ESD Protection – An Increasing Challenge with an Increasing Choice of Solutions

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Ensuring the protection of equipment against the damaging effects of electrostatic discharge (ESD) is an important part of the design process and a potential headache for engineers. Electronic products need to operate reliably and therefore be protected not only from damage caused by physical effects such as vibration, moisture and extremes of temperature, but also from ESD. Designers need to consider enclosure and PCB design, component selection and even software fixes to ensure compatibility with ESD standards such as IEC 61000-4-2. The use of protection components on critical circuit nodes such as input and output connectors is an important element of the ESD protection design process. Protection components for ESD are often called transient voltage suppressors (TVS). The main types of protection products available to system designers are reviewed and their properties compared in this article.

Transient Voltage Suppressors for ESD

The significantly raised input voltage seen at the input pins of many ICs during an 'ESD stress' can have a potentially damaging effect on the device. Between the normal operating voltage range and the onset of device damage is a region of safe overvoltage. There is some overlap in the safe overvoltage and device damage regions because larger over voltages can usually be tolerated if their duration is only very short. The role of a TVS is to maintain Vinput within the safe overvoltage range during an ESD event, without compromising system performance during normal operation. TVS devices are placed close to where an ESD event is likely to enter a system and act to limit the voltage on sensitive nodes and direct current to less sensitive nodes such as ground. To perform this function effectively the TVS must have high resistance for the normal operating voltage range. Outside of the normal operating voltage range the TVS should present low resistance, so that current is directed away from the sensitive node and voltage transients are limited. Although the basic performance needs for a TVS are application specific, the core requirements include: the ability to service expected ESD stress, high resistance (low leakage) in the normal voltage range and low resistance outside of normal voltage range, fast transition from high resistance to low resistance during and ESD stress, and capacitance that is not too high for the intended application.

There are two classification categories that should be understood before comparing types of TVS devices, they are unidirectional versus bidirectional and voltage clamping versus crowbar.

Unidirectional Versus Bidirectional

Both unidirectional and bidirectional TVS devices can protect against both positive and negative stress. The differences between them are best understood in terms of the voltage range over which they maintain a high resistance, low leakage state. This voltage range determines the types of circuit nodes the TVS device can be used to protect. A bidirectional TVS has symmetrical properties about zero volts, as can be seen in Figure1. These devices are best for protecting circuit nodes whose voltage is symmetric, or bidirectional, around zero volts. Unidirectional TVS products meanwhile have asymmetric behavior around zero volts - also shown in Figure 1. Unidirectional TVS devices are ideal for protecting circuit nodes whose voltage always has the same polarity.

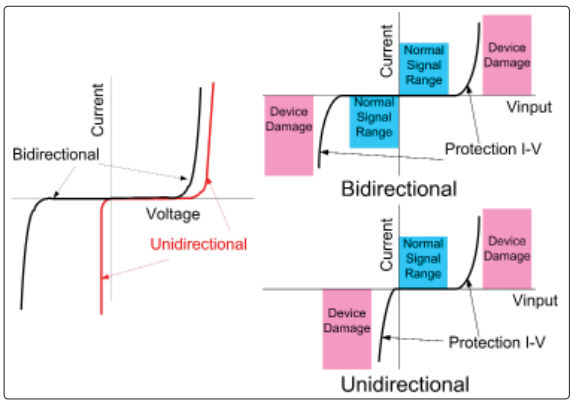

Figure 1.

Voltage Clamping Versus Crowbar

Voltage clamping devices change from a high resistance at low voltage to a low resistance above a turn-on voltage without a region of negative resistance as shown in Figure 2. The devices work by clamping the voltage above the turn-on voltage by providing a low resistance path to ground.

Crowbar devices also have high resistance at low voltages. At higher voltage, however, a new conductance mechanism is triggered and an increase in current is accompanied by a drop in voltage. A crowbar device therefore has a region of negative resistance. For some devices the trigger voltage can be quite high. If the crowbar TVS triggers fast enough it can often provide protection, even though the voltage appears to have reached a level that could cause damage.

