
Dealing with voltage surges in a 48 V automotive system and transient voltage suppressor (TVS)

INTRODUCTION

In the automotive systems, the 48 V network is not only supporting the mild hybrid EV (MHEV) actuation (BSG (belt-driven starter generator) or ISG (Integrated starter generator) on ICE (combustion engine)) but also allows supplying power to many kinds of loads (active suspension, electric power steering, electric brakes,...). The goal of the higher voltage than the usual 12/24 V is to minimize wire size, weight, and voltage drop losses. Carbon dioxide (CO₂) emission due to the load on the generator itself inducing fuel consumption of the engine will be decreased in proportion. The 48 V power bus and its loads needs to be protected with the right TVS protection devices.

For several years, tiers 1 and car makers requested for an international 48 V standard as only LV148 and VDA320 directive specification documents existed. These documents define electrical constraints as over/under voltages, arcing/fusing, loss ground,... and transient overvoltages. Now, the ISO21780 worldwide standard brings together the constraints already listed previously at the global level.

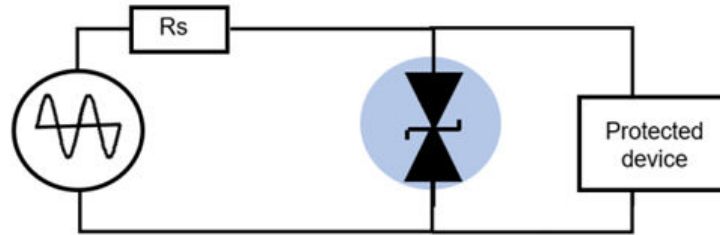
About transient overvoltages, the ISO21780 is not a replication of the ISO7637-2 for 12 V and 24 V systems. The latter explains and defines the different transient overvoltage configurations (positive pulse due to parasitic inductance harness wire, negative pulse due to inductive loads,...) and the pulse limits (peak voltage range, duration, equivalent resistance in series,...) to apply to the device, circuit, or system to test. On the other hand, the ISO21780 specifies that device, circuit, or system (source or sink) have to be autoprotected or autolimited in case of overvoltage and if it is not the case, countermeasures have to be taken to protect the system against overvoltages.

In both standard approaches, according to the overvoltage context, TVSs are mandatory. This application note wraps up the ISO21780 description and explanations how to limit overvoltage with a TVS. In the first part, we define TVS basics.

1 TVS basics

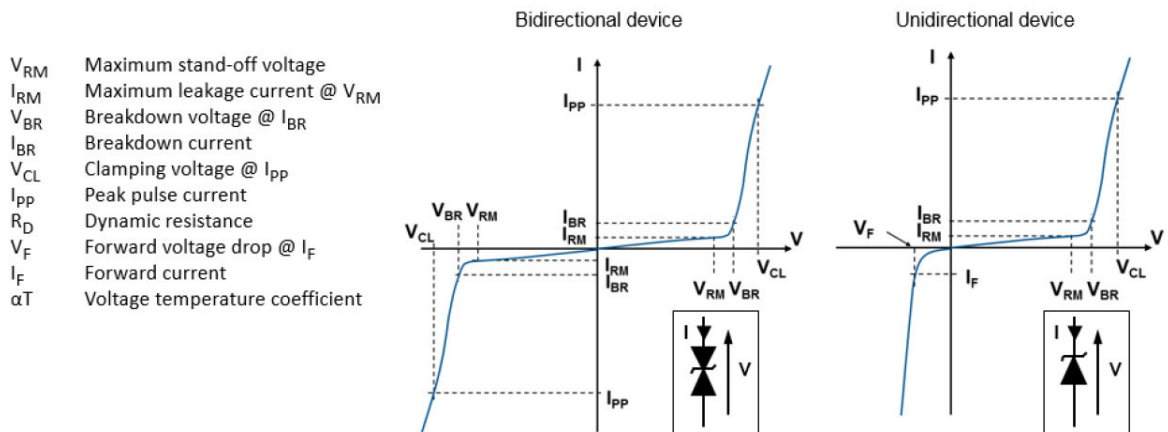
Sensitive semiconductor systems have to be protected against surges, spikes, overvoltages, ESD (electro static discharges) and, other electrical stresses, which lead to an electrical over stress (EOS). Usual solutions are to use TVS. This device is a PN junction semiconductor device and is mounted in parallel to the circuit to protect (see Figure 1).

