

# Protection of Automotive Application by Asymmetric TVS Diodes

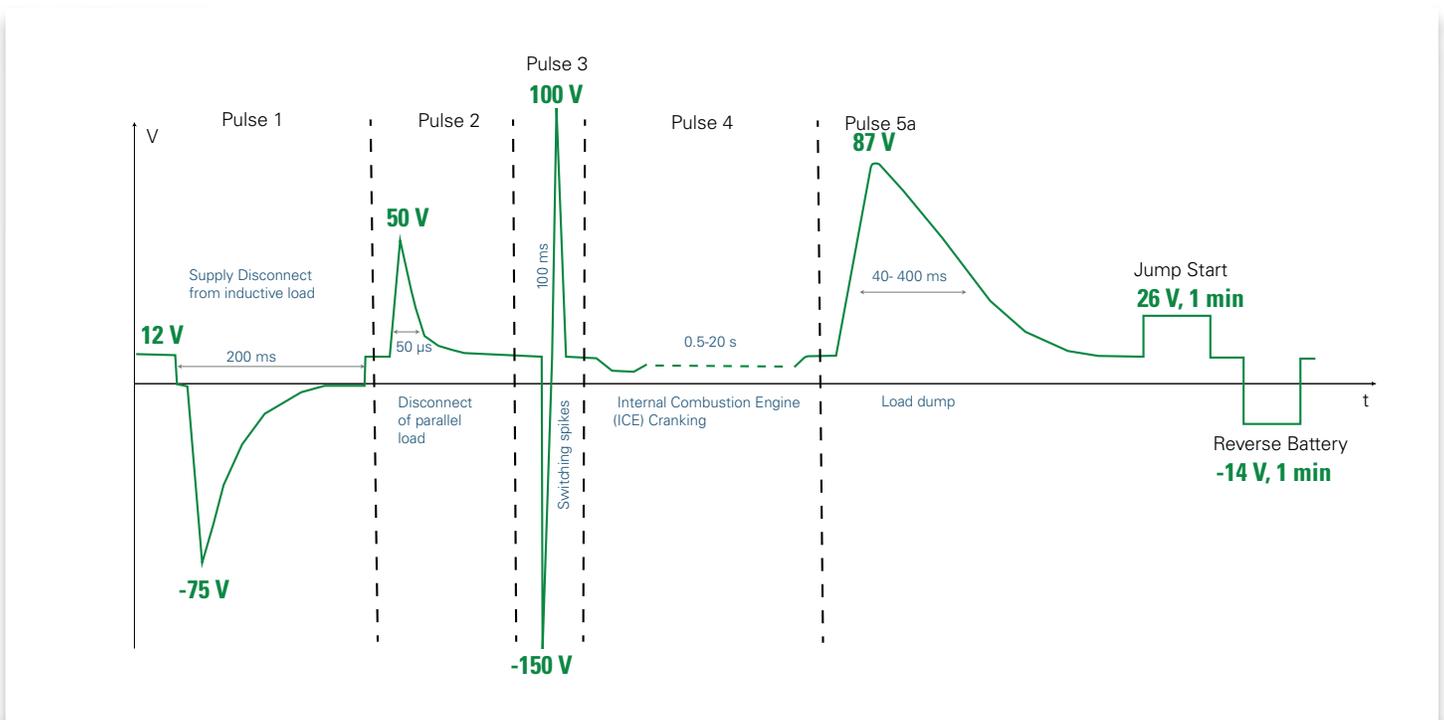
## Overview

Automotive designers face many difficulties in handling electrical disturbances in vehicles that happened on supply lines. These events occur in the form of electronic static discharge (ESD), transients and surges. Energy release from inductance causes most transients.

Transient surge protection is one of the essential criteria to make the automotive product robust and reliable and automotive standard ISO7637-2 defines most of these disturbances.

Negative overvoltage pulse protection is mandatory for reverse polarity protection circuits like Diodes or reverses polarity protection MOSFETs. Reverse polarity protection, pulse 1 and pulse 3a of the ISO7637-2 are the reasons to benefit from the use of an asymmetric low voltage TVS. The advantages and the selection criteria will be discussed in this application note.

**Fig.1. Automotive Battery Line Electrical Disturbances**



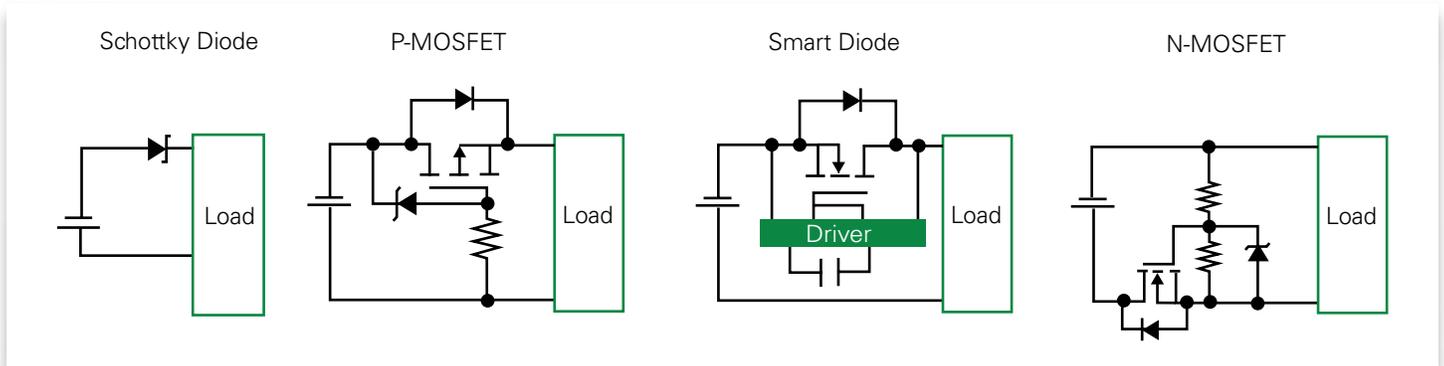
To survive these disturbances, the electronics must protect with overvoltage protection devices like TVS Diodes. These protection parts have to fulfill the "Failure Mechanism Based Stress Test Qualification for Discrete Semiconductors" AEC-Q101 of the Automotive Electronics Council (AEC) requirements. This is fulfilled by all Littelfuse automotive TVS Products.

The overvoltage protection part must be placed on the input of the circuit. Throughout this article, we will use TVS, a short for TVS diodes.

## Reverse Protection

The need for reverse protection is required for all the applications connected directly to the battery to protect for wrong connection. If the load current is approximately less than 2 A, a single Schottky diode can be used for this. If the load current is higher than 2 A, a MOSFET is more useful for less forward voltage drop and power dissipation. This could be an N-Channel MOSFET with a charge pump or a P-Channel MOSFET in the positive supply line. If the application ground is not connected directly to the chassis, the N-Channel MOSFET can be used in the negative supply line.

**Fig.2. Reverse Polarity Protection Solutions**



The semiconductor parts of the electronic control unit ECU are most sensitive against overvoltage and could be damaged or destroyed. Therefore, they have to be protected. For a system with 12 V applications, the general use are MOSFETs with a maximum Drain Source Voltage of 40 V.

## Unidirectional TVS-Diode Without Reverse Protection Requirement

What are the requirements to select a fitting TVS diode?

The selected TVS diode is not allowed to be triggered during the jump start (+26 V) or during the clamped load dump (+27 V), because the power dissipation will destroy the TVS diode if the diode is in clamping mode. But the TVS diode must protect against voltages transients over 40 V. An excellent choice is the unidirectional TVS diode TPSMA6L28A with a maximum clamp voltage of 36 V under Pulse 2a. During the tests, the drift of the voltage due to low and high temperatures has also to be considered. The typical maximum temperature coefficient is stated in the TVS diode datasheet. For more detailed information, contact the Littelfuse application engineering team.

Tester: Teseq NSG5500

Pulse 2a typical clamp voltage on TPSMA6L28A at both 25 °C and 85 °C as reference.

