MicroNotes

Series 120

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Selecting TVS Devices with Rated Peak Pulse Power and Waveform Energy Considerations

Transient Voltage Suppressors (TVSs) are primarily rated for Peak Pulse Power (P_{PP}) when selecting what type to use in a given environment. Most are rated at the 10/1000 µs double exponential waveform originating in telecommunications. However, other pulse widths and waveforms may also better describe transient threats. This also affects device selection and P_{PP} rating as shown in Figure 1. Each waveform shown behaves in a different manner primarily because energy or effective power integral over a specified pulsed time interval (t_W) will differ in severity. For TVS ratings, the P_{PP} of a given device is determined by the Peak Pulse Current (I_{PP}) multiplied by the Peak Clamping Voltage (V_C) of the TVS. This peak current may only briefly occur as in the initial portion of the 10/1000 µs pulse shown in Figure 2, or in unusual cases it may be at its effective peak during the entire specified pulse width in a worst case square wave condition of energy. These different transient impulse waveform and energy conditions will also result in different P_{PP} capabilities by the TVS as shown in Figure 1 from the three examples shown.

A well behaved relationship between P_{PP} capabilities and t_W is evident in Figure 1 in the declining slope region for all three waveforms shown until very long pulse widths are experienced. The declining slope region can be closely approximated in the following expression as:

$$P_{PP} = K(t_W)^{-0.5} \qquad \textbf{EQ. 1}$$

where K is a different constant for each waveform. This expression (also historically known as the Wunsch-Bell relation) is applicable for nonrepetitive pulse widths (t_W) significantly shorter than the dc thermal equilibrium time constant of the TVS package. Pulse widths of less than 10 ms fit this relationship very well, particularly when the active pn junction element (die) is bonded to the adjoining package materials as an immediate heatsink. For very long pulse widths approaching dc conditions, the P_{PP} continues to decline and level out as it approaches the dc power rating of the package design. Repetitive pulses of less than 10 ms but greater than 0.01% duty factor will require temperature derating of P_{PP} based on *average* power cumulative heating effects.

For TVS designs, the size of the effective silicon pn junction (zener area) is larger to permit comparatively high P_{PP} for short transients. The K factor in EQ.1 is dictated by the pulse waveform shape and is inversely proportional to the integrated area (or energy) under the current pulse-time waveform illustrated in the smaller insets of Figure 1. From the various wave shapes shown in Figure 1, it may be shown that a double exponential waveform has a K factor 1.5 times greater than a square wave. A one-half sinusoidal waveform with t_W=0.7t_P has a K factor 1.33 times greater than a square wave.

For various TVS design capabilities, EQ. 1 can be broadened in application by including yet another design factor C that is proportional to size of the effective silicon pn junction area. This added design feature would then further provide the P_{PP} capability expression:

$$P_{PP} = CK(t_W)^{-0.5} \qquad \textbf{EQ. 2}$$

Large and small TVS devices with their corresponding P_{PP} rating are primarily designed with this relationship where larger active die element pn junction areas increase the factor C for higher P_{PP} rating or visa versa for lower rating and sizes. As

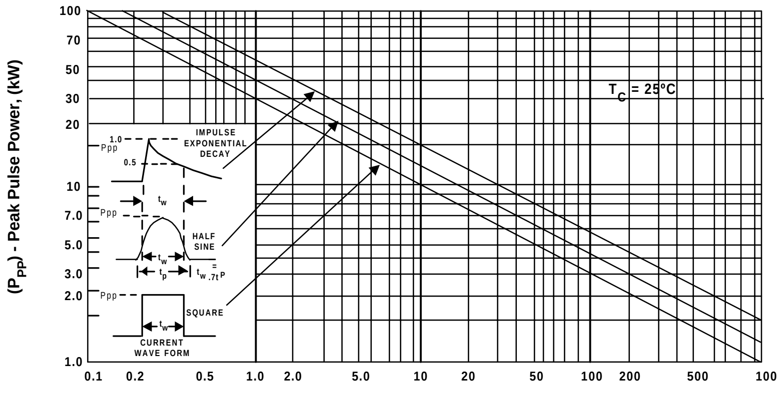

FIGURE 1
PEAK PULSE POWER VS. PULSE (tw) in µs
(For 1500 W Rated TVS @ 10/1000 µs Wave Form)

may be seen in this relationship, the same negative slope behavior on a log-log plot as in Figure 1 will result for different higher or lower P_{PP} designs versus t_W for various current impulse waveforms. This behavior provides a similar set of identical negative slope lines seen in Figure 1 translated up or down on the ordinate axis for higher or lower P_{PP} ratings when designing with larger or smaller TVS package and die elements.

