ESD protection: TVS versus MOV efficiency comparison

Introduction: Why a TVS vs MOV comparison

Protection against ESD (electro-static discharge) is key for electronic-devices to be compliant with the IEC 61000-4-2 standard and to secure device reliability in the field.

TVSs (transient voltage suppressors) are components dedicated to clamp overvoltage surges generated by EOS (electrical over stress), such as ESD.

MOV (metal oxide varistor) can also be found as protection devices in electronic systems.

However, as both components do not provide the same level of protection efficiency and reliability, this application note is made to show the differences in protection performances and help designers to choose the best protection solution.

To make this comparison campaign, similar MOV and TVS have been chosen for 5 different applications:

- Automotive CAN protection
- General purpose protection, where capacitance is not critical
- Low capacitance protection, for moderate data rate line
- Extra-low capacitance protection, for applications with high-speed differential links running at voltage lower than 5 V
- Extra-low capacitance protection, for applications requiring low insertion losses on a wide frequency spectrum and running at voltage up to 16 V, for example for antenna protection.

For each application, and to perform a relevant comparison, MOV and TVS have been chosen with the same or similar key parameters (capacitance, stand-off voltage, and package).

To illustrate the performances, the same measurements have been performed on MOV and TVS for each application:

- Remaining voltage (also called clamping voltage V_{CL}) following an IEC 61000-4-2 +/-8 kV contact discharge
- TLP (transmission line pulse) measurement (100 ns), positive polarity only as negative is the same (more information can be found on TLP in AN5241 : Fundamentals of ESD protection at system level)
- For the two first parts, static I/V measurements before and after 20 ESD shoots (10 positive shoots and 10 negative shoots).

1 Automotive CAN ESD protection

Automotive CAN bus ESD protection need to withstand a short circuit with the battery.

For a 12 V system, the battery can reach in worst case 24 V, in case of jump-start default.

Thus, V_{RM} or V_{BR} must be higher than 24 V.

Regarding capacitance value, the SAE J2962-2 requests a maximum total line-to-ground capacitance of 100 pF on each CAN line (CAN_H and CAN_L) on their test set-up for high-speed CAN transceivers qualification requirements. TVS should be chosen with the lowest possible capacitance, to leave more margin for the rest of the components of the circuit. More information can be found on AN5878: How to design a robust automotive CAN system.

Table 1 presents the selected TVS and MOV and their characteristics: V_{RM} / V_{BR} and capacitance values are very similar for a relevant comparison.

ST part is a dual TVS to protect both lines of CAN bus.

Table 1. General purpose ESD protection characteristics

Part	C (pF)	V_{RM} (V)	V_{BR} (V)	$I_{PP8/20}$ (A)	ESD capability (kV)	Package
ESDCAN04-2BWY (ST TVS)	17	25.5	28	3.7	30 contact / air 330 pF / 330 Ω	SOT323-3L
MOV (FLX0005)	17	18	26	4	25	0402

1.1 IEC 61000-4-2 +/-8 kV contact discharge

Remaining voltages have been measured on both parts

Figure 1. +8 kV ESD discharge remaining voltage (ESDCAN04-2BWY)

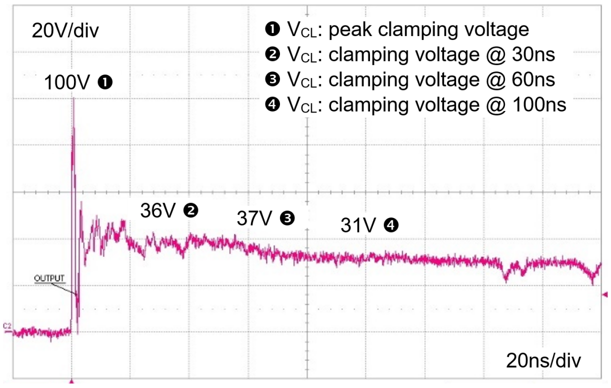


Figure 2. +8 kV ESD discharge remaining voltage (MOV)

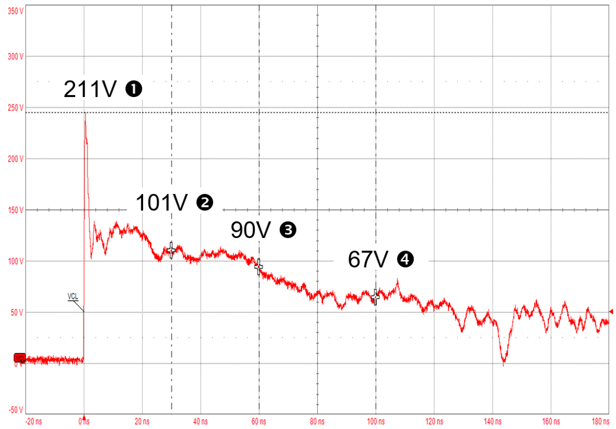


Figure 3. -8 kV ESD discharge remaining voltage (ESDCAN04-2BWY)

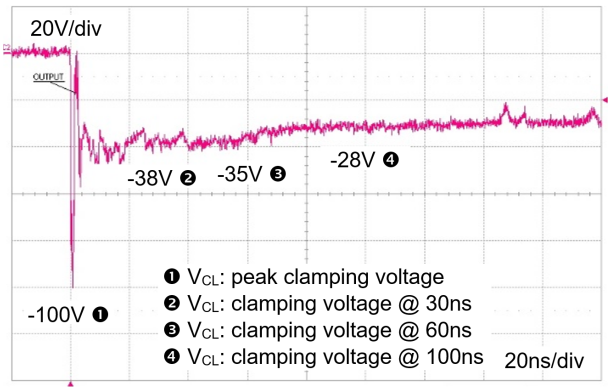
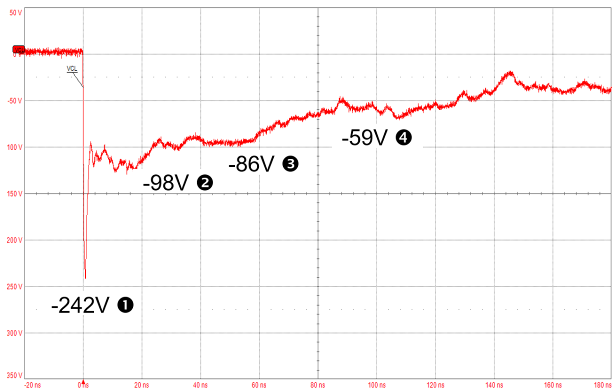