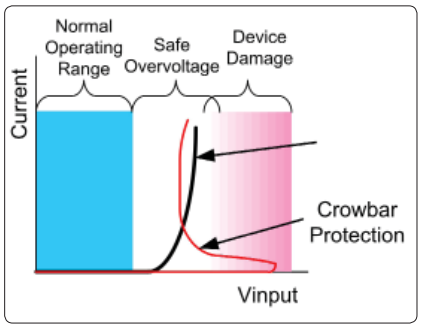

Figure 2.

Metal Oxide Varistors (MOV)

At low currents and voltages varistors exhibit high resistance, but at higher values their resistance drops dramatically; they are therefore classified as voltage clamping devices.

Varistors are bidirectional and are available with a very wide range of current and voltage capacities, this makes them suitable for applications ranging from high voltage transmission lines to small surface mount devices for ESD protection. However, they also have a high capacitance relative to their conductivity; this makes them of limited use for the protection of high speed signal lines. Varistors are also susceptible to degradation from multiple stresses well below their damage level from a single stress.

Polymer Surge Suppressors

Polymer surge suppressors are bidirectional crowbar devices; they have very low capacitance and are appropriate for use in high speed applications. However they have a high turn-on voltage, relatively poor on-state resistance and are susceptible to degradation under multiple stresses.

Diode TVS

Today, most diodes are solid state, two-terminal and made from silicon. They conduct current easily in one polarity and have a high resistance up to their breakdown voltage, in the opposite polarity. Diodes are inherently unidirectional and protect by voltage clamping.

Diode properties depend on the doping levels of the n and p regions, both near and far from the junction. Doping level adjustments allow the creation of diodes with reverse bias breakdowns from 100's of volts to just a few volts. Diodes with a well defined reverse bias breakdown voltage are usually called Zener diodes.

Offering a choice of unidirectional and bidirectional protection, diode based TVS products are more versatile than other ESD protection products. The basic diode is unidirectional and is the only such protection element available. The combination of two diodes in series easily creates bidirectional protection. Bidirectional protection can be achieved with either common cathode or common anode configurations. Bidirectional performance can be obtained using a pair of unidirectional TVS devices. There are a wide variety of bidirectional diode based TVS devices in which the two diodes are included in a single package and are often even integrated onto the same silicon substrate.

Type	Directionality	Voltage Clamp or Crowbar	Capacitance	Wearout	Voltage Accuracy	On Resistivity
Varistor	Bidirectional	Voltage Clamp	High	Yes	Poor	Medium
Polymer	Bidirectional	Crowbar	Very Low	Yes	Poor	Medium
Silicon Diode	Bidirectional or Unidirectional	Voltage Clamp	Medium to Very Low	No	Good	Low

Table 1.

In the past, the high capacitance of silicon based TVS devices gave them a disadvantage in protecting low voltage, high speed signal lines. Recent technology advances have overcome this by performing as if it were a simple Zener diode.

Comparisons

The basic properties of the three main types of TVS devices are summarized in table 1.

Circuit nodes that have asymmetric sensitivity to stress may require unidirectional protection which only diode based TVS products can supply. High speed applications require very low capacitance making polymer devices an attractive solution. The desire for low capacitance needs to be balanced with the protection capabilities of polymer devices. For polymer TVS products to be acceptable, the high speed node needs to be able to survive the transient to high voltage to turn on the polymer TVS and the medium resistivity in the 'on' state.

The low cost nature of varistors makes them appealing and they have the added advantage of not requiring a high voltage to turn on. However, they often have too high a capacitance for high speed applications if they are made large enough to provide low enough 'on' resistance to provide adequate protection. Diode based TVS products have good clamping capability and are now available in ultra-low capacitance versions suitable for the highest speed applications. Diodes are also useful since they are available as unidirectional devices that match the voltage range of many modern high speed digital signals.

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