AN1192

Understanding the Different Approaches to Input Reverse Voltage Protection (RVP)

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The vast majority of motor vehicles being manufactured today still include a low-voltage battery, commonly either 12V or 24V. These batteries usually are easily accessible for vehicle owners to remove and replace them when necessary. The problem is that batteries can be reinstalled incorrectly, resulting in reverse polarity voltages that can damage sensitive vehicle electronics. This application note looks at the two most common options for providing input reverse polarity protection, along with the advantages and disadvantages for each.

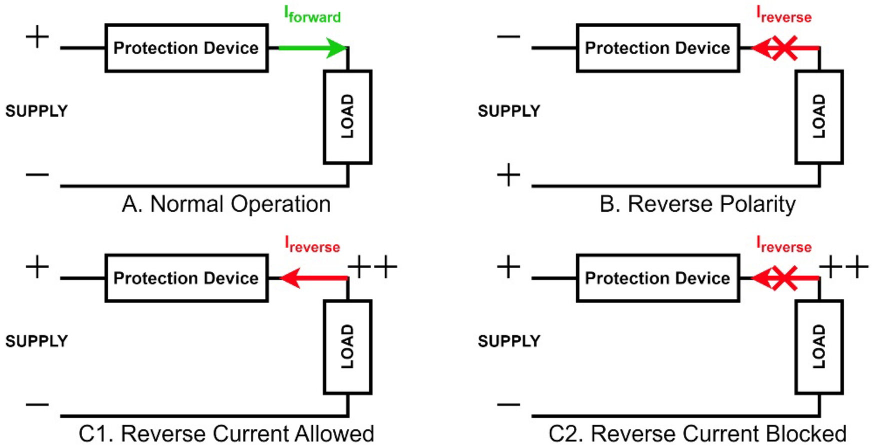


Figure 1: Voltage Polarities and Current Flows

In Figure 1, circuit A shows the system's normal operation, where the current flows from the positive side of the supply through the protection device and the load towards the negative side. Circuit B illustrates a situation where the polarity of the supply is reversed in comparison to circuit A. Here, the current flows in the opposite direction but is stopped by the protection device.

Circuits C1 and C2 show the scenarios where the supply is connected as shown in circuit A, but the positive side of the load is more positive than the supply (e.g., due to back EMF from a motor). In the case of C1, the protection device allows current to flow back to the supply. In circuit C2, the protection device blocks the current flow.

For a device to provide input reverse voltage protection, it must satisfy the conditions presented in circuits A and B. Different protection methods can satisfy either circuit C1 or C2, selectable according to the requirements of the specific application

Input reverse voltage protection can be implemented using a simple diode or a MOSFET (with some external control) as the blocking component. We will take a closer look at these solutions and discuss their advantages and disadvantages from an engineering point of view.

Input Reverse Voltage Protection with a Blocking Diode

Inserting a blocking diode into the circuit is the simplest solution for input reverse voltage protection to implement, as it consists of only one component.

Figure 2 shows a simple circuit of a diode connected in series with the load, which allows the current to flow only in forward bias mode and block the current in reverse bias mode, as shown in Figure 1's circuits A, B, and C2.

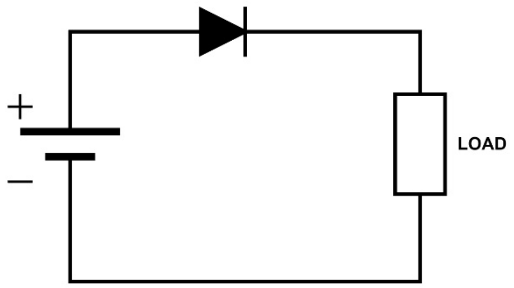


Figure 2: Input Reverse Voltage Protection Using a Diode

The blocking diode can be any diode or rectifier of an appropriate current and reverse voltage rating. The power dissipated in a forward-biased diode is:

$$P = V_F * I_{Load}$$

Where P is the power dissipated, V_F is the intrinsic forward voltage drop of the diode, and I_{Load} is the load current.

This power is lost as heat to the environment, therefore lowering the efficiency of the circuit and increasing the device and board temperature. The load current is set by the application and so the only control over the power dissipation is the selection of a lower V_F diode.

