AN3361
Application note

Schottky diode avalanche performance in automotive applications

Introduction

Electronic modules connected to automotive power rails may be affected by polarity inversion due to poor battery handling and load-dump surges when the battery is disconnected while the alternator is still charging. To protect against these phenomena, module manufacturers add reverse-battery protection, usually using diodes.

Schottky diodes are preferred over bipolar ones because of their higher performance in direct conduction. Schottky diodes feature a low forward voltage drop, and are able to withstand the pulses defined in ISO 7637-2.

However, the diode needs a breakdown voltage higher than 150 V in order to pass the tests for negative pulses 1 and 3a, whereas this tends to lower the forward performances. For Schottky diodes, the intrinsic trade-off obeys the rule: the higher the breakdown voltage, the higher the forward voltage drop.

There is a way to reconcile these conditions. Some Schottky diodes (depends on the technology) have the ability to dissipate some power in reverse condition. This concerns the P_{ARM} parameter (Repetitive Peak Avalanche Power). For instance a 100 V breakdown voltage Schottky diode may on the one hand support the negative pulse 1 and pulse 3a of the ISO 7637-2 standard and on the other hand offer a very good performance in forward voltage drop.

This Application note explains how to choose the best Schottky diode trade off in automotive applications in order to preserve the low forward voltage drop performance and the ability to pass the ISO 7637-2 pulses.

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1 Definition of the electrical transients and tests

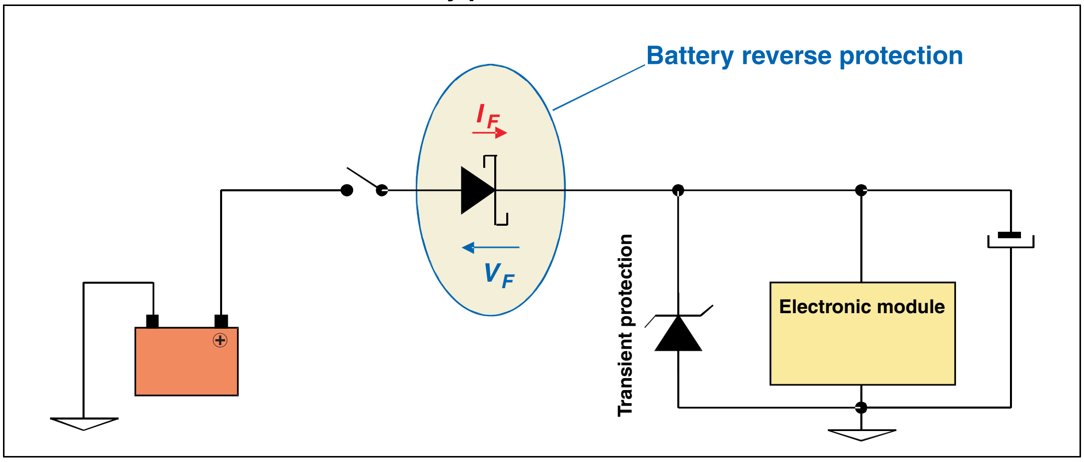
Two ISO standards are applicable to this situation.

- ISO 16750
- ISO 7637-2

The ISO 16750 standard defines the variations that automotive power rails may undergo. A reverse battery connection due to poor maintenance is described as a key condition to be considered. Electronic modules thus usually have a reverse battery protection device to guard against this condition. Most of the time this protection consists of a diode in series that prevents negative current from flowing if the battery connection is reversed (see *Figure 1*).

This solution involves a voltage drop across the diode and therefore some power dissipation. This is why a Schottky diode is preferred as its forward voltage drop is less than that of a conventional bipolar diode.

Figure 1. typical schematic of a powered automotive module using a Schottky diode as reverse battery protection



ISO 7637-2 specifies the methods and procedures to test for compatibility with conducted electrical transients of equipment installed on passenger cars and commercial vehicles fitted with 12 V or 24 V electrical systems, whatever the propulsion system (spark ignition or diesel engine, electric motor). The standard describes bench tests for both the injection and measurement of transients.

