AN1101
Automotive Reverse Battery Protection Diode

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This application note compares the performance of Diodes Inc. Super Barrier Rectifier™ (SBR) as an automotive reverse battery protection diode with other solutions. An overview of the reverse battery protection requirement and the qualification standards are also presented.

During the life time of the vehicle, it is necessary to replace the battery after its life time or reconnect it after maintenance work. During reconnection it is possible to reverse the battery polarities, such a connection can result in shorts and other errors in loads connected to the battery. Although this issue is being addressed by colouring the battery terminals and by mechanical design itself, it is still essential to cover this condition. Two popular solutions are 1) blocking diode 2) using MOSFETS as ideal diodes.

Blocking Diode:

This is the simplest available solution. A diode is connected in series with the battery allowing the current flow only in one direction. Figure 1 shows the typical topology.

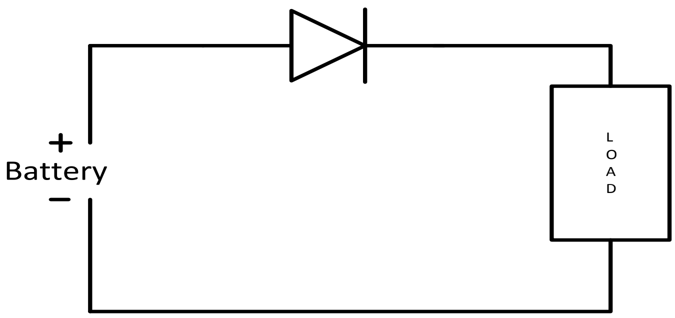


Figure 1: Reverse battery protection with a diode

The power efficiency of the scheme depends on the forward voltage ‘Vf’ of the diode across the load current range. A normal PN junction diode comes with a higher ‘Vf’, hence it is a common practise to choose low forward voltage diodes like a Schottky diode. However a Schottky’s reverse voltage blocking is extremely sensitive to temperature because of its high leakage characteristics over its operating temperature range. The low energy barrier metal design makes it easily susceptible to thermal runaway when a nominal amount of heat is applied.

The Super Barrier Rectifier™ (SBR) from Diodes Incorporated combines the low forward voltage characteristics of a Schottky diode, with the low and flat line leakage profile and stability close to that of a PN junction diode. Figure 2 compares the leakage profile over temperature and ‘Vf’ of an SBR with a similar sized Schottky and shows how the SBR improves the efficiency while ensuring the system reliability.

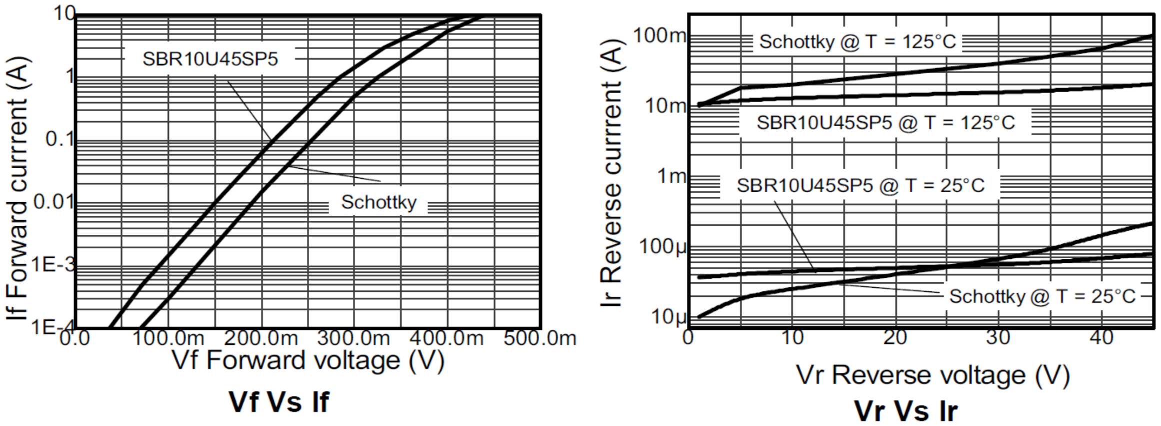


Figure 2: SBR Vs Schottky, forward and reverse characteristics

Using MOSFETS as ideal diodes:

In this solution a MOSFET is controlled to conduct only in one direction. With the proper polarity of the battery, the MOSFET is turned on to conduct and the resulting conduction losses are due to Rds (on) *I load, where Rds (on) is the on resistance of the MOSFET, and I load is the Load current.