It is common practice to choose a diode with low V_F, such as a Schottky diode. However, Schottky diodes exhibit high reverse current leakage at elevated temperatures, making them susceptible to thermal runaway. Therefore, Schottky diodes may not perform effectively in high-temperature environments and high-power applications.

Diodes Incorporated (Diodes) provides a variety of rectifiers suitable for industrial and automotive applications, covering a wide range of load currents. Super Barrier Rectifiers (SBR®) and Trench Super Barrier Rectifiers (SBRT) have a similarly low forward voltage characteristic to a Schottky diode, but the reverse leakage profile is lower at elevated temperatures.

The graphs in Figure 3 show the forward and reverse bias characteristics of Diodes' SBRT20U50SLPQ and a comparable Schottky diode. Both are rated for the same maximum forward current (20A).

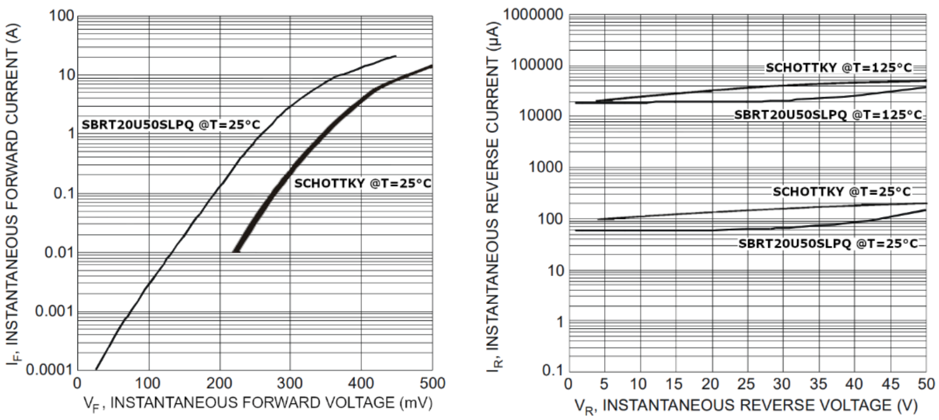


Figure 3: Schottky vs SBRT V_F in Forward Polarity (Left) and Leakage Current in Reverse Polarity (Right)

Example 1 – Diode Input Reverse Voltage Protection Efficiency

This example assesses the efficiency of a Schottky diode versus an SBRT when powering a typical vehicle infotainment system with 12V and 10A.

Schottky

V_{in}=12V, I_{in}=10A

$P_{total}=V_{in}*I_{in}$=120W

V_F= 0.46V (from graph @I=10A)

$P_{loss}=V_F*I_{in}$=4.6W

$$\eta=\frac{P_{total}-P_{loss}}{P_{total}}=96.16\%$$

Diodes' SBRT

V_{in}=12V, I_{in}=10A

$P_{total}=V_{in}*I_{in}$=120W

V_F= 0.37V (from graph @I=10A)

$P_{loss}=V_F*I_{in}$=3.7W

$$\eta=\frac{P_{total}-P_{loss}}{P_{total}}=96.92\%$$

The SBRT shows almost a 20% reduction in power dissipation compared to the Schottky, resulting in better efficiency and thermal management.

The diode should be selected according to the maximum expected output current in the application, as shown in Table 1. While the single-component input reverse voltage protection solution will have the smallest footprint in low-power applications, for high currents, the diode needed is much larger. When conducting high currents, the diode will also require more heatsinking copper area to ensure it stays within its operating temperature range.

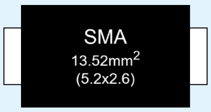
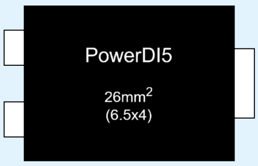
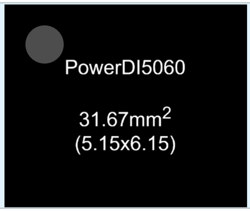
Footprints to Same Scale			
Part Number	SBR3A40SAQ	SBR10U45SP5Q	SBRT20U50SLPQ
Part Footprint Size (mm²)	13.52mm²	25.82mm²	31.67mm²
DC Blocking Voltage (V)	40	45	50
Max. Current @T_A=25°C (A)	3	10	20
V_F @T_A=25°C (V)	0.5	0.47	0.52
Max Recommended DC Current (A)	1.5	5	10
P_D @Rec Current (W)	0.75	2.35	3.7

Table 1: Comparison Between Different Diodes and their Footprints

Using MOSFETs for Input Reverse Voltage Protection

A MOSFET can be used as an ideal diode when placed in series with a load, such that its body diode is facing current flow in forward polarity, as depicted in Figure 4. By turning the MOSFET fully ON in the forward polarity, the power loss is equal to:

$$P_{loss}=I_{Load}^{\ 2}*R_{DS(ON)}$$

Where I_{Load} is the load current and $R_{DS(ON)}$ is the intrinsic ON resistance of the MOSFET.

