AN1142

TVS in Automotive Applications

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The automotive environment is challenging for electronics. Transient spikes, noise and discharges are common, and it is necessary to protect sensitive semiconductor devices from damage. This is done using Transient Voltage Suppressor (TVS) devices. This note will give an understanding of the characteristics of TVS devices, and then show where and how some might be used in a vehicle.

TVS Characteristics

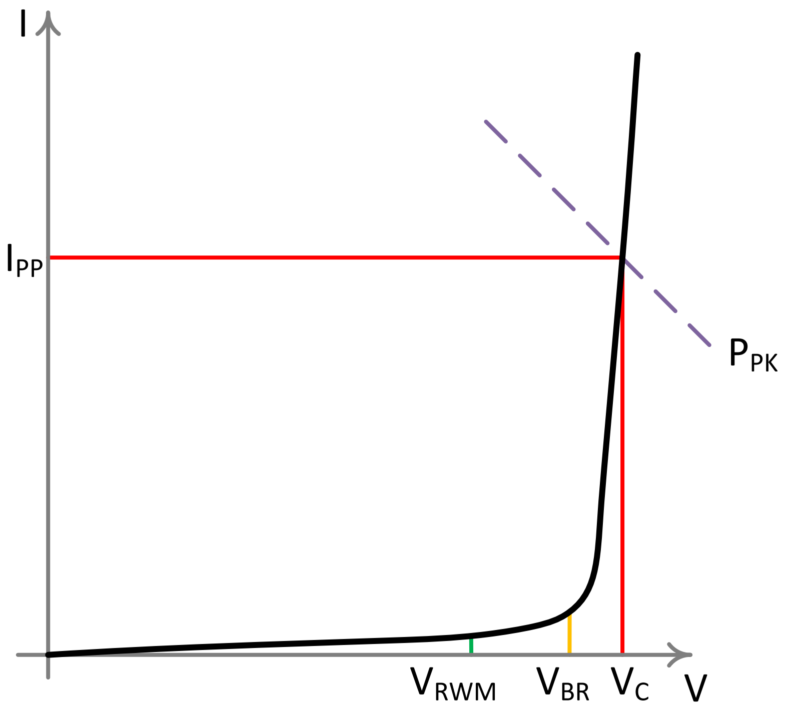

Figure 1: TVS I-V Characteristic

The Reverse Standoff Voltage, also known as the Reverse Working Voltage (**V_{RWM}**) is the specified voltage at which the device will draw only a very small leakage current (of the order of a few µA); this can be as low as 3.3V. It is allowable to select a device with a V_{RWM} equal to the typical working voltage of the circuit – For example, on a 3.3V microprocessor input or power supply you can choose a protection device with a V_{RWM} of 3.3V. V_{RWM} is not a measured figure – it is a nominal figure at which a maximum current is measured.

Reverse Breakdown Voltage (**V_{BR}**) is measured at the point where the device begins to conduct strongly, at a current of 1-10mA. V_{BR} can vary over a wide tolerance – it may even overlap with adjacent values in the range of TVS devices. This is a guide to where the knee of the I-V characteristic is. It is important to consider the minimum V_{BR} value against the tolerance of the circuit you are protecting so that the TVS does not conduct at the maximum tolerance of supply voltage.

Maximum Clamping Voltage (**V_C**) and Maximum Peak Current (**I_{PP}**) are measured from the I-V characteristic at the point where the line intersects the Peak Pulse Power limit (**P_{PK}**) of the device.

