

Efficient and Reliable Drive for Synchronous MOSFET Rectifiers

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Introduction

Many telecom and industrial applications require low voltage, high efficiency isolated power converters. Typical output voltages in these applications are between 1.8V and 12V, thus making a synchronous forward converter a good choice.

Synchronous forward converters require a pair of MOSFETs that rectify the output from the power transformer. The synchronous MOSFET rectifiers can be self-driven, transformer driven, or driven by an integrated MOSFET driver. The most efficient solution is to use a MOSFET driver, like the LTC3900, that is synchronized to the primary PWM controller. The LTC3900 has other advantages, such as protection features not found in other drive methods.

Synchronous Telecom Bus Converter

Figure 1 shows an example of a synchronous forward converter that generates an isolated, semi-regulated 12V output, which in turn is used to

generate all of the non-isolated low voltage rails on a system board. The converter in Figure 1 regulates its output by sensing the input voltage and adjusting its pulse width in order to maintain constant $V_{IN} \cdot T_{ON}$ product. The constant $V_{IN} \cdot T_{ON}$ product results in a constant output voltage. The only variations in output voltage in this type of circuit would be due to circuit parasitic elements like winding resistance, transformer coupling, MOSFET resistance and ramp errors.

The $V_{IN} \cdot T_{ON}$ product is generated by the RAMP pin of the LTC3723 in Figure 1. The input voltage develops current in resistor R1 that charges capacitor C1. When the voltage across capacitor C1 reaches the threshold of Ramp pin, the output pulse is terminated. Figure 2 shows the dependency of output voltage on input voltage and output current. The output voltage variation is well within the requirements for a bus converter. The specification for bus converter allows the output voltage to be proportional

to the input voltage. In other words, there is no requirement for input voltage regulation. This has also led to the term DC-Transformer to be used for bus-converters.

Efficiency is Everything

The main problem with using a bus converter is keeping the size small while processing all of the power required by the system board. Therefore, it is critical to obtain the highest efficiency in order to keep the power density high. For example, 90% efficient converter generating 100W of output power dissipates 11W of heat, which makes it difficult to keep the circuit small. In comparison, a 95% converter dissipates only 5.25W, which simplifies thermal management, and thus shrinks the circuit size.

The only way to obtain such high efficiencies is with synchronous output rectifiers, as shown in Figure 1. All of the switching and power handling components must be optimized in order to achieve the highest possible