Figure 4. -8 kV ESD discharge remaining voltage (MOV)



Comparison between remaining voltages show that:

- The first voltage peak observed on the MOV is twice higher than the one observed on ESDCAN04-2BWY
- Remaining voltages at 30 ns, 60 ns and 100 ns are much lower with ESDCAN04-2BWY than with the MOV.

ESDCAN04-2BWY provides a better protection efficiency than the MOV, as the remaining voltages, seen by the protected IC are much lower.

1.2 TLP measurements

100 ns TLP measurement results are presented in Figure 5 and Figure 6.

Figure 5. **100 ns TLP measurements (ESDCAN04-2BWY)**

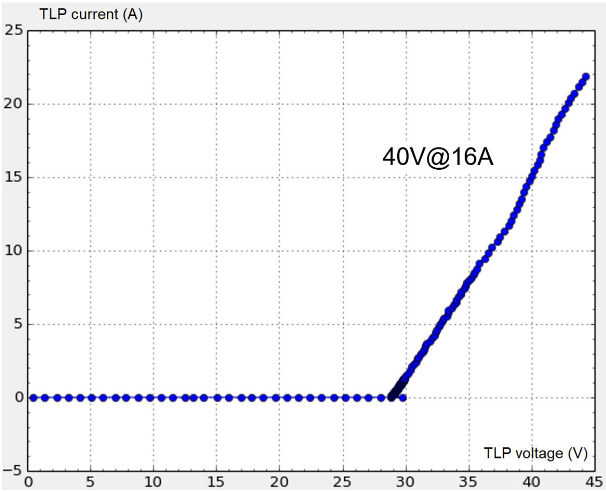
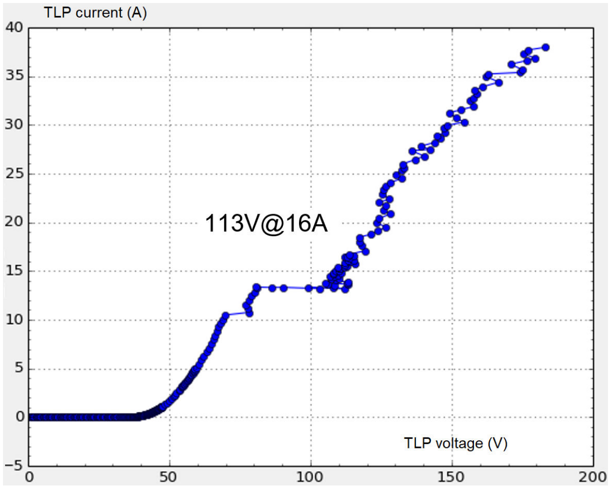


Figure 6. **100 ns TLP measurements (MOV)**



As seen on ESD remaining voltages measurements, the voltage at 16 A is lower for ESDCAN04-2BWY (40 V) than the MOV (113 V).

Also, MOV starts to operate at a voltage around 45 V, whereas it is lower (30 V) for ESDCAN04-2BWY.

TVS provides better protection than MOV.

1.3 I/V curve tracer measurements

To evaluate part performances evolution after multiple ESD events, I/V measurements have been performed before and after 20x ESD shoots (10 positive polarity shoots, and 10 negative polarity shoots), in accordance with the IEC 61000-4-2 standard.

Figure 7. I/V measurement before and after 20x ESD shoots (ESDCAN04-2BWY)

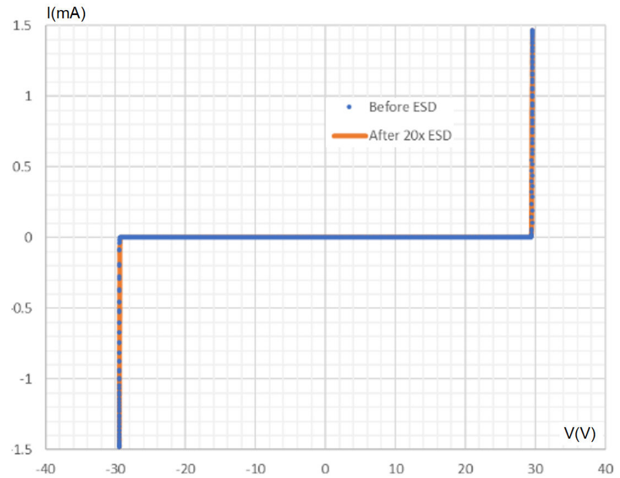
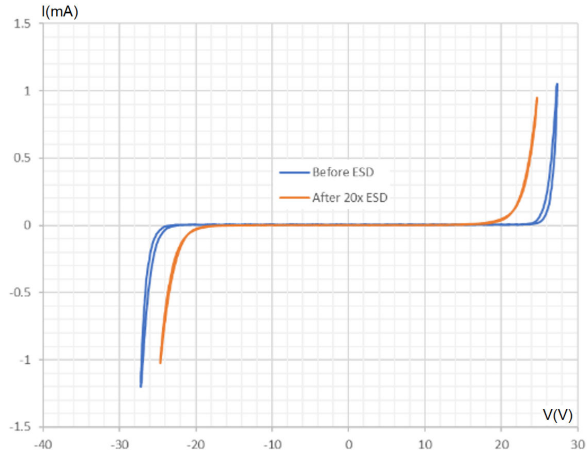


Figure 8. I/V measurement before and after 20x ESD shoots (MOV)



The MOV I/V curves show a degradation of MOV, V_{BR} is reduced, highlighting a change in the component structure. The initial characteristics of the component are no longer ensured.

