High-efficiency AC adapters for USB charging

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USB charging for electronic gadgets

Universal serial bus (USB) charging has become a common means for powering electronic gadgets. The AC power adapter/battery charger for many new consumer devices like smartphones, tablets, and e-readers is in the 5- to 25-W power range and presents a USB Standard-A receptacle. The adapter output voltage of 5 V has become the preferred choice for compatibility with PC/desktop-port charging and communication. The current dominant interface is via a standard (mini or Micro-B) USB cable or, in some cases, a nonstandard connector. With battery charging gaining consumer attention, the odd "wall wart" is transforming into a "cool," light, sleek, green charger. Beyond meeting standard regulatory requirements, original equipment manufacturers are pushing the performance envelope on adapter efficiency and no-load power, which is also known as vampire power. For example, leading manufacturers of mobile-phone chargers have agreed to a five-star (<30 mW of no-load power) charger-rating system. This makes it easy for consumers to compare and choose the most energy-efficient chargers.

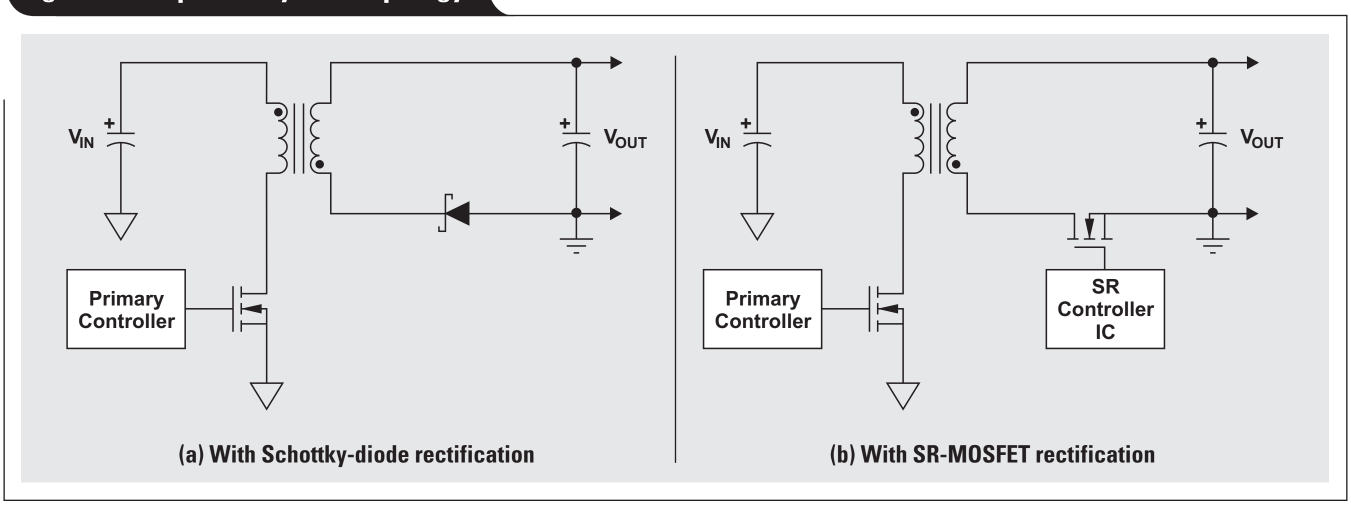
Recently, there has been much talk about standardizing the input to mobile phones and creating a universal charger to charge any cell phone. In 2006, China issued a new regulation aimed at standardizing the wall charger and its connecting cable. Similarly, the GSM Association (GSMA) is now leading the Universal Charging Solution adapter initiative for powering mobile phones with a micro USB connector. The common charger is required to provide 5 V ± 5%, a minimum of 850 mA, and <150 mW of no-load power. It must also comply with the USB Implementers Forum (USB-IF) Battery Charging Specification 1.1 (BC1.1).* Besides providing ease of use for consumers, the standardized charger could potentially eliminate a multitude of duplicate chargers. Additionally, AC adapters with multiple USB outlets offer consumers the convenience of charging multiple devices without the need for a dedicated charger for each gadget. Chargers with higher output current also allow the possibility of fast battery charging, a key advantage over standard USB 2.0 ports that are limited to 500 mA. The increasing demand for these improvements, along with the continued push towards adapter designs with a smaller form factor, makes thermal management in this "black box" a huge challenge for power-supply designers.