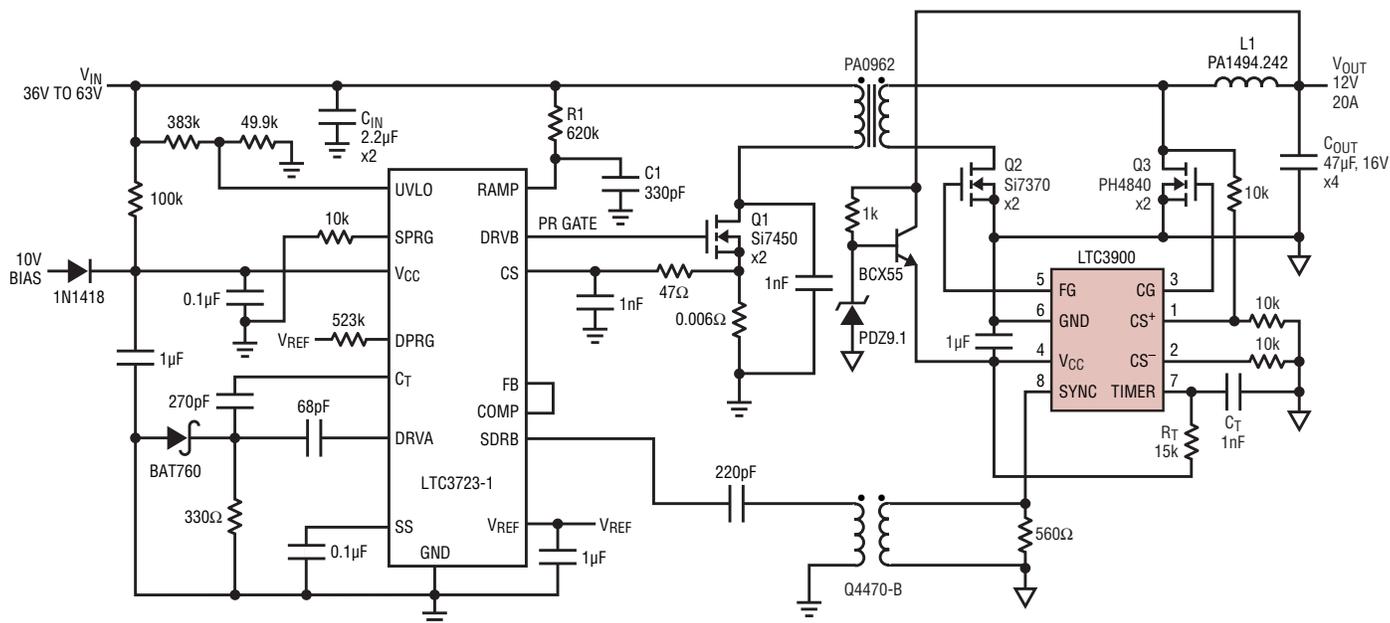


Figure 1. This highly efficient bus converter provides 12V at 20A of isolated, semi-regulated power. The 12V bus can be used by boards to provide low voltage rails via simple, non-isolated converter circuits.

efficiency. Once all of the components have been optimized, the only thing remaining is to provide the converter with precise timing of the synchronous output rectifiers. The LTC3900 synchronous output rectifier controller is not a typical controller. It provides critical timing and protection functions that make the converter in Figure 1 highly reliable and efficient. Efficiency is as high as 94.5% as shown in Figure 3.

LTC3900 Drive and Protection Features

MOSFET switching timing in the circuit of Figure 1 is critical in order to achieve high efficiency. The LTC3723-2 PWM controller generates the appropriate timing delay between the main MOSFET DRVB and synchronous MOSFET SDRB outputs. The synchronous MOSFET driver output, DRVB, is pulse coupled through a small transformer T2. Pulse coupling of the synchronizing signal has the benefit of not requiring the DC levels to be restored on the secondary side of transformer T2. The LTC3900 sync input was designed to accept symmetrical bipolar pulses and to convert these narrow pulses back into appropriate square wave pulses for driving the output synchronous MOSFETs. Another advantage of using pulse coupling is that the coupling transformer can be very small even at low switching frequencies.

One of the problems with driving synchronous MOSFETs has always

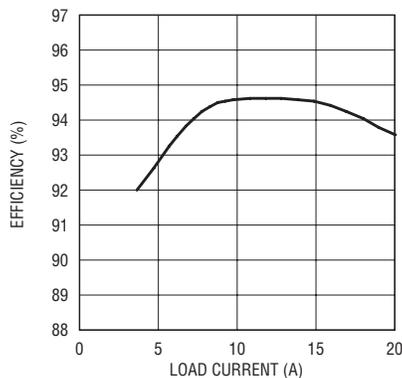


Figure 3. The efficiency of 12V converter is better than 94% over a wide range of loads. High efficiency makes it possible to fit this converter into 35mm by 55mm of space, since thermal management is simplified.

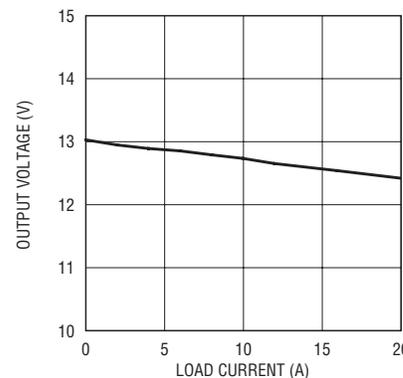
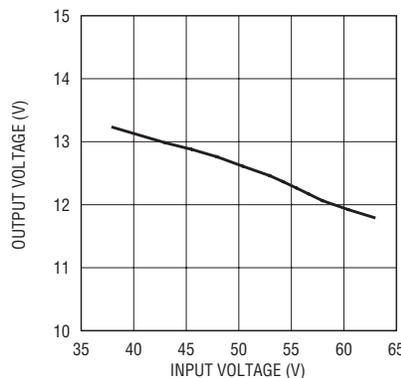


Figure 2. The output voltage of the circuit in Figure 1 depends on input voltage and output load. This is a semi-regulated bus supply, intended as input for downstream converters. Even though the output is inexact, its voltage variance remains well within the limits for a bus supply.

been the last pulse that comes from the primary PWM controller following converter shut-down. Depending on the primary controller, the last edge of last synchronizing pulse may leave one of the output MOSFETs turned ON. In that case, the output capacitor may drive a huge reverse current through the output inductor and cause a failure of one of the MOSFETs.