Figure 1. TVS in parallel protection schematic against electrical over stress (EOS) or ESD



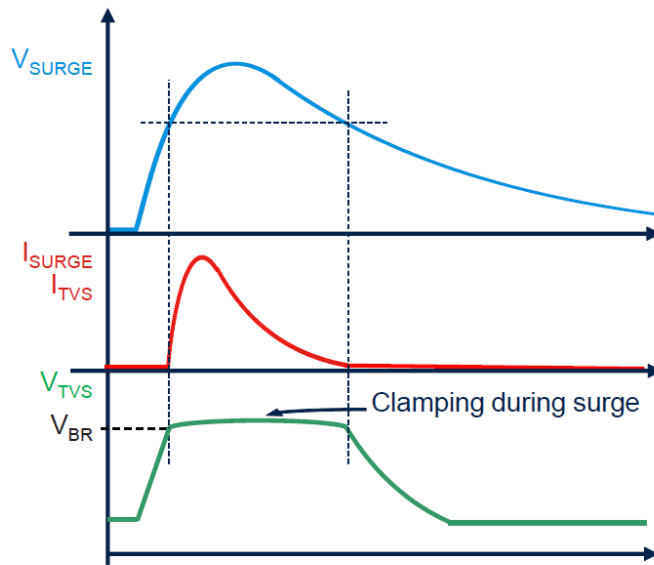
Any overvoltage rising above the TVS breakdown voltage (V_{BR}) is suppressed and limited. TVS can be a unidirectional or a bidirectional device (see Figure 2).

Figure 2. Electrical characteristics—parameter definitions



TVS limits the surge voltage by passing the surge current, and clamping the surge voltage. During this phase, TVS becomes a low impedance device. An ideal TVS has the same value for clamping voltage (V_{CL}) and breakdown voltage (V_{BR}) but in real, V_{CL} level changes according to the surge current value (see Figure 3).

Figure 3. Electrical behavior of the TVS



Refer to AN316 for full details.

Related links

[AN316: TVS clamping protection mode.](#)

2 Transient overvoltages defined in ISO21780

As defined in the standard: “If the voltage exceeds the upper transitory limit, countermeasures shall be taken via the component that is causing entry into the overvoltage range, such that the voltage exits the overvoltage range at the lower boundary.” The upper overvoltage range is defined in Figure 4 and is given for transient voltage higher than 60 V.

Figure 4. Supply voltage range

Upper overvoltage range	60 V Upper overvoltage limit
Overvoltage range	58 V Overvoltage limit
Upper transitory voltage range	54 V Upper transitory voltage limit
Nominal voltage range	52 V Upper nominal voltage limit
Lower transitory voltage range	36 V Lower nominal voltage limit
Undervoltage range	31 V Lower transitory voltage limit
Lower undervoltage range	24 V Undervoltage limit
	0 V Lower undervoltage limit

Only tests of the ISO21780 concerning transient overvoltages will be discussed.

2.1 Test-03, short term overvoltage and test-04, supply component load dump control test

This test-03 is intended to check the immunity of the device, circuit, or system to transient overvoltages and test 04 is a simulation of the load dump event.

For test-03, the maximum voltage is 70 V for 40 ms and then decreases to 58 V. During this overvoltage, higher than “Upper overvoltage limit,” the system:

- Shall meet a specified performance without deviation (functional status 1) for functional category 1 (FC1, communication)
- Shall meet a specified performance with deviation (functional status 2) for functional category 2 (FC2 voltage conversion, safety, propulsion) and functional category 3 (FC3 function to start)
- Can be switched off (functional status 3) for functional category 4 (FC4 comfort)

For test-04, the maximum voltage is also 70 V: this overvoltage is induced (load dump situation) “where the voltage transient occurs following a sudden reduction in the load current drawn from a generator, motor-generator, or DC/DC converter whilst the battery is either out of circuit or incapable of absorbing power.”

ISO21780 gives an output voltage profile and this “load dump surge” cannot exceed 70 V peak during 40 ms for the highest voltage value.

Two solutions regarding these two tests:

- Either generator, motor-generator or DC/DC converter providers have integrated an autoprotection with TVS, for example
- Either countermeasures as to be implemented by a designer with TVS, for example

2.2 Test-06: Long-term overvoltage

This test describes the possibility of a 48 V power rail and supply voltage to reach 60 V for a time period of 60 minutes. The goal of this test is to check the robustness of components against this long-term overvoltage (during a charging cycle for example). As no series resistance is specified, the worst case has to be taken into account, that is, a 0 Ω series resistance. With certainty, a TVS implemented directly on supply bus voltage must have its V_{BR} higher than 60 V otherwise the TVS is not able to withstand the long duration of the overvoltage.

2.3 Other overvoltage not described by ISO21780

Overvoltages are linked to EMI environment, di/dt transients, hot plugging, overcurrent detection cutoff or other stress events that are plentiful in the automotive vehicle. These uncontrolled transients voltages might even fall in categories not covered in the recommendations given in a standard and could be electrical overstress (EOS) and exceed the absolute maximum rating (AMR) of IC to protect. These EOS could result in immediate failures or late failures due to cumulated stress.

