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Increase Boost Regulator Efficiency With Synchronous Rectification

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Boost power converters are the most common topology used for applications where the required output voltage is larger than the input voltage. While this topology is inherently very efficient, there is an often unexplored opportunity to increase the efficiency further. Synchronous rectification techniques are commonly applied in buck (stepdown) applications, but rarely used in boost (stepup) applications.

Shown in Fig. 1 is a conventional boost regulator application. Each cycle when the boost MOSFET switch (Q1) is closed, the voltage across the inductor (L1) is held at V_{IN}. The inductor current rises, storing energy in the core. The diode (D1) is reverse biased at a potential of V_{OUT}. When the boost MOSFET switch opens the diode conducts releasing energy to the output. The voltage across the boost MOSFET is: $V_{OUT} + V_{D1}$, where V_{D1} is the diode voltage drop. The power dissipated in the diode can be significant.

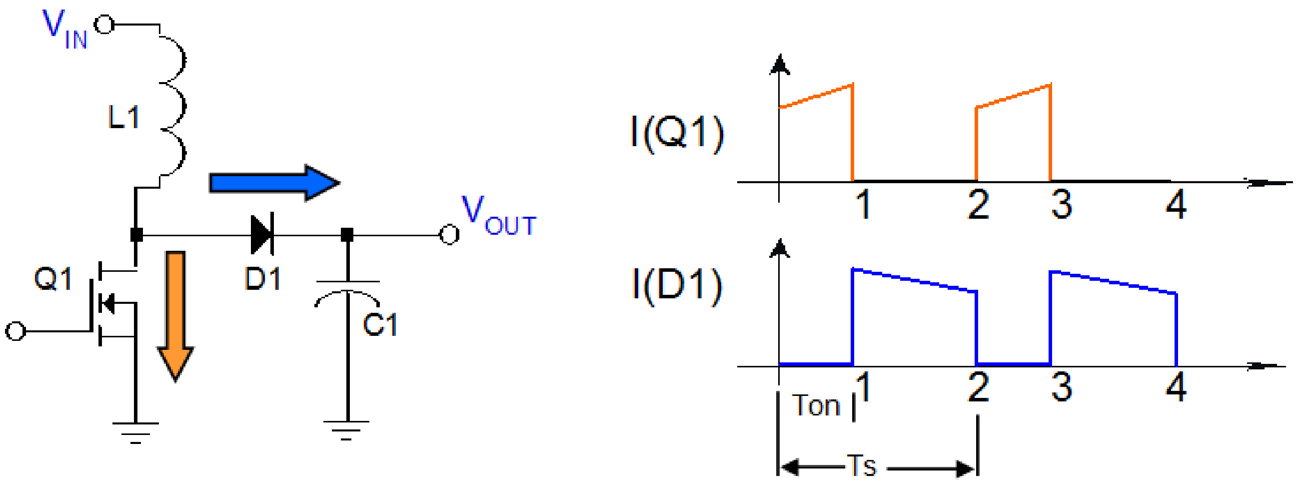

Fig. 1. Conventional boost regulator with diode rectification.

The basic transfer function of a boost regulator is:

$$V_{OUT} = V_{IN} \times \frac{1}{1-D}$$

Where D is the duty cycle of the boost MOSFET. For applications where the magnitude of the input and output voltages are very close, the duty cycle of the boost MOSFET is small, while the corresponding (1-D) duty cycle of the diode will be large. In these applications the diode is conducting for a large portion of the switching period and the diode losses are high. The first-order approximation of the power dissipation of the diode is:

$$P_{DIODE} = V_{D1} \times I_{IN} \times (1-D)$$

If the diode is replaced with a MOSFET, the first-order approximation of the power dissipation is:

$$P_{MOSFET} = R_{DS(ON)} \times I_{IN}^2 \times (1-D)$$

where $R_{DS(ON)}$ is the on-resistance of the MOSFET.

Shown in Fig. 2 is a schematic of a synchronous boost regulator. The diode has been replaced with a MOSFET to improve the conversion efficiency. The LM5025 (U2) is a popular voltage-mode PWM controller primarily intended for active clamp forward applications. The two outputs of this controller can be configured as a main PWM output and a compliment with adjustable dead-time between them. This configuration is well suited for the synchronous boost application.

