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# Integrated Ideal Diode, Source Selector, and eFuse Improve System Robustness

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## Abstract

This article will examine the ideal diode along with more advanced devices with a back-to-back MOSFET. It will also introduce an ideal diode solution that integrates functions for a total system protection. Diodes are extremely useful devices and important in many applications. Standard silicon diodes have a voltage drop of 0.6 V to 0.7 V. For Schottky diodes, it is 0.3 V. In general, that is not an issue, except in high current applications as each voltage drop generates a significant power loss. An ideal diode would be the ideal device in such applications. Fortunately, a MOSFET can replace standard silicon diodes and provide unexpected application advantages.


## Introduction

An ideal diode uses a low on-resistance power switch, commonly a MOSFET, to mimic the unidirectional current flow behavior of a diode, but without the lossy diode voltage drop penalty. With an additional back-to-back MOSFET and control circuitry, the solution can offer even more system controllability functions such as priority source selection, current limiting, inrush limiting, etc. Traditionally, these functions were scattered in different controllers, making it complex and cumbersome to realize full system protection. Let us examine the key circuit specifications of an ideal diode and look at an application example as well as a new ideal diode solution that also integrates other needed functions for a total system protection in a single IC.

## Ideal Diode Basic

Figure 1 illustrates a basic ideal diode where an N-channel power MOSFET is used. The MOSFET is placed in the direction where its intrinsic body diode is in the same direction of the diode function to mimic (top). When $V_A$ is higher than $V_C$, the current can naturally flow from left to right through the intrinsic diode. The control circuit turns on the MOSFET to reduce the forward voltage drop when the current is flowing in this direction. To prevent reverse current flow (right to left), the control circuit must turn off the MOSFET quickly when $V_C$ is higher than $V_A$. An ideal diode has a low voltage drop, determined by the $R_{DS(ON)}$ of the MOSFET and the current magnitude. For example, at a 1 A load, a 10 mΩ MOSFET has 1 A × 10 mΩ = 10 mV drop across its terminals, compared to a 600 mV typical drop across a regular diode. The ideal diode power dissipation is $1\ A^2 \times 10\ m\Omega = 10\ mW$, which is significantly lower compared to 1 A × 600 mV = 600 mW (typical) of a regular diode.

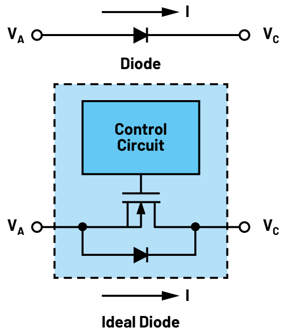


*Figure 1. A diode and an ideal diode.*

Advances in MOSFET technology provide low $R_{DS(ON)}$ MOSFETs. Adding a back-to-back MOSFET to an ideal diode solution increases the voltage drop a little but opens up a lot of system controllability functions. Figure 2 shows this circuit concept.

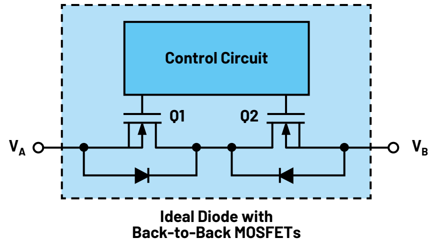


*Figure 2. An ideal diode with back-to-back MOSFETs.*

The original Q1 can control and block the reverse current going from $V_B$ to $V_A$. The additional MOSFET, Q2, can control and block the forward current from $V_A$ to $V_B$.

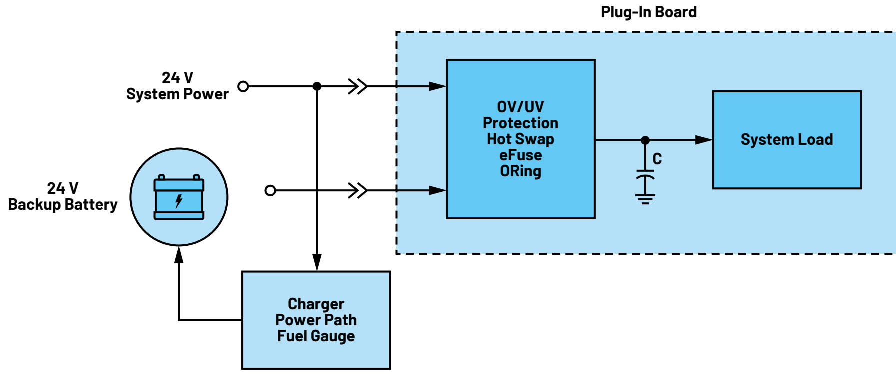


*Figure 3. An industrial UPS power backup system.*

This solution offers total system control by either turning on/off one or both MOSFETs, or limiting the current flowing through them in either direction.