TVSs help to increase the robustness of electronic circuits in case of hazard overvoltages. These TVSs have to be able to withstand the constraints given by ISO21780 that is, tests 03 and 06.

2.4 TVS choice

The SM4T68CAY TVS has a minimum V_{BR} value higher than 60 V, so that it is able to withstand tests-06 (60 V for 60 min). The test-03 waveform voltage (70 V for 40 ms and then decreases to 58 V as shown in Figure 5, reproduced by generator) is applied across the SM4T68CAY as shown in Figure 6 (blue: voltage across the SM4T68CAY, red: current through SM4T68CAY). This trial showed that the SM4T68CAY is suitable for this stress as the peak power, around 70 W (peak voltage multiplied by peak current from Figure 6), which is lower than 400 W for a 10/1000 μ s exponential duration guarantee for this SM4TY family.

Refer to AN316 for power capability calculation example.

Figure 5. Reproduced test 03 voltage

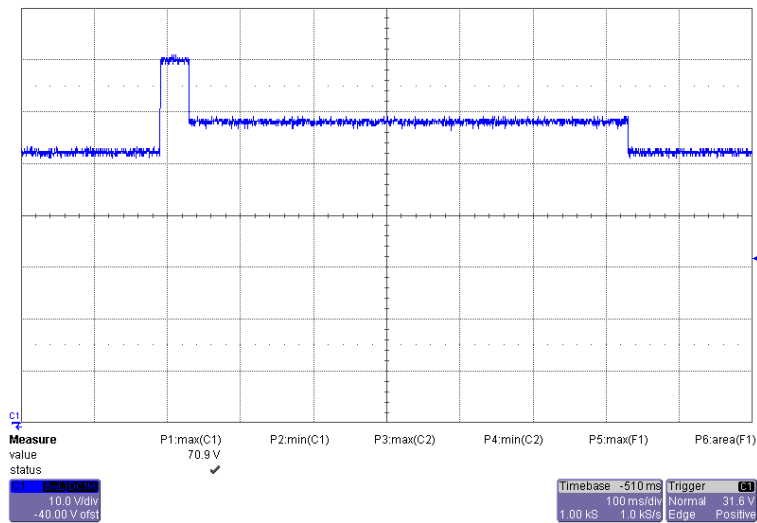
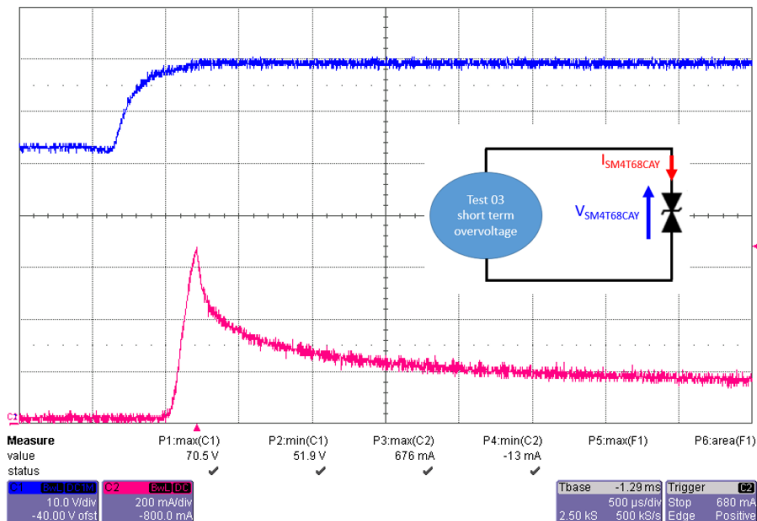


Figure 6. Zoom voltage and current through SM4T68CAY during test 03 from 52 V to 70 V applying



