

System-Level ESD Protection Guide



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Introduction

System-level protection for electrostatic discharge (ESD) is crucial in today's world, not only in the industrial space but also in the consumer and automotive space. It only takes one ESD strike to permanently damage a product, which makes ESD protection a critical component in a system design.

This selection guide will briefly explain how ESD devices from Texas Instruments can help avoid catastrophic system failures caused by ESD strikes.

Electromagnetic interference (EMI) is another challenge often faced in system design. EMI is a radio-frequency (RF) (800 MHz to 2 GHz) disturbance where electromagnetic conduction from an external source affects an electrical circuit. EMI can be avoided by using EMI filters that eliminate RF noise and maintain signal integrity.

To learn more about ESD protection and TI's ESD devices, visit:

www.ti.com/esd

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Overview of System-Level ESD Protection

→ What is ESD Protection?

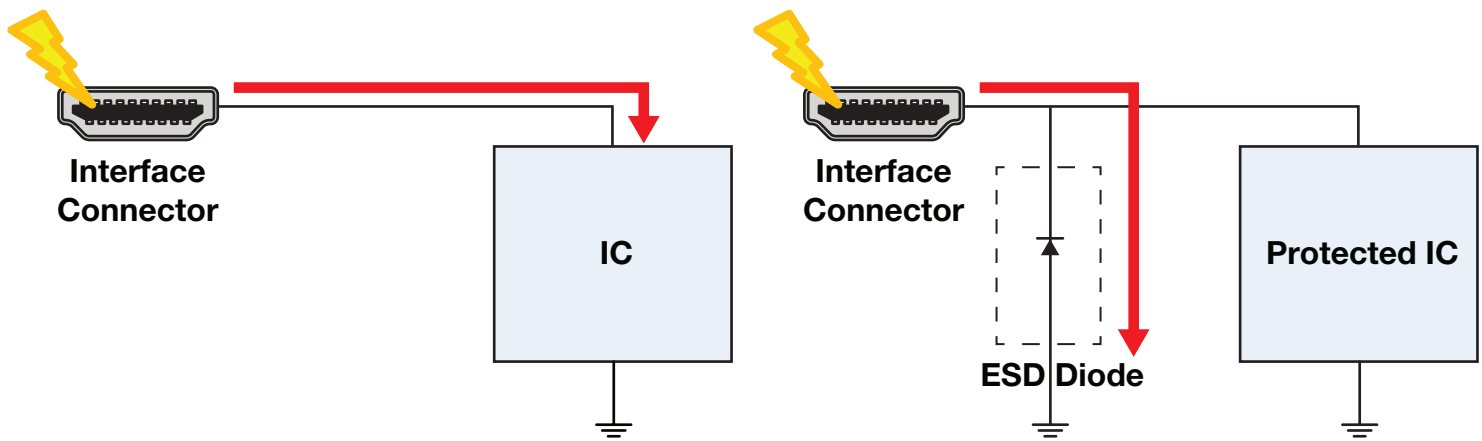
Electrostatic discharge (ESD) is the sudden release of electricity from one charged object to another when the two objects come into contact. While we've all experienced ESD when we've been shocked by a metal doorknob or car door, most ESD strikes are quite harmless to humans. However, for sensitive 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 via an interface connection would cause 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.

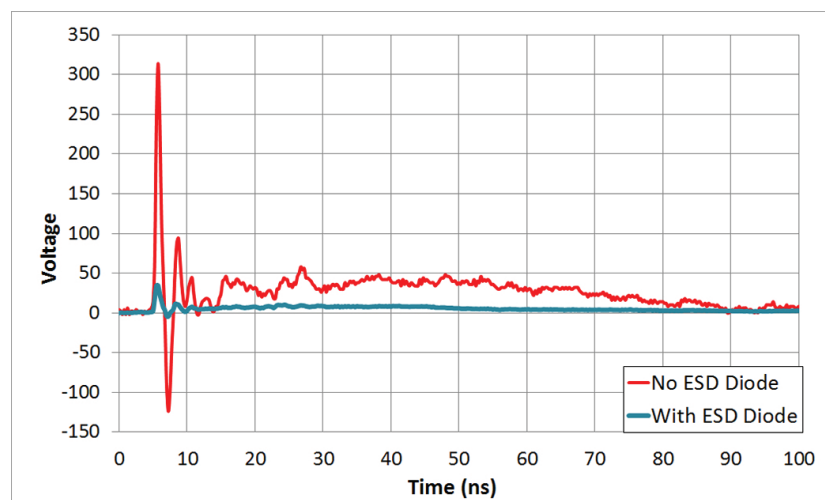
In the event of an ESD strike, the ESD diode would breakdown and create a low impedance path that limits the peak voltage and current by diverting the current flow to ground, thereby protecting the IC.

The plots below compares the peak voltage of a typical ESD strike without protection (black) to the same ESD strike on a signal line with ESD diode protection (red).



ESD strike without protection.

ESD strike with protection.



Voltage waveforms with and without ESD protection.

Overview of System-Level ESD Protection

→ Why External ESD?

Semiconductor devices based off of advanced processes only offer device-level ESD specifications like the charge device model (CDM) and the human body model (HBM) shown below. Device-level ESD specifications are not sufficient to protect devices in a system.

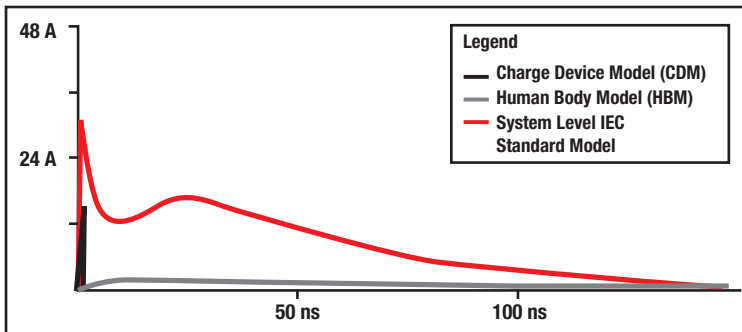
The energy associated with a system-level ESD strike is much higher than a device-level ESD strike. This means a more robust design is required to protect against this excess energy.

