

# DESIGN NOTES

## Industry's First 4-Switch Buck-Boost Controller Achieves Highest Efficiency Using a Single Inductor – Design Note 369

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### Introduction

One of the most common DC/DC converter problems is generating a regulated voltage that falls somewhere in the middle of a wide range of input voltages. When the input voltage can be above, below or equal to the output voltage, the converter must perform step-down and step-up functions. Unlike solutions requiring bulky transformers, the LTC<sup>®</sup>3780 meets these requirements in the most compact and efficient manner, using just one off-the-shelf inductor and a single current sense resistor.

The LTC3780 uses a constant frequency current mode architecture which allows seamless transitions between buck, boost and buck/boost modes with a wide 4V to 30V (36V maximum) input and output range. Burst Mode<sup>®</sup> operation and skip cycle mode provide high efficiency operation at light loads, while forced continuous mode and discontinuous mode reduce output voltage ripple by operating at a constant frequency. A soft-start feature reduces output overshoot and inrush currents during start-up. Overvoltage protection, current foldback and on-time limitation provide protection for fault conditions, including short circuit, overvoltage and inductor current runaway. The LTC3780 is available in low profile 24-pin TSSOP and 32-lead 5mm × 5mm QFN packages.

### High Efficiency 4-Switch Buck-Boost Converter

Figure 1 shows a simplified LTC3780 4-switch buck-boost converter. When  $V_{IN}$  exceeds  $V_{OUT}$ , the LTC3780 operates in buck mode. With switch D on and switch C off, switches A and B turn on and turn off alternately, as they would in a typical synchronous buck regulator. Conversely, when  $V_{IN}$  is lower than  $V_{OUT}$ , the LTC3780 operates in boost mode. With switch A on and synchronous switch B off, switch C and synchronous switch D turn on and turn off alternately, behaving as a typical synchronous boost regulator.

When  $V_{IN}$  is close to  $V_{OUT}$ , the controller is in buck-boost mode. Switches A and D are on for most of each period. Brief connections between  $V_{IN}$  and ground, and  $V_{OUT}$  and ground, are made through the inductor and switches B-D and A-C to regulate the output voltage. In buck-boost mode, inductor peak-to-peak current is much lower than that of SEPIC converters and traditional buck/boost converters. Figure 2 shows the inductor current and switch node waveforms.

Low inductor ripple current and the use of synchronous rectifiers allow the LTC3780 to achieve very high

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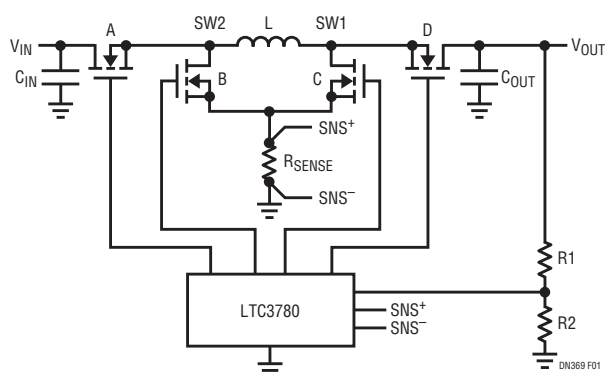


Figure 1. 4-Switch Buck-Boost Converter

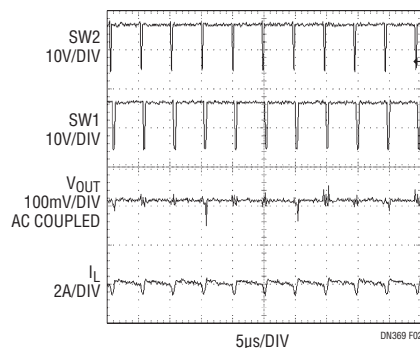
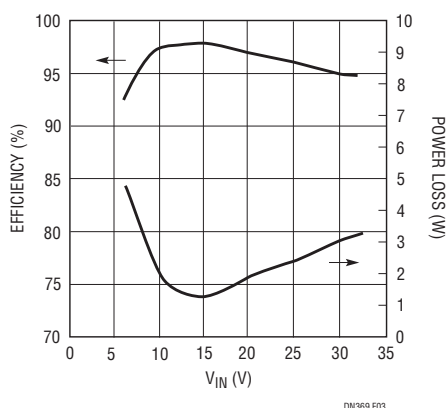


