MicroNote 133

Repetitive Surge on Transient Voltage Suppressors

By Kent Walters

The peak pulse power (P_{PP}) ratings provided in datasheets for transient voltage suppressors (TVSs) are primarily for individual impulses with sufficient time to allow cooling before the next transient. This is also known as “random recurring” impulses from external causes where their effects have completely disappeared before the next transient arrives. This is also identified in JEDEC Standard 210 (JESD210) for “Avalanche Breakdown Diode (ABD) Transient Voltage Suppressors” and other related documents. In these type surge applications, the p-n junction temperature is allowed to briefly exceed the maximum rated operating temperature shown in datasheets, typically 150 °C, 175 °C, or 200 °C depending on packaging materials. This notable exception also agrees with other industry documents including military test specifications, such as MIL-STD-750, paragraph 4.8 for nondestructive test descriptions. Typical maximum p-n junction temperatures for TVS devices during these brief surge events can often approach 275 °C when tested at their full rated P_{PP} at an ambient of 25 °C. As a result, the voltage during surge also increases due to the positive temperature coefficient of the avalanche breakdown voltage (V_{BR}) and significantly contributes to higher clamping voltage (V_C) in addition to expected Ohmic resistance effects.

Repetitive Surge Heating

When repetitive surges exist in short duration, cumulative heating will occur. The surge rating capability will also decline in overall performance from resulting elevated temperatures. This would also be expected when viewing P_{PP} temperature derating curves. On many TVS datasheets, a percent repetition rate (or duty factor) may also be specified for its rated P_{PP} and pulse width test conditions that are often with reference to a double exponential impulse of 10/1000 µs (rise/fall time to 50% decay point). In many TVSs, this is a conservative 0.01%. The square wave equivalent of any applied repetitive P_{PP} surges multiplied by the % repetition rate and divided by 100 must be less than the rated dcpower. This feature should be conservative, because extra care must also be taken to ensure it reflects worst-case conditions in mounting the TVS for the significantly lower dc power ratings of these devices compared to the much higher P_{PP} ratings.

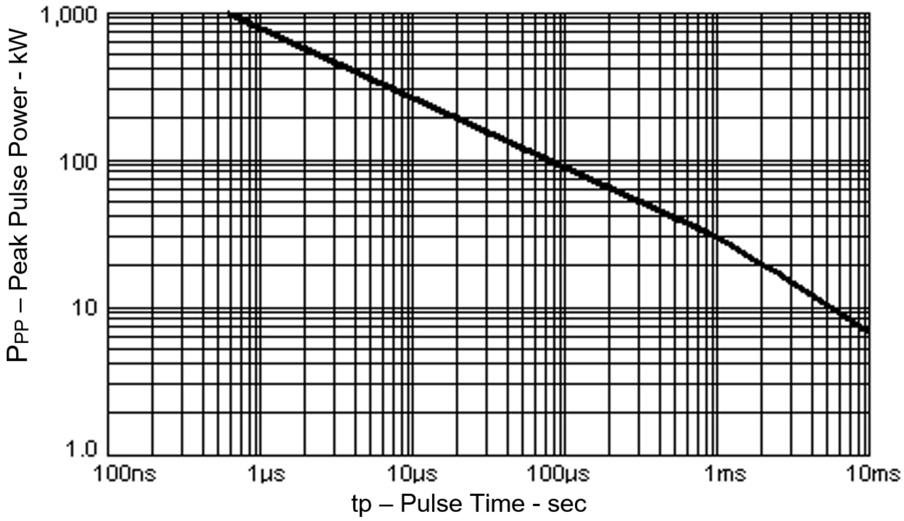
TVS Thermal Management

The dc power ratings on TVS datasheets may also include various mounting (heat sinking) conditions as additional information, since that is a further variable in application beyond the component itself similar to thermal management issues for many other semiconductor devices.

