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# *Boost Power Converters Finally Get Some Respect!*

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Boost power converters have long been the less popular, less respected topology as compared to buck converters. Over the years, IC vendors have continuously developed newer, faster, more-feature-rich buck controllers and regulators. Meanwhile, controller choices for boost power converters have remained limited.

Recently, new boost applications, such as automotive start-stop, have emerged. These applications require higher efficiency, higher power density, and novel protection features that are unavailable with existing boost controllers. New boost controller ICs are now available with features such as fully synchronous operation and interleaved multiphase capability along with robust protection options.

This article presents single- and dual-phase synchronous boost power converter designs based on a recently introduced boost controller, the LM5122. The operation of these converter circuits and the unique features offered by the controller—features not previously available in a boost controller—are discussed here. Measured results for efficiency and simulated results for output current ripple are also presented, demonstrating the benefits of synchronous rectification and interleaved, multiphase operation in boost applications.

## *Synchronous Operation*

Synchronous rectification techniques are commonly applied in step-down applications, but historically were rarely used in step-up applications. Shown in Fig. 1 is a conventional boost power converter.

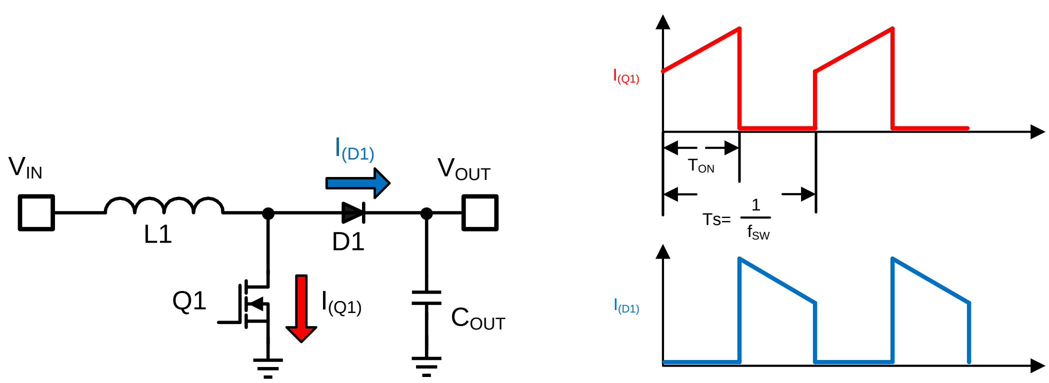


*Fig. 1. Block diagram of a conventional boost converter with diode rectification.*

For each cycle, when the boost MOSFET switch is closed, the voltage across the inductor is held at $V_{IN}$. The inductor current rises, storing energy in the core. The diode is reverse biased at a potential of $V_{OUT}$. When the boost MOSFET switch opens the diode conducts, releasing energy to the output. The power dissipated in the diode can be significant. The voltage across the boost MOSFET is: $V_{OUT}$ + $V_d$, where $V_d$ is the diode voltage drop. The basic transfer function of a boost power converter is:

$$P_{DIODE} = V_D \times I_{OUT} \times (1 - D) \qquad (1)$$

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 is large. In these applications the diode is conducting for a large portion of the switching period and the diode losses can be very high. The first-order approximation of the diode’s power dissipation is:

$$P_{DIODE} = V_D \times I_{IN} \times (1 - D)\,. \quad (2)$$

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

$$P_{MOSFET} = R_{DS(ON)} \times I_{IN}{}^2 \times (1 - D) \quad (3)$$

Shown in Fig. 2 is a test schematic of a synchronous boost power converter. The MOSFET replaces the diode to improve conversion efficiency. In our test we used the LM5122, which contains integrated gate drivers designed to directly control the low-side boost MOSFET and the floating high-side synchronous MOSFET. An internal adaptive deadtime circuit avoids shoot-through between the two MOSFETs while optimizing the efficiency.