Power-supply architecture

For the power levels under consideration here, the flyback topology shown in Figure 1 is the preferred choice today due to its simplicity and low cost. The conduction loss on the secondary-side Schottky-diode rectifier (Figure 1a) becomes a limiting factor in achieving high-efficiency, compact adapter designs. For instance, in a typical 5-V/3-A adapter, the power loss in the diode rectifier alone at full load can be 30 to 40% of the total system losses (neglecting the compounding effect of secondary losses on increased primary-side losses). Implementing a synchronous rectifier (SR) for the output (Figure 1b) can increase the overall efficiency of the converter and, because much less heat is generated (fundamentally important in adapter designs), ease system thermal management.

*USB-IF BC1.2 extends the charging-current range from 1.5 A to 5 A.

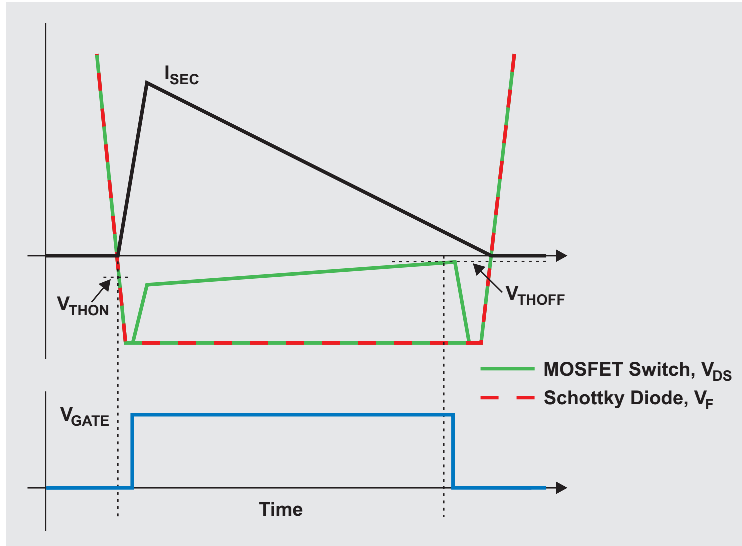
Figure 1. Simplified flyback topology



The conceptually simple change of adding an SR to the classic flyback topology can significantly reduce overall system power losses. The power level at which such a modification is practical has been decreasing with the rapid advancement in power MOSFET technology. Hence, synchronous rectification is now applicable to an ever-growing range of products. The lower power dissipation of an SR allows designers to take advantage of smaller components that have less heat sinking, thus increasing power density while lowering assembly costs, product size, and shipping weight.

Note that if the SR MOSFET is allowed to switch during no-load/standby conditions, the system power performance could be compromised. The SR-MOSFET switching losses, in addition to the quiescent power required by the SR controller IC, can be limiting factors in achieving the best possible system no-load performance.

Figure 2. Simplified flyback waveforms with Schottky-diode and SR-MOSFET output rectification

