User's Guide

Reading and Understanding an ESD Protection Data Sheet

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Protection Devices

ABSTRACT

Hardware engineers must choose all components for their designs carefully. Selecting the correct ESD protection device can be challenging since protecting devices on a PCB against ESD stress has become an increasingly complex task. Texas Instruments offers a wide range of ESD protection devices. Understanding the parameters of an ESD diode data sheet are paramount in selecting the correct device for a successful design. This user guide explains the key terminology, sections, and figures of an ESD protection device data sheet.

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Trademarks

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1 Introduction

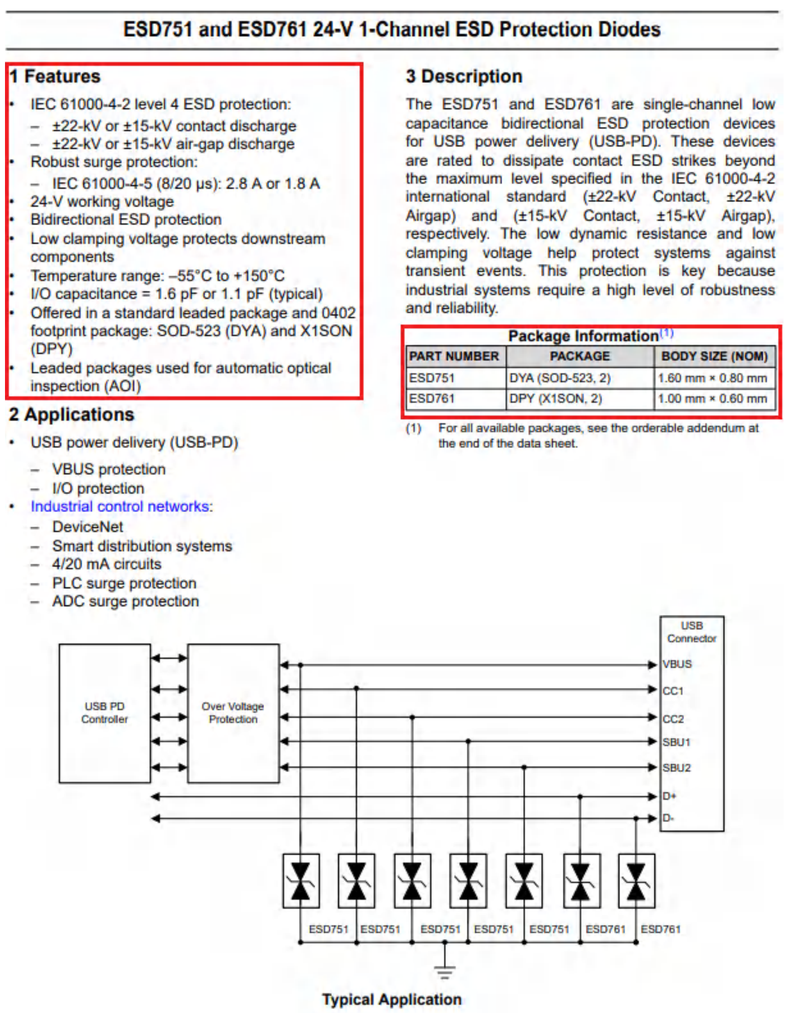
This user guide is a synopsis of a typical TI ESD protection device data sheet. The purpose is to assist when selecting an ESD protection device. The information includes the following key features to pay attention to:

- Definitions of parameters
- Description of plots
- Testing procedures used for common applications

2 Device Summary

The front page of a data sheet provides an overview and highlights key features that are particular to the device. If a spec or package option stands out, then exploring more of the data sheet can be worthwhile. Also, not all end equipments and interfaces are listed for the device under applications, only the most common for the specific device.

In the example below, the ESD751/ESD761 data sheet has key areas to note highlighted. A few things to point out from looking at the data sheet, the 24-V working voltage, the ESD ratings (IEC61000-4-2), the 1.6-pF or 1.1-pF capacitance, and the packages the devices comes in.