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, it becomes increasingly difficult and more costly to integrate sufficient system-level protection with microcontroller or core chipsets.

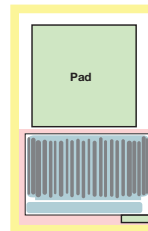
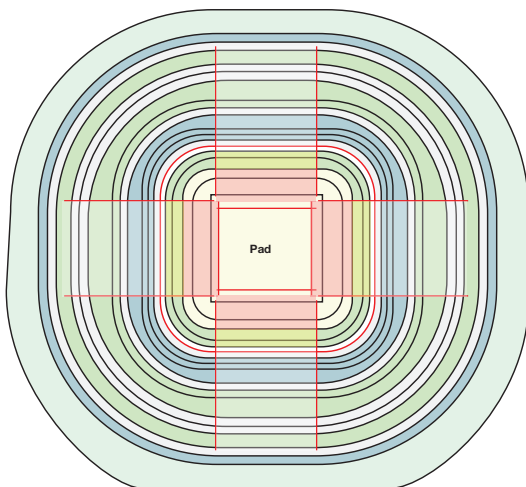
System-level ESD protection can be added with discrete components. However, in many applications, discrete solutions consume board space, complicate layout, and compromise signal integrity at high data rates.

Stand-alone ESD devices from Texas Instruments (TI) provide space-saving and cost-effective solutions 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 need flexibility to select an ESD device that does not compromise the PCB layout or consume additional board space. TI's ESD solutions with flow-through packaging allow designers to add ESD components in the final stages of a design without any change in the board layout.



ESD Models for CDM, HBM and IEC.



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

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

ESD-Solutions Quick Reference by Interface

Channel	Device	1394 (up to 1.6 Gbps)	4-20-mA Loop	Antenna	Audio	Display Port	Ethernet	GPIO	HDMI 1.4/1.3	PC	LCD Display (17 pF)	LED (up to 24 pF)	HART	LVDS (up to 1.5 Gbps)	SD/SIM Card	MHL (3 Gbps)	Pcie Gen 3 (8 Gbps)	Keypad/Push Button	RS-485/432/422/232 (15 pF)	SATA (6 Gbps)	USB 2.0	USB 3.0	USB 3.1 Gen 2 (10 Gbps)	USB Type-C	SIM Card	VGA (2.5 pF)
1	ESD401									R	R										R					
	TPD1E01B04			R												★	★			R		R	R	R		
	TPD1E04U04	R				R			R					R	R					R		★				R
	TPD1E05U06	R				R		★		R	R			★							★					R
	TPD1E0B04			★														R						R	R	
	TPD1E10B06									★								★								
	TPD1E10B09					★																				
	TPD1E1B04					R				R									R		R					
	TPD1E6B06							R			R				R				R							
	TVS3300		★											★												
2	ESD122	R				R			R					R			R				R	R	★	★		
	TPD2E001						R																			
	TPD2E007					R						R		R				R	R							
	TPD2E009	R													R											R
	TPD2E1B06					R											R				R					
	TPD2E2U06							★	★					★							★					
4	TPD4E001						R																		R	R
	TPD4E02B04	R				★			★											R		R				
	TPD4E05U06	R				R	R		R					R		R				★		★		R		R
	TPD4E101														★										★	
	TPD4E1U06						★					R														
	TPD4E6B06						R								R										R	
	TPD4F202											R														
	TPD4S009							R										R								
6	TPD6E05U06								R													R				★
	TPD6F003										R			R											R	
	TPD6F202										★														R	
8	TPD8E003							R																		
	TPD8F003										R				R										R	
	TPD8S009						R																		R	

★ Best Solution

R Recommended Solution

ESD Solutions by Application

→ Definitions of ESD Device Specifications

The following sections show ESD protection solutions for popular interface applications and includes selection tables with recommended ESD protection. The selection tables highlight some important specifications and features of the devices. Below are descriptions of the parameters used in the selection tables.

1 Working Voltage (V_{RWM})

The working voltage is the recommended operating voltage of the ESD device. The interface's signal voltage should not exceed the working voltage of the ESD device in either the negative or positive direction to prevent unwanted clamping and leakage.

Learn more: www.ti.com/ESD-VRWM

2 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 air-gap 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.

Learn more: www.ti.com/ESD-Rating

3 Capacitance

Since the ESD diodes are connected in parallel to the signal trace, they 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.

Learn more: www.ti.com/ESD-Capacitance

4 Channels

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

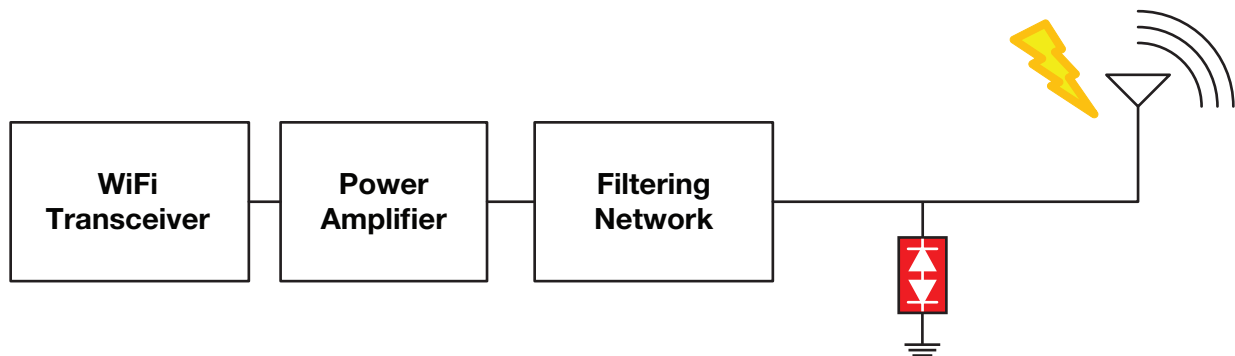
5 Clamping Voltage at 16-A TLP

When an ESD strike occurs, the ESD diode will “clamp” the voltage so that the downstream circuitry will not be 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 8-kV IEC ESD strike is best approximated with a transmission line pulse (TLP) at 16 A.

