Application Brief

Data Line ESD Protection: TVS Diodes or Chip Varistors?

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Introduction

Transient protection has become more prevalent on data lines in today electronics since most modern integrated circuits are built with increasingly smaller transistors each generation to support higher data rates and lower power consumption. Transient events such as electrostatic discharge (ESD) and surges can produce very large voltages or currents at the inputs and outputs (I/O) of IC's which can need to be clamped to a lower voltage to protect sensitive circuity from these high discharge voltages.

There are many different options for transient protection circuitry, to choose a protection device that best protects your downstream circuitry, it is important to understand the key specifications of protection devices. This paper compares two common protection devices, transient voltage suppressor (TVS) diodes and varistors.

Causes of ESD and Surge

Systems with exposed interface connectors are susceptible to electrostatic discharge (ESD). These events can be caused by human contact during assembly or during normal use by an end user. All IC's have built in device-level ESD structures that protect from ESD in the manufacturing process with ratings according to the: charged device model (CDM) and human body model (HBM). ESD events experienced in an end user scenario are considered system-level ESD which inject much higher voltage and currents onto data or power lines. Figure 1 compares the device level and system level ESD models.

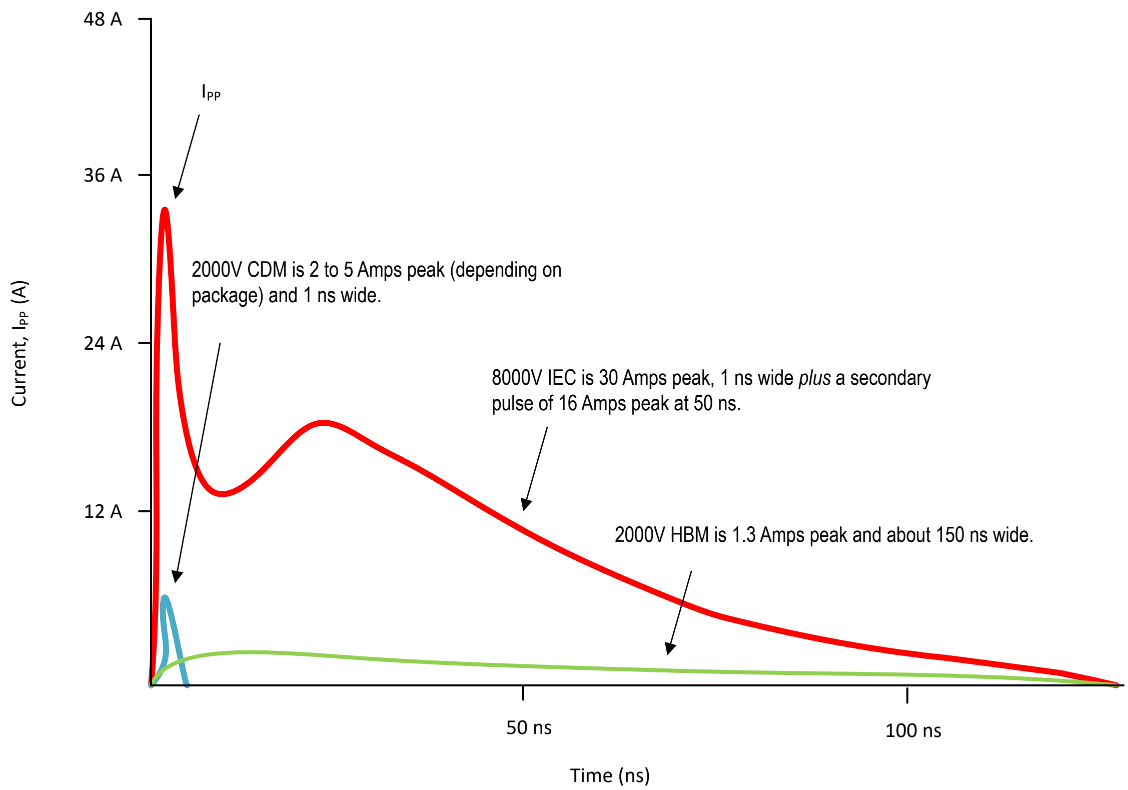

Figure 1. HBM vs. CDM vs. IEC ESD Pulses

Three of the most common system-level transient immunity standards are under the IEC 61000-4-x standards: System ESD Immunity (IEC 61000-4-2), Electrical Fast Transient Immunity (EFT) (IEC61000-4-4), and Lightning/Surge Immunity (IEC 61000-4-5). Many system designs can require a certain level of protection on exposed digital communication ports or power lines with at least one of the standards mentioned. Varistors and TVS diodes are often cost effective designs against system level transients with data sheet specifications available in accordance with the IEC standards mentioned.

