TVS Diodes to Meet Automotive Load Dump Standard

Automotive Load Dump Standard

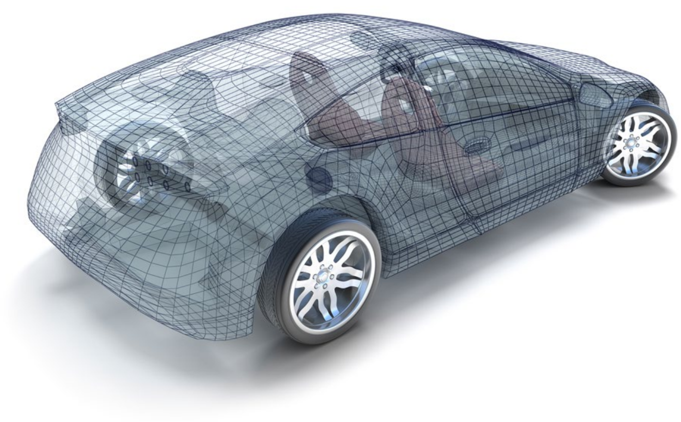
(ISO16750-2 Vs. ISO7637-2 for pulse 5 compliance to Pulse 5a and 5b surge test)

Littelfuse TVS products in ISO16750-2

The automotive market has major two standards that outline protection against transient surges: JASO and ISO7637-2 (Surge) test for the Japanese, American, and international markets.

ISO16750-2 was developed by Technical Committee of ISO/TC 22, Road vehicles, Subcommittee SC 3, Electrical and electronic equipment. In 2010, ISO16750-2 replaced ISO7637-2 for load dump pulse 5a and 5b portion. Littelfuse has published the automotive protection needs on ISO7637-2 in 2013. Now, we discuss the differences between these two standards and give a guideline for load dump protection component selection.

In the last page, a quick table about JASO D001-94 will be included as well as our product test results for a quick reference.

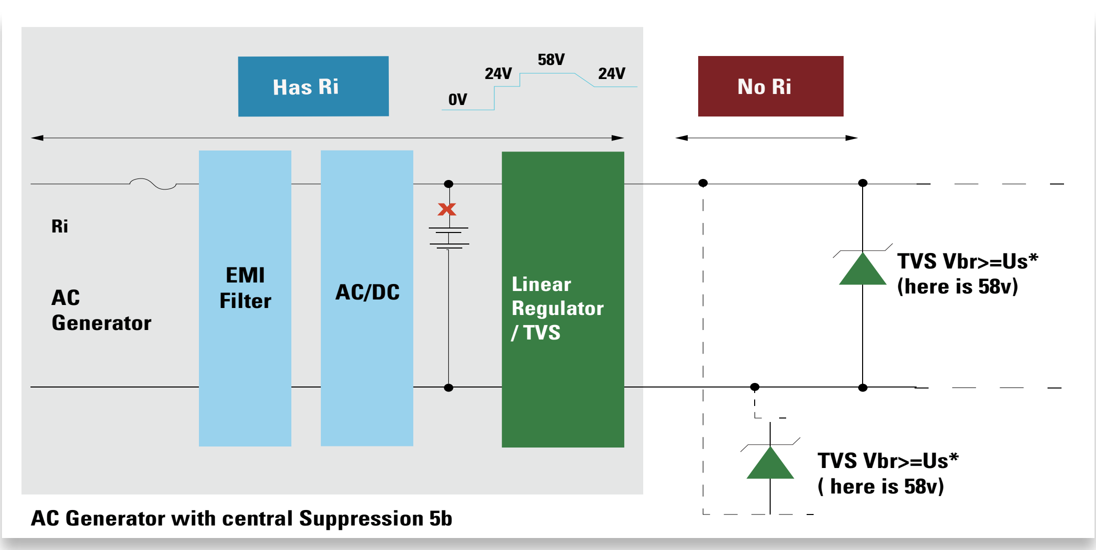


Load dump

This test is a simulation of a load dump transient occurring in the event of a discharged battery being disconnected while the alternator is generating charging current to other loads remaining on the alternator circuit.

