What They Don't Teach about Synchronous Rectifiers in School – Selected Topics from Real Designs

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In recent years, global regulatory agencies have proposed efficiency standards to further improve global energy savings. It has become mandatory for manufacturers to improve the efficiency of existing standalone power supply products to meet DoE Level VI in order to sell them to the US market. Additionally, manufacturers are also expected to design products under other energy specifications, such as EU CoC V5Tier2 specs.

To push for higher efficiency in AC/DC adapters, many have found that switching a flyback output Schottky diode to a synchronous rectifier (SR) controller with a MOSFET generally saves efficiency by 2~3% or more. Some have also found that using SRs help save diode heatsink and assembly cost, designers can also use a cheaper primary MOSFET or thinner output cables to save cost and still meet the target efficiency.

While this article does not intend to cover all aspects of SR design, it does present a few selected topics related to a few practical concerns in engineers' real lives.

SR at Continuous Conduction Mode (CCM)

In Figure 1, a flyback SR controller is used to drive a MOSFET switch in an AC/DC adaptor. Here, the flyback controller may operate at critical conduction mode (CrM), continuous conduction mode (CCM), or discontinuous conduction mode (DCM).

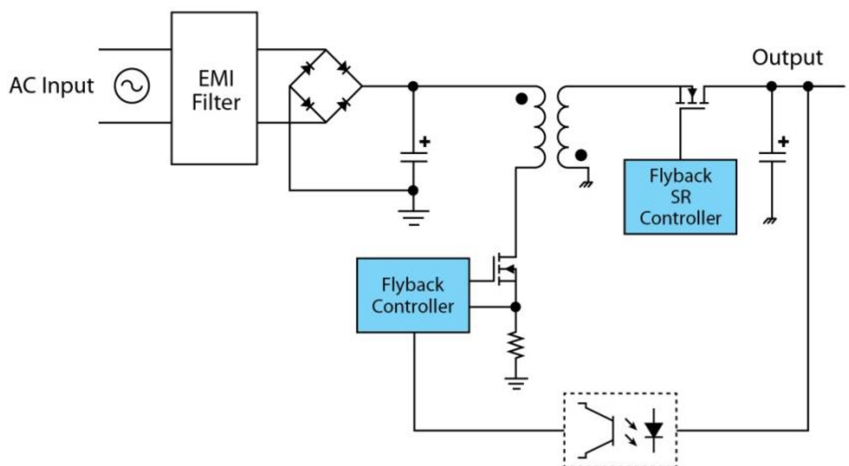

Figure 1: Typical Block Diagram for a Flyback Power Supply Used in Fast Chargers

When adaptors runs at CCM mode at start-up or full load, the current in the SR switch is designed to avoid falling to zero when the primary switch tries to turn on. Therefore, it is critical to turn off the SR very quickly to prevent a shoot-through from the primary to secondary side, which results in high spikes and potential damage. MPS's solution is to adjust the SR switch V_G to keep the MOSFET's V_{DS} constant. As the current drops during CCM, the driver's V_G also drops, so the MOSFET is running in linear mode (see Figure 2). Therefore, when the voltage finally reverses, the driver turns off very quickly at a low V_G to ensure safe CCM operation. This is a robust control method, as it is independent of the line input condition. Additionally, the body diode conduction time is minimized to ensure optimum efficiency. MPS's SR controllers are designed not only to support CCM, but DCM and CrM as well.

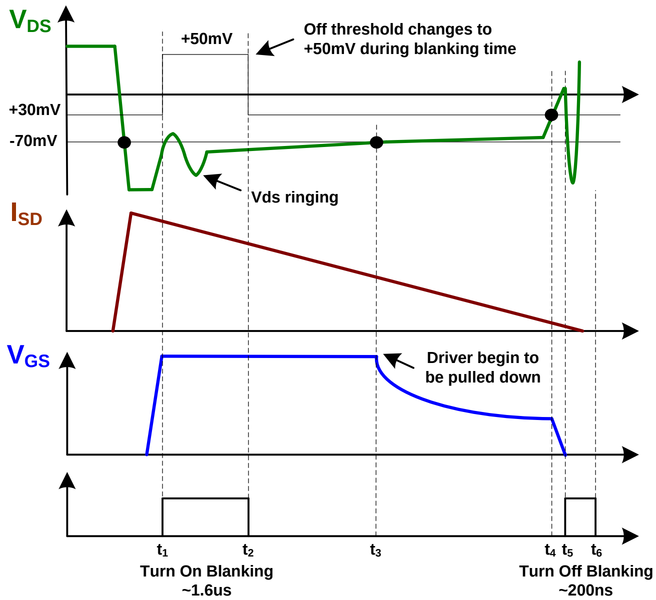

Figure 2: MPS SR Controller Operation Principles

For a detailed explanation of MPS' CCM-compatible SR operation and design tips, please refer to the AN077 application note [1].

MOSFET Package Inductance Influence at CCM and CrM

There is always some ramp up/down time at the secondary current switching decided by the input/output, transformer turns ratio, and inductance. The MOSFET package inductance also affects the secondary current turn-off.