In opposition, the ESDCAN04-2BWY I/V curve remains unchanged before and after 20 ESD shoots, no drift of the electrical parameter thus no evolution of the structure. Initial performances are still fully ensure.

2 General purpose ESD protection

General purpose ESD protection is used when there is no constraint on capacitance value. They are used on DC lines, or low-speed signals, such as keypads.

Table 2 gives the characteristics of the TVS and MOV used for comparison: the V_{RM} and the capacitance values are very similar.

Table 2. General purpose ESD protection characteristics

Part	C (pF)	V_{RM} (V)	V_{BR} (V)	$I_{PP8/20}$ (A)	ESD capability IEC 61000-4-2 (kV)	Package
ESD051-1BF4 (ST TVS)	45	5	5.8 min	10	30 contact / air	0201
MOV (VC020105T500WP)	50	5.6	10 - 15.6	5	8 At least	0201

2.1 IEC 61000-4-2 +/-8kV contact discharge

Remaining voltages have been measured on both parts.

Figure 9. +8 kV ESD discharge remaining voltage (ESD051-1BF4)

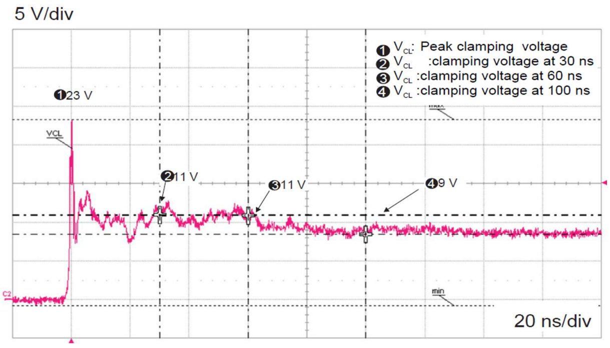


Figure 10. +8 kV ESD discharge remaining voltage (MOV)

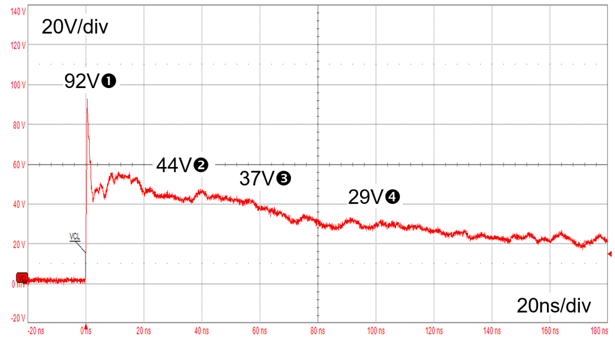


Figure 11. -8 kV ESD discharge remaining voltage (ESD051-1BF4)

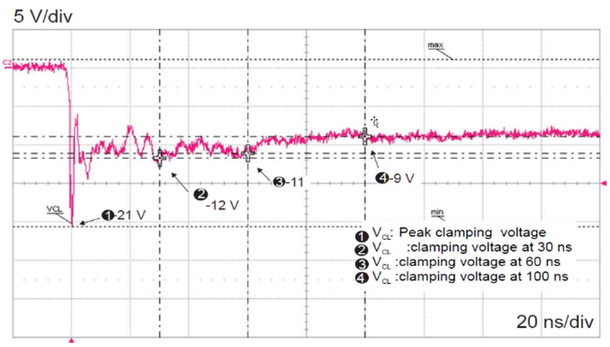
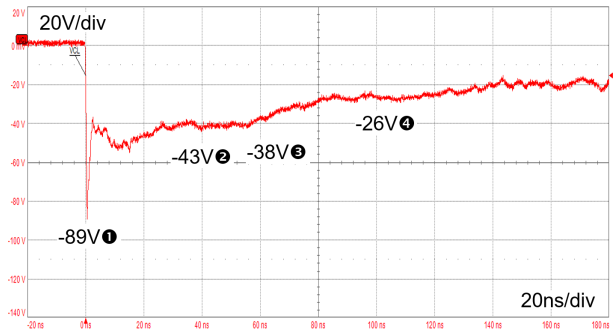


Figure 12. -8 kV ESD discharge remaining voltage (MOV)



Comparison between remaining voltages shows significant differences between the silicon TVS and the MOV:

- The first peak is around 22 V for ESD051-1BF4, whereas it is around 90 V for the MOV
- At 30 ns, it is around 12 V for ESD051-1BF4, whereas it is around 44 V for the MOV

Protection efficiency is much higher with a silicon TVS than with a MOV, as the voltage applied to the protected circuit is much lower with a TVS.

2.2 TLP measurements

Positive TLP measurements have been performed on both parts (as both parts are symmetrical, negative and positive measurements are identical).