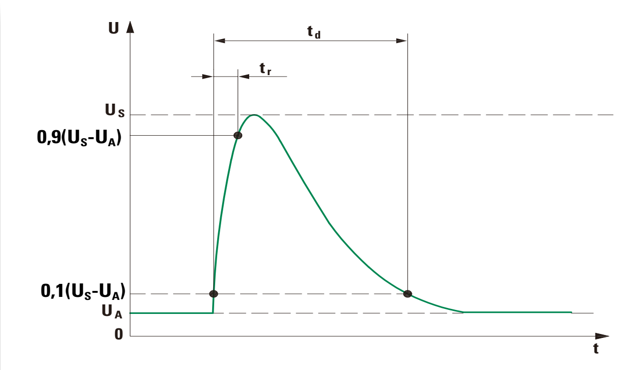
The grey shaded area is the car generator and its voltage regulator circuitry. Behind this is the outside connection to the different car systems. The alternator generates the unstable voltage during the car cruising, and this is rectified and conditioned after the linear voltage regulator to a stable voltage to provide power to different car system such as infotainment and air-conditioner.

Figure1. Alternator Load Dump Topology



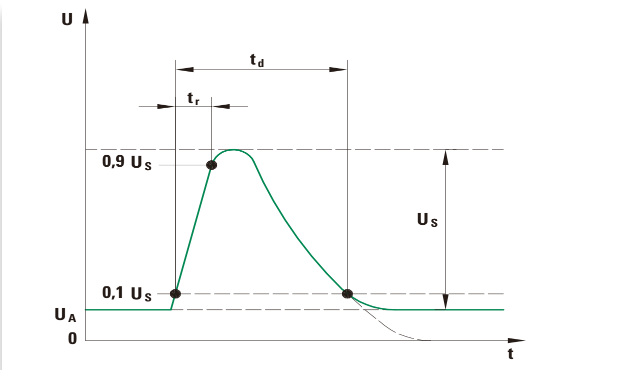
The TVS added in the power line is to ensure that the unwanted voltage spike and transient voltage has been removed.

Figure 2. Pulse 5a Waveform in ISO16750-2



- t time
- U test voltage
- td duration of pulse
- tr rising slope
- UA supply voltage for generator in operation (see ISO 16750-2)
- US supply voltage

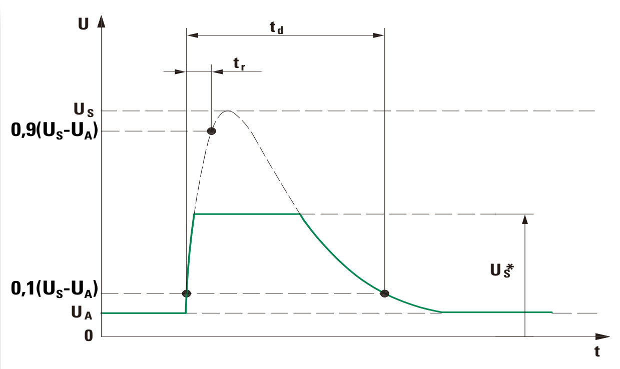
Figure 3.Pulse 5a Waveform in ISO7637-2



- t time
- U test voltage
- td duration of pulse
- tr rising slope
- UA supply voltage for generator in operation (see ISO 7637-2)
- US supply voltage (Does not include UA)

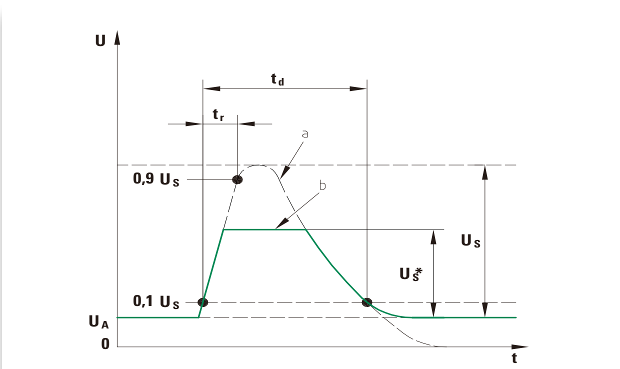
Base on above waveform definition, we can see there are different definitions for pulse 5a Us in ISO16750-2 and ISO7637-2.

