MicroNote 120

Selecting TVS Devices with Rated Peak Pulse Power and Waveform Energy

By Kent Walters

Transient voltage suppressors (TVSs) are primarily rated for peak pulse power (P_{PP}) when determining which 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 the following illustration. 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 occur briefly in the initial portion of the 10/1000 µs pulse, shown in the following illustration. In unusual cases, it may be at its peak effectiveness during the entire specified pulse width in a worst-case, square wave condition of energy. These differing transient impulse waveform and energy conditions will also result in different P_{PP} capabilities by the TVS, as shown in the three examples in Figure 1 (see page 1).

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

Equation 1:

$P_{PP} = K(t_W)^{-0.5}$

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.

Figure 1: Peak Pulse Power vs. Pulse

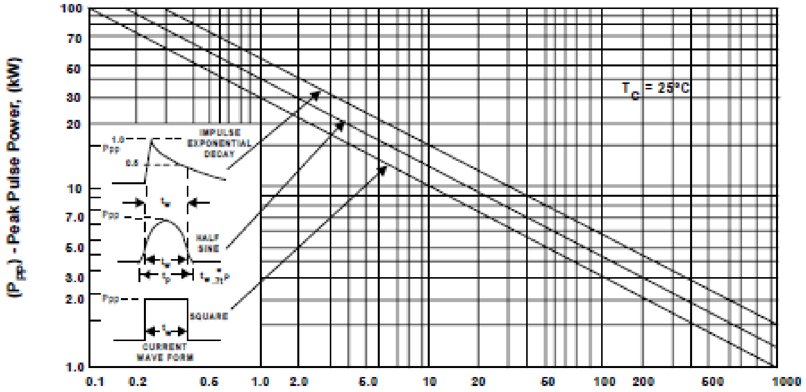

FIGURE 1
PEAK PULSE POWER VS. PULSE (tw) in µs
(For 1500 W Rated TVS @ 10/1000 µs Wave Form)

For TVS designs, the size of the active silicon pn junction (avalanche breakdown area) is larger in order to permit comparatively high P_{PP} for short transients. The K factor in Equation 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 (see page 1). From the various wave shapes shown in Figure 1 (see page 1), it may be shown that a double exponential waveform has a K factor 1.5x greater than a square wave. A one-half sinusoidal waveform with $t_W= 0.7t_P$ has a K factor 1.33x greater than a square wave.

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

Equation 2:

$P_{PP}= CK(t_W)^{-0.5}$

Large and small TVS devices, and their corresponding P_{PP} ratings, are primarily designed so that the larger active die element pn junction areas increase the factor C for higher P_{PP} ratings, and visa versa for lower ratings and sizes. As demonstrated by this relationship, the same negative slope behavior on a log-log plot (like in Figure 1 (see page 1)) will result in 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 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 absorbed by a TVS can be derived by integrating power with time as follows:

Equation 3:

$$E = \int_0^{t_W} P(t)\, dt$$

where the power P(t) is a function of time t as primarily dictated by pulse wave shape of surge current, multiplied by the clamping voltage V_C. For a TVS clamp characteristic, the latter V_C is often considered relatively constant. The current waveshape, however, is a function of time i(t) as shown in Figure 2 (see page 3). It should be noted that P(t) is not the P_{PP} in Equation 2, except for the special case of a square wave. For various current impulse wave shapes, Equation 3 then becomes:

Equation 4:

