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# Technical Paper

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Reverse Battery Protection Using  
PPTC Devices



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# Reverse Battery Protection Using PPTC Devices

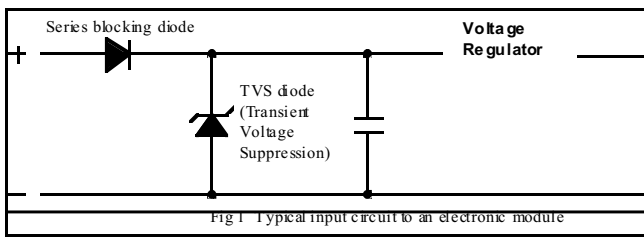
Tyco Electronics Power Components  
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The electronics in today's vehicles need to be protected from reverse polarity power sources. A reverse voltage can occur when jumper cables are connected to the wrong polarity of a dead or excessively discharged battery or when a new battery is installed backwards. Without protection, excessive heating can lead to failures in electronic modules or inadvertent activation of vehicle loads such as solenoids and motors that can lead to unsafe conditions. Traditional protection techniques can be expensive or cause an excessive voltage drop reducing the performance of some systems. New techniques that use polymeric positive temperature coefficient (PPTC) devices such as Raychem's PolySwitch products can address both of these shortcomings and provide additional advantages.

## Traditional Diode Protection

A common practice to protect the electronics module from damage under reverse battery conditions uses a series blocking (rectifying) diode (Fig 1).



The blocking diode serves as a simple solution by prohibiting current from flowing in the reverse direction. The fundamental disadvantage of using a series blocking diode is the inherent voltage loss (0.7 – 1.0V), resulting in a lower available voltage to operate the electronic module. In some automotive electronic modules (e.g., engine control) the system operating voltage is very critical, therefore, minimizing any voltage drop (i.e., across a blocking diode) is important to ensure vehicle starting under low-battery conditions. In other cases (e.g., audio systems) the system voltage has a direct impact on the available output power ( $P_o = V * I = V^2 / R$ ), or in other words, audio performance. To minimize voltage loss, some electronic modules use a Schottky diode, to reduce the voltage drop to typically less than 0.5V.

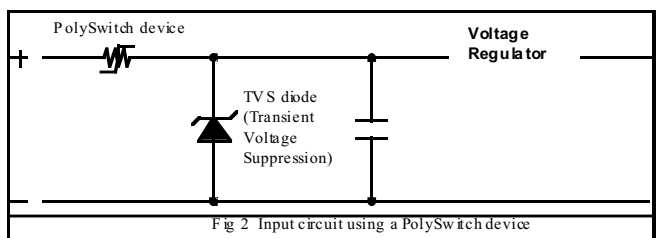
If either a standard rectifying diode or Schottky diode is used for reverse polarity protection, the current carrying capacity (amperage rating) of the diode will be determined by loads that

will be connected to it. When the current draw through the electronic module is less than 1A, the cost of the standard rectifying blocking diode may be relatively inexpensive (<\$0.05). However, if a Schottky diode is used, or the current exceeds 1A, the cost can be considerably higher. A secondary factor, considered when selecting the size of the blocking diode, is the surge current capacity, and the ability to absorb and dissipate the surge current created during a "load dump" event. Disconnecting the vehicle battery when the alternator is supplying a charging current causes the "load dump" event. The load dump waveform typically reaches peak voltage level within a few milliseconds, and then exponentially decays over several hundred milliseconds. It is typically a worst case rating consideration for silicon devices.