ESD751 and ESD761 24-V 1-Channel ESD Protection Diodes

1 Features

- IEC 61000-4-2 level 4 ESD protection:
  - ±22-kV or ±15-kV contact discharge
  - ±22-kV or ±15-kV air-gap discharge
- Robust surge protection:
  - IEC 61000-4-5 (8/20 µs): 2.8 A or 1.8 A
- 24-V working voltage
- Bidirectional ESD protection
- Low clamping voltage protects downstream components
- Temperature range: –55°C to +150°C
- I/O capacitance = 1.6 pF or 1.1 pF (typical)
- Offered in a standard leaded package and 0402 footprint package: SOD-523 (DYA) and X1SON (DPY)
- Leaded packages used for automatic optical inspection (AOI)

2 Applications

- USB power delivery (USB-PD)
  - VBUS protection
  - I/O protection
- Industrial control networks:
  - DeviceNet
  - Smart distribution systems
  - 4/20 mA circuits
  - PLC surge protection
  - ADC surge protection

3 Description

The ESD751 and ESD761 are single-channel low capacitance bidirectional ESD protection devices for USB power delivery (USB-PD). These devices are rated to dissipate contact ESD strikes beyond the maximum level specified in the IEC 61000-4-2 international standard (±22-kV Contact, ±22-kV Airgap) and (±15-kV Contact, ±15-kV Airgap), respectively. The low dynamic resistance and low clamping voltage help protect systems against transient events. This protection is key because industrial systems require a high level of robustness and reliability.

Package Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
ESD751	DYA (SOD-523, 2)	1.60 mm × 0.80 mm
ESD761	DPY (X1SON, 2)	1.00 mm × 0.60 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Typical Application

Figure 2-1. ESD751/ESD761 Front Page

3 Pin Configuration and Functions

The pin configuration and functions section varies depending on the ESD protection device. The section consists of the device package or packages and gives an overview of the pin functions for the specific package or packages. Instead of showing package options for a device, Table 3-1 lists and explains the pin functions that may be seen in an ESD protection device data sheet. For more information on packaging and layout, refer to the application note *ESD Packaging and Layout Guide*.

Table 3-1. Pin Functions and Descriptions

Pin Name	Type	Description
GND	Ground	Connect to ground
Exposed thermal pad (EP)	Ground/NC	The thermal pad allows for a better ground connection and thermal performance. The larger surface area to ground lowers the impedance helping dissipate large ESD currents resulting in less inductance to ground meaning lower voltage spikes. Some devices, specifically TVS bi-directional devices, require the thermal pad to be floating or not connected due to failures when the applied voltage is negative.
IO (D+/D-)	Input/Output	IO and D+/D- are common when referring to an ESD protected channel. For these pins, always place as close to the source of ESD (usually an interface connector to the outside world) as possible to limit the possibility of EMI coupling.
IN	Input	IN is the terminology used for a surge protected channel such as in the TVS device family. The optimum placement for these pins are as close to the source of ESD as possible to also minimize the potential of EMI coupling.
V_{CC}	Protection pin	V_{CC} can be used for protecting a USB bus voltage (V_{BUS}). V_{CC} can also be used to set voltages for IO pins resulting in an increase in the clamping voltage (example is TPD4E001) along with other use cases. A V_{CC} pin is not as common on ESD devices because a separate diode generally provides better protection compared to a device with built in protection. A 0.1-µF ceramic capacitor is recommended to be placed between the V_{CC} trace and the V_{CC} pin on the diode to filter out noise.
No connect (NC)	NC	NC pins are not connected internally and can be left floating, grounded, or used for straight-through routing.

4 Specifications

The following sections include all the necessary information for evaluating an ESD protection device and deeming the device fit for a specific application.

4.1 Absolute Maximum Ratings

The absolute maximum ratings specify the stress levels that may cause permanent damage to the device if exceeded. Table 4-1 is an example of an absolute maximum ratings table. The ratings typically consist of the storage and ambient operating temperatures as well as the IEC 61000-4-5 power and current ratings and some devices include IEC 61000-4-4 EFT immunity ratings.

The IEC 61000-4-5 is a surge immunity test that evaluates a device's ability to survive surge events, which are large increases in current for a duration in the µs range. Outdoor operation, long cabling, frequent load changes, and many other situations have greater risks of exposure to surge events. An important parameter to consider when selecting a device is the I_{PP}, the peak current a system takes during a surge event. This is because surge pulses contain significant amounts of energy and require more protection due to the length of a surge event.

