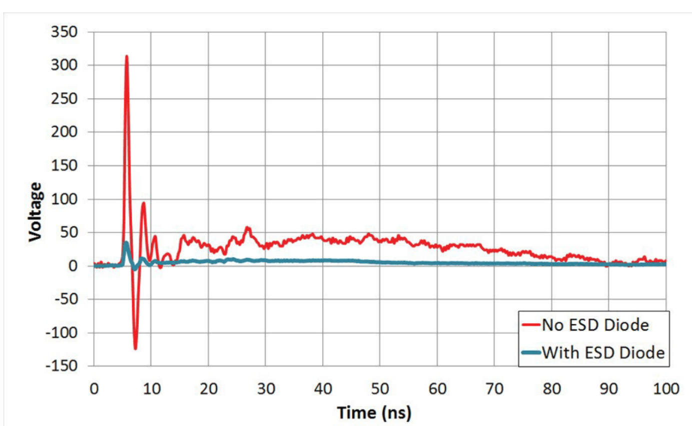


Figure 1-3. Voltage Waveforms With and Without ESD Protection

1.2 Why External ESD?

Many semiconductor devices based off advanced processes only offer device-level ESD specifications such as the charge device model (CDM) and the human body model (HBM) shown in Figure 1-4. Device-level ESD specifications are not sufficient to protect devices in a system. The energy associated with a system-level ESD strike is much higher than a device-level ESD strike. This means a more robust design is required to protect against this excess energy.

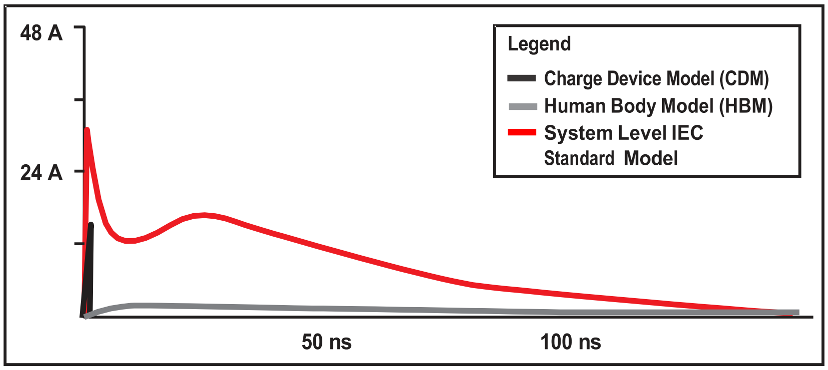
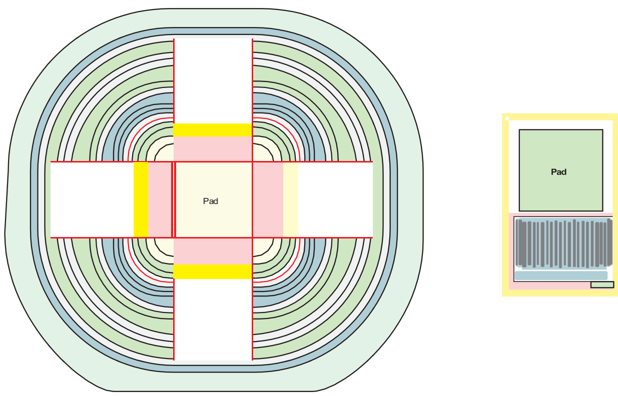


Figure 1-4. IEC vs. CDM vs. HBM

The silicon area required to implement system-level ESD protection is much larger than what is required for device-level HBM and CDM. This difference in silicon area translates to additional cost. As technology gets smaller, technology becomes increasingly difficult and more costly to integrate sufficient system-level protection with microcontroller or core chipsets.



Left: Silicon die areas for system-level ESD (8-kV IEC).

Right: Silicon die areas for device-level ESD (2-kV HBM).

Figure 1-5. Silicon Die Area Comparison

System-level ESD protection can be added with discrete components. However, in many applications, discrete designs consume board space, complicate layout, and compromise signal integrity at high data rates. Stand-alone ESD devices from Texas Instruments (TI) provide space-saving designs to protect system ICs from external ESD strikes while maintaining signal integrity.

ESD protection is often considered at the last phase of system design. Designers require flexibility to select an ESD device that does not compromise the PCB layout or consume additional board space. TI's ESD designs with pass-through packaging as shown in Figure 1-6 allow designers to add ESD components in the final stages of a design with minimal change in board layout.

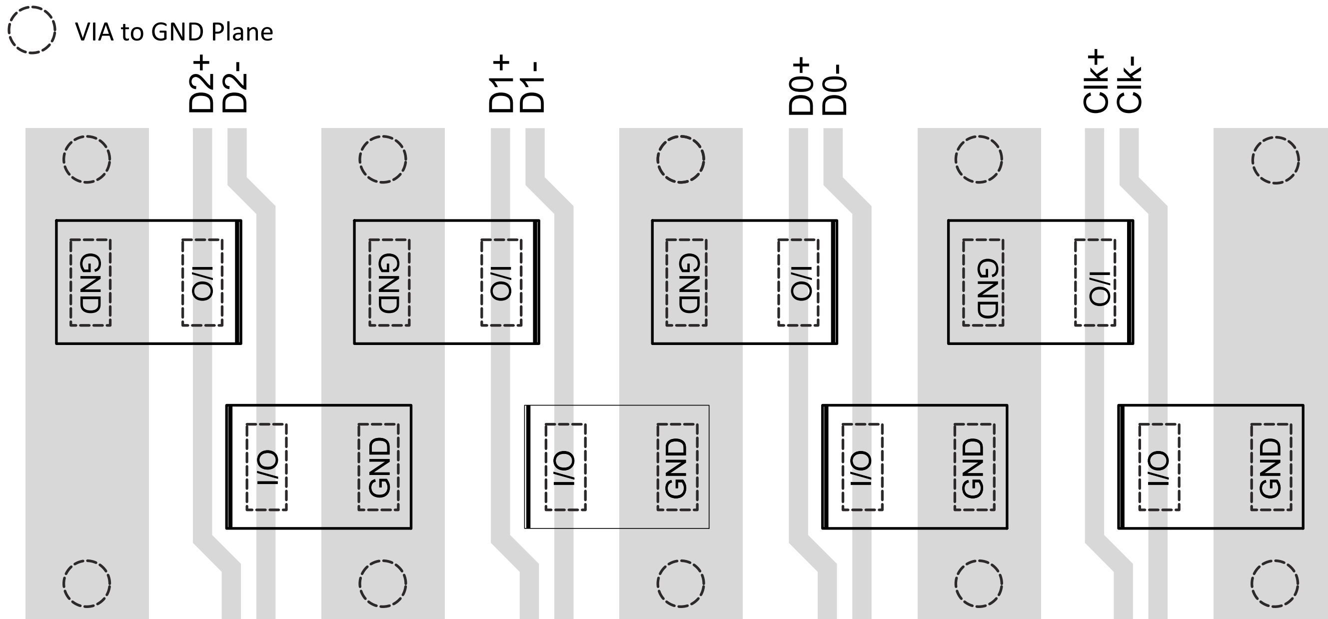


Figure 1-6. Example of Pass-Through Routing

2 Definitions of ESD Device Specifications

2.1 Working Voltage (V_{RWM})

The working voltage is the recommended operating voltage of the ESD device. The signal voltage of the interface must not exceed the working voltage of the ESD device in either the negative or positive direction to prevent unwanted clamping and leakage. To learn more, click here.

2.2 Polarity

An ESD diode is bidirectional or unidirectional. A bidirectional diode has a breakdown voltage range from $+V_{rwm}$ to $-V_{rwm}$, which allows the diode to support signals with negative ranges such as analog audio. A unidirectional diode has a breakdown range from 0V to $+V_{rwm}$, which helps protect downstream devices that cannot tolerate a negative voltage. To learn more, click here.

2.3 Channels

ESD devices can come in a variety of channels and configurations. Depending on the interface, multichannel devices can offer board space savings over single-channel devices. In other applications, single-channel devices can offer more design flexibility than multichannel designs.

2.4 IEC 61000-4-2 Rating

A system-level ESD standard that shows the robustness of the ESD device. The IEC 61000-4-2 rating consists of two measurements. First, the contact rating shows the maximum voltage a device can withstand when the source of ESD is discharged directly onto the device. Second, the airgap rating shows the maximum voltage a device can withstand when the source of ESD is discharged over a gap of air onto the device. The higher the IEC 61000-4-2 rating, the higher a voltage the ESD device can withstand. To learn more, click here.

2.5 Capacitance

Since the ESD diodes are connected in parallel to the signal trace, the diodes add some parasitic capacitance to the system. The capacitance of the ESD device becomes especially important in high-speed interfaces because capacitance must be minimized to maintain signal integrity. To learn more, click here.

2.6 Clamping Voltage at 16A TLP

When an ESD strike occurs, the ESD diode *clamps* the voltage so that the downstream circuitry is not exposed to a voltage greater than the clamping voltage. Therefore, clamping voltage is a measurement of how well the diode can protect downstream circuitry. The clamping voltage of a device exposed to an 8kV IEC ESD strike is best approximated with a transmission line pulse (TLP) at 16A. Clamping voltage is a function of the dynamic resistance of the device during an ESD strike. To learn more, click here.

