Merits of multiphase buck DC/DC converters in small form factor applications

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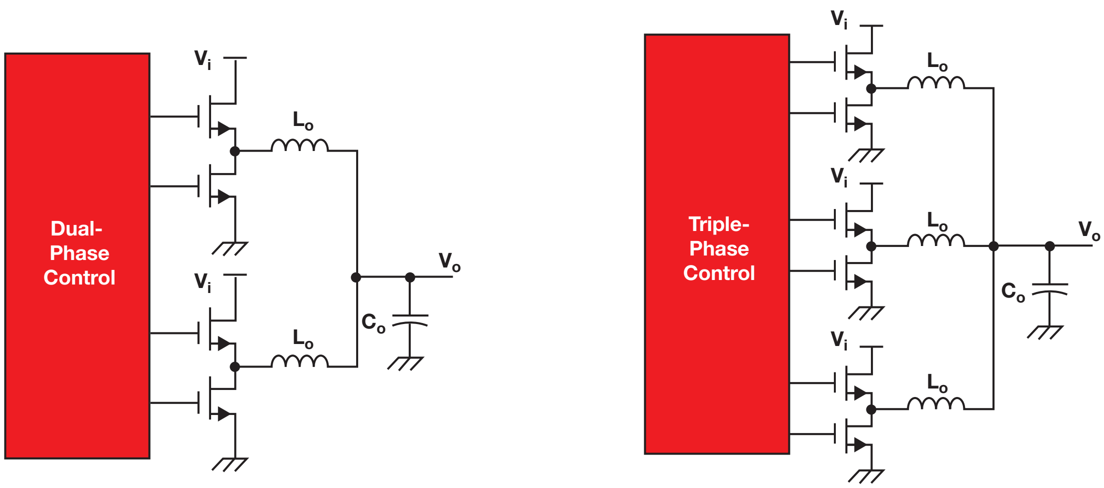
Multiple inductors operating in parallel allow multiphase converters to operate beyond the saturation current rating of a single inductor and require less RMS current from the input capacitor; thereby, reducing the solution size and cost.

Traditionally, multiphase buck DC/DC converters have been employed in high-power processor applications such as servers or PC desktops and laptops. Application processors are common in small form factor designs such as smartphones and tablets that have had their peak-power demands steadily increase. As a result, the selection of an output inductor starts to become an issue in the single-phase buck converter because of the lower saturation current of the single packaged inductor. In these types of applications, multiphase buck converters can become an attractive option. The following sections present the merits of employing multiphase buck DC/DC converters in small form factor applications that are under size and space constraints.



a. Dual-phase buck converter.

b. Triple-phase buck converter.

Figure 1: Example configurations of multiphase buck-converter power trains.

Examples of dual- and triple-phase converters

Figure 1 illustrates dual- and triple-phase buck-converter power trains. The input voltage is V_i, the output voltage is V_O, the output inductors are L_O, and the output capacitor is C_O. The high- and low-side power FETs are also shown. The control methods for multiphase converters are typically similar to single-phase converters—such as voltage-mode or current-mode PWM control. Multiphase converters also have the same features found in their single-phase conterparts—such as over- and under-voltage protection, short-circuit protection, in-rush current limiting, auto PFM operation, output voltage slew-rate control, and optimization of efficiency across the load current range. In addition, a multiphase converter offers a unique set of advantages like flexible phase configurations and phase shedding to ensure the converter is operating in an optimal state.