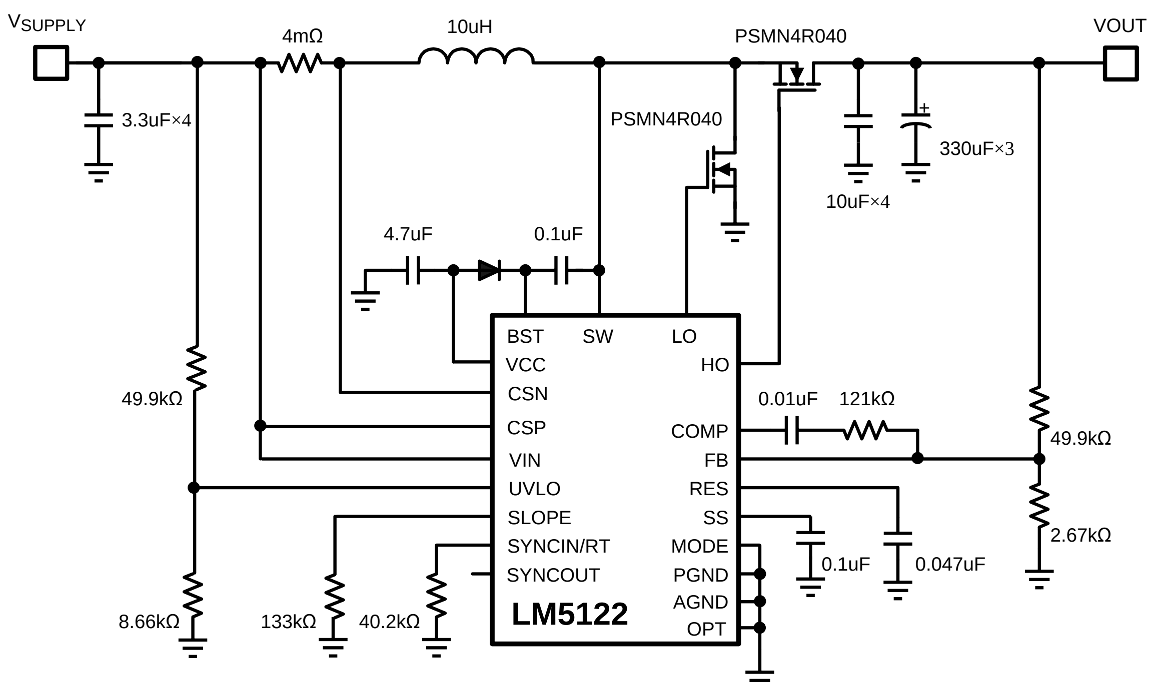


*Fig. 2. A single-phase boost converter based on the LM5122 controller performs synchronous rectification.*

The power converter shown in Fig. 2 is designed for a 24-V output with a nominal 12-V input (9 V minimum). The converter is designed to operate with a switching frequency of 250 kHz. The maximum output-current capability is 5 A. When the output current is at the maximum rating of 5 A, the input current is approximately 10.5 A. The MOSFET on-resistance is approximately 5 mΩ.

Referring back to the MOSFET power-loss equation (equation 3), the predicted power dissipation in the high-side MOSFET with 10.5 A of input current is approximately 0.28 W. If a Schottky diode with a 0.5-V forward drop is used instead of a MOSFET, the predicted power dissipation in the diode is approximately 2.6 W (per equation 2.)

Based upon these approximations, there is 2.32 W to be gained by substituting the MOSFET for the diode. In practice the improvement is less due to gate-drive loss and the required dead time. However, to minimize losses due to deadtime, a small Schottky diode can be 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 power converter. The efficiency plots were taken with a nominal 12-V input, in the full synchronous configuration as shown in Fig. 2, and in a conventional asynchronous diode configuration. In the diode configuration, the synchronous MOSFET is replaced with a 45-V Schottky, the CSHD10-45.

In the full synchronous case, the measured efficiency at 5-A load current is 96.4%. In the diode asynchronous case, the measured efficiency at 5-A load current is 94.5%. The reduction in power dissipation is almost 2%, or 2.4 W at full output power. A 2% efficiency gain may not appear that impressive, but you have to consider with the efficiency already quite high, 2% represents a 35% reduction in the overall power dissipation for the solution!

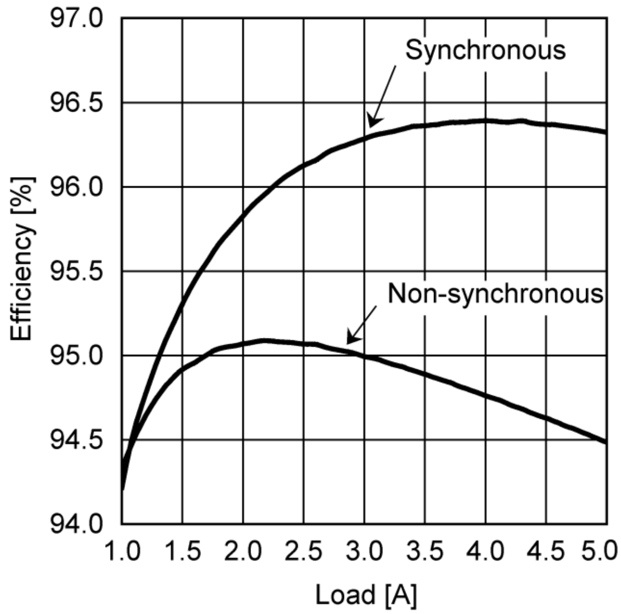


*Fig. 3. The measured efficiency of the single-phase boost converter shown in Fig 2 is increased by nearly 2% when synchronous rectification is used in place of nonsynchronous rectification. These results were obtained with 12-V input and 24-V output.*