The IEC 61000-4-4 EFT is specific to testing fast transient/burst immunity. Typically, the testing is required for networking systems, field cable transmissions, and other industrial applications. For more details on the specifics of IEC 61000-4-5 and IEC 61000-4-4 testing, refer to the application note *IEC 61000-4-x Tests for TI's Protection Devices*.

Table 4-1. Absolute Maximum Ratings Example

		MIN	MAX	UNIT
P_{PP}	IEC 61000-4-5 Power (t_p - 8/20 µs)		57	W
I_{PP}	IEC 61000-4-5 Current (t_p - 8/20 µs)		6	A
EFT	IEC 61000-4-4 EFT Protection		±80	A
T_A	Ambient Operating Temperature	-55	150	°C
T_{stg}	Storage temperature	-65	155	°C

4.2 ESD Ratings - JEDEC

The JEDEC standards are useful in verifying the components ability to survive manufacturing, assembly, and shipping but does not represent what a component experiences in an end-user scenario. Table 4-2 is an example of what the JEDEC standard looks like in a typical ESD protection device data sheet. The two ratings are the Human Body Model (HBM) and the Charged Device Model (CDM). The HBM simulates a human body discharging onto a grounded device in a controlled factory environment. The CDM simulates electrostatic discharge from a charged device through a grounded material.

Table 4-2. JEDEC Standards Example

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001	±2500	V
		Charged device model (CDM), per JEDEC specification JS-002	±1000	

4.3 ESD Ratings - AEC

The Automotive Electronics Counsel (AEC) standards are based on the JEDEC ratings but are specific to automotive devices. The difference between the two is the testing the device undergoes. Both ratings, the AEC and JEDEC, commonly have the same value for HBM and for CDM. An example of the AEC ratings table found in auto-qualified ESD protection device data sheets is shown in Table 4-3.

Table 4-3. AEC Ratings Example

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per AEC Q101-001	±2500	V
		Charged device model (CDM), per AEC Q101-005	±1000	

4.4 ESD Ratings - IEC

The IEC 61000-4-2 rating consists of two measurements: contact and air. The contact rating is the maximum voltage a device can withstand from discharging an ESD pulse directly onto the device. The air-gap rating is similar, instead of discharging directly onto the device, this test involves discharging an ESD pulse over a gap of air onto the device. The higher the rating, the higher the voltage a device can withstand.

Table 4-4 breaks down the different levels to the IEC 61000-4-2 ratings. Most, if not all of TI ESD protection devices comply with the level 4 or higher rating for contact discharge, and most comply to level 4 or higher rating for air-gap discharge.

Table 4-4. IEC Example

Level	Contact Discharge	Air Discharge
	Test Voltage (± kV)	Test Voltage (± kV)
1	2	2
2	4	4
3	6	8
4	8	15
X	Custom	Custom

Table 4-5 shows the IEC ratings in a data sheet for an ESD protection device with a level 4 rating in both contact and air-gap discharge. The device is able to function up to the values provided in Table 4-5. For example, some ESD devices are able to function up to 30-kV contact/30-kV air-gap discharge which is greater than level 4 IEC rating.

Table 4-5. IEC Ratings in Data Sheets

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	IEC 61000-4-2 contact discharge	±8000	V
		IEC 61000-4-2 air-gap discharge	±15000	

4.5 ESD Ratings - ISO

The ISO standard is partly based on the IEC 61000-4-2 ratings explained above, but has key differences specific to automotive applications. The main difference between the ISO and IEC standards is the coupling network used to simulate different ESD strikes. The 330-pF, 330-Ω test conducted in the ISO standard has the highest current flow that needs to be shunted to ground. For more information on the differences between ISO 10605 and IEC 61000-4-2, refer to the application note *ISO 10605 Road Vehicles Test Methods for Electrical Disturbances from Electrostatic Discharge*. Table 4-6 is an example of the ISO rating table found in auto-qualified TI ESD protection device data sheets.

Table 4-6. ISO Ratings Example

				VALUE	UNIT
$V_{(ESD)}$	ISO 10605 Electrostatic discharge	C = 150 pF; R = 330 Ω	Contact Discharge, all pins	±30000	V
			Air-gap Discharge, all pins	±30000	
		C = 330 pF; R = 330 Ω	Contact Discharge, all pins	±30000	
			Air-gap Discharge, all pins	±30000	

4.6 Recommended Operating Conditions

The recommended operating conditions set the specific requirements a device should operate in. For most ESD protection device data sheets, the recommended operating conditions include the input pin voltage and the operating free-air temperature, as shown in Table 4-7. If the device is operating outside of these recommended conditions but within the *Absolute Maximum Ratings*, the device may not be fully functional. This may affect device reliability, functionality, performance, and shorten the device lifetime.

