Introduction

The transient voltage suppressor (TVS) is an avalanche diode specially designed to clamp overvoltage and dissipate high transient power.

The latest generation of TVS diodes delivers market-leading power density, handling 600 W and 1500 W transient power in SMB flat, and 400 W and 600 W in SMA flat packages that are just 1.0 mm high.

In addition to the lower profile, ST’s new 1500 W SMB flat package has transient power capability equivalent to that of conventional devices in SMC packages. SMB flat devices increase cost effectiveness by fitting in a footprint 50% smaller. The 400 W and 600 W SMA flat and SMB flat devices are fully footprint compatible with alternatives in conventional SMA and SMB packages. The leakage current is five times lower compared with other TVS diodes on the market, minimizing impact on system operation and power consumption while in non-protection stand-by.

After a short introduction on TVS parameters and operation, clamping voltages and power capability of flat and standard packages are compared.
A TVS is a solid state, monolithic PN junction device. TVS are used along sensitive semiconductors in a parallel protection configuration against electrical overstress (EOS) or electrostatic discharges (ESD) (see Figure 1). A TVS clamps any overvoltage above its breakdown voltage ($V_{BR}$). TVSs can be unidirectional or bidirectional (see Figure 2).

Figure 1. TVS in parallel to protect against EOS or ESD

![Protection provided by a TVS diagram](image)

Figure 2. Electrical characteristics - parameter definitions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{BR}$</td>
<td>Breakdown voltage</td>
</tr>
<tr>
<td>$I_{BR}$</td>
<td>Breakdown current</td>
</tr>
<tr>
<td>$V_{CL}$</td>
<td>Clamping voltage @ $I_{SP}$</td>
</tr>
<tr>
<td>$I_{SP}$</td>
<td>Peak pulse current</td>
</tr>
<tr>
<td>$R_D$</td>
<td>Dynamic resistance</td>
</tr>
<tr>
<td>$I_F$</td>
<td>Forward current</td>
</tr>
<tr>
<td>$V_F$</td>
<td>Forward voltage drop</td>
</tr>
<tr>
<td>$\alpha_T$</td>
<td>Voltage temperature coefficient</td>
</tr>
</tbody>
</table>

A TVS is used to protect another electronic device or circuit. A TVS is activated when the surge voltage across the protected device rises $V_{BR}$. In its active state, the TVS becomes a low impedance device. It clamps the surge voltage by conducting the surge current when above $V_{BR}$. Ideally, the clamping voltage of a TVS ($V_{CL}$) is equal to $V_{BR}$, but in reality, the clamping voltage ($V_{CL}$) is proportional to the surge current (see Figure 3).
Figure 3. Electrical behavior of the TVS

Refer to AN316 for full details.
2 Voltage and current waveforms comparison of flat SMA and SMB packages versus TVS in standard SMB and SMC packages

Depending on the requirements of the standards, the surge generator parameters differ according to duration pulse, peak current or voltage and series resistance. For example, the Telcordia GR-1089-Core standard, for the Telecom segment, specifies a 10/1000 µs duration at 50% of peak current and in automotive, the ISO7637-2 standard requires several pulses stress (1, 2a, 3a, 3b,...) and as example, a pulse 2a voltage ramp with a duration of 50 µs at 10% of peak voltage.

Waveforms comparison for Industrial grade TVS

We can compare clamping and power dissipation performances between standard package (SMB, SMC) and flat package (SMAF, SMBF) with the same die in each package (example: SMBJ58A and SMA6F58A with a 600 W 10/1000 µs die for both). The waveforms comparison below shows that the voltage (blue curve: $V_{TVS}$) across the TVS during clamping and the current inrush (red curve: $I_{TVS}$) through the TVS during clamping are showing the same shape even if the SMA flat package has a smaller size than the SMB package. Also, the peak clamping voltage remains identical. The overall clamping performance is the same (see Figure 4 and Figure 5).

