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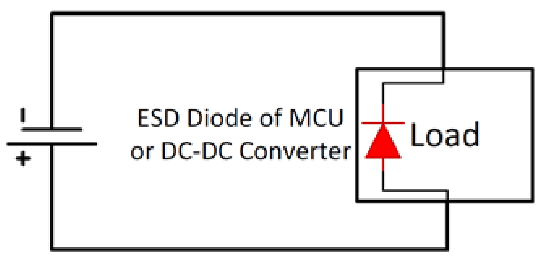
MURRAY SLOVICK, Contributing Editor

Ideal-Diode Controllers Help Boost Battery Input Protection Performance

Sponsored by Texas Instruments: To prevent damage to MCUs and other ICs when high electrical current flows through automotive batteries during engine startup, designers can add ideal-diode controllers to protect against reverse-battery or -polarity conditions.

Many power systems are required to withstand a short interruption in the supply line or input and continue to function uninterrupted. Yet during maintenance of a car battery or when jump-starting a vehicle, the battery can be connected in reverse polarity during reinstallation and cause damage to the connected subsystems and circuits. This reverse-voltage condition—also known as a reverse-battery condition—occurs when battery terminals or jumper cables are connected backward, usually due to operator error.

When this happens, since automotive batteries are designed to produce the high electrical current required to start the engine, a large current can flow through microcontrollers, dc-dc converters, or other integrated circuits, causing severe damage *(Fig. 1)*. As a preventative measure, input reverse-polarity protection and reverse-current blocking features are required.



1. An MCU or dc-dc converter are susceptible to damage in a reverse-connected battery.

Here's one rule of thumb to remember: Subsystems that directly run from battery power require protection from reverse-battery connection or dynamic reverse-polarity conditions during an inductive load disconnect from the battery. Put another way, the main rail powering the downstream load can't flow back into the secondary supply and potentially damage the system.

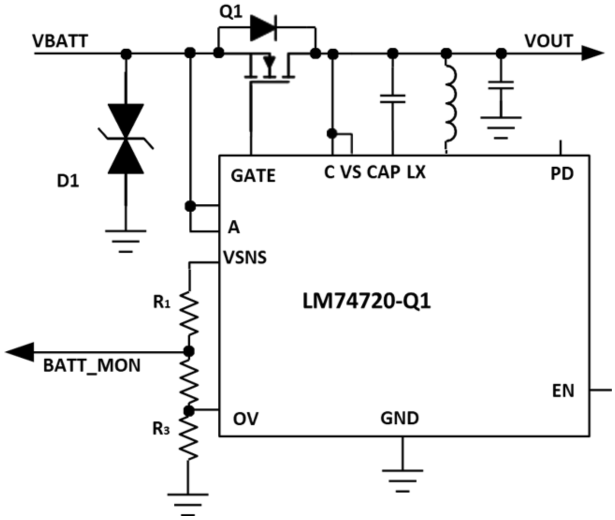
The Basics and Advantages of Ideal Diodes

Discrete diodes are commonly used to protect against reverse-current and reverse-polarity events. But while using discrete Schottky diodes or P-channel MOSFETs to block unwanted reverse current and protect during input micro-shorts will work, discrete diodes have high reverse leakage current, which results in higher power dissipation.

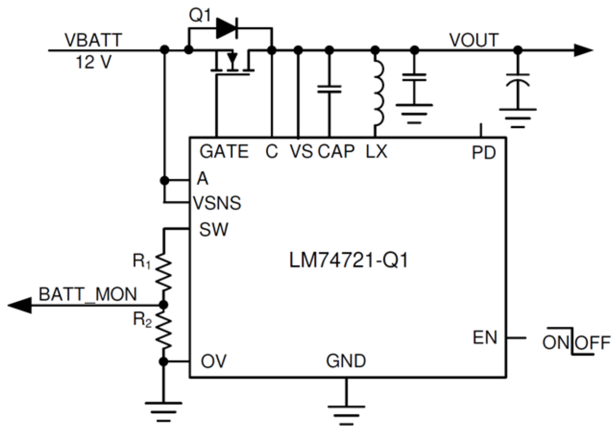
Another challenge with the Schottky diode is the high power dissipation due to a high forward voltage drop across it. As such, the Schottky diode is suitable to be used only in very-low-power designs. In addition, the forward voltage drop leads to a shortened battery life and lower system efficiency.

