

TVS diode (ESD protection diode)

ESD (electrostatic discharge) refers to the instantaneous discharge current that occurs when two charged bodies (for instance, a person and an electronic device) come into contact. ESD can cause electronic components to malfunction or fail and may even cause irreparable damage to devices. TVS diodes, also known as ESD protection diodes, are used to suppress and/or eliminate ESD from electronic components as a way to prevent damage to a device or system.

ESD protection is required at locations that human or other living creature may come into contact with. This includes places that hands and fingers touch, such as USB ports on a phone or the USB or HDMI ports on a laptop computer. On a component production line, ESD protection is necessary for processes such as connecting substrates together with a cable.

This document describes ESD test specifications, outlines the basic principles of the TVS (ESD protection) diode.

1. ESD test standard

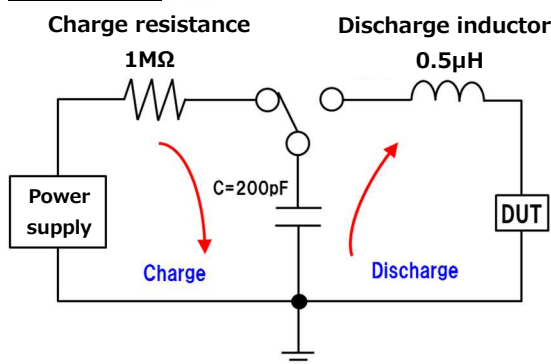
ESD test standard is required depend on usage or application etc., it can be roughly divided into "Device level test" and "System level test". The types and outlines of the ESD tests are described below.

1 – 1 Device level test (MM, HBM and CDM)

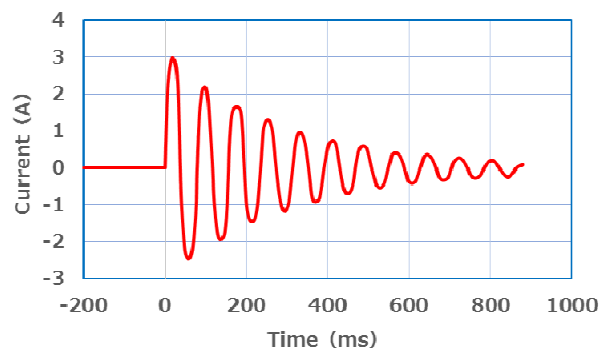
① MM (Machine Model) test

This test replicates discharge from a conductive body such as a metal frame or jig. Electric charge starts building up in production equipment as soon as the power is switched on. This charge transferred to internal components such as ICs in the form of electrical discharge. The MM test is designed to reproduce this form of ESD.

Test circuit



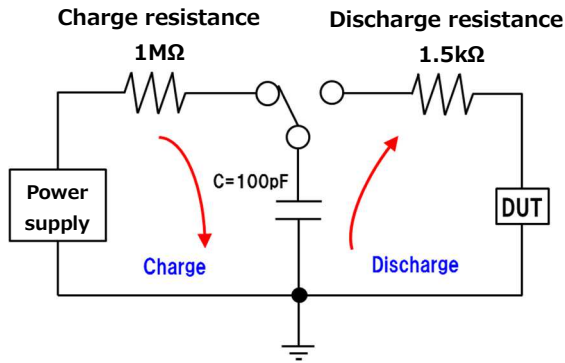
Ex. Discharge current waveform



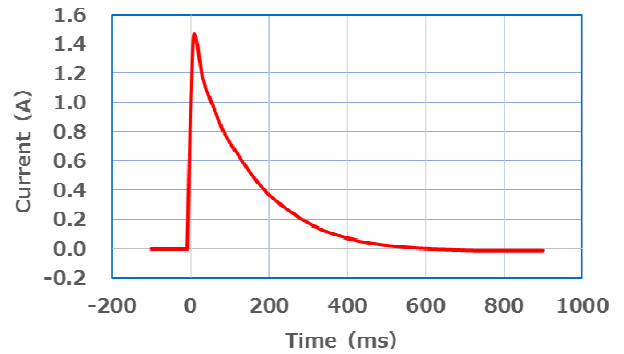
② HBM (Human Body Model) test

The HBM test, the most commonly known ESD test, replicates discharge from the human body or a charged device into an electronic component.