Figure 13. **100 ns TLP measurements (ESD051-1BF4)**

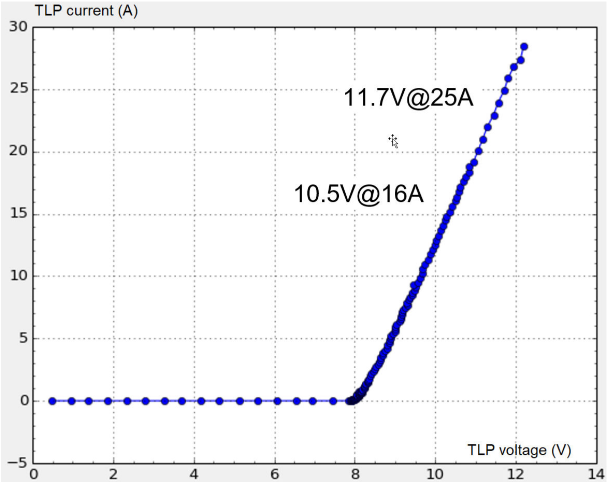
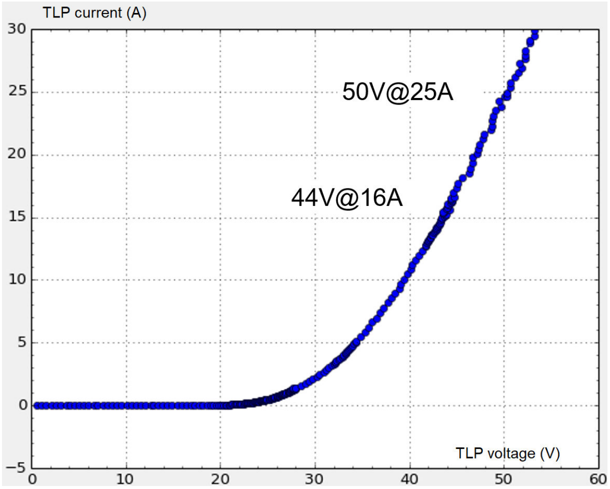


Figure 14. **100 ns TLP measurements (MOV)**



TLP comparisons are in accordance with the ESD remaining voltage comparisons: ESD051-1BF4 protection efficiency is much higher than the MOV.

Also, ESD051-1BF4 starts to clamp at 8 V, whereas it is 22 V for MOV, this can make a significant difference for the IC to be protected.

The MOV require to select an IC much more robust on ESD whereas the silicon TVS drastically reduces this constraint.

2.3 I/V curve tracer measurements

I/V curves have been performed before and after ESD shoots.

Figure 15. I/V measurement before and after 20 ESD shoots (ESD051-1BF4)

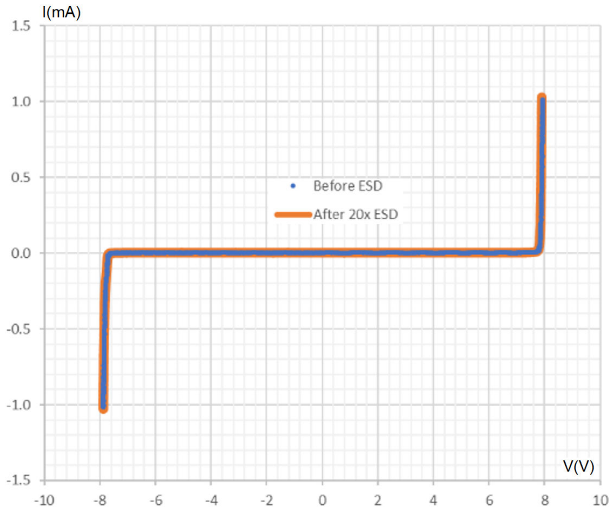
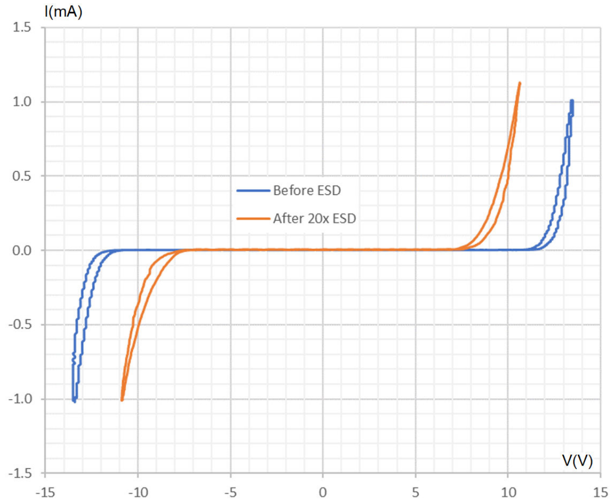


Figure 16. I/V measurement before and after 20 ESD shoots (MOV)



Here also, the I/V measurements highlight a degradation of the MOV characteristics, with the reduction of the V_{BR} at 1 mA value.

For ESD051-1BF4, there is no evolution of the I/V curve, showing a very good behavior to ESD repetitive stress.

3 Low capacitance ESD protection

Low capacitance ESD protection devices are commonly used on data lines, with data rate up to 100 Mbps. Table 3 gives the characteristics of the silicon TVS and the MOV used for this comparison: the V_{RM} and the capacitance values are close for a relevant comparison.

Table 3. Low capacitance ESD protection characteristics

	C (pF)	V_{RM} (V)	V_H (V)	V_{BR} (V)	Leakage at V_{RM} (A)	$I_{PP8/20}$ (A)	ESD IEC 61000-4-2 contact (kV)	ESD IEC 61000-4-2 air (kV)	Package
ESDZV5-1BF4 (ST TVS)	6	5.5	4	5.8 Min	0.1µ	7	18	30	0201
MOV (B72440C0050H160)	7	5.6	NA	17 Min	1µ	-	8	15	0201

3.1 IEC 61000-4-2 +/-8kV contact discharge

The remaining voltages have been measured on both parts

Figure 17. +8 kV ESD discharge remaining voltage (ESDZV5-1BF4)

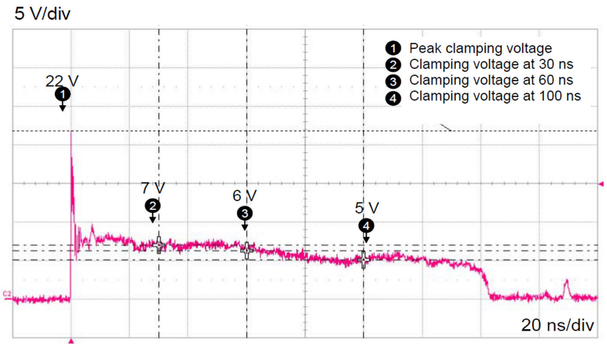


Figure 18. +8 kV ESD discharge remaining voltage (MOV)