Figure 4. SMBJ58A for 10/1000 µs stress applied on TVS

6.49 A

81.2 V

$V_{TVS}$ (20 V/div)

$I_{TVS}$ (1 A/div)

500 µs/div
Figure 5. Same 10/1000 µs stress applied on SMA6F58A

6.58 A
81.2 V

$V_{TVS}$ (20 V/div)
$I_{TVS}$ (1 A/div)

A waveforms and clamping performance comparison have also been performed for a shorter pulse: 1.2/50 µs, 8/20 µs applied on samples and give identical results: see Figure 6 and Figure 7 below:

Figure 6. 1.2/50 µs, 8/20 µs stress applied on TVS SMBJ58A

33.3 A
90.9 V

$V_{TVS}$ (20 V/div)
$I_{TVS}$ (5 A/div)
Waveforms comparison for automotive AEC-Q101 grade TVS

For the automotive environment, ISO7637-2 pulse 2a have been used, and the comparison have been performed between:

- SM6T30AY (SMB standard package) and SMA6F26AY (SMA flat package) providing both a 600 W 10/1000 µs protection level (see Figure 8 and Figure 9) with same electrical characteristics
- SM15T30AY (SMC standard package) and SMB15F26AY (SMB flat package) providing both a 1500 W 10/1000 µs level (see Figure 10 and Figure 11) with same electrical characteristics

For both comparisons, the clamping voltage values and waveforms are very close to another even if the package is smaller for flat ones.
Figure 9. Same ISO7637-2 pulse 2a stress applied on SMA6F26AY

34 V

41.9 A

V_{TVS} (5 V/div)

I_{TVS} (10 A/div)

Figure 10. ISO7637-2 pulse 2a applied on SM15T30AY

33.3 V

42.8 A

V_{TVS} (5 V/div)

I_{TVS} (10 A/div)
Figure 11. Same pulse 2a stress applied on SMB15F26AY

- $V_{TVS}$ (5 V/div)
- $I_{TVS}$ (10 A/div)

Measure | Value | Status
--- | --- | ---
P1 | 33.6 V | ✓
P2 | min(C1) | ✓
P3 | max(C2) | ✓
P4 | min(C2) | ✓
P5 | max(f1) | ✓
P6 | area(f1) | ✓

Timebase: 20 μs/div
Horizontal: 20 μs/div
Vertical: 5 V/div
Gain: 100 MΩ
Slope: Positive
3  Power capability comparison (single pulse and repetitive surge comparison)

Power dissipation is important in case of single pulse or in repetitive surges. For both cases, we need to check the peak power dissipation versus the \( t_p \) duration (pulse current duration through TVSs at half amplitude of the peak current, see Figure 12 below) and in the case of a repetitive stress, we need to calculate the average power with the surge frequency to get the junction temperature into the TVS die.

Figure 12. Pulse duration definition for electrical characteristics

Here are below examples (see Figure 13 and Figure 15) with SMA6F26AY and SM6T30AY (\( V_{BR} = 30 \) V for both parts):

- Blue curve (\( V_{TVS} \)) is the remaining voltage across TVS during clamping
- Red curve (\( I_{TVS} \)) is the current through TVS during clamping
- Orange curve (\( P_{TVS} \)) is the power dissipated through TVS during clamping

For both packages, identical chip (600 W 10/1000 µs with typical \( V_{BR} = 30 \) V) has been assembled. A power curve has been obtained from the oscilloscope with voltage and current instantaneous multiplication. To get a value of the energy dissipated through the TVS, the oscilloscope integrates the instantaneous power waveform (see Figure 14 and Figure 16).

For both packages, the same peak power and energy calculation methods are used.
Figure 13. Remaining voltage (blue curve), current (red curve) and power (orange curve) dissipated through SM6T30AY

468 W
34.9 V
14.3 A

V_{TVS} (10 V/div)
I_{TVS} (5 A/div)
P_{TVS} (100 W/div)

200 µs/div

Figure 14. Energy dissipated through SM6T30AY obtained by instantaneous power waveform integration

468 W
147.7 mJ

P_{TVS} (100 W/div)

200 µs/div
To check if TVS is compliant with stress, we need to verify the peak power value versus the $t_p$ time. As explained above, $t_p$ is obtained at half of peak current as shown below: $t_p = 210 \mu s$ (see Figure 17).
Figure 17. $t_p$ duration at half of peak current on current waveform

![Current waveform diagram]

A figure “Maximum peak pulse power versus exponential pulse duration” in datasheet is given for each TVS family. For example, we can use the Figure 18 from SMA6FY datasheet and verify the power capability at $t_p = 210 \mu s$.