As the secondary current starts to change polarity and turn off (t1 in Figure 4), the MOSFET package inductance (Ls) causes an instantaneous voltage on the sensed Vds, as shown in Equation (1) and Equation (2):

$$V_{DS} = -I_{DS} \cdot r_{DS(ON)} + V_{LK} \quad (1)$$

$$V_{LK} = L_S \cdot \frac{dI}{dt}, \frac{dI}{dt} = \frac{Vd}{Ls}, Vd = Vout + Vin_{dc}/n \quad (2)$$

Where Vin_{dc} is the input average DC, n is the transformer turns ratio, and Ls is the leakage inductance.

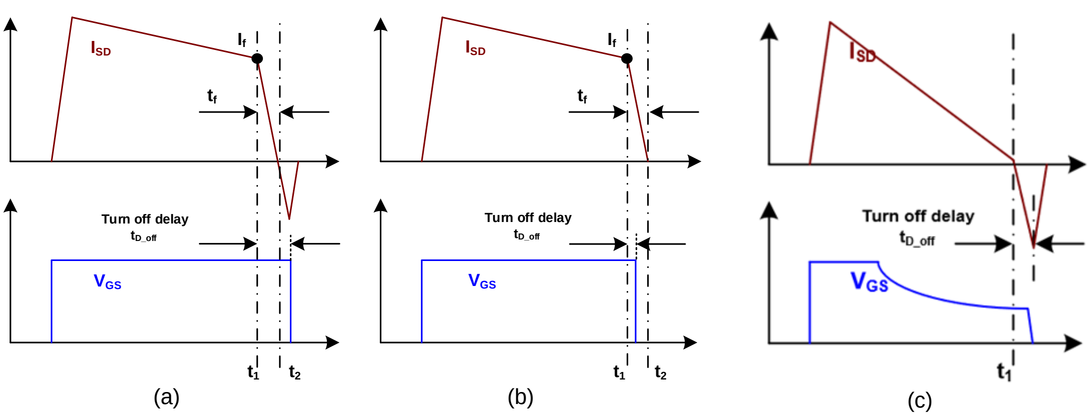

Figure 3: Various Turn-Off Waveforms when Affected by Package Inductance

For MOSFETs in TO220 packages, the package inductance can be as high as 6.4nH at 100kHz, and Vlk can be as high as a few hundred mV, hitting the SR controller turn-off threshold and causing the SR controller to turn the gate off (starting from t1). Since t1 is an early turn-off time, the package inductance is helpful for preventing shoot-through, especially in deep CCM condition.

For various circuit designs, we may see different turn-off waveforms under CCM (see Figure 3a and Figure 3b). For Figure 3a, the current drops to zero, but the SR is not completely turned off. Therefore, cross conduction may occur and reflects in reverse current. For Figure 3b, the SR is able to turn off just before the secondary current turns to zero (t2). This is the optimal design. More importantly, Figure 3c shows that in CrM, the SR controller turns off when the secondary current is almost zero, meaning there is always a reverse current of dI/dt*Toff.

When a MOSFET has much less package inductance (such as in QFN or SOIC), the SR turns off the gate at a later time when the MOSFET current is falling lower. Even with a lowered Vg under Vds regulation control, the reverse current is still higher than a MOSFET with a higher package inductance. This is independent of the Vds control introduced in Section 1.

Some improvement options are listed below and can be combined in one design.

- Choose SR MOSFETs with very low Qg (to speed up turn-off).
- Add an RC snubber across the SR MOSFET (to absorb the reverse spike).
- Use SR controllers with high turn-off current
- Increase transformer leakage inductance to slow down the secondary current dI/dt at turn-off (at tradeoff of higher primary MOSFET voltage spike) or slow down the turn-on of the primary MOSFET (at small efficiency tradeoff)
- Use a SR controller with a higher regulated voltage (70mV in Figure 2 using the MP6902). With a higher regulated Vds, Vg can drop fairly low before turning off, resulting in a faster turn-off.

Ringing – Good and Bad

When MOSFETs turns on and off, there is always some ringing caused by stray inductance in the layout, system, component parasitic capacitances, etc. Failure to accommodate the influence caused by ringing may lower the efficiency and even cause fatal problems.

An example of a ringing-induced issue is shown in Figure 4. As the secondary current falls to zero, the primary switch Vds has resonance between the transformer main inductance and MOSFET Cds [2], which is reflected to the secondary side. Normally, the valley of this resonance should not touch the ground level, but sometimes the resonance valley may drop low enough to reach the SR turn-on threshold. This can be caused by factors such as the reverse recovery of the diode in the primary-side RCD snubber.

As the slew rate of this Vds resonance is always much lower than the real turn-off slew rate (thanks to large main inductance), MPS MP6908 uses a unique slew rate programming pin to help decide when is the real turn off, and when is the normal Vds resonance (see Figure 4).