Learn more: www.ti.com/ESD-ClampingVoltage

ESD Solutions by Application

→ Antenna Circuit Protection



Description: In wireless applications such as GPS, WLAN, Wi-Fi®, etc., 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 up to 15 GHz which means that any capacitance on signal paths must be minimized to avoid signal degradation. The peak-to-peak voltage of these signals do not usually exceed ± 1 V so ESD diodes must have a working voltage to tolerate these voltage swings.

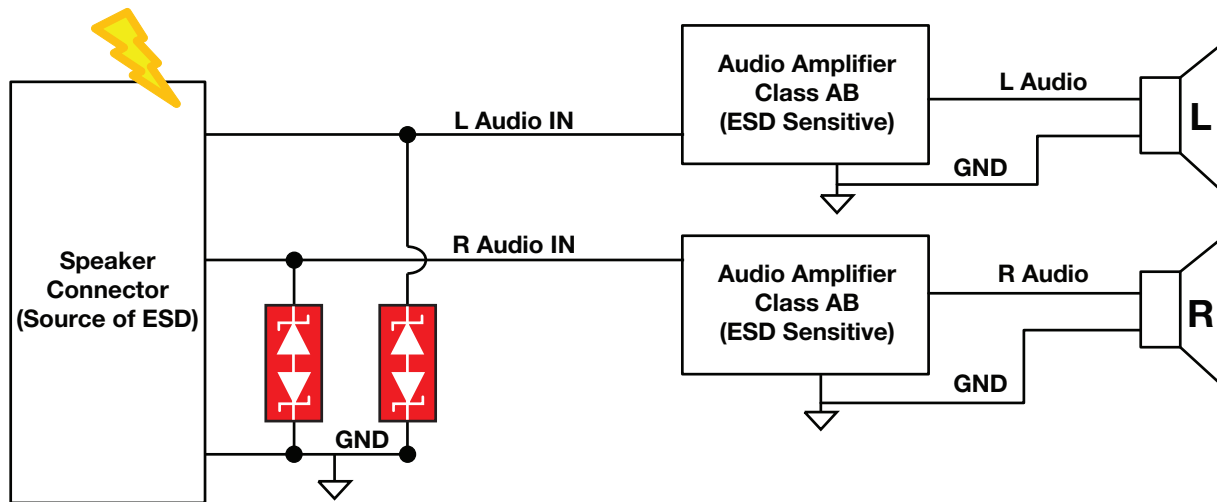
Solution: The ESD solutions in the table below provide IEC 61000-4-2 ESD protection with ultra-low capacitance to maintain signal integrity. These solutions come in a variety of flow-through footprint options, including 0201 (0.6 x 0.3 mm), 0402 (1.0 x 0.6 mm) and DFN (2.5 x 1.0 mm). Each device also supports up to a ± 3.6 -V working voltage making it a suitable solution for antenna applications.

ESD Solutions for Antenna Applications

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact/Air Gap)	Capacitance (pF)	Channels	Package Size (mm)	Package
TPD1E0B04DPY	± 3.6	8/9	0.13	1	1.0 x 0.6	0402
TPD1E0B04DPL	± 3.6	8/9	0.13	1	0.6 x 0.3	0201
TPD1E01B04DPY	± 3.6	15/17	0.18	1	1.0 x 0.6	0402
TPD1E01B04DPL	± 3.6	15/17	0.18	1	0.6 x 0.3	0201

ESD Solutions by Application

→ Audio Circuit Protection



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

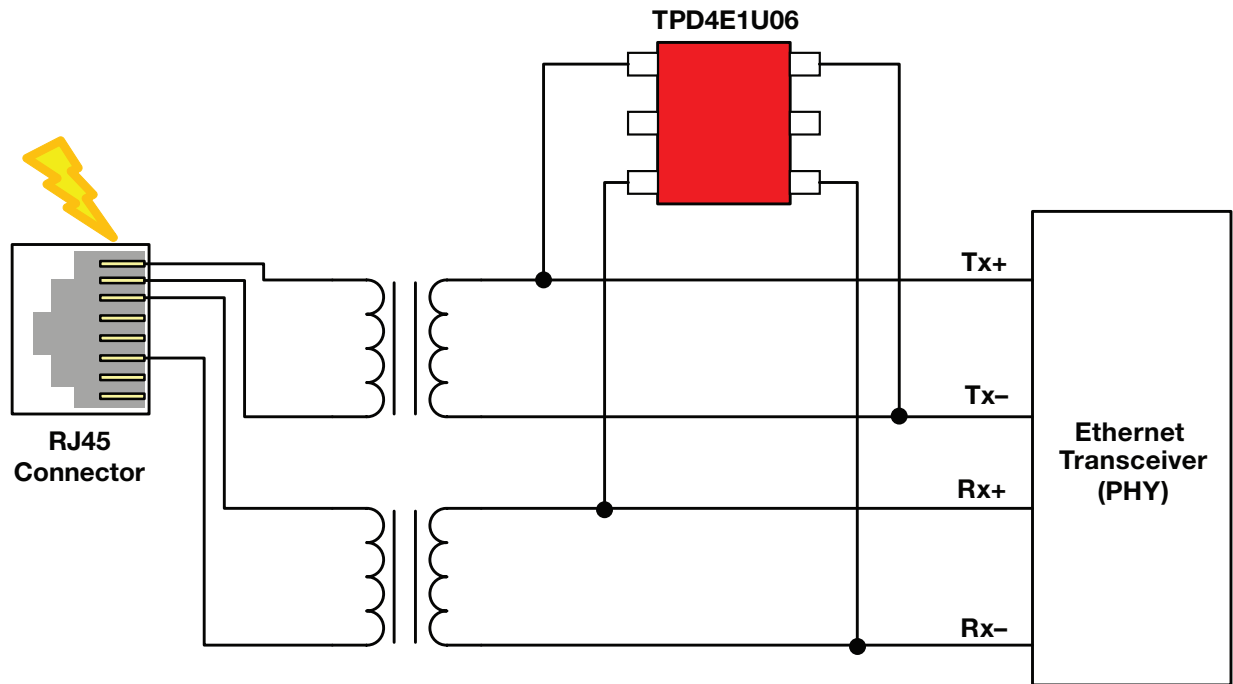
Solution: The ESD solutions below offer ESD protection that exceeds the IEC 61000-4-2 level 4 standard. These solutions are bidirectional while allow for both the positive and negative voltage swings of audio signals. The solutions below also come in a variety of working voltages to support different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

