Failure Modes and TVS Devices

By: Dave Hutchins

Transient voltage suppressors (TVS) will fail if they are subjected to conditions beyond their designed limits. Thus, it is important to understand the types of failure modes associated with TVS devices before designing them into a circuit application. There are three basic types of failure modes:

- Shorted devices conduct current away from the circuit or system affecting its performance.
- Open devices are transparent to the circuit/system and will not usually disturb circuit functions. In either case, it is difficult to determine if the TVS is still functioning properly while in the circuit.
- Degraded devices are the most difficult to detect within the circuit. These can be devices with high leakage currents, which may not adversely affect circuit performance, except under elevated operating temperatures.

Misunderstanding Fail Safe Conditions

With the thought that a TVS device can fail, there are some additional terms that designers would like to impose on manufacturers to ease this problem. One such term is a "Fail Safe" condition. The term implies some level of safety which cannot be used in conjunction with a TVS device. Due to the very nature of the unknown transient threat, there are no guarantees against failure. "Fail Safe" is one of the most misunderstood terms regarding transient protection. It is important to define the term and discuss why it should not be used in reference to TVS devices.

Words have different meanings to different people, which is the case with the term "Fail Safe". A TVS device cannot assure a fail safe environment. Unfortunately, a TVS will fail when subjected to a transient beyond its designed capability. For instance, if the circuit or system is not properly fused, a shorted TVS can become a safety hazard, conducting operating currents through the return path. Even with the proper design-in and adherence to good engineering practices, this term should not be used in describing the function of the protection network.

Quite often, an unknown transient threat, along with some of the guesswork regarding the sizing (Peak Pulse Power Rating) of the TVS device, will suggest some level of risk in the overall protection of the system. The risk, in this case, is the trial and error method used to determine proper TVS device selection. This type of process may take some time to accomplish when the transient threat cannot be fully defined. "Fail Safe" may be used in conjunction with a complete system approach, but not with a component such as a TVS device.

Short TVS Devices

Device shorts can occur at the semiconductor chip junction surface interface or within the bulk material. On the junction surface, this type of short will appear as a burn spot on the junction surface or as a dark spot on the top or bottom of the silicon chip.

For bulk material, a device short will be a function of the amount of transient current that was passed through the silicon chip. The burn spot can be as a small as a pin hole or as large as a funnel hole of a few millimeters in diameter.

In both cases, there will be evidence of remelted semiconductor material. Its size depends on the current amplitude of the transient and any additional follow-on current that is present over a short period of time. Longer pulses will usually remelt the solder material which can bridge the silicon chip causing the shorted condition (removal of the solder bridge will allow the TVS device to recover).

In most applications, if a component is going to fail, the preferred mode would be a short, which is the easiest to identify. A short is defined when the TVS device has a resistance value of less than 1 Ohm at a DC voltage of 0.1 Volts (Ref. IEEE/ANSI C62.35). A shorted device will start to conduct a significant amount of operating current to ground as shown in Figure 1. The actual current shunted to ground will depend upon the resistance in the line ahead of the TVS device. For the power line, this could mean a significant amount of current depending upon the available current from the power supply or source. With data lines, this can be somewhat limited, but will depend upon the operating current of the circuit.

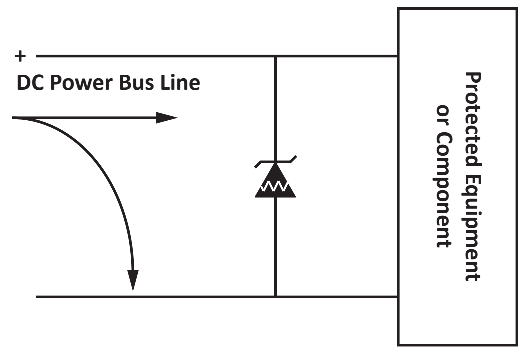

Figure 1. Current Path for Shorted Surge Suppressor

Open TVS Devices

An open TVS device is defined as a diode that has a breakdown voltage $V_{(BR)}$ greater than 150% of the pretested value at an applied test current (I_P) (Ref. IEEE/ANSI C62.35). For this test, the unit must be taken out of circuit for verification. An open device within the circuit will not exhibit any of the standard electrical characteristics such as leakage current or clamping voltage. Once out of the circuit, the TVS device can be tested on a curve tracer for verification of the open conditions.

In an improperly fused circuit, a device that has been shorted can become open after an applied operating current is allowed to conduct through the device for a period of time. When this occurs there is usually some visible evidence in the form of a burn mark on or within the device, indicating an open unit.

Degraded TVS Devices

Devices that degrade are more difficult to detect. These types of failed devices will exhibit an increase in the reverse leakage current under normal operating voltages (equivalent to the stand-off voltage). According to IEEE/ANSI C62.35, a degraded failure mode has occurred when the avalanche junction surge suppressor has a stand-by current greater than the maximum specified. On the power bus line, this level of current may not be noticed until the leakage current reaches the upper limit of the power supply current, or when the unit shorts from increased current conduction. For data lines, this value may be much less due to the fact that there can be loss of data transmission of information. A device will act as a low impedance shunt path to ground.

IDENTIFYING FAILURES

One of the most difficult problems is identifying failures. In-line tests are often used as the checkout procedure for the system/circuit performance. With a transient voltage suppressor, this may not be the best solution. The first step is the identification of the problem area - the power bus or the data line. The second step is to perform a visual inspection to locate the failed device or see evidence of a burn spot on a component. The last step is to apply power to the circuit for performance testing and test for any loss of data.