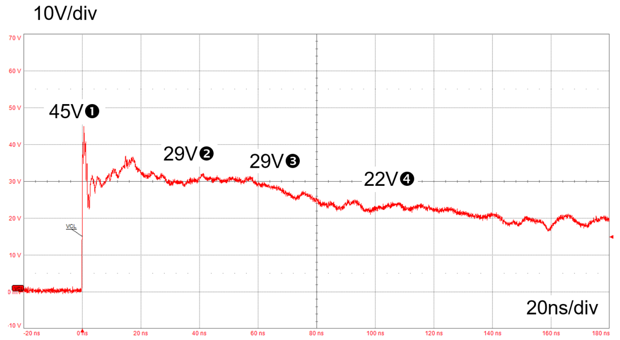


Figure 19. -8 kV ESD discharge remaining voltage (ESDZV5-1BF4)

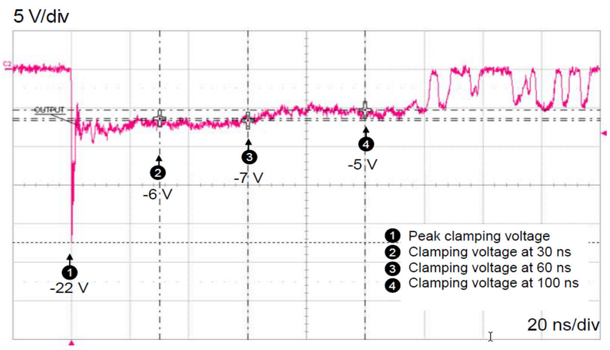


Figure 20. -8 kV ESD discharge remaining voltage (MOV)

The comparison between the remaining voltages shows significant differences between the silicon TVS and the MOV:

- The first peak is around 22 V for TVS, whereas it is around 45 V for the MOV
- At 30 ns, it is around 7 V for TVS, whereas it is around 29 V for the MOV

The protection quality is much higher with ESDZV5-1BF4 than with the MOV.

3.2 TLP measurements

Positive TLP measurements have been performed on both parts (as both parts are symmetrical, negative, and positive measurements are identical).

Figure 21. 100 ns TLP measurements (ESDZV5-1BF4)

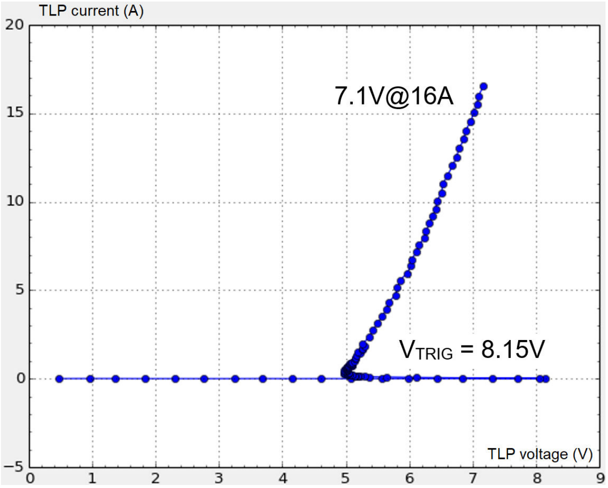
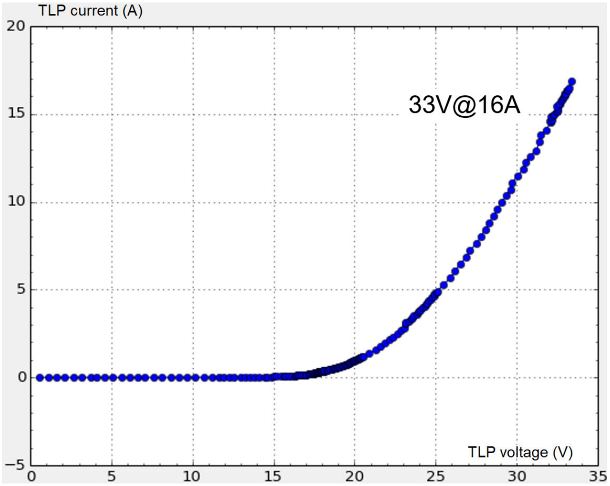


Figure 22. 100 ns TLP measurements (MOV)



The clamping voltage at 16 A is much lower for ESDZV5-1BF4 than the MOV, and it starts to protect at 8.15 V. These two parameters ensure a very good protection efficiency, far better than the MOV device.

4 Extra-low capacitance ESD protection, V_{RM} = 5 V

For high-speed differential links (such as USB 2, 3, 4, HDMI, DisplayPort, MIPI, FPD-Link, GMSL), extra low capacitance ESD protection devices are needed to secure a bandwidth wide enough to keep full signal integrity.

Table 4 gives the characteristics of the silicon TVS and the MOV used for this comparison: the V_{RM} and the capacitance values are similar.

