Advanced TVS Construction Improves Lightning Protection

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Lightning strikes on military and commercial aircraft are common, and today’s structures and systems are required to withstand such events and continue operating. Lightning protection is particularly important for fly-by-wire systems that move primary flight control commands over an aircraft's data bus and power wiring. Also the latest carbon composite aircraft skins pose additional challenges for protecting these on-board systems, which has led to new standards. Now, advances in transient voltage suppressor (TVS) technology are enabling manufacturers to meet today’s more stringent lightning-protection specifications.

When lightning strikes all-metal aircraft, its skin becomes part of the conduction path and acts as a Faraday cage. Current flows over the structure’s outer surface while induced fields inside remain manageable. Carbon composites, which are now used to fabricate significant portions of the skin area on aircraft like the Airbus 350 and 380 and the Boeing 787, approach the lightning-handling performance of metal sheets by using techniques such as embedding high-conductivity metal mesh, but they may offer less shielding for flight systems than is provided by metal skin equivalents.

The American Radio Technical Committee for Aeronautics (RTCA) and European Civil Aviation Electronics (EUROCAE) have defined harmonized standards for how much interference systems must tolerate. For instance, RTCA/DO-160 specifies that avionics sub-systems must survive exposure to direct and induced strike pulses in single-stroke, multiple-stroke and multiple-burst sequences. The transient waveforms defined in the DO-160 standard are injected into connector pins, interconnected cables and power leads. Any given conductor is subject to primary effects induced by the incident pulse, plus secondary effects due to transients induced in adjacent conductors. DO-160 also sets conditions for coupled transient tests in cable bundles.

A typical negative strike comprises between one and 11—and up to a maximum of 24—separate strokes, most of which occur at approximately 100 ms intervals.TVS devices are used to protect signal lines during these events, and their construction can have a significant bearing on thermal management, system performance and failure rates.

TVS Overview

Transients that appear on interconnection wiring must be diverted to ground by TVS devices before they can enter and disrupt terminal equipment at each end of the connection. Avionics TVSs are invariably semiconductor devices, such as avalanche breakdown diodes (ABDs). To handle the specified transient levels, these devices take the form of a single diode die or stacks of series-connected diode dice for high-

power devices.

Many devices do not allow internally-dissipated heat to escape quickly enough to keep junction temperature below the semiconductor device's maximum operating range. A key parameter is the peak pulse power (PPP), however this is specified in terms of randomly-occurring events separated by long enough intervals to eliminate heat build-up. Data sheets may refer to an interval between surge events, and give a dc power rating that is much less than the specified peak power rating, in which case dc conditions should be specified with heat-sinking arrangements to manage steady-state conditions.

Heat sinking is regarded as irrelevant for short, infrequent transient events that conclude before heat can reach the TVS' exterior. Data must be carefully interpreted to ensure identical conditions apply throughout. For extended rapid repetition rates of pulse events, thermal management does become relevant due to cumulative heating effects. Specifications associated with controlled temperatures measured at the case, lead or end-cap may imply that robust heat-sinking arrangements are in place without explicitly defining what those arrangements are.

Other key TVS parameters include: the clamping voltage (VC) for the maximum voltage response provided to the protected line once the TVS has acted; the maximum working or stand-off voltage (VWM) for the highest continuous value at which the device is rated to operate in standby mode before being driven into avalanche breakdown; and the standby current (ID) for the leakage current at VWMwhere the TVS is normally operated before a transient occurs. With low standby currents, TVS devices are simply idling at very low power between any random recurring surge events.

The pulse shape used to define TVS device performance and test its response is typically a transient with exponential rise and decay waveforms. Different time constants apply to rise and decay curves. A device might be rated as 130 kW at 6.4/69 µs (it can safely dissipate a transient that peaks at a 130 kW power level in a pulse shape that rises to its maximum in 6.4 µs and decays from its peak to the 50 percent level in 69 µs). For longer pulses, the peak power value is derated to ensure internal p-n junction temperatures do not become excessive.

TVS Construction

One fabrication method is an axial-leaded design (see Figure 1), which minimizes opportunities to mount devices directly on a heatsink. The thermal path is from where heat is dissipated in the stack of diode dice by conduction along the leads and by convection through the casing. A relatively high thermal resistance from diode (p-n) junction to leads or ambient can be expected, particularly from multiple p-n junctions in the center of a TVS package's stacked-die design.