Test circuit



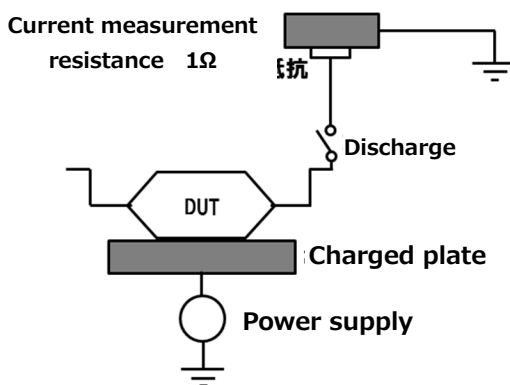
Ex. Discharge current waveform



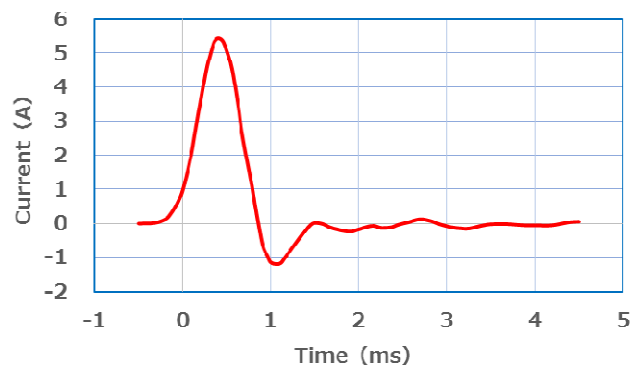
③ CDM (Charged Device Model) test

Modern ICs and electronic components are made via automated assembly processes and seldom come into contact with human operators. As a result, HBM failure rates are on the decline. The CDM test replicates the discharge phenomena that are more likely to occur on a modern production line. Production line ICs and electronic components are often maintained with floating and isolated electric potential. This is conducive to buildup of charge, which is then discharged if a device contacts a metal surface such as equipment or jigs. The CDM test is designed to reproduce this form of ESD.

Test circuit



Ex. Discharge current waveform



1 – 2 System level tests (IEC61000-4-2, 4-5 試験)

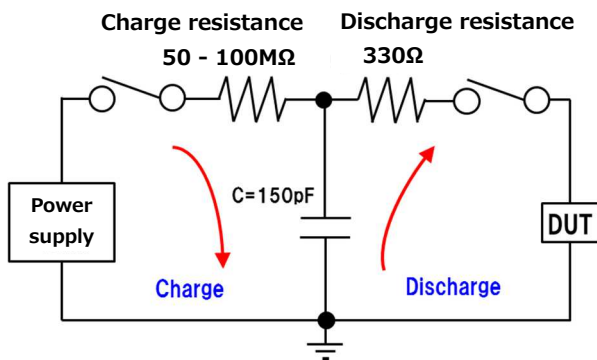
① IEC61000-4-2 test (ESD immunity test — human model)

The IEC61000-4-2 test is designed to replicate ESD from the human body, similar to the HBM test. Electric charge tends to build up in the body in low humidity conditions, and also in specific scenarios such as walking across carpet (a poor conductor) or wearing clothes made from synthetic fiber. This test is designed to reproduce the discharge of this kind of electric charge built

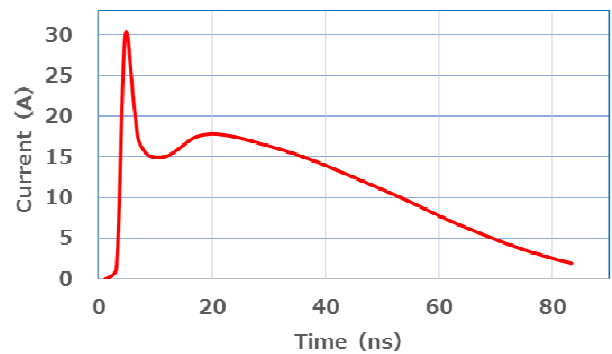
TVS diode (ESD protection diode)

up in the body. The test uses two scenarios for ESD discharge from the body to the device. Contact discharge is based on the scenario of direct contact with the device, and the contacts of the testing equipment are physically touching the device. Air discharge replicates discharge when the device is not in contact with the body, and the equipment contacts are positioned a short distance from the device to create an air gap. Generally, contact discharge is used for devices with a metal surface and air discharge for devices with plastic or other shielding. Most TVS diodes are tested for both scenarios.