Table 4. Extra low capacitance ESD protection characteristics

	C typ (pF)	V_{RM} (V)	V_{BR} (V)	Leakage @ V_{RM} (nA)	$I_{PP8/20}$ (A)	ESD IEC 61000-4-2 contact (kV)	ESD IEC 61000-4-2 air (kV)	Package
ESDAXLC6-1BU2 (ST TVS)	0.4	3	6 min	70 max	1.3	16	25	0201
ESDARF02-1BU2CK (ST TVS)	0.2	3.6	5 min 6.6 typ	5 typ 100 max	1.5	8	20	0201
MOV (CG0201MLC-05H)	0.2	5	250 (V_{TRIG})	10 typ	-	8	15	0201

4.1 IEC 61000-4-2 +/-8kV contact discharge

The remaining voltages have been measured on all parts

Figure 23. +8 kV ESD discharge remaining voltage (ESDAXLC6-1BU2)

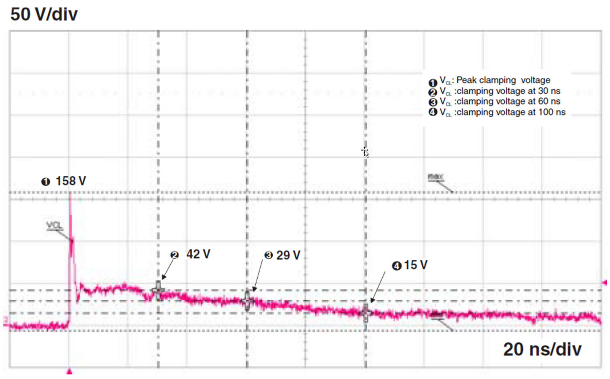


Figure 24. +8 kV ESD discharge remaining voltage (MOV)

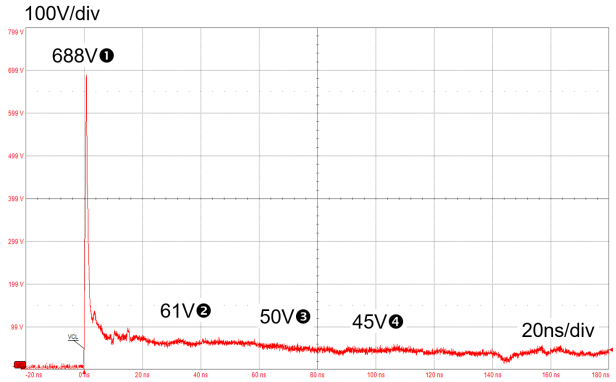


Figure 25. +8 kV ESD discharge remaining voltage (ESDARF02-1BU2CK)

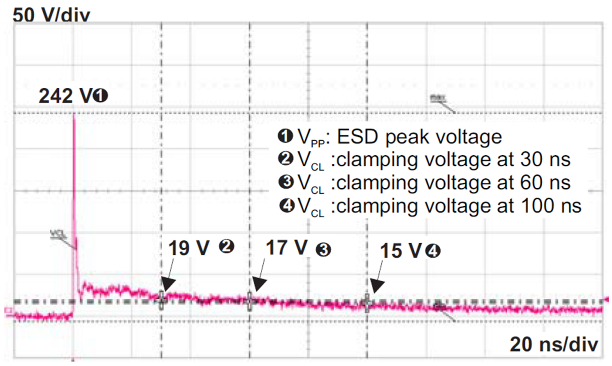


Figure 26. -8 kV ESD discharge remaining voltage (ESDAXLC6-1BU2)

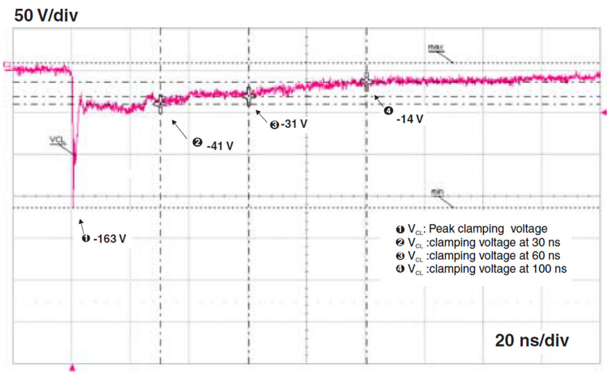
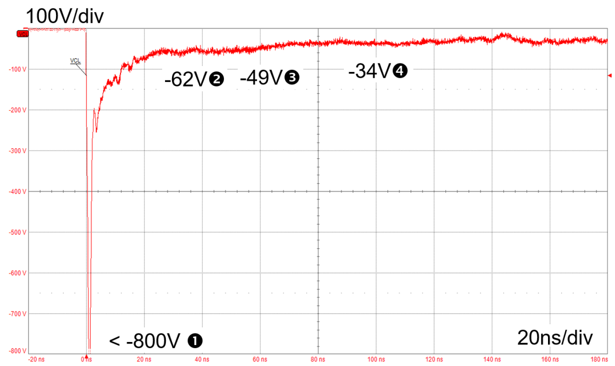


Figure 27. -8 kV ESD discharge remaining voltage (MOV)



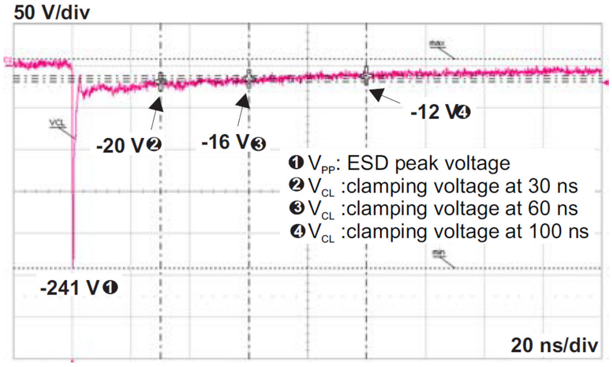


Figure 28. -8 kV ESD discharge remaining voltage (ESDARF02-1BU2CK)

In the field of extra low capacitance protection also, the first peak voltage of the silicon TVS is much lower than the MOV. Indeed, 800 V_{PEAK} for the MOV is a very high voltage to sustain for a high-speed IC to be “protected”. The low performance of the MOV in this application probably damage the circuit. The silicon TVS clamping voltages at 30 ns, 60 ns, and 100 ns are lower than the MOV clamping voltages.

4.2 TLP measurements

Positive TLP measurements have been performed on both parts (as both parts are symmetrical, negative, and positive measurements are identical).