Directionality

An important aspect of TVS devices is directionality. The most basic type of TVS is unidirectional:

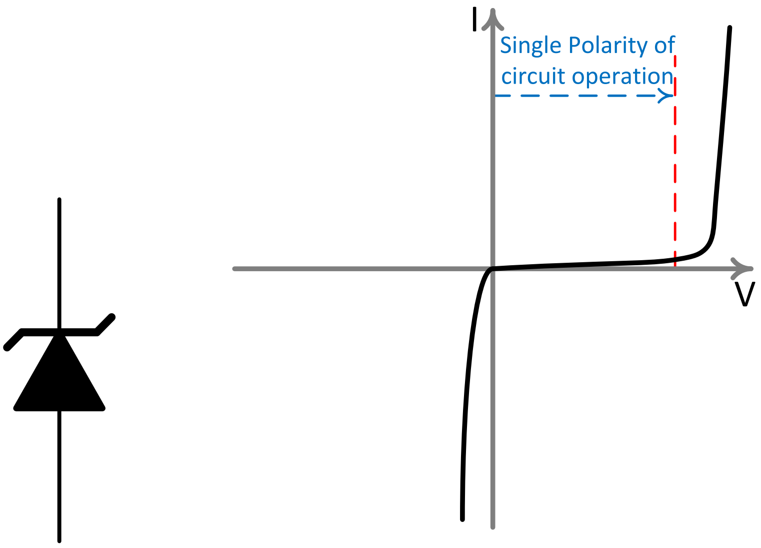

Figure 2: Unidirectional TVS device symbol and characteristic

This type of device is used where the operating area of the circuit to be protected is always positive, for example 0 to +5V. The device will protect against positive and negative transients (immediately, as forward conduction in the device).

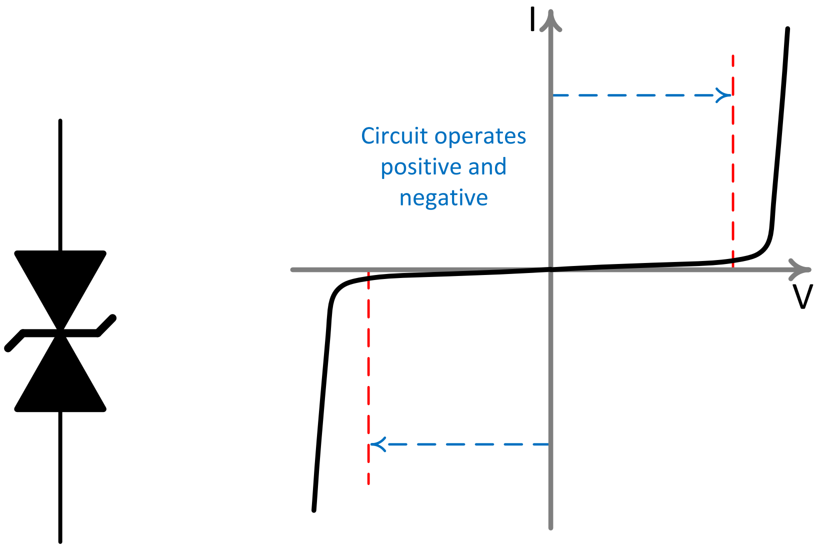

Figure 3: Bidirectional TVS device symbol and characteristic

Where the circuit has both positive and negative operation, such as a split rail audio system or a differential signalling scheme, a bidirectional TVS provides protection for transients that go beyond the safe operating area – either positive or negative.

Bidirectional TVS can be either symmetrical (V_{BR} is the same in both directions) or asymmetrical (V_{BR} is greater in one direction than the other direction).

Why are **Reverse** Standoff Voltage and **Reverse** Breakdown Voltage positive?

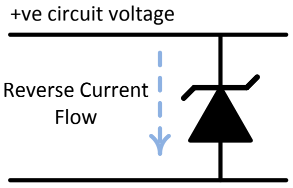

Figure 4: Reverse current flow

V_{RWM}, V_{BR} and V_C are positive, like the operating voltages of the circuit being protected – the voltage that transients will be limited to. This is the convention used across the industry, even though the device is being used in the reverse direction.

Zener TVS compared to Zener Diode

Often the same symbols are used for Zener TVS devices as for Zener Diodes, and it may give rise to questions about the differences between the two. Both devices rely on the Zener breakdown effect and have I-V characteristics that look very similar. What is the difference?