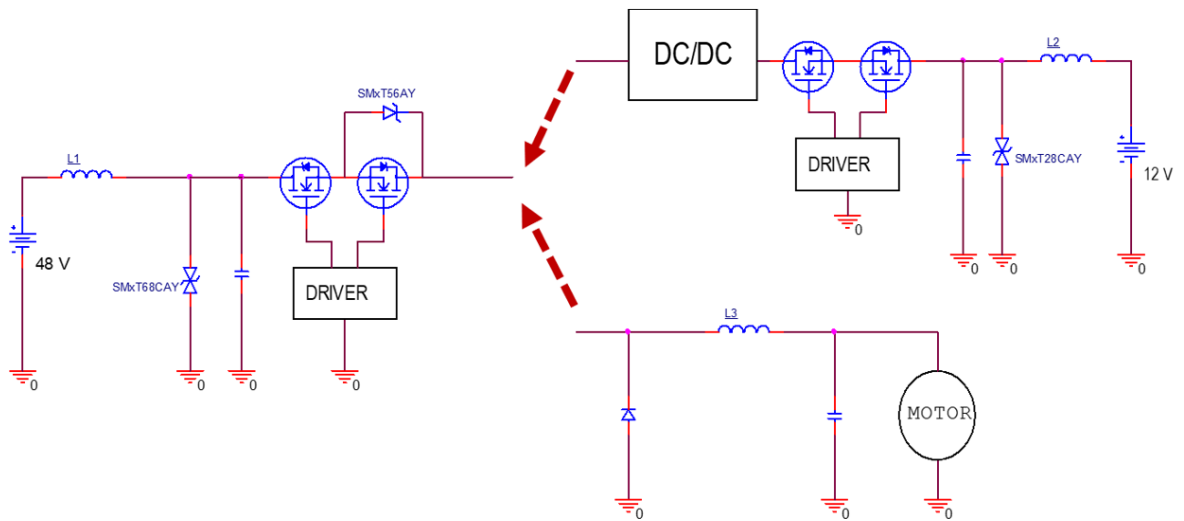
ISO21780 indicates that the number of cycles is 1000. SM4T68AY or CAY has been tested for 1000 short term overvoltage pulses without damage or parameters evolutions.

So, with the confirmation robustness against test-03 and test-06, SM4T68AY or CAY can be implemented on 48 V power rails and will protect electronic circuits against other pulse hazards.

3 E-breaker for 48 V battery voltage

Another surge example is linked to e-breaker functions performed with MOSFETs implemented in the DC / DC converter (48 V / 12 V for example) or between the 48 V supply battery and loads. These MOSFETs switches are driven abruptly to open state in case of short-circuit or overcurrent detection. Due to the stray inductance of the harness, an overvoltage is applied at once across the MOSFET when the current is turned-off. The overvoltage can damage the MOSFET when the absolute maximum rating is exceeded: TVSs are mandatory to protect it. For this purpose, several TVSs can be used in series or parallel or series-parallel to get the best V_{BR} / V_{CL} ratio.

Figure 7. Example of TVSs' protection implementation in a bidirectional e-breaker



In the **Figure 7**, the overvoltage is induced by the di/dt turn-off in the stray inductance of the cable harness.

The L1, L2, and L3 components simulate the distributed stray inductance of the wiring harness between boards and loads (battery, motor,...). The length of these wiring harnesses can measure up to 15 m, equivalent to a stray inductance of 15 μ H. In case of current interruption, an overvoltage appears across these inductances. These overvoltages must be clamped to a reasonable value.

The **Figure 7** shows a 48 V battery, which supplies either a DC/DC converter for 12 V battery charging or a motor, which can be used as generator (in case of braking for example) to charge the 48 V battery.

On the 12 V battery side, the bidirectional TVS SMxT28CAY withstands the 12 V reverse battery stress, jump start constraint (in case of wrong connection of two 12 V batteries in series or connection of a 24 V truck battery) and limits the overvoltage across the e-breaker MOSFET in case of its overcurrent opening protection. Thanks to this TVS, the voltage is limited to a lower value than the maximum voltage admissible by MOSFET. The same situation is implemented with the SMxT68CAY on the 48 V side but also, this TVS is able to withstand the test-03 short term overvoltage stress up to 70 V. SMxT56AY limit the overvoltage with a motor load in the case where the MOSFET is opening while the current is flowing from motor to battery. A free-wheeling diode in parallel serves as a bypass for the energy of motor and harness inductances in case of an e-breaker opening while the current is flowing from battery to motor.

4 Conclusion

The ISO21780 48 V standard is a guide for overvoltage stress categories and points out that countermeasures are mandatory in case of overvoltage higher than 60 V limits. Several different surges and pulses are listed in ISO21780 and the standard guidelines for good performance of 48 V electronic circuits. But, for each electronics function and topology, other surges not defined in the standard can introduce high stress and particular studies are mandatory. TVSs and, in particular SM4T68CAY for ISO21780, protect against constraints given by standards but also against each surge in particular situations such as e-breaker overcurrent circuit breaking. STMicroelectronics has developed a large range of power TVS (from 400 W to 5000 W) with a large range of voltages. Trade-offs in component power, voltage headroom, and packages are then easier to find and help the designer to enhance the reliability of the circuit.

Revision history

Table 1. Document revision history

Date	Revision	Changes
06-Jun-2023	1	Initial release.

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