Designing a Synchronous Rectification Solution to Reduce Excessive Heat (Part II)

Introduction

This article is the second part of a two-part series exploring how to design a secondary-side synchronous rectifier for ultra-small, fast charge adapters. Part I discussed the topology designs and power supplies for synchronous rectifiers. Part II will review how a synchronous rectifier opens and shuts down, and how new devices utilize quick shutdown technology.

Opening the Synchronous Rectifier

A self-powered circuit provides the necessary connections to open the secondary MOSFET tube. Designers should consider timing when opening a synchronous rectifier.

The MP9989, which was first discussed in Part I, is a continuous conduction mode (CCM) and discontinuous conduction mode (DCM) flyback ideal diode. When the primary-side MOSFET is turned off, the secondary-side MOSFET freewheels through the body diode, and the positive V_{DS} drops to -0.7V. When the chip detects this voltage shift, it opens the secondary MOSFET tube to ensure that current flows continuously.

When compared to the straightforward process for the secondary MOSFET tube, the reactive power supply while operating in intermittent mode presents difficulties. Figure 1 shows the V_{DS} and side current waveforms in intermittent mode. The MOSFET tube closes when the current stops flowing. This can be followed by V_{DS} voltage shock. Under certain operating conditions, the magnitude of the V_{DS} shock is relatively large, where the valley voltage can even reach 0V. The secondary-side synchronous rectifier may mistakenly open the MOSFET tube, which results in anomalies due to continuous current flow.

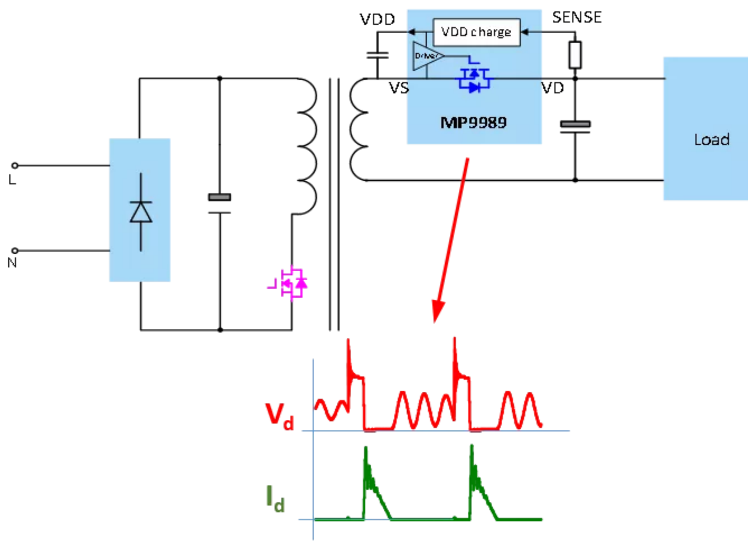


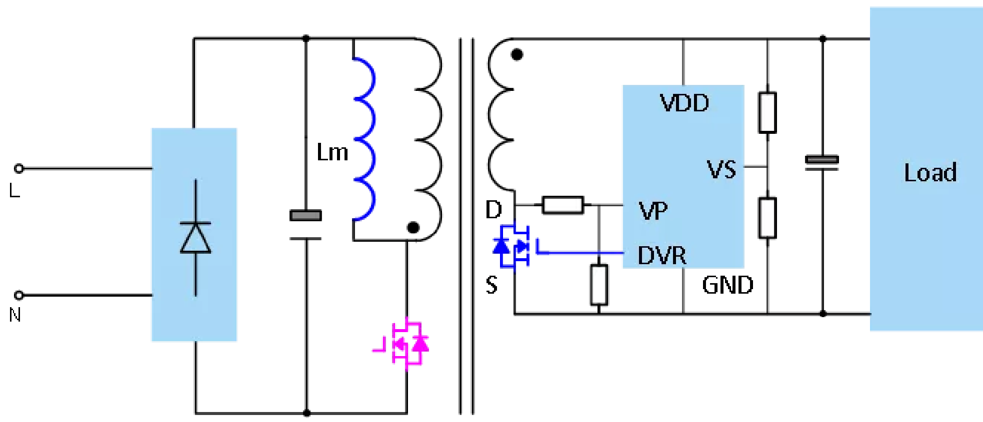
Figure 1: V_{DS} and Side Current Waveforms in Intermittent Mode

After observing the V_{DS} waveforms during the original edge MOSFET's shutdown and during DCM, it is determined that V_{DS} changes much more slowly when it oscillates than when it changes during a normal opening sequence. Based on this difference, the MP9989 includes a slew rate when the internal clock starts and when the side V_{DS} drops to 2V. If V_{DS} does not drop to -80mV within 30ns, an abnormal signal is detected, and the device does not turn on. This prevents misleading communication due to accidental conduction.