3 ESD Devices by Application

3.1 Antenna Circuit Protection

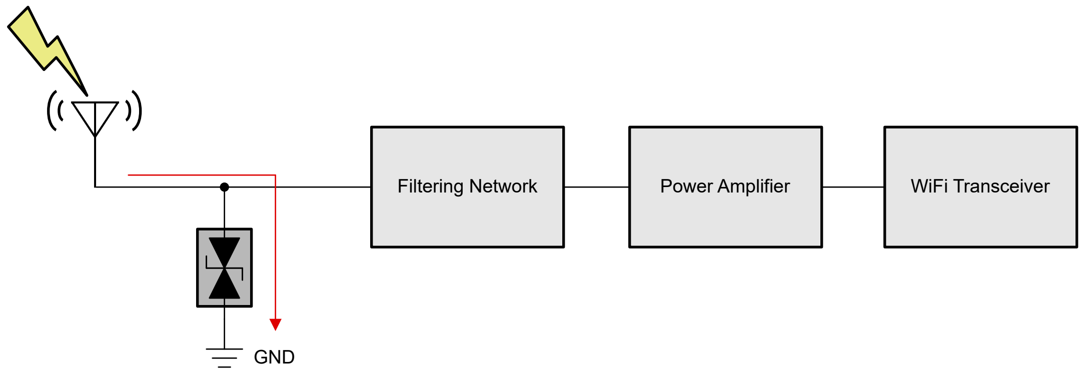


Figure 3-1. Antenna Application Diagram

Description

In wireless applications such as GPS, WLAN, Wi-Fi®, and so on., the antenna can act as a low-impedance path for ESD strikes to enter the system and damage downstream circuitry such as the filtering network, amplifier or transceiver. Signal frequencies in these applications can reach upwards of 15GHz which means that any capacitance on signal paths must be minimized to avoid signal degradation.

Design

The ESD devices listed in Table 3-1 provide IEC 61000-4-2 ESD protection with ultra-low capacitance to maintain signal integrity. These designs are available in a variety of small flow-through footprint options, including 0201 (0.6 × 0.3mm) and 0402 (1.0 × 0.6mm). These devices also come in a wide range of working voltages to support a variety of antenna applications.

Table 3-1. ESD Designs for Antenna Applications (*Click here for more products on Ti.com*)

Device	Working Voltage (V)	IEC 61000-4-1-2 ESD Rating (kV) (Contact)	Capacitance (pF)	Channels	Package Size (mm)	Package
TPD1E0B04	±3.6	8	0.13	1	0.6 × 0.3 1.0 × 0.6	DFN0603 DFN1006
TPD1E01B04-Q1	±3.6	15	0.2	1	0.6 × 0.3 1.0 × 0.6	DFN0603 DFN1006
ESD601-Q1	±18	15	0.3	1	1.0 × 0.6	DFN1006
ESD701-Q1	±24	15	0.3	1	1.0 × 0.6	DFN1006

3.2 Audio Circuit Protection

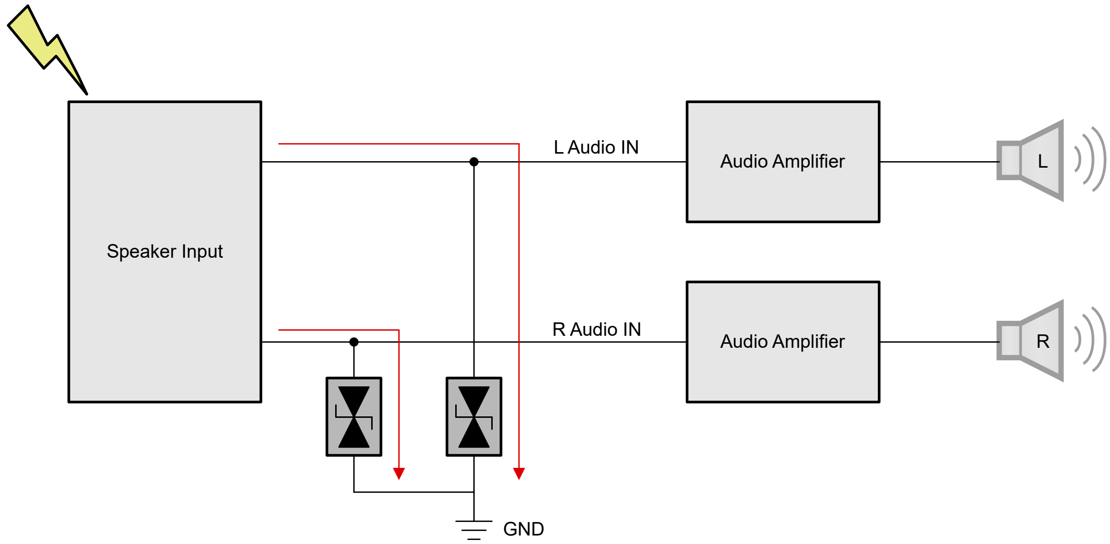


Figure 3-2. Audio Application Diagram

Description

Audio jacks and connectors can present an entry point for ESD to enter the system. Analog audio signals do not typically exceed ±5V before amplification but can reach higher voltages after the amplifier. Since the maximum frequency does not exceed 30kHz, the capacitance of the ESD diode is not a concern. Because analog audio can have both positive and negative voltage swings, ESD designs must be bidirectional to prevent premature breakdown which can interfere with the signal.

Design

The ESD designs below offer ESD protection that exceeds the IEC 61000-4-2 level 4 standard. These designs are bidirectional which allow for both the positive and negative voltage swings of audio signals. The designs below also come in a variety of working voltages to support different audio-voltage levels.

Table 3-2. ESD Designs for Audio Applications (*Click here for more products on Ti.com*)

Device	Working Voltage (V)	IEC 610000-4-2 ESD Rating (kV) (Contact)	Capacitance (pF)	Channels	Package Size (mm)	Package
ESD341	±3.6	30	0.66	1	0.6 × 0.3	DFN0603
ESD451	±5.5	30	0.5	1	0.6 × 0.3	DFN0603
TPD1E10B09	±9	20	10	1	1.0 × 0.6	DFN1006
ESD501-Q1	±12	15	0.3	1	1.0 × 0.6	DFN1006
ESD761-Q1	±24	15	1.1	1	1.0 × 0.6	DFN1006

3.3 CAN Circuit Protection

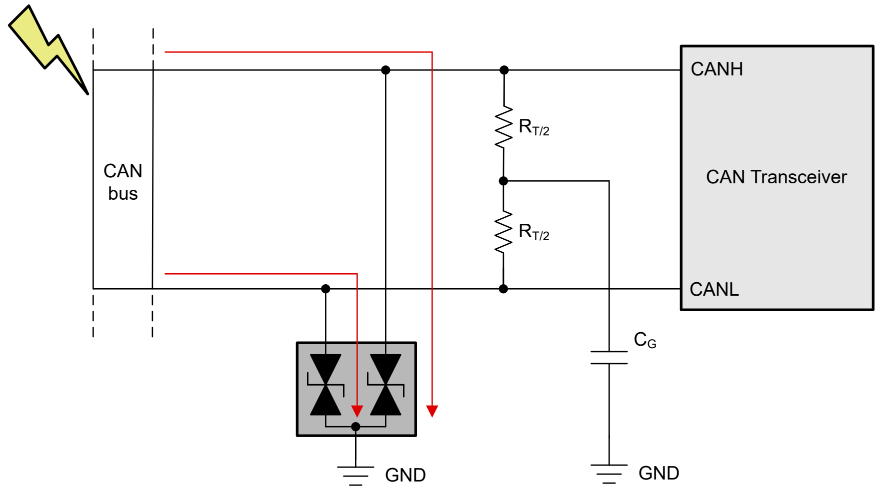


Figure 3-3. CAN Application Diagram

Description

The CAN interface has two lines that require ESD protection (CANH and CANL). In the common 12V battery automotive systems, there is also the requirement to allow for 24V. This is due to the possibility miswiring when the battery is being charged, shorting the signal line to the CAN bus.

Design

For automotive systems a 24V working voltage diode is required and uses two channels for layout and capacitance matching. TI offers devices for CAN, CAN-FD, and CAN-XL, in addition to supporting working voltages up to 36V. For more details about CAN ESD protection, see *Protecting Automotive CAN Bus Systems from ESD Overvoltage Events*.