Test pulse 2a ISO 7637-2 (+112 V, 50  $\mu$ s, 2  $\Omega$ )

Fig.3. 25 °C Pulse 2a (ISO7637-2)

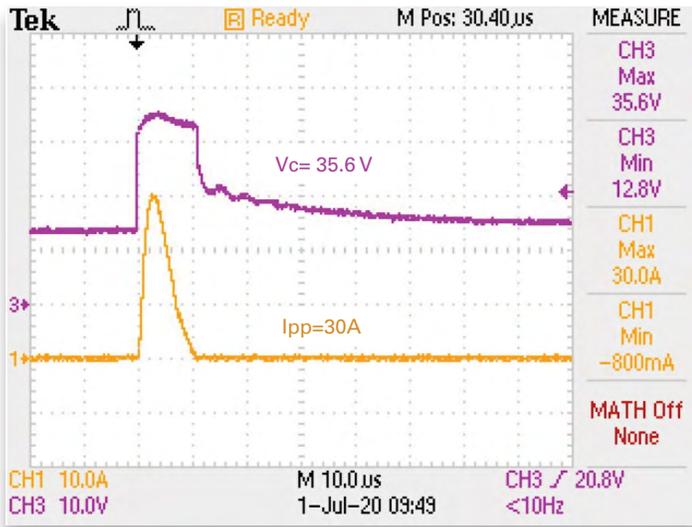
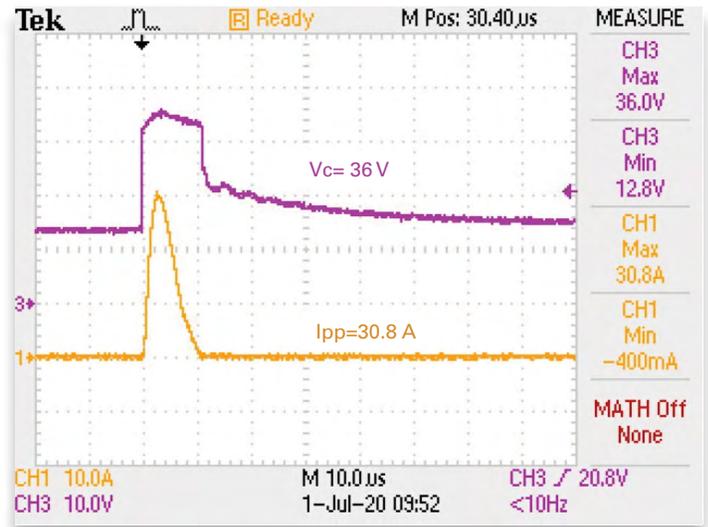
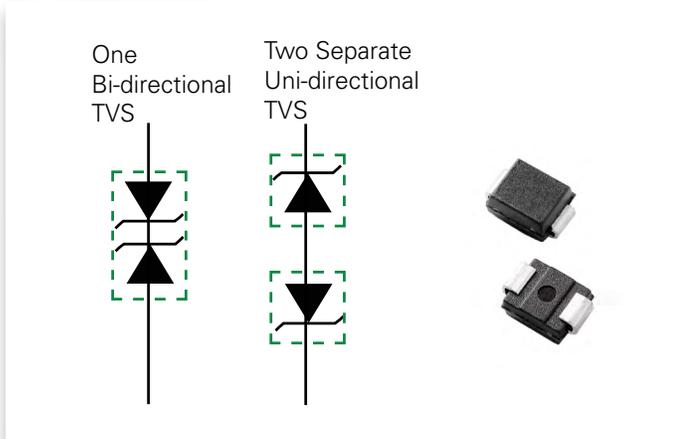


Fig.4. 85 °C Pulse 2a (ISO7637-2)



If the reverse battery voltage test is mandatory, it is suggested to use a bidirectional TVS Diode or an anti-series connection of two unidirectional TVS Diodes.

Fig. 5. A Bidirectional TVS and Two Unidirectional TVS in Back to Back Series Connection



## Bidirectional TVS Diode with Reverse Protection Requirement

The reverse battery voltage test is -14 V. Regarding the need not to be clamped under load dump voltage and jump-start voltage, the bidirectional TVS clamping voltage has to be about +27 V. Considering 40 V working voltage reverse protection Schottky diode or MOSFET, the right choice would be **TPSMB30CA**.

Test Pulse 1 ISO 7637-2 (-150 V, 2 ms , 10 Ω)

Fig. 7. 25 °C Pulse 1 (ISO7637-2) on TPSMB30CA

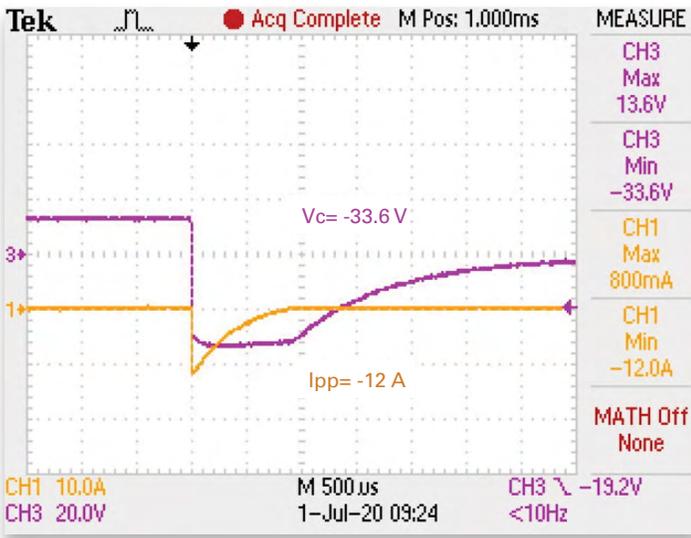


Fig. 6. Bidirectional TVS with Reverse Protection

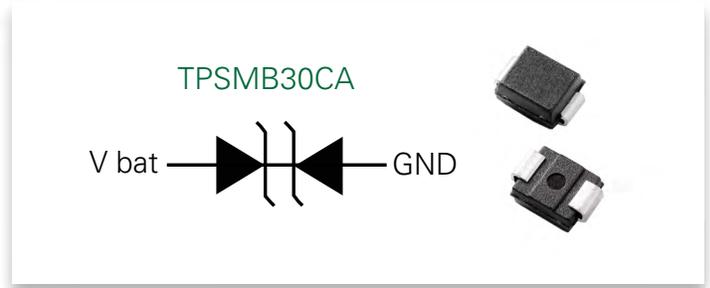
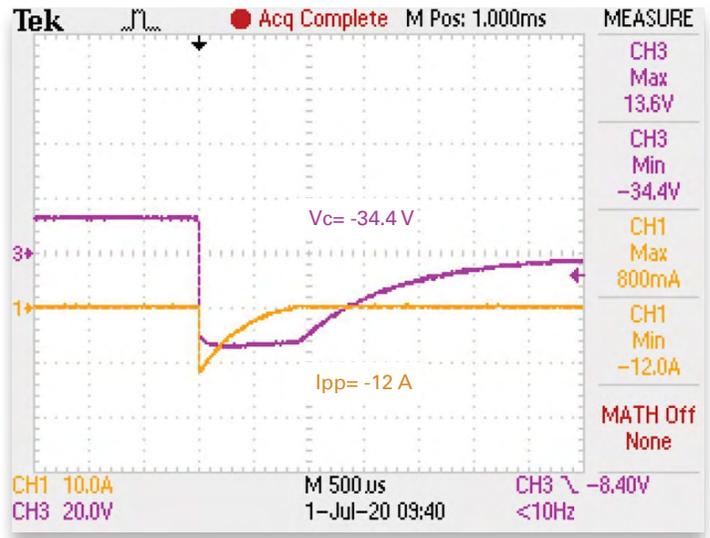


Fig. 8. 85 °C Pulse 1 (ISO7637-2) on TPSMB30CA



Test Pulse 2a ISO 7637-2 (+112 V, 50 μs, 2 Ω)

Fig. 9. 25 °C Pulse 2a (ISO7637-2) on TPSMB30CA

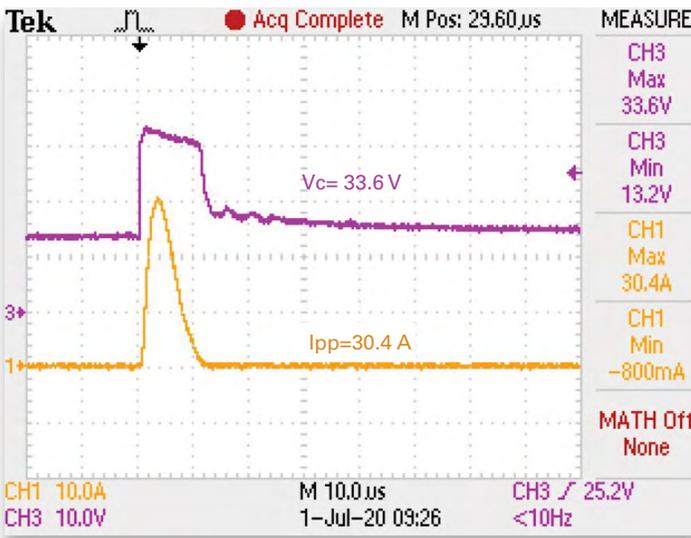
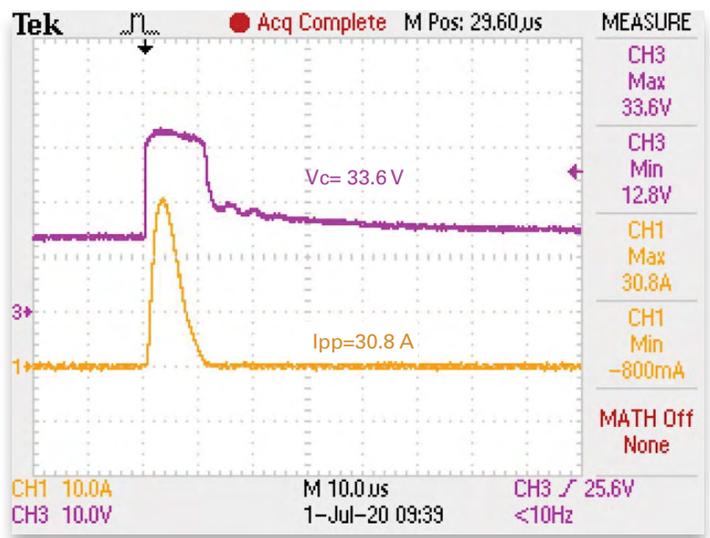