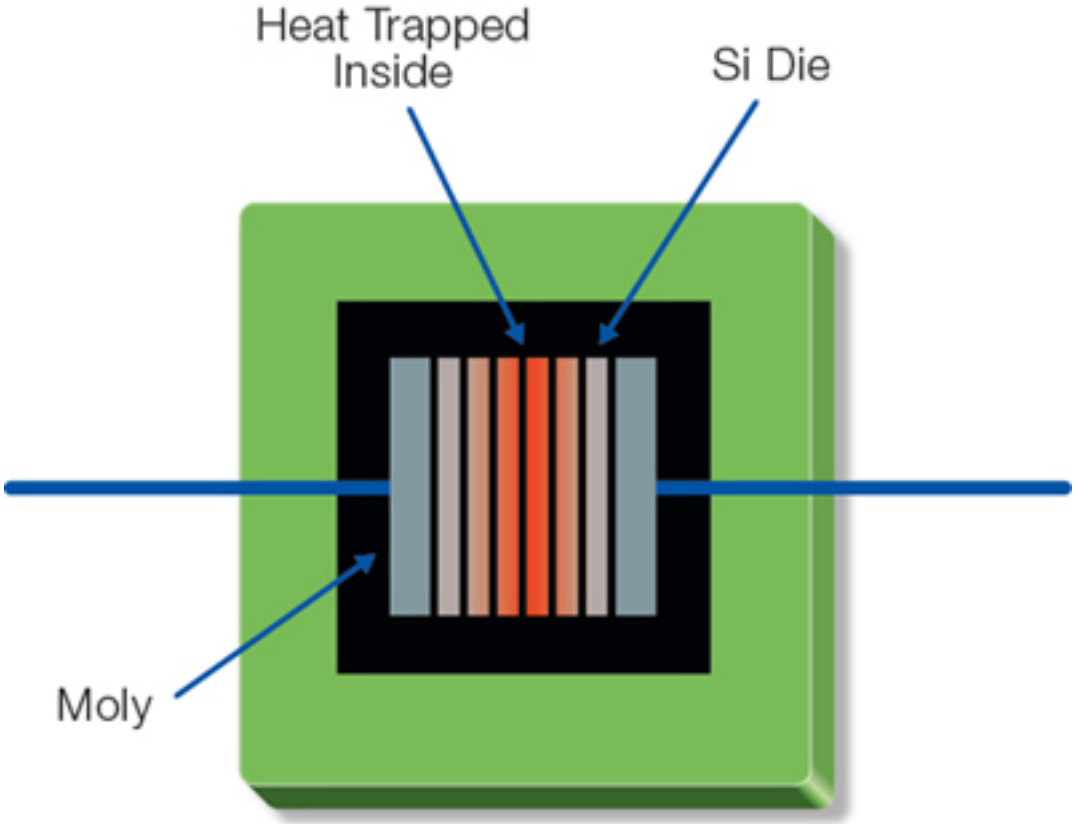

Figure 1. Axial-leaded TVS design with stacked die

Alternatively, the dice can be assembled in a surface-mount stack, with the exposed base contact pad serving as both electrical and thermal contact (see Figure 2). Thermal conductivity from the lowest die to the substrate is good, but deteriorates for the stack's higher dice. The thermal path from the top of the stack is poor, as only a bond wire connects the last diode to the second electrical terminal.