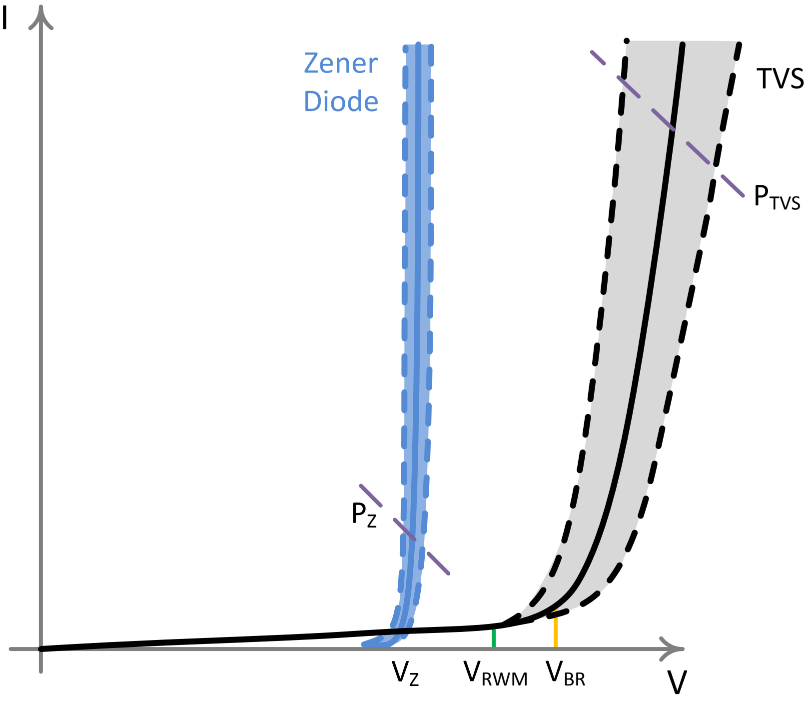

Figure 5: Zener and TVS I-V characteristics compared

Although they appear similar, a closer look at the I-V characteristics in Figure 5 immediately shows the differences. The Zener Diode (blue trace, Vz) has a much sharper knee, steeper slope and tighter voltage tolerance (dashed lines and shaded region) than a TVS device.

These differences come from design and optimization – the purpose of a Zener Diode is to provide an accurate voltage clamp within a signal circuit, or as a reference or regulator. A Zener diode will normally have current flowing through it either constantly or for longer periods of time (several seconds in a clamp application) The TVS exists to handle the energy from spikes and transients that might otherwise cause damage to sensitive components. The TVS device is designed to absorb a large amount of energy in a very short time (nanoseconds to milliseconds). The peak currents can be very large but not for continuous operation. The accuracy of a TVS is less important than the accuracy of a Zener Diode.

During normal circuit operation the TVS device should not conduct other than leakage.

Power Rating

On first inspection the power ratings of TVS devices seem extraordinarily high, but the power rating is a pulse rating. A TVS device is not intended for continuous operation.