Fig. 10. 85 °C Pulse 2a (ISO7637-2) on TPSMB30CA



Test Pulse 3a ISO 7637-2 (-150 V, 150 ns, 50 Ω)

Fig. 11. 25 °C Pulse 3a (ISO7637-2) on TPSMB30CA

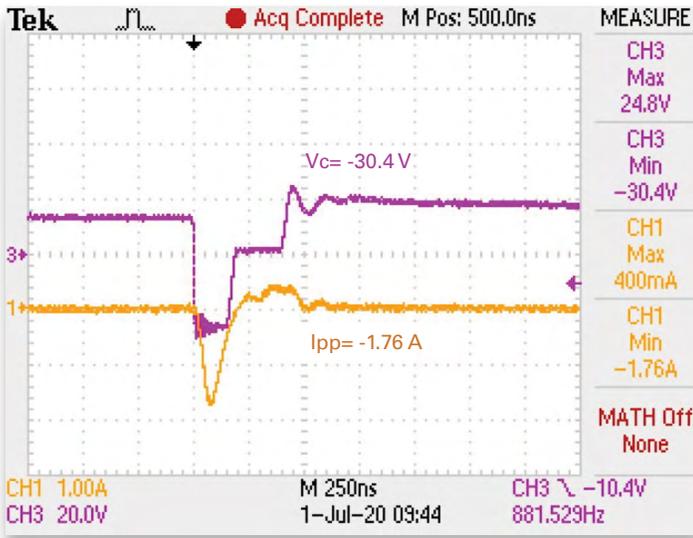
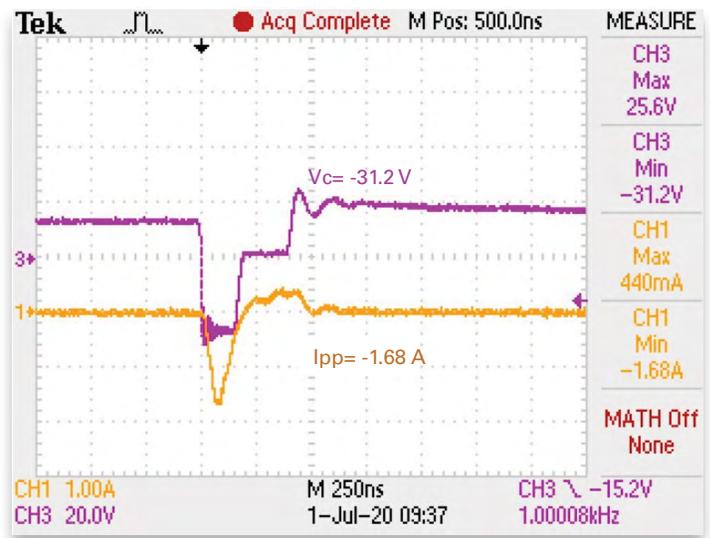


Fig. 12. 85 °C Pulse 3a (ISO7637-2) on TPSMB30CA



Test Pulse 3b ISO 7637-2 (+150 V, 150 ns, 50 Ω)

Fig. 13. 25 °C Pulse 3b (ISO7637-2) on TPSMB30CA

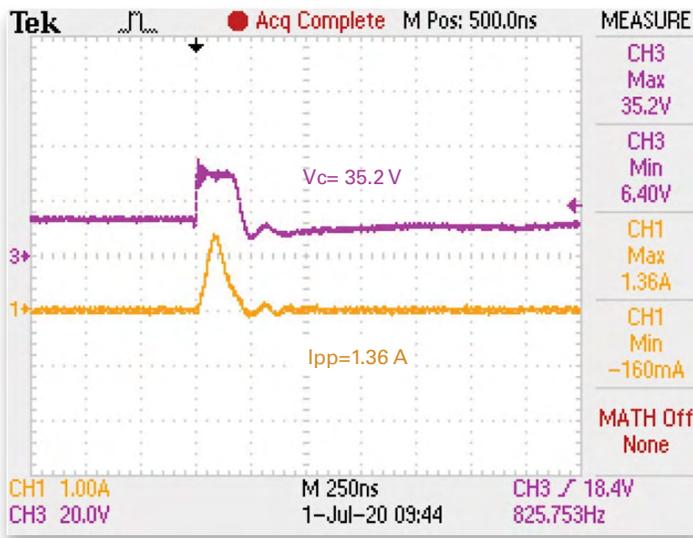
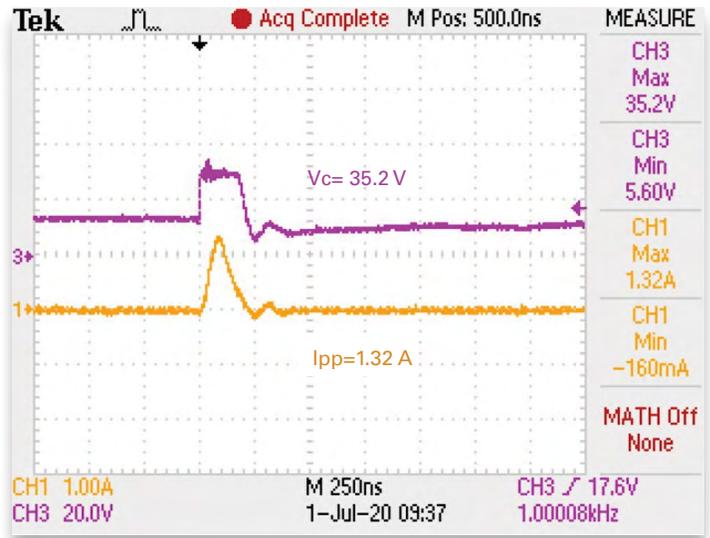


Fig. 14. 85 °C Pulse 3b (ISO7637-2) on TPSMB30CA

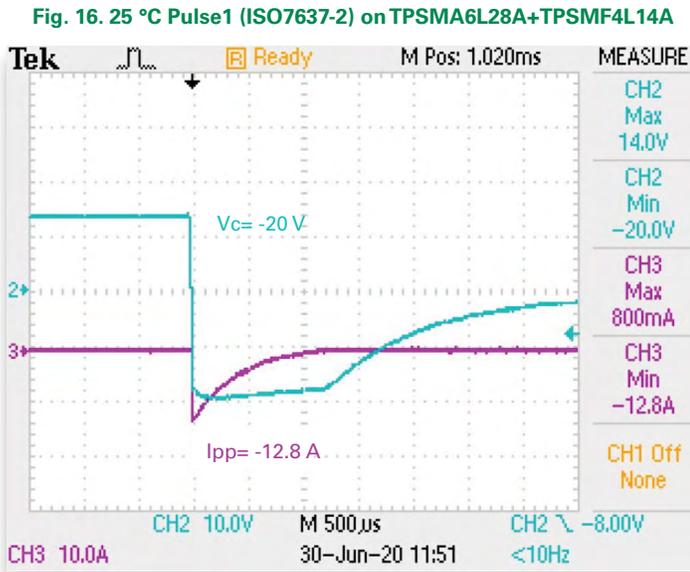


The above figure 7 to 14 list the TVS clamp response of the TPSMB30CA for the pulse 1, 2a, 3a and 3b for 25 °C and 85 °C. All of the pulse waveforms have a clamping voltage of less than 40 V, which is within the safe operating voltage level of Schottky diodes with a maximum of 40 V Reverse Voltage or MOSFETs with maximum 40 V Drain Source Voltage.

## Two Unidirectional TVS Diodes with Reverse Protection Requirement

The other possibility would be the unidirectional **TPSMA6L28A (600W)** and a unidirectional **TPSMF4L14A (400W)** for the overvoltage protection of the reverse protection circuit.