As in a traditional single-phase converter, the high- and low-side power FETs are driven in a complementary manner with a given duty-cycle, D, that is based upon the input and output voltage relationship. This is shown in Equation 1 for a buck converter. The converters are driven by an oscillator frequency, f_S, where the phases are shifted based upon the number of power trains, N. For example, a dual-phase converter is shifted 180 degrees (0°, 180°), while a three-phase converter is phase shifted 120 degrees (0°, 120°, 240°), and so on. Equation 2 shows the ideal duty-cycle relationships among the multiple phases.

$$D = \frac{V_o}{V_i} \qquad (1)$$

$$D = D_1 = D_2 = D_3 = \cdots = D_N \qquad (2)$$

Merits of multiphase design in output inductor and output capacitor selection

A multiphase design allows significant flexibility when choosing the output inductors, which is extremely important in small form factor applications. One example is when powering multi-core application processors, where peak current consumption requirements are near 8 A or more. With physically small inductors like those with a 1.2-mm or less surface-mount height, it is difficult to find inductors in the range of 0.47 µH to 1.5 µH that support such a high current because of the aforementioned saturation-current limitations. This is when single-phase converters become less attractive. In a single-phase converter, one alternative is to decrease the effective inductor value. One method is to parallel multiple inductors to increase the effective current capability. However, the lower inductor value will result in higher ripple current and higher output ripple voltage. The relationship between ripple current, the output ripple voltage, and the external LC components are approximated in Equations 3 and 4.

$$\Delta I_o \approx \frac{V_o}{f_{sw} \cdot L_o}\left(1 - \frac{V_o}{V_i}\right) \qquad (3)$$

$$\Delta V_o \approx \Delta I_o \left(\frac{V_o}{8 \cdot f_{sw} \cdot C_o} + R_{esr}\right) \qquad (4)$$

This is where ΔV_o is the output ripple voltage, V_o is the output voltage, ΔI_o is the inductor ripple current, V_i is the input voltage, L_o is the output inductance, f_{sw} is the switching frequency, C_o is the output capacitor, and R_{esr} is the ESR of the output capacitor.

The solution for high ripple is to put multiple power trains in parallel (shown in **Figure 1**) to circumvent the saturation-current constraint of the inductor. A multiphase design helps to ease ripple problems because of the intrinsic time interleaved operation as shown in **Figures 2 and 3**. **Figure 2** illustrates the effective inductor ripple-current cancellation of the buck converter when operating in the dual-phase mode.

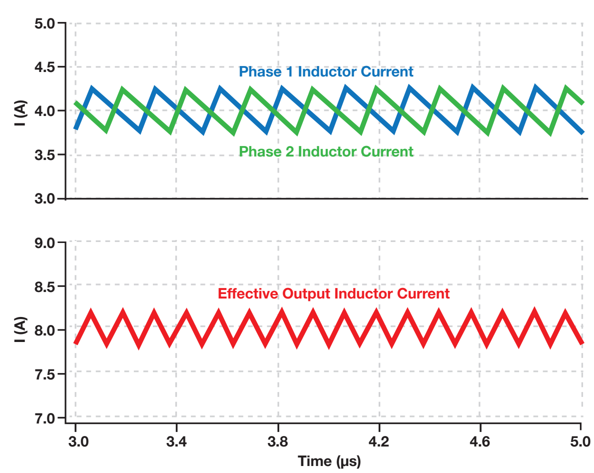


Figure 2: *Cancellation of inductor ripple current in a dual-phase converter.*

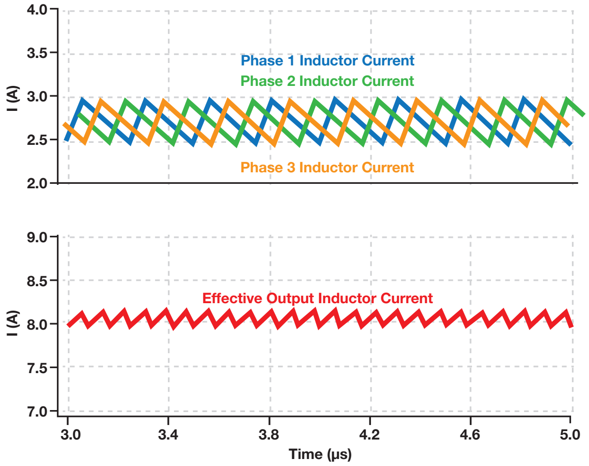


Figure 3: Cancellation of inductor ripple current in a three-phase converter.