Table 3-3. ESD Designs for CAN Applications (*Click here for more products on Ti.com*)

Device	Working Voltage (V)	IEC 610000-4-2 ESD Ratings (kV) (Contact)	Capacitance (pF)	Channels	Package Size (mm)	Package
ESD2CAN24-Q1	±24	30	3	2	2.92 × 1.3 2.0 × 1.25	SOT-23-3 SC-70-3
ESD2CANFD24-Q1	±24	25	2.5	2	2.92 × 1.3	SOT-23-3
ESD2CANXL24-Q1	±24	20	1.7	2	2.92 × 1.3	SOT-23-3
ESD2CAN36-Q1	±36	25	2.8	2	2.92 × 1.3	SOT-23-3
ESD2CANFD36-Q1	±36	18	2.6	2	2.92 × 1.3	SOT-23-3

3.4 DisplayPort Circuit Protection

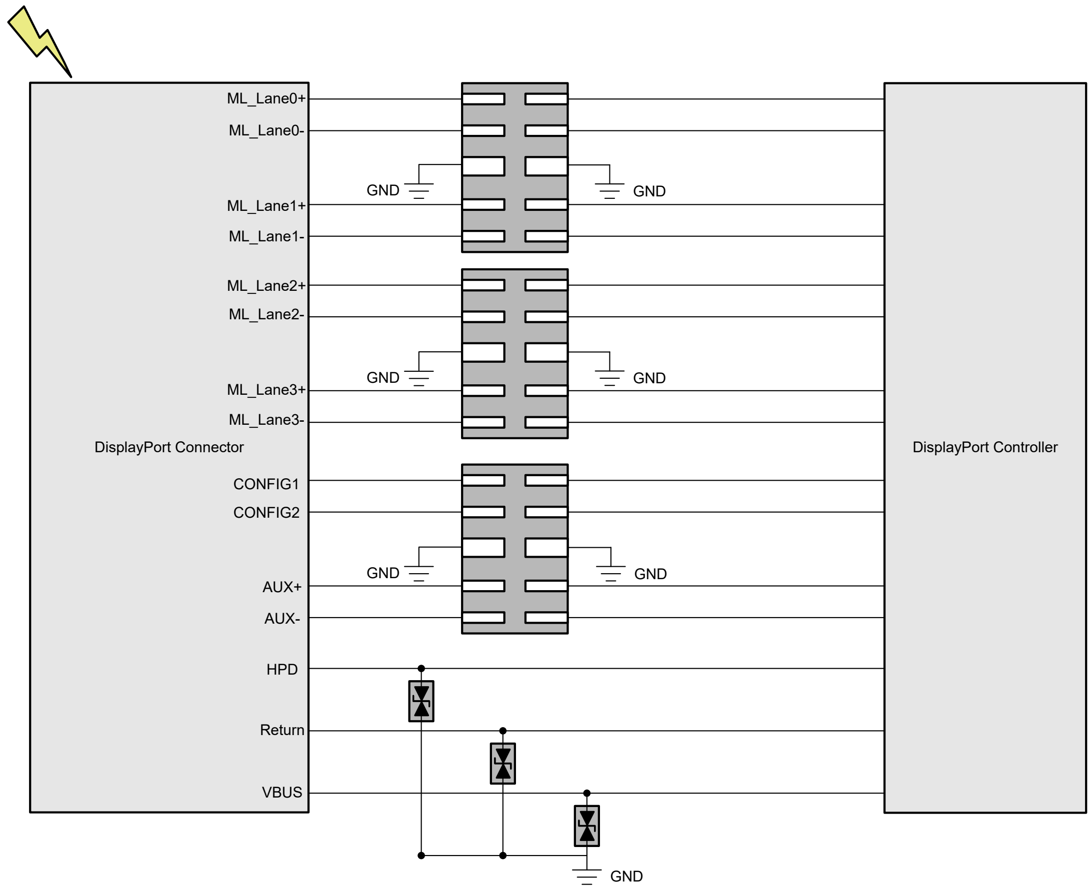


Figure 3-4. DisplayPort Application Diagram

Description

DisplayPort connectors require protection on eight high-speed ML data lines and four low-speed data lines, all at 3.3V. DisplayPort 2.1 uses four UHBR data lines which can reach speeds of 20Gbps, or 80Gbps total. At these speeds, protection requires ultra-low capacitance to maintain signal integrity.

Design

For the eight high-speed UHBR lines, TI recommends using two 4-channel ESD devices with ultra-low capacitance. TI also recommends using another 4-channel device for the four low-speed lines, although the capacitance requirements are not as strict. To protect the remaining lines, single channel, 3.3V tolerant devices can be used. These lines are not passing data, so the capacitance of the device is not very important.

Table 3-4. ESD Designs for DisplayPort Applications (*Click here for more products on Ti.com*)

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact)	Capacitance (pF)	Channels	Package Size (mm)	Package
ESD204	±3.6	30	0.55	4	2.5 × 1.0	DFN2510
ESD341	±3.6	30	0.66	1	0.6 × 0.3 1.0 × 0.6	DFN0603 DFN1006
TPD4E02B04-Q1	±3.6	12	0.25	4	2.5 × 1.0	DFN2510
TPD1E01B04-Q1	±3.6	15	0.18	1	0.6 × 0.3	DFN0603

3.5 Ethernet Circuit Protection

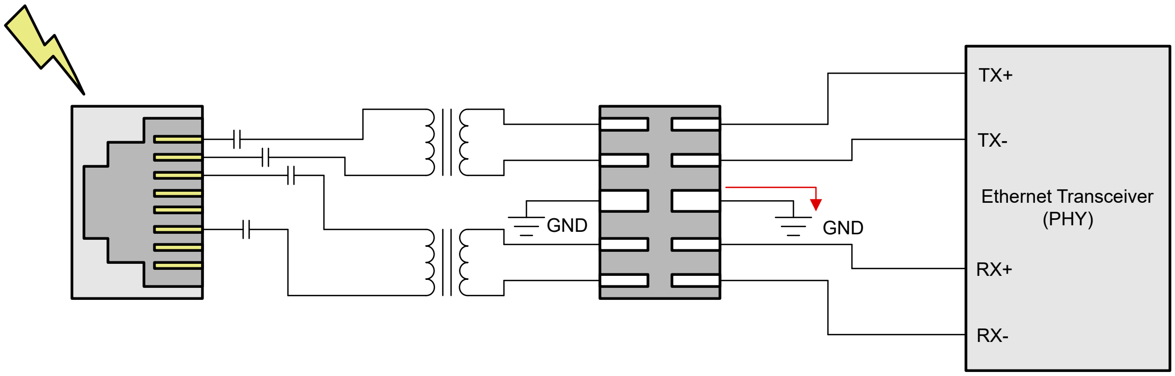


Figure 3-5. Ethernet Application Diagram

Description

Ethernet applications requires four channels of ESD protection for the Tx/Rx signal lines in the connector. The voltage of these signals can range from 1V to 2.5V and the bandwidth options include 10Mbps, 100Mbps for Fast Ethernet, and 1Gbps for Gigabit Ethernet. At these speeds, the capacitance of the ESD diode must be considered.

Design

4-channel devices are recommended for Ethernet applications for layout convenience. To maintain signal integrity, capacitance also must be considered, especially for Gigabit Ethernet (< 5pF is recommended). For more details on Ethernet protection, see *Protecting Ethernet Ports from Surge Events*.

Table 3-5. ESD Designs for Ethernet Applications (*Click* here *for more products on Ti.com*)

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact)	Capacitance (pF)	Channels	IEC 61000-4-5 Surge (A)	Package
ESDS304	3.6	30	2.3	4	12	SOT-23
ESD204	±3.6	30	0.55	4	5.5	DFN2510
TPD4E02B04-Q1	±3.6	12	0.25	4	2	DFN2510
TPD2E2U06-Q1	5.5	25	1.5	2	5.5	SOT-23-3 SC-70-3
TPD1E01B04-Q1	±3.6	15	0.2	1	0.6 × 0.3 1.0 × 0.6	DFN0603 DFN1006

3.6 FPD-Link Protection

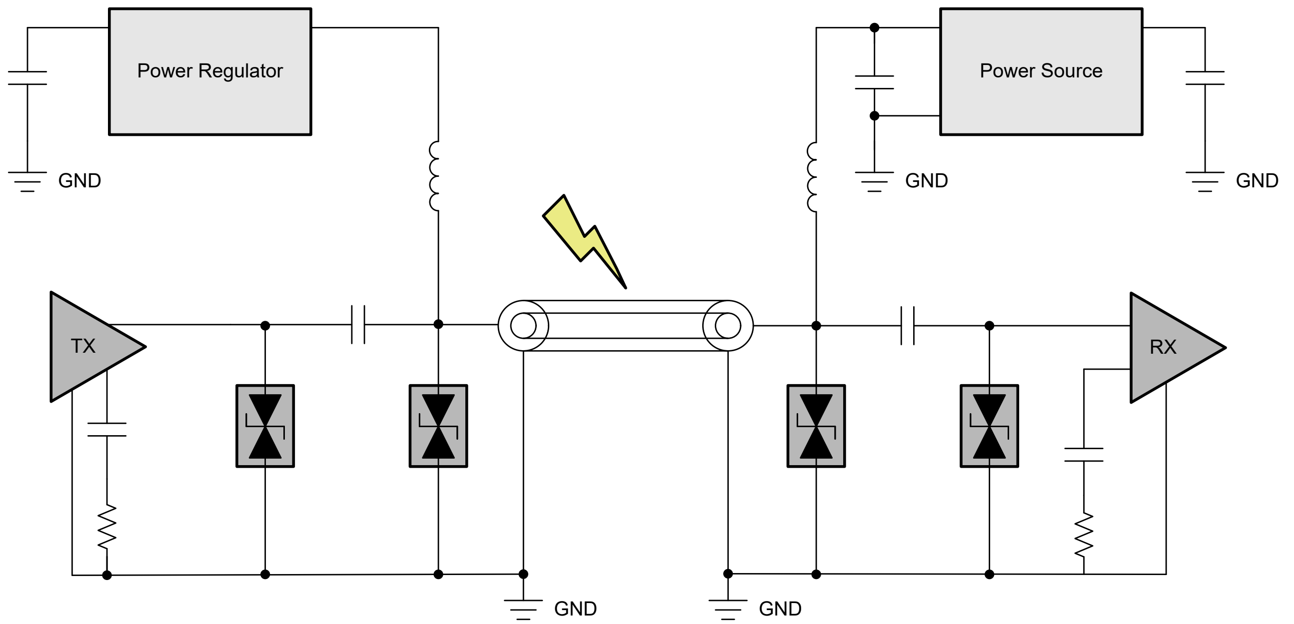


Figure 3-6. FPDLink Application Diagram

Description

FPD-Link is commonly used in vehicles for video applications, such as camera feeds or touchscreens. FPD-Link enables these high bandwidth signals to be sent over relatively cheap coaxial or twisted pair cables. The forward channel can reach speeds up to 7.55Gbps, meaning that diode capacitance is an important factor to minimize.