## Ideal Diode Application Example and Key Specifications

An ideal diode finds itself in many applications. Let us look at an industrial UPS backup power system (Figure 3). The system uses 24 V as its main power source. This power source operating range is 19.2 $V_{DC}$ to 30 $V_{DC}$, with transient voltage up to 60 V. A 24 V battery is used as backup power. To ensure maximum backup power, the battery is fully charged to 24 V during normal operation (when the battery is on standby). When the main power source is interrupted, the battery provides backup power, discharging from 24 V to below 19.2 V until the system is no longer operable, or until the main power source comes back, whichever is sooner. An ideal diode circuit is needed here as an ORing function to switch between the system power source and backup battery. Besides an ORing function, the system also requires overvoltage, undervoltage, hot swap, and eFuse protection to improve system robustness against common system faults.

### ORing vs. Source Selector

Figure 4 illustrates a power source ORing concept. For simplicity, diode symbols are used here instead of an ideal diode circuit. In this simple ORing configuration, the power source with higher voltage dominates and powers the load while the other source is standing by. This solution works effectively if the power sources have different voltage values. The power sources might switch back and forth when the two voltages are close to each other or when there is voltage fluctuation, which causes the voltage values to cross.

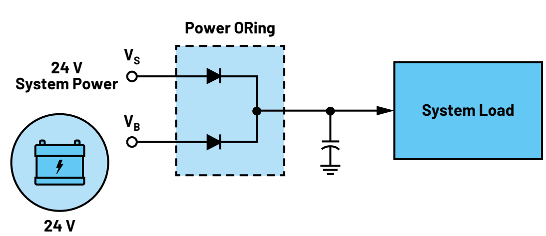


*Figure 4. Input power ORing.*

A simple ORing function is not adequate in this use case for two reasons. First, the battery voltage is like the system nominal voltage at 24 V. The two sources might switch back and forth, which is undesirable. The effect of source impedance and load current further amplifies this issue. For example, when $V_S$ is providing power to the load, the load current causes a voltage drop across $V_S$ source impedance, making its terminal voltage drop slightly below the battery terminal voltage (currently at no load). The battery is then switched on and now carries the load current, which similarly causes a voltage drop across the battery impedance, causing the battery terminal voltage to drop. Meanwhile, without loading, the main power source terminal voltage rises, which makes $V_S$ try to take over. In this situation, vacillation between the two power sources continues until the two voltages drift from each other.

Secondly, the 24 V system power voltage range is 19.2 $V_{DC}$ minimum to 30 $V_{DC}$ maximum, with peak voltage transient up to 60 V. As the backup battery voltage is charged to 24 $V_{DC}$, the battery takes over when the main supply voltage drops below the battery voltage but is still in its operating range. This is also undesirable as the battery discharges to a less optimum backup voltage. The system might try to charge and discharge the battery at the same time whenever the system voltage is less than 24 V and above its minimum operating range. This is where a source selector becomes handy. Figure 5 shows a source selector concept using an ideal diode with the back-to-back MOSFET. With the back-to-back MOSFETs, the controller can completely switch off the current path in both directions, just like opening a mechanical switch. Figure 6 is a symbolic representation of the ideal diode with back-to-back MOSFETs. This symbol is used in Figure 5 to realize a source selector function. In this configuration, $V_S$ is set to high priority. $V_B$ is switched off and only turned on when $V_S$ drops below its operating voltage range.

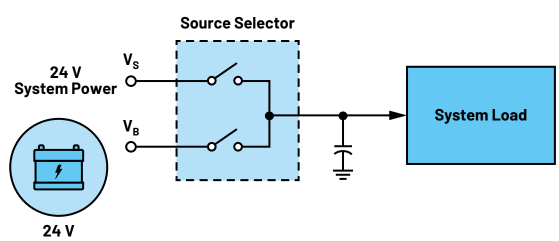


*Figure 5. An input source selector.*

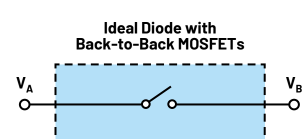


*Figure 6. Symbolic representation of ideal diode with back-to-back MOSFETs.*

Figure 7 illustrates the source selector operation while the battery is on standby and during backup.