In most TVS applications that only involve random recurring impulses of 1 ms or less, the mounting or heat sinking is not a concern since the event is concluded before the heat starts to escape from the device. However, that does not apply for dc power or extended repetitive surges. For example, mounting devices on small size 1 oz copper pads (using FR4 printed circuit boards for products rated well beyond 1.0 W in steady-state power) can be compromised in overall thermal management compared to what may otherwise be achieved when better controlling the case, lead, or end-cap temperatures to lower values, as is often further referenced for dc power ratings on data sheets for optimum performance. These added “specmanship” methods in controlling device temperatures at their terminations also imply good heat sinking.

In addition to overall thermal management, any extended repetitive surges in various applications require other considerations as well. For individual random recurring pulses, the performance of a TVS is typically shown in a peak pulse power (P_{PP}) vs pulse width or pulse time (tp) curve including Microsemi datasheets, such as the example below in Figure 1 (see page 2) for a TVS device rated at 30 kW at 1 ms (10/1000 µs).

Figure 1: Peak Pulse Power vs. Pulse Time



This characteristic behavior is also shown for many other Microsemi TVS datasheets where TVS devices with lower P_{PP} ratings will portray the same negative slope, but will be positioned lower with respect to the ordinate (P_{PP}) axis. The intersection at 1 ms will coincide with its P_{PP} rating if referenced at 10/1000 µs.

Wunsch-Bell Curve

The “curve” in Figure 1 (see page 2) is a straight line with a negative slope on a log-log plot out to the 1 ms area where P_{PP} is inversely proportional to the square root of pulse width. These illustrations have also been historically known as a Wunsch-Bell curve, where the applied P_{PP} and time correlates to a relatively constant elevated p-n junction temperature during the brief surge event before devices begin to fail above this curve. If the p-n junction surge temperatures are maintained below these failure-threshold levels, TVSs will continue to perform without degradation—unlike MOV devices that have been observed to degrade over time with many random recurring surges. The subject of P_{PP} versus time in performance curves is also further discussed in MicroNote 104 and MicroNote 120 for TVSs.

Averaging Repetitive Surges

From Figure 1 (see page 2), it is apparent the P_{PP} capability of a TVS at 25 °C will be lower at longer overall time durations t_P for any individual surge. This can also include repetitive surges where averaging the power (P_{PPAVG}) over longer time durations t_W for a closely spaced set of identical surges can be used to determine performance capability in this same illustration. However, this type of analysis is limited to the same time domain (10 ms or less), shown in Figure 1 (see page 2) as provided in many individual TVS datasheets. This is necessary to ensure mounting or heat sinking variables do not become an issue at longer times. If the overall time duration of repeated surges is sufficiently short, the method involving a P_{PPAVG} calculation can also apply to Figure 1 (see page 2) of the applicable datasheets despite them exceeding the repetition rate described earlier in many TVS datasheets for longer continuous time durations.

For evaluation purposes in calculating P_{PPAVG}, each of the short multiple surges would have a defined pulse waveform decay time (tp) and a repetition-rate (RR) in percent over a longer duration in total time (t_W). With those features, the P_{PPAVG} for the longer total duration t_W is derived by the equation: $P_{PPAVG} = P_P \times RR/100$. It is necessary to divide by 100 when using a repetition-rate (RR) in percent.

In this method of calculating P_{PPAVG},the P_P is that of the individual identical short pulses where $P_P = I_P \times V_C$ for the peak pulse current and clamping voltage, respectively. This P_{PPAVG} calculation for the overall longer duration (t_W) of repetitive surges can then again be compared to the P_{PP} capability curve in Figure 1 (see page 2) of the applicable TVS datasheet for the same waveform over the longer overall duration t_W of repeated events. This is only valid if the time domain, shown in Figure 1 (see page 2) for various TVS products, starts occurring before other themal management variables or limitations, as earlier described. This is typically for total-time durations less than 1 ms to 10 ms, due to the fact that variables with longer mounting/heat sinking times as cumulative heating need to escape from the TVS device to avoid excessive internal temperatures at the p-n junction(s). The P_{PP} ratings for TVSs are at 25 °C with reference to device terminals. However, this also still approximates ambient temperature for short pulses. To evaluate repetitive surges in longer time domains, further analysis must be made that is not shown on TVS datasheets due to mounting variables and increased device temperatures as a result of heat soak.