Test circuit



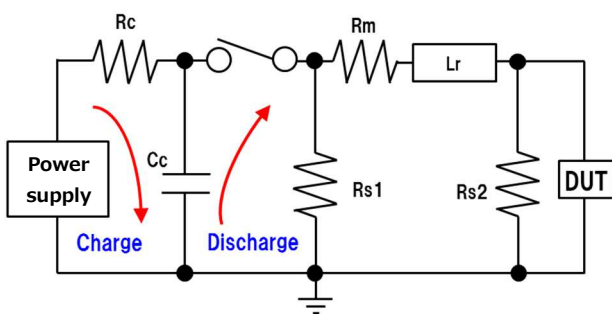
Ex. Discharge current waveform



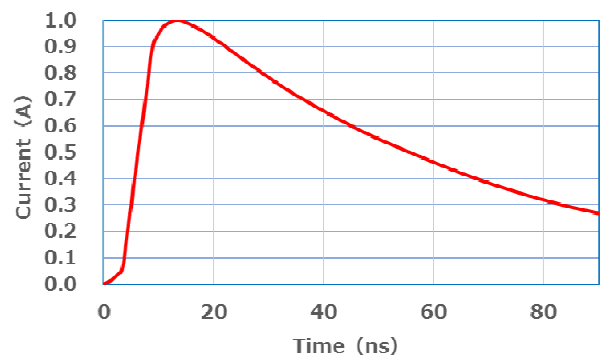
② IEC61000-4-5 test (Surge immunity test – lightning)

The IEC61000-4-5 surge immunity test, also known as the lightning test, replicates the transient phenomena associated with a direct lightning strike along with local impacts such as surge voltage and current. It also replicates transient switching phenomena in electrical systems, such as sudden load changes and even short circuiting that can occur when the power is switched on to a large piece of machinery, for instance. This is the strictest type of system level immunity test in terms of applied surge current level and period.

Test circuit



Ex. Discharge current waveform

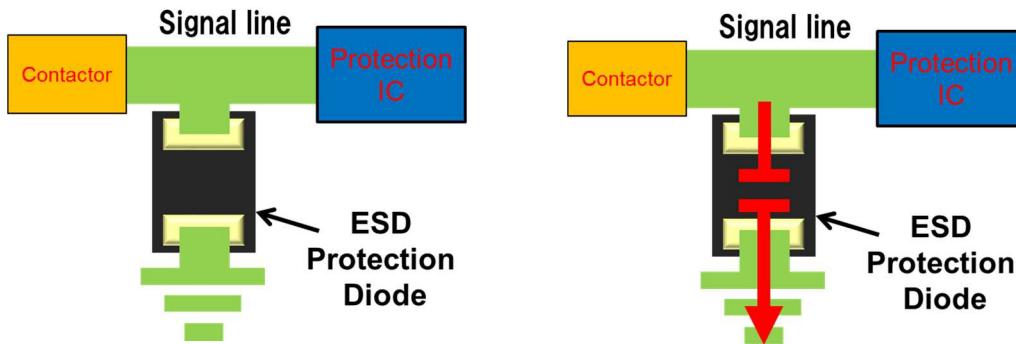


ESD testing may be performed at the device level or the system level. Manufacturers currently tend to attach more importance to system level ESD testing. To this end, the Toshiba TVS diode has been designed with system level testing in mind.