ESD Solutions for Audio Applications

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact/Air Gap)	Capacitance (pF)	Channels	Package Size (mm)	Package
TPD1E10B09DPY	± 9	20/20	10	1	1.0 x 0.6	0402
TPD1E1B04DPY	± 3.6	30/30	1	1	1.0 x 0.6	0402
TPD2E1B06DRL	± 5.5	10/15	0.85	2	1.6 x 1.2	SOT-6
TPD2E007YFM	± 12	8/15	15	2	0.77 x 0.77	DSLGA-4

ESD Solutions by Application

→ Ethernet Circuit Protection



Description: Ethernet applications will require 4 channels of ESD protection for the Tx/Rx signal lines in the connector. The voltage of these signals can range from 1 V to 2.5 V and the bandwidth options include 10 Mbps, 100 Mbps for Fast Ethernet, and 1 Gbps for Gigabit Ethernet. At these speeds, the capacitance of the ESD diode should be taken into account.

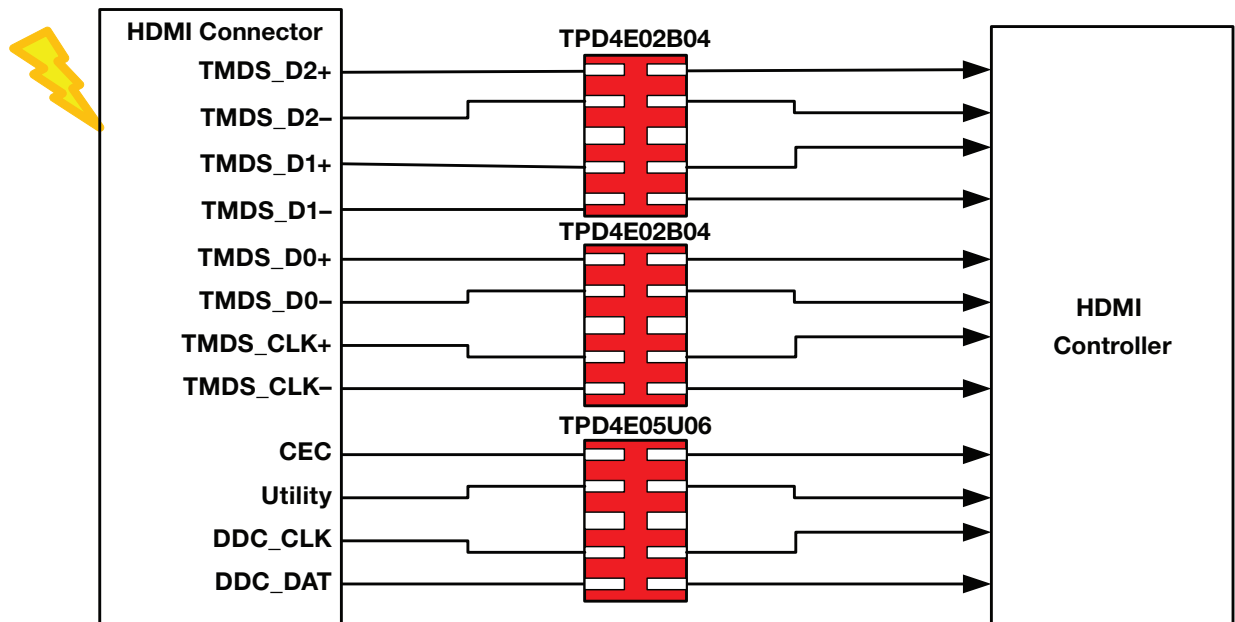
Solution: Unidirectional ESD protection devices are recommended for Ethernet applications because they offer superior protection in the negative direction. Capacitance also needs to be taken into account, especially for Gigabit Ethernet (<4.5 pF is recommended).

ESD Solutions for Ethernet Applications

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact/Air Gap)	Capacitance (pF)	Channels	Package Size (mm)	Package
TPD4E1U06DCK	5.5	12/15	0.8	4	2.0 x 1.25	SC70
TPD4E05U06DQA	5.5	12/15	0.4	4	2.5 x 1.0	USON-10
TPD1E05U06DPY	5.5	12/15	0.5	1	1.0 x 0.6	0402

ESD Solutions by Application

→ HDMI Circuit Protection



Description: The HDMI connector requires ESD protection for all 12 data lines: eight low-voltage, high-speed TMDS lines and four 5-V control lines. The speed of the TMDS lines can reach a maximum of 6 Gbps per lane (18 Gbps for the whole connector) for HDMI 2.0 so minimizing capacitance is crucial.