Figure 2. Switch Nodes and Inductor Current Waveforms ( $V_{IN} = V_{OUT} = 12V$ )

efficiency over a wide  $V_{IN}$  range. When the input and output voltages are both 12V, the 4-switch buck-boost has 99% efficiency at 2A load and 98% at its maximum 5A load (Figure 3). With its current mode control architecture, the converter has excellent load and line transition response, minimizing the required filter capacitance and simplifying loop compensation. As a result, very little filter capacitance is required. The single sense resistor structure dissipates little power (compared with multiple resistor sensing schemes) and provides consistent current information for short circuit and overcurrent protection.



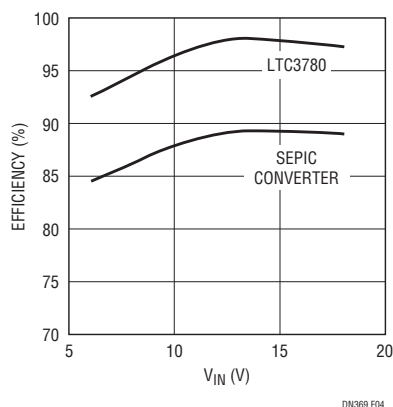
**Figure 3. Efficiency and Power Loss ( $V_{OUT} = 12V$ ,  $I_{LOAD} = 5A$ )**

### Replacing a SEPIC Converter

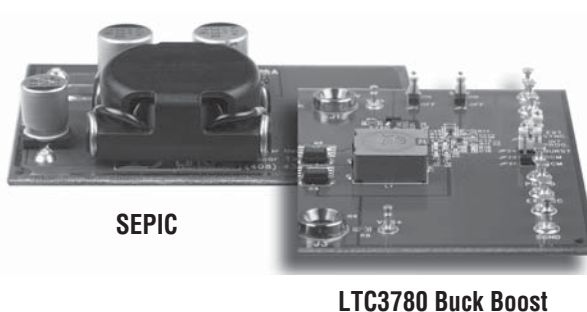
This single inductor buck-boost approach has high power density and high efficiency. Compared with a coupled inductor SEPIC converter, its efficiency can be 8% higher. Figure 4 shows the efficiency comparison between the LTC3780 4-switch buck-boost and a typical SEPIC converter. Note that a SEPIC converter has a maximum switch voltage equal to the input voltage plus the output voltage. So for a given maximum input voltage, a SEPIC would dictate the use of a higher voltage external switch than is required with the LTC3780. Moreover, the typical inductor occupies about 1/5th of a SEPIC transformer's footprint, less than 1/15th the volume and less than one-half the profile, as shown in Figure 5.

### Protection for Boost Operation

The basic boost regulator topology provides no short circuit protection. When the output is pulled low, a large current can flow from the input to the output.



**Figure 4. Efficiency Comparison Between the LTC3780 and a SEPIC Converter ( $V_{OUT} = 12V$ ,  $I_{LOAD} = 5A$ )**



**Figure 5. Inductor Size Comparison Between the LTC3780 5A/12V Converter (Right, 12.7mm × 12.7mm × 4mm) and a Typical SEPIC (Left, 21mm × 21mm × 10.8mm)**

Without shutting down the whole circuit, the LTC3780 circumvents this problem by forcing the converter into buck mode and using current foldback to limit the inductor current.

### Simplify

For certain applications such as those requiring low current or not requiring current sinking, Switch D can be replaced with a Schottky diode. This simplified topology has approximately 2% lower efficiency.

### Conclusion

The LTC3780 is a constant frequency current mode buck-boost switching regulator controller that allows the input voltage to be above, below or equal to the output voltage. Its high efficiency, high power density and single inductor topology make this product ideal for automotive, telecom, medical and battery-powered systems.

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