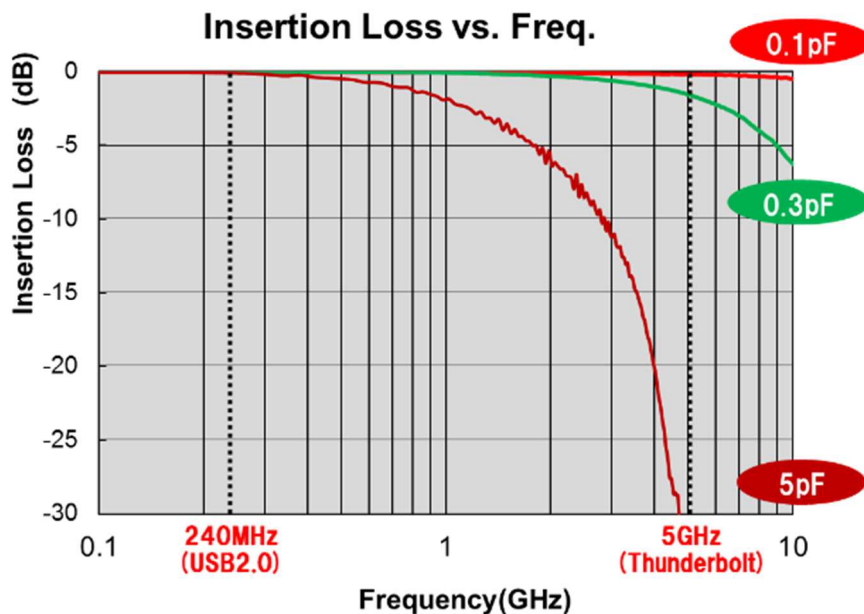
2. How the TVS diode works

2 – 1 Steady state (TVS diode : OFF)

The TVS diode is situated between the normal signal line and GND, so the diode has capacitance during steady-state operation. Particularly for high-speed signal such as USB 3.0 and USB 3.1, this capacitance provides impedance, resulting in signal loss (also known as insertion loss or IL) that affects signal quality.

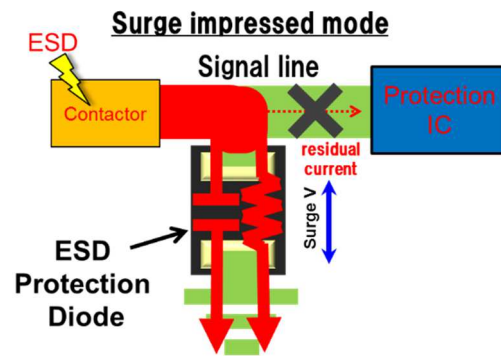
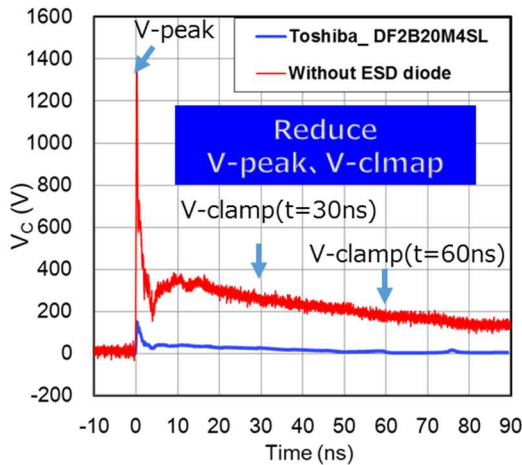


The graph below shows capacitance versus insertion loss. The higher the capacitance, the larger the insertion loss (with significant fluctuation in the negative quadrant), to the extent that it cannot keep up with the signal. In the case of USB 2.0 (480 Mbps, frequency equivalent 240 MHz) and Thunderbolt (10 Gbps, frequency equivalent 5 GHz), at low capacitance (0.1–0.3 pF) there is low insertion loss, so the TVS diode is suitable for both. At high capacitance, the diode is suitable for USB 2.0 but not for the higher speeds of Thunderbolt. It is important therefore to allow sufficient capacity for the signal speed.