Test Pulse 1 ISO 7637-2 (-150V, 2 ms , 10 Ω)



Test Pulse 2a ISO 7637-2 (+112 V, 50 μs, 2 Ω)

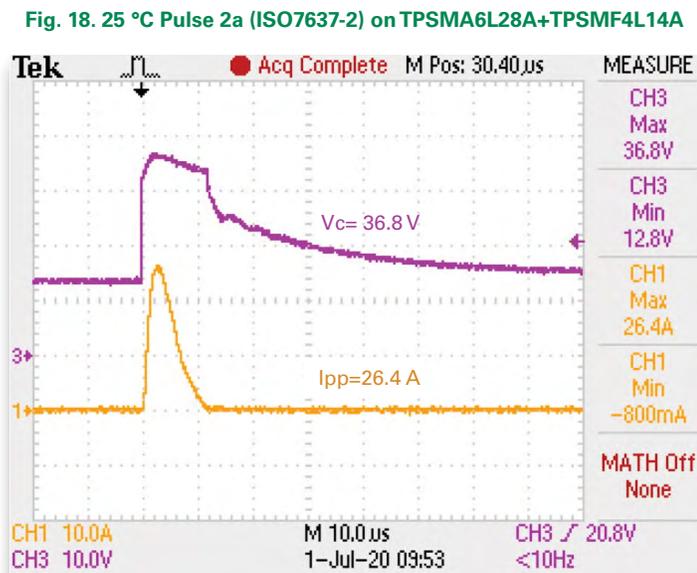


Fig. 15. Two Unidirectional TVS with Reverse Protection

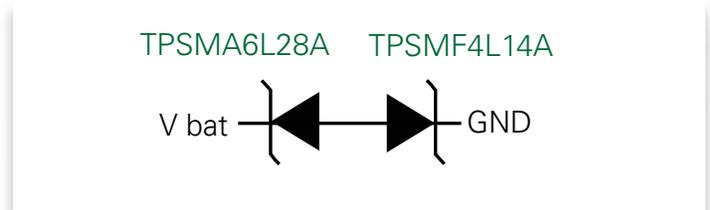


Fig. 17. 85 °C Pulse1 (ISO7637-2) on TPSMA6L28A+TPSMF4L14A

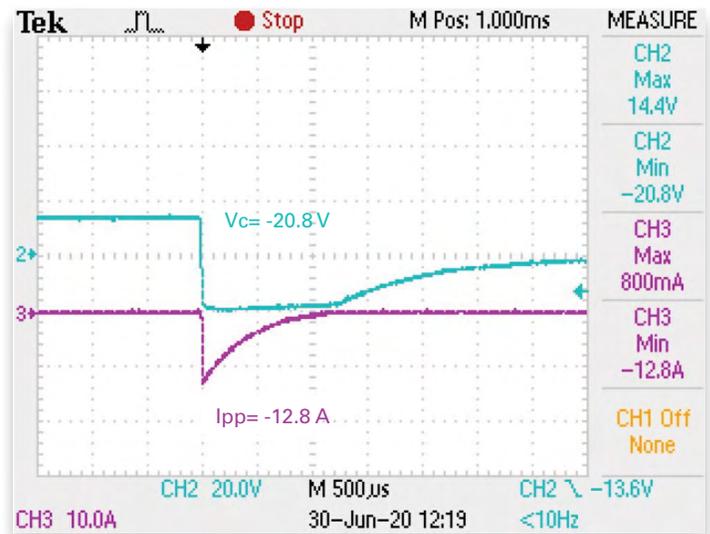
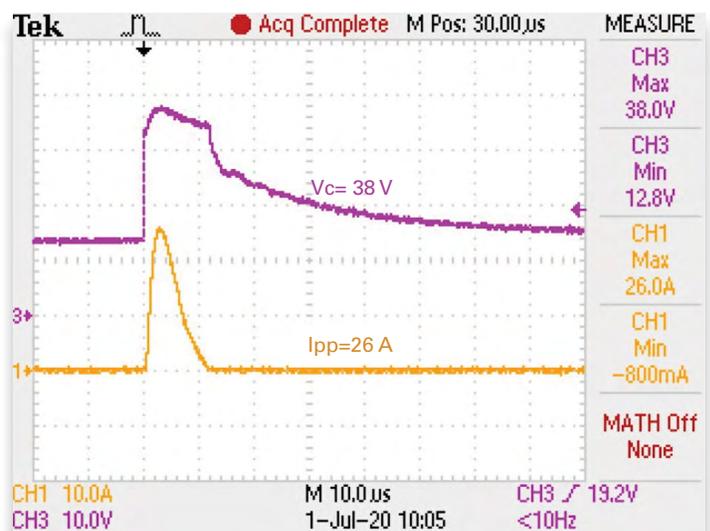


Fig. 19. 85 °C Pulse 2a (ISO7637-2) on TPSMA6L28A+TPSMF4L14A



Test Pulse 3a ISO 7637-2 (-150 V, 150 ns, 50 Ω)

Fig. 20. 25 °C Pulse 3a (ISO7637-2) on TPSMA6L28A+TPSMF4L14A

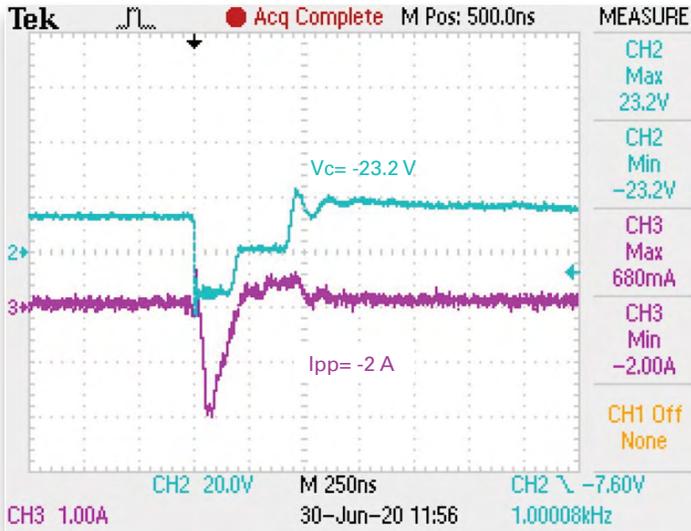
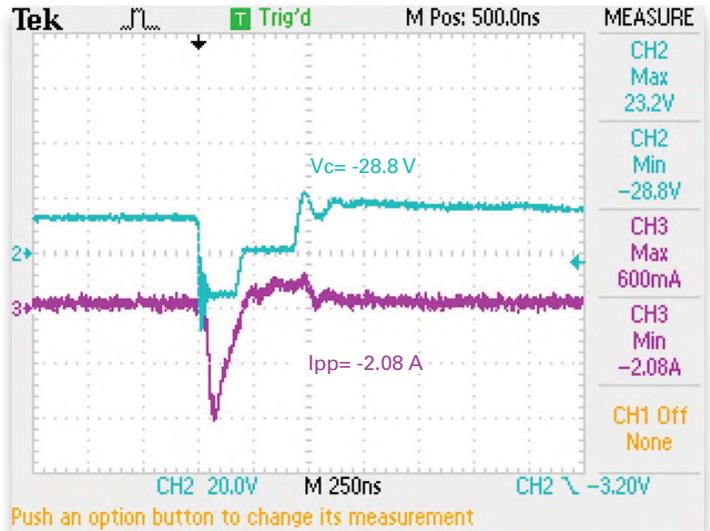


Fig. 21. 85 °C Pulse 3a (ISO7637-2) on TPSMA6L28A+TPSMF4L14A



Test Pulse 3b ISO 7637-2 (+150 V, 150 nS, 50 Ω)

Fig. 22 25 °C Pulse 3b (ISO7637-2) on TPSMA6L28A+TPSMF4L14A

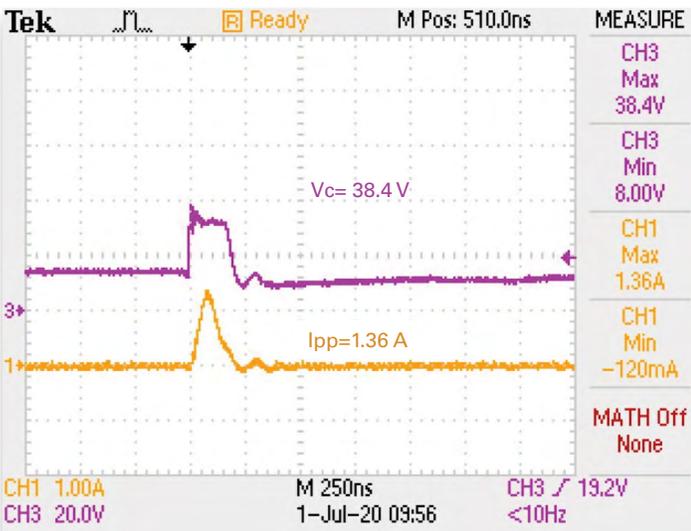
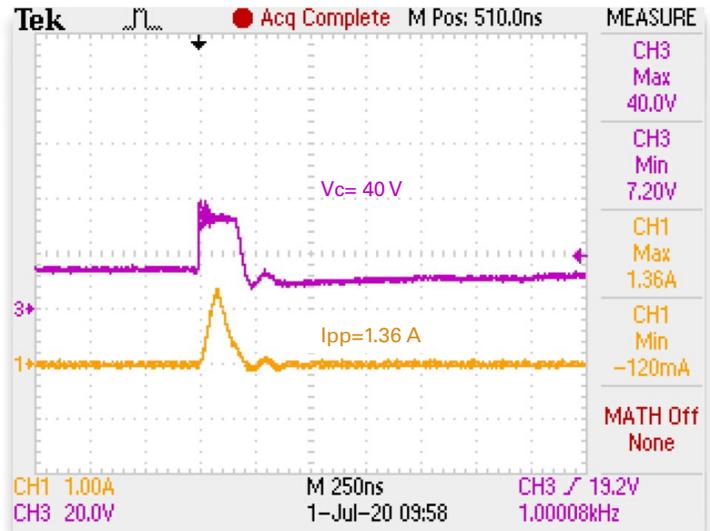


Fig. 23. 85 °C Pulse 3b (ISO7637-2) on TPSMA6L28A+TPSMF4L14A



The above figure 16 to 23 list the TVS clamp response of the TPSMA6L28A + TPSMF4L14A for the pulse 1, 2a, 3a and 3b for 25 °C ad 85 °C. All of the pulse waveforms have a clamping voltage of less than -30 V, which is within the safe operating voltage level of Schottky diodes with a maximum of 30 V Reverse Voltage or MOSFETs with maximum 30 V Drain Source Voltage.