$$E = V_C \int_0^{t_W} i(t)\, dt$$

Figure 2: Pulse Wave Form

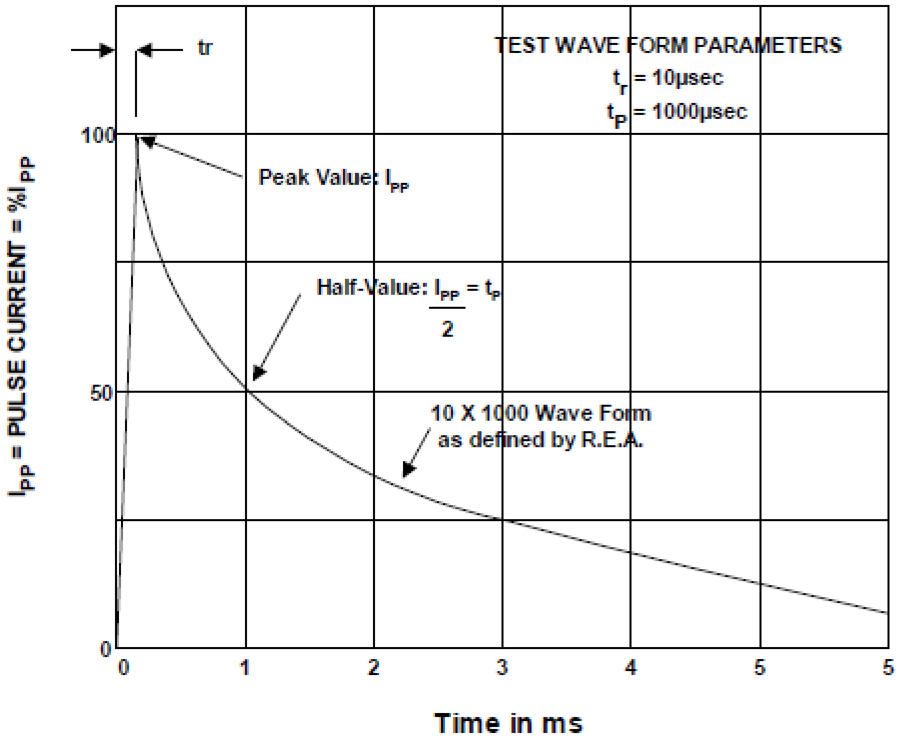

FIGURE 2
PULSE WAVE FORM

To gain insight of how the 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 Equation 3. This constant P(t) also equates to the value of P_{PP} described previously in Equation 2. Substituting this P_{PP} value into Equation 3 for a square wave and integrating for a solution will result in:

Equation 5:

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

As seen in Equation 5, the energy (in joules) that can be absorbed by the TVS increases with the square root of the pulse width (t_W). If plotted according to the illustration in Figure 1 (see page 1), there would be a positive slope (like that shown in Figure 3 (see page 4)) 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 is 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, the most important feature is the highest magnitude surge current over a short period of time. For example, in an exponentially decaying wave or a damped sinusoidal wave, the initial highest magnitude region of the impulse is the most important part of selecting a TVS. Equation 5 shows this best, considering how the TVS energy rating decreases with pulse width while peak pulse power increases. This is also illustrated in Figure 3 (see page 4).

Transient voltage suppressors are characterized and rated with this feature in mind, as P_{PP} is high at short time intervals and energy-absorbing capabilities are minimal—although it 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 that the TVS can safely absorb in the prolonged tail region of the impulse. Double exponential waveforms such as those shown in Figure 2 (see page 3) are therefore simply described as a 1-ms pulse to their 50% decay point. It can also be said that such waveforms decay faster than the P_{PP} capability curve vs pulse width t_W in Figure 1 (see page 1), thus making prolonged, exponentially declining 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. This is the also the case 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:

Equation 6:

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

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 eight cycles, if Q is less than 36. Typical values of Q can 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 onboard systems of aircraft and ship applications.

Figure 3: Peak Pulse Power and Energy vs. Time

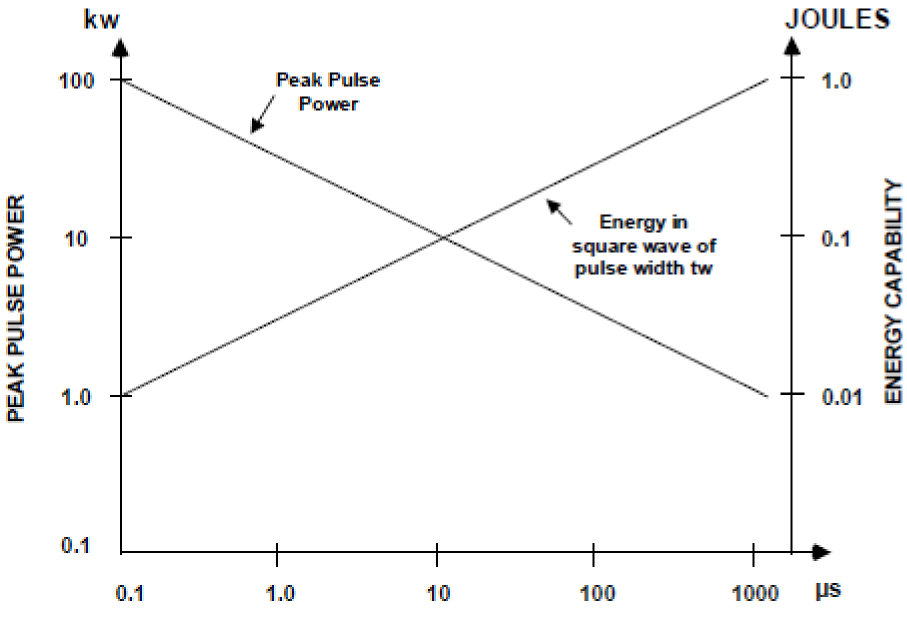

FIGURE 3
PEAK PULSE POWER AND ENERGY VS
TIME (tw) in µs
(Example shown is for square wave)

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 shown in Figure 1 (see page 1). When transient current pulse widths or shapes are not well defined (in magnitude or shape), it is wise to design conservatively and select TVSs with higher P_{PP} ratings. Even if not needed, this also results in improved (lower) clamping voltage performance and added margin of reliability during surges, as described in MicroNote 108.

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