Figure 4. Pulse 5b waveform in ISO16750-2



- t time
- U test voltage
- td duration of pulse
- tr rising slope
- UA supply voltage for generator in operation (see ISO 16750-1)
- US supply voltage
- US* supply voltage with load dump suppression

Figure 5.Pulse 5b Waveform in ISO7637-2



- t time
- U test voltage
- td duration of pulse
- tr rising slope
- UA supply voltage for generator in operation (see ISO 16750-1)
- US supply voltage(Does not include UA)
- US* supply voltage with load dump suppression (not include UA)

Based on above waveform definition, we can see there are different definitions for pulse 5b US and US* in ISO16750-2 and ISO7637-2.

Table 1. Pulse parameter difference comparison between ISO16750-2 and ISO7637-2

Parameter	ISO16750-2			ISO7637-2		
	UN=12V	UN=24V	Min Test Requirements	UN=12V	UN=24V	Min Test Requirements
US (V)	79=<US=<101V	151=<US=<202V	10 pulses at intervals of 1 minute	65=<US=<87V	123=<US=<174V	1 pulses
US* (V)	35	65		defined by user	defined by user	
UA (V)	14	28		13~14	26~28	
Ri (Ohm)	0.5=<Ri=<4	1=<Ri=<8		0.5=<Ri=<4	1=<Ri=<8	
td (ms)	40=<td=<400	100=<td=<350		40=<td=<400	100=<td=<350	
tr (ms)	10+0/-5	10+0/-5		10+0/-5	10+0/-5	

Note:

- Ri is defined as the Alternator internal resistance

$$R_i = \frac{10x\ U_{nom}\ x\ N_{act}}{0.8x\ I_{rated}\ x\ 12000min^{-1}}$$

Unom: Specified voltage of the alternator
Irated: Specified current at an alternator speed of 6000 min–1 (as given in ISO 8854)
Nact: Actual alternator speed, in reciprocal minutes.
For example, a traditional compact car with a 14V, 60A alternator:

- The Ri at Nact 3000min-1 is 10 x 14 x 3000 / (0.8 x 60 x 12000), or, about 0.73ohm.

Table 2: 5a and 5b protection difference

Load Dump	Alternator	Need Load Dump Protection	Meet Pulse 1,2a,2b,3a, 3b
5a	Without centralized load dump suppression	Yes	Yes
5b	With centralized load dump suppression	No	Yes

Major Differences:

1. ISO16750-2 defines 10 pulses in 10 minutes with 1 minute interval, while the old ISO7637-2 standard defines only 1 pulse. Thus, the protector must have a higher reliability for this load dump protection new requirement.
2. ISO16750-2 defines a higher US and more stressful voltage range than that of ISO7637-2
3. Note that US* in ISO7637-2 is defined by user or manufacturer, while it is well defined in ISO16750-2

Table 2 shows the different Alternator vs load dump surge types. For an Alternator which has centralized load dump suppression integrated, it doesn’t need to meet the load dump protection, then the designer needs to select the surge protector with protection voltage higher than 5b US* to make sure they can survive during the 5b clamping voltage. If the protection voltage is lower than the 5b US* value, it will cause high current to flow through the TVS diode and cause it to break down or become shorted. If the designer is going to meet the 5a surge in the alternator without centralized load dump suppression, then it needs a much higher power TVS diode (such as Littelfuse SLD series or SM8x series) to meet the surge requirement.

Meeting 5a test in both ISO7637-2 and ISO16750-2

As seen in figures 5 & 6 below, we use typical 12V and 24V AEC-Q101 qualified TVS for load dump pulse 5a test confirmation and comparison between ISO16750-2 and ISO7637-2.

Below is typical open load dump waveform for 12V and 24V systems.

