



MicroNote™ 133

REPETITIVE SURGE ON TRANSIENT VOLTAGE SUPPRESSORS

BACKGROUND

The Peak Pulse Power (P_{PP}) ratings provided in data sheets 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 data sheets (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}). This also contributes to higher Clamping Voltage (V_C) in addition to expected parasitic 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 data sheets, a percent repetition rate (or duty factor) may also be specified for its rated P_{PP} and pulse width test conditions that is often with reference to a double exponential impulse of 10/1000 μ s (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 times the % repetition rate divided by 100 must be less than the rated dc power. This feature should be conservative since 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 data sheets 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 Watt 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 (t_p) curve including Microsemi data sheets such as the example below in Figure 1 for a TVS device rated at 30 kW at 1 ms (10/1000 μ s).

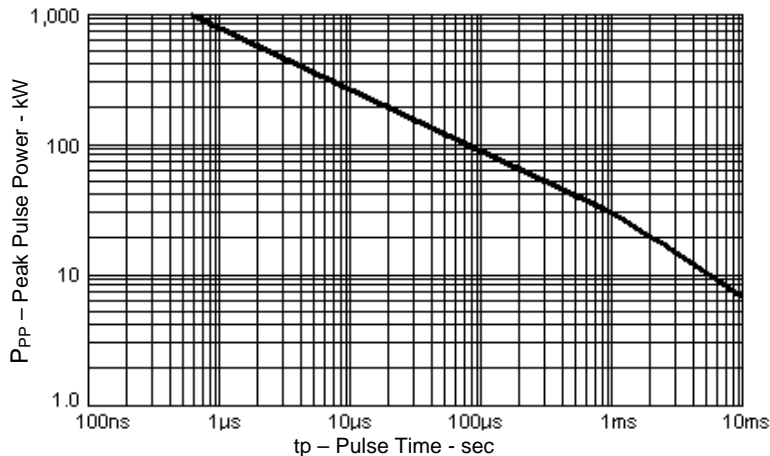


FIGURE 1
Peak Pulse Power vs. Pulse Time

This characteristic behavior is also shown for many other Microsemi TVS data sheets 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 μ s.



WUNSCH-BELL CURVE

The “curve” in Figure 1 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 MicroNotes 104 and 120 for TVSs.

AVERAGING REPETITIVE SURGES (P_{PPAVG})

From Figure 1, it is apparent the P_{PP} capability at 25 °C of a TVS 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 as provided in many individual TVS data sheets. 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 of the applicable data sheets despite them exceeding the repetition rate described earlier in many TVS data sheets 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 (t_p) 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: $P_{PPAVG} = P_P \times RR/100$. The division by 100 is needed when using a Repetition-Rate (RR) in percent.

The P_P in this method of calculating P_{PPAVG} 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 described 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 of the applicable TVS data sheet for the same waveform over the longer overall duration t_w of repeated events. This is only valid if within the time domain shown in Figure 1 for various TVS products before other thermal management variables or limitations start occurring as earlier described. This is typically for total-time durations less than 1 to 10 ms due to variables with mounting/heat sinking for longer times as cumulative heating needs 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 data sheets due to mounting variables and increased device temperatures due to 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 (typically a few milliseconds), the device power capability features would decline and eventually approach the much lower dc power ratings for very long extended times.

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} vs pulse-width curves shown in Figure 1 of Microsemi TVS data sheets 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 P_{PP} versus time declining at a much faster rate (compared to Figure 1) 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.

MULTIPLE STROKE TRANSIENT THREATS

The multiple stroke transient aircraft threats also 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 as is found in Figure 22-7 of the RTCA/DO-160 spec over longer extended time such as 1.5 seconds. This is shown below in Figure 2. In addition to overall device



thermal management variables with mounting the device for these longer times (t_w), this method of calculation when using a P_{PPAVG} would require further computer modeling to determine the correct form factor if also trying to compare with Figure 1. 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 in the order of 10 milliseconds. However that can also still be influenced by package design and how it is mounted.

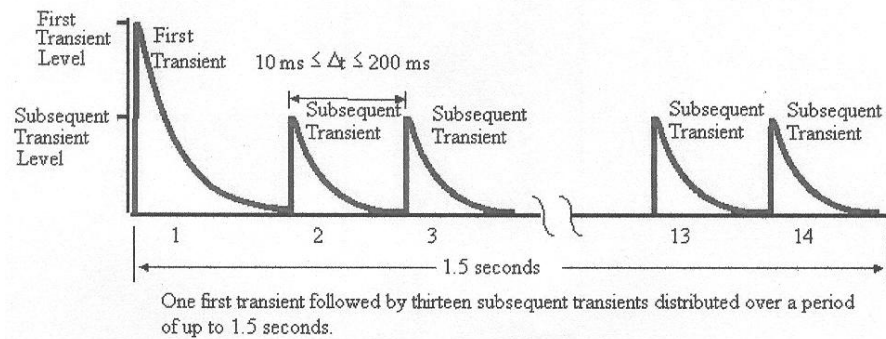


Figure 22-7 Multiple Stroke Application

Figure 2

OPTIMUM TVS PACKAGES FOR REPETITIVE SURGES

For these reasons, Microsemi is also now seeing interest in the newer PLAD15KPxxxx and PLAD30KPxxx devices 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 at the following web link. <http://www.microsemi.com/datasheets/MPLAD15KP.pdf> 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 PLAD15KPxxx devices is only 0.2 °C/W from junction to base at the mounting surface 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 100 times that value (20 °C/W) despite both products having a surge rating of 15 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 data sheet, it is also evident 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.

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 newer PLAD15KPxxx surface mount product versus older conventional axial-leaded 15KPxxx product with and without heat sinking to further demonstrate advantages as pulse width are increased well beyond the 10 ms range.

CONTACTS and ADDITIONAL TECHNICAL INFORMATION

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