Generally speaking, among the drawbacks of using Schottky diodes for reverse-battery protection are:

- *Power dissipation:* Forward conduction results in significant efficiency loss at higher load currents.
- *Thermal management:* A heatsink may be needed to manage power dissipation, increasing cost and space.
- *Reverse leakage current:* Reverse leakage current of high-voltage Schottky diodes increase dramatically with junction temperature, resulting in higher power dissipation during reverse conduction.



2. A low-I_Q ideal diode like TI's LM74729-Q1 is effective in protecting and controlling automotive battery-powered ECUs in EVs and semi-hybrids.



3. The LM74721-Q1 low-I_Q TVS-less ideal diode, with active rectification, is targeted at 12-V battery-powered automotive applications.

A Better Way

Ideal-diode ORing controllers provide protection against reverse-polarity conditions by monitoring an external FET, significantly reducing power loss, and blocking reverse current. On that front, Texas Instruments' ideal-diode controllers can be used to improve efficiency and performance in battery input protection applications and power-supply ORing applications.

An ideal-diode controller, when paired with an external N-channel MOSFET, provides low-loss protection against both input supply reversal as well as reverse current flowing from output loads back to the input. The controller drives an external N-channel MOSFET to emulate an ideal diode with a very low forward voltage drop and negligible reverse current.

Key features such as low operating quiescent current, very low shutdown current, regulated forward voltage, and fast reverse-current response enable ideal-diode controllers to emulate an ideal diode in a variety of applications.

The power MOSFET is connected in such way whereby its body diode blocks reverse current when the MOSFET is turned OFF. Forward voltage drop and power dissipation are reduced significantly as the MOSFET is turned ON during forward conduction. Ideal-diode controllers sense the reverse current through the MOSFET and turn it OFF, allowing the body diode to block reverse current.

In addition to these features, ideal-diode controllers also can support other characteristics like overvoltage protection, inrush current control, and transient-voltage-suppression (TVS)-less operation. TVS diodes are solid-state PN junction devices specifically designed to protect sensitive semiconductors from the damaging effect of transient voltages.

Low-I_Q Ideal-Diode Controller with Active Rectification

Rectified alternator output voltages may contain ac voltage ripple superimposed on the battery voltage during the lifetime of the vehicle (depending on the operating conditions). The ac voltage ripple is superimposed on the dc battery line due to variation in engine speed, regulator duty cycle with field current switching ON/OFF, and electrical load variations.

In fully electric systems or semi-hybrid systems, the entire electrical load is fed through dc-dc converters. The TI LM74720-Q1 ideal-diode controller drives and controls external back-to-back N-channel MOSFETs to emulate an ideal-diode rectifier with power-path ON/OFF control and overvoltage protection *(Fig. 2)*.

The wide input supply of 3 to 65 V allows for protection and control of 12- and 24-V automotive battery-powered ECUs. The device can withstand and protect loads from negative supply voltages down to –65 V. The part features low quiescent current of 35-µA (max) in operation, which enables always ON system designs.

"TVS-Less" Ideal-Diode Controller

While blocking diodes are easy to understand and apply, their forward drop results in significant power dissipation, making them unsuitable in both low-voltage and high-current applications. TVS diodes are an effective solution to protect other semiconductors from any damaging surge levels they may be exposed to.

A "TVS-less" low-IQ reverse-battery protection ideal-diode controller with active rectification, such as TI's LM74721-Q1, is an ideal-diode controller that drives and controls an external N-channel MOSFET to emulate an ideal-diode rectifier with power-path ON/OFF control and overvoltage protection *(Fig. 3)*.

Again, a wide input supply allows for protection and control of 12-V automotive battery-powered ECUs. The device can withstand and protect the loads from negative supply voltages down to –33 V dc. An integrated VDS clamp feature enables input TVS-less system designs for automotive ISO7637 pulse suppression. The VDS clamp helps protect the device when switching an inductive load.

Eliminate the Voltage Drop and Save Power

This article has discussed the drawbacks of existing methods and the benefits of using ideal-diode controllers for input protection. TI's ideal-diode controllers help reduce the energy lost across the forward voltage drop of a diode. They trim power loss and protect power sources and loads against reverse-polarity conditions, overcoming the common limitations of Schottky diodes or P-channel MOSFETs.

Summing up, TI's ideal diodes and ORing controllers offer space-saving and scalable solutions to protect systems against reverse voltage or reverse current. These devices significantly reduce the energy typically lost across the forward voltage drop of traditional discrete silicon or Schottky diodes.