# Efficiency of synchronous versus nonsynchronous buck converters

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Choosing the right DC/DC converter for an application can be a daunting challenge. Not only are there many available on the market, the designer has a myriad of trade-offs to consider. Typical power-supply issues are size, efficiency, cost, temperature, accuracy, and transient response. The need to meet ENERGY STAR® specifications or green-mode criteria has made energy efficiency a growing concern. Designers want to improve efficiency without increasing cost, especially in a high-volume consumer electronics application where reducing power consumption by one watt can save megawatts from the grid. The semiconductor industry has recently developed low-cost DC/DC converters that employ synchronous rectification and that are thought to be more efficient than nonsynchronous DC/DC converters. This article will compare the efficiency, size, and cost trade-offs of synchronous and nonsynchronous converters used in consumer electronics under various operating conditions. It will be shown that synchronous buck converters are not always more efficient.

## Typical application

To demonstrate the subtle differences between the two converter topologies, a typical point-of-load application was chosen. Many low-cost consumer applications use a 12-V rail that accepts power from an unregulated wall adapter or an off-line power supply. Output voltages usually range from 1 to 3.3 V, with output currents under 3 A. The Texas Instruments devices in Table 1 were chosen to compare actual efficiency measurements under various output-current and output-voltage conditions. The rated output current, which is the level of output current each device is marketed to deliver, was taken directly from the data sheets (see References 1 and 2).

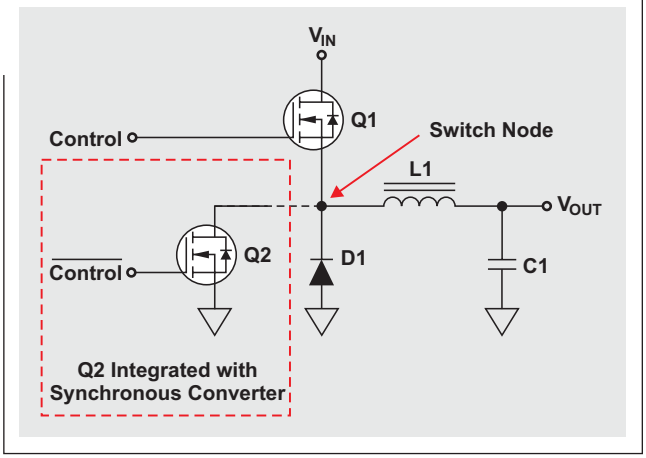
**Table 1. Device comparison**

| PART NUMBER | TOPOLOGY | INPUT VOLTAGE RANGE (V) | RATED $I_{OUT}$ (A) |
|---|---|---|---|
| TPS54325 | Synchronous buck | 4.5 to 18 | 3 |
| TPS54331 | Nonsynchronous buck | 4.5 to 28 | 3 |

## Basic operation

A typical block diagram for a step-down (buck) regulator is shown in Figure 1. The main components are Q1, which is the high-side power MOSFET; L1, the power inductor; and C1, the output capacitor. For a synchronous-buck topology, a low-side MOSFET (Q2) is used. In a nonsynchronous-buck topology, a power diode (D1) is used. In a synchronous converter, such as the TPS54325, the low-side power MOSFET is integrated into the device. The main advantage of a synchronous rectifier is that the voltage drop across the low-side MOSFET can be lower than the voltage drop across the power diode of the nonsynchronous converter. If there is no change in current level, a lower voltage drop translates into less power dissipation and higher efficiency.

**Figure 1. Synchronous and nonsynchronous buck circuits**




## Choosing the power diode

Nonsynchronous converters are designed to operate with an external power diode (D1). The three key specifications a designer needs to consider when choosing a power diode are the reverse voltage, the forward voltage drop, and the forward current. First, the rated reverse voltage must be at least 2 V higher than the maximum voltage at the switch node. Second, the forward voltage drop should be small for higher efficiency. Third, the peak-current rating must be greater than the maximum output current plus one-half the peak-to-peak inductor current. When the duty cycle is low (i.e., at low output voltages), D1 operates as a catch diode that conducts more current than the high-side MOSFET. A fourth consideration is to make sure the package of the diode chosen can handle the power dissipation. The diode chosen for the TPS54331 was the B340A, which has a reverse voltage rating of 40 V, a forward voltage drop of 0.5 V, and a forward current rating of 3 A.