For further details on these three standards please see *TI's IEC 61000-4-x test for protection devices* and *Demystifying Surge Protection*

TVS Diodes

TVS diodes are used to clamp system level transients down to lower voltages to avoid damaging sensitive circuitry. These diodes are constructed with a PN junction that exhibit an avalanche breakdown which can sustain large amounts of current flow. They are typically placed in parallel with the sensitive circuitry and can behave like a capacitor at voltages near the working voltage (Vrwm). Once the voltage on the line exceeds the breakdown voltage (Vbr), which normally is only during a transient event, the diode can begin conducting large amounts of current to ground. ESD/TVS diodes can specify a protection rating according to both system level ESD and surge models.

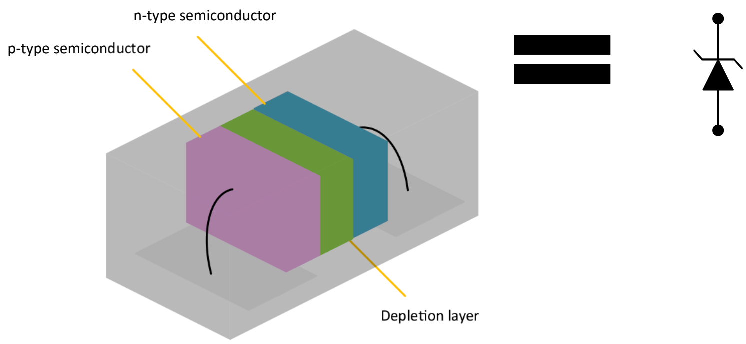

Figure 2. Simplified TVS Diode

Varistors

These devices are built primarily using zinc oxide (ZnO) along with a small amount of other metal oxides. The body of the varistor contains a matrix of conductive zinc oxide grains separated by grain boundaries that create the P-N junction semiconductor characteristics similar to TVS diodes. The devices work in a similar fashion by allowing the desired lower voltage signals to pass by on a protected trace when connected in parallel. Whenever a voltage above the defined varistor voltage (similar to TVS breakdown voltage), the varistor's resistance drops suddenly and allows current to flow.

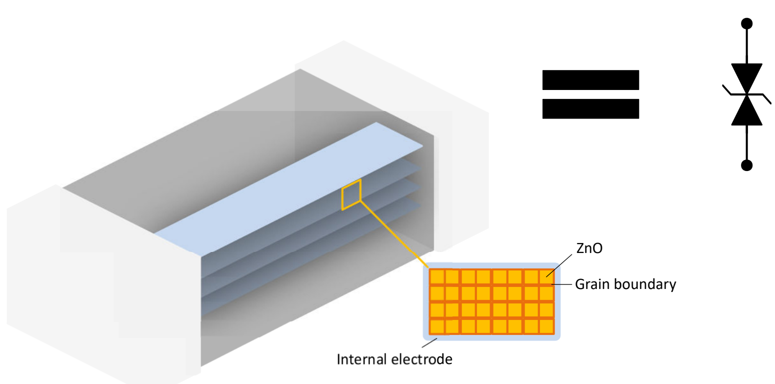

Figure 3. Simplified Chip Varistor

Chip varistors and TVS diodes can be used to protect both data and power lines, however TVS diodes are offered in configurations that are designed for data line protection of any interface. Although these transient protection designs share many characteristics, varistors are limited by process to achieve certain specifications needed for high-speed data line protection. TVS diodes are better designed for data line protection since the diodes can better protect sensitive low voltage circuitry due to their ultra-low clamping voltage and ultra-low capacitance specifications. TI's latest TVS diodes also have very low leakage currents which are good for battery powered applications.

ESD Protection Device Specifications

The specifications that vary between TVS and varistors can be discussed in the following. For further information on all specifications of ESD protection devices, please see Reading and Understanding an ESD data sheet.