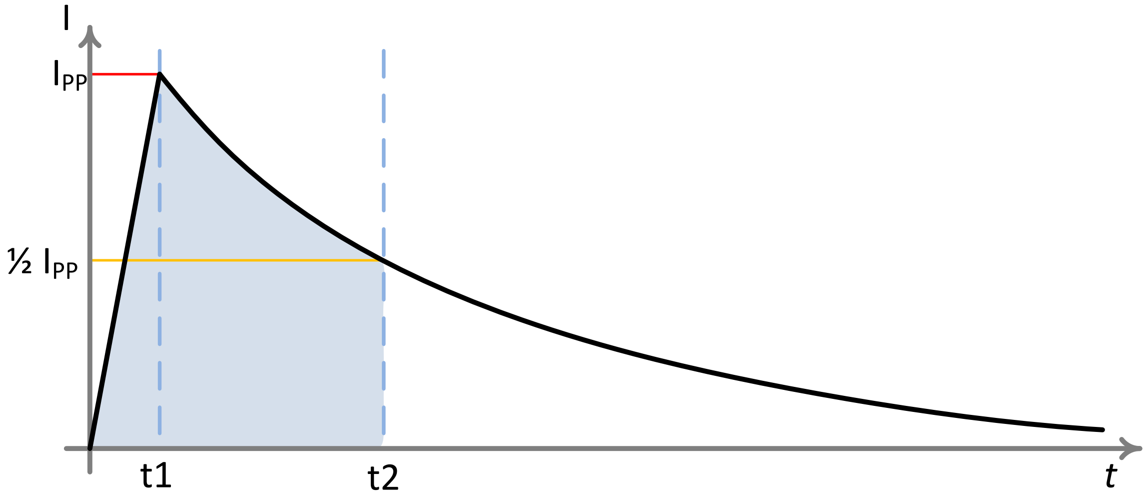

Figure 6: TVS Test Pulse

A typical pulse waveform is shown in Figure 6. Two common waveforms are used, with different values of t1 and t2. Those waveforms are known as 8/20 (t1 = 8µs, t2 = 20µs, defined in IEC61000-4-5) and 10/1000 (t1 = 10µs, t2 = 1000µs, defined in IEC61643-321). Note that t2 is elapsed time from 0, not t1.

The 8/20 pulse shows how the device will handle events like ESD discharge and lightning strikes. The 10/1000 pulse shows how the device will handle slower speed higher energy events like power supply surges. In automotive applications, these events are likely to come from the alternator and inductive loads.

A TVS device may have two different power ratings, one relating to each of these pulses, and they are quite different. It is much clearer why that is the case if the two pulses are overlaid to scale as shown in figure 7.

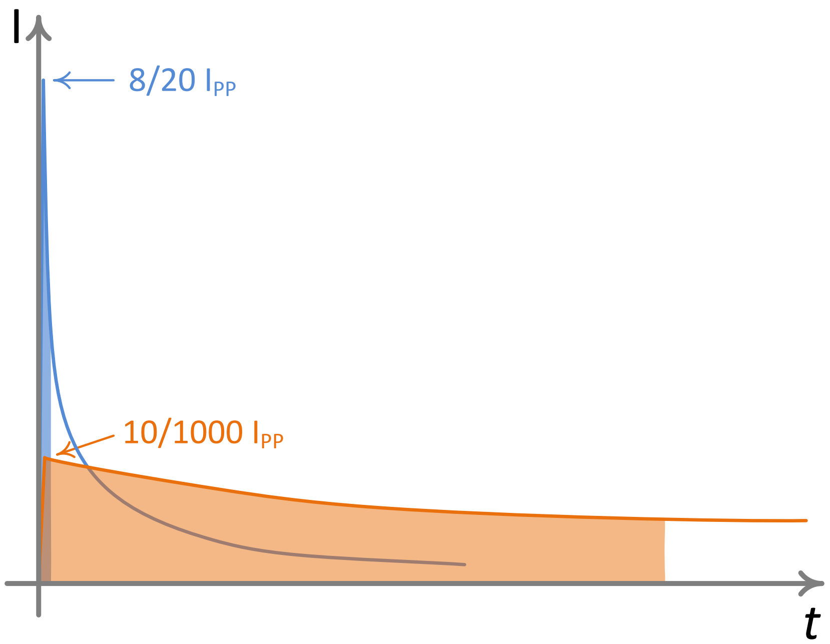

Figure 7: TVS 8/20 compared with 10/1000

The published power figure is $V_C \times I_{PP}$. V_C varies with I_{PP} – therefore the lower I_{PP} of the 10/1000 pulse also gives a lower V_C, again reducing the Peak Power figure.

For the shorter time duration spike on the 8/20 pulse (Blue trace), the device can handle a much higher current. The important thing is the energy of the pulse, represented by the area under the curve (shaded blue area, 0-20µs). Compare to the 10/1000 pulse (Orange trace) and it's clear that the area under the curve (shaded orange area, 0-1000µs) is much greater, limiting the peak figure.

The easiest way to think about this is that the device has an internal capacity to absorb a set amount of energy as heat. That can happen at very high rates for a very short time, or lower rates for a longer time.

