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Reduce Costs in the Long Run: Use the Same Qualified Parts for Both Positive and Negative Output DC-to-DC Converters

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Introduction

One relatively easy way for manufacturers to reduce the cost of electronic components is by using the same designs or components for disparate applications. The cost savings manifest not only in the obvious bulk procurement of identical parts, but also in minimizing the number of required qualification processes. Qualification is especially critical for the transportation industry—particularly for automobile manufacturers. Usually it is an expensive process involving testing for ruggedness, reliability, and longevity of units.

This article shows how to use the same components—an IC controller and power train—in two very different topologies: a common buck converter and in an inverting buck-boost converter. The component requirements are explored for the inverting buck-boost converter by specifically examining the reverse voltage fluctuation on the output of the inverting buck-boost, and ways to use the least expensive polarized capacitors in this topology. As a result, a simple and cost-effective solution for designing positive buck and negative buck-boost converters using the same IC is presented.

Positive Output, Buck Converter

The electrical schematic of the positive output, buck converter is presented in Figure 1. The converter generates a stable V_{OUT} of 5 V at 15 A from the input voltage V_{IN} range of 5 V to 38 V. The power train includes modulating (high-side) MOSFETs Q1 and Q2, rectifying (low-side) MOSFETs Q3 and Q4, inductor L1, a combination of the electrolytic and ceramic input filter capacitors C_{IN1} and C_{IN2}, and a similar combination of capacitors for the output filter and the controller.

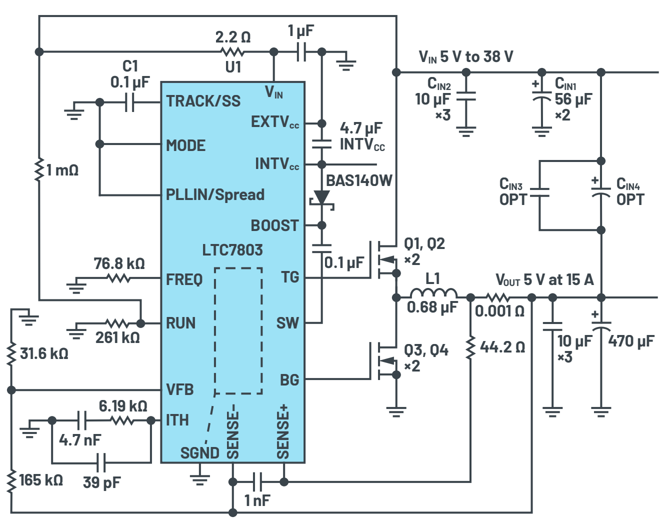

Figure 1. Electrical schematic of a step-down, buck converter with V_{IN} 5 V to 38 V, and V_{OUT} 5 V at 15 A.

The resistor R_S can be used as a current-sense element if the peak current mode controller is employed, or as part of the short-circuit protection circuitry in voltage mode control. The input capacitors C_{IN1} and C_{IN2} are terminated to GND; however, the optional C_{IN3} and C_{IN4} are terminated to the output and are employed in the negative buck-boost solution.

The functionality of buck converters is widely studied and easily obtainable. In this article, we just briefly note voltage and current stress on the power train components. It is relevant to the preliminary selection of components in new designs and rough evaluation of the existing solutions. Assuming continuous conduction mode (CCM) operation, the following expressions can be used.

$$D = \frac{V_{OUT}}{V_{IN}} \qquad \text{Duty cycle}$$

$$V_{DS} = V_{IN} \qquad \text{Maximum voltage stress on Q1 through Q4 and L1}$$

$$I_L = I_{OUT} + 0.5 \times \Delta I \qquad \text{Inductor L1 peak current, where } \Delta I \text{ is peak-to-peak ripple current.}$$

Negative Output, Negative Buck-Boost Converter

The schematic of the negative buck-boost converter presented in Figure 2 is similar to the buck converter schematic in Figure 1. Notably, both use the same components for the power train, interconnections, and controller. Differences arise in the grounding of the controller, switching MOSFETs, and input/output filter. The ground of these inverting converter components is $-V_{OUT}$. The inductor L1 is terminated to the system (input) ground.

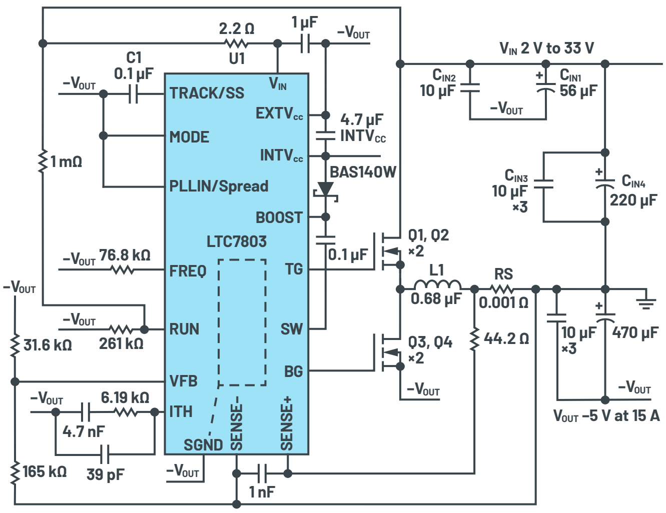

Figure 2. Electrical schematic of an inverting buck-boost converter with V_{IN} 2 V to 33 V, V_{OUT} –5 V at 15 A, and start-up input voltage +5 V.