Table 4-7. Recommended Operating Conditions

		MIN	NOM	MAX	UNIT
V_{IN}	Input voltage	-5.5		5.5	V
T_A	Operating free-air temperature	-55		150	°C

4.7 Thermal Information

Thermal information is standard in the majority of TI device data sheets. An example of a table that is found in most ESD protection device data sheets is shown in Table 4-8. The most commonly reported metric is the junction to ambient thermal resistance, $R_{\theta JA}$. This metric measures the thermal performance of an IC package mounted on a specific test coupon and is intended to be used to compare the thermal performance of a package for a TI part to other companies. For more detail into the specifics of each thermal metric, refer to the application note *Semiconductor and IC Package Thermal Metrics*.

Table 4-8. Thermal Information Example

THERMAL METRIC		ESD451	UNIT
		DPL (X2SON)	
		2 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	356.9	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	201.2	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	136.4	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	2.6	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	135.9	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	NA	°C/W

4.8 Electrical Characteristics

The electrical characteristics section of the data sheet is arguably the most important. This section discusses in detail the specific ESD protection device parameters which must be understood thoroughly for choosing the most applicable protection device. Table 4-9 is an electrical characteristics table from an ESD protection device data sheet with parameters typically seen across all ESD device data sheets.

Table 4-9. Electrical Characteristics Example

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{RWM}	Reverse stand-off voltage	I_{IO} <100 nA, across operating temperature range	-5.5		5.5	V
I_{LEAK}	Reverse leakage current	V_{IO} = 5.5 V, IO to GND or GND to IO		5	50	nA
V_{BRR}	Break-down voltage	I_{IO} = 1 mA, IO to GND	7	8	9	V
V_{BRF}	Break-down voltage	I_{IO} = 1 mA, GND to IO	7	8	9	V
V_{HOLD}	Holding Voltage	TLP, IO to GND or GND to IO		7.2		V
V_{CLAMP}	Clamping Voltage with TLP	I_{PP} = 1 A, TLP, IO to GND		7.6		V
		I_{PP} = 5 A, TLP, IO to GND		8.2		V
		I_{PP} = 16 A, TLP, IO to GND		10.4		V
		I_{PP} = 1 A, TLP, GND to IO		7.6		V
		I_{PP} = 5 A, TLP, GND to IO		8.2		V
		I_{PP} = 16 A, TLP, GND to IO		10.4		V
	Clamping voltage with surge strike	I_{PP} = 6 A, t_p = 8/20 µs, IO to GND		9.5		V
		I_{PP} = 6 A, t_p = 8/20 µs, GND to IO		9.5		V
R_{DYN}	Dynamic resistance	IO to GND		0.19		Ω
		GND to IO				
C_L	Line capacitance	V_{IO} = 0 V; *f* = 1 MHz, V_{pp} = 30 mV, IO to GND or IO to GND		0.5		pF

4.8.1 Reverse Standoff Voltage (V_{RWM})

The reverse standoff voltage, also more commonly known as the reverse working voltage, is the recommended operating voltage of the protected line. The working voltage is defined as the maximum positive or negative voltage that the interface's signal can not exceed to prevent unwanted leakage.

4.8.2 Breakdown Voltage (V_{BR})

The breakdown voltage is the limit where the ESD device starts to conduct significant amounts of current when exceeded. Figure 4-1 shows the voltage range and breakdown voltage for a unidirectional ESD diode and a bidirectional ESD diode