Extended Repetitive Surges

Most TVS products are used for 1 ms transients or less. Nevertheless, they can also be used for longer periods if the overall thermal management is carefully considered. If the applied average power involving repetitive surges continues well beyond the thermal time constant of the TVS package, the device power capability features will decline and eventually approach the much lower dc power ratings for very long extended times. Also see MicroNote 134 concerning Zener and TVS combinations.

As with other semiconductor components, the continuous power rating capability is also dependent on other design features of the package and its mounting methods. The P_{PP} versus pulse-width curves shown in Figure 1 (see page 2) of Microsemi TVS datasheets could be extended in an idealistic manner along the same negative slope previously shown until it asymptotically levels out and approaches the dc power level. However, that is not what generally occurs due to other thermal impedance effects at longer heating times as heat escapes from the package with extended time. This can also result in the negative slope of Ppp versus time declining at a much faster rate (compared to Figure 1 (see page 2)) before it eventually levels out to its dc power level depending on mounting conditions.

RTCA/DO-160 Aircraft Requirements

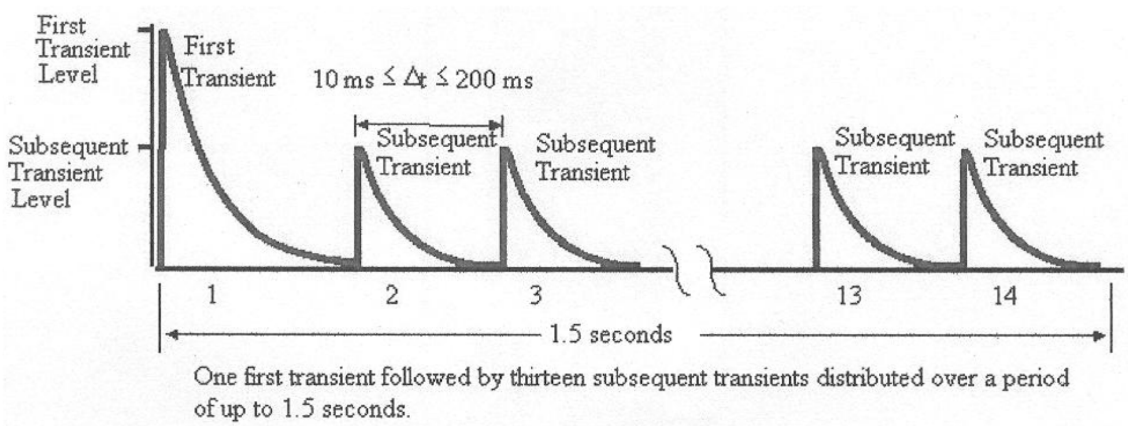
It is for these reasons that lightning threats, defined in the RTCA/DO-160 specification for aircraft, are much more difficult to characterize in overall needed TVS performance features for multiple stroke or multiple burst events as described in Section 22 with Figures 22-7 and 22-8. These threats extend to many hundreds of milliseconds or seconds where overall heat soaking of the device becomes an issue with TVS device mounting variables. These longer threats for repeated surges apply to “cable bundles” for applicable equipment or system level testing in aircraft and are further described in Table 22-4 and 22-5 of that specification. This is beyond the individual pin injection threats (single pulse) for individual lines described in Table 22-2. It is these individual lines where most TVS devices are applied for protection line to ground or line to line.

Considerations must also be given to how these multiple stroke or multiple burst threats will directly affect individual lines within a “cable bundle” needing TVS protection. Such tests only apply to the overall equipment as shown in Figure 22-14 of the RTCA/DO-160 spec. A significant part of these induced equipment threats are to determine electromagnetic compatibility that can also be absorbed by shielding around the cable or by other very low resistance ground lines in the bundle, rather than by the more sensitive lines in the overall cable bundle that require their own TVS protection.

