MicroNote 125

Selecting Transient Voltage Suppressors

By Kent Walters

Before selecting the optimum component, there are important transient voltage suppressor (TVS) characteristics that require careful comparisons to circuit component limitations and transient conditions. When using these TVSs, the most important parameters to consider are 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). Other TVS parameters and how they might further influence selection of TVS components are described herein.

The primary purpose of a TVS is to serve as a shunt-voltage clamp across sensitive components in the circuit to prevent damage from high voltage transients. 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. Also see MicroNote 103 for further details.

TVS Voltage Selection with Vwm

The first step in selecting a TVS is to determine the highest continuous peak normal operating voltage 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. This also excludes any higher undesired voltage transients that need to be clamped or suppressed. This 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 25 °C conditions in TVS datasheets, the V_{WM} is a value that is also applicable over the specified operating temperature range. This is typically –55 °C to 150 °C for plastic components and –55 °C to 175 °C for glass or metal hermetically sealed components. The Microsemi TVS products are available with V_{WM} voltages ranging from 2.7 V to 400 V 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 in which 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 in that it 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}. 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 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 that 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} 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 Ppp

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 Microsemi 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 peak impulse current (I_{PP}), pulse width, and waveform. The P_{PP} is the product of the clamping voltage multiplied by the peak impulse current, or $P_{PP} = V_C \times I_{PP}$. Since the maximum V_C can be identified by its relation with the previously selected V_{WM}, the I_{PP} is the only other item 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 included 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, and lightning conditions, respectively, for the IEC standards. When surge conditions are identified in this manner, source impedance (Z_S) can be determined by Ohm's 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 seen 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 the P_{PP} 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 datasheets 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 (tenfold increase) for every two decades decrease in pulse width (100-fold decrease). This is further described in MicroNotes 104 and 120. When also operating TVS devices at elevated temperatures, the P_{PP} must be derated. These methods are shown in MicroNote 115.

TVS Power Selection by Approximation of Ppp

Surge events by their very nature can sometimes be 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 can also serve as approximations in selecting a TVS. There are three basic levels of protection (that have been recognized in the industry), where TVS components may be used or located at primary, secondary, and board levels. Since the last one requires the lowest P_{PP} protection, we will start with that example first.

Board-level designs 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 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 areas that need protection 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. This is achievable by simply oversizing the TVS in P_{PP} to reduce the V_C experienced from a specific known surge condition. See MicroNote 108 for further details.

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 Microsemi 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 pn junction TVSs, these larger TVS designs also do not have wear-out mechanisms as do other high-power suppression devices, like MOVs.

Other TVS Parameter Selections

TVS capacitance can also be important 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 Microsemi in a variety of sizes or P_{PP} ratings, including 100 pF for 1500 W ratings or 50 pF at 500 W ratings with 10/1000 µs surges. A great variety in TVS arrays are also available for I/O signal lines in order to protect 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 bidirectional, respectively. See MicroNote 117 and MicroNote 121.

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

Support

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