Figure 18. Maximum peak pulse power versus exponential pulse duration

![Power capability graph]

SMA6FY TVS family has a 1100 W power capability for $t_p = 210 \mu s$. As peak power measured on oscilloscope is 469 W, SMA6F26AY is suitable to clamp the overvoltage stress applied.

In case of repetitive over-voltage stress, for example each 0.33 s (frequency equal to 3 Hz), we can calculate the average power ($P_{av}$) from energy obtained on oscilloscope (integration of orange curve):

$$P_{av} = \text{Energy} \times \text{frequency} = 146.7 \text{ mJ} \times 3 \text{ Hz}$$

$$P_{av} = 0.44 \text{ W}$$
Every TVS family datasheet gives the value of the thermal resistance junction-ambient $R_{th(j-a)}$ (usually with a curve “Thermal resistance junction to ambient versus copper area under each lead” see below Figure 19 for SMA6F26AY and Figure 20 for SM6T30AY), so we can calculate the temperature increase due to the average power loss:

$$\Delta T = P_{av} \times R_{th(j-a)}$$

(2)

**Figure 19.** Thermal resistance junction to ambient versus copper area under each lead (SMA6FY)

**Figure 20.** Thermal resistance junction to ambient versus copper area under each lead (SM6TY)
$R_{th(j-a)} = 150 \, ^\circ C/W$ with minimum copper area for both packages, so

$$\Delta T = P_{av} \times R_{th(j-a)} = 0.44 \, W \times 150 \, ^\circ C/W, \quad \Delta T = 66^\circ C$$  \hspace{1cm} (3)

We can calculate the junction temperature $T_j$ with this formula:

$$T_j = T_{amb} + P_{av} \times R_{th(j-a)} = T_{amb} + \Delta T$$  \hspace{1cm} (4)

with $T_{amb} =$ the ambient temperature

For example, if $T_{amb} = 105 \, ^\circ C$:

$$T_j = 105 \, ^\circ C + 66 \, ^\circ C = 171 \, ^\circ C/W$$  \hspace{1cm} (5)

The maximum operating junction temperature admissible by TVS is given in all datasheets (see Table 1 for SMA6F26AY and Table 2 for SM6T30AY).

### Table 1. Extract of SMA6FY table 1: Absolute maximum ratings ($T_{amb} = 25 ^\circ C$)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_j$</td>
<td>Operating junction temperature range</td>
<td>-55 to +175</td>
<td>^\circ C</td>
</tr>
</tbody>
</table>

### Table 2. Extract of SM6TY table 1: Absolute maximum ratings ($T_{amb} = 25 ^\circ C$)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_j$</td>
<td>Operating junction temperature range</td>
<td>-55 to +150</td>
<td>^\circ C</td>
</tr>
</tbody>
</table>

For the SMA6FY range, the maximum operating junction temperature is $175 \, ^\circ C$, higher than the calculated $T_j$ ($171^\circ C$). So the SMA6F26AY is suitable for repetitive over-voltage stress, as given above, without additional heat sinking copper area. The given minimum copper area (0.02 cm²) for each lead footprint is enough.

But for SM6TY, the maximum operating junction temperature is $150 \, ^\circ C$, lower than the $171^\circ C$ calculated junction temperature. An additional heat sinking copper area is mandatory to keep the junction temperature lower than $150 \, ^\circ C$.

For this, $R_{th(j-a)}$ must be equal to:

$$R_{th(j-a)} = \left(\frac{T_j - T_{amb}}{P_{av}}\right) = \frac{(150 \, ^\circ C - 105 \, ^\circ C)}{0.44 \, W}$$  \hspace{1cm} (6)

$$R_{th(j-a)} = \left(\frac{T_j - T_{amb}}{P_{av}}\right) = 102 \, ^\circ C/W$$

From Figure 20, around 0.4 cm² copper area for each pad must be available for the SM6T30AY footprint to get a $R_{th(j-a)}$ around $100 \, ^\circ C/W$.