Reliable Shutdown of the Synchronous Rectifier

A synchronous rectifier's shutdown process requires different considerations. In principle, the synchronous rectifier shuts down when the edge MOSFET opens while the side MOSFET closes. However, it is difficult for the side MOSFET to respond in time to the edge MOSFET's lead communication signal since there is no communication mechanism between the side edges.

The traditional approach uses the excitation inductor's volt-second balance scheme to calculate when the device shuts down (see Figure 2). In theory, the shutdown time can be calculated based on the side MOSFET to determine when to turn off the side MOSFET.



$$T_{off} * nV_o = V_{in} * T_{on} \qquad T_{off} = \frac{V_{in} * T_{on}}{nV_o}$$

Figure 2: Common Volt-Second Balance Scheme

When the load increases, the original edge winding's flux changes accordingly to stabilize the output voltage. Volt-second balance is not valid during dynamic adjustment. Therefore, a short circuit occurs when the secondary MOSFET tube does not shut down within a set time.

In addition, the volt-second balancing principle means the transformer's excitation inductive voltage should be measured while the device is on and off. The accuracy of the voltage sampling resistance and voltage shock caused by parasitic parameters can lead to errors when calculating the volt-second balance, which significantly impacts reliability.

The key points for a synchronous rectifier's shutdown process are summarized below:

- Volt-second balance is only established under steady state conditions because the secondary MOSFET tube often fails to turn off under dynamic conditions, which results in short circuits.
- Peak voltage (V_P) sampling and V_S sampling are affected by peripheral resistance accuracy, which can result in computational errors.
- The oscillation caused by parasitic parameters can make it impossible to sample V_P, which results in a calculation error.

Quick Shutdown Technology

Quick shutdown technology dynamically adjusts the gate voltage of the synchronous rectifier's MOSFET tube. For example, the opening delay of the MP9989's MOSFET tube initiates continuous flow when V_{DS} quickly drops from positive to negative voltage (see Figure 3).

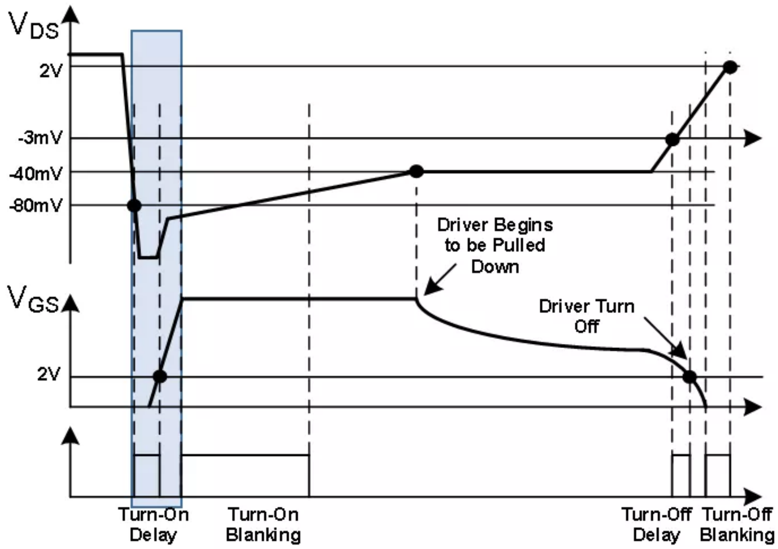


Figure 3: MP9989's V_{DS} Pressure Drop Leads to Open Delay of MOSFET Tube

During this time, the side MOSFET has a large continuous current, and V_{DS} is equal to the current multiplied by the on impedance. V_{DS} decreases as the current continues to flow (see Figure 4).