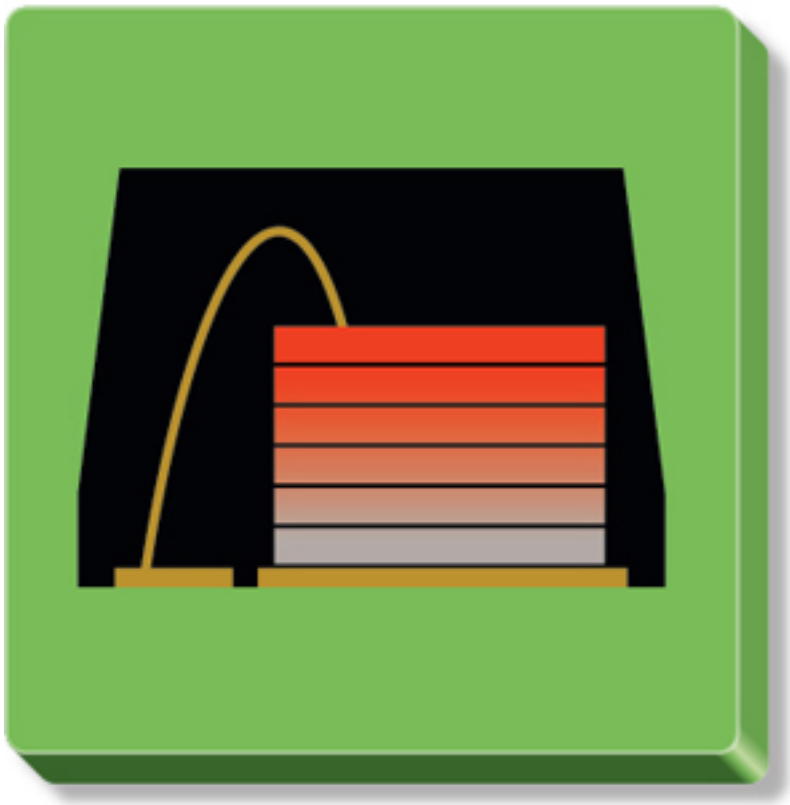

Figure 2. Surface-mount TVS design with stacked die

Figure 3 illustrates the DO-160 multiple-stroke transient waveform—one peak transient followed by a pulse train peaking at 50 percent of the original peak level, within 1.5 sec. For both device structures shown in Figures 1 and 2, the effective PPPderating for these rapid multiple strokes will be substantially greater than data sheets show for widely-spaced random-recurring pulses. Heat will accumulate within the semiconductor device stack and won’t efficiently diffuse to the heatsink or to ambient within the rapid test pulse train’s timescale, which can lead to very high junction temperatures, impaired performance or even failure.

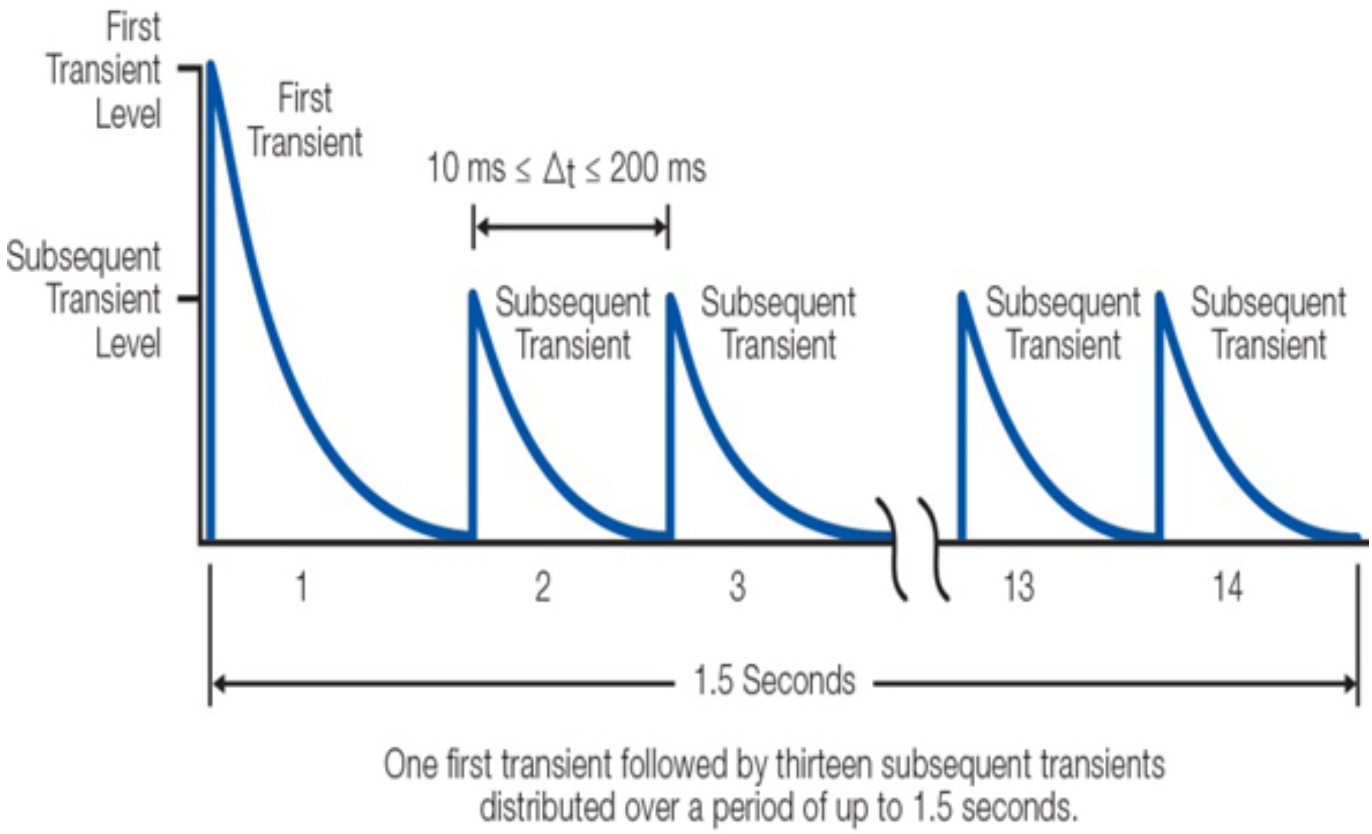

Figure 3. Multiple stroke transient waveform

To eliminate these problems, only one or two semiconductor die of large area (depending on PPP rating) should be connected to a large contact/thermal pad. The top contact is formed by a copper clip exiting the package that acts as the second electrical contact and provides an additional thermal path.