As the above measurements have shown, the bidirectional TVS TPSMB30CA (600 W) has a maximum Voltage of 33.6 V at 25 °C under Test pulse 2a ISO 7637-2 (+112 V, 50 μs, 2 Ω).

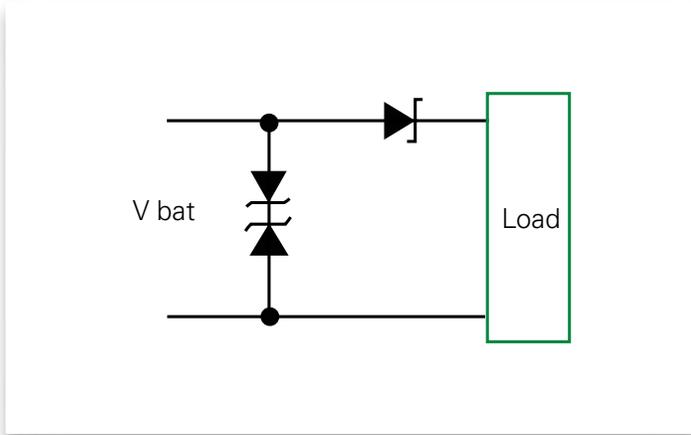
Also, it has shown the unidirectional TPSMA6L28A (600 W) and a unidirectional TPSMF4L14A (400 W) with a maximum voltage of 36.8 V at 25 °C under Test pulse 2a ISO 7637-2 (+112 V, 50 μs, 2 Ω).

Depending on the actual protection requirements and cost considerations in the competitive automotive market, customers may choose a lower cost 30V Schottky diode or 30V MOSFET for the reverse voltage protection circuit.

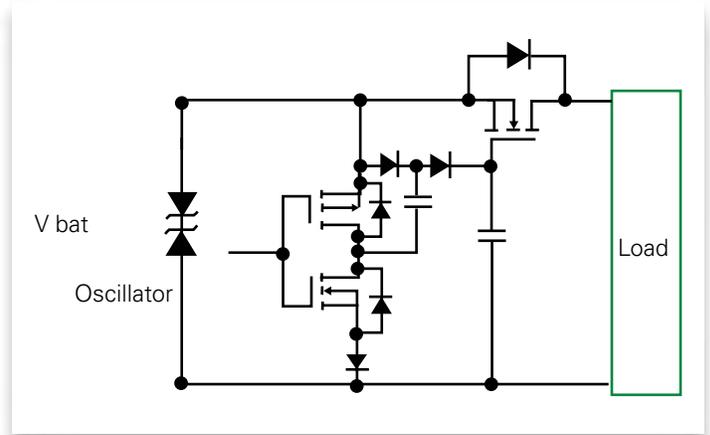
Traditional single bi-directional TVS provides symmetrical overvoltage protection. The protection voltage from the positive side is equal to the negative side. However, it is not sufficient to meet a maximum voltage of under 30V.

The ideal solution is to develop a two different breakdown voltage uni-directional TVS (TPSMB30A + TPSMB16A) with back to back series connection. This solution with two different standoff voltage TVS diodes is widely used for such protections.

**Fig. 24. Schottky Diode for Reverse Protection**



**Fig. 25. N-MOS for Reverse Protection**



Figures 24 and 25 show the addition of two uni-directional TVS with back-to-back series connection to protect the following electronics and the load.

Because of creating a simple and space-saving approach, Littelfuse single Asymmetric TVS is designed especially for such protection with AECQ-101 qualification, it brings customer cost-saving and better bill of material management. Even lower clamp voltage benefits from its smaller package stray inductance with single TVS chip inside.

Littelfuse TPSMB2616CA TVS diode (+26 V / -16 V) is designed to pass ISO16750-2 5b test with 35 V clamp overvoltage protection integrated into the alternator. If there is a higher clamp voltage integrated by the alternator, then a higher breakdown side TVS voltage (higher than the Us) needs to be used accordingly.

**Table 1. TPSMB2616CA and other TPSMBxx1xCA Electrical Characteristics**

Part Number	Marking	K to A							A to K						
		Maximum Reverse Leakage $I_{R1} @ V_{R1}$ ( $\mu A$ )	Stand off Voltage $V_{R1}$ (V)	Breakdown Voltage $V_{BR} @ I_{T1}$ (V)		Maximum Clamping Voltage $V_{C1} @ I_{PP}$ (V)	Maximum Peak Pulse Current $I_{PP1}$ (A)	Test Current $I_{T1}$ (mA)	Maximum Reverse Leakage $I_{R2} @ V_{R2}$ ( $\mu A$ )	Stand off Voltage $V_{R2}$ (V)	Breakdown Voltage $V_{BR}$ (V) @ $I_{T2}$		Maximum Clamping Voltage $V_{C2} @ I_{PP}$ (V)	Maximum Peak Pulse Current $I_{PP2}$ (A)	Test Current $I_{T2}$ (mA)
				Min	Max						Min	Max			
TPSMB2412CA	2412	1	24	26.6	29.4	38.9	15.5	1	1	12	13.3	14.7	19.9	30.2	1
TPSMB2616CA	2616	1	26	28.9	31.9	39.5	14.3	1	1	16	17.8	19.7	26.0	23.1	1
TPSMB2818CA	2818	1	28	31.1	34.4	42.5	13.3	1	1	18	20.0	22.1	29.2	20.6	1
TPSMB3018CA	3018	1	30	33.3	36.8	48.4	12.4	1	1	18	20.0	22.1	29.2	20.6	1

**Note:**  
Datasheet Vc is defined by 10/1000  $\mu S$  pulse, different decay time pulse can make different clamp voltage level.

## Detail Clamp Voltage of TPSMB2616CA Based on ISO7637-2 Waveforms

Here are some test results showing how the asymmetrical TPSMB2616CA protects different pulses (positive and negative) with and without capacitors.

### Without Capacitor

Test Pulse 1 ISO 7637-2 (-150V, 2 ms, 10 Ω)

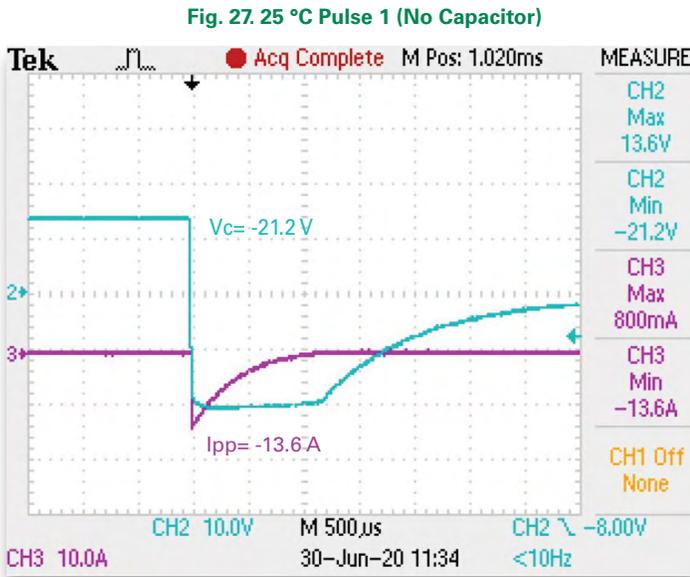
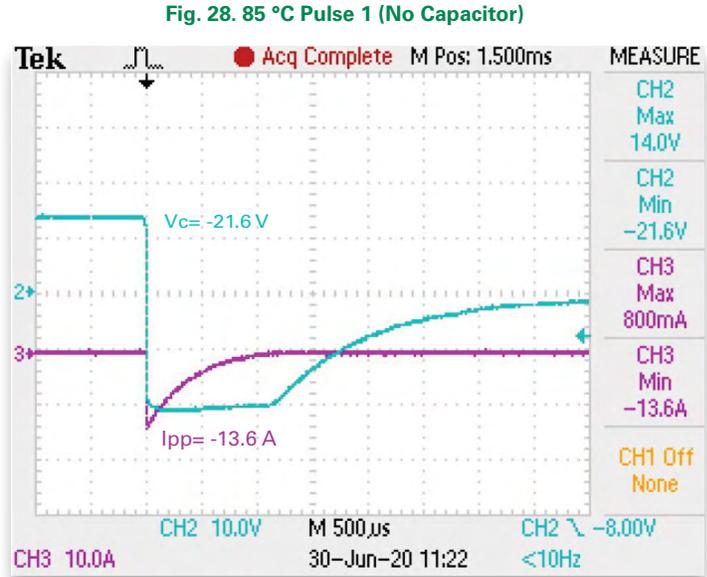
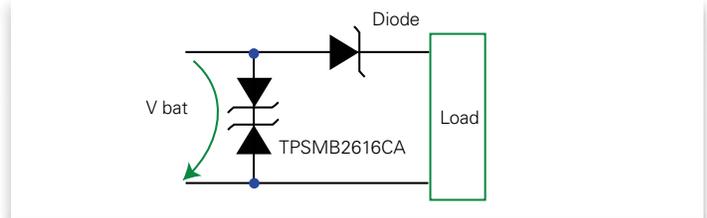
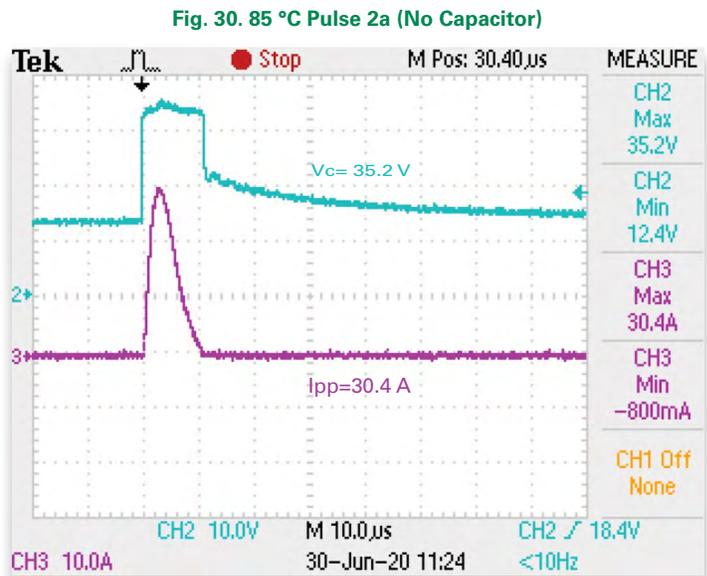
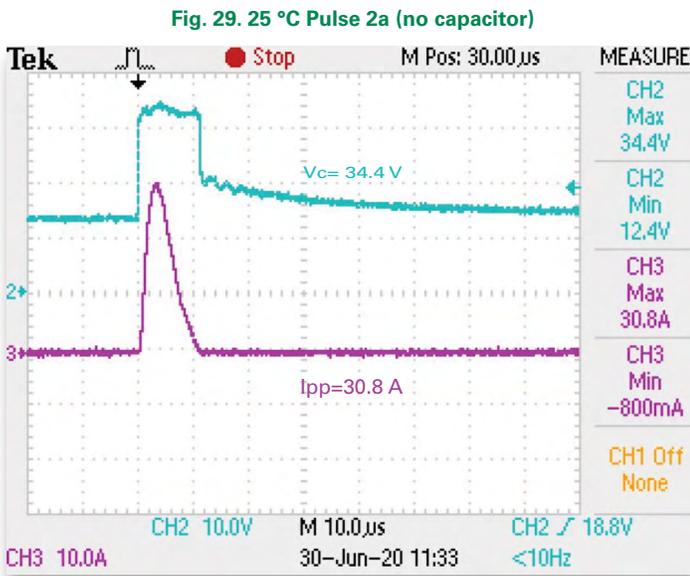