The LM5122 contains an internal charge pump that allows the high-side synchronous MOSFET to operate at a 100% duty cycle. This feature is particularly useful for applications such as voltage-stabilizer or boost-on-demand where the boost converter output is set just below the nominal input voltage. While the input voltage is at this nominal level (or higher), the converter output approximately tracks the input with the controller feedback satisfied with no boost action occurring. During this time the synchronous MOSFET is fully enhanced at 100% duty cycle. It's in this operating mode that the greatest benefit from a synchronous MOSFET is realized. If the input voltage drops below the output set-point level, the boost converter seamlessly starts boost operation, regulating the output to the desired set-point level.

As is the case with a synchronous buck, there are tradeoffs when operating the synchronous MOSFET in either forced pulse-width modulation (PWM) or diode-emulation mode. Forced PWM (capability for bidirectional current in the synchronous MOSFET) allows for better transient response, but has lower efficiency under light-loading conditions. An integrated gate driver can be configured for either operating mode, and can be configured to skip cycles to further increase the efficiency at light load. The threshold for the onset of skip cycle is user programmable.

## *Interleaving For Higher-Power Applications*

The use of interleaved, multi-phase buck converters, especially for high-performance point-of-load (POL) applications, has been widespread for many years. However, all of the advantages of interleaving, such as higher efficiency, lower component stresses and reduced input and output ripple can also be realized in the boost topology. For high-power applications, interleaved boost designs are a powerful tool to keep input currents manageable and increase efficiency, while still maintaining good power density.

In a two-phase interleaved boost converter, two power stages operate 180° out-of-phase. By splitting the current into two power paths, conduction ($I^2R$) losses can be reduced, while spreading the associated power dissipation among the two power stages, reducing component stresses. Since the two phases are combined at the output capacitor, the effective ripple frequency is doubled, reducing the output ripple current. Likewise, the current drawn from the input capacitors is staggered, reducing the input ripple current level.

Interleaving can be expanded well beyond two phases to further increase power capability. A difficult challenge when designing any boost converter is selecting the output capacitor(s) to withstand the high-ripple current inherent to the topology. The high-ripple current flows through the equivalent series resistance (ESR) of the capacitor, increasing the capacitor temperature and ripple voltage.

Shown in Fig. 4 is a normalized ($I_{PP}/I_{OUT}$) output capacitor ripple current versus duty cycle for both a single-phase and a dual-phase boost converter. At 50% duty cycle, which occurs when $V_{OUT}$ is twice $V_{IN}$, the output capacitor ripple current is approximately equal to the dc output current for a single-phase design. Notice that a dual-phase boost converter has almost zero ripple current in the output capacitor, while operating at 50% duty cycle.

While ripple reduction is maximum at a 50% duty cycle, there is still an appreciable reduction in output-capacitor ripple current in a dual-phase design versus a single-phase design, at any value of duty cycle, as illustrated in Fig. 4. There is also an appreciable reduction in input ripple current when using interleaving.

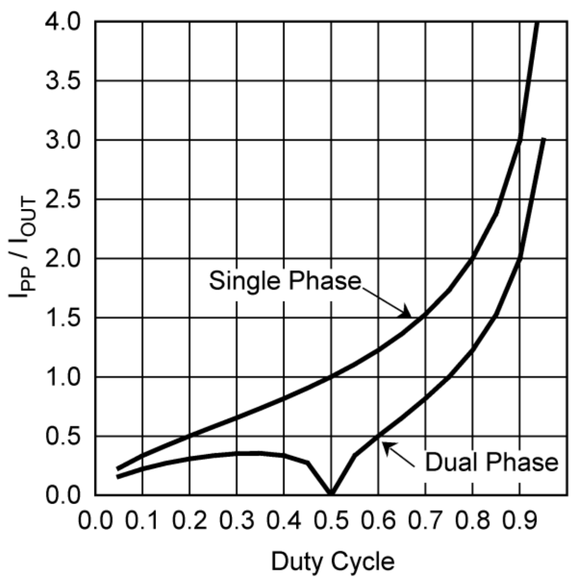


*Fig. 4. A plot of normalized output capacitor ripple current reveals that a dual-phase, interleaved design reduces ripple current significantly versus that of a single-phase boost converter design.*

Shown in Fig. 5 is a dual-phase, fully synchronous boost power converter schematic. The power converter is designed for a 28-V output with a nominal 12-V input (9 V minimum.) The operating frequency is set to 250 kHz. The maximum output current capability is 7 A. The design goals for this power converter are high efficiency, low component stress, and good power density.