Thanks to a maximum $T_j$ equal to $175 \, ^\circ C$ for the SMA6FY range, the SMA6F26AY saves a significant area on the PCB in comparison with an SMB SM6T30AY for the same repetitive overvoltage stress.
The series of measurements performed on 600 W and 1500 W TVSs shows that flat packages provide the same performances as standard packages, with a smaller area on PCB.

A comparison was made between the SMA6F and SMB packages. The flat package achieves $T_J = 175 \, ^\circ\text{C}$ (as it is $150 \, ^\circ\text{C}$ for standard packages), which further saves space on PCB ($15 \, \text{mm}^2$ versus $22 \, \text{mm}^2$).

The necessary copper area addition, if any, will be limited, with low power derating to temperature (flat packages provide a maximum $T_J = 175 \, ^\circ\text{C}$, whereas it is $150 \, ^\circ\text{C}$ for standard SMD packages). With a higher maximum junction temperature, the new family of TVS in flat package can save significant space on the PCB in case of large repetitive overvoltage stress.

The SMA flat range extends the application coverage in two ways compared to the SMB TVS of the same power: firstly through the better $T_J \text{ max}$ and therefore smaller PCB copper area as demonstrated, secondly through an enlarged choice of $V_{BR}$ voltages in the SMD flat packages range versions (14 voltages versus 8).

Flat SMD packages will fit a larger range of protection designs in industrial and automotive AEC-Q101 compact systems than their predecessors.
Revision history

Table 3. Document revision history

<table>
<thead>
<tr>
<th>Date</th>
<th>Version</th>
<th>Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>14-Dec-2020</td>
<td>1</td>
<td>Initial release.</td>
</tr>
</tbody>
</table>
Contents

1 TVS basics ................................................................. 2
2 Voltage and current waveforms comparison of flat SMA and SMB packages versus TVS in standard SMB and SMC packages ........................................... 4
3 Power capability comparison (single pulse and repetitive surge comparison) .... 9
4 Conclusion ............................................................... 15

Revision history ......................................................... 16
Contents ................................................................. 17
List of figures ........................................................... 18
List of figures

Figure 1. TVS in parallel to protect against EOS or ESD .............................................. 2
Figure 2. Electrical characteristics - parameter definitions ............................................. 2
Figure 3. Electrical behavior of the TVS. .......................................................... 3
Figure 4. SMBJ58A for 10/1000 µs stress applied on TVS ............................................. 4
Figure 5. Same 10/1000 µs stress applied on SMA6F58A ............................................. 5
Figure 6. 1.2/50 µs, 8/20 µs stress applied on TVS SMBJ58A ........................................ 5
Figure 7. Same 1.2/50 µs, 8/20 µs stress applied on SMA6F58A ........................................ 6
Figure 8. ISO7637-2 pulse 2a applied on SM6T30AY ................................................ 6
Figure 9. Same ISO7637-2 pulse 2a stress applied on SMA6F26AY ................................. 7
Figure 10. ISO7637-2 pulse 2a applied on SM15T30AY ............................................. 7
Figure 11. Same pulse 2a stress applied on SMB15F26AY ............................................. 8
Figure 12. Pulse duration definition for electrical characteristics .......................................... 9
Figure 13. Remaining voltage (blue curve), current (red curve) and power (orange curve) dissipated through SM6T30AY ................................................. 9
Figure 14. Energy dissipated through SM6T30AY obtained by instantaneous power waveform integration ................................................. 10
Figure 15. Remaining voltage (blue curve), current (red curve) and power (orange curve) dissipated through SMA6F26AY ........................................... 11
Figure 16. Energy dissipated through SMA6F26AY obtained by instantaneous power waveform integration ........................................... 11
Figure 17. \( t_p \) duration at half of peak current on current waveform ....................................... 12
Figure 18. Maximum peak pulse power versus exponential pulse duration ................................ 12
Figure 19. Thermal resistance junction to ambient versus copper area under each lead (SMA6FY) ........................................... 13
Figure 20. Thermal resistance junction to ambient versus copper area under each lead (SM6TY). ........................................... 13