The bench tests consist in applying positive or negative pulses to the modules. The test is successful if there is no damage on the device. Each pulse models an abnormal behavior. The most sever cases are given in *Table 1.*

Table 1. ISO 7637-2 main surge pulses

Pulse	Origin	Pulse polarity	12V system	
			V_{peak}	t_p
N° 1	Supply disconnection from inductive loads	Negative	-100 V	2 ms
N° 2a	The sudden interruption of current through a device connected in parallel with the device under test (DUT) due to the inductance of the wiring harness	Positive	+50 V	50 µs
N° 2b	DC motor acting as a generator after the ignition is switched off	Positive	10 V	2 s
N° 3a	Occur as a result of the switching processes	Negative	-150 V	100 µs
N° 3b	Occur as a result of the switching processes	Positive	100 V	200 µs
N° 4	Voltage reduction caused by energizing the starter-motor of internal combustion engines	Negative	-7 V	40 ms
N° 5b	Load-dump transient occurring in the event of a discharged battery being disconnected while the alternator is generating charging current, case with auto-protected alternator	Positive	87 V	Application dependant

The most severe positive pulse is pulse 5b (*Figure 2*). Its voltage range commonly varies from +24 V to +48 V with a pulse duration up to 400 ms and a minimum series resistance that can be as low as 0.5 Ω.

Figure 2. ISO 7637-2 pulse 5b clamped load-dump

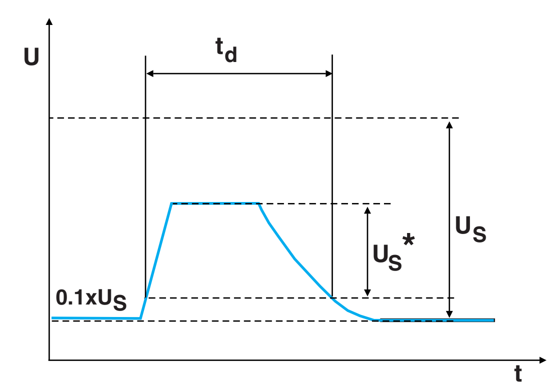


Table 2. Parameter values for test pulse 5b

Parameter	12 V system
U_S	65 V to 87 V
U_S *	As specified by customer
t_d	40 ms to 400 ms
R_i	0.5 to 4 Ω

The most severe negative pulse is pulse 1 (*Figure 3*). It can reach -100 V during 2 ms and a peak current of 10 A in shorted conditions.

Figure 3. ISO 7637-2 pulse 1

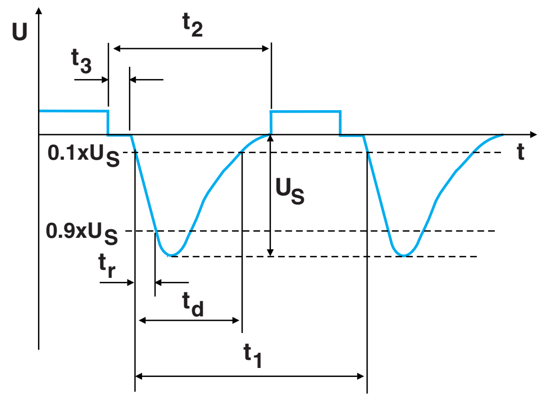


Table 3. Parameter values for test pulse 1

Parameter	12 V system
U_s	-75 V to -100 V
R_i	10 Ω
t_d	2 ms
t_r	1 µs
t_1(1)	0.5 s to 5 s
t_2	200 ms
t_3(2)	<100 µs

1. Period t_1 shall be chosen such that the DUT is correctly initialized before the application of the next pulse.
2. Period t_3 is the smallest possible time necessary between this disconnection of the supply source and the application of the pulse.

Pulse 3a (*Figure 4*) is specified at -150 V but with 50 Ω series resistor and 100 ns duration which is far less energy than for pulse 1. This means that, if the Schottky diode specification is compliant with pulse 1, pulse 3a will be covered as well.