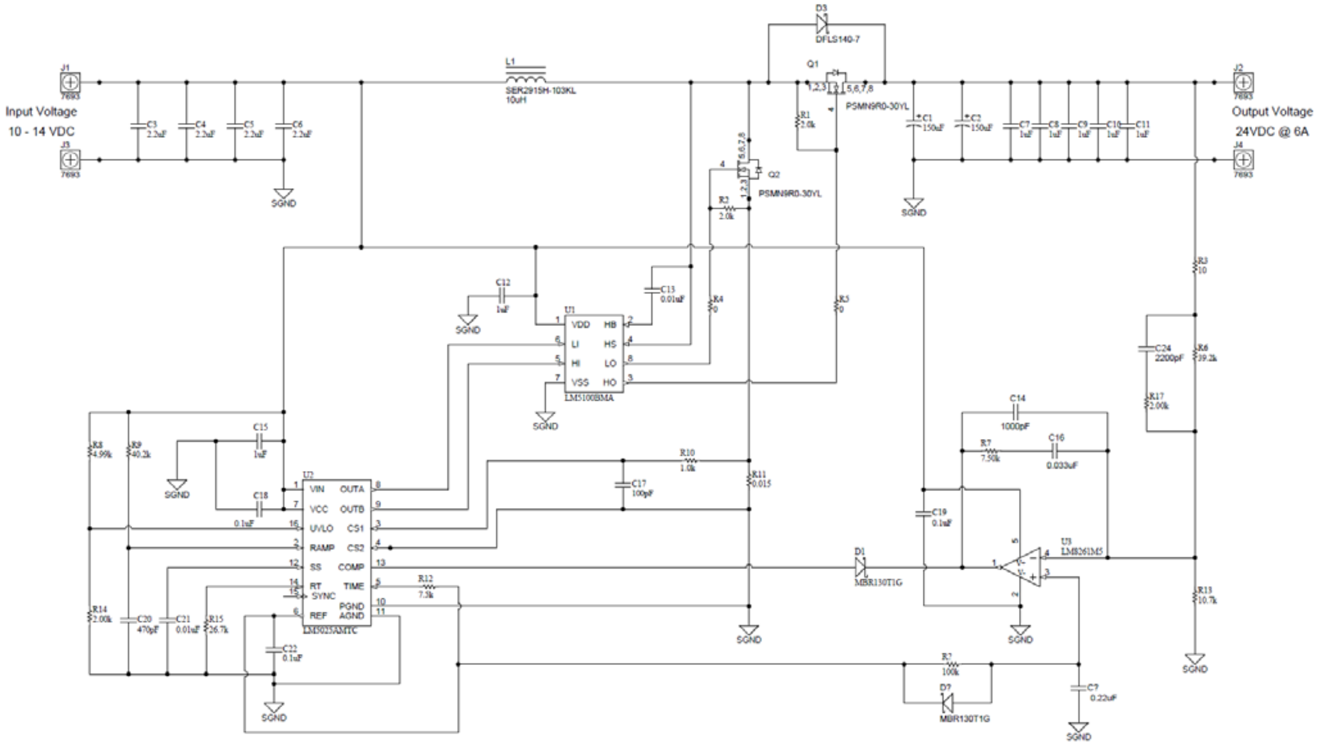

Fig. 2. Boost regulator with synchronous rectification. (Click on image to view enlarged diagram.)

The main output (OUT_A) controls the boost MOSFET (Q2) while the complimentary output (OUT_B) controls the synchronous MOSFET (Q1). The dead-time is required to avoid shoot-thru between the two MOSFETs. Adjusting the dead-time to a minimum with no shoot-thru optimizes the efficiency.

The LM5100 half-bridge gate driver (U1) is used to level shift and drive the boost MOSFET and the synchronous MOSFET. The LM5100 uses a bootstrap technique to provide charge for the floating synchronous MOSFET gate driver. The LM5025 controller does not contain an error amplifier, so an external op amp is required. The LM5025 +5-V reference can be used for the feedback reference.

Since the control is voltage-mode, a type-III compensation network is implemented. The loop bandwidth must be kept fairly low in order to stay clear of the right-half plane (RHP) zero, which is unavoidable in a continuous-conduction boost converter. The RHP zero is lowest at maximum load.

Cycle-by-cycle current limit sensing is implemented with a resistor in the boost MOSFET source, but like all boost regulators the cycle-by-cycle current limiting is only effective while the output voltage is larger than the input voltage. Once the output voltage falls below the input voltage, the MOSFET body diode will conduct and there is no current limiting.

The power converter shown in Fig. 2 is designed for a 24-V output with a nominal 12-V input. The maximum output current capability is 6 A. When the output current is 6 A, the input current will be approximately 12.5 A. The MOSFET on-resistance is approximately 7 mΩ. Referring back to the MOSFET power loss equation, the predicted power dissipation in the MOSFET with 12.5 A of input current will be approximately 0.55 W. If a Schottky diode with a 0.5-V forward drop was used instead of a MOSFET, the predicted power dissipation in the diode would be 3.1 W. Based upon these approximations, there is approximately 2.5 W to be gained by substituting the diode for the MOSFET.