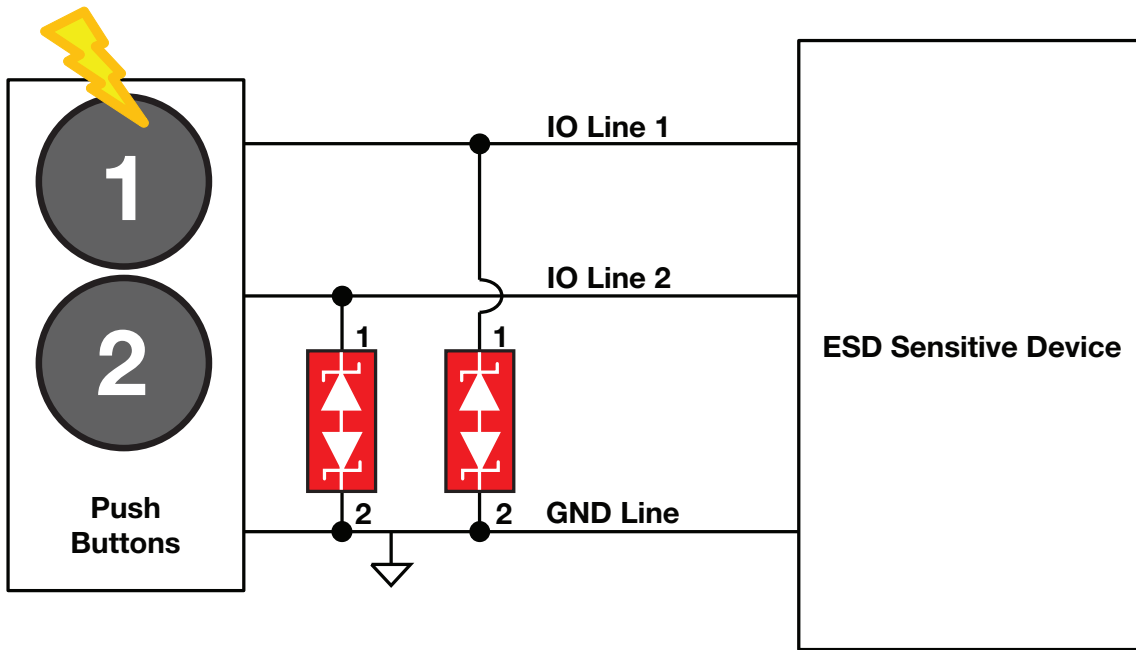
Solution: For the 8 TMDS lines, two 4-channel ESD devices with ultra-low capacitance are recommended to minimize board layout and maintain signal integrity. A 5-V tolerant, 4-channel device should be used to protect the lower-speed control lines. A 5-V tolerant, 6-channel device can be substituted here to protect the 5-V power line as well.

ESD Solutions for HDMI Applications

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact/Air Gap)	Capacitance (pF)	Channels	Package Size (mm)	Package
TPD4E02B04DQA	±3.6	12/15	0.25	4	2.5 x 1.0	USON-10
TPD4E05U06DQA	5.5	12/15	0.4	4	2.5 x 1.0	USON-10
TPD1E04U04DPL	3.6	16/16	0.5	1	0.6 x 0.3	0201
TPD6E05U06RVZ	5.5	12/15	0.47	6	3.5 x 1.35	USON-14

ESD Solutions by Application

→ Keypad and Pushbutton Circuit Protection



Description: Pushbuttons/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 (<5 V).

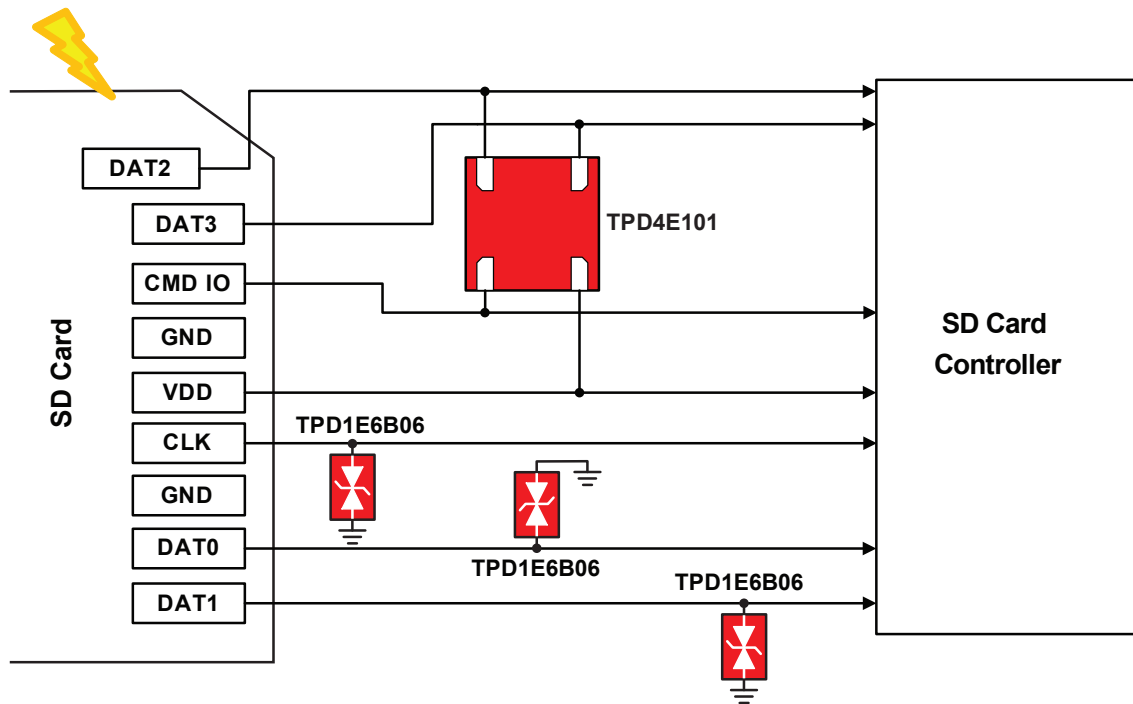
Solution: Since the signal frequency of pushbuttons is low, the capacitance of the ESD device is not very important. Single-channel and multi-channel solutions with IEC 61000-4-2 ESD protection are suitable solutions.