The energy which a TVS absorbs can be derived by integrating power with time as follows:

$$E = \int_0^{t_W} P(t)\,dt \qquad \textbf{EQ. 3}$$

where the power P(t) is a function of time t as primarily dictated by pulse wave shape of surge current multiplied times the clamping voltage V_C. For a TVS *clamp characteristic*, this latter V_C is often considered relatively constant whereas the current waveshape is a function of time i(t) as shown in the Figure 2 example of a double exponential 10/1000µs. It should be noted that P(t) is *not* the P_{PP} in EQ.2 except for the special case of a square wave. For various current impulse wave shapes, the EQ. 3 then becomes:

$$E = V_C \int_0^{t_W} i(t)\,dt \qquad \textbf{EQ. 4}$$

To gain insight of how *energy capability* of a TVS device behaves with time t in a *simplified example*, we will use a square wave impulse where the current i(t) is constant during the pulse width t_W. In this case, the power P(t) also remains constant over the pulse width t_W in EQ. 3. This constant P(t) also equates to the value of P_{PP} described previously in EQ. 2. Substituting this P_{PP} value into EQ. 3 for a square wave and integrating for a solution will result in:

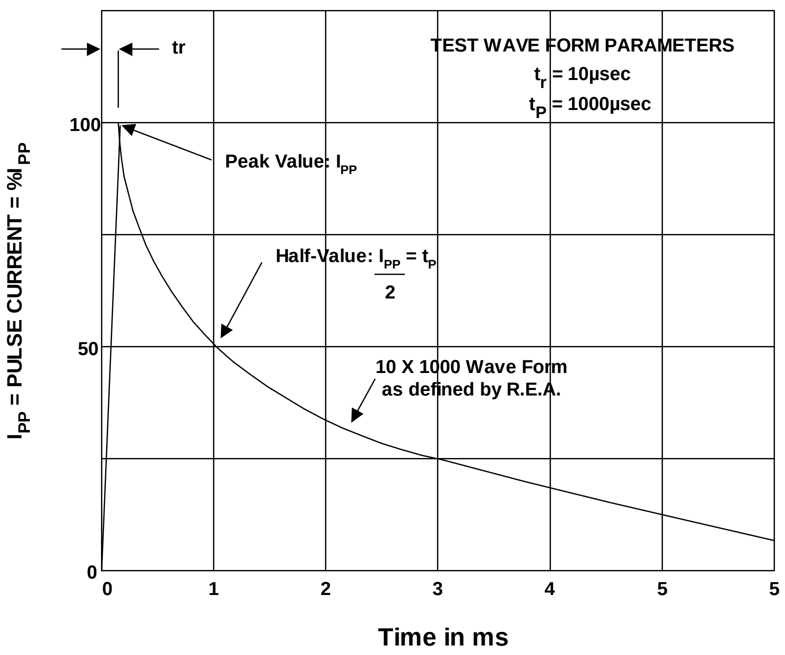

FIGURE 2
PULSE WAVE FORM

$$E = CK(t_W)^{-0.5} \int_0^{t_W} dt = CK(t_W)^{0.5}$$

EQ. 5

As may be seen from EQ. 5, the energy (joules) that can be absorbed by the TVS increases as the square root of the pulse width (t_W). If plotted in a similar manner as in Figure 1, it would instead have a positive slope as shown in Figure 3 with the same magnitude as the negative slope for transient peak pulse power as t_W is increased. Although different in slope direction, the TVS rating in energy is also still dependent on the pulse width t_W. For this reason, simply rating a TVS in power or energy is not adequate without defining a pulse width as well.