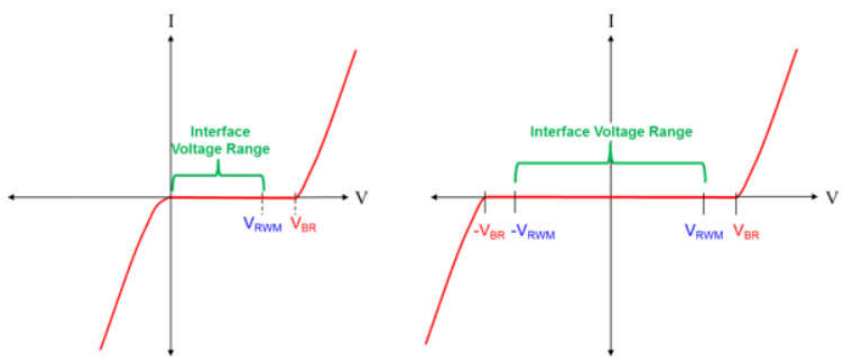


Figure 4-1. I-V Curves for a Unidirectional ESD Diode (left) and a Bidirectional ESD Diode (right)

4.8.3 Leakage Current (I_{LEAK})

Leakage current and reverse working voltage go hand-in-hand. The leakage current of an ESD protection diode is the amount of current that leaks when the reverse working voltage is applied. In TI ESD protection device data sheets, the leakage current is specified at the typical and max values. To determine if a diode is designed to protect a device, check the max leakage current especially for applications that require ultra-low leakage such as medical equipment.

4.8.4 Dynamic Resistance (R_{DYN})

The dynamic resistance is an important factor when evaluating the effectiveness of the ESD clamping voltage. When an ESD event occurs, R_{DYN} characterizes the steepness of the device's I-V curve. Minimizing the dynamic resistance usually provides better clamping voltage and protection.

4.8.5 Line Capacitance (C_L)

Line capacitance is the result of a diode's depletion region storing electric charge. If the line capacitance is not properly accounted for then the diode can degrade signal integrity. With high speed data applications, a low capacitance is required to maintain signal integrity or the signal can be distorted beyond recognition.

4.8.6 Clamping Voltage (V_{CLAMP})

Clamping voltage is the amount of voltage a system is exposed to during a transient event and measures how well an ESD diode protects the downstream system circuitry. The clamping voltage is one of the most important specs for an ESD protection device and can be determined from the Transmission Line Pulse (TLP) plot, mentioned in the next section, if not in the data sheet. Table 4-10 shows the comparison between an IEC strike and the TLP current. For most ESD devices, the clamping voltage is specified at 16-A/8-kV IEC.

Table 4-10. IEC Strike vs. TLP Current Example

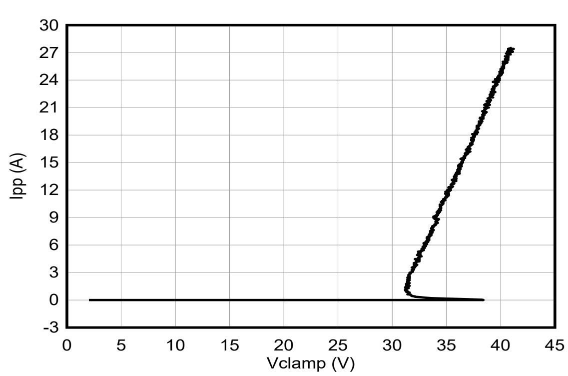
IEC ESD	TLP Current
2 kV	4 A
4 kV	8 A
6 kV	12 A
8 kV	16 A

4.9 Typical Characteristics

ESD protection devices often include specialized plots that aid in selecting the right protection device for a given system-level design. This section provides a detailed discussion of the specific plots normally seen in ESD data sheets.

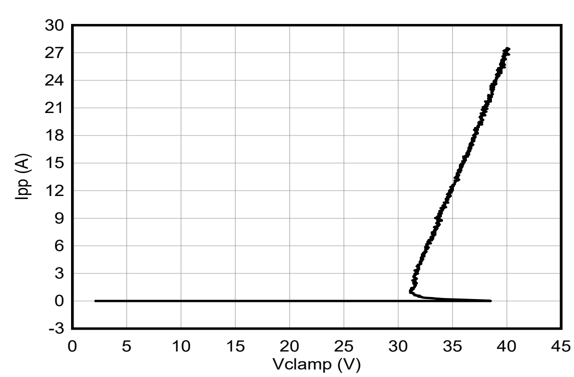
4.9.1 TLP Plot

Transmission line pulse (TLP) plots test the behavior of a device in the current and time domain during an ESD event. The pulse width and rise time can easily be changed, but typically, the testing involves a rectangular current pulse of 1 to 5-ns rise time and 100-ns pulse width. The TLP plot provides important parameters, the breakdown voltage and the dynamic resistance of the clamp. As mentioned in Section 4.8.6, the clamping voltage can be derived from the TLP plot if the clamping voltage is not explicitly provided in the data sheet. An example is shown from the ESD2CANFD24 data sheet. For this device, looking at 16-A, the clamping voltage is estimated to be 36-V. The device does experience snap-back which is a technique used to reduce the overall voltage drop during an ESD event. Since ESD2CANFD24 is a bi-directional diode, the positive and negative TLP plots are almost identical, this is not the case for uni-directional diodes.