TVS Products in an Automotive System

In a vehicle there are several specific areas in which TVS devices might be used, protecting against somewhat different threats.

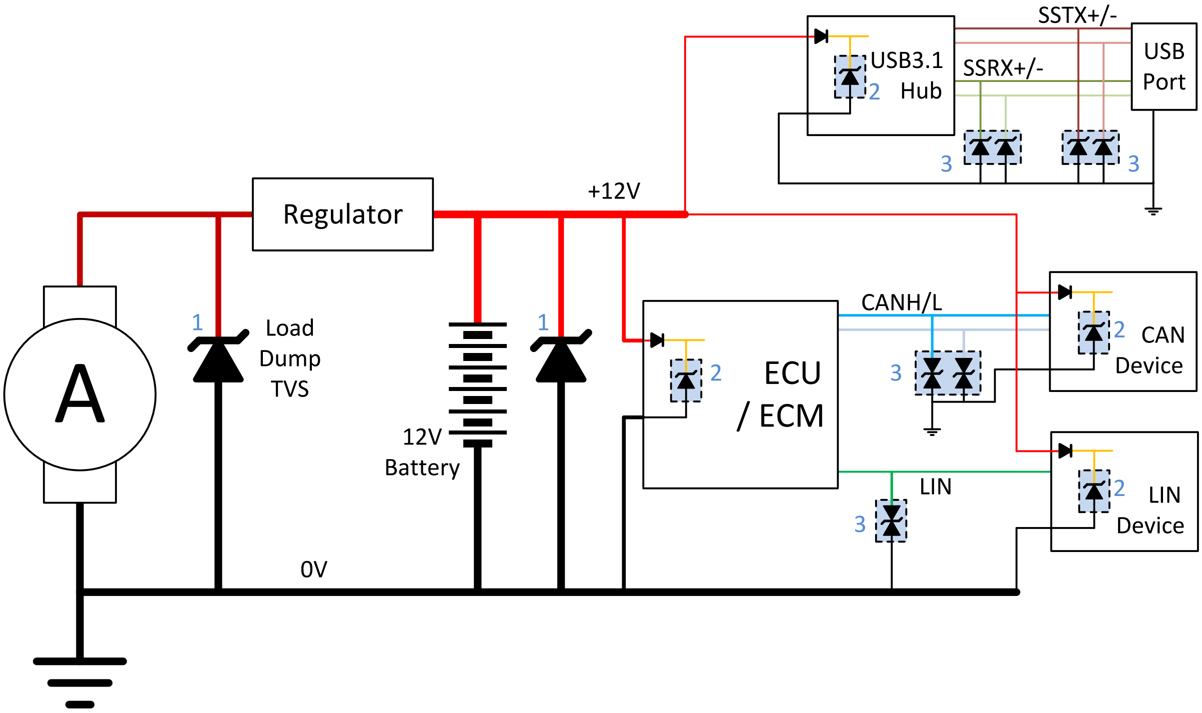

Figure 8: TVS Devices within an Automotive System

The 12V system of a traditional car is powered from the Alternator, and its output is rectified and regulated to provide the nominal 12V to charge the battery and provide power to accessories.

Because both the generation and some of the loads (e.g. window motors, wiper motors, seat motors, etc.) are inductive, there can be significant spikes and dips on the 12V power system as loads are connected, disconnected, stall, etc. Of course, cranking and ignition of an Internal Combustion Engine also presents a very significant and difficult load. This rail also experiences ESD discharges and noise from many systems like ignition coils, injectors and HID lamps.

To protect the systems within the vehicle there are multiple levels of TVS devices. There are very large TVS devices fitted around the alternator and regulator (marked 1 in figure 10) to absorb high-energy events like load dump, field decay, etc.

Each electronic module attached to the 12V power will have its own TVS (marked 2 in figure 10) and reverse polarity protection. The data buses that connect these various modules are not directly vulnerable to the power rail threats, but they will be liable to pick up noise and ESD discharges, which connect to the relatively sensitive low-voltage microprocessors. These buses have protection devices also (marked 3 in figure 10).

