Synchronous Rectification in High-Performance Power Converter Design
Power converters are becoming increasingly commonplace in the electrical industry. Product manufacturers and suppliers of electrical equipment are demanding ever-increasing functionality (i.e., lower input and output voltages, higher currents, faster transient response) from their power supply systems.

To meet these demands, switching power supply designers in the late 1990s began adopting Synchronous Rectification (SR)—the use of MOSFETs to achieve the rectification function typically performed by diodes. SR improves efficiency, thermal performance, power density, manufacturability, and reliability, and decreases the overall system cost of power supply systems. This article will examine the advantages of SR and discuss the challenges encountered in its implementation.
1.5A, 36V SIMPLE SWITCHER® Synchronous Step-Down Regulator

Constant-On-Time (COT) LM3100 Regulator Needs No External Compensation and Provides Stability with Ceramic Capacitors

LM3100 Features
- Synchronous conversion for efficient operation below 3.3 V_{OUT}
- COT architecture provides lightning-fast transient response
- Stable with ceramic capacitors
- Near-constant frequency operation from unregulated supplies
- No external compensation reduces external component count
- Frequency adjustable up to 1 MHz
- Available in TSSOP-20 packaging

Ideal for use in embedded systems, industrial controls, automotive telematics and body electronics, point-of-load regulators, storage systems, and broadband infrastructure

For FREE samples, datasheets, and more information, visit www.national.com/pf/LM/LM3100.html
**Drawbacks of Diode Rectification**

Nonsynchronous and synchronous buck converters are shown in *Figure 1*. A nonsynchronous buck converter uses a FET and Schottky diode as its switches (*Figure 1a*). When the FET turns on, energy is delivered to the output inductor and the load. When the FET turns off, the current in the inductor commutates to the Schottky diode. Provided the load current is higher than half the ripple current of the output inductor, the converter operates in the continuous conduction mode.

The Schottky diode is selected by its forward voltage drop and reverse leakage current characteristics. But as output voltages drop, the diode's forward voltage is more significant which reduces the converter's efficiency. Physical limitations prevent the forward voltage drop of diodes from being reduced below approximately 0.3V.

In contrast, the on resistance, $R_{DSON}$, of MOSFETs can be lowered, either by increasing the size of the die or by paralleling discrete devices. Consequently, a MOSFET used in place of a diode can have a significantly smaller voltage drop at a given current than the diode.

This makes SR attractive, especially in applications sensitive to efficiency, converter size, and thermal performance, such as portable or handheld devices. MOSFET manufacturers are constantly introducing new MOSFET technologies that have lower $R_{DSON}$ and total gate charge, $(Q_g)$, which makes it easier to implement SR in power converter design.

**What is Synchronous Rectification?**

In the synchronous buck converter, for example, the efficiency is increased by replacing the Schottky diode with a low side MOSFET (*Figure 1b*). The two MOSFETs must be driven in a complimentary manner with a small dead time between their conduction intervals to avoid shoot–through. The synchronous FET operates in the third quadrant, because the current flows from the source to the drain. In contrast to its nonsynchronous counterpart converter, the synchronous buck converter always operates in continuous conduction, even down to no load.

During the dead time periods, the inductor current flows through the lower FET’s body diode. This body diode usually has a very slow reverse recovery characteristic that can adversely affect the converter’s efficiency. An external Schottky diode can be placed in parallel with the low-side FET to shunt the body diode and prevent it from affecting the converter's performance. The added Schottky can have a much lower current rating than the diode in a nonsynchronous buck converter because it only conducts during the small dead time (which is typically less than a few percent of the switching cycle) when both FETs are off.

**Benefits of Synchronous Rectification**

The advantages of using SR in high-performance, high-power converters include better efficiency, lower power dissipation, better thermal performance, lower profile, increased quality, improved manufacturing yields though automated assembly processes (higher reliability), and inherently optimal current sharing when synchronous FETs are paralleled.