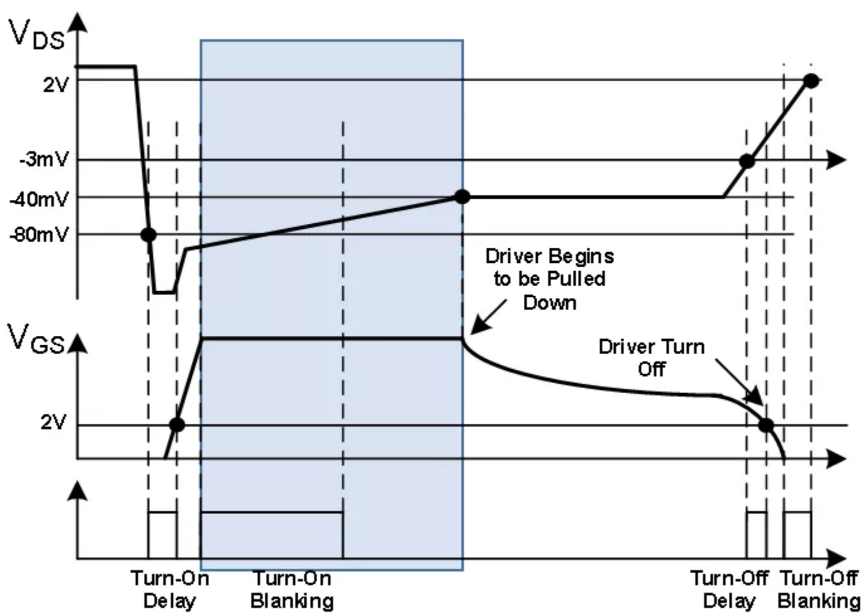


Figure 4: The MP9989's V_{DS} Decreases with a Large Side Continuous Current

When V_{DS} reaches 40mV, the MP9989 dynamically reduces the gate drive voltage and increases the on impedance. The MP9989 controls V_{DS} as it drops to 40mV while the current continues to drop (see Figure 5). At this point, the MOSFET tube enters a semi-on state and the gate voltage is low.

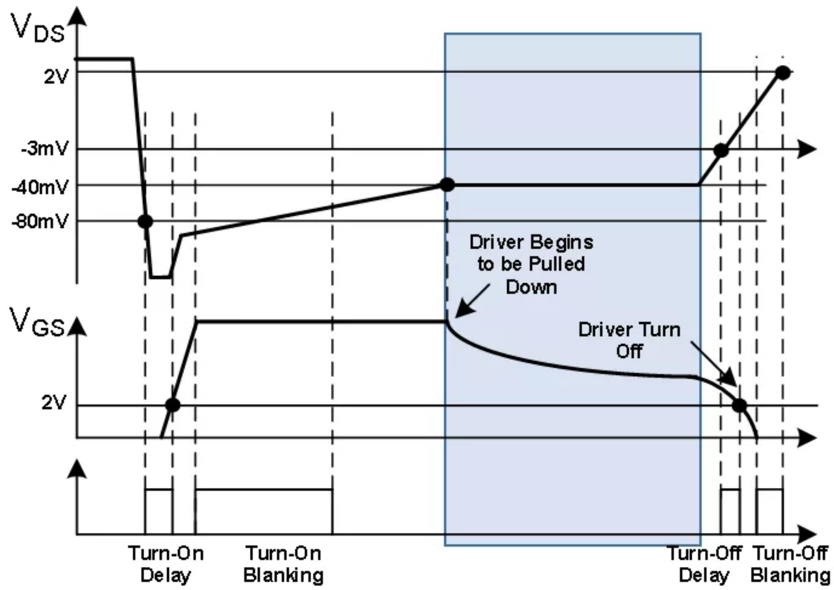


Figure 5: Dynamic Control of the MP9989's V_{DS} Drop to 40mV

When the reactive edge's MOSFET tube is open at the next duty cycle, the secondary MOSFET's tube gate can be quickly switched off from the previously lower voltage level. This ensures reliable operation. With the addition of quick shutdown technology, MPS synchronous rectifier products can support a 600kHz switching frequency (f_{SW}) and adapt to CCM, DCM, quasi-resonant, active clamp, and other reflux applications. These products include the MP9989 and MP6908A.

