Reduce Diode Losses in Redundant Systems With Integrated Power MUXes

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ABSTRACT
This document demonstrates how diode implementation with the TPS25942A active ORing feature effectively replaces a lossy Schottky diode. Inrush current limit and overload, and the short circuit and over/undervoltage fault protections are also addressed.

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1 Introduction
Many power management applications use Schottky diodes for the parallel operation of multiple power sources. This type of power redundancy is often found in systems with solid-state drives (SSDs), hard disk drives (HDDs), programmable logic controllers (PLCs), peripheral component interconnect express (PCIe) cards, network and graphic cards, and some others used in automotive, industrial, personal electronics, and telecommunications infrastructure applications. The diodes do a great job of isolating redundant power sources to keep the system operational in the event that any one power source fails, while also preventing current flow from one supply to the other.

The diode power-muxing configuration gives a seamless transition from one voltage rail to the other (Figure 1). However, system and circuit designers need to find methods to reduce circuit losses associated with these diodes. The diode also reduces the available supply voltage at the system input. This becomes critical for the lower side of the input operating voltage range. A 0.5-V drop across a diode represents four percent of the power consumption in a 12-V system.
A second consideration is overcurrent protection to prevent bus droops during overload events and short circuits. Maintaining load voltage above the undervoltage level prevents system interrupts while reducing downtime and increasing customer satisfaction.

For a number of years there has been a trend moving away from MUXing with power diodes and moving towards MUXing with ideal diodes. An Ideal diode is a circuit that “makes a FET act like a diode.” Although somewhat more complex than a simple diode, the ideal diode can significantly improve system efficiency and consume less power supply margin. There are many controllers in the market today that can make a FET behave like a diode. There are also integrated devices that have a FET and a controller in a single package. Typically these are available for lower voltages and currents. The devices in the spotlight of this article contain an ideal diode as part of a total, integrated solution.

To determine power loss in a diode simply multiply current by $V_F$, the forward voltage drop of the diode. $V_F$ is temperature- and current-dependent, and typically ranges from 0.3 to 0.7 V.

To calculate power loss in a FET, simply multiply $R_{DS(ON)}$ by the square of the load current. $(I^2 \times R_{DS(ON)})$. Modern MOSFETs have very low on-state resistance, $R_{DS(ON)}$, which results in a low-voltage drop even under load. In turn, this results in much lower power losses than the equivalent system using diodes. This means greater system efficiency, more available power supply margin, and fewer thermal issues during design.

Effective and reliable active ORing is not as simple as it may appear and comes with a few tradeoffs. When the MOSFET is turned ON by its associated controller, the current can flow in either direction through its channel. Should the input power source fail due to a short circuit or voltage drop at the input, this will not prevent a reverse-current flow. A longer period of reverse current will discharge the output bus voltage, causing system-level damage. These conditions mandate that the active ORing control be capable of detecting the reverse current accurately, and turn OFF the MOSFET immediately.

An example of an intelligent ORing control that provides seamless transition between two power sources is shown in Figure 2. This solution gives a distinctive feature set of true-reverse current blocking, auto-forward conduction, and fast switchover.
2 Auto-Power Multiplexing

In addition to the best possible diode implementation, the schematic in Figure 2 limits inrush current and protects each rail from potential overload, short circuit, and over/undervoltage faults. Now take a look at the operation and experimental results of this implementation.

When the main supply, $V_{IN1}$, drops more than 10 mV below $V_{OUT}$, the internal FET (master device) is turned OFF in less than 1 $\mu$s. This blocks the reverse current flow from $V_{OUT}$ to $V_{IN1}$.

As the forward voltage drop between $V_{IN2}$ and $V_{OUT}$ grows larger than 100 mV, the auxiliary supply, $V_{IN2}$, turns ON the internal FET (slave device) in less than 4 $\mu$s. This creates a seamless transition between two voltage rails (Figure 3). Such swift switchover keeps the load powered with no undervoltage transients, which is often the case with diodes. However, this happens at a much lower loss compared to diode ORing.

The $I_{MON1}$ shows the current drawn from the $V_{IN1}$ power supply, and $I_{MON2}$ represents current drawn from the $V_{IN2}$ supply. These waveforms provide a clear indication of the power drawn during changeover from one rail to the other.
Figure 3. Active ORing Changeover from $V_{\text{MAIN}}$ ($V_{\text{IN1}} = 12$ V) to $V_{\text{AUX}}$ ($V_{\text{IN2}} = 3.3$ V)

Figure 4 depicts an active ORing changeover from $V_{\text{MAIN}}$ ($V_{\text{IN1}} = 12$ V) to $V_{\text{AUX}}$ ($V_{\text{IN2}} = 3.3$ V), and $V_{\text{OUT}}$ jumps to 3.3 V. Note the load-current transfer from 12 V ($I_{\text{MON1}}$) to 3.3 V ($I_{\text{MON2}}$).