As mentioned above, a number of MOSFETs can be paralleled to handle higher output currents. Because the effective $R_{DSON}$ in this case is inversely proportional to the number of paralleled devices, conduction losses are reduced. Also, the $R_{DSON}$ has a positive temperature coefficient so the FETs will automatically tend to share current equally,
High-Performance, Half-Bridge Controller-Driver for Compact, Efficient Converters

Highly Integrated LM5035 Half-Bridge Controller-Driver Maximizes Efficiency and Power Density

LM5035 Typical Application Circuit

LM5035 Features

- 105V / 2A Half-bridge gate drivers
- Synchronous rectifier control outputs with programmable delays
- Oscillator synchronization (patent pending)
- Programmable line under-voltage lockout
- Line over-voltage protection
- Versatile dual mode over-current protection with hiccup delay timer
- Direct opto-coupler interface

Ideal for use in telecommunications and data communications systems, industrial power supplies, distributed power systems, and consumer electronics

For FREE samples, datasheets, and more information, visit
Synchronous Rectification in High Performance Power Converter Design

facilitating optimal thermal distribution among the SR devices. This improves the ability to remove heat from the components and the PCB, directly improving the thermal performance of the design. Other potential benefits from SR include smaller form factors, open frame configurations, lower profiles, higher ambient operating temperatures, and higher power densities.

Design Trade-Offs in Synchronous Rectified Converters

In an effort to minimize the size of the converter and decrease output ripple voltage for low-voltage applications, designers often increase the switching frequency to reduce the size of the output inductor and capacitor. If multiple FETs are paralleled, this increase in frequency can also increase gate drive and switching losses.

Design trade-offs must be made on a per-application basis. For example, in a high input voltage, low output voltage synchronous buck converter, since the operating conditions are such that the high-side FET has a significantly lower RMS current than the low-side FET, the high-side FET should be chosen with less $Q_G$ and higher $R_{DSON}$. It is more critical to lower switching losses for this device than conduction losses. Conversely, the low-side FET carries more RMS current so its $R_{DSON}$ should be as low possible.

Selecting controllers with stronger gate drivers in synchronous converters reduces switching losses by minimizing the time the FETs take to switch. However, faster rise and fall times generate high frequency noise that can lead to system noise and EMI compliance issues.

Driving Synchronous Rectifiers in Isolated Topologies

Power converters utilizing isolated topologies are used in systems requiring galvanic isolation among system grounds. Such systems include distributed bus architectures, Power-over-Ethernet systems, and wireless basestations. (Figure 2).

Using SR in isolated converters can improve their performance significantly. All isolated topologies: forward, flyback, push-pull, half and full bridge (current and voltage fed), can be synchronously rectified. However, providing adequate and well-timed gate drive signals to the SRs in each topology presents its own set of challenges.

There are basically two types of drive schemes for FETs on the secondary stage of isolated topologies: self-driven gate signals taken directly from the secondary transformer windings, and control-driven gate signals derived from the PWM controller or some other primary referenced signal. For a given application several different implementations of these drives are possible. The designer should choose the simplest solution that also meets the performance requirements.

The self-driven scheme is the simplest, most straight forward SR drive scheme (Figure 3) and works well in topologies where the transformer
Synchronous Buck Controller with 1% Voltage Feedback Accuracy Across -40 to +125°C

National’s LM2747 Controller Provides Down Conversion to Output Voltages as Low as 0.6V

**LM2747 Features**

- Switching frequency from 50 kHz to 1 MHz
- Switching frequency synchronize range 250 kHz to 1 MHz
- Startup with a pre-biased output load
- Power stage input voltage from 1V to 14V
- Control stage input voltage from 3V to 6V
- Power Good flag and shutdown
- Output overvoltage and undervoltage detection
- Available in TSSOP-14 packaging

Ideal for use in cable modems, DSL and ADSL, laser and ink jet printers, low voltage power modules, DSP, ASIC, core, and portable computing

For FREE samples, datasheets, and more information, visit www.national.com/pf/LM/LM2747.html
Synchronous Rectification in High Performance Power Converter Design

Figure 3. Self-driven synchronous rectification output stage

The main problem with self-driven SRs in topologies where the transformer voltage periodically goes to and stays at zero is that there is no signal to drive the gates of the SR FETs during these intervals. During these times, body diodes of the SRs conduct the load current, thus increasing power losses. Lower output voltages may require additional windings to increase the normal operating voltage applied to the SR FET gates to an adequate level.