Figure 3 illustrates the effective inductor ripple-current cancellation when operating in the three-phase mode. The effective output inductor current ripple is reduced because of the multiple phases. In general, as the number of phases increase, the magnitude of the output ripple current and voltage decrease. **Figure 4** depicts the normalized inductor ripple current versus the operating duty cycle ratio, based upon the number of phases.

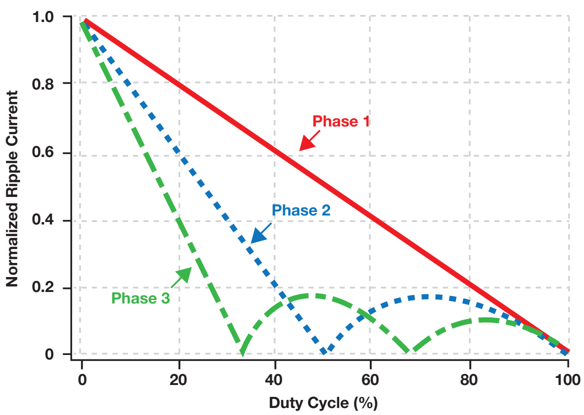


Figure 4: Normalized inductor ripple current vs. operational duty cycle with one, two, and three phases.

For lower duty cycle operation, the effective ripple current of a multiphase design is approximated in Equation 5 as I_{OUTpp}. This characteristic allows a multiphase design to employ a smaller value inductor, which usually has a higher saturation current rating for a given case size.

$$I_{OUTpp} \approx \frac{V_o}{f_{sw} \cdot L_o}\left(1 - N\frac{V_o}{V_i}\right) \quad (5)$$

This is where V_o is the output voltage, V_i is the input voltage, L_o is the output inductance, f_{sw} is the switching frequency, and N is the number of phases.

Merits of multiphase design in input capacitor selection

Another advantage of a multiphase design is that the input RMS current is smaller than in its single-phase counterpart, again due to the interleaved nature of the phases as shown in **Figure 5**. For the same amount of output current delivered, the input decoupling capacitance can be reduced as well.

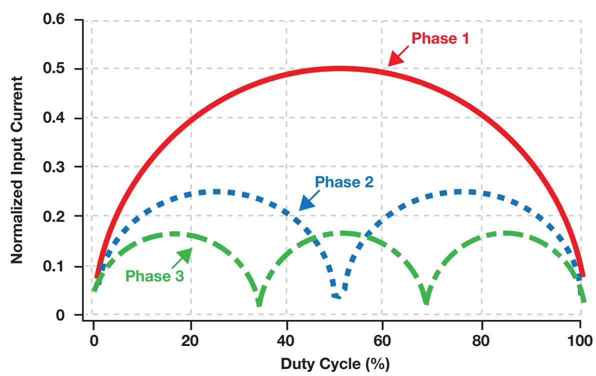


Figure 5: Normalized input RMS current vs. operational duty cycle with one, two, and three phases.

Summary

Multiphase buck converters remain the best choice for high-current designs, and they naturally support smaller form factors. These converters also have the benefits of higher operating current with smaller inductor sizes; thereby, providing optimal use of board space. The reduction of inductor ripple current and output ripple voltage, along with lower RMS input currents, are benefits of the interleaved phase control. The lower RMS input currents allows smaller input decoupling capacitors, which means even more space savings. TI's TPS65913 is a good representative of a highly integrated PMIC that targets small form factor, high peak-power applications. This PMIC contains configurable single, dual, and triple phase converters that are optimized to leverage the benefits of multiphase designs and deliver a wide range of outputs in a compact solution.

References

1. Baba, David. "Benefits of a Multiphase Converter," Application Note, Texas Instruments, 2012.
2. Hegarty, Tim. "Benefits of multiphasing buck converters – Part I," EE Times, November 17, 2007.

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