Volume 25 Issue 13 | **Contents**

CIE
COMPONENTS IN ELECTRONICS

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Subscriptions: Components in Electronics magazine is published ten times each year on a controlled circulation basis in the UK.
Register online at:www.cieonline.co.uk
CIE is also available on annual subscription in the UK and Europe (£51), and the rest of the World (£96). Subscribe online at: www.cieonline.co.uk/subscribe

Published by Specialist Media Ltd
8-10 Dryden Street, Covent Garden,
London, WC2E 9NA

Member of the Audit Bureau of Circulations
ABC recycle
Printed by Williams Press

Making the right choice

Rob Ashton reviews and compares some of the protection products available to system designers

Customer satisfaction demands that electrical systems from mobile phones and entertainment systems to high-end computers not affected by electrostatic discharge (ESD). To ensure system robustness against ESD, products are tested, against standards such as IEC 61000-4-2 and system designers use a variety of techniques to ensure compatibility with prevailing ESD standards including: case design, board design, component selection and even software fixes. One important tool is the use of protection components on critical circuit nodes such as input and output connectors. Protection components for ESD are often called transient voltage suppressors (TVS).

TVS basics for ESD

Many ICs have potentially sensitive inputs making them susceptible to damage if they are subject to an input voltage significantly above the normal operating voltage range as occurs during an ESD stress. 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 be tolerated if their duration is only very short. The job of a TVS is to maintain Vinput within the safe overvoltage range during an ESD event, without compromising system performance during normal operation. The TVS device is placed near to where an ESD event is likely to enter a system and is intended to limit the voltage on sensitive nodes and to direct current to less sensitive nodes such as ground. To perform this function the TVS must have high resistance for the normal operating voltage range. Outside of the normal operating voltage range the TVS must have low resistance, such that current is directed away from the sensitive node and voltage transients are limited.

The basic requirements for a TVS are application specific but in general are:

- Ability to survive the expected ESD stress
- High resistance (low leakage) in the normal voltage range
- Low resistance outside of the normal voltage range
- Turn on voltages that are correct for the application
- Fast transition from high resistance to low resistance during stress
- Capacitance that is not too high for the intended application

There are two classification categories which need to be understood before comparing specific types of TVS devices:

Unidirectional versus Bidirectional

Both unidirectional and bidirectional TVS devices can protect for both positive and negative stress. The differences between the terms is best understood in terms of voltage range over which the TVS maintains 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.

Bidirectional devices are best for protecting circuit nodes whose voltage is symmetric, or bidirectional, around zero volts. Unidirectional TVS products meanwhile have asymmetric behaviour around zero volts as shown in Figure 1. Unidirectional TVS devices are perfect for protecting circuit nodes whose voltage always has the same polarity, for example a 0V to 5 V signal.

Clamping versus Crowbar

Voltage clamping devices work by changing 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 device works by clamping the voltage above the turn-on voltage by providing a low resistance path to ground.

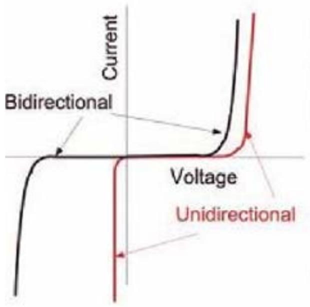
Crowbar devices also have high resistance at low voltages. At higher voltage, however, a new conductance mechanism is triggered and an increase in current is accompanied by a drop in voltage. A crowbar device therefore has a region of negative resistance. For some crowbar devices the trigger voltage 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. Crowbar devices are sometimes called 'snapback' devices because the voltage snaps back.

There are three primary technologies used for ESD TVS devices: varistors, polymers and silicon diodes.

Metal Oxide Varistors (MOV)

At low currents and voltages varistors have a high resistance but at higher voltages and currents their resistance drops dramatically; they are therefore voltage clamping devices.

Varistors are bidirectional and are manufactured with a very wide range of current and voltage capacities for



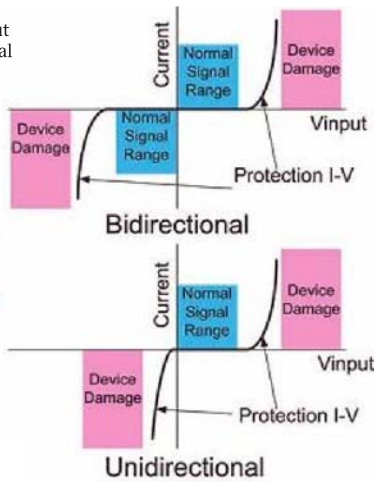


Figure 1: *Unidirectional and bidirectional TVS devices compared*

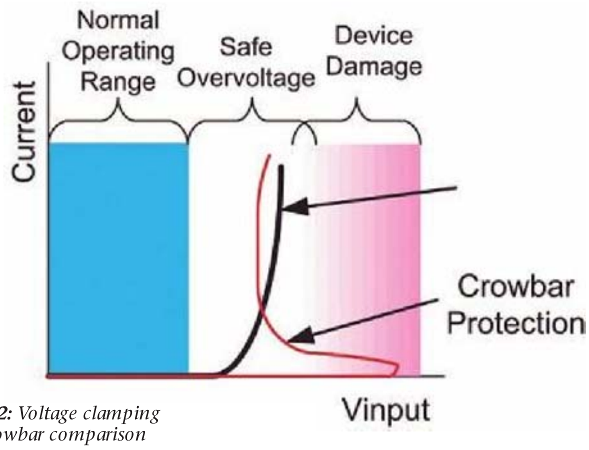


Figure 2: Voltage clamping and crowbar comparison

applications ranging from high voltage transmission lines and lightning protection to small surface mount devices intended for ESD protection. However, they also have a high capacitance relative to their conductivity; this means that they have limited use in the protection of high speed signal lines. Varistors can also be subject to degradation from multiple stresses well below their damage level from a single stress.

Polymer Surge Suppressors

Polymer surge suppression devices are crowbar devices and are always bidirectional. They have very low capacitance and are attractive for use in high speed applications. Their down side is a high turn-on voltage, relatively poor on state resistance and their susceptibility to degradation under multiple stresses.

Diode TVS

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

The properties of diodes depend on the doping levels of the n and p regions, both near and far from the junction. Adjustments of doping levels allow the creation of diodes with reverse bias breakdowns from hundreds of volts to just a few volts. Diodes designed to have a well defined reverse bias breakdown voltage are usually called Zener diodes.

Diode based TVS products have a versatility not available in other ESD protection products - the choice between unidirectional and bidirectional protection. The basic diode is a unidirectional product and is the only unidirectional 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.

In the past, silicon based TVS devices had a disadvantage protecting low voltage, high speed signal lines due to high capacitance. However, recent technology advances are eliminating this disadvantage. New products such as ON Semiconductor's ESD9L5.0 combine the advantages of silicon-based protection with the low capacitance required for high speed applications. The ESD9L5.0 behaves as if it were a simple Zener diode. In fact the ESD9L5.0 includes a low breakdown Zener diode and a pair of high breakdown, and therefore low capacitance, standard diodes.

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 very attractive. 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.

Varistors are often attractive due to their low cost and they do not require a high voltage to turn on. 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 even the highest speed applications. Diodes are also attractive since they are available as unidirectional devices that match the voltage range of many modern high speed digital signals.

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