Because the secondary winding voltage varies with input line voltage, the voltage on the SR gates will vary. The efficiency is impacted because $R_{DS,ON}$ depends on the gate-source voltage ($V_{GS}$). In wide input voltage range converters this $R_{DS,ON}$ variation can be as high as 2:1.

There are alternate gate drive techniques that can be employed for transformer-based topologies. In low-voltage, high-current applications, these drive techniques both reduce losses associated with the dead time intervals and produce nearly constant-amplitude gate drive pulses so efficiency is not adversely impacted by varying line voltages.

Control-driven schemes tend to solve the limitations of self-driven methods. However, they are typically more complex and expensive (Figure 4). Depending on how parts-intensive the self-driven scheme is, a control-driven scheme may actually be the better alternative. The control signals used to drive the SR FETs can be derived from a primary or secondary side referenced controller.

Conclusion

Synchronous switching power converters give better performance than nonsynchronous converters in low output voltage, high output current systems applications. Ensuring the proper timing of the gate drive signals for the SRs is an important task that designers must address to maximize converter performance.

Acknowledgement: The author would like to thank Dr. Haachita Mwee for his feedback on the article.
WEBENCH® Online Design Environment
Our design and prototyping environment simplifies and expedites the entire design process.
1. Choose a part
2. Create a design
3. Analyze a power supply design
   – Perform electrical simulation
   – Simulate thermal behavior
4. Build it
   – Receive your custom prototype kit 24 hours later
webench.national.com

Reference Designs
National’s power reference design library provides a comprehensive library of practical reference designs to speed system design and time-to-market.
www.national.com/refdesigns

Don't miss a single issue!
Subscribe now to receive email alerts when new issues of Power Designer are available:
power.national.com/designer
Read our Signal Path Designer™ online today at:
signalpath.national.com/designer

National Semiconductor
2900 Semiconductor Drive
PO Box 58090
Santa Clara, CA 95052
1 800 272 9959
Visit our website at: power.national.com
For more information, send email to: new.feedback@nsc.com

©2006, National Semiconductor Corporation. National Semiconductor, WEBENCH, SIMPLE SWITCHER, and Analog University are registered trademarks, and Signal Path Designer is a service mark of National Semiconductor. All other brand or product names are trademarks or registered trademarks of their respective holders. All rights reserved.
IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI’s standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for the products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal and regulatory requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use. TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal and regulatory requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

<table>
<thead>
<tr>
<th>Products</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio</td>
<td>Communications and Telecom</td>
</tr>
<tr>
<td>Amplifiers</td>
<td>Computers and Peripherals</td>
</tr>
<tr>
<td>Data Converters</td>
<td>Consumer Electronics</td>
</tr>
<tr>
<td>DLP® Products</td>
<td>Energy and Lighting</td>
</tr>
<tr>
<td>DSP</td>
<td>Industrial</td>
</tr>
<tr>
<td>Clocks and Timers</td>
<td>Medical</td>
</tr>
<tr>
<td>Interface</td>
<td>Security</td>
</tr>
<tr>
<td>Logic</td>
<td>Space, Avionics and Defense</td>
</tr>
<tr>
<td>Power Mgmt</td>
<td>Transportation and Automotive</td>
</tr>
<tr>
<td>Microcontrollers</td>
<td>Video and Imaging</td>
</tr>
<tr>
<td>Microcontrollers</td>
<td>Video and Imaging</td>
</tr>
<tr>
<td>RFID</td>
<td></td>
</tr>
<tr>
<td>OMAP Mobile Processors</td>
<td></td>
</tr>
<tr>
<td>Wireless Connectivity</td>
<td></td>
</tr>
</tbody>
</table>

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2011, Texas Instruments Incorporated