Figure 29. 100 ns TLP measurements (ESDAXLC6-1BU2)

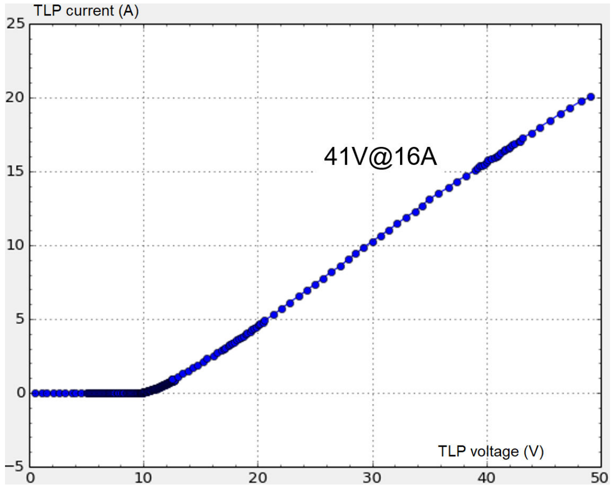


Figure 30. 100 ns TLP measurements (MOV)

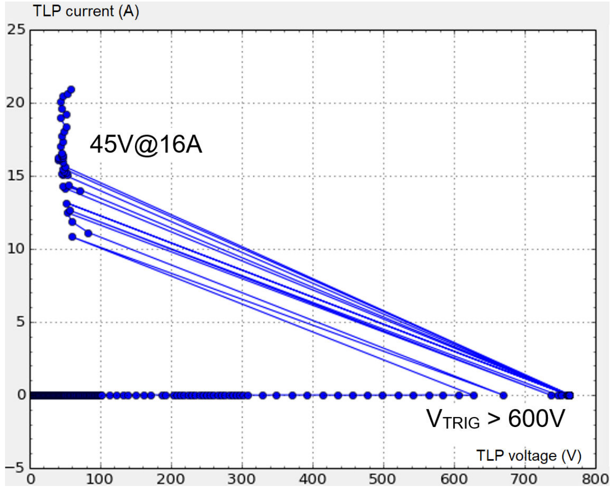
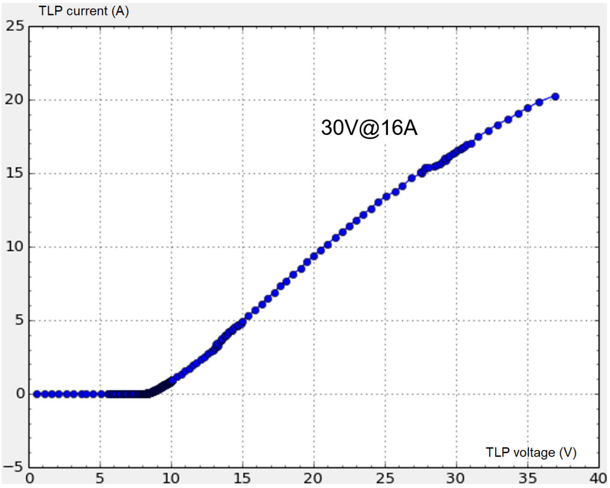


Figure 31. 100 ns TLP measurements (ESDARF02-1BU2CK)



As observed on ESD remaining voltage measurements, the MOV triggering voltage is very high, 600 V: this means that MOV not block any ESD event below 600 V. Knowing that the IEC 61000-4-2 ESD gun is much more severe than HBM, it can destroy the high-speed IC. Also, the MOV TLP measurements show a non-constant triggering value, as it can be 620 V or 750 V.

5 Extra-low capacitance ESD protection, V_{RM} = 16 V

RF antennas request ESD protection parts with extra low capacitance featuring high bandwidth, but also V_{RM} in the range of RF signal amplitude, 16 V is then commonly used.

Table 5. Extra low capacitance ESD protection characteristics

	C (pF)	V_{RM} (V)	V_H (V)	V_{trig} (V)	Leakage at V_{RM} (A)	$I_{PP8/20}$ (A)	ESD IEC 61000-4-2 contact (kV)	ESD IEC 61000-4-2 air (kV)	Package
ESDZX168B-1BF4 (ST TVS)	0.12 typ	16	16	18 min	90n max	2	12	30	0201
MOV (PGB2010201KR-15NR)	0.05 typ	15	NA	300	10n typ	-	8	15	0201

5.1 IEC 61000-4-2 +/-8kV contact discharge

The remaining voltages have been measured on all parts

Figure 32. +8 kV ESD discharge remaining voltage (ESDZX168B-1BF4)

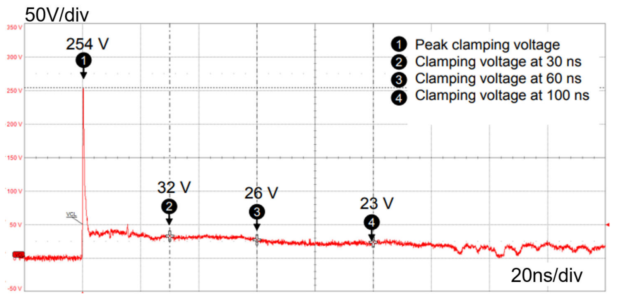


Figure 33. +8 kV ESD discharge remaining voltage (MOV)

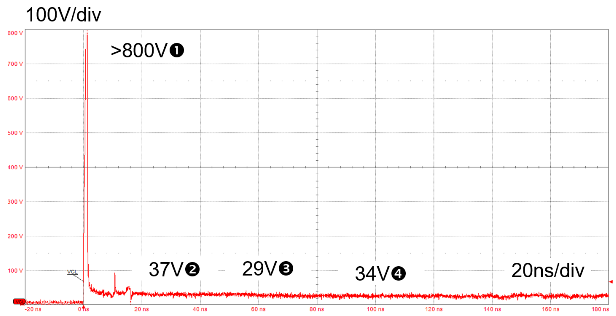


Figure 34. -8 kV ESD discharge remaining voltage (ESDZX168B-1BF4)