Design

FPD-Link transceivers can support 3.3V or 5V signaling, so selected devices must match this working voltage. TI recommends placing ESD diodes on both sides of cable to protect both the transceiver and receiver. At these data speeds, capacitance must be <= 0.3pF to minimize signal attenuation.

Table 3-6. ESD Designs for FPD-Link Applications (*Click here for more products on Ti.com*)

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact)	Capacitance	Channels	Package Size (mm)	Package
TPD1E01B04-Q1	±3.6	15	0.2	1	0.6 × 0.31.0 × 0.6	DFN0603 DFN1006
ESD501-Q1	±12	15	0.3	1	1.0 × 0.6	DFN1006
ESD601-Q1	±18	15	0.3	1	1.0 × 0.6	DFN1006
ESD701-Q1	±24	15	0.3	1	1.0 × 0.6	DFN1006
ESD801-Q1	±36	15	0.3	1	1.0 × 0.6	DFN1006

3.7 HDMI Circuit Protection

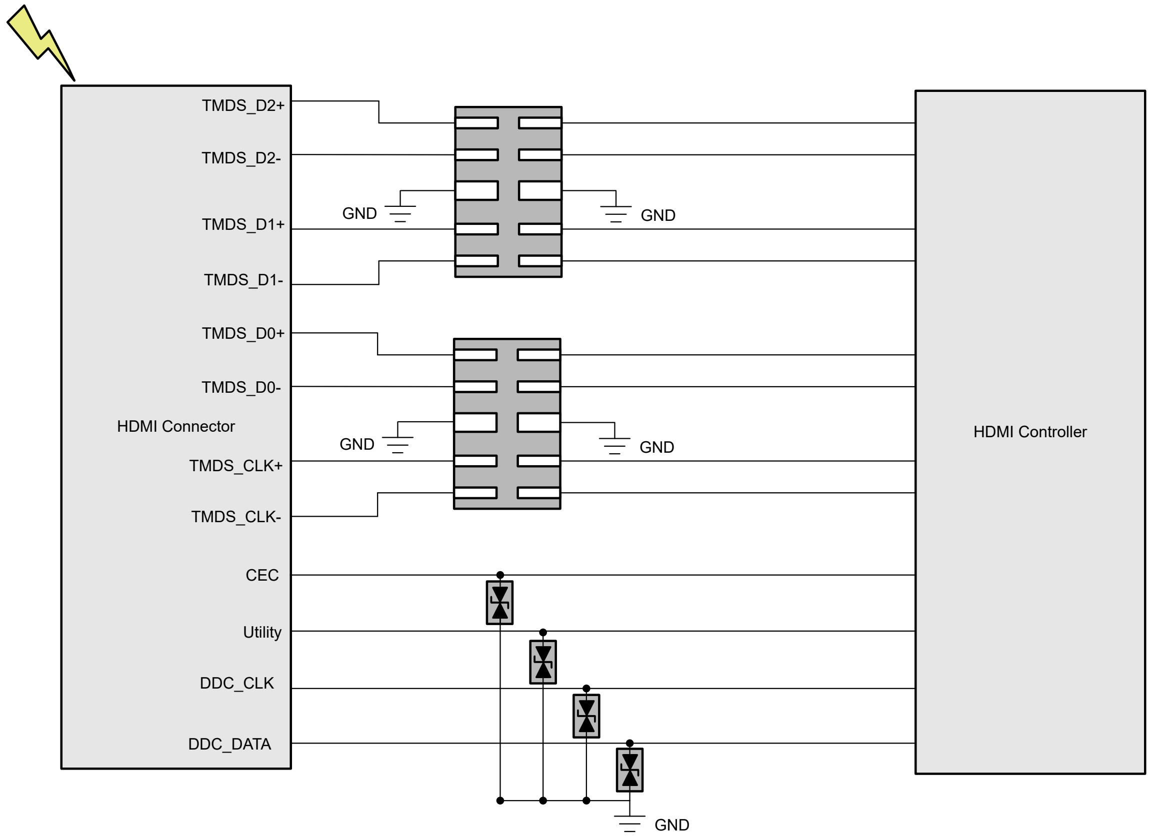


Figure 3-7. HDMI Application Diagram

Description

The HDMI connector requires ESD protection for all 12 data lines: eight low-voltage, high-speed TMDS lines and four 5V control lines. The speed of the TMDS lines can reach a maximum of 16Gbps per lane (48Gbps for the whole connector) for HDMI 2.1 so minimizing capacitance is crucial.

Design

For the eight TMDS lines, TI recommends using two 4-channel ESD devices with ultra-low capacitance to minimize board layout and maintain signal integrity. A 5V tolerant, 4-channel device must be used to protect the lower-speed control lines. 5V tolerant, single-channel devices can also be used for greater layout flexibility. For more details about HDMI protection, see *ESD Protection for HDMI Applications*.

Table 3-7. ESD Designs for HDMI Applications (*Click here for more products on Ti.com*)

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact)	Capacitance (pF)	Channels	Package Size (mm)	Package
ESD441	5.5	30	1.1	1	0.6 × 0.3	DFN0603
TPD4E05U06	5.5	12	0.4	4	2.5 × 1.0	DFN2510
TPD1E01B04-Q1	±3.6	15	0.2	1	0.6 × 0.3 1.0 × 0.6	DFN0603 DFN1006
TPD4E02B04-Q1	±3.6	12	0.25	4	2.5 × 1.0	DFN2510

3.8 Keypad and Pushbutton Circuit Protection

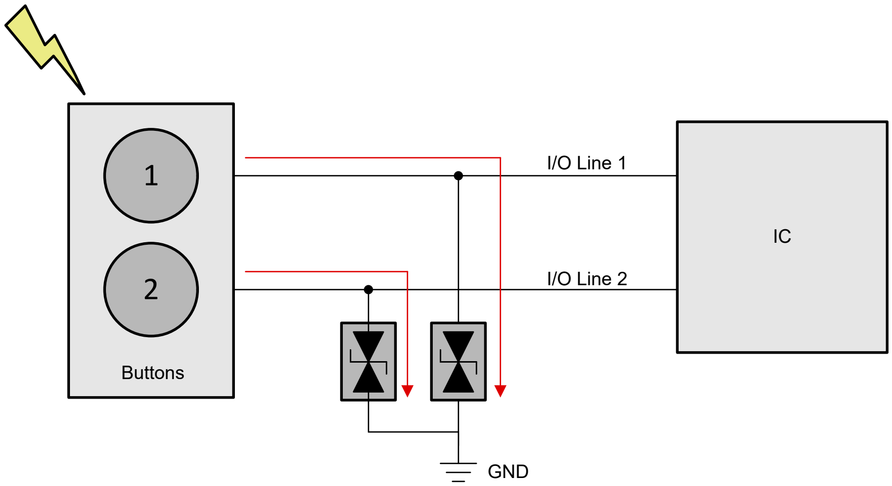


Figure 3-8. Pushbutton Application Diagram

Description

Pushbuttons and keyboards on cell phones, laptops and TVs are high-contact areas that can present a low-impedance path for ESD to enter the system. These I/O signals are typically low speed and low voltage (< 5V).

Design

Since the signal frequency of pushbuttons is low, the capacitance of the ESD device is not very important. Single-channel and multichannel designs with IEC 61000-4-2 ESD protection are preferred designs. For more information on Keypad and Pushbutton protection, see *ESD Protection for Keypads, Pushbuttons, and Side Keys*.

Table 3-8. ESD Designs for Keypad/Pushbutton Applications (*Click* here *for more products on Ti.com*)

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact)	Capacitance (pF)	Channels	Package Size (mm)	Package
TPD1E6B06	±5.5	15	6	1	0.6 × 0.3	DFN0603
ESD341	±3.6	30	0.66	1	0.6 × 0.3	DFN0603
TPD1E10B06-Q1	±5.5	30	12	1	1.0 × 0.6 1.6 × 0.8	DFN1006 SOD-523

3.9 LIN Circuit Protection

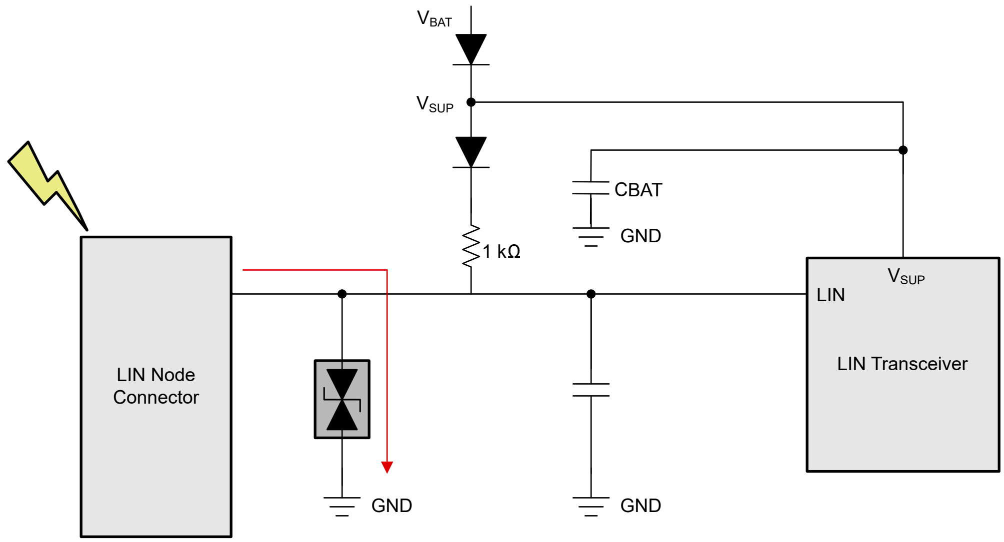


Figure 3-9. LIN Application Diagram

Description

LIN is a common interface used across automotive and industrial applications and favored because LIN offers a robust design. Unlike CAN, LIN uses a single ended connection only requiring one wire. However, LIN also must be protected from possible ESD events introduced during assembly or maintenance to keep the system robust.