The TPS54325 does not need a power diode, since a 70-mΩ low-side MOSFET is integrated into the chip. The integrated MOSFET saves space; but the complexity of the control circuitry must be increased to ensure that both MOSFETs do not conduct simultaneously, which would result in a direct path from the input to ground. Any cross conduction would result in lower efficiency and could even overload and damage the system.

## Efficiency calculations

To calculate the efficiency of a DC/DC converter, the total power dissipation needs to be computed. The key contributors to the power dissipation for a DC/DC converter in continuous conduction mode (CCM) are the high- and low-side switching losses and the IC's quiescent-current loss. The formulas for these losses are as follows:

$$P_{Conduction_HS} = I_{OUT}^2 \times R_{DS(on)} \times \frac{V_{OUT}}{V_{IN}} \quad (1)$$

$$P_{SW} = V_{IN} \times V_{OUT} \times 0.5(t_{Rise} + t_{Fall}) \times f_{SW} \quad (2)$$

$$P_{Quiescent} = V_{IN} \times I_q \quad (3)$$

Equations 1 through 3 apply to both the synchronous and the nonsynchronous converter in CCM. However, the losses in the low-side MOSFET for the synchronous buck converter (Equation 4) and in the low-side power diode ($P_{D1}$) for the nonsynchronous buck converter (Equation 5) need to be included:

$$P_{Conduction_LS} = \underbrace{\left[I_{OUT}^2 \times R_{DS(on)} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)\right]}_{\text{Low-Side MOSFET}} + \underbrace{(2 \times t_{Delay} \times f_{SW} \times I_{OUT} \times V_{Fwd})}_{\text{Body Diode}} \quad (4)$$

$$P_{D1} = V_{D1_Fwd} \times I_{OUT} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \quad (5)$$

In Equation 4, the first component represents the conduction loss in the low-side MOSFET, and the second component represents the conduction loss in the body diode. The current flowing through the body diode is about an order of magnitude lower than the current flowing through the low-side MOSFET and is negligible at 2 A.

These equations make it evident that there are several factors influencing full-load efficiency, such as the drain-to-source resistance, drain-to-source forward voltage, duty cycle, frequency, and power MOSFET rise and fall times. The AC and DC losses of the inductor and the equivalent series resistance of the output capacitance are similar in the application, since the same LC filter can be used for both devices. For a DC/DC converter, the duty cycle is given, and only the drain-to-source resistance, forward voltage drop, and switching frequency can be chosen. Typically, the MOSFET rise and fall times are not stated in the data sheet but are important specifications to consider, since the faster they are, the less power is dissipated. The trade-off is noisy ringing at the switch node when a power MOSFET is turned on too quickly. Start-up time can be reduced to improve thermal performance so that a less costly package can be chosen to house the smaller power MOSFET with a higher drain-to-source resistance.

## Efficiency results at high loads

Two circuits were built with the devices shown in Table 2 so that the efficiencies of the circuits could be compared. The devices used the same LC filter in the bill of materials. Even though the two devices had slightly different fixed switching frequencies, there was not enough impact on circuit efficiency to alter the conclusion of this demonstration. An input voltage of 12 V was chosen, and efficiency measurements were taken by simply varying the output voltages.

**Table 2. Basic device characteristics**

| PART NUMBER | HIGH-SIDE $R_{DS(on)}$ (mΩ) | LOW-SIDE $R_{DS(on)}$ (mΩ) | FREQUENCY (kHz) |
|---|---|---|---|
| TPS54325 | 120 | 70 | 700 |
| TPS54331 | 80 | N/A ($V_{D1_Fwd}$ = 0.5 V) | 570 |

Figure 2 shows the efficiency of both devices with a 12-V input and a 1.5-V output. The figure clearly shows that the TPS54325 had higher efficiency at full load. Since the duty cycle was 12.5%, the power diode of the nonsynchronous solution with the forward voltage drop of 0.5 V dissipated more energy than the 70-mΩ MOSFET, despite the TPS54325's high-side drain-to-source resistance.