Figure 4. ISO 7637-2 pulse 3a

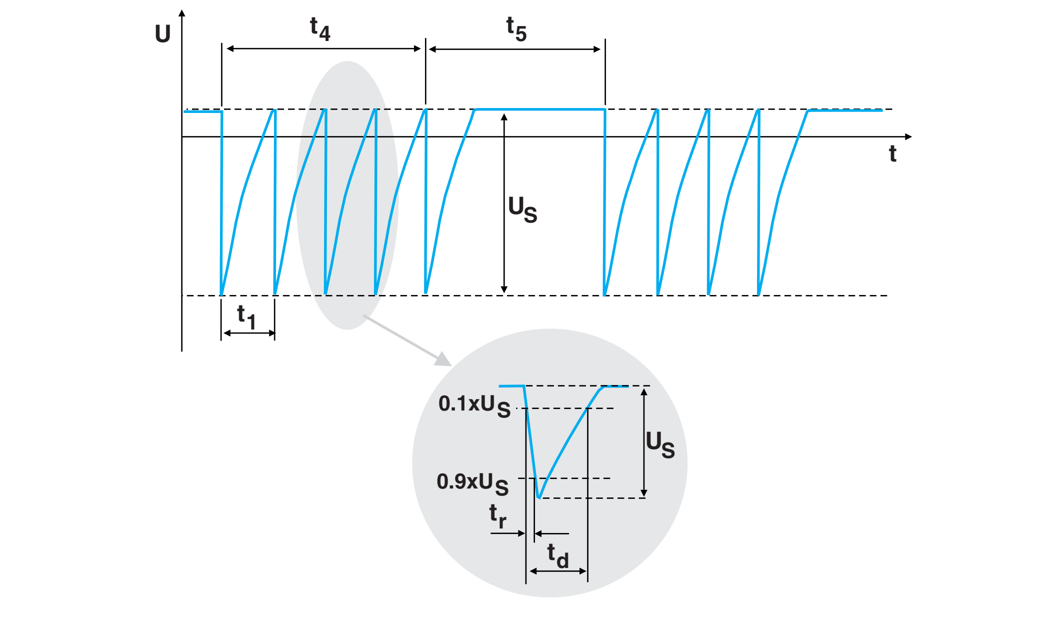


Table 4. Parameter values for test pulse 3a

Parameter	12 V system
U_s	-112 V to -150 V
R_i	50 Ω
t_d	0.1 µs
t_r	5 ns
t_1	100 µs
t_4	10 ms
t_5	90 ms

2 Choosing the appropriate Schottky diode

Schottky diode choice for reverse battery protection is determined by the electronic module normal operating current on the one hand, and the need to pass the ISO 7637-2 pulse tests on the other. Each module has its own normal operating current, which is defined by its characteristics. So here we will consider only the method to choose an appropriate Schottky diode to meet the ISO 7637-2 requirements.

2.1 Load-dump surge compatibility criteria

The first criterion is the compatibility between surge current and I_{FSM} specified in the diode datasheet.

2.1.1 Load-dump peak current calculation

Figure 6 shows the current shape through the Schottky diode during a load-dump surge according to the schematic described in *Figure 5.*

Figure 5. Pulse 5b surge test schematic

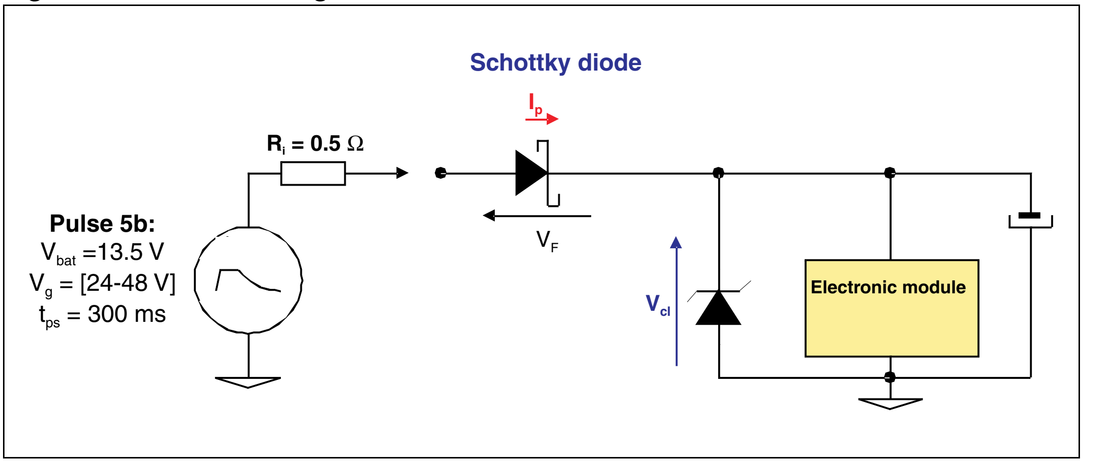
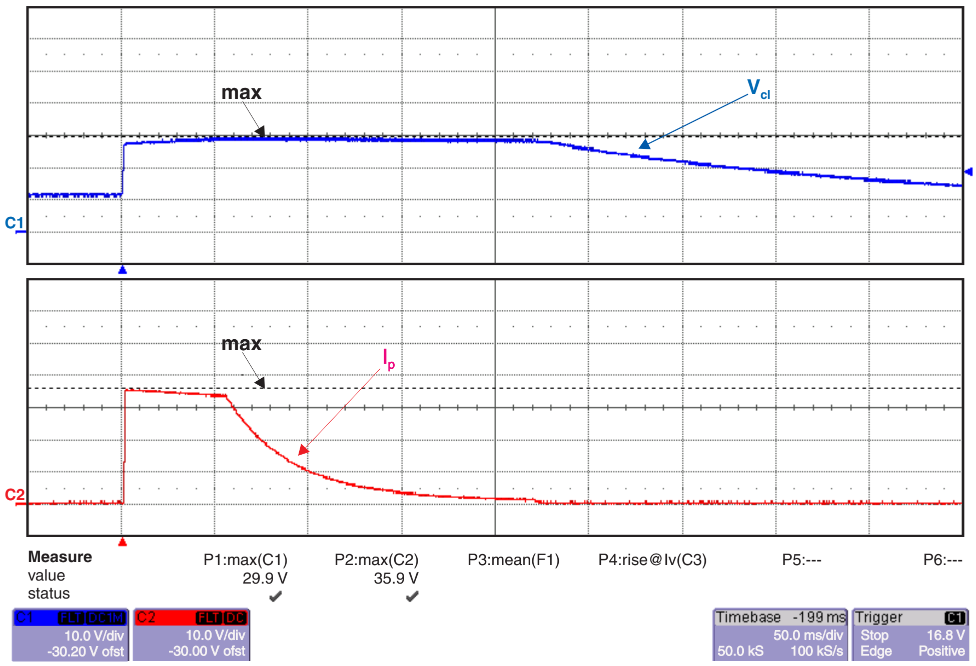