Design

In the more common 12V battery automotive systems, an ESD diode with a 24V working voltage diode is required. This is due to the possibility of a battery miswire, putting 2x battery voltage on the lines. A single channel device is typically preferred due to the flexibility that the single channel device gives in layout. Also, minimizing capacitance helps add robustness to the signal integrity of the bus. For more information on LIN protection, see *ESD Protection for LIN Data Lines*.

Table 3-9. ESD Designs for LIN Applications (*Click here for more on Ti.com*)

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact)	Capacitance (pF)	Channels	Package Size (mm)	Package
ESD1LIN24-Q1	±24	30	3	1	2.5 × 1.2	SOD-323
ESD751-Q1	±24	22	2.5	1	1.6 × 0.8	SOD-523
ESD761-Q1	±24	15	1.1	1	1.0 × 0.6	DFN1006

3.10 LVDS Circuit Protection

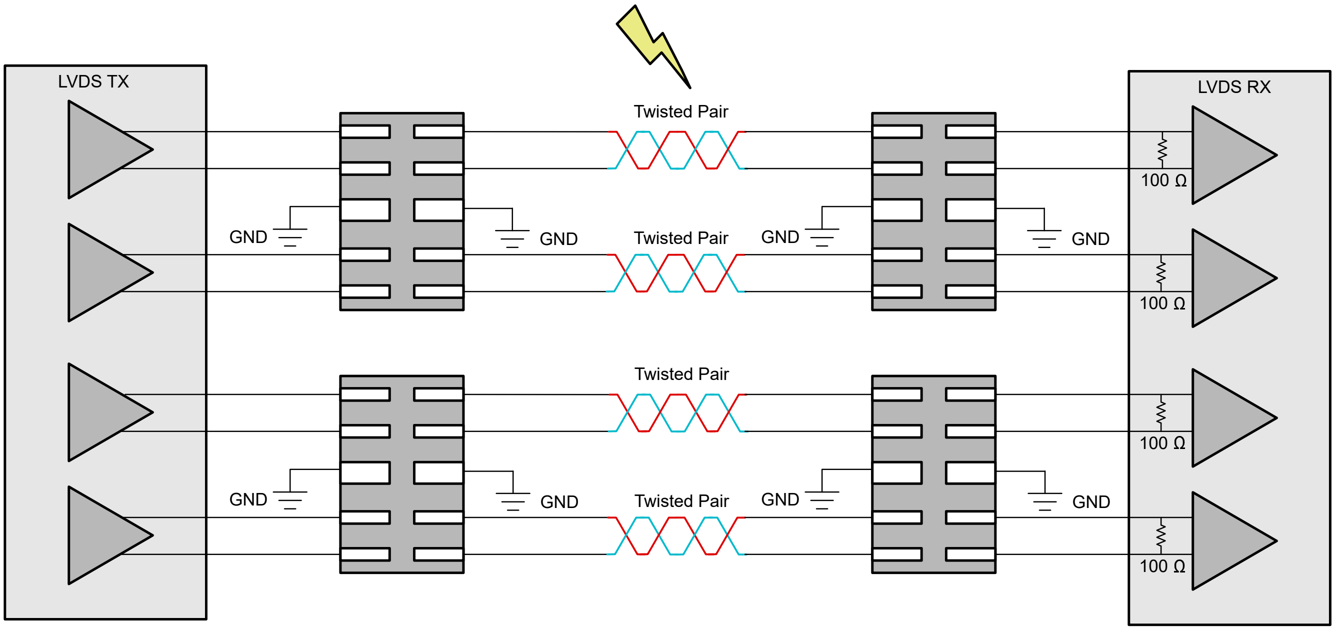


Figure 3-10. LVDS Application Diagram

Description

LVDS (Low Voltage Differential Signaling) is a popular standard used for high speed, long distance communication, reaching speeds up to 1.3Gbps. At these speeds, minimizing capacitance is crucial. Protecting both the transceiver and receiver from ESD events is important, with the strike occuring from the twisted pair.

Design

At these data speeds, a capacitance of < 3pF is required to maintain signal integrity. TI recommends a 5V tolerant, 4-channel device with low capacitance to protect two tranceivers or receivers, with a device required on both ends of the line. A 2-channel device is a good choice to protect a single tranceiver or receiver.

Table 3-10. ESD Designs for LVDS Applications (*Click here for more products on Ti.com*)

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact)	Capacitance (pF)	Channels	Package Size (mm)	Package
ESD122	±3.6	18	0.2	2	1.0 × 0.6	DFN1006-3
TPD4E1U06	5.5	15	0.8	4	2.0 × 1.25 2.9 × 1.6	SC70 SOT-23
TPD4E05U06-Q1	5.5	12	0.5	4	2.5 × 1.0	DFN2510

3.11 MHL Circuit Protection

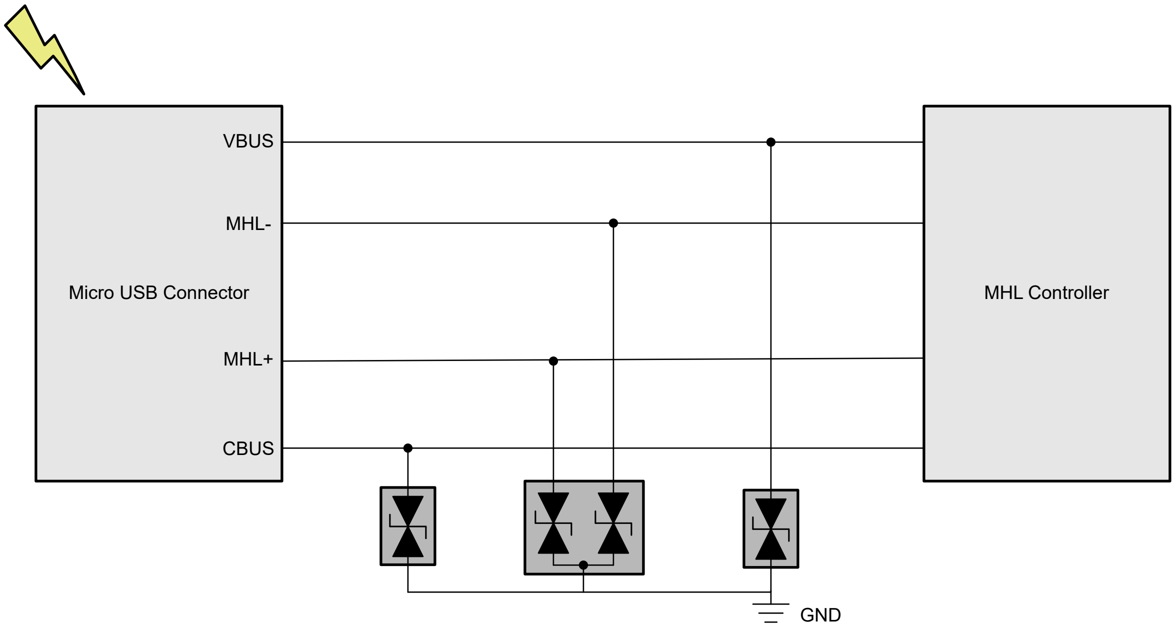


Figure 3-11. MHL Application Diagram

Description

MHL (Mobile High-Definition Link) has three data lines and one power line that require protection. The MHL+/ MHL- lines can reach speeds of up to 6Gbps, meaning devices must have capacitance < 0.5pF. The CBUS line passes data at a rate of up to 750Mbps, which also requires low capacitance.

Design

An ultra-low capacitance, two-channel device is used to protect the MHL lines while minimizing board layout. Single channel devices can also be used if required. The CBUS line must be protected by a 5V tolerant, low capacitance device. The VBUS line does not pass data, so a 5V device with a higher capacitance is sufficient.