## PPTC Protection

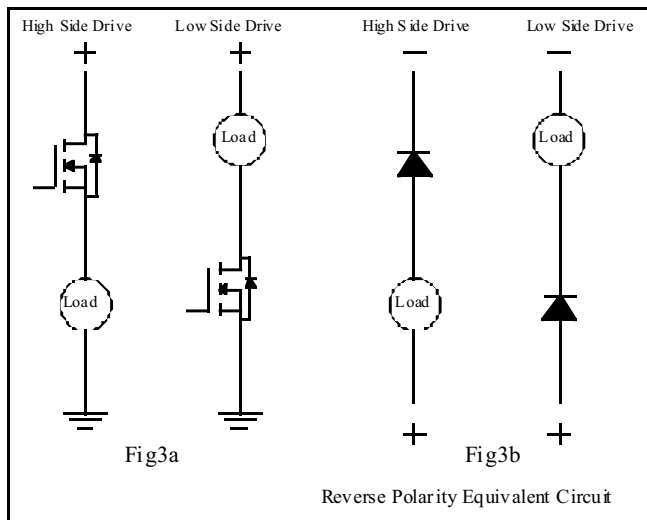
PPTC devices such as PolySwitch products are based on a composite of semicrystalline polymer and conductive particles. Under normal operating conditions the conductive particles provide a low resistance path allowing current to flow. Under fault conditions that cause excessive temperature, such as excessive current flow or an excessively high ambient temperature, the crystallites in the polymer melt and become amorphous causing separation of the particles resulting in a large, non-linear increase in resistance. The increase in resistance is typically three orders of magnitude or more, reducing the current to a relatively low and safe level. PolySwitch PPTC devices reset after the fault is cleared and the power to the circuit is removed.

The use of a PPTC device in lieu of the blocking diode in the previous applications (Fig 2) provides multiple benefits including reduced voltage loss since the voltage drop across the PPTC device will typically be about 0.1V. Secondly, the PPTC device may provide additional circuit protection to other electronic components (traces, wire, relays, and solid-state components, etc.).



## Protecting Power MOSFET Circuits

When electronic modules use power MOSFETs for solid-state switching of various loads, other reverse-polarity concerns are created in either high side or low side drive configurations (Fig 3a). With a reverse polarity, the power MOSFET's inherent internal diode becomes forward-biased and allows current to flow to the motor, lamp or solenoid load to which it is connected (Fig 3b).