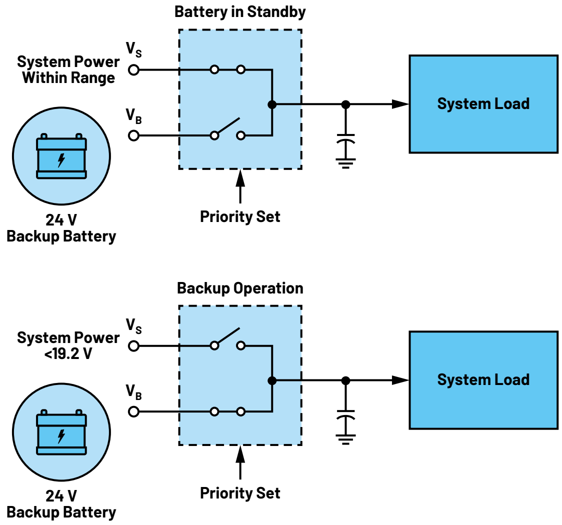


*Figure 7. An input source selector operation.*

## Other Important System Protection Requirements

Even though Figure 6 depicts a mechanical switch that is either closed or open, note that with proper current sensing circuitry, the controller can regulate the current flow as well. Valuable functions such as inrush limit (hot swap), overload/short circuit protection (eFuse), and undervoltage/overvoltage (UV/OV) can be realized using the same power MOSFETs already have.

### Hot Swap

As shown in Figure 3, our system board requires a hot-swap function to limit the inrush current charging the input capacitor, C, when the board is plugged into the backplane (where the main system power and backup battery reside). This hot-swap function is done by sensing and controlling the current flowing through Q2 in Figure 2.

### eFuse

This function protects the system from overcurrent or short circuit conditions. Using the same Q2 in Figure 2, monitor, limit, and shutdown the current flowing through it. The current limit threshold accuracy in an eFuse application is important to optimize system power budget.

### UV/OV

The controller constantly monitors the voltage of the power source. Undervoltage lockout (UVLO) keeps Q2 (Figure 2) securely off until the power source voltage rises above its minimum operating level (19.2 V in this case). Overvoltage protection (OV) turns off Q2 when the input voltage transients above a set maximum level (a chosen value of >30 V in this case).

## Important Ideal Diode Circuit Specifications and How These Affect System Performance

Let us circle back to the ideal diode and examine some critical specifications when using it in an ORing or source selector function.

### Reverse Current Response Time

Referring to Figure 2, this is the time for Q1 to turn off after the voltages $V_A$ and $V_B$ reverse and make $V_B$ greater than $V_A$. This reverse current response time, $t_R$, must be small (100 ns) to prevent reverse current flowing from $V_B$ back to $V_A$. In this system, reverse voltage can happen when the dominant power source $V_S$, while driving the load, either turns off, transients to a low voltage, or short circuits. In this situation, $t_R$ prevents or minimizes reverse current flowing from the board capacitor, C, or from the backup battery back to $V_S$.

### Recovering After an Overvoltage Condition

In systems without backup battery (Figure 8), the capacitor C provides the backup power, commonly known as a holdup capacitor. In this configuration, a transient overvoltage condition on $V_S$ triggers Q2 (Figure 8) to turn off. The capacitor provides the necessary power to keep the system running while its voltage drops due to discharge. As $V_S$ returns to normal operating range, Q2 turns back on. The time for Q2 to turn back on, $t_{ON}$, must be small to minimize the capacitor voltage drop. Figure 9 shows a relative comparison, where half $t_{ON}$ reduces the voltage drop to half given the same amount of holdup capacitance.

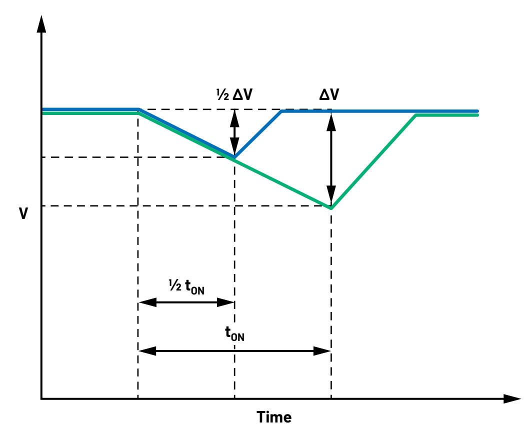


*Figure 9. Voltage drop vs. $t_{ON}$.*

We have examined different functions such as source selector, hot swap, eFuse, UV/OV, and critical specifications to improve system robustness against common system faults. To implement all of these using many single function ICs is cumbersome. The solution is complex and requires many components. The MAX17614 is a new, highly integrated solution that provides a high performance ideal diode function as well as many other functions to fully protect the power system in a single IC. The device operates from 4.5 V to 60 V and provides a 3 A