Working Voltage and Polarity

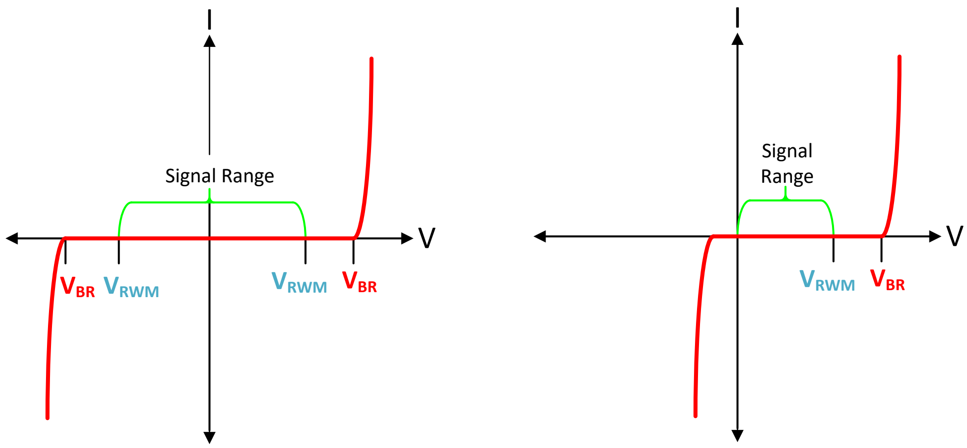

Figure 4. Bi-directional vs. Unidirectional Polarity

Varistors come exclusively in a bi-directional configuration due to their symmetric internal metal layers that make up the body. TVS diodes are widely available in both unidirectional and bi-directional configurations. The unidirectional polarity is best for signals that only swing in a positive voltage range since they exhibit lower clamping voltage for negative ESD events thus better protecting the downstream circuitry.

Capacitance

Varistor capacitance is typically quite large and cannot support high data rate communication protocols. This is due to the high dielectric constant of the materials used to make varistors. TVS diodes can achieve ultra-low line capacitance making them best suited for data lines since the signal integrity won't be comprised by adding a low capacitance diode on the line. TI's portfolio features protection diodes with capacitance below 0.2pF that can support interfaces with the highest data rates.

Clamping Voltage

Varistors tend to have worse clamping performance compared to TVS diodes due to their much larger resistance to ground during an ESD/Surge event. The following formula is to estimate the clamping voltage.

$$V_{Clamp} \approx V_{BR} + I_{PP} \times R_{DYN} + I_{Paristic} \times \left(dI_{PP}\right)/dt \quad (1)$$

New TVS diode processes can achieve dynamic resistances close to 0.1 Ohms, providing the lowest clamping voltage design of any small form factor ESD design.

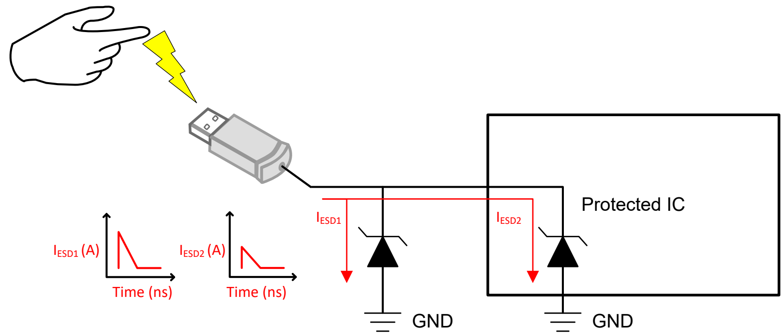

Figure 5. ESD Current flow

The resistance of the external protection device during a transient event can affect the dissipation of ESD currents between the internal ESD cells of the downstream protected IC. Ideally the dynamic resistance of the external protection device is much lower than the internal ESD clamp diodes to provide the lowest impedance path to ground this can steer more current to ground through the external protection device instead of through the internal ESD diodes.

ESD protection devices can always exhibit some large voltage spikes while clamping the first peaks of the ESD strike. These overvoltage's have such short durations, they do not typically damage devices so the clamping voltage is often specified around 30ns once the voltage has settled. Nonetheless, these voltage spikes can be harmful to very sensitive IC's and the quicker the peaks are clamped, the more robust the design can be from system level ESD.