Figure 6. 12V system 101V 400mS pulsei

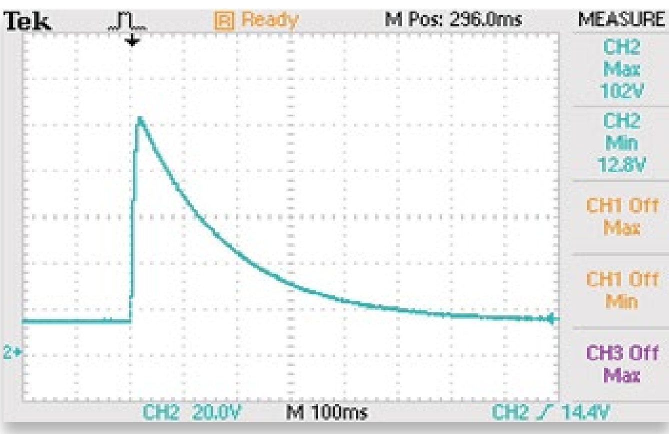
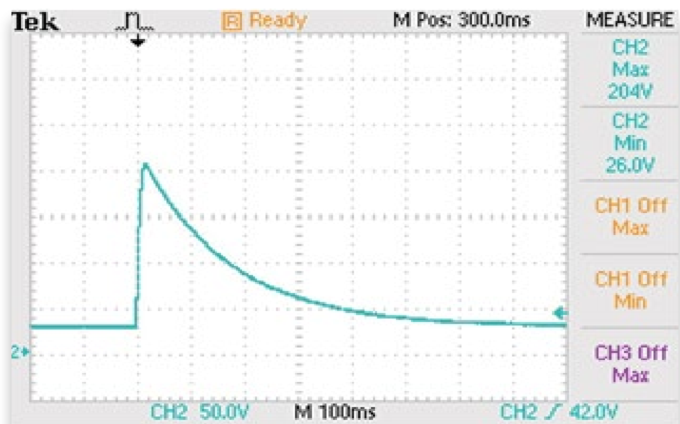


Figure 7. 24V system 202V 350mS pulsei



In 12V system with TVS Diode SLD15-018

In Figures 8 and 9 below, we have a comparison test of ISO16750-2 and ISO7637-2 with different pulses duration in the 12V system. For the supply voltage Us 65 to 87V range, the Ri resistance required to withstand different pulses (40mS, 220mS and 400mS) needs to be greater than 1.14 ohm in the ISO7637-2. The upper region of the Figure 7 & 8 is the safe operation area of SLD15-018 device. Thus, we have to ensure that the resultant resistance (Alternator source impedance) on the line exceeds 1.14 ohm to provide sufficient protection for ISO7637-2 pulses. But, in the case of the Figure 8 with ISO16750-2 test requirement, the minimum resistance required on the line is 1.5ohm which is more than that of the ISO7637-2 due to a higher voltage US range up to 101V.

Note: SLD15-018 is a uni-directional TVS diode with 2200W power rating and a reverse standoff voltage 15V and a minimum breakdown voltage 16.7V.

Figure 8. 12v system single pulse (ISO7637-2) Us Vs. Ri

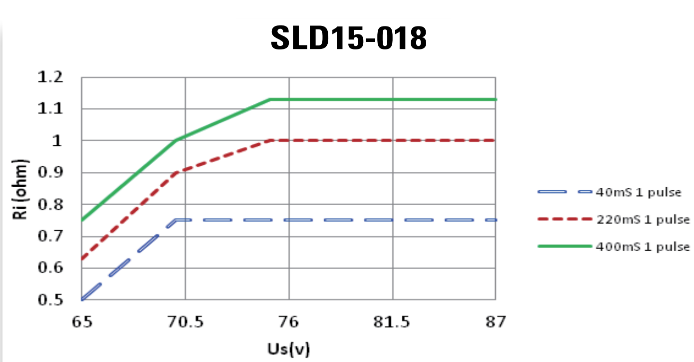
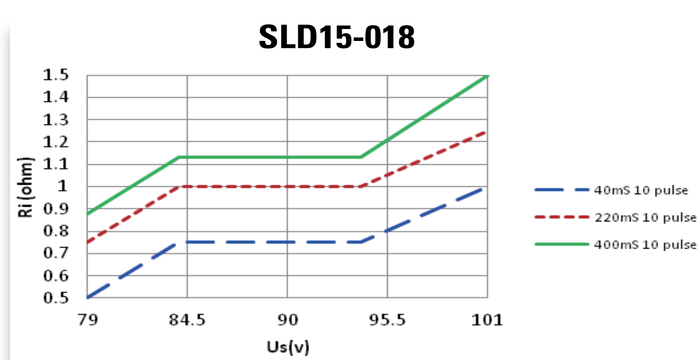