Control is accomplished by using two LM5122 controllers operating as a master and slave. These controllers are designed to be easily configured as a master or a slave through strapping of the feedback pin. The error amplifier of the slave device is disabled, allowing both devices to be controlled by the master's error amplifier. The master also controls the soft-start and fault sequencing. Connecting the SYNCIN (of the slave) to the SYNC OUT (of the master) configures the slave to operate 180º out of phase with respect to the master. Inductor current is sensed in each phase independently. The sensed-phase currents are compared to a common error signal, using current-mode control to ensure the currents in both phases are well balanced.

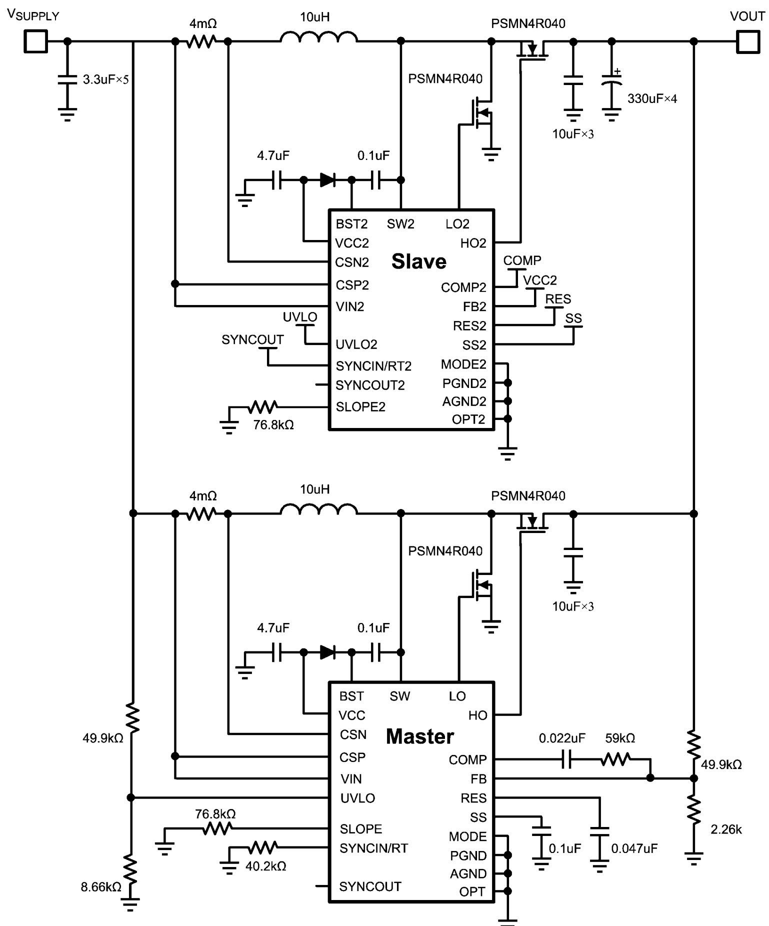


*Fig. 5. A dual interleaved synchronous boost converter employs two LM5122 controllers operating as master and slave.*

Shown in Fig. 6 is the efficiency plot for the dual-phase boost shown in Fig. 5. The peak measured efficiency approaches 97% with a nominal input volt of 12 V.

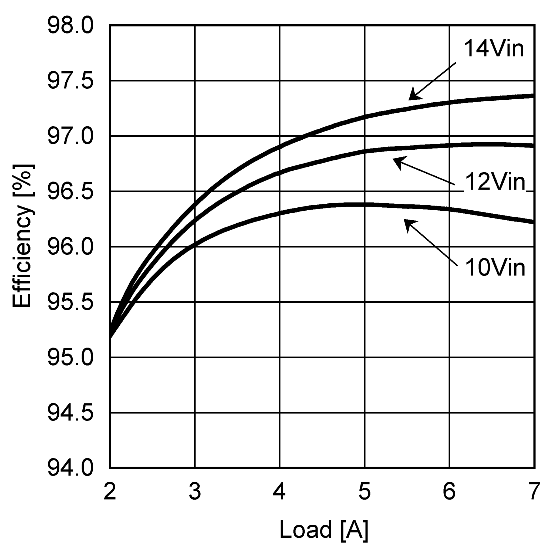


*Fig. 6. The measured efficiency of the dual-phase boost converter shown in Fig 5 varies as a function of input voltage and load. The converter is configured for an output voltage of 28 V.*

 

Shown in Fig. 7 is a photograph of both the single-phase and dual-phase boost converters, as previously described. Spiral wound inductors were selected due to their low resistance. The output capacitors of a boost converter need to be carefully selected due to the large ripple current stress. Attention to the capacitor ripple current rating and equivalent series resistance (ESR) keeps the capacitors within temperature ratings and the output voltage ripple within specifications. No heatsinking other than the copper in the PCB is used.