ESD Solutions for Keypad and Pushbutton Applications

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact/Air Gap)	Capacitance (pF)	Channels	Package Size (mm)	Package
TPD1E10B06DPY	±5.5	30/30	12	1	1.0 x 0.6	0402
TPD1E1B04DPY	±3.6	30/30	1	1	1.0 x 0.6	0402
TPD1E6B06DPL	±5.5	15/15	6	1	0.6 x 0.3	0201
TPD2E007YFM	±12	8/15	15	2	0.77 x 0.77	DSLGA-4

ESD Solutions by Application

→ SD- and SIM-Card Circuit Protection



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 2.6- to 3.3-V power pin (V_{DD}). The sequential write speed of the fastest SD speed class is 90 Mbps (VSC90) so the capacitance on these interface lines do not need to be minimized. SIM cards have similar specs and do not need capacitance to be minimized.

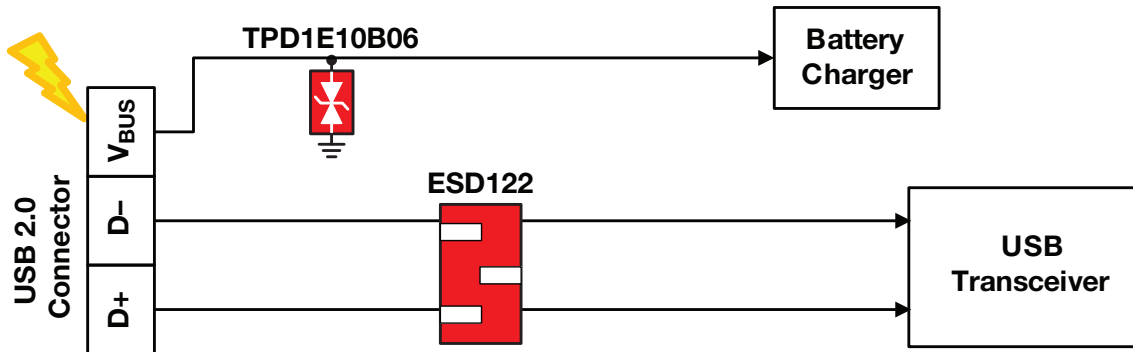
Solution: The footprint of the ESD solutions must be as small as possible because the board space around the SD card is very constrained. The TPD4E101DPW is one of the smallest 4-channel ESD devices in the industry but single-channel devices can also be used to minimize board space.

ESD Solutions for SD- and SIM-Card Applications

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact/Air Gap)	Capacitance (pF)	Channels	Package Size (mm)	Package
TPD4E101DPW	±5.5	15/15	4.8	4	0.8 x 0.8	X2SON-4
TPD1E6B06DPL	±5.5	15/15	6	1	0.6 x 0.3	0201
TPD1E04U04DPL	3.6	16/16	0.5	1	0.6 x 0.3	0201

ESD Solutions by Application

→ USB 2.0 Circuit Protection



Description: The USB 2.0 connector has four pins: V_{BUS} for power, D+ and D- for differential data signals and a ground pin. The V_{BUS} pin will carry a 5-V DC power supply so the capacitance on this line will be of little importance. The D+ and D- data lines will carry a 480-Mbps differential signal.

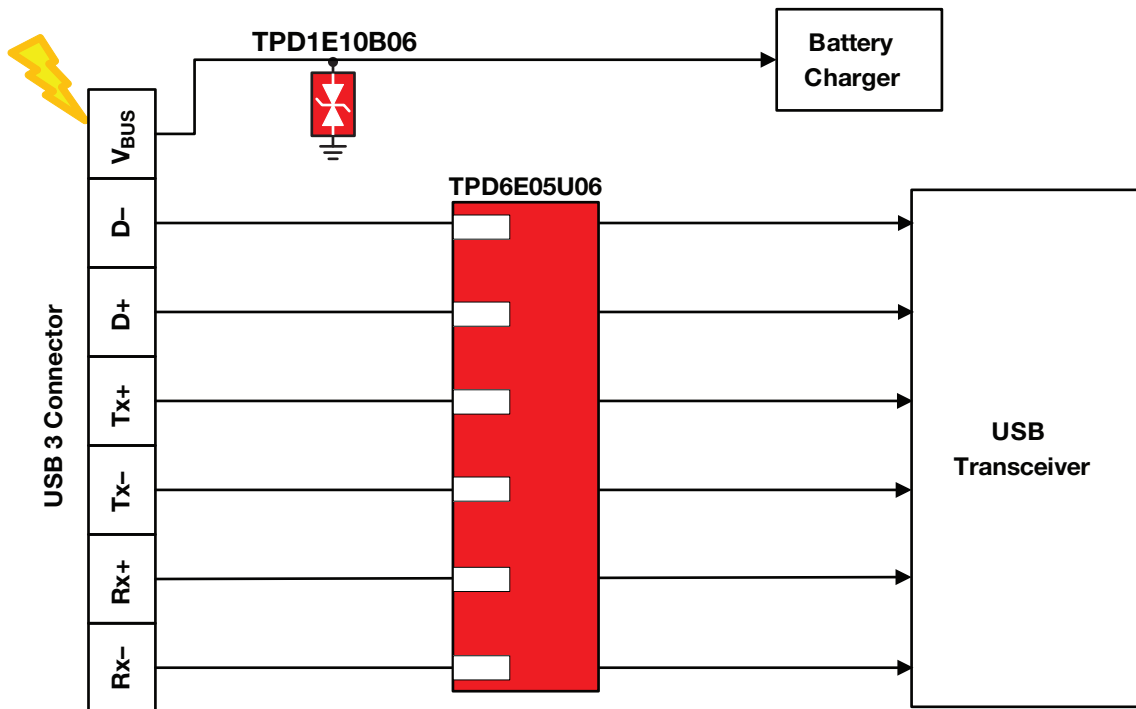
Solution: The V_{BUS} line will require ESD protection with at least a 5-V working voltage to ensure that breakdown does not occur in normal operation. The D+ and D- data lines will require low-capacitance ESD protection that can support a 480-Mbps signal. Single-channel and dual-channel devices are good solutions to simplify routing.