Table 3-11. ESD Designs for MHL Applications (*Click here for more products on Ti.com*)

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact)	Capacitance (pF)	Channels	Package Size (mm)	Package
ESD122	±3.6	17	0.2	2	1.0 × 0.6	DFN1006-3
ESD451	±5.5	30	0.5	1	0.6 × 0.3	DFN0603
TPD1E10B06	±5.5	30	12	1	1.0 × 0.6 1.6 × 0.8	DFN1006 SOD-523

3.12 PCIe Circuit Protection

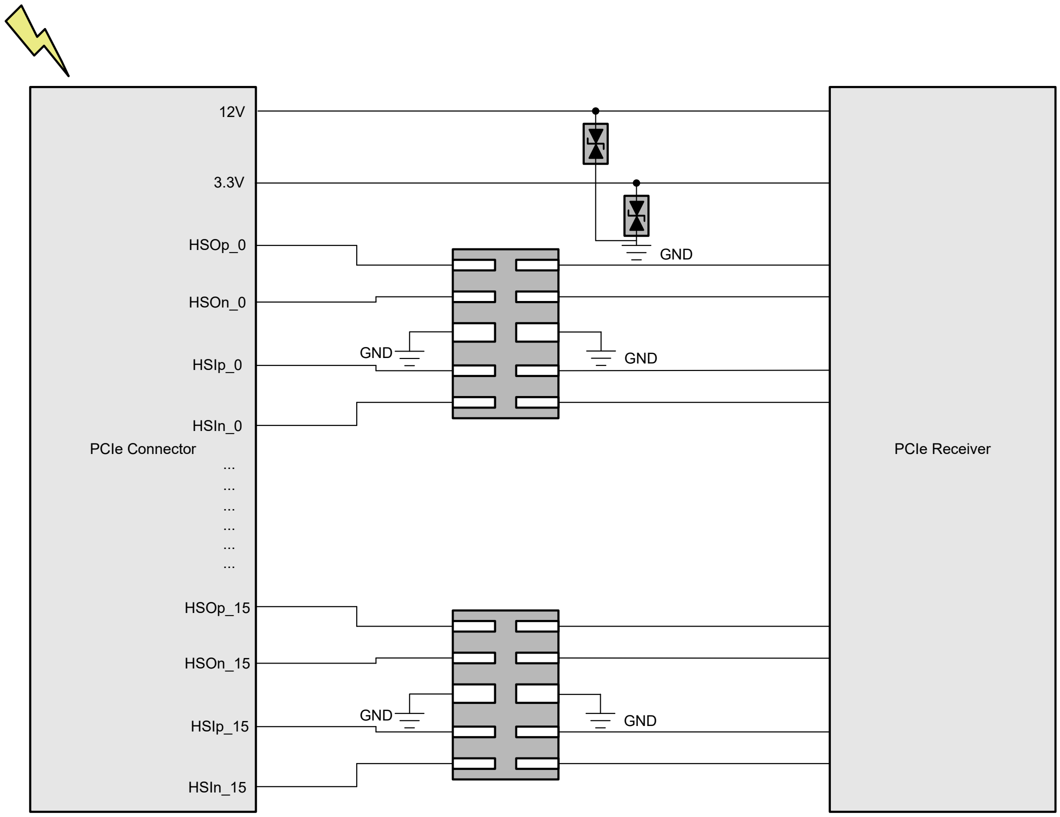


Figure 3-12. PCIe Application Diagram

Description

A PCIe connector has two power lines at 12V and 3.3V, as well as numerous high speed HSI/HSO data lines. The number of data lines depends on the length of the connector. These lines can run at extremely high rates, from 16Gbps for 4.0 HSI/HSO all the way to 64Gbps for 6.0 HSI/HSO. This requires ultra-low capacitance devices to maintain the signal.

Design

TI recommends using a 4-channel device to minimize board space while protecting a set of HSI/HSO high speed lines. TPD4E02B04 has a capacitance of 0.25pF which can support data rates up to 20Gbps. In case higher data rates are used, TI also offers devices with lower capacitance to support those requirements.

Table 3-12. ESD Designs for PCIe Applications (*Click here for more products on Ti.com*)

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact)	Capacitance (pF)	Channels	Package Size (mm)	Package
TPD4E02B04	±3.6	12	0.25	4	2	DFN2510
ESD122	±3.6	17	0.2	2	1.0 × 0.6	DFN1006-3
TPD1E0B04	±3.6	8	0.13	1	0.6 × 0.3 1.0 × 0.6	DFN0603 DFN1006
TSD12	12	30	12	1	2.65 × 1.3	SOD-323
ESD341	±3.3	30	0.66	1	0.6 × 0.3	DFN0603

3.13 RS-485 Protection

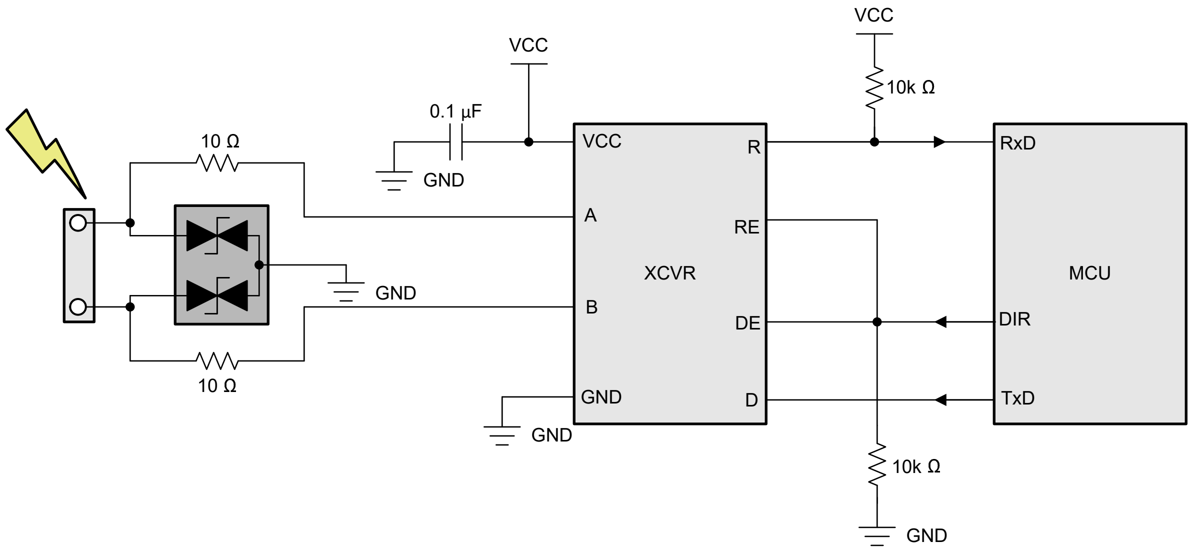


Figure 3-13. RS-485 Application Diagram

Description

RS-485 is an electrical standard used in many industrial applications, where RS-485 is able to transmit data over long distances while still remaining robust. RS-485 also supports multipoint communication, allowing many devices to communicate over the network. Signaling rates can reach up to 50Mbps, meaning that capacitance is not important to minimize.

Design

ESD diodes for RS-485 must be bidirectional to provide support for positive and negative voltages on the lines. TI recommends using a 2-channel device at the connector to protect both signaling lines. The standard defines that the receiver and transceiver must operate between -7V and 12V, so any diode must have a working voltage of 12V.

Table 3-13. ESD Designs for RS-485 Applications (*Click here for more products on Ti.com*)

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact)	Capacitance	Channels	Package Size (mm)	Package
ESDS552	±12	30	9.5	2	2.92 × 2.37	SOT-23-3
ESD562	±12	22	1.5	2	2.92 × 2.37	SOT-23-3
ESD501	±12	15	0.3	1	1.0 × 0.6	DFN1006

3.14 SD- and SIM-Card Circuit Protection

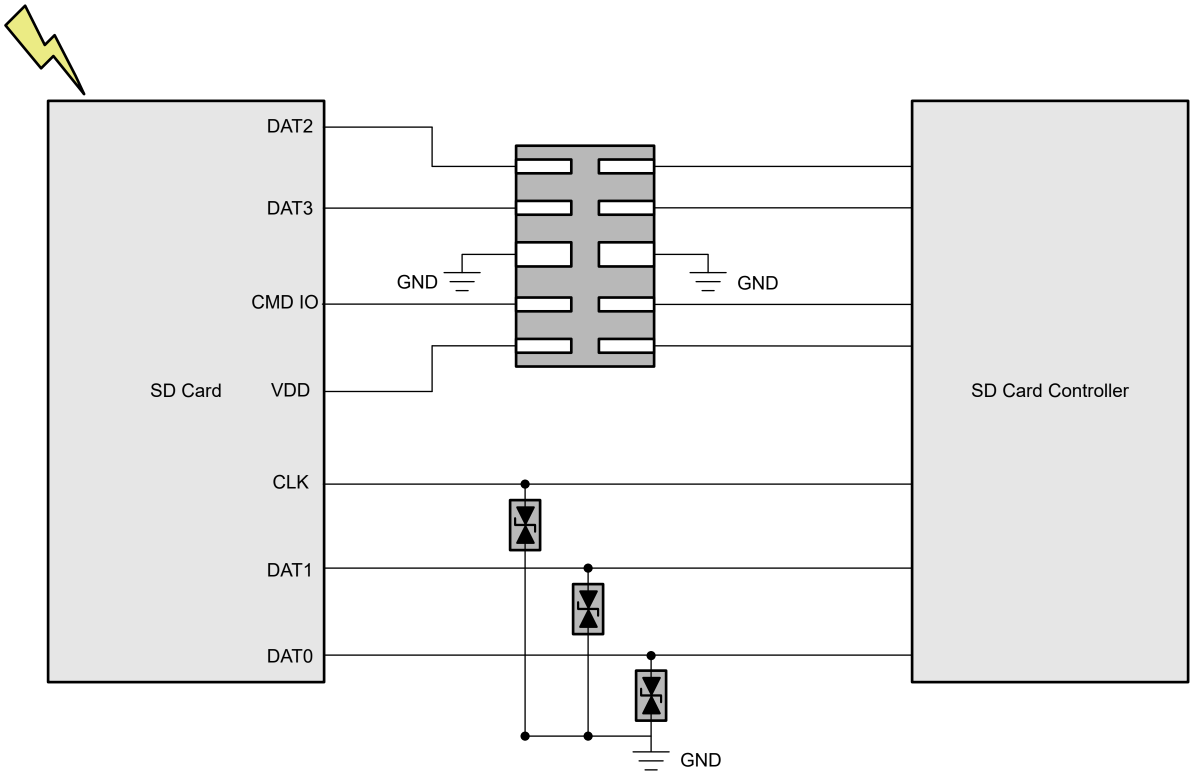


Figure 3-14. SD/SIM Application Diagram

Description

SD cards have seven pins that require ESD protection: four data pins (DAT0, DAT1, DAT2, DAT3), a clock pin (CLK), input and output command (CMD IO), and the 2.6V to 3.3V power pin (VDD). The sequential write speed of the fastest SD speed class is 90Mbps (VSC90) so the capacitance on these interface lines do not need to be minimized. SIM cards have similar specs and do not require capacitance to be minimized.