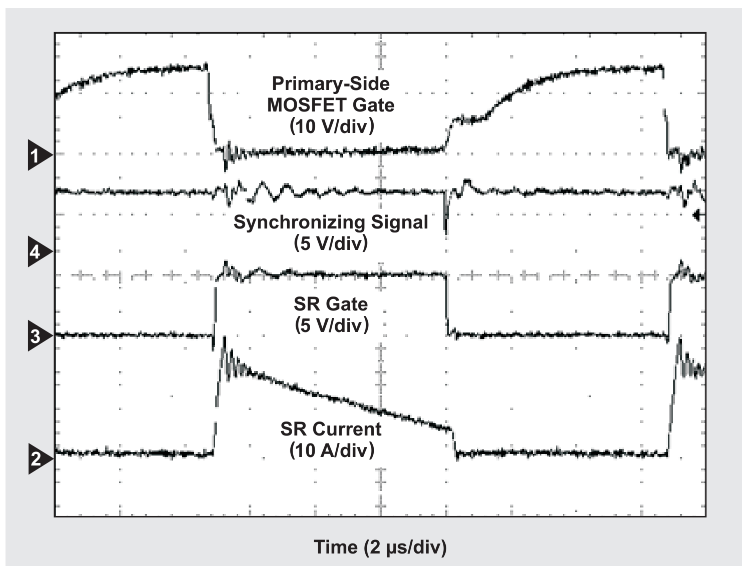


Green output rectification: Full load to no load

This article will now discuss how an IC such as the Texas Instruments (TI) UCC24610 Green Rectifier™ controller can simplify USB charger designs and enable high system efficiency across the full load range. Simplified system waveforms for a flyback converter with and without synchronous rectification are shown in Figure 2. The waveforms are the results of a control scheme that directly senses the MOSFET drain-to-source voltage (V_{DS}). This control method is widely adopted today instead of other implementation choices such as primary-side synchronization or synchronous control from a secondary-side current transformer. Having the SR controller's turn-off threshold (V_{THOFF}) as close as possible to zero in this control scheme allows maximum conduction time in the MOSFET channel.

Flyback converters can be designed to operate in different modes depending on the end-application requirements. For designs operating in continuous-conduction mode (CCM), the current in the transformer secondary does not fall to zero before the primary-side MOSFET is turned on, which results in a period of cross-conduction. When synchronous rectification is implemented in such converters, it is imperative that the SR MOSFET be turned off as soon as the primary-side switch turns on. This prevents reverse conduction and limits additional power losses and device stresses. Instead of waiting for the V_{THOFF} threshold detection, the synchronizing function in the Green Rectifier detects the primary-side turn-on transition and turns off the SR MOSFET. Figure 3 illustrates how the SR-gate turn-off transition is now controlled by a synchronizing signal from the primary side and not by V_{DS} sensing.

Figure 3. Typical CCM flyback waveforms with primary-side synchronization



As described earlier, implementing synchronous rectification could possibly compromise light-load efficiency and no-load power consumption. The major contributors to loss at light or no load are SR-MOSFET switching and SR controller-IC bias. The Green Rectifier overcomes these issues with (1) an automatic light-load-detection circuit that disables gate switching of the SR MOSFET when its conduction time falls below a certain threshold, and (2) an EN function to put the IC in sleep mode and disable quiescent power loss. The light-load-detection circuit compares the SR conduction time and the programmed minimum ON time (MOT) for every switching cycle. When the load decreases, the secondary conduction time becomes shorter than the MOT, and the next SR gate pulse is disabled. Further reduction in no-load power can be achieved by using the EN function of the controller IC. A simple averaging circuit on the MOSFET drain voltage can be used to put the IC in sleep mode at a no-load condition that limits the IC's bias-current consumption to 100 µA. An additional 10 mW of no-load power consumption can be saved with this approach. The last gasp in improving no-load performance is to add a low-current Schottky diode in parallel with the SR MOSFET.

As an example, a USB charger with a 3-A current rating was designed using two controller chipsets, TI's UCC28610 and UCC24610, for a tablet-PC end application. The reference design for this charger, the PMP4305, can be seen at the Web site listed at the end of this article. The UCC24610 is good for applications with a 5-V flyback switch-mode power supply and can operate within the specified USB voltage range of 4.75 to 5.25 V. Hence, this SR controller was biased directly from the converter output, eliminating the need for an auxiliary winding on the main power transformer. The controller also allowed external programming of two blanking timers to prevent SR false triggering from V_{DS} ringing sensed during the turn-on and turn-off transitions. Figure 4 shows typical power-stage waveforms of the PMP4305 at full load. The IC control scheme was not affected by the severe ringing on the V_{DS} signal at turn-on because the programmable MOT timer disabled the V_{THOFF} comparator during this period.