The MP9989 provides the following features:

- Integrated 100V/10mΩ MOSFET
- No need for auxiliary winding for high-side or low-side rectification
- Wide output voltage (V_{OUT}) range down to 0V
- Ringing detection to prevent false turn-on during DCM
- 110μA quiescent current (I_Q)
- Supports DCM, CCM, and quasi-resonant operations

Figure 6 shows a typical application for the MP9989.

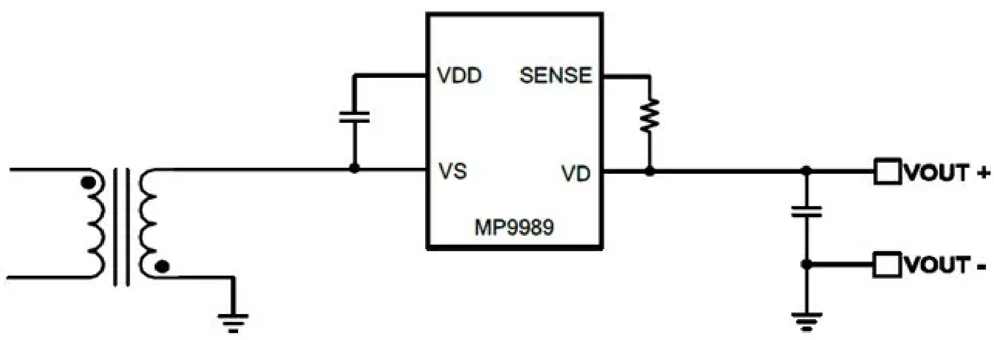


Figure 6: Typical Application Diagram of the MP9989

The MP6908A provides the following features:

- Supports up to 600kHz f_{SW}
- 30ns fast turn-off and turn-on delay
- No need for auxiliary winding for high-side or low-side rectification
- Wide V_{OUT} range down to 0V
- Ringing detection prevents a false turn on during DCM
- ~100µA quiescent current
- Supports DCM, CCM, and quasi-resonant operations for an active-clamp flyback
- Available in a TSOT23-6 package

Figure 7 shows a typical application for the MP6908A.

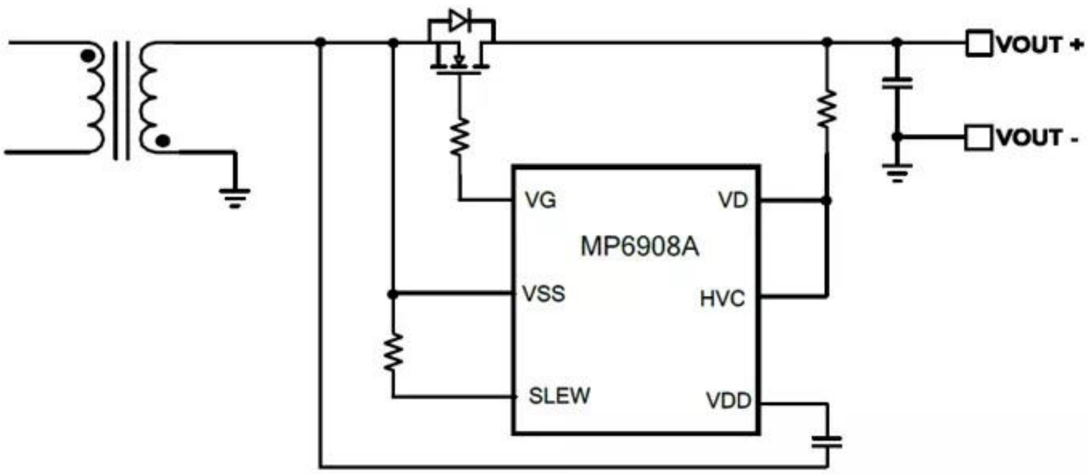


Figure 7: Typical Application Diagram of the MP6908A

Conclusion

This article reviewed strategic considerations to help time when a secondary-side synchronous rectifier opens and shuts down. It also observed the effectiveness of quick shutdown technology with the MP9989. Based on the information from this article, secondary-side synchronous rectifier solutions using a MOSFET tube are able to overcome the major challenges with standard rectifier solutions to create ultra-small, fast charge solutions.