Automotive Power Rail Pulses

The standards ISO 7637-2 and ISO 16750 set out a series of defined pulses on the 12V power rail that must be dealt with by the system. Figure 9 gives a sense of these pulses – their magnitude and what they are meant to model. (Note: not to scale)

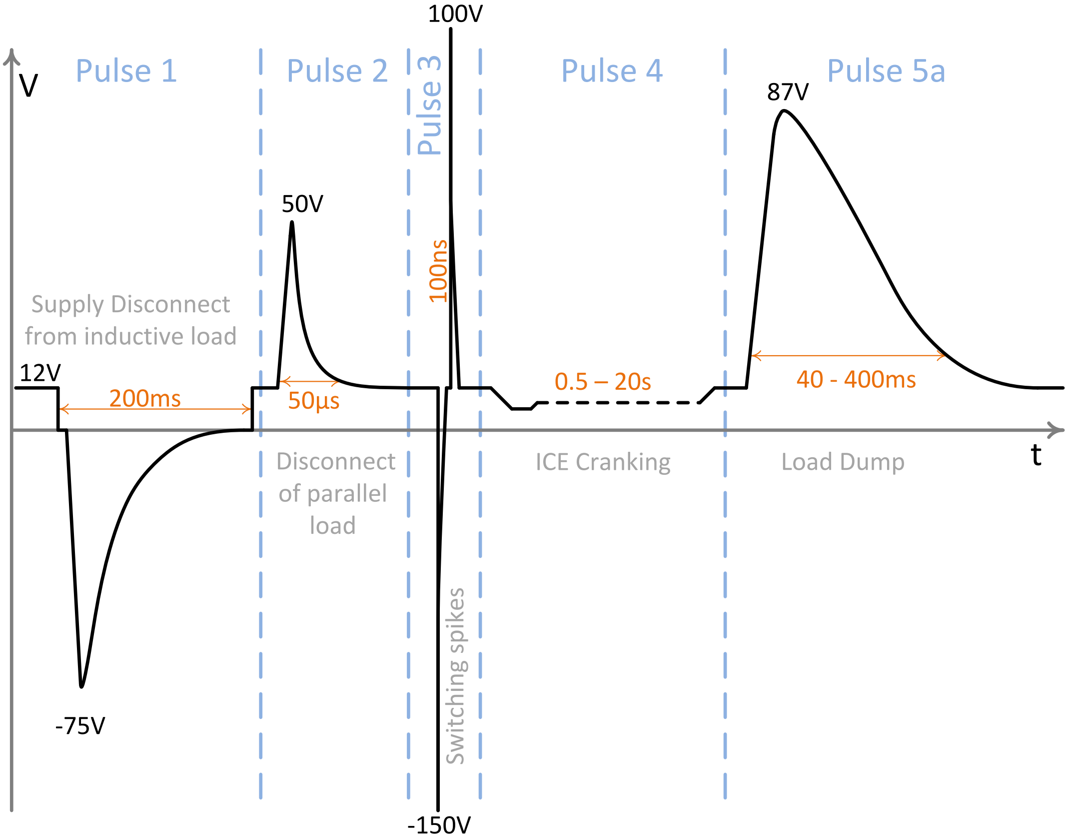

Figure 9: Automotive test pulses

It is important to consider the system as a whole – for example, there may be a main Load Dump TVS which is very large and placed close to the alternator. This will absorb most of the energy in a load dump event, and for this reason there is an option to test automotive modules with the remaining load dump energy that would reach them:

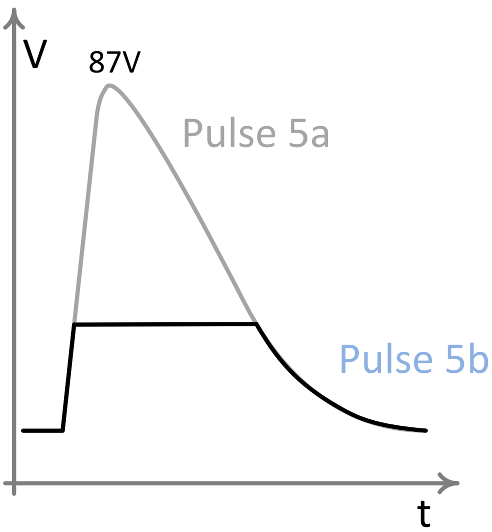

Figure 10: Pulse 5a compared with Pulse 5b

The magnitude of pulse 5b is determined by the customer, by defining the voltage of the main load dump TVS.