Figure 6. Current and voltage at the transient suppressor side (with a 24 V V_{br} clamping device and V_g = 36V)



The equations below apply to the circuit shown in *Figure 5*.

Equation 1

$$V_{surge} = V_g + V_{bat}$$

$$V_{surge} = V_{cl} + V_F(I_p) + R_i I_p$$

$$V_F(I_p) = V_{T0} + R_d \cdot I_p$$

The calculation of V_{T0} and R_d is explained in the application note AN604: “Calculation of conduction losses in a power rectifier”. Values are provided in the datasheets.

Then:

Equation 2

$$I_p = \frac{V_{surge} - V_{cl} - V_{T0}}{R_d + R_i}$$

In the example presented in *Figure 6* the generator surge voltage (V_g) is 36 V, its internal series resistor is 0.5 Ω, the battery voltage is 12 V and the protection voltage clamping level of the protection device is 29.9 V. The diode dynamic resistor R_d is 0.009 Ω.

As $V_{T0} << V_{surge} - V_{cl}$ the above relation can be simplified to:

Equation 3

$$I_p = \frac{(36 + 12) - 29.9}{0.009 + 0.5}$$

So the peak current I_p is equal to 35.56 A.

2.1.2 Method to compare I_p and I_{FSM}

I_{FSM} is the maximum peak current of a sinusoidal waveform pulse during 10 ms. The load-dump peak current can be approximated with a constant and an exponential waveform pulse. To compare both peak currents, I_{FSM} and load-dump peak current, one method is to calculate the equivalent sinusoidal surface of the exponential waveform in order to deduce the equivalent pulse duration.

The surge load-dump surface is modeled using the following equation:

Equation 4

$$S_{surge} = \int_0^{t_1} I_0 \cdot dt + \int_{t_1}^{\infty} I_0 \cdot e^{\frac{-(t-t_1)}{\tau}} dt$$

Where I_0 is the maximum load-dump current. The equivalent sinusoidal waveform is:

Equation 5

$$S_{sin} = \int_0^{t_{sin}} I_0 \cdot \sin\left(\frac{2\pi}{2 \cdot t_{sin}} t\right) dt$$

The equivalent pulse duration is t_{sin}, since:

Equation 6

$$S_{sin} = S_{surge}$$

Then:

Equation 7

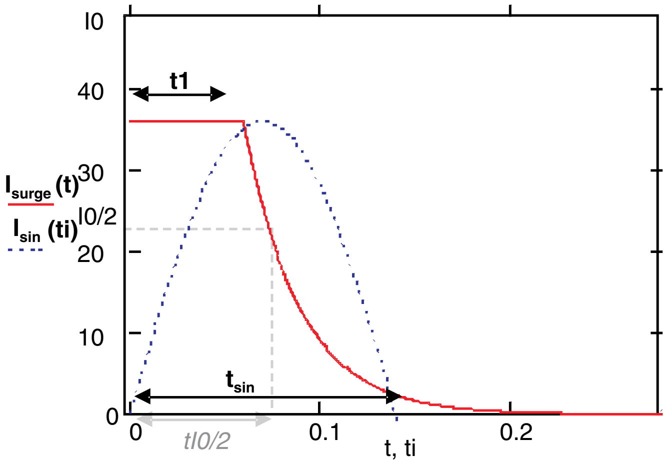
$$t_{sin} = \frac{\pi}{2}(\tau + t_1)$$

Where

Equation 8

$$\tau = \frac{t_{\frac{I_0}{2}} - t1}{\ln 2}$$

Figure 7. Equivalent sinusoidal surface of clamped load-dump surge surface



In our example the equivalent sinusoidal waveform pulse time duration t_{sin} is 140 ms.

2.1.3 I_{FSM} value versus pulse time

Using the equations:

Equation 9

I^4 x t = C_{ste} for t_{sin}>10 ms
I^3 x t = C_{ste} for 20 µs <t_{sin}>10 ms
I^2 x t = C_{ste} for t_{sin}<20 ms

In the example for the STPS20L60C in *Figure 7*, as the pulse duration t_{sin} is 140 ms, the following law from *Equation 9* can be used:

Equation 10

$$I^4_{FSM@tsin} \times t_{sin} = I^4_{FSM} \times 10 \cdot 10^{-3}$$

Where:

I_{FSM} is the non repetitive forward surge current given in the data sheet.

$I_{FSM\ @\ t\ sin}$ is the non repetitive forward surge current for a pulse duration t_{sin}.

For the example of *Figure 6*, the I_{FSM} = 220 A

Equation 11

$$I_{FSM@140ms} = \sqrt[4]{\frac{10 \cdot 10^{-3} \times I^4{}_{FSM}}{t_{sin}}}$$

$$I_{FSM@140ms} = \sqrt[4]{\frac{10 \cdot 10^{-3} \times 220^4}{140 \cdot 10^{-3}}}$$

The equivalent peak current is I_{FSM}@140 ms = 113.73 A.

The peak current delivered by the test system is I_p = 35.56 A and it is less than I_{FSM} @140 ms. So the STPS20L60C meets the ISO 7637-2 requirements.

Table 5 gives a matrix of which Schottky diode is compatible with load-dump surge (pulse 5b) depending on surge voltage level and with the conditions: V_{bat} = 13.5 V, R_i = 0.5 Ω and with load-dump surge duration of 300 ms.

Table 5. Which Schottky diodes are good for which load-dump surge level

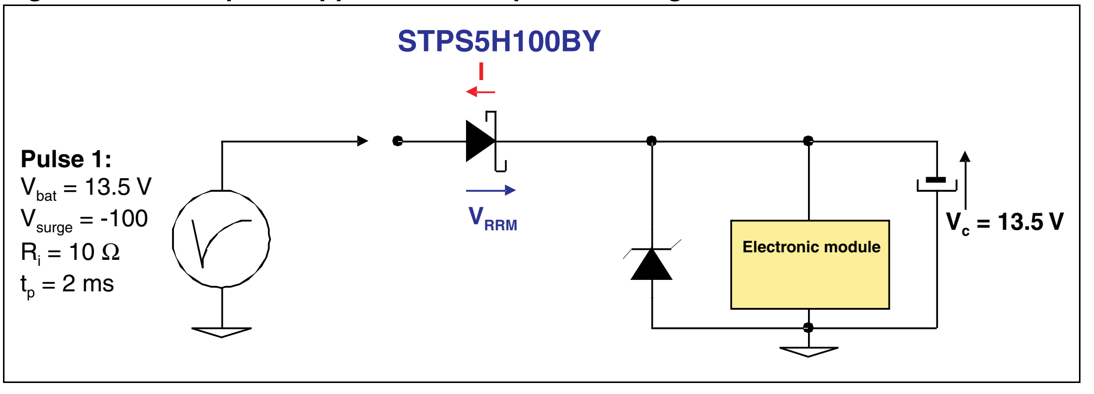
Pulse 5b load-dump surge voltage (V_g)	24	30	36	42	48
STPS160AY	Yes				
STPS3L60SY	Yes	Yes			
STPS20L60CGY	Yes	Yes	Yes	Yes	Yes
STPS1H100UY	Yes				
STPS2H100UY	Yes	Yes			
STPS5H100BY	Yes	Yes	Yes		
STPS8H100GY	Yes	Yes	Yes	Yes	Yes

2.2 Most severe negative surge compatibility criteria

Now if we consider pulse 1 as shown in *Figure 3*, things are different since the Schottky diode is reverse polarized.