In practice, the gain will be less due to gate-drive loss and the required dead time. A small Schottky diode is placed across the synchronous MOSFET in an effort to keep the MOSFET body diode from conducting during the dead-time.

Shown in Fig. 3 are efficiency plots for this boost regulator. The efficiency plots were taken in the full synchronous configuration as shown in the schematic of Fig. 2 and in a conventional asynchronous diode configuration. In the conventional asynchronous diode configuration the synchronous MOSFET was replaced with an MBR1035 35-V Schottky diode.

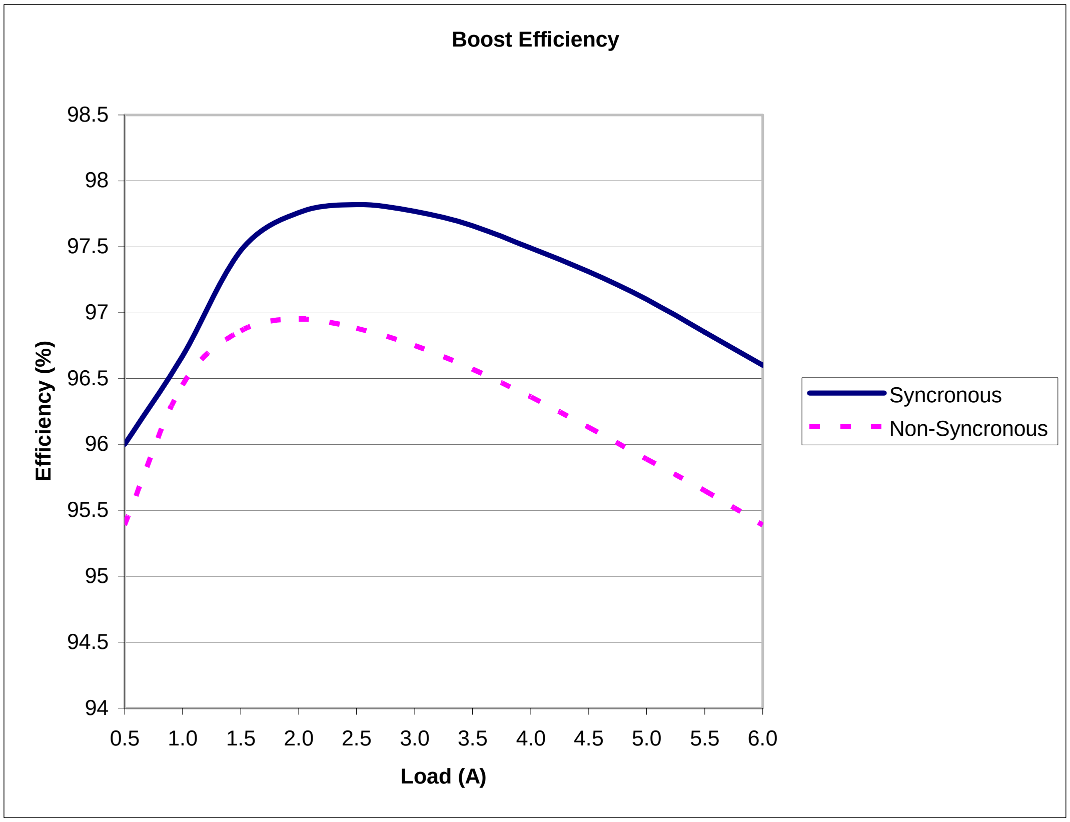

Fig. 3. Measured efficiency data for boost converter shown in Fig. 2.

In the full synchronous case, the peak efficiency approaches 98% while the efficiency at 6 A is 96.6%. In the diode asynchronous case, the peak efficiency approaches 97% while the efficiency at 6 A is 95.4%. The reduction in power dissipation is 1.2% or 1.7 W at full output power. A 1.2% efficiency gain may not appear that impressive, but you have to consider that the efficiency is already quite high and 1.2% represents a 25% reduction in the overall power dissipation for the solution!

As stated earlier the efficiency improvements are even greater if the boost ratio is less, which forces the diode to conduct for a larger portion of the switching period. For boost applications where the maximum optimal efficiency is desired, the synchronous boost configuration delivers.

About the Authors

Robert (Bob) Bell is the applications engineering manager for the National Semiconductor design center in Phoenix, Ariz. Products designed at the Phoenix design center include integrated switching regulators, next-generation PWM power controllers, gate drivers, and hot-swap and load-share controllers. He has been with National Semiconductor since September 2001. Prior to joining National, Bob designed power converters for military and space applications. Bob holds a Bachelor of Science degree in Electronic Engineering from Fairleigh

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For further reading on boost converters, see the How2Power Design Guide and search the Topology category and select the Boost subcategory.