This solution can be realised with both N channel and P channel MOSFETS as shown in Figure 3 and Figure 4 respectively.

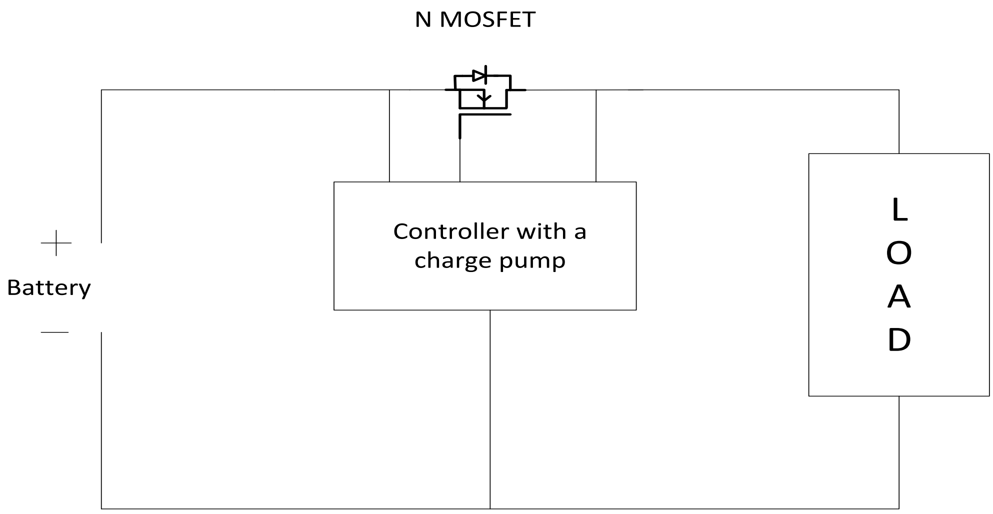


Figure 3: N-channel MOSFET as blocking diode.

An N-channel MOSFET offers the lowest power loss topology by virtue of its low Rds (on) characteristic, but it requires a gate voltage higher than the battery voltage to turn it on. Normally a switching circuit is implemented to act as a charge pump. Apart from increasing the component count, cost and design complexity, it can create EMI issues.

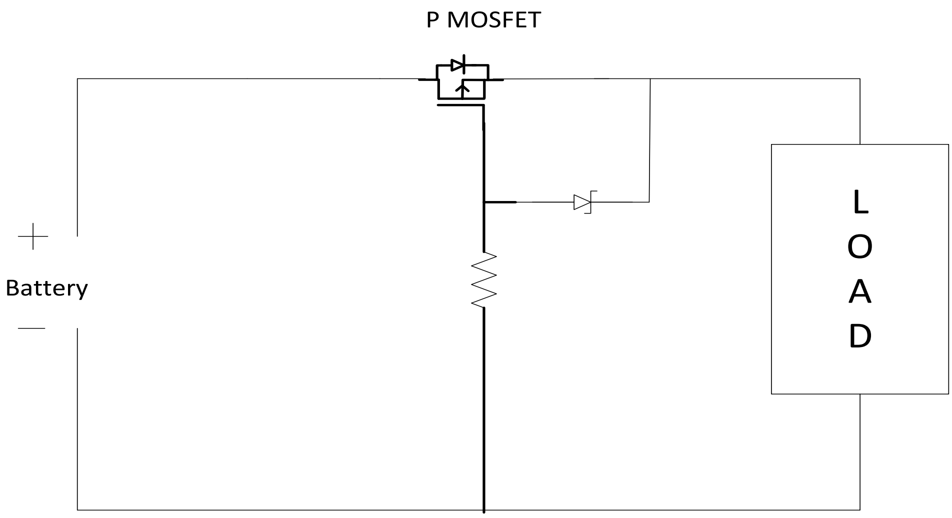


Figure 4: P-Channel MOSFET as blocking diode.