ESD Solutions for USB 2.0 Applications

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact/Air Gap)	Capacitance (pF)	Channels	Package Size (mm)	Package
TPD1E10B06DPY	±5.5	30/30	12	1	1.0 x 0.6	0402
TPD1E05U06DPY	5.5	12/15	0.5	1	1.0 x 0.6	0402
TPD1E1B04DPY	±3.6	30/30	1	1	1.0 x 0.6	0402
ESD122DMX	±3.6	18/18	0.2	2	1.0 x 0.6	DMX
TPD2E1B06DRL	±5.5	8/15	0.85	2	1.6 x 1.2	SOT-6

ESD Solutions by Application

→ USB 3.1 Gen 1 Circuit Protection



Description: USB 3.1 Gen 1 incorporates the Tx/Rx differential lines to handle speeds up to 5 Gbps. For these speeds, the capacitance of ESD protection must be minimized to maintain signal integrity.

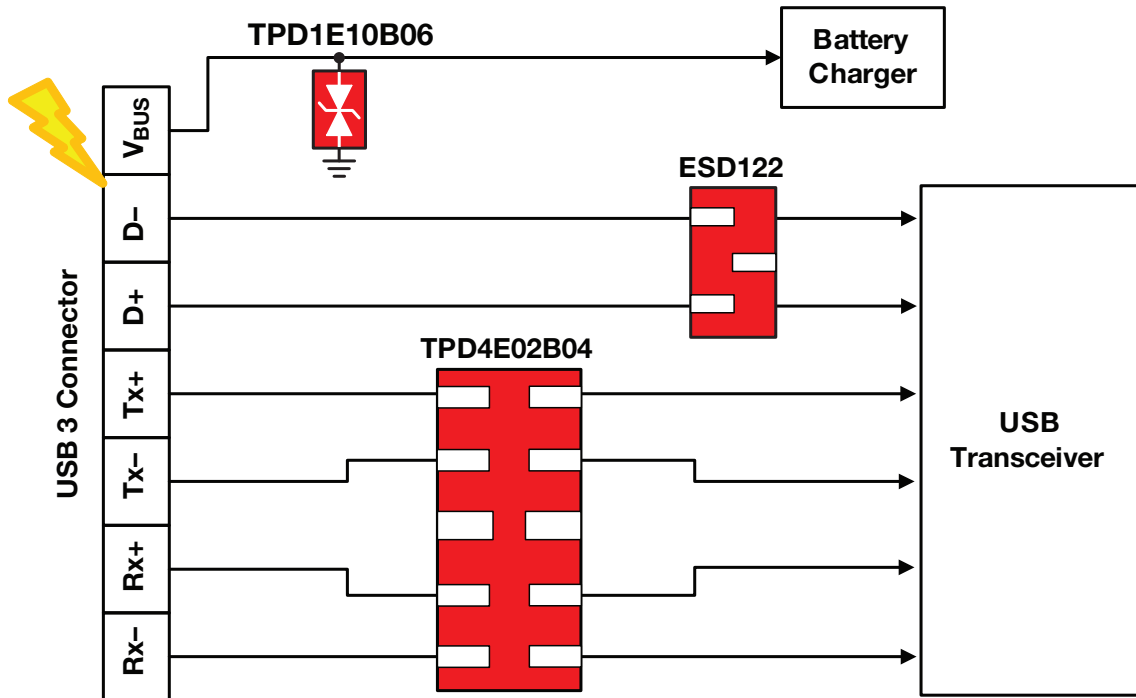
Solution: ESD solutions for USB 3.1 Gen 1 should have a capacitance of 0.5 pF or lower for signal-integrity purposes and have a working voltage of >3.6 V. A low-capacitance, 6-channel ESD solution for the data lines (D+/D-, Tx, Rx) combined with a 5-V single-channel ESD device for the V_{BUS} lines would be one solution for USB 3.1 Gen 1.

ESD Solutions for USB 3.1 Gen 1 Applications

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact/Air Gap)	Capacitance (pF)	Channels	Package Size (mm)	Package
TPD6E05U06RVZ	5.5	12/15	0.47	6	3.5 x 1.35	USON-14
TPD1E10B06DPY	±5.5	30/30	12	1	1.0 x 0.6	0402
TPD4E05U06DQA	5.5	12/15	0.4	4	2.5 x 1.0	USON-10
TPD1E05U06DPY	5.5	12/15	0.5	1	1.0 x 0.6	0402

ESD Solutions by Application

→ USB 3.1 Gen 2 Circuit Protection



Description: USB 3.1 Gen 1 incorporates the Tx/Rx differential lines to reach speeds up to 10 Gbps. For these speeds, the capacitance of ESD protection must be minimized to maintain signal integrity.

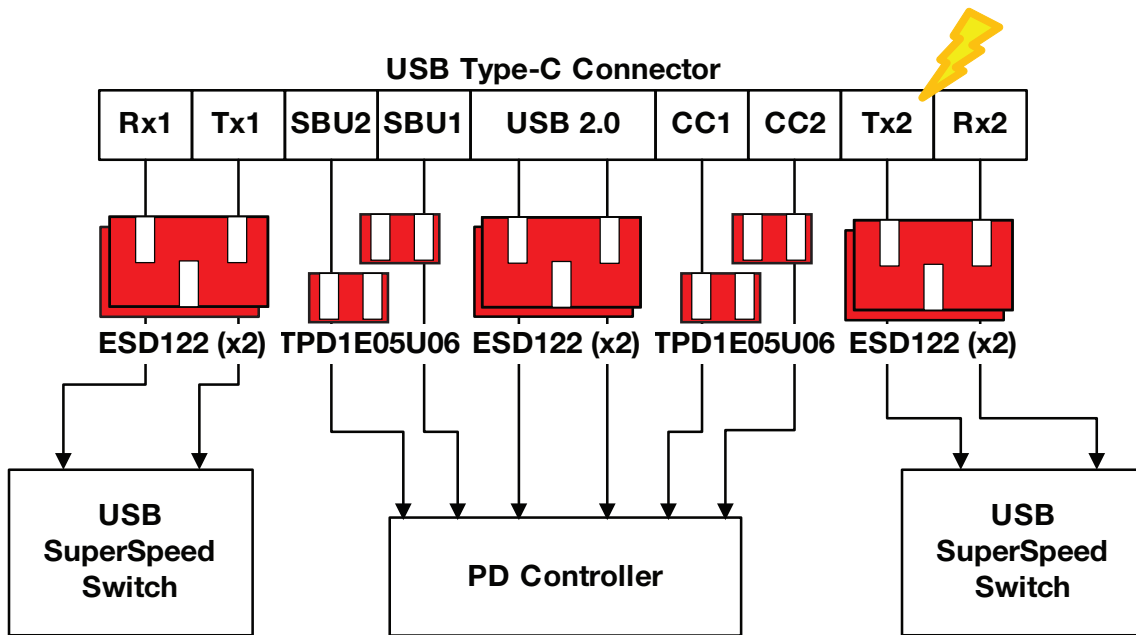
Solution: ESD solutions for the Tx/Rx lines of USB 3.1 Gen 2 should have a capacitance of 0.3 pF or lower for signal integrity purposes and have a working voltage of >3.6 V. One solution is a 4-channel ESD device with ultra-low capacitance for the datalines (Tx, Rx), combined with a 2-channel ESD device with low capacitance for D+/D- and a single-channel ESD device for the V_{BUS} line.