Pulses 1 and 5 in Figure 9 have a significantly longer time duration than the 10/1000µs test pulse described on page 4. TVS products in automotive applications therefore will require greater power handling than those in a non-automotive environment.

Power Rail TVS

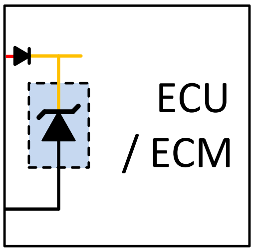

Figure 11: TVS power rail device within an automotive module

Each module within a vehicle will tend to have both reverse battery polarity protection (shown here as a diode, but often implemented as a MOSFET) and a TVS device to protect that module from transients. A TVS device fitted to the power input of an ECU must be rugged and capable of dissipating a significant energy, although it will not be trying to handle the entire energy of a load dump event, for example. Industry-standard devices such as SMCJ28C/CAQ, packaged in the 1.5kW (10/1000µs) rated SMC package, are typically deployed to protect powerlines.

However, the drive toward high-power dissipation and reduced footprint has resulted in the development of TVS in the small form factor thermally efficient PowerDI®5 package. The D28V0HU12P5Q is the first TVS to be packaged in the thermally efficient PowerDI®5 package. The device features a reverse stand-off voltage of 28V and low reverse leakage while being able to dissipate up to 1800W of power per 10/1000s transient, which is 20% higher than comparable SMC solutions while occupying just 40% of the PCB area.

CAN bus and FlexRay

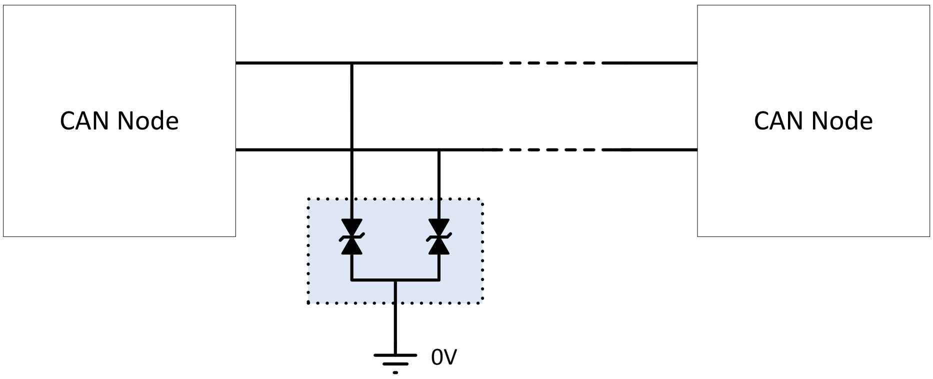

Figure 12: CAN bus TVS protection device

Modern vehicles carry a lot of data over buses such as CAN and FlexRay. These buses can carry safety-critical information so they must not only be rugged but also reliable. It is important that these buses are protected from transients and noise and are protected in a way that does not reduce the bandwidth of the signal. These buses are more likely to encounter low-energy noise and ESD than high-energy transients like load dump. For this reason, smaller, lower power protection devices are appropriate.

CAN bus and FlexRay are differential buses, and so they require dual bidirectional TVS to protect both of the data lines. They should be low capacitance to maintain signal integrity.

CAN bus is not necessarily ground referenced – different nodes in the vehicle may experience different ground voltages. The TVS device can limit both common and differential mode spikes to protect the CAN devices.