A P-channel MOSFET of similar size to that of an N-channel MOSFET comes with a higher Rds (on), and although power losses in this topology are less compared to diode topologies, they are higher than N-channel MOSFET. The drive circuit required for a P-channel MOSFET can be achieved with passive elements as shown in figure 4; this makes the design simple and eliminates the EMI issues seen with an N-channel MOSFET.

Figure 5 shows the efficiency comparison between a Schottky, SBR, N-channel MOSFET and P-channel MOSFET topologies.

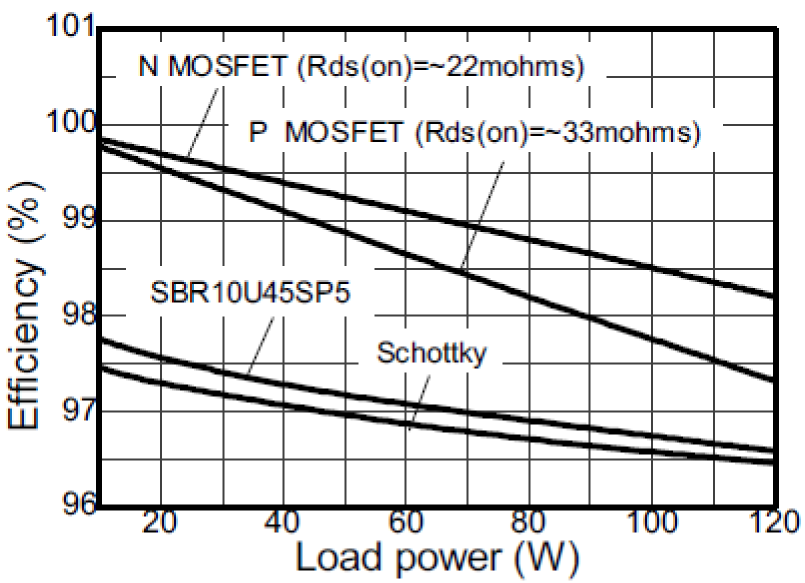


Figure 5: Efficiency comparison of different solutions

ISO Pulses:

In addition to meeting the system efficiency, complexity and cost requirements, each solution must robust enough to support the requirement stated by ISO7637-2 pulses.

The harshest of these pulses, for the devices performing the reverse battery protection function, are Pulse1 and Pulse5A.

Pulse 1:

This pulse represents the case of supply disconnection while powering an inductive load, where the rectifier is subjected to a high negative voltage pulse. ISO defined pulse conditions are shown in figure 6

Conducted Immunity on Power Lines: Paramet	
Pulse parameters	12 V systems
U_A	13.5 V
Us	- 100 V
t_d	2 ms
t_r	1 µs
t_2	200 ms
t_1	0.5 s
t_3	≤ 100 us
Ri	10 Ohm
No of pulses	5000

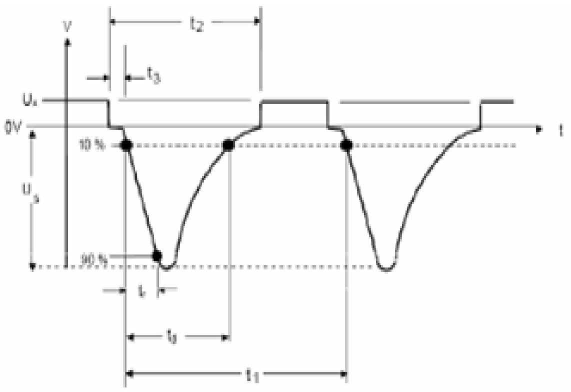


Figure 6: Pulse 1 conditions

Apart from this pulse, pulse 3a also subjects the device to high negative voltage, but the duration of this pulse is very low (0.1us). This pulse represents the switching transients.

These negative voltages make it necessary to choose high voltage devices. High reverse breakdown voltages results in a significant increase in the ‘Vf’ of diodes, which in turn increase conduction losses. Though this effect is relatively low in MOSFET solutions, nevertheless higher breakdown voltages increase the Rds (on) of the MOSFETS, which has a direct impact on conduction losses again.