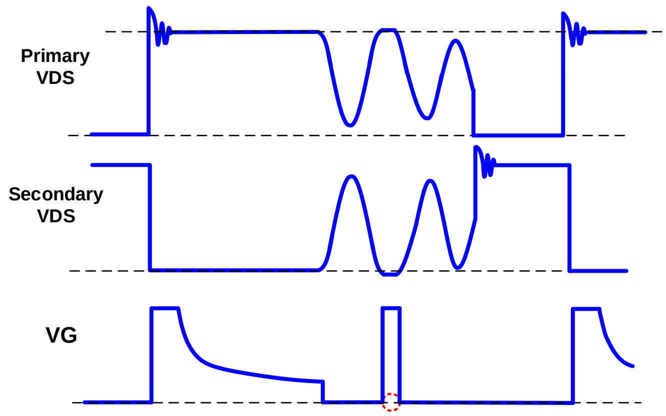

Figure 4: SR Waveform with Potentially False Turn-On during Demagnetizing Ringing

The Need for Real Drop-In Replacement of Schottky Diodes

Although the advantage of SR is well-accepted, changing an existing design from using Schottky diode to SR drivers plus an SR MOSFET still involves adding quite a few components to the BOM, redoing many qualifications, and so on.

An alternative solution is to integrate the SR MOSFET inside the SR driver IC, creating a co-pack and an entirely new design with minimal BOM change (see Figure 5). This solution is called an ideal diode.

The benefits of MPS's new ideal diodes include:

- Minimal BOM and board space.
- Drop-in replacement of Schottky diodes without auxiliary winding at high or low side.
- Optimized integrated gate driver.
- Optimized MOSFET for different power levels and voltage ratings.
- Flexible SMT and thru-hole package options

Why is the MPS MP6908 a Suitable Option for Practical SR Control Designs?

The MP6908 is the latest SR control IC from MPS. There will also be a series of ideal diodes created based on the MP6908 controller. Some key features for this controller IC include:

- No need for auxiliary winding for high-side or low-side rectification.
- Supports DCM, quasi-resonant, and CCM operations.
- Supports a wide output range down to 0V (even at an output short circuit, the SR is kept powered, and MOSFET body diode never conducts to the short-circuit current).
- Ringing detection prevents a false turn-on.
- Superfast 15ns propagation delay and 30ns turn-off delay.

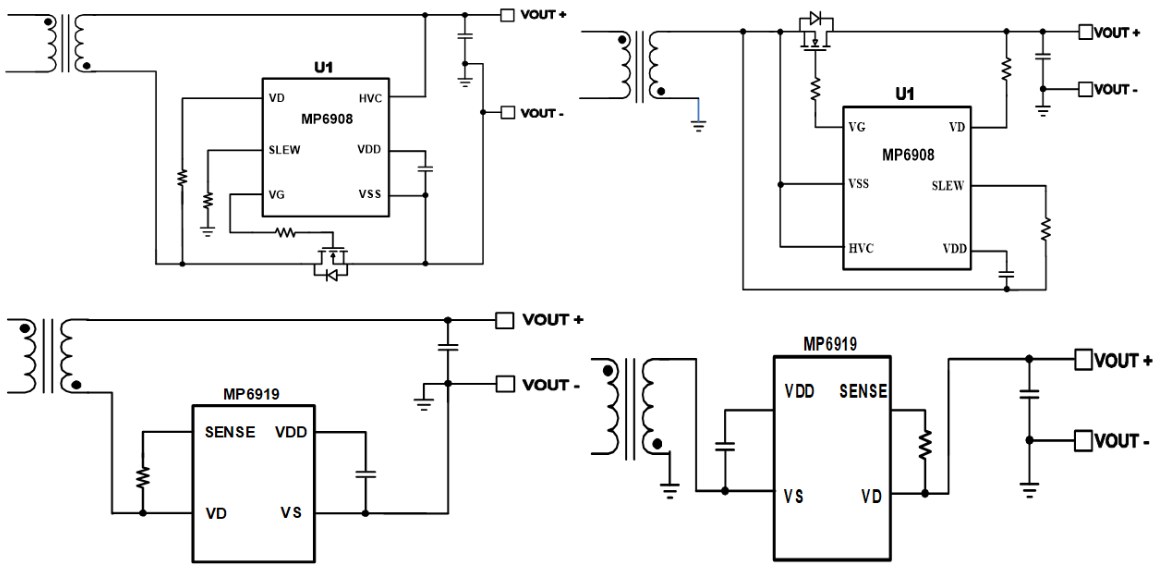

Figure 5: MP6908 Controller and Ideal Diode Application Circuit on Low Side and High Side

Summary

This article introduced some topics related to real-life engineering situations in synchronous rectifier (SR) designs. By understanding more about end applications, MPS is able to define and create better SR control ICs.

For more detailed SR controller and other AC/DC IC information from MPS, please visit www.monolithicpower.com or contact your local MPS sales office and FAE for consultation.

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[1] MPS MP6902 Application note: http://www.monolithicpower.com/pub/media/document/AN077_r1.0.pdf

[2] https://www.fairchildsemi.com/application-notes/AN/AN-4147.pdf