tp = 100 ns, Transmission Line Pulse (TLP)

Figure 4-2. Positive TLP Curve



tp = 100 ns, Transmission Line Pulse (TLP)

Figure 4-3. Negative TLP Curve

4.9.2 ± 8kV Clamped IEC Waveform

The ± 8kV Clamped IEC Waveform is the results of the IEC 61000-4-2 ratings mentioned earlier with measuring a 8-kV contact discharge. Important parameters to consider for this testing is the rise time and the pulse width. An example from the ESD441 data sheet is shown in Figure 4-4. The lower the peaks and the faster decaying the peaks are, the higher the chances for the device to successfully protect the system components.

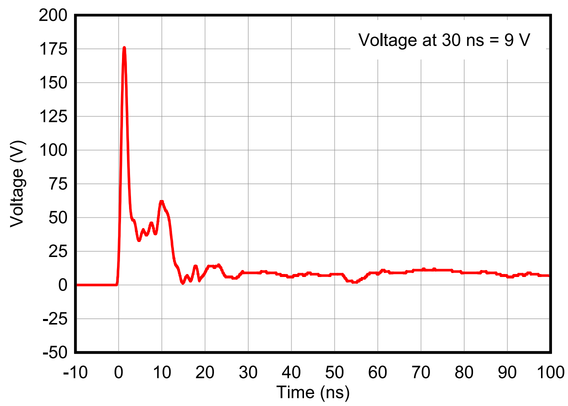


Figure 4-4. +8-kV Clamped IEC Waveform

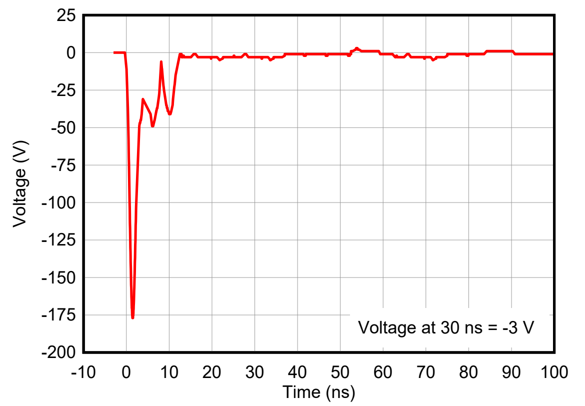


Figure 4-5. -8-kV Clamped IEC Waveform

4.9.3 Capacitance vs. Bias Voltage

The capacitance vs bias voltage plot shows the variation in capacitance over the operating voltage. The plot shown below from the ESD751 data sheet depicts a bi-directional device only showing the positive operating range, 0 to 24-V. As seen in the plot, the capacitance varies slightly across the positive operating voltage.

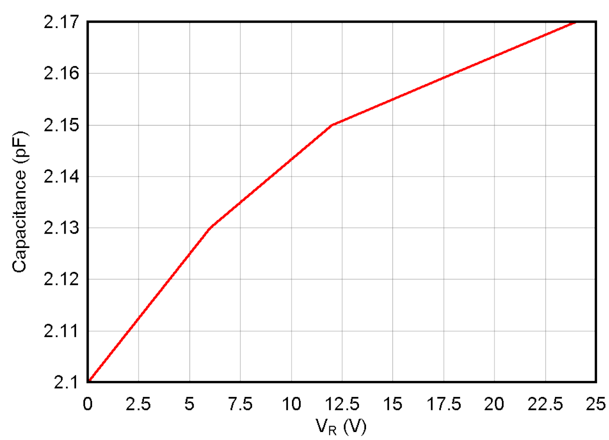


Figure 4-6. Capacitance vs Bias Voltage

4.9.4 Leakage Current vs. Temperature

This plot takes the recommend operating temperature from the data sheet and measures the leakage current across the temperature range, -40 to 125. Below shows an example of the leakage current vs temperature plot from the TPD1E05U06 data sheet.