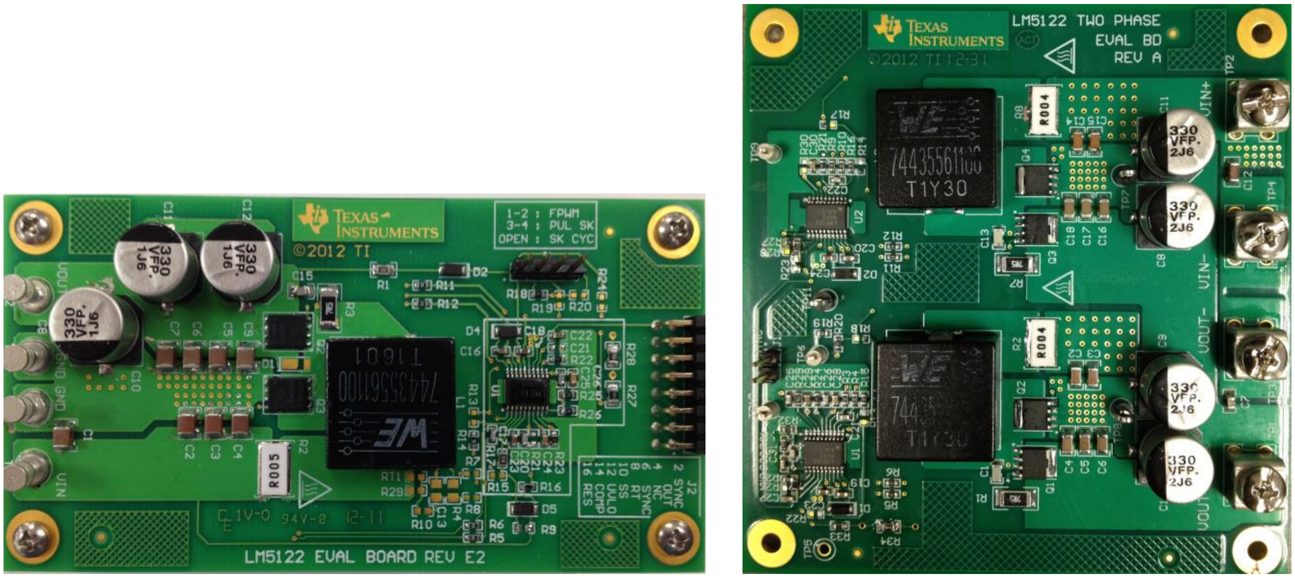


*Fig. 7. The single-phase (left photo) and dual-phase (right photo) boost power converters pictured here are the evaluation board implementations of the circuits in Figs. 2 and 5, respectively.*

## Summary

There are still opportunities for further improvements in boost controllers, particularly with regard to multiphase controllers and fault protection. For extremely high-power applications, the benefits of interleaving can be expanded well beyond two phases. A boost power converter, by definition, does not have output short-circuit protection. But when using synchronous rectification techniques, incorporating two MOSFETs in a back-to-back configuration could be one way to guard against short circuits. However, this approach may result in an unacceptable reduction in efficiency.

Another approach is to add a disconnect MOSFET at the input to the power converter. This can be accomplished today with one of the many hot-swap controllers currently available. The benefit of this approach is that the MOSFET only needs to be rated for the maximum input voltage. The MOSFET could also be used to limit the initial inrush current surge, as well as disconnect, if a fault is detected. Fully integrated boost controllers with multiphase capability and expanded fault protection features, are on the horizon.

The designs presented in this article illustrate the many benefits of synchronous rectification and interleaving, which are routinely used in buck power converters, and apply equally well to boost power converters. New controllers are now available that allow designers the ability to optimize synchronous, interleaved boost power converters.

**Reference**


The LM5122 datasheet is available at www.ti.com/lm5122-ca.

## About The Authors

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*For further reading on boost converters, see the How2Power Design Guide, select the Advanced Search option, go to Search by Design Guide Category and select "Boost" in the Topology category.*