For various transient waveforms it is the highest magnitude surge currents over a short period of time that are the most critical. For example in an exponentially decaying wave or a damped sinusoidal wave, it is the initial highest magnitude region of the impulse that is of greatest concern in selecting a TVS. This can best be understood from EQ. 5 since the TVS energy rating decreases with pulse width while peak pulse power increases. This is illustrated in Figure 3.

Transient Voltage Suppressors are characterized and rated with this feature in mind since P_{PP} is high at short time intervals, whereas energy absorbing capabilities are minimal but improves with longer pulse widths. For example, the region beyond the half-value decay point on a double exponential waveform becomes negligible in comparative added energy the TVS can safely absorb in the prolonged tail region of the impulse. Double exponential waveforms such as shown in Figure 2 are therefore simply described as a 1 ms pulse to their 50% decay point. It may also be said that such waveforms decay faster than the P_{PP} capability curve vs pulse width t_W in figure 1, thus making prolonged pulse widths negligible in rating the capability of the TVS device.

Similarly on damped sinusoidal transient voltage surges (not shown), only the initial worst case half-sine wave needs to be considered for TVS selection in each direction *if* the transient decays to one half the initial peak within eight periods of oscillation. After considering source impedance with these described transient voltage waveforms, the peak sinusoidal transient currents (I_{PP}) may be used to determine P_{PP} when multiplied by their rated TVS clamping voltages (V_C). These transient currents may be shown in damped sinusoidal waveforms with the formula:

$$i(t) = I_{PP}\, e^{(-\pi ft/Q)} \sin(2\pi ft)$$

where f = frequency, Q = damping factor, and I_{PP} approximates the initial half sinewave peak surge current. The sinusoidal peaks will subsequently decay to less than 50% of the initial peak within 8 cycles if Q is less than 36. Typical values of Q range from 6 to 24 in many applications. The actual Q factor is dependent on the resonant frequency of the system where such transients are observed due to length of electrical lines and other factors. These type waveforms are often experienced from lightning induced transient bursts such as with on-board systems of aircraft and ship applications.

In summary, the transient power capability (P_{PP}) of a TVS is inversely proportional to the square root of short transient pulse widths t_W. In contrast energy is proportional to the square root of these same short pulse widths. Since TVSs are primarily rated in terms of P_{PP}, defining the pulse width t_W and its shape are both vital in the overall selection process of a TVS as may be seen in Figure 1. When transient current pulse widths or shapes are not well defined (magnitude or shape), it is wise to design conservatively and select TVSs with higher P_{PP} rating. Even if not needed, this also results in improved (lower) clamping voltage performance and added margin of reliability during surges as described in Micro Note 108.

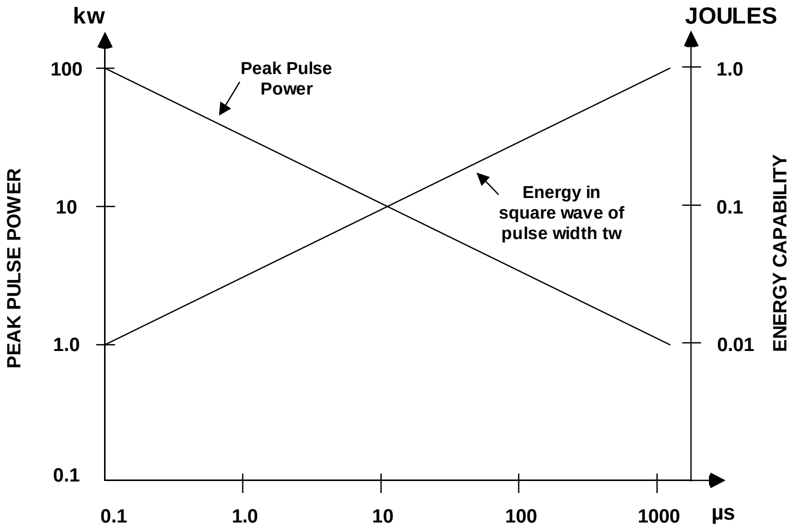

FIGURE 3
PEAK PULSE POWER AND ENERGY VS TIME (tw) in µs
(Example shown is for square wave)