In some cases, tripping of a circuit breaker or a blown fuse will indicate some type of line problem. Trace the line to the problem area. When a circuit breaker or fuse does not function, do not reset the circuit breaker or replace the fuse, until source has been identified. With data lines, this can be somewhat difficult if the fusing link does not function due to improper sizing.

Problems on the data line can manifest as loss of data, erroneous input or internal damage to the component. The quickest way to determine if the problem exists on the data line is to systematically replace components. Use caution when replacing some circuit components that insure system performance will not always allow in-circuit testing if the transient suppressor has failed or is out of specification.

Lastly, it is important to identify any defective pins in TVS devices that have package configurations with multiple leads. This will help define the potential source of the problem and provide information relative to the lack of input coordination between pins on a given component.

TRIAL AND ERROR

The transient threat and the location of the transient voltage suppressor in the equipment will also have a major influence on the type of failure mode. In some applications, the transient currents and impulse waveform cannot be completely defined. As a result, the correct TVS device may not be designed into the application. Choosing the correct TVS device is a trial and error process. A TVS device is designed to withstand a specific level (power) of transient threat as defined by a peak pulse power (P_{PP}) rating for a specific waveshape (i.e., 8/20µs) as shown in Figure 2.

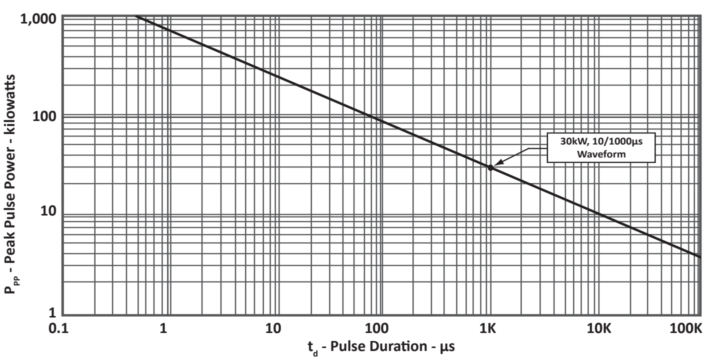

Figure 2. Peak Pulse Power vs Pulse Time

Most manufacturers will provide a peak pulse power versus time curve on their individual product specifications. This will provide the designer with the maximum power limit within a product family or series of devices. It is up to the circuit or system designer to translate this product information into the appropriate threat level. Threat levels should always be defined in terms of the peak current, amplitude, and impulse waveforms rather than to calculate the energy of the TVS device from the power curve.

Energy is not a key parameter. Energy contained within the transient event is not the energy deposited into the TVS. Equating the transient current threat to the peak pulse current rating of the TVS will ensure proper device selection and continuous operation of the protector in the application.

However, there are those applications in which the actual transient current cannot be defined. At best, the identification of the source of the transient is necessary; that is, lightning, switching, ESD or EMP. From this information, the manufacturer can provide the direction for initial product selection.

Product selection begins as follows:

1. Stand-Off Voltage > Operating Voltage
2. Peak Pulse Current > Transient Current
3. Voltage Protection > Clamping Voltage

It is necessary to equate the transient current to the peak pulse current of the TVS device. Transient Current must be less than the peak pulse current of the TVS for continuous operation, as it is the transient current that causes the TVS device to short.

Fusing

Follow-on current after a TVS device has shorted can become a safety or performance problem. For these reasons, it is suggested that a fuse or fusible link be inserted in the line ahead of the TVS device for both power and data line applications. Selection, as well as location of a fusing element is important. It is possible to determine the I^2t value necessary to select the fuse for any follow-on current. As this data is defined as the clearing time for a TVS device to open up for a continuous applied current, it is necessary to select a fuse with an I^2t characteristic below the device capability.

Location of the fuse should be as close to the TVS device as possible (Figure 3).

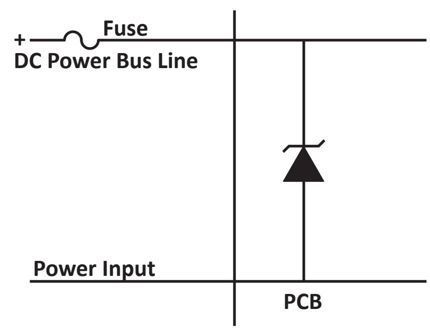

Figure 3. Fuse Location Relative to the TVS Device

For equipment and high level systems protection, the fusing element can be a circuit breaker located at the point of power entry. At this location, the power and transient currents are terminated at the point of power entry input to the equipment preventing any additional problems such as safety hazards, data errors or component damage.

Data lines operating in the milliampere range are more difficult to fuse. In either case, it is important to provide some type of fusing in the line to open up the circuit when a TVS device does short as shown in Figure 3.

The fusing element must take into consideration two possibilities. First, does it have the ability to handle the required transient current without interrupting the circuit functions. Second, is it able to open the line when the TVS device does short.

SUMMARY

TVS products can fail when subjected to conditions beyond their design limits. It is important to understand the types of failures that can effect a TVS device. Identifying the circumstances of how and where these failures occur will help a designer choose the correct TVS device for the application. Lastly, understanding TVS device parameters as they relate to these transient threats that cause failure, will ensure proper device selection and continuous operation of the protector in the application.

COMPANY INFORMATION

COMPANY PROFILE

ProTek Devices, based in Tempe, Arizona USA, is a manufacturer of Transient Voltage Suppression (TVS) products designed specifically for the protection of electronic systems from the effects of lightning, Electrostatic Discharge (ESD), Nuclear Electromagnetic Pulse (NEMP), inductive switching and EMI/RFI. With over 25 years of engineering and manufacturing experience, ProTek designs TVS devices that provide application specific protection solutions for all electronic equipment/systems.

ProTek Devices Analog Products Division, also manufactures analog interface, control, RF and power management products.

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