Figure 3 shows the changeover (ORing) from $V_{\text{AUX}}$ ($V_{\text{IN2}} = 3.3$ V) to $V_{\text{MAIN}}$ ($V_{\text{IN1}} = 12$ V). In active ORing, the priority is always to go with the higher voltage rail (for example, 12 V). Whenever this rail is active, the load current is transferred to the 12-V rail ($I_{\text{MON1}}$). Figure 2 can be extended for multiple power supply active ORing configurations, as is shown in Figure 4.

Figure 4. Active ORing Changeover from $V_{\text{AUX}}$ ($V_{\text{IN2}} = 3.3$ V) to $V_{\text{MAIN}}$ ($V_{\text{IN1}} = 12$ V)

The load-feeding priority by default with diode ORing, and even with active ORing, always has a higher voltage input. For example, consider the case shown in Figure 1 where the $V_{\text{IN1}}$ rail is 3.3 V and the $V_{\text{IN2}}$ rail is 12 V. These two rails are ORed with diodes. The 12 V always feeds the load until it falls below 3.3 V, therefore, the 12-V rails have priority over the 3.3-V rail.

What if the system requires that a 3.3 V ($V_{\text{IN1}}$ rail) power the load until this rail voltage is within 2.7 V to 3.5 V? If the $V_{\text{IN1}}$ rail voltage is out of this range, then the $V_{\text{IN2}}$ rail needs to power the load. However, this is not possible with a Schottky ORing diode, nor with an active ORing mechanism.

A priority power multiplexing implementation is shown in Figure 5 using two devices (master and slave). Now look at a priority power-muxing operation and its experimental results.
Figure 5. Multiple Power Supply Active ORing Configuration

When mains power, $V_{IN1}$ is present and the master device in the $V_{IN1}$ path powers the $V_{OUT}$ bus. Irrespective of auxiliary power, $V_{IN2}$ is greater than or less than $V_{IN1}$.

Once the voltage on the $V_{IN1}$ rail falls below the user-defined threshold (can be programmed by R6 and R7 in Figure 5), the master device on $V_{IN1}$ issues a power-good signal (PG) to the slave device on $V_{IN2}$ (to OVP pin), to switch over to auxiliary power, $V_{IN2}$, to feed power to the output. The transition happens seamlessly in less than 125 $\mu$s, with negligible output voltage droop on the output bus. Combining the output capacitance, $C_{OUT}$, with larger load current demands minimizes the output voltage drop ($V_{DROP}$) during changeover time. The required $C_{OUT}$ can be calculated using Equation 1.

$$C_{OUT} = \frac{I_{LOAD} \times 125 \mu s}{V_{DROP}}$$

When $V_{IN1}$ recovers, the device connected to $V_{IN1}$ is turned ON at a defined slew rate and the device in $V_{IN2}$ path turns OFF. This allows a seamless transition from auxiliary to main voltage supply with minimal droop and without shoot-through current. Figure 7–Figure 8 show the smooth changeover from 3.3-V to 12-V rail, and vice versa.
Figure 6. Example Schematic of Priority Power Muxing Implementation

Figure 7. Priority Multiplexing Change Over From $V_{\text{MAIN}}$ ($V_{IN1} = 3.3$ V) to $V_{\text{AUX}}$ ($V_{IN2} = 12$ V)

Figure 7 shows a changeover from $V_{\text{MAIN}}$ ($V_{IN1} = 3.3$ V) to $V_{\text{AUX}}$ ($V_{IN2} = 12$ V), and how VOUT jumps to 12 V when 3.3 V collapses. See the load-current transfers from 3.3-V ($I_{\text{MON1}}$) to 12-V rail ($I_{\text{MON2}}$).
**Conclusion**

Figure 8 shows the priority changeover from $V_{AUX}$ ($V_{IN2} = 12\text{V}$) to $V_{MAIN}$ ($V_{IN1} = 3.3\text{V}$), even though a 12-V supply is present at $V_{IN2}$. Still, when $V_{MAIN}$ ($V_{IN1} = 3.3\text{V}$) becomes active, the load gets power from the 3.3-V rail. Note the transfer of the load current from 12-V rail ($I_{MON2}$) to 3.3-V rail ($I_{MON1}$). This shows that the 3.3-V rail has priority over the 12-V rail.

![Figure 8. Priority Multiplexing Changes Over From $V_{AUX}$ ($V_{IN2} = 12\text{V}$) to $V_{MAIN}$ ($V_{IN1} = 3.3\text{V}$)](image)

3 Conclusion

Diode implementation with the TPS25942A active ORing feature effectively replaces a lossy Schottky diode. Also addressed are the inrush current limit and overload, and the short circuit and over/undervoltage fault protections. A priority power multiplexing feature allows the designer to decide the priority of one rail over another, regardless of the voltage level of the input rails.

4 References

Download the TPS25942x/44x 2.7V-18V, 5A eFuse Power MUX with Multiple Protection Modes TPS25942A datasheet ([SLVSCE9](#)).
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