However for devices that are capable of surviving these avalanche instances, it is possible to use a low voltage device with a well-defined avalanche spec. The avalanche capability of the device presented as shown in Figure 7 (measured on SBR30A60CTBQ) is essential for a selecting a low voltage diode that can withstand the ISO Pulse 1. Other negative pulse, pulse 3A, is a transient pulse for a very small duration of time (100ns). Hence, if a device complies with pulse 1, then pulse 3A will also be covered. The avalanche energy based on the Pulse 1 specification can be calculated as below;

$\mathbf{P}_{avalacne\_peak} = \mathbf{V}_{avalanche} * \mathbf{I}_{avalanche\_Peak}$

$\mathbf{P}_{avalanche\_avereage} = 0.5 * \mathbf{V}_{avalanche} * \mathbf{I}_{avalanche\_peak}$

$\mathbf{I}_{avalanche\_Peak} = \mathbf{V}_{avalanche}/R_i = 100V/10\Omega = 10A$

(Refer to Figure 6 for Pulse 1 conditions, U_S = 100V and R_i = 10Ω)

$\mathbf{P}_{avalanche\_avereage} = 0.5 * 100V * 10A = 500W$

Stated pulse width in ISO7637-2 Pulse 1 is 2mS. From figure 7 it can be seen that the avalanche performance of the SBR30A60CTBQ is better than the requirement.

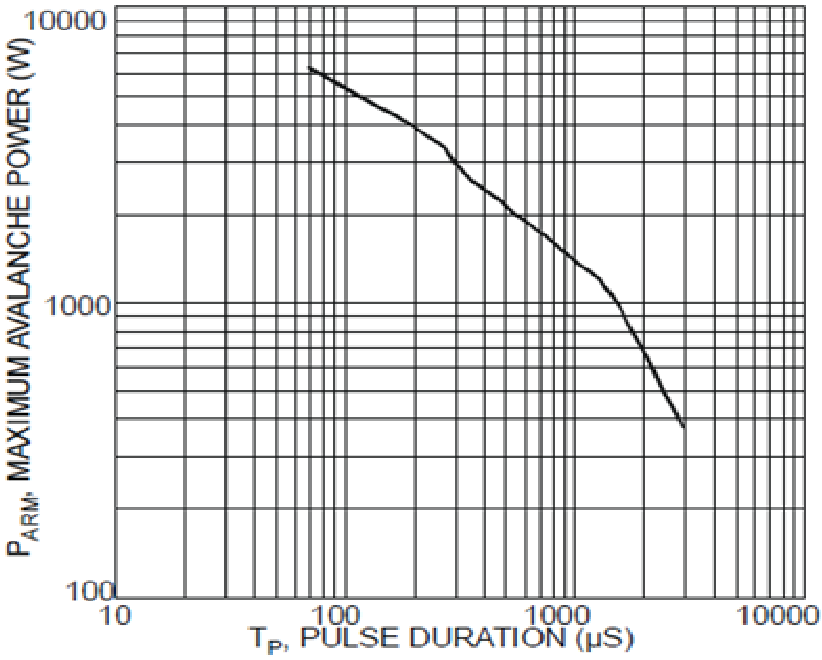


Figure 7: Pulse Duration vs Max Avalanche rating

Figure 8 compares the avalanche capability of a 10A 45V SBR to similar competing Schottky. As can be seen the SBR has an avalanche capability that is between 3 and 10 times better than Schottky technology. The SBR is therefore better suited to reverse battery applications where reverse avalanche conditions occur. With careful design avalanche ruggedness similar to SBRs can be achieved with the MOSFET solution too.