LIN bus

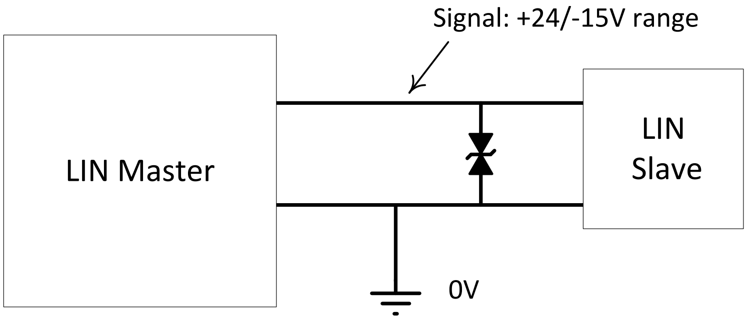

Figure 13: LIN bus TVS protection device

In simple physical terms the LIN bus is a 2 wire bus comprising of signal and ground wires. The signal can potentially be between +24V and -15V (due to ground level variance around a vehicle), so an asymmetrical bidirectional device is required.

The Diodes Inc. DESD1CAN2S0Q and DESD1FLEX2S0Q are dual bidirectional parts suitable for CAN and FlexRay respectively. The DESD1LIN2WSQ is a compact 2-terminal asymmetric TVS device suited to LIN applications.

Part	Application	V_{RWM} (V)	$V_{BR(min)}$ (V)	$V_{BR(max)}$ (V)	V_C (V) @ 3A	I_{PP} (A)	Package
DESD1CAN2S0Q	CAN	24	25.4	30.3	70	3	SOT23
DESD1FLEX2S0Q	FlexRay	24	25.4	30.3	70	3	SOT23
DESD1LIN2WSQ	LIN	24/15	25.4/17.1	27.8/18.9	50/35	3	SOD323

USB/Data

USB and high-speed data buses like HDMI may also require TVS protection. These connections have multiple lines and run at high speed, so low capacitance is key to preserve data integrity. For multiple data lines small packaging is critical to fit multiple devices into limited board area.

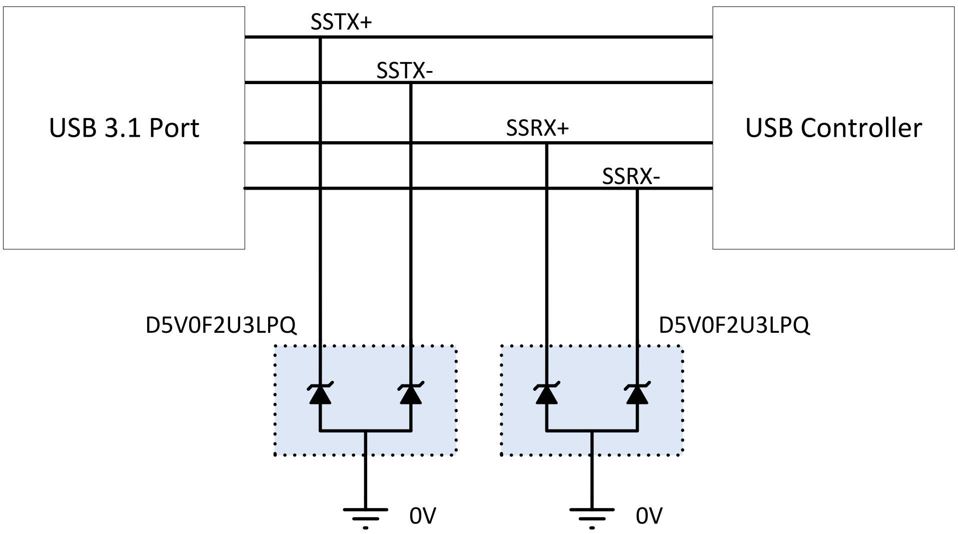

Figure 14: USB 3.1 data line protection TVS device

For high-speed data applications, devices such as the D5V0F2U3LPQ offer low capacitance to maintain signal integrity. The small X-DFN1006-3 package allows dual devices to be fitted into less board space – ideal for high speed data pairs in USB 3.1.