Fig. 26. Asymmetrical TPSMB2616CA Protects Different Pulses



As shown in figures 27 & 28, single Pulse 1 power on TVS is about  $0.5 \times 21.2 \text{ V} \times 13.6 \text{ A} = 144 \text{ W} @ 1 \text{ ms}$ , which is less than TPSMB 600 W @ 1 ms. The average power for Pulse 1 on TVS is about  $144 \text{ W} \times 0.001 \text{ s} / 0.5 = 0.29 \text{ W}$ . The TPSMB package has a  $R_{th(j-a)} = 100 \text{ }^\circ\text{C/W}$ . So, the TVS temperature increase is only about  $0.29 \text{ W} \times 100 \text{ }^\circ\text{C/W} = 29 \text{ }^\circ\text{C}$ . It is well within the safe operating area of TPSMB2616CA.

Test Pulse 2a ISO 7637-2 (+112V, 50 µs, 2 Ω)



As shown in figure 29 & 30, single Pulse 2a power on TVS is about  $0.5 \times 34.4 \text{ V} \times 30.8 \text{ A} = 530 \text{ W} @ 10 \text{ } \mu\text{s}$ , which is less than TPSMB 600 W @ 1 ms. The average power for Pulse 1 on TVS is about  $530 \text{ W} \times 10 \text{ } \mu\text{s} / 200000 = 0.027 \text{ W}$ . The TPSMB package has a  $R_{th(j-a)} = 100 \text{ }^\circ\text{C/W}$ . The TVS temperature increase is only about  $0.027 \text{ W} \times 100 \text{ }^\circ\text{C/W} = 2.7 \text{ }^\circ\text{C}$ . It is well within the safe operating area of TPSMB2616CA.

Test Pulse 3a ISO 7637-2 (-150 V, 150 ns, 50  $\Omega$ )

Fig. 31. 25 °C Pulse 3a (No Capacitor)

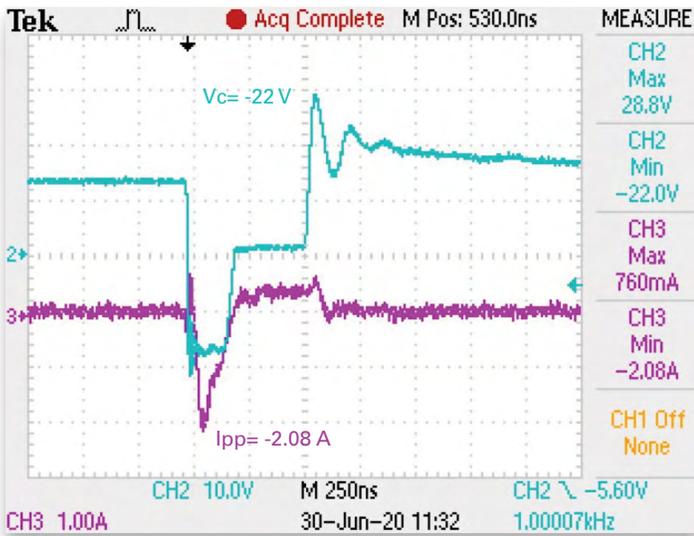
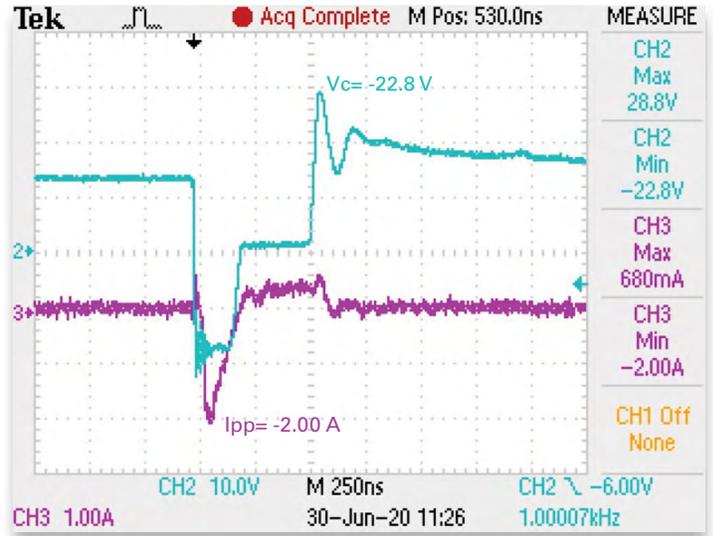


Fig. 32. 85 °C Pulse 3a (No Capacitor)



Test Pulse 3b ISO 7637-2 (+150 V, 150 ns, 50  $\Omega$ )

Fig. 33. 25 °C Pulse 3b (No Capacitor)

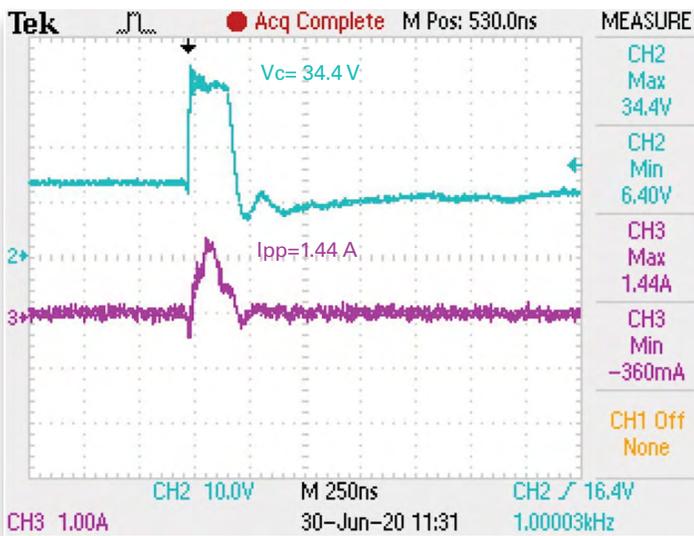
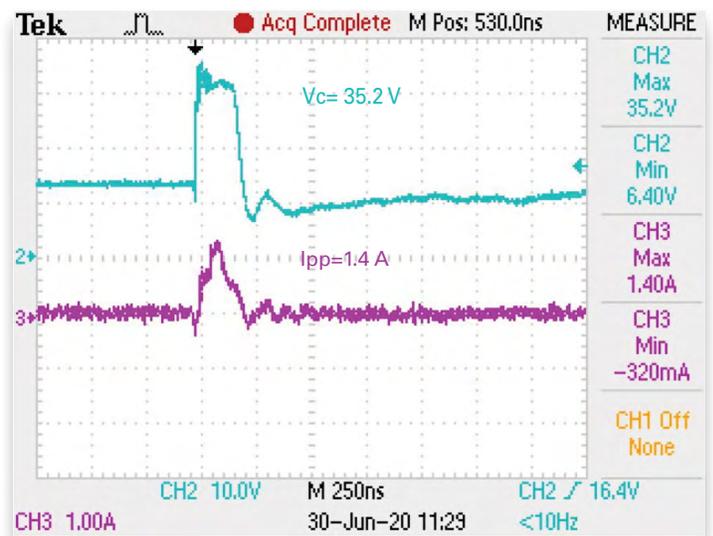