The current flow is stopped by turning the MOSFET OFF in reverse polarity. This can be achieved with the use of the right circuitry. Power dissipation can be adjusted through the selection of an adequate MOSFET.

P-channel MOSFETs (pMOS) can be used for input reverse voltage protection.

Input Reverse Voltage Protection with Self-Biased MOSFET Circuit

A simple self-biased input reverse voltage protection circuit using a P-channel MOSFET (pMOS) is shown in Figure 4.

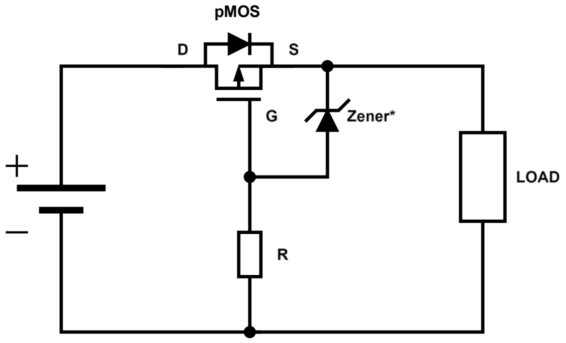


Figure 4: Self-Biasing Input Reverse Voltage Protection Circuit Using a pMOS in a High-Side Configuration

*In the circuit above, the Zener diode protects the MOSFET by ensuring that the gate voltage does not exceed the maximum V_{GSS} rating. However, the Zener's clamping voltage must be high enough for the MOSFET to be fully turned ON to minimize losses.

Under normal operation conditions, represented in Figure 1, circuit A, the MOSFET turns ON and allows the forward current flow with losses determined by the $R_{DS(ON)}$. In the reverse polarity condition, represented in Figure 1, circuit B, the MOSFET remains OFF, and its body diode prevents the reverse flow of current.

Referring to the conditions represented in Figure 1, circuit C1, the circuit shown in Figure 4 allows the reverse current to flow back to the supply because the MOSFET remains biased ON.

Input Reverse Voltage Protection with Ideal Diode Controller

Ideal diode controllers are devices that control an external MOSFET to provide a high-side input reverse voltage protection to the system. Unlike the self-biasing circuit presented in Figure 4, during normal operation (Figure 1, circuit A), the ideal diode controller actively turns the MOSFET ON. It then turns the MOSFET OFF in the input reverse polarity scenario (Figure 1, circuit B). Additionally, the ideal diode controller can control the MOSFET to allow or block reverse current (Figure 1, circuits C1 and C2).

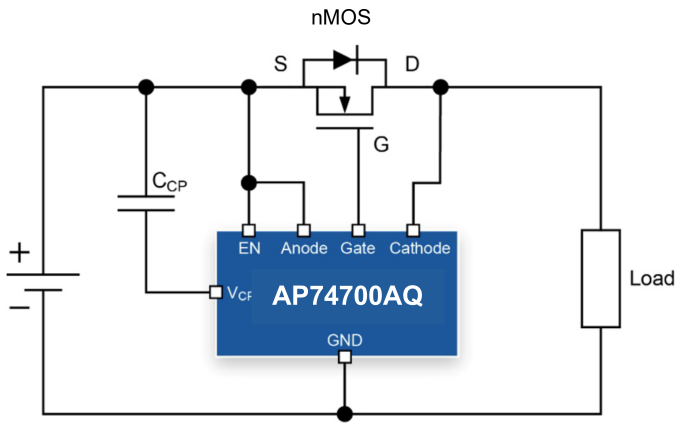


Figure 5: High-Side Input Reverse Voltage Protection with an nMOS and AP74700AQ Ideal Diode Controller

The circuit shown in Figure 5 features the AP74700AQ ideal diode controller, which includes an internal charge pump that generates an above input rail voltage to drive the gate of the N-channel MOSFET (nMOS). In forward conduction (Figure 1, circuit A), the AP74700AQ monitors the voltage differential between the anode and cathode pins (V_{DS}) and modulates the gate of the nMOS to regulate the V_{DS} voltage drop to 20mV.