2 – 2 ESD (surge/disturbance noise) impressed mode

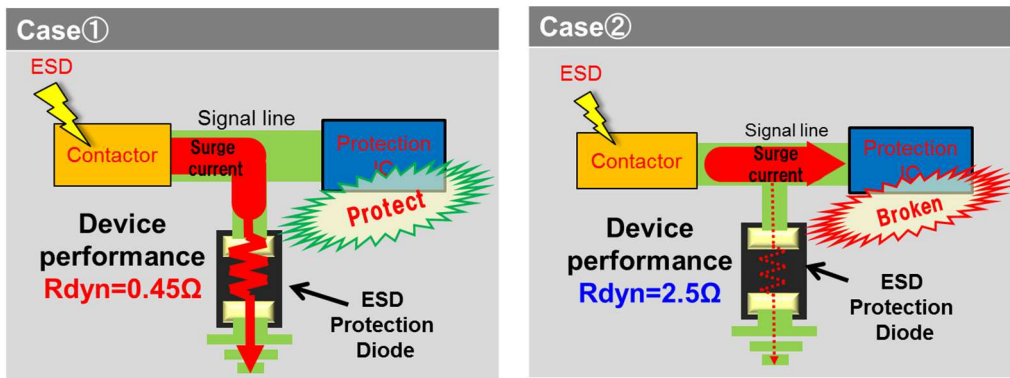
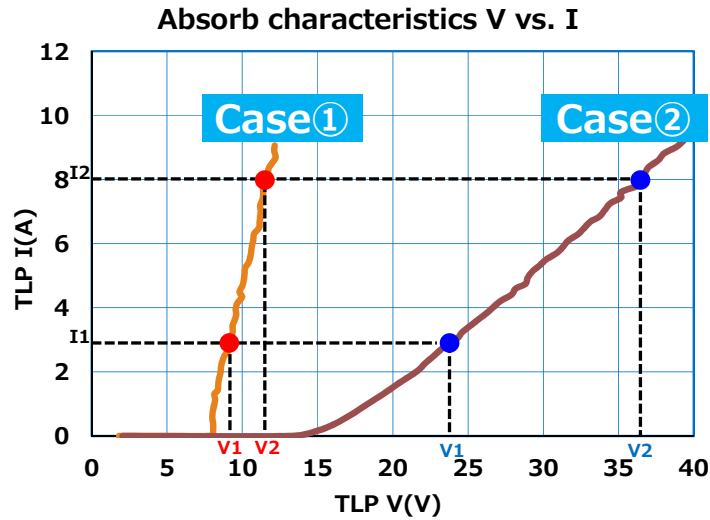
In the mode of ESD such as surge or disturbance noise, a TVS diode provides critical protection for post-stage components such as the IC by safely redirecting the surge current to ground. Without a TVS diode, the surge current impacts directly on these components, potentially causing malfunction or failure. The key parameters are the initial peak voltage of the ESD (the V-peak voltage) and the V-clamp voltage at 30 ns and at 60 ns. The lower the V-peak and V-clamp values, the better the protection provided by the TVS diode. Similarly, a smaller waveform area indicates less damage to post-stage components. The diagram below compares surge voltage waveforms (clamp waveforms) with and without the TVS diode, illustrating the importance of the TVS diode.



Ex. IEC61000-4-2 Clamp voltage waveform

Another key parameter in both the steady-state and ESD scenarios is the dynamic resistance (R_{dyn}) of the TVS diode. A lower dynamic resistance value means that more surge current can be absorbed into the ground. Lower dynamic resistance also reduces the voltage across the dynamic resistance interval at the ends (i.e. the clamp voltage) and minimizes the residual current (excess surge current not absorbed by the TVS diode), providing further protection for post-stage components.

$$\text{Dynamic resistance (Rdyn)} = \frac{(\text{TLP V2} - \text{TLP V1})}{(\text{TLP I2} - \text{TLP I1})}$$



3 Conclusion

The TVS diode absorbs the ESD and the surge noise entering from the outside, it is used in various sets to prevent malfunction of the circuit and to protect the ICs. We have lined up TVS diodes that are suitable for variety of applications, including mobile devices, consumer devices and etc. Please refer to the ESD test standards and the operation of TVS diodes mentioned above for consideration.

Toshiba TVS diode : <https://toshiba.semicon-storage.com/en/product/diode/esd-protection-diode.html>

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