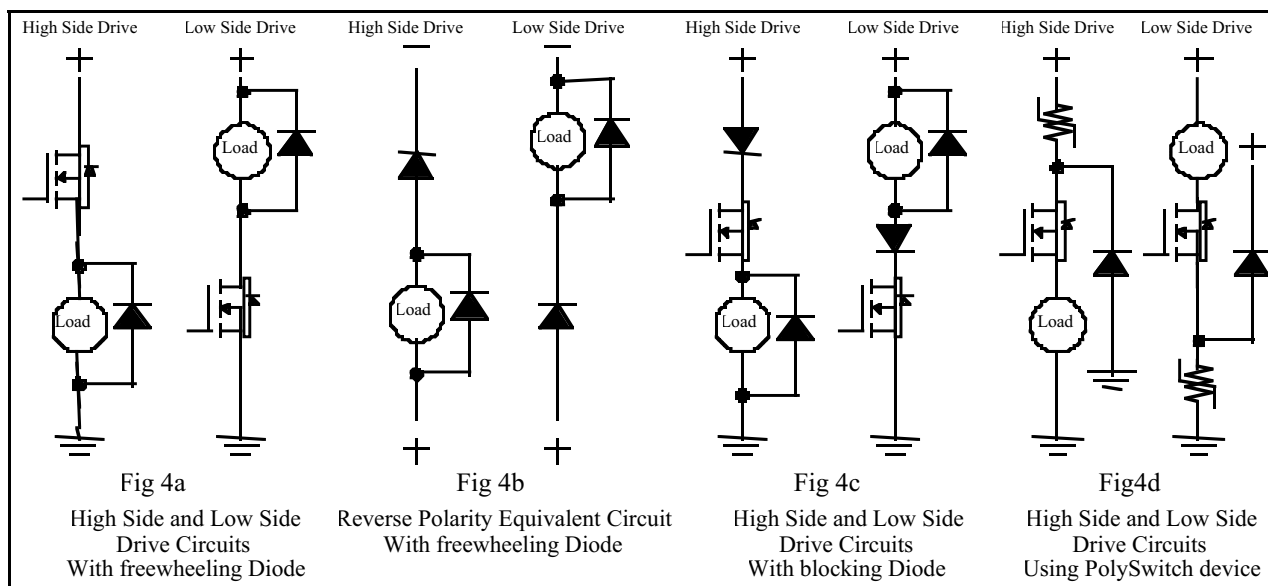


This does not create an instantaneous catastrophic failure condition. However, the FET's power dissipation will increase by about 5 times normal since the voltage drop across the device is now approximately 1V (as current flows through the P-N junction of the intrinsic diode) rather than a nominal forward VDS voltage of 0.2V (measured across the Drain to Source). Unless proper thermal management practices are followed such as using a heat sink adequately sized to dissipate the heat generated for the duration of time the reverse-polarity

condition would exist, sustained operation under this condition would eventually cause thermal destruction to the MOSFET. This additional heatsinking adds cost, weight and size to the application. These are all items that car makers and suppliers want to reduce. Even a thermally protected FET, such as a TEMPFET® cannot protect itself from destruction under this condition, since the gate of the FET does not control current through the intrinsic diode. The addition of a PPTC device in series with the load coupled with a bypass diode (see Fig 4d) can help provide the reverse battery protection and allow a smaller heatsink to be sized for normal operation. More importantly, by preventing current flow in the reverse direction, the inadvertent activation of a solenoid or motor can be avoided.

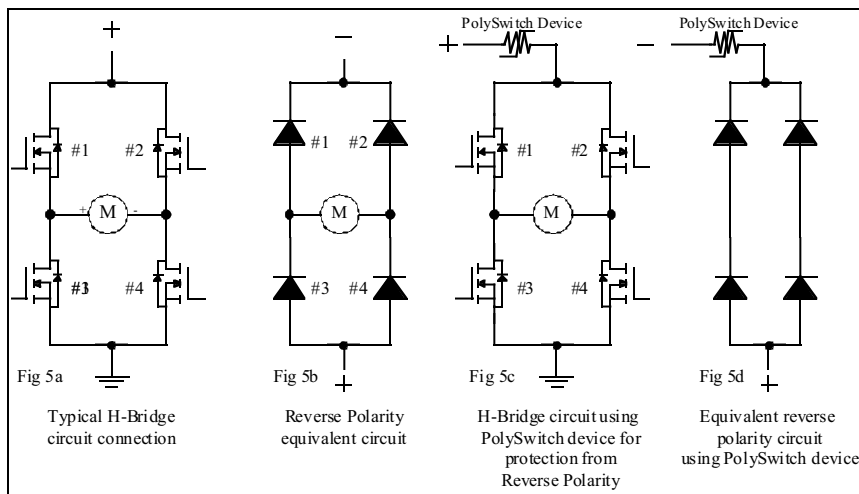
## Inductive Loads and Reverse Battery

A common practice with inductive loads uses a freewheeling diode connected across the load to suppress the voltage spike generated when the load is turned off. Figure 4a shows a power MOSFET used as a high side and as a low side switch with an inductive load. Under a reverse-polarity situation, current would flow through the forward-biased intrinsic diode of the FET and through the free-wheeling diode across the load, creating a direct short circuit between the positive and negative terminals of the power source (Fig 4b). One easy method to prohibit the current from flowing is to use a series blocking diode as shown in Fig 4c. However, high current loads may make this solution cost prohibitive as noted previously. An alternative solution is to use a PPTC device coupled with a smaller rectifying diode (Fig 4d), which provides an economical solution, while virtually eliminating the voltage loss inherent with the series blocking diode. In this configuration, a smaller rectifying diode can be used since it is only required to withstand the surge current necessary to "trip" the PPTC device, unlike a series blocking diode, which must support the full load current continuously.