If a reverse voltage greater than 10mV is detected across the nMOS, the gate pin is internally connected to the anode pin, turning the nMOS OFF. This prevents reverse currents from flowing under the conditions shown in Figure 1, circuits B and C2.

Example 2 – MOSFET Input Reverse Voltage Protection Efficiency

Two MOSFETs of different polarity in the same PowerDI®3333 package were chosen for this example: a pMOS (DMP4013LFGQ) and an nMOS (DMTH43M8LFGQ). These two devices are presently Diodes' lowest $R_{DS(ON)}$ 40V MOSFETs available in this package.

An nMOS with the same $R_{DS(ON)}$ as a pMOS will have a die area of approximately one-third the size. Consequently, the nMOS will be smaller and less expensive. The following example compares their performance under the same conditions as the Schottky diode and SBRT in Example 1.

pMOS

$$V_{in}=12V,\ I_{in}=10A$$

$$P_{total}=V_{in}*I_{in}=120W$$

$$R_{DS(ON)}=13m\Omega\ @V_{GS}=10V$$

$$P_{loss}=I_{in}^{2}*R_{DS(ON)}=1.3W$$

$$\eta=\frac{P_{total}-P_{loss}}{P_{total}}=98.92\%$$

nMOS

$$V_{in}=12V,\ I_{in}=10A$$

$$P_{total}=V_{in}*I_{in}=120W$$

$$R_{DS(ON)}=3m\Omega\ @V_{GS}=10V$$

$$P_{loss}=I_{in}^{2}*R_{DS(ON)}=0.3W$$

$$\eta=\frac{P_{total}-P_{loss}}{P_{total}}=99.75\%$$

As shown in the calculations, the pMOS and the nMOS dissipate significantly less power than the diodes in Example 1. The nMOS is the most efficient solution of all input reverse voltage protection methods outlined thus far. Due to the lower power dissipation, the nMOS will have a much lower temperature increase than a diode or a pMOS of a similar footprint. This, together with the fact that nMOS devices are usually smaller and cheaper than pMOS, can further reduce the design cost.

In Table 2, small external components are selected for the self-biasing pMOS and the nMOS with the ideal diode controller methods to show their difference in footprint size. All resistors are in 0402 package sizes, and the Zener diode in the self-biasing example is in a DFN-1006 package. The charge pump capacitor for the nMOS ideal diode controller is in a 0805 package to account for the higher voltage rating and capacitance, which is required to drive the MOSFET.

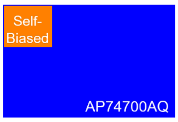
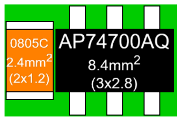
	Self-Biasing Circuit External Components for pMOS	Ideal Diode Controller + External Components for nMOS
Footprints to Same Scale 		
Footprint Size (mm²)	1.24	12.05
Max. Voltage (V)	MOSFET V_{DS}	65V or nMOS V_{DS} (whichever lowest)
Max. Current (A)	MOSFET $R_{DS(ON)}$	nMOS $R_{DS(ON)}$ limited
High-Side Configuration for Automotive Applications	Yes	Yes
Minimum Forward Voltage	$R_{DS(ON)}$ limited	~20mV
Reverse Current Protection	No	Yes

Table 2: MOSFET Biasing Method Footprint Size, Specifications and Features

The AP74700AQ ideal diode controller provides the charge pump functionality, allowing for use of the nMOS on the high side, as well as controlling the FET to block reverse currents.

Diodes Incorporated offers a wide variety of MOSFETs suitable for input reverse voltage protection solutions, ranging from low currents to more than 40A.

Example solutions using 60V MOSFETs in SOT23, DFN-2020, PowerDI3333, and PowerDI5060 packages are shown in Table 3.