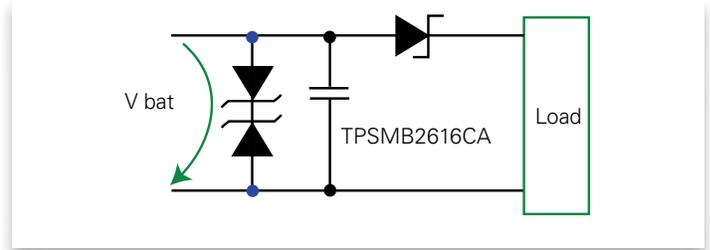
Fig. 34. 85 °C Pulse 3b (No Capacitor)



## Measurement of clamping voltage and current of the asymmetrical TVS with one capacitor of 10 $\mu\text{F}$ parallel

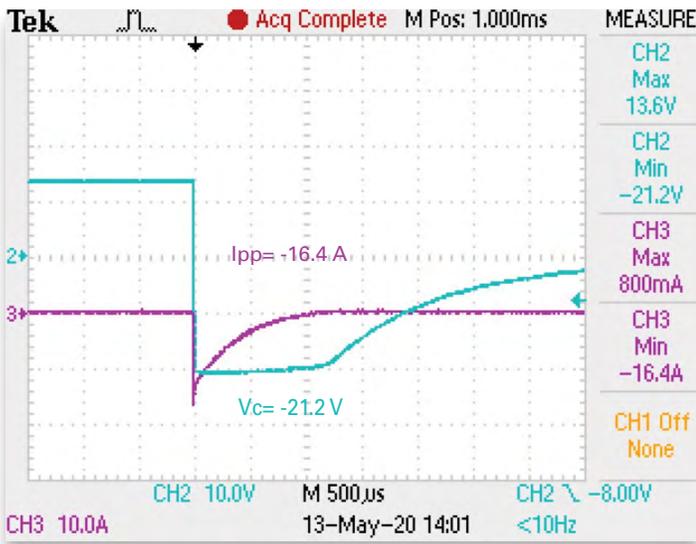
Bluepoint in figure 35 shows the voltage across the TVS diode

Fig. 35. Asymmetrical TVS with One Capacitor of 10  $\mu\text{F}$  Parallel



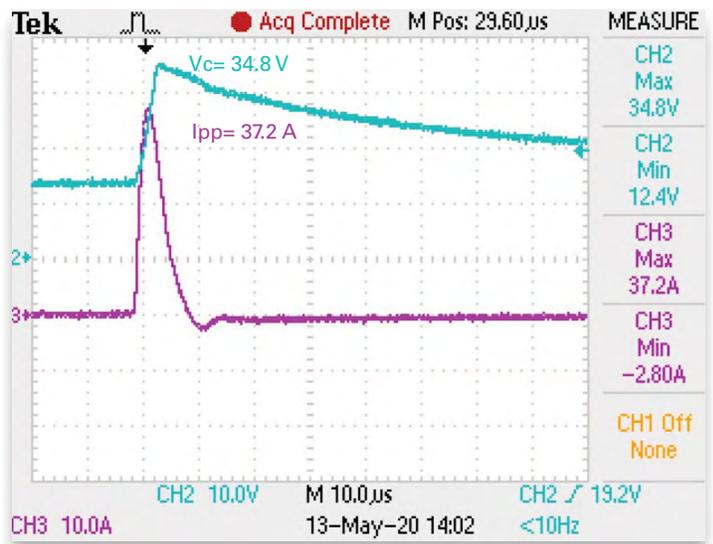
Test Pulse 1 ISO 7637-2 (-150 V, 2 ms, 10  $\Omega$ )

Fig. 36. Clamp Voltage on Pulse1 (with 1pcs X5R 10  $\mu\text{F}$ )



Test Pulse 2a ISO 7637-2 (+112 V, 50  $\mu\text{s}$ , 2  $\Omega$ )

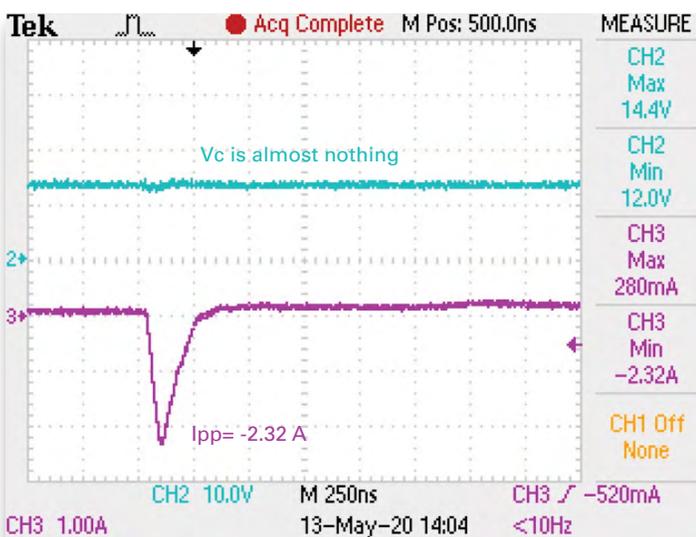
Fig. 37. Clamp Voltage on Pulse 2a (with 1pcs X5R 10  $\mu\text{F}$ )



As shown in Figures 36 & 37, with a parallel-connected capacitor of 10  $\mu\text{F}$  beside TVS. Pulse 2a clamping voltage  $V_c$  was less than 34.8 V.

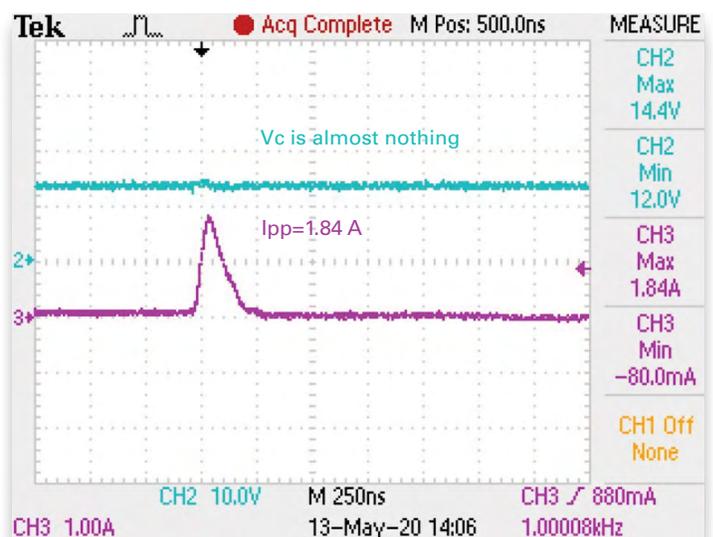
Test Pulse 3a ISO 7637-2 (-150 V, 150 ns, 50  $\Omega$ )

Fig. 38. Clamp Voltage on Pulse 3a (with 1pcs X5R 10  $\mu\text{F}$ )



Test Pulse 3b ISO 7637-2 (+150 V, 150 ns, 50  $\Omega$ )

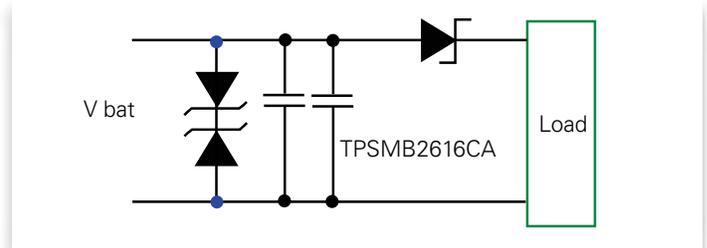
Fig. 39. Clamp Voltage on Pulse 3b (with 1pcs X5R 10  $\mu\text{F}$ )



As shown in Figures 38 & 39, with a parallel-connected capacitor, Pulse 3a/3b surge energy was absorbed and the clamping voltage  $V_c$  is smaller.