Figure 9. 12v system 10pulses (ISO16750-2) Us Vs. Ri



In 24V system with TVS Diode SLD33-018

In Figure 10 and 11 below, we have a comparison test of ISO16750-2 and ISO7637-2 with different pulses duration in the 24V system. For the Supply voltage Us 123 to 174V range, the Ri resistance required to withstand different pulses (100mS, 220mS and 350mS, here we tested wider range for a reference) is greater than 4.3 ohm in the ISO7637-2. The upper region of the Figure 10 & 11 is the safe operation area of SLD33-018 device. Thus, we have to ensure the resultant resistance (Alternator source impedance) on the line exceeds 4.3 ohm to provide sufficient protection for ISO7637-2 pulses when using a single TVS diode SLD33-018. But, in the case of the Figure 11 with ISO16750-2 test requirement, the minimum resistance required on the line is 4.5ohm which is a little bit larger than that of the ISO7637-2.

Note: SLD33-018 is a bi-directional TVS diode with 2200W power rating and a reverse standoff voltage 33V and a minimum breakdown voltage 36.7V.

Figure 10. 24v system single pulse(ISO7637-2) Us Vs. Rii

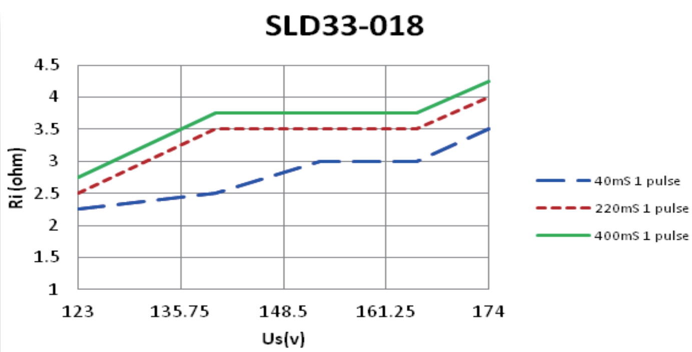
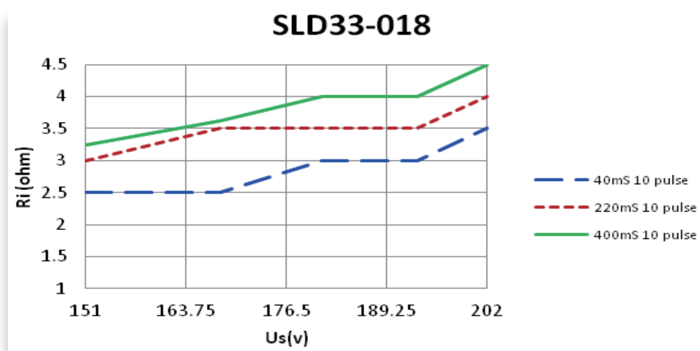


Figure 11. 24V system 10 pulses(ISO16750-2) Us Vs. Rii



What should we do if a single, discrete TVS diode is not sufficient to meet the above surge requirement or impedance requirement?

From the above curve, we can select a TVS diode for different load dump waveform protection. For example, if we are going to pass 202V, 350mS waveform by using SLD33-018, The minimum Ri value is 4.5ohm. If we want to pass Ri = 2.0 ohm test, we need to use 3 pieces (2.0 ohm x 3 > 4.5 ohm) of TVS Diodes to handle this energy. However, we also need to keep the breakdown voltage of these two options the same. Hence, we need to connect 3 TVS diodes with the same power rating but each with only 1/3 of the Vbr of the standalone solution. These TVS Diodes are placed in series to triple the surge power and yet retain the same, effective Vbr voltage. Thus, we need at least 3 pcs of SLD10-018 (Vbr is 11.5V) connected in series. The resultant working voltage of these 3 TVS diodes is very similar to that of a SLD033-018. (In order to increase the protection capability of the over voltage solution like TVS, connection in series is always suggested rather connection in parallel)

Figure 12: Three SLD10-018 form a protection solution with three times the power of a single SLD33-018 TVS Diode