Unlike in the buck converter, the capacitors C_{IN3} and C_{IN4} are not optional in this solution; they function as the input filter. The capacitors C_{IN1} and C_{IN2} filter ac between the V_{IN} and $-V_{OUT}$ rails. The following expressions can be used to estimate the stresses on the power train components, assuming CCM operation.

$$D = \frac{|V_{OUT}|}{V_{IN} + |V_{OUT}|} \quad \text{Duty cycle}$$

$$V_{DS} = V_{IN} + |V_{OUT}| \quad \text{Maximum voltage stress on Q1 through Q4}$$

$$I_L = \frac{I_{OUT}}{1 - D + 0.5\Delta I} \quad \text{Inductor L1 peak current, where } \Delta I \text{ is peak-to-peak ripple current.}$$

Converter Functionality and Testing

There's plenty of literature covering the basic and even advanced functionality of these two types of converters.[1] In the remainder of this article we'll examine rarely discussed factors.

First, there is a fundamental difference in functionality of the output filters between the buck and buck-boost topologies. In the buck configuration, the inductor is hardwired to the output filter, providing continuous output current in CCM. Unlike the buck, the buck-boost topology does not connect the inductor only to the output. During the Q1/Q2 on-time, the inductor L1 is disconnected from the output filter and the output filter capacitance is the only source of energy to the load. Consequently, it's important to have enough output capacitance to absorb the discontinuous output capacitor current and support the specified output voltage ripple.

There is a drawback in negative buck-boost and, in fact, most inverting topologies. At startup there is a reverse voltage swing at the output filter with amplitude not more than one diode voltage drop, as shown in Figure 3. This brief reverse voltage is due to the flow of the controller's operating current through the forward-biased diode to system ground. The existence of the reverse voltage on polarized capacitors appears unacceptable at first glance. Hence, some designers eliminate polarized capacitors from the output filter, resorting to ceramic-only capacitors. This approach creates other problems associated with the size, cost, and dc bias of the ceramic capacitors. Nevertheless, it is possible to use polarized capacitors in inverting buck-boost applications with some limitations. The guidelines vary by vendor—an example of such recommendations can be found in *Polymer, Tantalum, and Niobium Oxide Capacitors: Application Guidelines.*[2]

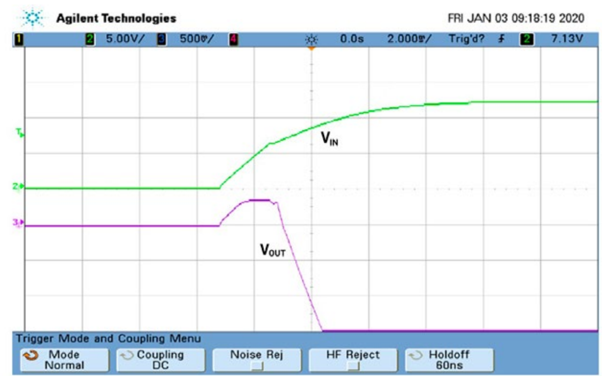

Figure 3. An inverting buck-boost converter with start-up waveforms. Channel 2's V_{IN} is 5 V/div, while Channel 3's V_{OUT} is 0.5 V/div with a 2 ms/div timescale.

The converters shown in Figure 1 and Figure 2 were thoroughly tested and evaluated. Their efficiency is shown in Figure 4. To simplify the design with a low pin count and wide input voltage range, making it applicable to a wide variety of solutions, the LTC7803 advanced controller was used in both cases. The evaluation board DC2834A was used as a basis (with some modification) to verify both applications. To reduce EMI, the spread spectrum feature of this controller can be employed. Figure 5 shows a photo of the buck DC2834A converted to inverting buck-boost.

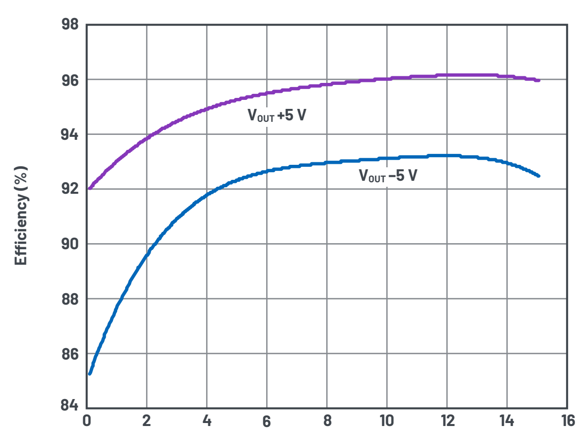

Figure 4. Efficiency of the converters in Figure 1 and Figure 2 (V_{IN} 12 V, natural convection cooling, no air flow).

Figure 5. DC2834A converted to inverting buck-boost from the original, off-the-shelf step-down converter.

Conclusion

This article presents a way to use the same controller and a number of identical components for positive step-down and negative buck-boost converters. In this way, costs for qualifying components can be reduced. Costs can be further reduced by using a controller that requires a minimal number of power train components and supports synchronous rectification, resulting in efficient, low EMI, wide input voltage range solutions.

References

[1] Robert W. Erickson and Dragan Maksimovic. *Fundamentals of Power Electronics*, 3rd edition. Springer Nature Switzerland AG, 2020.

[2] *Polymer, Tantalum, and Niobium Oxide Capacitors: Application Guidelines*. AVX Corporation.

About the Author

Victor Khasiev was a senior applications engineer at ADI with extensive experience in power electronics both in ac-to-dc and dc-to-dc conversion. He holds two patents and has written multiple articles. These articles are related to using ADI semiconductors in automotive and industrial applications. Topics cover step-up, step-down, SEPIC, positive-to-negative, negative-to-negative, flyback, and forward converters, and bidirectional backup supplies. His patents include efficient power factor correction solutions and advanced gate drivers. Victor enjoys supporting ADI customers by answering questions about ADI products, designing and verifying power supply schematics, laying out printed circuit boards, and troubleshooting and participating in testing final systems.

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