MicroNote 133 Multiple Stroke Transient Threats

The multiple stroke transient aircraft threats often have an initial surge current or voltage with a peak power (P_P) that is higher in value than all the following surges in the sequence over longer extended time, such as 1.5 s (as is found in Figure 22-7 of the RTCA/DO-160 spec). This is shown below in Figure 2 (see page 4). In addition to overall device thermal management variables with mounting the device for longer times (t_W), this method of calculation would require further computer modeling when using a P_{PPAVG} to determine the correct form factor if also trying to compare with Figure 1 (see page 2). However, that method is again limited in excessive time domain, since the P_{PPAVG} will also then be influenced in performance by the other notable variables in mounting methods, where the thermal-time-constant for heat escaping from a package is greater than 10 milliseconds as influenced by package design.

Figure 2: Figure 22-7 Multiple Stroke Application



Optimum TVS Packages for Repetitive Surges

For these reasons, Microsemi is also now seeing interest in the PLAD15KPxxx and PLAD30KPxxx devices, or the newer PLAD18KPxxx and PLAD36KPxxx, with only one or two very large die and much lower thermal resistance from junction to case. This method has advantages for achieving high P_{PP}, instead of using many smaller die stacked up in series within axial-leaded package configurations to generate high P_{PP} capabilities, as otherwise described in MicroNote 112. The use of only one or two die in the PLAD packages will also reduce the thermal resistance from the p-n junction to package terminals to better dissipate heat over longer periods of time as is also needed for repetitive surges. When using only one or two die, these PLAD designs can also be extended to lower TVS voltages, compared to those designed with many smaller die in series where voltages are additive.

The PLAD devices have a large metal base as shown in the following web link: https://www.microsemi.com/existing-parts/parts/140051#resources. These surface mount designs can also take advantage of better heat sink mounting methods and provide much lower thermal resistance junction to case or ambient to permit better performance with repetitive surges or very long "multiple stroke" threats. For example, thermal resistance of the PLAD18KPxxx devices is only 0.7 °C/W from junction to base at the mounting surface (with very short thermal time constant) compared to an axial leaded device with smaller stacked die, such as the 15KPxxx devices where thermal resistance junction to lead—at 3/8 inch distance from the body (typical mounting point)—is much greater (20 °C/W), despite both products having similar surge ratings of 15 kW to 18 kW at a very short 10/1000 µs impulse.

As earlier described, the much lower thermal resistance of the PLAD packages can be of significant advantage if any prolonged repeated surges occur where cumulative heating can otherwise handicap performance. From the PLAD15KPxxx datasheet, it is also evident that the dc power capabilities can be very high when well heat sunk where the case temperature can more easily be maintained closer to 25 °C. All of this becomes advantageous for multiple stroke lightning criteria that can last as long as 1.5 seconds as shown in Figure 22-7 of the RTCA/DO-160 spec for aircraft if needed for cable-bundle testing. This type of extended threat is also shown in Figure 2 (see page 4).

Further data is pending for showing thermal impedance curves over a broad spectrum of pulse widths (heating times) in the next update of this MicroNote. This will focus on product comparison for the PLAD15KPxxx, or the newer PLAD18KPxxx, surface mount product versus older conventional axial-leaded 15KPxxx product with and without heat sinking to further demonstrate advantages as pulse widths are increased beyond the 10 ms range.

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References

[1] Clark, O.M. and Walters, K. MicroNote 104, Microsemi Corp., 1994.

[2] Walters, K. MicroNote 120, Microsemi Corp., 1998.

[3] Clark, O.M. MicroNote 132, Microsemi Corp., 2006.

[4] RTCA/DO-160E, Section 22.

[5] Clark, O.M. and Walters, K. MicroNote 112, Microsemi Corp., 1995.

[6] Walters, K. MicroNote 130, Microsemi Corp., 2005.

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