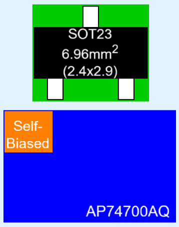
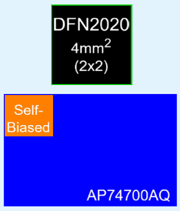
Solution Footprint Size (mm²)				
pMOS				
MOSFET	DMPH6250SQ	DMP6110SFDFQ	DMP6023LFGQ	DMP6018LPSQ
Solution Footprint Size (mm²)	8.2	5.24	12.13	32.91
$R_{DS(ON)}$	155	110	25	18
Solution Recommended Max. Current (A)	**1.5**	**1.75**	**4.25**	**10**
P_D @Rec. Max. Current (W)	0.35	0.34	0.45	1.8
nMOS				
MOSFET	DMN6075SQ	DMTH6016LFDFWQ	DMTH6005LFGQ	DMTH61M5SPSWQ
Solution Footprint Size (mm²)	19.01	16.05	22.94	43.72
$R_{DS(ON)}$	85	18	4.1	1.5
Solution Recommended Max. Current (A)	**2.2**	**5**	**20**	**40**
P_D @Rec. Max. Current (W)	0.41	0.45	1.64	2.4

Table 3: 60V pMOS & nMOS Comparison Table

The N-channel MOSFET provides the most efficient, power-dense solution and is enabled on the high side by the ideal diode controller. These factors make the ideal diode controller and N-channel MOSFET a particularly good choice for use in high-power automotive applications.

Selecting the right MOSFET for the application is key to ensure optimal system performance. See Application Note AN1193 for a guide in selecting the right MOSFET for use with an ideal diode controller, such as the AP74700AQ. However, the selection process shown in AN1193 is also valid for selecting a MOSFET for the self-biasing pMOS circuit.

Conclusion

This application note has shown different approaches to providing input reverse voltage protection. There is a choice to be made, whether to allow or block reverse currents in a positive polarity situation. Table 4 shows a comparison of three such solutions with similar current and voltage ratings and highlights their advantages and disadvantages.

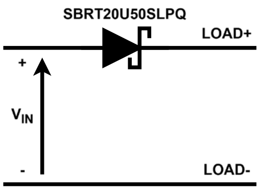
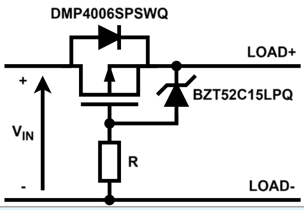
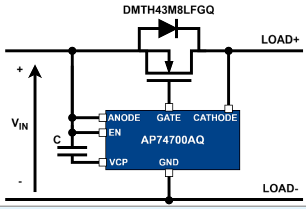
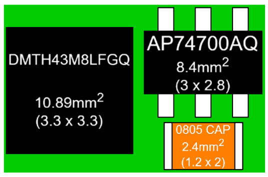
Solution		Schottky or SBR	pMOS + Zener	Ideal Diode Controller + nMOS
Part Names		SBRT20U50SLPQ	DMP4006SPSWQ + BZT52C15LPQ	AP74700AQ + DMTH43M8LFGQ
Max. Reverse Voltage (V)		50	40*	40*
Max. Forward Current (A)		20	25*	29*
Power Dissipated @I=10A		3.7W	0.52W	0.3W
Circuit				
Application circuit complexity		Simplest	Simple	Simple
Footprint (same scale)				
PCB Footprint area (mm^2)		31.67	37.38	28.03
Features	Input Reverse Voltage Protection (A & B)	✓	✓	✓
	Allows Reverse Current (C1)	✗	✓	✗
	Blocks Reverse Current (C2)	✓	✗	✓
Advantages		• Lowest cost at low currents • SBR – most robust • Smallest footprint at low currents	• Lower power dissipation than diode • Simple sizing for different load currents • Allows reverse current	• Lowest power dissipation • Regulates MOSFET enhancement • Fast MOSFET turn-off • MOSFET sizeable to load current • Blocks reverse currents
Disadvantages		• Highest power dissipation • Large temperature increase	• Allows reverse current • More expensive than just diode	• Highest cost at small load currents • Blocks reverse currents

Table 4: Solution Comparison for Input Reverse Voltage Protection

*Note: The maximum voltage and current are limited by the V_{DS} and $R_{DS(ON)}$, respectively, of the selected MOSFET.

The optimum solution for a specific application will depend upon a variety of factors such as cost, solution size, efficiency, power dissipation, complexity, and features required. Diodes Incorporated offers a large portfolio of automotive compliant diodes, MOSFETs, and ideal diode controllers to build high-power density, reliable, and effective input reverse voltage protection solutions.

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