The MOSFET driver circuit LTC3900 has two functions that protect synchronous MOSFETs following PWM shut-down. Figure 4 shows a condition where after the last PWM pulse, the output inductor current has reversed to -25A. The LTC3900 in this case was programmed to turn the forward rectifier MOSFET OFF in order to prevent further reverse current increase. Otherwise, the current could increase far beyond MOSFETs ratings and thus result in MOSFET failure.

As can be seen in Figure 4, the pulse width of the last forward gate pulse can be quite long. The duration of this pulse can be programmed by the Timer function of the LTC3900. The Timer pulse duration doesn't have to be any longer than the normal switching period of primary PWM controller. However, the Timer pulse should not be any shorter than the longest required ON time of the synchronous MOSFETs. If the Timer pulse is too short, the synchronous MOSFET will be turned off too soon and the MOSFET's body diode will have to conduct which will result in far greater power dissipation. A better Timer pulse duration than the one shown in Figure 4 is shown in Figure 5. The Timer dura-

tion programmed in Figure 5 produces reverse current of only -10A, which is well within the ratings of synchronous MOSFET used in this application.

In addition to the Timer function, the LTC3900 also has a reverse current detector. The reverse current detector monitors catch MOSFET Q3 in Figure 1 and terminates the catch MOSFET conduction if current through the MOSFET reverses. In normal operation, the catch MOSFET current creates a negative drain-to-source voltage. If the inductor current reverses, the catch MOSFET drain-to-source voltage becomes positive. If the drain-to-source voltage exceeds a 21mV threshold (10.5mV at CS+

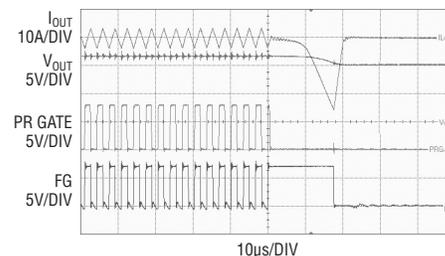


Figure 4. Output inductor reverse current following last PWM pulse keeps increasing until Q3 is turned off. A high reverse current can damage the MOSFET Q3.

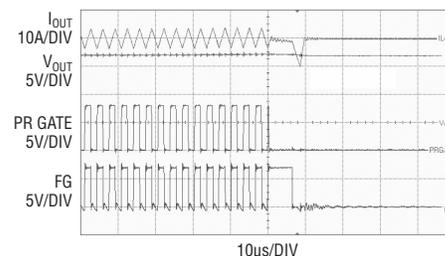


Figure 5. The reverse inductor current is reduced with a shorter TIMER period.

input), the catch MOSFET turns OFF. The 10.5mV current sense threshold of CS+ input is temperature dependent so it can follow the temperature variation of the MOSFET's $R_{DS(ON)}$, as long as it is mounted close to the MOSFET on the PC board. To calculate the amount of reverse current that turns

the catch MOSFET off, use $R_{DS(ON)}$ at room temperature with a 10.5mV current sense threshold. Just as with the Timer function, the catch MOSFET should not be turned off under normal conditions. Therefore, a catch MOSFET with sufficiently low $R_{DS(ON)}$

should be used or voltage divider on the CS+ pin can be added.

Conclusion

The LTC3900 MOSFET is a comprehensive solution for implementing robust, high efficiency, high performance synchronous converters. 