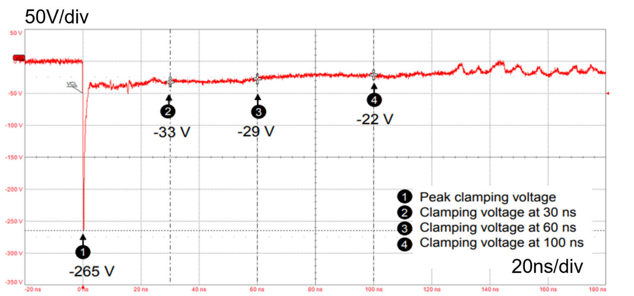
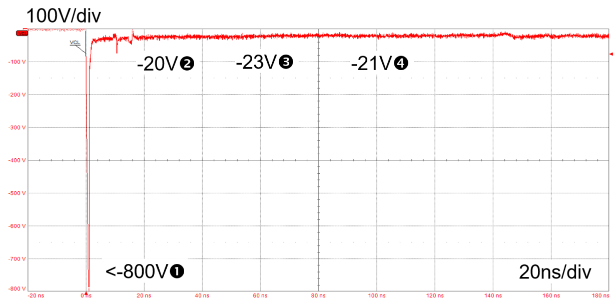


Figure 35. -8 kV ESD discharge remaining voltage (MOV)



The remaining voltage measurements, at +8 kV and -8 kV, show that the first peak generated by the MOV is very high (higher than 800 V), which cannot be absorbed by IC to protect in most of the cases.

For the ESDZX168B-1BF4, the first peak is much lower (in the range of 260 V), providing a better protection efficiency than the MOV.

5.2 TLP measurements

Positive TLP measurements have been performed on both parts (as both parts are symmetrical, negative, and positive measurements are identical).

Figure 36. 100ns TLP measurements (ESDZX168B-1BF4)

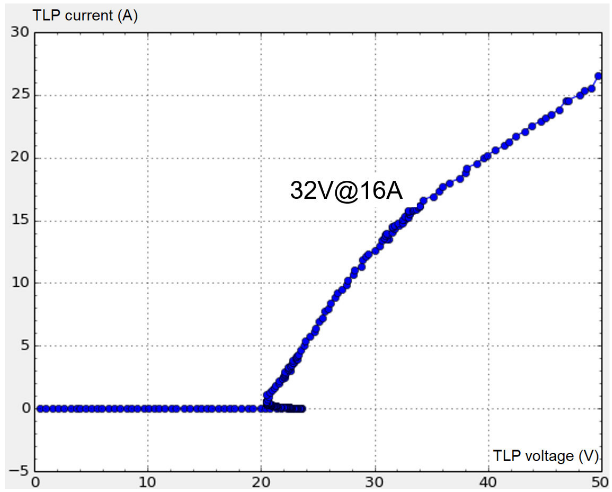
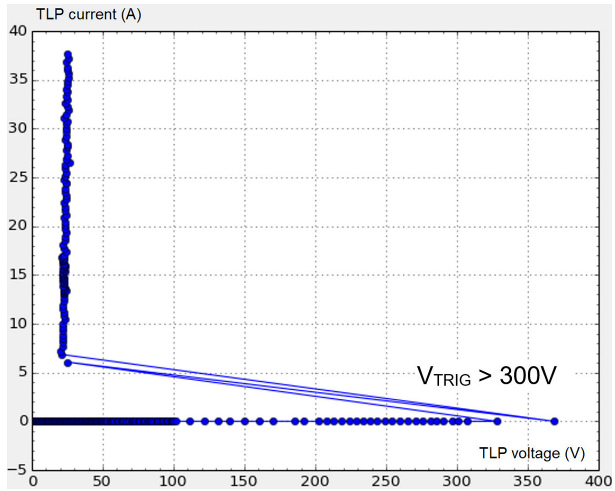


Figure 37. 100ns TLP measurements (MOV)



Here again the MOV triggering voltage is very high (300 V) whereas it is 24 V for ESDZX168B-1BF4.

6 Conclusion

The comparisons between the MOV and the silicon TVS have been performed choosing similar functional performances, that is, V_{RM} and capacitance values, and packages to get relevant results.

For all selected use cases (Automotive CAN protection, General purpose protection, Low capacitance protection, 5 V Extra-low capacitance protection and 16 V Extra-low capacitance protection), the same measurements on the silicon TVS and the MOV have been performed:

- Remaining voltage following an IEC 61000-4-2 +/-8 kV contact discharge
- TLP (Transmission Line Pulse) measurement (100 ns), positive polarity
- For the two first parts, static I/V measurements before and after 20 ESD shoots (10 positive shoots, 10 negative shoots)

All measurements are showing that for silicon TVS the protection efficiency is much higher than the MOV:

- The first peak ESD remaining voltage is always lower with the silicon TVS
- The ESD remaining voltage after 30 ns is lower with the silicon TVS
- The TLP triggering voltage is lower with the silicon TVS (the MOV can be up to 600 V)
- The TLP at 16A voltage is lower with the silicon TVS

Also, the I/V curves before and after 20 consecutive ESD shoots show no effect on TVS characteristics, whereas the MOV characteristics are degraded (V_{BR} is lower after ESD shoots).

For safe and reliable systems, design engineers should be aware of these differences in performances. The silicon TVS or ESD diodes should be selected to secure the best possible protection efficiency, keeping protected circuits or the IC is safe and fully operational, whatever the application and the operating environment.

ST's ESD protection portfolio includes:

- General-purpose ESD protection
- Low capacitance (< 1 pF) ESD protection
- Automotive ESD protection

Revision history

Table 6. Document revision history

Date	Revision	Changes
26-Apr-2024	1	Initial release.

Contents

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