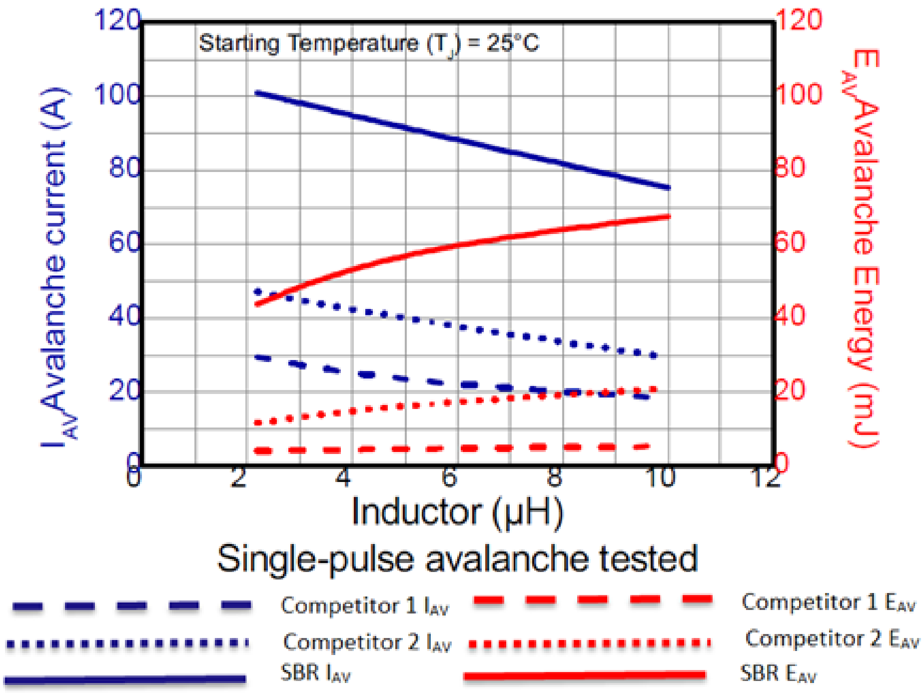
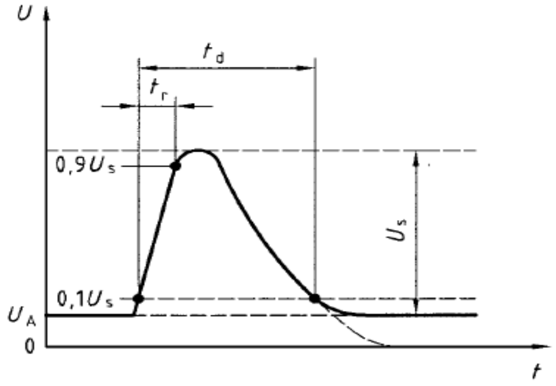


Figure 8: avalanche capability of SBR Vs Schottky

PULSE 5a:

Pulse 5a represents the condition of load dump that occurs when the discharged battery is disconnected while the alternator is charging it. This is the most severe positive pulse the device can see. The ISO7637 pulse 5a definition is shown in figure 9.



Parameter	12 V system	24 V system
U_s	65 V to 87 V	123 V to 174 V
R_i	0,5 Ω to 4 Ω	1 Ω to 8 Ω
t_d	40 ms to 400 ms	100 ms to 350 ms
t_r	$\left(10\ {}^{0}_{-5}\right)$ ms	

Figure 9: ISO 7637 Pulse 5a, Load dump pulse, definition

Consideration of pulse 5a leads to the conclusion that information about the forward surge current capability of the device is essential while choosing the reverse battery blocking device. ACQ101 qualified SBRs from Diodes Inc, come with this information in datasheets.

Finally, the thermal capability of the device has a direct impact on the device's robustness to ISO pulses. Diodes Inc. offers the SBR solution in a variety of packages to suit the thermal performance and PCB space requirements of the application. Please refer to Diodes website, www.diodes.com, for more details on these packages.

The performance of each solution for different priorities is summarised in the table below:

Merit	Preference #1	Preference #2	Preference #3	Preference #4
Efficiency	N MOSFET	P MOSFET	SBR	SCHOTTKY
component count, cost and simplicity	SBR SCHOTTKY	SBR SCHOTTKY	P MOSFET	N MOSFET
EMI emissions	SBR SCHOTTKY	SBR SCHOTTKY	P MOSFET	N MOSFET
ISO PULSE ruggedness	SBR N MOSFET P MOSFET	SBR N MOSFET P MOSFET	SBR N MOSFET P MOSFET	SCHOTTKY

Conclusion:

Automotive manufacturers provide a reverse battery blocking device to safeguard possible reverse battery connection during maintenance operations. The performance of the prominent solutions has been compared in terms of system efficiency, ISO 7637 pulse ruggedness, component count, EMI emissions, cost and simplicity. Each solution provides a different combination of characteristics that allows the system designer to choose which trade off best suits his application.