Figure 3 shows the efficiency of both devices with a 12-V input and a 2.5-V output. It is evident that the efficiency of the TPS54331 improved dramatically. In this case, the duty cycle was 21%, and the two full-load efficiencies were nearly the same. The power diode of the nonsynchronous device conducted less often, and the high-side MOSFET with low ON resistance conducted more often. When the dissipation of the low-side power diode was lower at higher duty cycles, the nonsynchronous solution became more efficient.

**Figure 2. Device efficiencies with 12-V input and 1.5-V output**

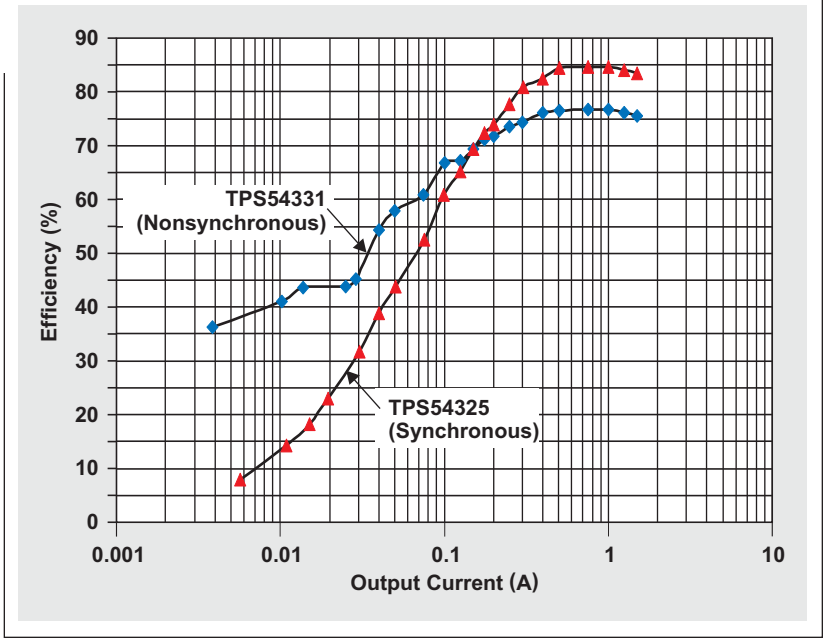



**Figure 3. Device efficiencies with 12-V input and 2.5-V output**

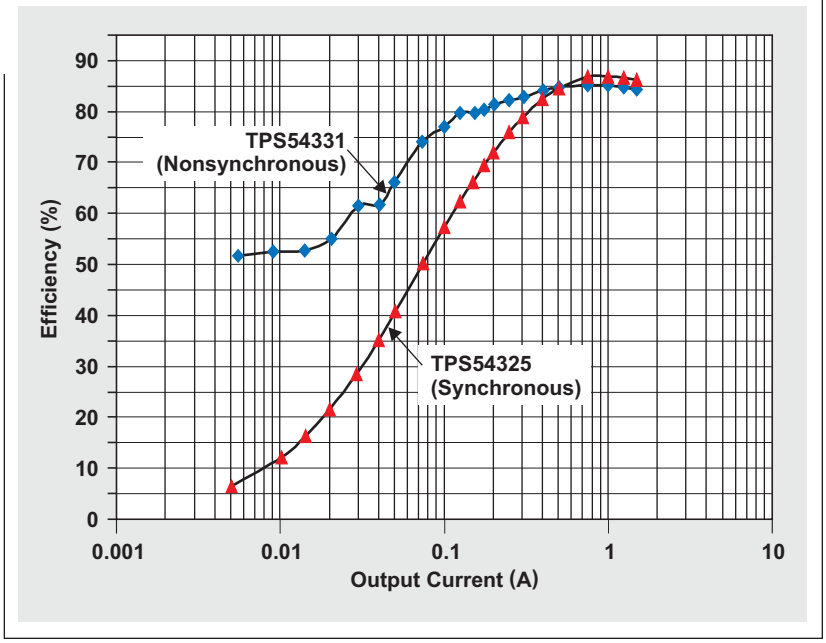
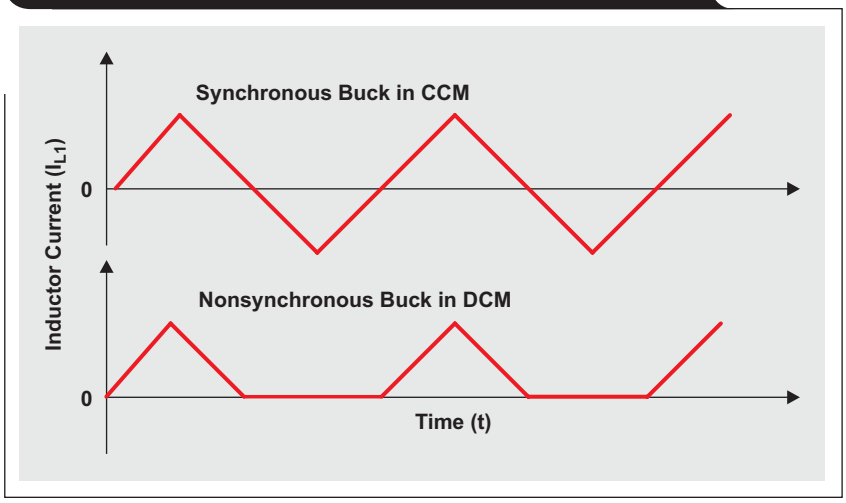


**Figure 4. Inductor-current waveforms in CCM and DCM**




## Considerations for light-load efficiency

In some applications, the need for light-load efficiency outweighs the need for higher full-load efficiency. Nonsynchronous buck converters switch in discontinuous conduction mode (DCM) at light loads. In the nonsynchronous buck converter, the inductor current flows in only one direction. With the synchronous buck converter, current is allowed to flow in both directions, and power is dissipated when reverse current flows. Figure 4 illustrates the difference between inductor-current waveforms generated in CCM versus those generated in DCM.