A comparison of the efficiency of SR-MOSFET versus Schottky-diode output rectification at 115- and 230-V AC line conditions is shown in Figure 5. Implementing synchronous rectification enables over 80% efficiency from full load down to about 25% of full load. Additionally, for this load range, an SR configuration can achieve a three- to five-point improvement in efficiency over Schottky-diode rectification.

Figure 4. Full-load waveforms from PMP4305

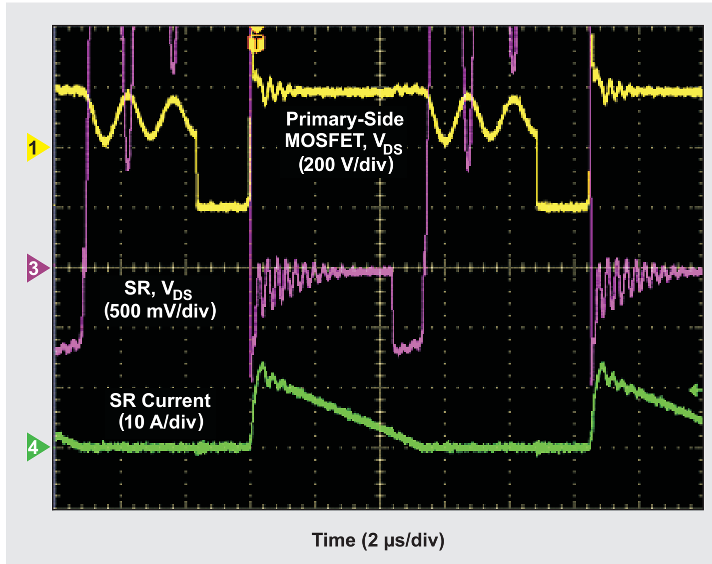
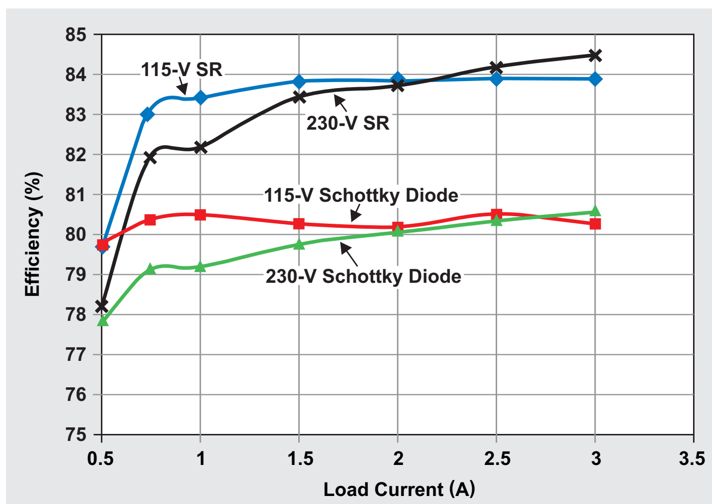


Figure 5. Comparison of system efficiency with Schottky diode versus synchronous rectifier (SR)



Conclusion

USB power charging for consumer devices is gaining traction. A universal standard for 10- to 25-W chargers with USB outlets that power multiple devices eliminates the need for a new wall charger with every new gadget purchase. High-efficiency AC/DC converters are needed to satisfy the push towards high-density, small-form-factor adapters. Devices like the UCC24610 Green Rectifier can help improve AC/DC converter efficiency and enable the high-density USB-charger designs.

Related Web sites

power.ti.com
www.ti.com/product/UCC24610
www.ti.com/product/UCC28610

Reference design for tablet-PC charger:
www.ti.com/tool/PMP4305

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