Design

The footprint of the ESD designs must be as small as possible because the board space around the SD card is very constrained. TI recommends using single-channel devices to minimize footprint but 4-channel devices can also be used if necessary.

Table 3-14. ESD Designs for SD- and SIM-Card Applications (*Click here for more products on Ti.com*)

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact)	Capacitance (pF)	Channels	Package Size (mm)	Package
TPD4E05U06	5.5	12	0.5	4	2.5 × 1.0	DFN2510
ESD441	5.5	30	1	1	0.6 × 0.3	DFN0603
ESD341	±3.6	30	0.66	1	0.6 × 0.3	DFN0603

3.15 USB 2.0 Circuit Protection

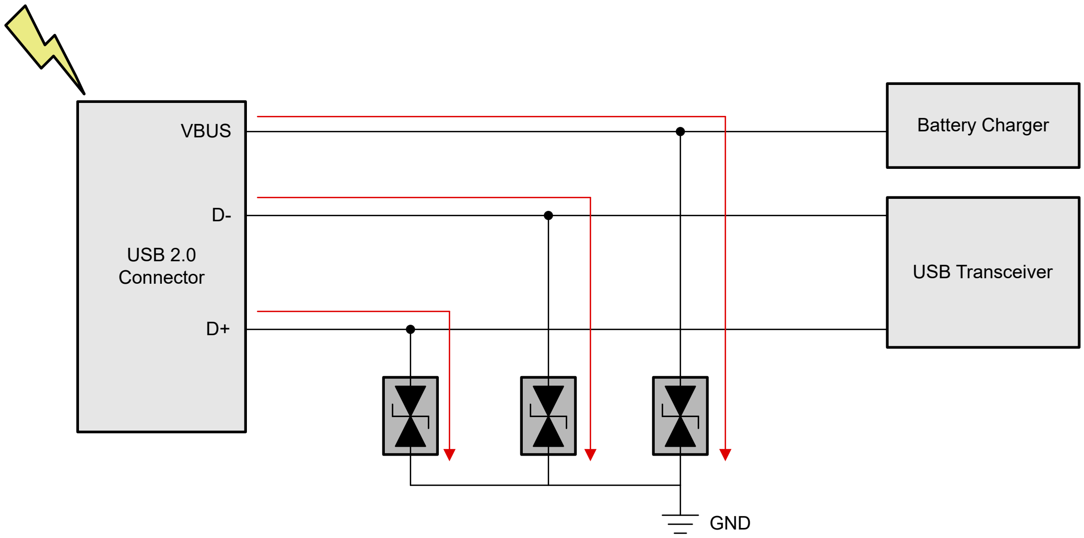


Figure 3-15. USB 2.0 Application Diagram

Description

The USB 2.0 connector has four pins: VBUS for power, D+ and D– for differential data signals and a ground pin. The VBUS pin carries a 5V DC power supply so the capacitance on this line is of little importance. The D+ and D– data lines carry a 480Mbps differential signal.

Design

The VBUS line requires ESD protection with at least a 5V working voltage to make sure that breakdown does not occur in normal operation. The D+ and D– data lines require low-capacitance ESD protection that can support a 480Mbps signal. Single-channel and dual-channel devices are designs to simplify routing. For more details about USB protection, see *ESD and Surge Protection for USB Interfaces*.

Table 3-15. ESD Designs for USB 2.0 Applications (*Click here for more products on Ti.com*)

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact)	Capacitance (pF)	Channels	Package Size (mm)	Package
ESD341	±3.6	30	0.66	1	0.6 × 0.3	DFN0603
ESD122	±3.6	17	0.2	2	1.0 × 0.6	DFN1006-3
ESD441	5.5	30	1	1	0.6 × 0.3	DFN0603
TPD1E01B06	±5.5	30	12	1	1.0 × 0.6	DFN1006

3.16 USB 3.1 Circuit Protection

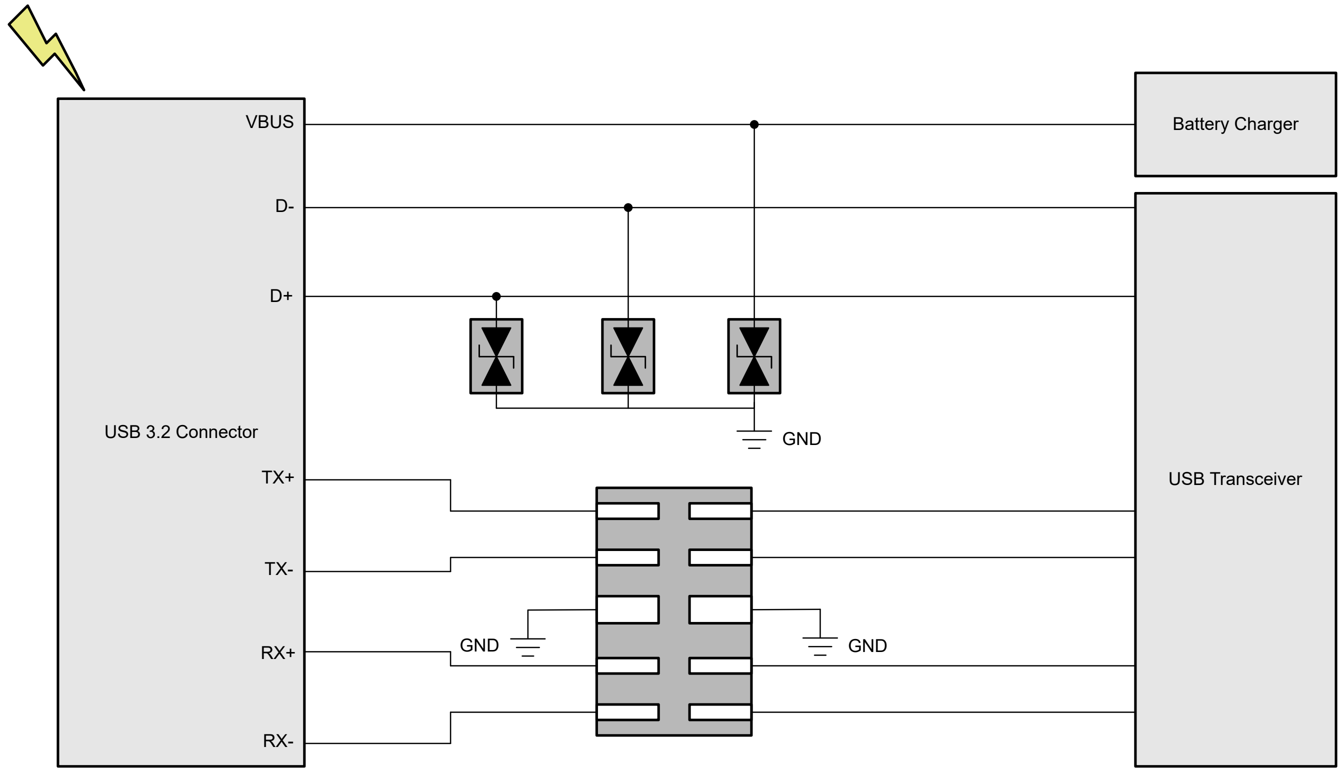


Figure 3-16. USB 3.1 Application Diagram

Description

USB 3.1 incorporates the Tx/Rx differential lines to reach speeds up to 10Gbps. For these speeds, the capacitance of ESD protection must be minimized to maintain signal integrity.

Design

ESD designs for the Tx/Rx lines of USB 3.1 Gen 2 must have a capacitance of 0.3pF or lower for signal integrity purposes and have a working voltage of >3.6V. One design is a 4-channel ESD device with ultra-low capacitance for the datalines (Tx, Rx), combined with a 2-channel ESD device with low capacitance for D+/D– and a single-channel ESD device for the VBUS line. For more details about USB protection, see *ESD and Surge Protection for USB Interfaces*.