ESD Solutions for USB 3.1 Gen 2 Applications

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact/Air Gap)	Capacitance (pF)	Channels	Package Size (mm)	Package
TPD4E02B04DQA	±3.6	12/15	0.25	4	2.5 x 1.0	USON-10
ESD122DMX	±3.6	18/18	0.2	2	1.0 x 0.6	DMX
TPD1E10B06DPY	±5.5	30/30	12	1	1.0 x 0.6	0402

ESD Solutions by Application

→ USB Type-C™ Circuit Protection



Description: USB Type-C™ has a 24-pin connector that can support USB 3.1 Gen2, DisplayPort, HDMI, and a variety of other alternate modes. There are 16 pins that require ESD protection. Since the SuperSpeed USB lines for USB 3.1 Gen2 (Tx1+, Tx1-, Rx1+, Rx1-, Tx2+, Tx2-, Rx2+ and Rx2-) can reach speeds up to 10 Gbps, 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 5.5 V and while low capacitance is not required, it is recommended for applications that use alternate modes.

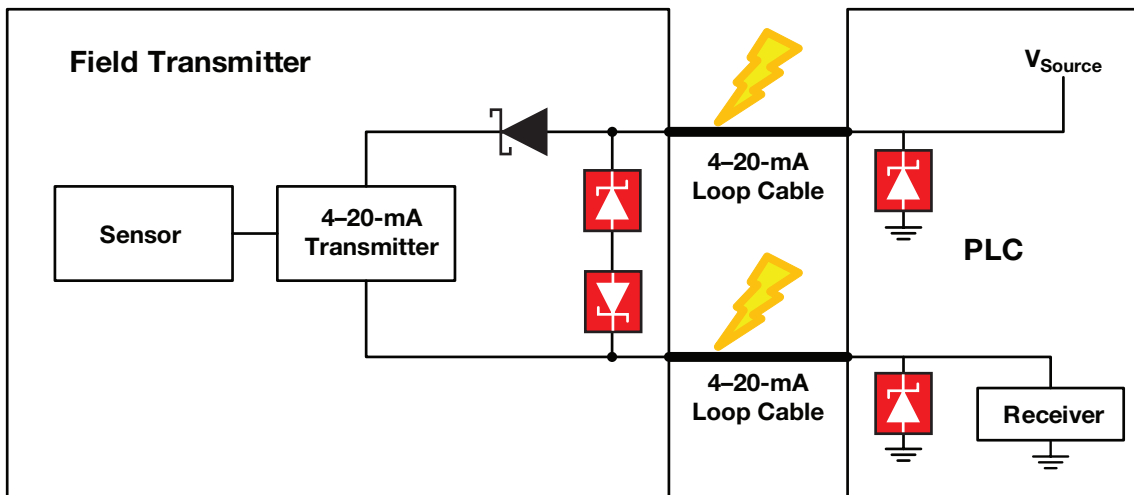
Solution: The USB Type-C connector houses 24 pins in a small form factor so board space becomes very constrained. For this reason, space-saving 2-channel ESD devices with ultra-low capacitance (ESD122) are recommended for all high-speed data lines in USB Type-C. Single-channel 5.5-V ESD devices (TPD1E05U06) are recommended for the SBU and CC lines to simplify routing to the PD or CC controller. However, 4-channels can also be used if preferred.

ESD Solutions for USB Type-C Applications

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact/Air Gap)	Capacitance (pF)	Channels	Package Size (mm)	Package
ESD122DMX	±3.6	18/18	0.2	2	1.0 x 0.6	DMX
TPD1E05U06DPY	5.5	12/15	0.42	1	1.0 x 0.6	0402
TPD1E01B04DPY	±3.6	15/17	0.18	1	1.0 x 0.6	0402
TPD4E02B04DQA	±3.6	12/15	0.25	4	2.5 x 1.0	USON-10

ESD Solutions by Application

→ 4-20-mA Protection



Description: The 4–20-mA 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) will supply a voltage source to power the system. The field transmitters and sensors will use this source to transmit the data they receive from the external environment in the form of a 4–20-mA current which is measured by the receiver in the PLC. This 4–20-mA loop has the advantage of transmitting data with little to no signal loss. However, since the 4–20-mA 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.

Solution: 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 4–20-mA cable. Since most 4–20-mA voltage sources are 24 V, a diode with a slightly higher working voltage is a suitable solution. Since PLC I/O modules and field transmitters can get space constrained, the smaller the protection diodes, the better.

ESD Solutions for 4-20mA Loop Applications

Device	Working Voltage (V)	IEC 61000-4-2 ESD Rating (kV) (Contact/Air Gap)	IEC 61000-4-5 Surge Rating (A)	Channels	Package Size (mm)	Package
TVS3300YZF	33	11/30	35	1	1.1 x 1.1	WCSP-4
TVS3300DRV	33	14/30	35	1	2 x 2	SON-6

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