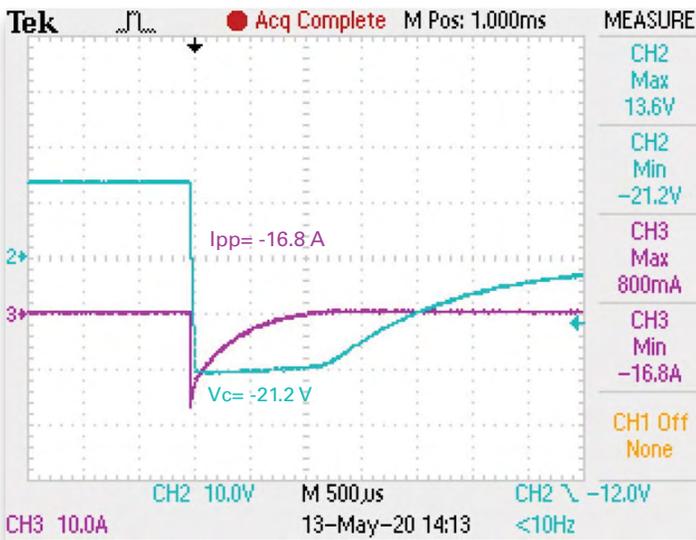
## Measurement of Clamping Voltage and Current of The Asymmetrical TVS with 2 Capacitors of 10 $\mu\text{F}$ in Parallel

Fig. 40. Asymmetrical TVS with Two Capacitors of 10  $\mu\text{F}$  Parallel



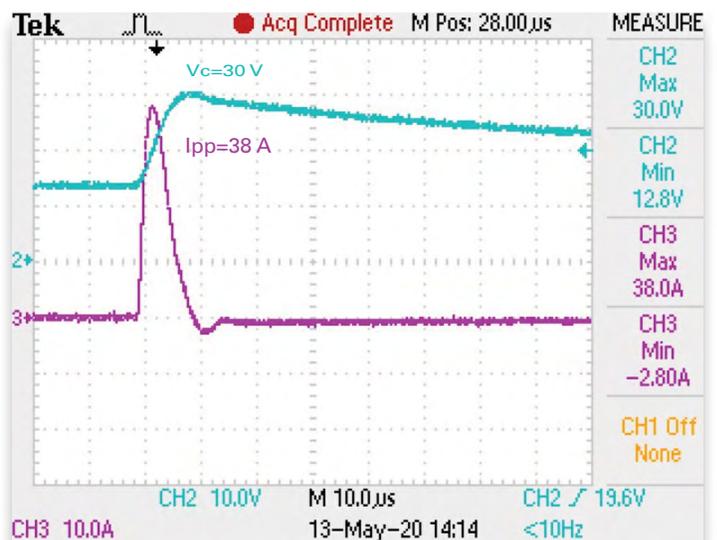
Test Pulse 1 ISO 7637-2 (-150 V, 2 ms, 10  $\Omega$ )

Fig. 41. Clamp Voltage on Pulse1 (with 2pcs X5R 10  $\mu\text{F}$ )



Test Pulse 2a ISO 7637-2 (+112 V, 50  $\mu\text{s}$ , 2  $\Omega$ )

Fig. 42. Clamp Voltage on Pulse 2a (with 2pcs X5R 10  $\mu\text{F}$ )

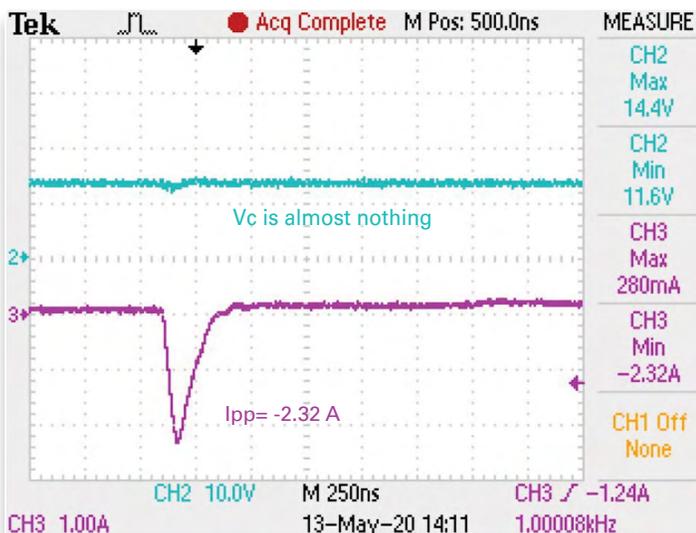


As shown in figure 41 & 42, with 2 parallel-connected capacitors beside the asymmetrical TVS.

Pulse 2a clamping voltage  $V_c$  can be further improved accordingly down to  $V_c = 30\text{V}$ .

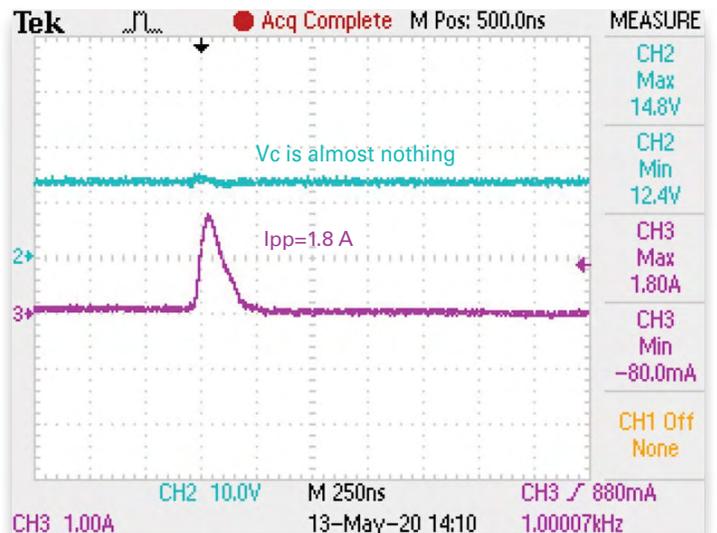
Test Pulse 3a ISO 7637-2 (-150 V, 150 ns, 50  $\Omega$ )

Fig. 43. Clamp Voltage on Pulse 3a (with 2pcs X5R 10  $\mu\text{F}$ )



Test Pulse 3b ISO 7637-2 (+150 V, 150 ns, 50  $\Omega$ )

Fig. 44. Clamp Voltage on Pulse 3b (with 2pcs X5R 10  $\mu\text{F}$ )



As shown in Figures 43 & 44, with 2 parallel-connected capacitors with the asymmetrical TVS. Pulse 3a/3b waveform was absorbed and the clamping voltage is almost nothing.

## Typical Asymmetrical TVS Leakage Current Test at 25 °C and 85 °C

Fig. 45. 26 V TVS Side Leakage vs. Temperature

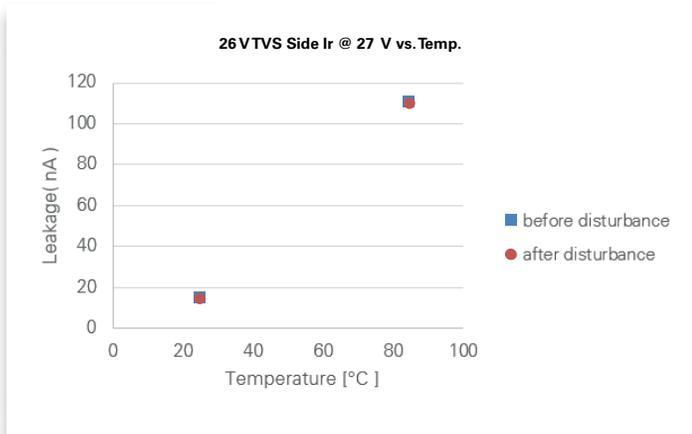
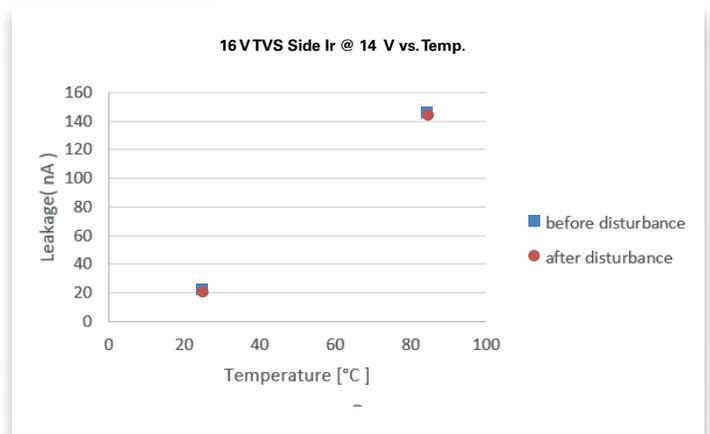


Fig. 46. 16 V TVS Side Leakage vs. Temperature



As shown in figures 45 & 46, the disturbance test did not impact TVS leakage current level. They stayed almost the same.

### Conclusions

Littelfuse’s new asymmetric automotive-grade TVS diode is ideal for helping automotive electronic designers to meet the different levels of surge tests of ISO-7637 and provide extra safe protection with low clamping voltages and low leakage current under disturbance test. With the asymmetrical TVS Littelfuse offers a unique possibility to reduce the cost for overvoltage protection, to save space on the PCB, and increase the quality with proven performance compare to an approach with two TVS Diodes in series. Please contact us for design support and more information.

For more detail information about [TPSMB asymmetric series TVS Diodes](#), please go to Littelfuse.com and search “ TPSMB asymmetric ” or you can visit the link above.