## Protecting Motors

Most of the fractional horsepower motors used in vehicles for comfort and convenience are brush DC motors. The solid-state method to drive a bi-directional motor (e.g., power windows, power seats, power locks, etc.) uses an “H-bridge” configuration consisting of four Power MOSFETs connected as shown in Fig 5a. To rotate the motor in the positive direction, MOSFET #1 and #4 are turned on simultaneously. To rotate the motor in the negative direction, MOSFET #2 and #3 are turned on simultaneously. The reverse-polarity connection to an H-bridge circuit produces the equivalent circuit of two series intrinsic diodes connected in parallel between the positive and negative terminals of the power source (Fig 5b) essentially creating a short circuit. For the same reasons as stated above, the use of a series blocking diode, may not be economically feasible. However, the use of a series PPTC device helps provide reverse-polarity protection economically while minimizing the voltage loss in the system (Fig 5c). The equivalent circuit in a reverse-polarity condition is shown in Fig 5d. Generally, the FET’s intrinsic diode will easily provide the momentary surge current necessary to cause the PPTC device to trip within milliseconds.



For the circuits shown in Fig 2, Fig 3b, Fig 4d, and Fig 5d, the diodes that created the current path under the reverse-polarity conditions must have surge capacity ratings that will cause the PPTC device to trip while keeping within the “Safe Operating Area” (SOA) of the diode. In other words, the “time-to-trip” of the PPTC device must not exceed the diode’s surge current-time capability. PPTC devices are available with a range of current and maximum time-to-trip ratings to satisfy most applications.

## Reducing Power Losses in Vehicles

The increasing number of vehicle loads has caused automakers and their electronic system suppliers to define a next-generation vehicle power supply system that would eventually replace the 12V battery system that has been in US cars since the mid-1950s. The PowerNet specification defines the voltage

limits in a vehicle power supply that is three times today’s regulated system. This 42V system includes tighter specifications for those 12V products that could still be used in dual-voltage architecture. Today’s lower power products will be used for many years with higher power products that are put on the 42V bus. However, the costs associated with changing to a 42V power supply are causing manufacturers to delay its implementation until there is no other alternative. As a result, vehicle makers are looking at every potential for reducing the power consumption to avoid making a transition to a higher, 42V, power supply.

One of the ways to reduce power consumption is the use of brushless DC motors instead of brush motors, especially for higher-power applications. Brushless DC motors also have advantages of no brushes to wear out and reduced electromagnetic interference since there are no brushes to arc. In a three-phase brushless motor the MOSFET bridge topology has three legs similar to the two legs in the brush DC motor. Reverse battery has the same impact on brushless DC motors, but fortunately the same reverse-battery protection as proposed in Fig 5c using a PPTC will also apply to brushless DC motors.

Using a PPTC device in place of a series diode has an additional advantage for vehicles that are already near the limit of their available power supply system. Since the power lost across a series diode is proportional to the voltage, reducing the 0.7V diode drop to approximately 0.1V for the PPTC device in a 20 amp circuit would reduce the power by  $(0.7-0.1)*20=12$  watts. With dozens of motors in even the average vehicle, it is easy to see how 100 watts or more could be saved. These kinds of savings will help postpone the transition to the higher voltage for a few years. Some vehicles, such as General Motors GMC Sierra

and the Chevrolet Silverado, will have limited 42V systems in some 2004 models. Reverse battery is not allowed in the specifications that are being developed for 42V vehicles. The approaches that have been discussed could help vehicle manufacturers ensure that these specifications are met.

## A Safe Path to the Future

As vehicle manufacturers add more and more electronic features, the potential for failures increases for any single fault such as reverse battery. Using the lowest power consumption solution as well as staying within cost targets is increasingly important. PPTC devices can help meet these criteria to allow manufacturers to improve their vehicles as they continue to provide more electronic features for customers.

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