The TPS54331 has a pulse-skipping feature called Eco-mode™ that improves light-load efficiency. This mode of operation turns on the power MOSFET less often, resulting in lower switching losses. The differences in light-load efficiency shown in Figures 2 and 3 are due to the TPS54331's Eco-mode feature and its low operating quiescent current. For more information on Eco-mode, please see Reference 1.

## Cost and space considerations

A synchronous converter with an integrated low-side MOSFET offers benefits such as reduced size, lower parts count, and easier design. However, if reducing cost is the main objective, a nonsynchronous converter with an external power diode may be less expensive than a synchronous buck converter.

## Conclusion

Synchronous buck converters have become very popular recently and are widely available. However, they are not always more efficient. Nonsynchronous buck converters may have adequate efficiency at higher duty cycles and lighter loads. By paying attention to the data-sheet specifications, especially the drain-to-source resistance and the quiescent current, the designer can make the best choice based on the goals of a specific design.

## References

For more information related to this article, you can download an Acrobat® Reader® file at www-s.ti.com/sc/techlit/*litnumber* and replace "*litnumber*" with the **TI Lit. #** for the materials listed below.


| **Document Title** | **TI Lit. #** |
|---|---|
| 1. "4.5-V to 18-V, 3-A Output Synchronous Step Down Switcher with Integrated FET (SWIFT™)," TPS54325 Data Sheet | slvs932a |
| 2. "3A, 28V Input, Step Down SWIFT™ DC/DC Converter with Eco-mode™," TPS54331 Data Sheet | slvs839b |


## Related Web sites

**power.ti.com**
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