How To Select Transient Voltage Suppressors

There are important Transient Voltage Suppressor (TVS) data sheet characteristics and ratings that require careful comparisons to circuit-component limitations and transient conditions before selecting the optimum component. When using these TVSs, the most important parameters are identified as the Rated Working Peak Voltage or Rated Standoff Voltage (V_{WM}), the Peak Pulse Power Dissipation (P_{pp}), Peak Impulse Current (I_{pp}), and Clamping Voltage (V_C). Further parameters are also described herein and how they might further influence selection of TVS components.

It is important to recognize that a TVS is primarily intended to serve as a shunt-voltage clamp across sensitive components in the circuit to prevent high voltage transients from damaging them. Until these transients occur, the TVS will be idling at very low standby current levels and appear "transparent" to the circuit. When a high voltage transient does occur, the device clamps the voltage by avalanche breakdown.

TVS Voltage Selection with V_{WM}

The first step in selecting a TVS is to determine what the highest continuous peak normal operating voltage will be at the point of intended protection in the circuit. This should include continuous dc or repetitive ac peak voltages such as sinusoidal peaks intended for normal operation, but excludes any higher undesired voltage transients that need to be clamped or suppressed. This highest operating voltage will then determine the Rated Standoff Voltage (V_{WM}) selection of the TVS component. This is also identified as the rated working peak voltage for the selected TVS device where it provides high impedance and low standby current (I_D) in the circuit during normal operation. Although most of the electrical characteristics are given only for 25ºC conditions in TVS data sheets, the V_{WM} is a value that is also applicable over the specified operating temperature range. This is typically -55ºC to +150ºC for plastic components and -55ºC to +175ºC for glass or metal hermetically sealed components. The MCC TVS products are available with V_{WM} voltages ranging from 2.7 volts to 400 volts or higher.

The next higher voltage characterized for TVS devices is the breakdown voltage V_{BR}. It is typically 10 to 15% above V_{WM} and is the voltage that TVS devices go into avalanche similar to a zener diode. It may be specified with both minimum and maximum or with just the minimum at a relatively low specified current value. The V_{BR} also has a temperature coefficient of $\alpha_{V(BR)}$ similar to zeners that must be considered when operating over a broad temperature range. Since the $\alpha_{V(BR)}$ has a maximum of +0.1%/°C for TVS products, it is also the primary reason the V_{WM} is located at least 10% below V_{BR} for the rated standoff voltage. When devices are operated in cold conditions down to -55°C (for example), the V_{BR} declines in value thus reducing the margin remaining between rated standoff or working peak voltage V_{WM}.

The highest voltage parameter specified for a TVS is V_C or clamping voltage under high-current pulse conditions. It is typically 35 to 40 % higher than V_{BR} (or 60 % higher than V_{WM}) and represents the maximum clamping voltage during the specified peak impulse current I_{pp}. When making this V_C comparison to the circuit, it is important the clamping voltage does not exceed the instantaneous voltage level acceptable for safe operating conditions of the other components that are protected by the TVS in the circuit. Most of this V_C voltage increase above the initial V_{BR} during surge is a result of the positive temperature effects from energy and heat inside the TVS component that is briefly generated during the high-current-surge event. The remainder is due to parasitic resistance effects of the TVS during the impulse for the typically specified 10/1000 µs or 8/20 µs surges.

TVS Power Selection by Calculation of P_{PP}

All TVS devices are rated in various Peak Pulse Power dissipation (P_{pp}) levels to allow economic and safe suppression of a variety of different surge conditions. This typically ranges from 150 W to 90,000 W and higher for MCC TVS components in safely clamping various impulses. To select a component in P_{pp} by calculated methods, it is necessary to define the transient conditions in both Peak Impulse Current (I_{pp}), pulse width and waveform. The P_{pp} is the product of the clamping voltage multiplied times the peak impulse current or $P_{pp} = V_C \times I_{pp}$. Since the maximum V_C is already known by its described relation with the previously selected V_{WM} above, the I_{pp} is the primary item further needed to determine P_{pp}. This worst-case surge current can be determined if the open-circuit-transient voltage (V_{OC}) and short-circuit current (I_{SC}) are identified. These conditions are often include in various industry standards such as the IEC1000-4-2, 1000-4-4 and 1000-4-5 International Standards or RTCA/DO-160 for avionics. These describe ESD, EFT, or lightning conditions respectively for the IEC standards. When surge conditions are known in this manner, the source impedance (Z_S) can be determined by Ohms Law where $Z_S = V_{OC}/ I_{SC}$. Any other resistance in the circuit (R_C)