TVS diodes can have quicker turn on times than varistors, clamping the transient voltages on the line to an acceptable voltage much quicker thus better protecting sensitive circuitry such as a modern microprocessor. TVS diodes are a good design for sensitive IC's since the diodes provide a lower resistive path to ground, thus lower clamping voltage.

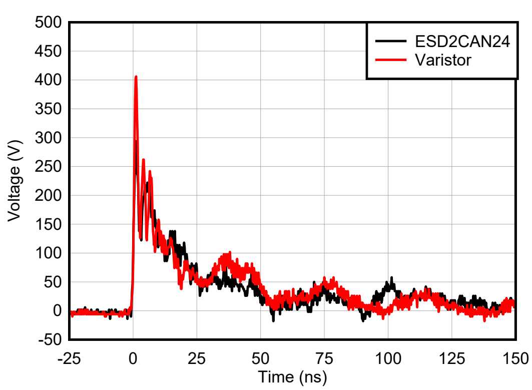

Figure 6. 15kV IEC ESD Strike

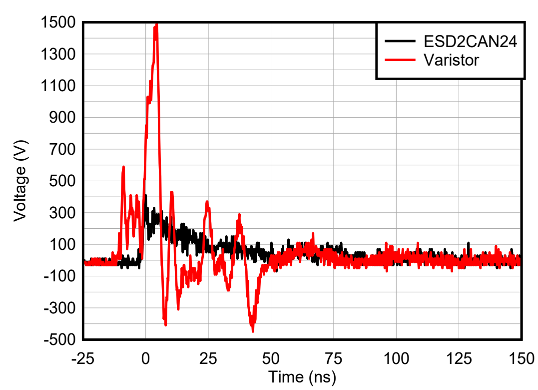

Figure 7. 25kV IEC ESD Strike

The different clamping response between a 24V TVS diode and 24V varistor is shown above for two different IEC ESD strikes. Both of these devices are commonly used to protect CAN data lines. As the IEC ESD voltages increase you can see the gap between clamping voltage increasing. For a 25kV IEC ESD strike, the varistor clamps at a peak of 1500V at about 5ns while the TVS diode clamps this voltage to a peak of 400V at about 5ns.The poor clamping performance of varistors can prevent them from protecting CAN transceivers from higher voltage ESD strikes if the CAN bus voltage tolerance is on the lower end. The CANH/CANL pins max voltage ratings typically range from 40V to 70V.

Low voltage applications such as USB can require even lower clamping voltage due to very sensitive circuitry downstream that can only handle a few volts at the I/Os, such as a USB controller. TVS diodes can provide the best protection for lower voltage applications.

Leakage Current

Varistors have a higher leakage current than most modern TVS diodes, often specified in the uA range. TVS diodes can offer much lower leakage specifications in the nA range for voltages at or below the working voltage. Certain applications such as battery powered equipment can have a need to minimize the leakage of all components on a trace for the most efficient design.

Package

Chip varistors come in small packages such as the industry standard 0603 and 0402 metric packages. TVS diodes can come in very small packages below 1mm x 1mm and are also offered in multi-channel arrays for flexible routing. This is good for high speed differential pairs that need close impedance matched traces.

Optimizing Layout for ESD Protection

The PCB layout can heavily influence the dissipation of large transient currents. Implementing a low-impedance ground connection can help reduce risk of downstream components from ESD. It is important to place ESD protection devices as close as possible to the source of ESD, which is most often an exposed interface connector. This can help steer the ESD current into the TVS.

For further layout guidelines, please see our ESD Protection Layout Guidelines

Conclusion

Varistors can have very high clamping voltages that cannot protect very sensitive IC's and typically have high line capacitance values which cannot support higher speed data lines. These specifications limit the use of varistors on high speed data line applications and are thus better suited for power line protection.

TVS diodes can be effectively used to protect power lines and data lines since the diodes process technologies can achieve ultra-low dynamic resistance and capacitance characteristics. TVS diodes are better suited than varistors for data line applications where the control circuitry is low voltage and requires very low clamping voltage to be protected. Line capacitance values for TI's ESD diodes can reach sub 0.2pF and support almost any high-speed interface.

References

- Texas Instruments, *Reading and Understanding an ESD*, data sheet.
- Texas Instruments, *TI's IEC 61000-4-x Test for Protection Devices*, application note.
- Texas Instruments, *Demystifying Surge Protection*, white paper.
- Texas Instruments, *ESD Protection Layout Guidelines*, application note.