For instance, the voltage applied on a diode with a maximum repetitive reverse voltage (V_{RRM}) of 100 V will be V_R = -113.5 V ($V_R = V_{surge} + V_c$ due to the charge of the capacitor).

Figure 8. Example of application with pulse 1 using an STPS5H100BY



A Pspice simulation shows the power involved in an STPS5H100BY, for example, as shown in *Figure 10*, according to the schematic of *Figure 9*.

Figure 9. Pspice model of Pulse 1 surge test using STPS5H100BY Schottky diode

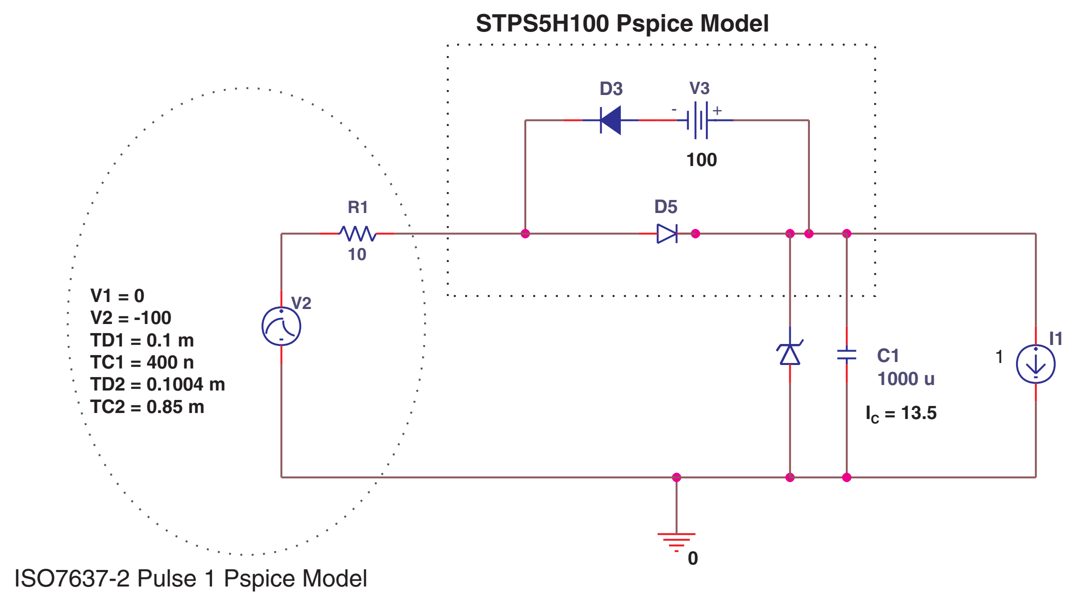
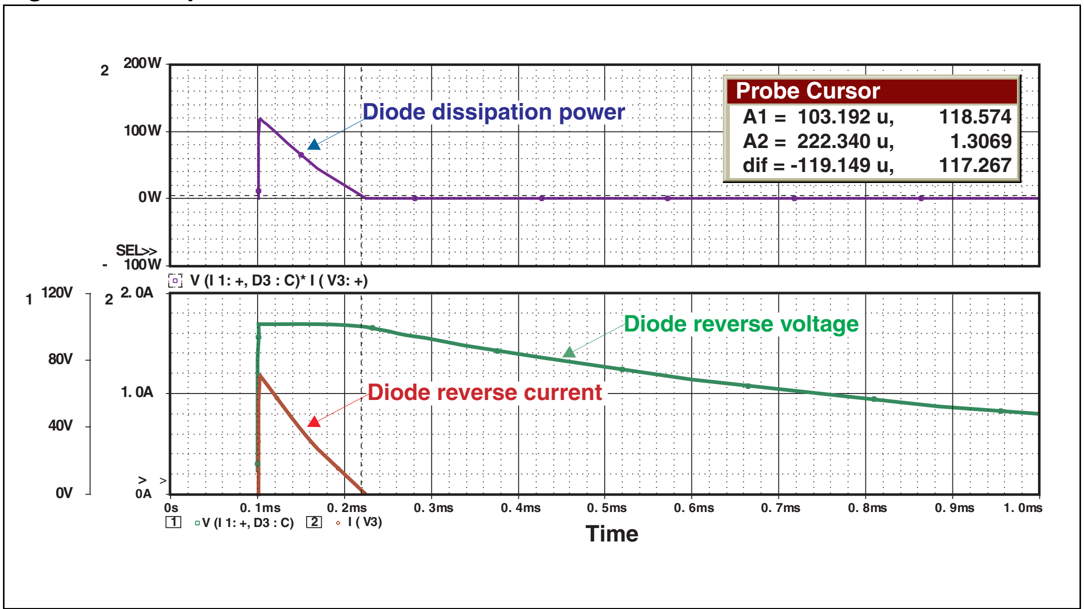