Smart Batteries, continued from page 6

LTC4100 including the SMBus accelerators except it is designed to work with two batteries (see Figure 5). Traditionally, dual battery systems are sequential-discharge systems designed to simply increase total battery run time. Dual-battery systems are increasingly used in parallel-discharge systems to satisfy current requirements beyond the capability of a sequential, battery 1 then battery 2 discharge priority system. The LTC1760 addresses the issue by allowing the safe parallel discharge of two batteries.

It also charges the batteries in parallel. A parallel-charge, parallel-discharge dual-battery system can reduce charge times and increase run times over an equivalent sequential system¹—see Figures 3 and 4.

The key to allowing the LTC1760 to safely control two batteries in parallel is the utilization of the ideal diode² concept where the power MOSFETs are driven to act like diodes as opposed to simple on-off switches.

It is no simple feat to safely juggle the charge and discharge state of multiple batteries and a DC input

power source. Supply continuity is paramount—changing from one power path to another should not interrupt power to the system. This daunting task has historically fallen to the host running custom application software. The LTC1760 avoids the need for complicated software development by operating in a *stand-alone* Level 3 Bus Master mode, thus precluding the need for host intervention. The LTC1760 polls each battery at an accelerated rate so that it can continuously optimize battery charging and PowerPath switching modes between two batteries and a wall adapter. It also has built in crises power management hardware to keep the power flowing even if the SMBus is jammed with traffic.

If there is a feature that will shorten charge times, lengthen run times or make the system more robust, it has been included in the LTC1760:

- Proprietary charge algorithms allow parallel charging even for two batteries of different chemistries or cell configuration.
- Level 3 capabilities allow the LTC1760 to implement a servo charge current and charge voltage system that eliminates hardware

related losses that would extend charge time (see Figure 7).

- A turbo-charge mode maximizes the charge current for the fastest battery charging possible.
- Support for full dual battery conditioning, another name for gas gauge calibration for less sophisticated gas gauges.

As sophisticated the LTC1760 is, it remains easy to use. There are only four key parameter choices to make. You can literally drop it into your system, throw some smart batteries and an AC adapter at it, and it will start working right away. A full schematic is shown in Figure 6 (Figure 5 shows a simplified schematic).

Conclusion

The LTC4100 offers a simple and reliable Smart Battery System implementation that uses a single battery. The LTC1760 represents perhaps the most comprehensive single chip dual battery system, providing more control, safety, and automatic crisis management compared to any other solution available today. Both parts offer minimal NRE effort needed to get up and running as a complete battery standalone charger system—no battery expertise required. They are also reduce solution cost, PCB space and part count. 

Notes

¹ For a more in depth description of parallel charge, parallel discharge systems, see *Linear Technology Magazine*, December 2001, page 12, "Monolithic Dual Battery Power Manager Increases Run Time and Decreases Charge Time".

² For more about ideal diodes, see *Linear Technology magazine*, December 2002, page 1, "Ideal Diode Controller Eliminates Energy Wasting Diodes in Power OR-ing Applications", or any materials describing the LTC4412.

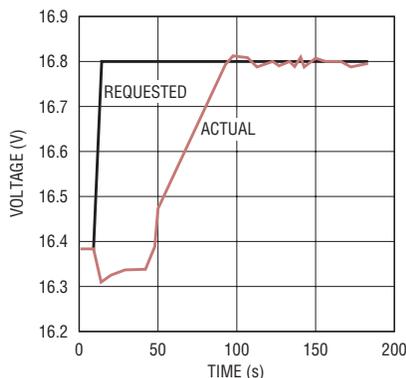
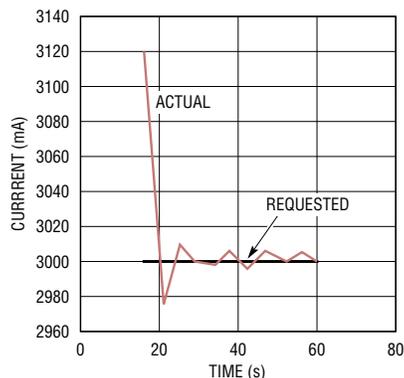


Figure 7. The LTC1760's servo charge current and voltage system eliminates hardware related inefficiencies, therefore decreasing charge times. This is only one of the many unique performance-enhancing features in the LT1760.