between the transient source and the TVS location should also be included before calculating the peak impulse current I_{pp} value. Other inductance and capacitance effects in the line have been neglected for this simplified worst-case analysis. With these values we can again determine:
$I_{PP} = (V_{OC} - V_C) / (Z_S + R_C)$ by Ohm's Law. As may be observed in this example, the voltage difference between the transient open-circuit voltage and the clamping voltage of the TVS occurs across the combined source resistance and added circuit resistance. We can then determine what the P_{PP} is for the TVS by multiplying the I_{PP} by V_C or:
$P_{PP} = V_C \times (V_{OC}-V_C)/(Z_S + R_C)$. If the clamping voltage of the TVS component is very low compared to the open-circuit transient voltage and there is no other added circuit resistance R_C, then the surge current is simply the short-circuit surge current I_{SC} or V_{OC}/Z_S as a worst-case (highest) peak impulse current analysis. In this worst case, the
$P_{PP} = V_C \times I_{SC}$.

In addition to these power calculations, the actual pulse width and waveform must be considered for accurate selection of a TVS. Many TVS devices have their P_{pp} rated for either 10/1000 µs or 8/20 µs surges. However TVS data sheets also show how this P_{pp} is affected by shorter or longer pulse widths or waveforms on a log-log plot. These generally follow a Wunsch-Bell curve relation where P_{pp} capabilities will increase by one decade (ten fold increase) for every two decades decrease in pulse width (100 fold decrease). When also operating TVS devices at elevated temperatures, the P_{PP} must be derated.

TVS Power Selection by Approximation of P_{PP}

Surge events by their very nature can sometimes be very allusive or undefined. If the surge conditions are not known with open-circuit-transient voltage and short-circuit current or by means of oscilloscope evaluation during a surge event, other guidelines have also been used to serve as approximations in selecting a TVS. There are three basic categories in levels of protection that have been recognized in the industry as to where TVS components may be used or located . These are "primary", "secondary", and "board" levels. Since the last one requires the lowest P_{PP} protection, we will start with that example first.

In **"board level"** designs, they can still experience high-voltage spikes but also have the highest source or circuit resistance. As a result of these current-limiting effects, they have the lowest comparative peak impulse currents and transient P_{pp} requirements. Applications at this level most often use TVS power selections of 400 W to 600 W at 10/1000 µs or 300 W to 500 W at 8/20 µs. These latter shorter-pulse width ratings are designed for ESD threats and low-level induced lightning at the board level that are suitable for protection against HBM test levels up to 15,999 V and higher.

In **"secondary level"** designs, the needed protection areas will normally be preceded with a transformer or a given series resistance and inductance. The peak impulse currents are greater than board level, but not of the high level otherwise experienced on low-impedance lines. A 1500 W TVS will typically be sufficient for most of these "secondary" protection levels, however engineering judgment should still be used for each example. There are also individual TVS components now available up to 5000 W or even 15,000 W without resorting to larger arrays. These can also be useful if tighter clamping-voltage ratios (V_C/V_{WM}) are needed by simply over sizing the TVS in P_{PP} to reduce the V_C experienced from a specific known surge condition.

The **"primary level"** of protection is the most severe transient environment. It usually has a very low source impedance as well as a low series resistance. For example this might involve transmission lines that are exposed to the highest degree of voltage transients such as power switching or lightning strikes. As a result of this combination, a single TVS may not be adequate protection. However MCC does offer a series of custom modules involving TVS arrays to fit individual requirements with up to 90 kW of P_{pp} or higher. Like any of the silicon p-n junction TVSs, these larger TVS designs also do not have wear-out mechanisms as do other high-power-suppression devices such as MOV's.

Other TVS Parameter Selections

The capacitance of a TVS can often become an added characteristic of importance if the frequency or baud rate on signal lines is relatively high. Otherwise the capacitance contributed by the TVS will cause excessive losses in the circuit. There are many low-capacitance options available from MCC in a variety of sizes or P_{PP} ratings such as 100 pF for 1500 W ratings or 50 pF at 500 W ratings with 10/1000 µs surges. Also a great variety in TVS arrays are available for I/O signal lines for protecting transceivers and other sensitive components from damaging ESD events. These latter examples are available down to 2.5 pF and 5 pF in various SO-8 and SO-16 examples including unidirectional or bi-directional respectively.

All of the MCC TVS devices can also be provided in both unidirectional and bi-directional configurations where the latter is most often distinguished by adding a "C" or "CA" suffix to the part number.