Figure 10. Pspice simulation result



The blue curve in *Figure 10* is the power dissipated in the diode avalanche. It is a triangular shape curve with a peak power at 118 W during 120 µs. This waveform is equivalent to a 59 W square shape pulse of 120 µs duration.

In order to evaluate if the diode is able to dissipate this energy in the avalanche, two elements are relevant:

- P_{ARM}(1 µs, T_j = 25° C) is the repetitive peak avalanche power
- $P_{ARM}(T_p)$/ P_{ARM}(1 µs, T_j = 25 °C) curve *Figure 11.*

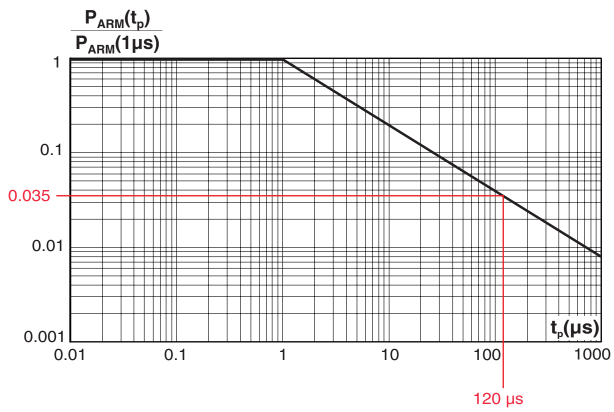
In the example, we have selected the STPS5H100BY where:

P_{ARM}(1 µs, T_j = 25 °C) = 7200 W.

The derating curve *Figure 11* shows the equivalent avalanche power the STPS5H100BY is able to dissipate is 0.035 · P_{ARM} (1 µs, T_j = 25 °C) = 252 W

Therefore in this example the STPS5H100BY meets the ISO 7637-2 requirements and ensures a good reverse battery protection.

Figure 11. Normalized avalanche power derating versus pulse duration for STPS5H100BY



Note: The derating curve for STPS5H100BY can be found as Figure 3 in the datasheet for this device.

Table 6 indicates which Schottky diode can withstand Pulse 1 of ISO 7637-2 standard.

Table 6. Compliance of Schottky diodes with ISO 7637-2 Pulse 1

Pulse 1 surge voltage (V)	V_S = -100 V
STPS2H100UY	Yes
STPS5H100BY	Yes
STPS8H100GY	Yes

Table 6 shows that only a few Schottky diodes can handle this constraint.

3 Conclusion

Protecting automotive electronic modules from polarity inversion due to poor battery handling and load-dump surge during battery disconnection while the alternator is still charging usually involves the use of diodes, especially Schottky diodes rather than bipolar ones because of their better performance in direct conduction. The choice must consider the worst-case surge conditions of ISO 7637-2 which are pulses 1 and 5b.

Usually Schottky diodes with a breakdown voltage of 150 V are preferred for this application. This article shows that a breakdown voltage of 100 V may be selected to withstand avalanche mode during the negative pulse 1 test (starting from a 2 A Schottky type). This results in the saving of power during direct conduction.

Note: ST parts numbers listed in this application note were given as examples and are not an exhaustive list. Please contact your sales or marketing representative for more automotive grade rectifier devices.

4 Revision history

Table 7. Document revision history

Date	Revision	Changes
09-Sep-2011	1	Initial release.