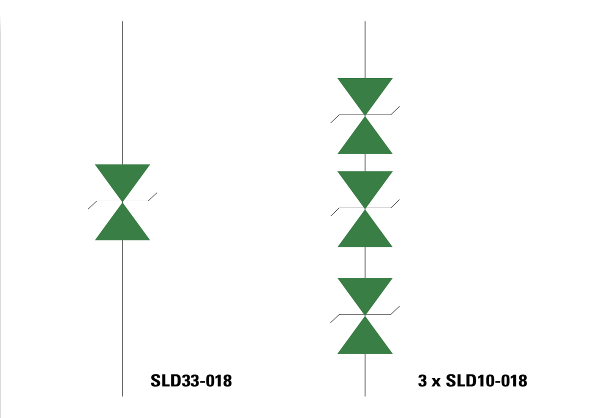
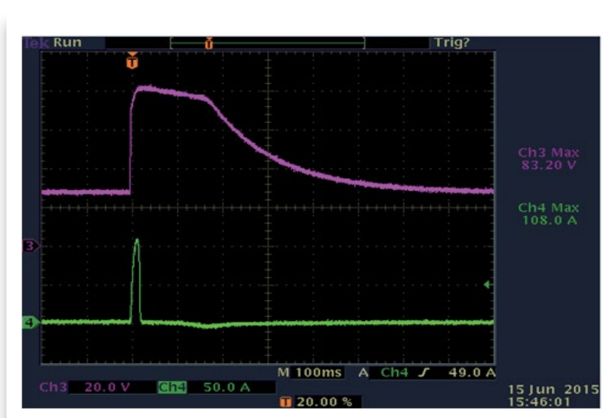


Figure 13: 24V system 10pulses by 202V, 350mS, 1 ohm Ri with 5 SLD10-018 connected in series



In all of the above Figures (7 to 13), data were collected under normal room temperature. Actual pulse withstand capability will vary with different application environments. The TVS Load dump energy should be de-rated to a lower level with higher environmental temperature. That means, for the same US level, Ri could rise a little bit.

Table 3. SLD series Ipp min with different pulse width and number of pulses

Part Number	Single Pulse			10 Pulses		
	40mS	220mS	400mS	40mS	220mS	400mS
SLD15-018	96A	82A	73A	98A	76A	69A
SLD33-018	50.4A	44A	44A	49.6A	40.8A	38.4A

Table 4. SLD series Vclamp max with different pulse width and number of pulses

Part Number	Single Pulse			10 Pulses		
	40mS	220mS	400mS	40mS	220mS	400mS
SLD15-018	25.2V	24.2V	25.1V	24.8V	23.8V	23.7V
SLD33-018	50V	50.4V	50.1V	50V	50V	49.6V

As shown in tables 3 & 4 above, we have already tested and recommended suitable parts for the load dump protection with different pulses.

Here we will work through to verify if SLD33-018 can meet the below protection requirement.

- Voltage: 24V system:
- Alternator resistance Ri = 4Ω
- Peak voltage of alternator output in load dump = 202V
- Target clamping voltage = 65V
- Pulse width = 200ms
- Pulse numbers = 10 pulses in 10 minutes

From table 3, we know that SLD33-018 has a 40.8A clamping capability in 10 pulses condition at 220mS pulse width. From table 4, we know that SLD33-018 has max clamping voltage 50V in 10 pulses condition at 220mS pulse width.

The actual load dump peak clamping current can be calculated as (202V - 50V) / 4Ω=38A which is lower than the 40.8A. Hence, SLD33-018 can protect the load dump surge (40.8A > 38A).

In tables 5 and 6 below, we have already tested suitable part for the load dump protection under JASO D001-94

Table 5. Pulse parameter about JASO D001-94

JASO D001-94					
Parameter	Unit	UN=12V	Min. Test Requirements	UN=24V	Min Test Requirements
E1	(V)	14	1 pulse	28	1 pulse
Vp	(V)	70		110	
Ri	(Ohm)	0.8		1.5	
td	(ms)	200		400	
tr	(us)	1		10+0/-5	

Table 6.Test result from Littelfuse automotive TVS SLD5S & SLD6S Series for JASO D001-94 System

JASO D001-94						
Littelfuse Product	Parameter	Unit	UN=12V	UN=24V	Min Test Requirements	Test Result
SLD5S Series AutomotiveTVS	E1	(V)	14	-	1 pulse	Pass
	Vp	(V)	56	-		
	Ri	(Ohm)	0.75	-		
	td	(ms)	200	-		
	tr	(us)	10	-		
SLD6S Series AutomotiveTVS	E1	(V)	-	28		
	Vp	(V)	-	110		
	Ri	(Ohm)	-	1.5		
	td	(ms)	-	400		
	tr	(us)	-	10+0/-5		