Table 3-16. ESD Designs for USB 3.1 Applications (*Click here for more products on Ti.com*)

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact)	Capacitance (pF)	Channels	Package Size (mm)	Package
TPD4E02B04	±3.6	12	0.25	4	2.5 × 1.0	DFN2510
ESD122	±3.6	18	0.2	2	1.0 × 0.6	DFN1006-3
TPD1E01B04	±3.6	15	0.18	1	0.6 × 0.3 1.0 × 0.6	DFN0603 DFN1006
ESD441	5.5	30	1	1	0.6 × 0.3	DFN0603

3.17 USB Type C Circuit Protection

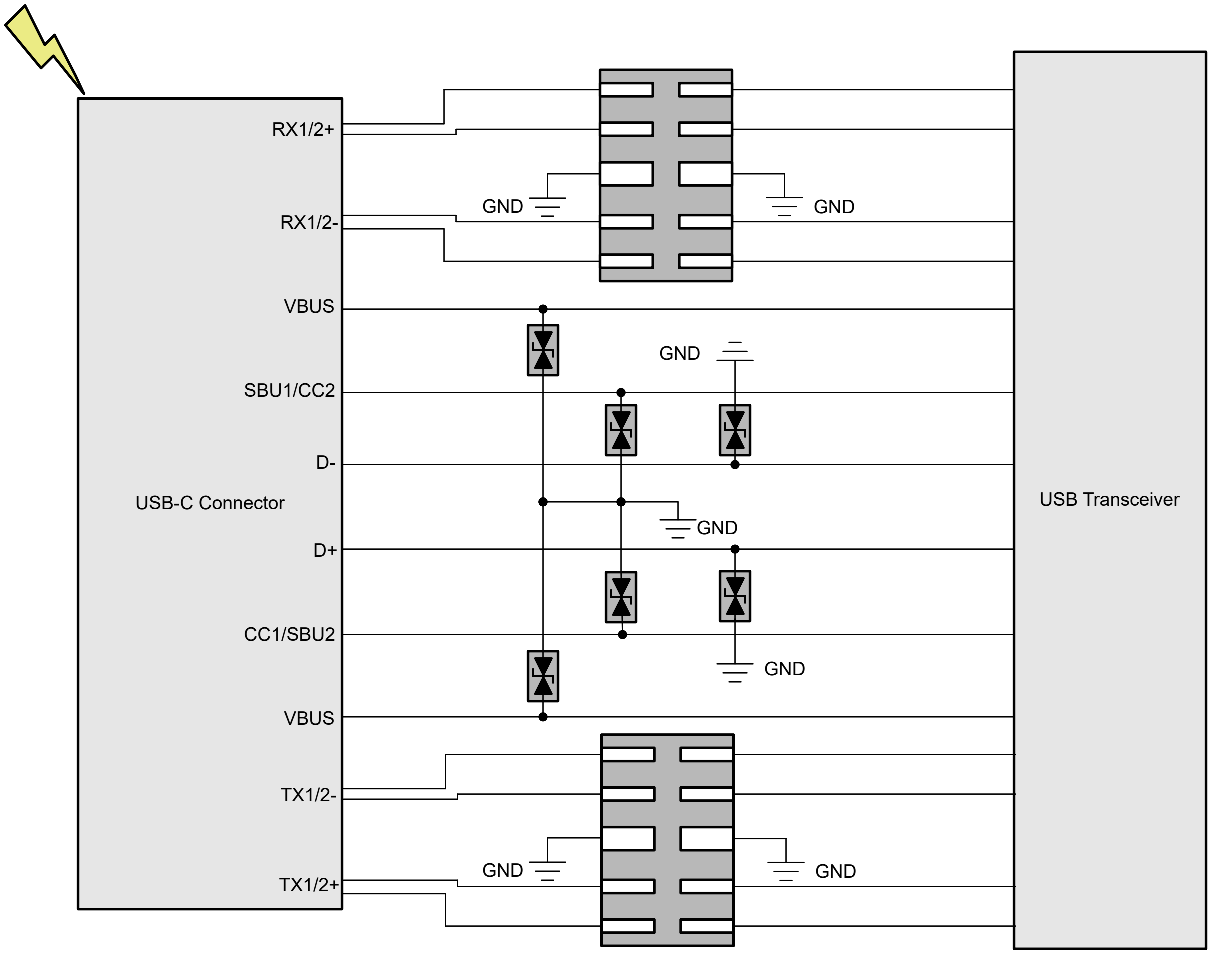


Figure 3-17. USB Type C Application Diagram

Description

USB Type C™ has a 24-pin connector that can support USB 3.2, USB 4.0, DisplayPort, HDMI, and a variety of other alternate modes. There are 16 pins that require ESD protection. Since the SuperSpeed USB lines for USB 4.0 (Tx1+, Tx1–, Rx1+, Rx1–, Tx2+, Tx2–, Rx2+ and Rx2–) can reach speeds up to 20Gbps, capacitance must be minimized. The USB 2.0 lines (D+ top, D+ bottom, D– top and D– bottom) also require low capacitance. The CC1, CC2 and SBU1, SBU2 Type-C pins can reach up to 5.5V and while low capacitance is not required, TI recommends using low capacitance for applications that use alternate modes. The VBUS lines can also supply power at voltages up to 20V for fast charging applications.

Design

The USB Type-C connector houses 24 pins in a small form factor so board space becomes very constrained. For this reason, space saving 4-channel ESD devices with ultra-low capacitance (TPD4E02B04) are recommended for all high-speed data lines in USB Type-C. Low capacitance 2-channel devices (ESD122) can be used for Tx/Rx lines if preferred. Single-channel 5.5V ESD devices (ESD441) are recommended for the SBU and CC lines to simplify routing to the PD or CC controller. However, 4-channels can also be used. For power delivery applications, the VBUS lines can be protected with a flat clamp device, which can operate at higher voltages while still maintaining low clamping. For more details about USB protection, see *ESD and Surge Protection for USB Interfaces*.

Table 3-17. ESD Designs for USB Type C Applications (*Click here for more products on Ti.com*)

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact)	Capacitance (pF)	Channels	Package Size (mm)	Package
TPD4E02B04-Q1	±3.6	12	0.25	4	2.5 × 1.0	DFN2510
ESD122	±3.6	18	0.2	2	1.0 × 0.6	DFN1006-3
TPD1E01B04	±3.6	15	0.18	1	1.0 × 0.6	DFN1006
ESD341	±3.6	30	0.66	1	0.6 × 0.3	DFN0603
TPD1E05U06	5.5	12	4.2	1	1.0 × 0.6	DFN1006
ESD441	5.5	30	1	1	0.6 × 0.3	DFN0603
TVS2200	22	17	105	1	2.0 × 2.0	DFN2020

3.18 4-20mA Protection

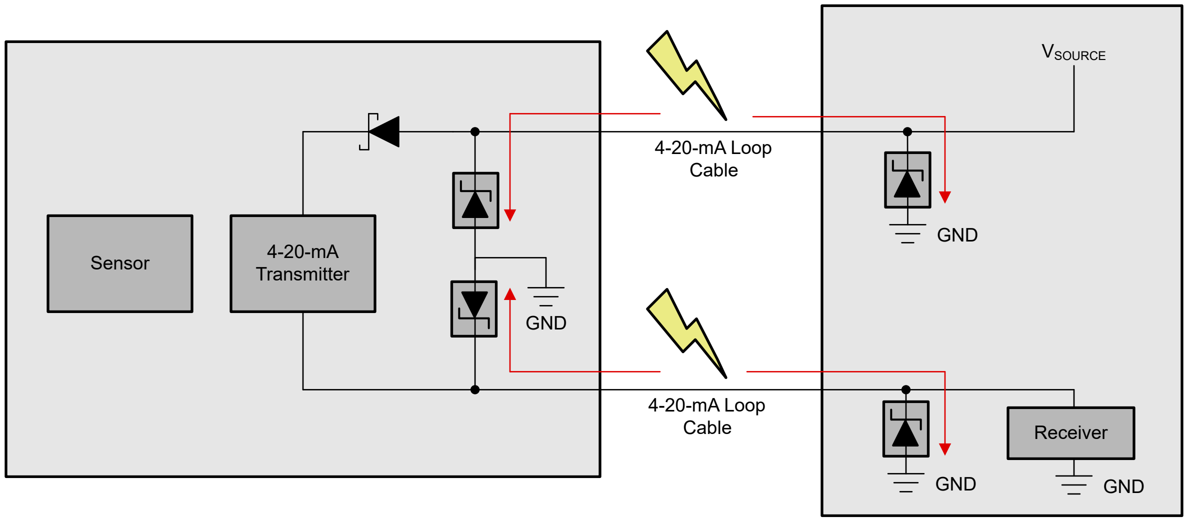


Figure 3-18. 4-20mA Application Diagram

Description

The 4–20mA signal standard is one of the most popular interfaces for sensor-signal transmission in industrial applications. At a high level, the programmable logic controller (PLC) supplies a voltage source to power the system. The field transmitters and sensors uses this source to transmit the data the transmitters and sensors receive from the external environment in the form of a 4–20mA current which is measured by the receiver in the PLC. This 4–20mA loop has the advantage of transmitting data with little to no signal loss. However, since the 4–20mA cables can be very long, there are opportunities for ESD (IEC 61000-4-2) and surge (IEC 61000-4-5) pulses to couple onto the cable and damage the system.

Design

Surge diodes that are rated to IEC 61000-4-2 and IEC 61000-4-5 must be placed in front of the transmitter, source, and receiver to protect them from a surge or ESD strike that can couple onto the long 4–20mA cable. Since most 4–20mA voltage sources are 24V, a diode with a slightly higher working voltage is a preferred design. Since PLC I/O modules and field transmitters can get space constrained, the smaller the protection diodes, the better.

Table 3-18. ESD Designs for 4-20mA Loop Applications (*Click here for more products on Ti.com*)

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact)	IEC 61000-4-5 Surge Rating (A)	Channels	Package Size (mm)	Package
TVS3300	33	11	35	1	1.1 × 1.1 2 × 2	WCSP-4 SON-6
TVS3301	±33	8	27	1	3 × 3	SON-8
TSM36A	36	30	41	1	2.92 × 2.37	SOT-23

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