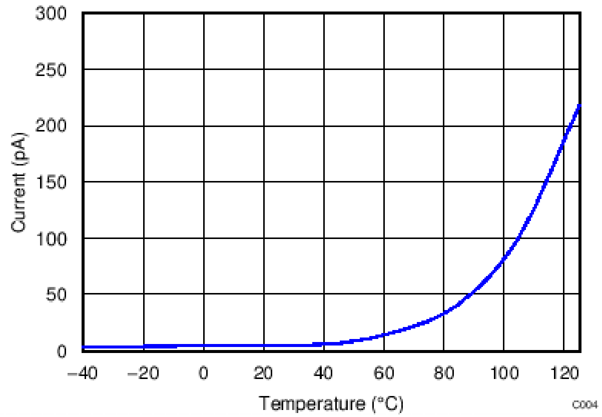


Figure 4-7. Leakage Current vs Temperature

4.9.5 Capacitance vs. Temperature

Similar to the leakage current vs temperature plot, this plot measures the capacitance of the device across the recommended operating temperature range, -55 to 150. Using the ESD451 device data sheet, an example of the capacitance vs temperature is shown in Figure 4-8. For this specific device, the capacitance is 0.5-pF (typ). As seen in the plot, the capacitance decreases at lower temperatures.

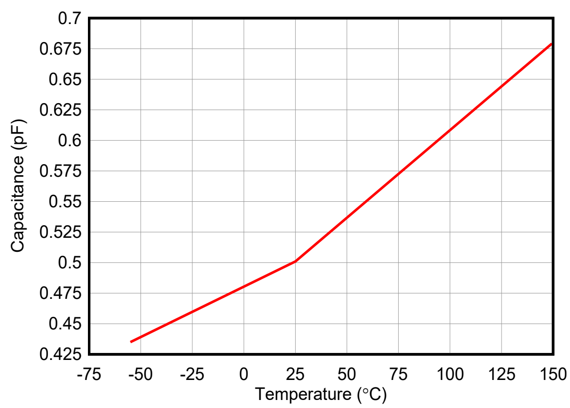


Figure 4-8. Capacitance vs Temperature

4.9.6 Insertion Loss

Insertion loss is the amount of power loss or signal strength that occurs when a device is inserted into a circuit. This is important for ESD protection devices since a large capacitance can lead to degraded signal quality. Below shows an example of an insertion loss plot from the ESD341 data sheet. Usually, the device is able to support the signal speed between the 0 and -3-dB range. The device shown in Figure 4-9 and supports up to 5-GHz.

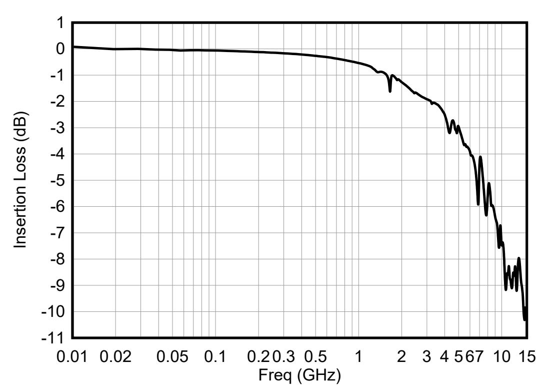


Figure 4-9. Insertion Loss

5 Summary

The purpose of this user guide is to help someone read and understand an ESD protection device data sheet. The information provided in this guide can help assist in selecting the right device to achieve a successful design. If any additional assistance is needed when selecting a protection device, please reach out to the Protection Device product line at TI.

6 References

- Texas Instruments, *ESD Packaging and Layout Guide*, application note.
- Texas Instruments, *IEC 61000-4-x Tests for TI's Protection Devices*, application note.
- Texas Instruments, *ISO 10605 Road Vehicles Test Methods for Electrical Disturbances from Electrostatic Discharge*, application note.
- Texas Instruments, *Semiconductor and IC Package Thermal Metrics*, application note.

7 Revision History

Changes from Revision * (May 2010) to Revision A (September 2023)	Page
• Updated the numbering format for tables, figures, and cross-references throughout the document	1
• Updated information to better reflect an ESD protection device data sheet	1