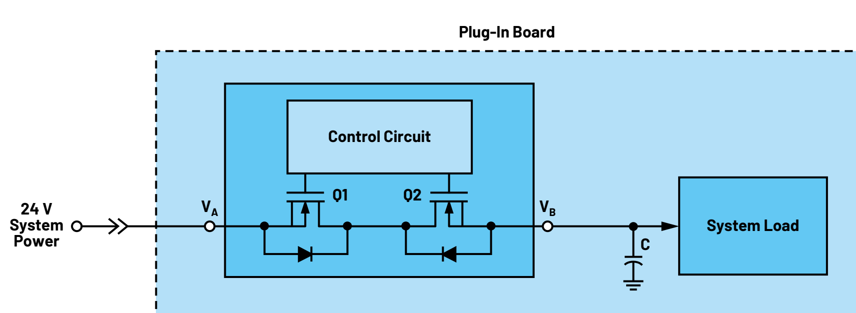


*Figure 8. A system with a holdup capacitor.*

output solution featuring ideal diode/priority power source selector functions with adjustable current limit, hot swap, eFuse, UV, and OV protection. Figure 10 and Figure 11 show simplified schematics of the MAX17614 in an ORing application as well as a priority power source selector application, respectively.

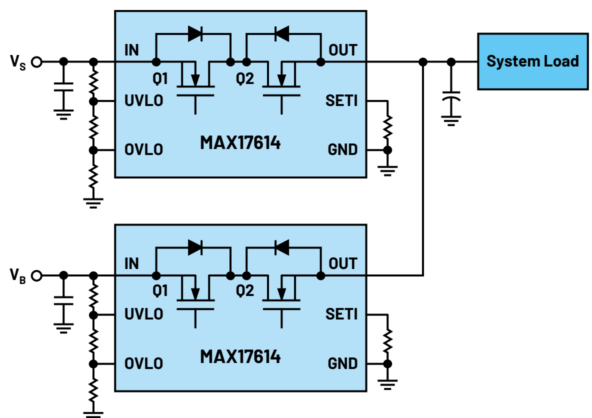


*Figure 10. Voltage ORing with the MAX17614.*

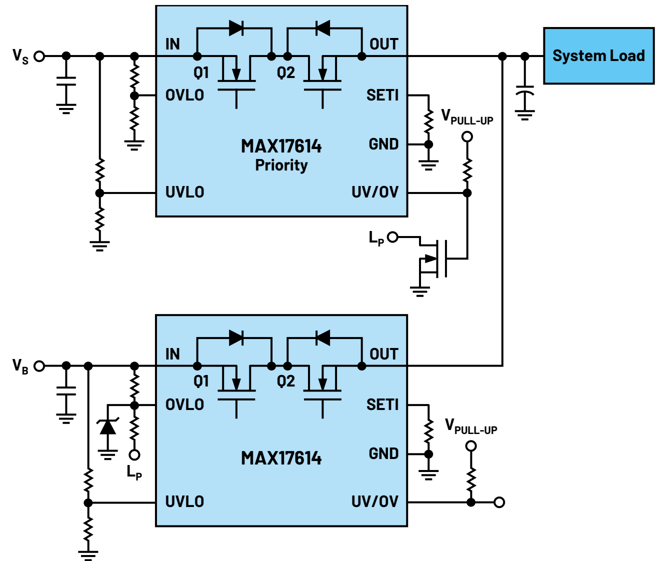


*Figure 11. A priority power source selector with the MAX17614, where $V_S$ has priority.*

## Conclusion

The back-to-back MOSFET solution offers more system controllability functions such as source selection, hot swap, eFuse, UV/OV, etc. Traditional solutions using a combination of single function ICs to provide complete system protection are complex and cumbersome. We have examined a UPS power backup application and quickly looked at an ideal diode solution that also integrates other needed functions for a total system protection in a single IC.

## About the Author

Anthony T. Huynh (aka Thong Anthony Huynh) was a principal member of technical staff (MTS), applications engineering, at Maxim Integrated (now part of Analog Devices). He has more than 20 years of experience designing and defining isolated and nonisolated switching power supplies and power management products. At ADI, he has defined more than 100 power management products including DC-to-DC converters, hot swap controllers, Power over Ethernet, and various system-protection ICs adopted by the world's leading manufacturers.

Anthony holds four U.S. patents in power electronics and has written several public articles and application notes in this area. He has a B.S. degree in electrical engineering from Oregon State University and has completed all coursework for an M.S. degree in electrical engineering at Portland State University, where he also taught a power electronics class as an adjunct instructor.