Microsemi’sPlastic Large Area Device (PLAD) TVS device illustrates the benefits of this construction (see Fig. 4). It has a junction-to-heatsink thermal resistance of 0.2°C/W, enabling it to undergo the DO-160 multi-stroke test sequence with minimized heat accumulation near the p-n junctions. The bonds between semiconductor elements and contacts use joining techniques that relieve mechanical stresses resulting from heating during the transient event. Additional benefits of this construction include the ability to fabricate low-profile (sub-3.3 mm) devices, and achieve an extremely low-inductance current path, which further improves lightning-strike test response.

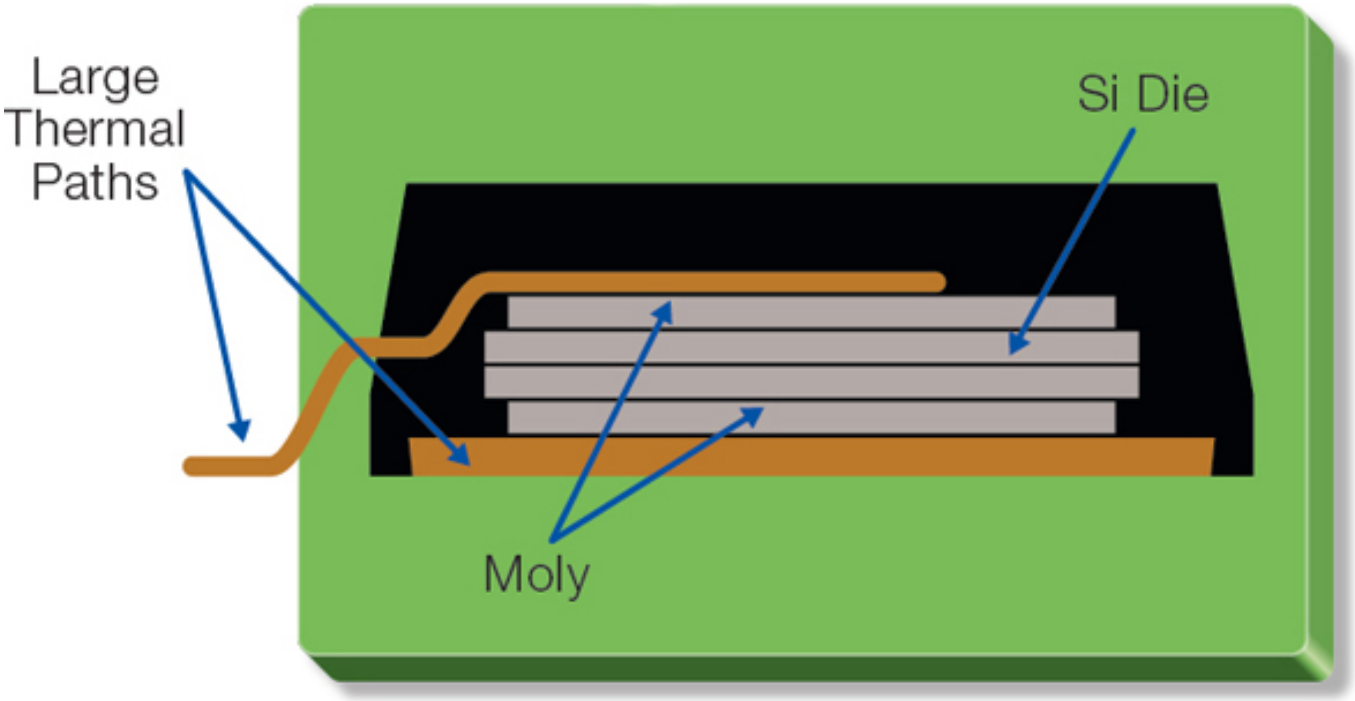

Figure 4. Microsemi PLAD construction

Today's carbon composite-skinned aircraft with fly-by-wire systems have spurred the development of more stringent lightning-protection standards. New packaging techniques play a key role in enabling TVS devices to meet these challenging multiple-burst requirements.

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