TECHNICAL ARTICLE

Configuring Four-Switch Buck-Boost μModule Regulators for Versatile Applications: Step-Up, Step-Down, or Inverting Output

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Abstract

Many power conversion applications need to support wide input or output voltage ranges. Analog Devices has a high current, high efficiency, fully integrated four-switch buck-boost power module for such applications. This device integrates the controller, MOSFETs, power inductor, and capacitors within an advanced 3D integrated package, enabling compact design and robust performance. This μModule® regulator delivers high power density, exceptional efficiency, and excellent thermal performance across a wide range of input and output voltages. This article further highlights the versatility, demonstrating its ability to operate in various topologies, including buck (step-down), boost (step-up), and inverting buck-boost configurations for negative output applications.

Utilize the Four-Switch Buck-Boost Topology as a Buck (Step-Down) Regulator

ADI has introduced multiple 40 V step-down μModule regulators. Figure 1 highlights the available regulators capable of supporting a maximum load current exceeding 4 A. However, these buck regulators are limited in their voltage and current range. By employing the newly released four-switch buck-boost μModule regulator, the LTM4712, as a step-down converter, the operating range can be significantly extended, simplifying system design for customers.

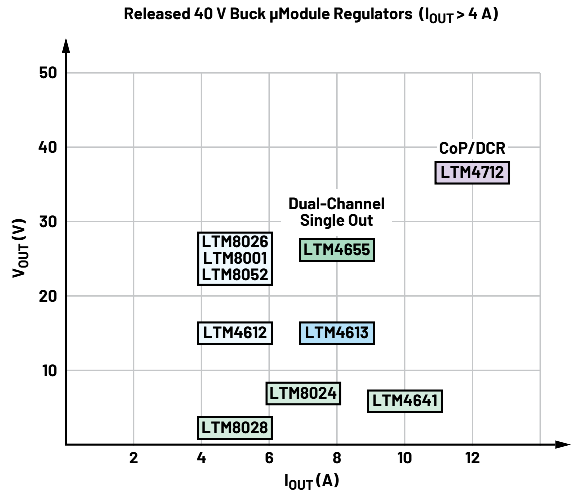

Figure 1. 40 V_{IN} (>4 A) buck μModule regulators.

The four-switch buck-boost converter can be effortlessly configured as a buck converter without requiring any special adjustments. When V_{IN} > V_{OUT}, the internal controller keeps power FET M3 off and M4 continuously on. M1 and M2 regulate the output, operating like a standard buck converter, as illustrated in Figure 2. Compared to the previous step-down regulator, the LTM4613, the new device achieves superior power efficiency, despite the additional conduction loss introduced by M4, as shown in Figure 3. This improvement is made possible by advancements in MOSFET and inductor technologies.

The thermal comparison without forced cooling, shown in Table 1, underscores the efficiency advantage of the buck-boost converter. Despite delivering significantly higher power than the buck regulator, the new device operates at a cooler temperature with a similar footprint area.

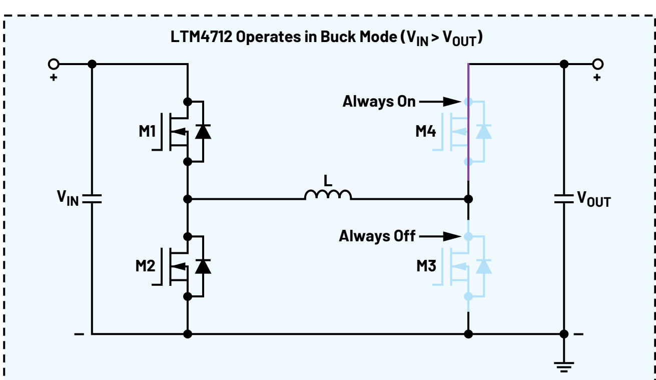

Figure 2. Utilizing as a buck regulator.

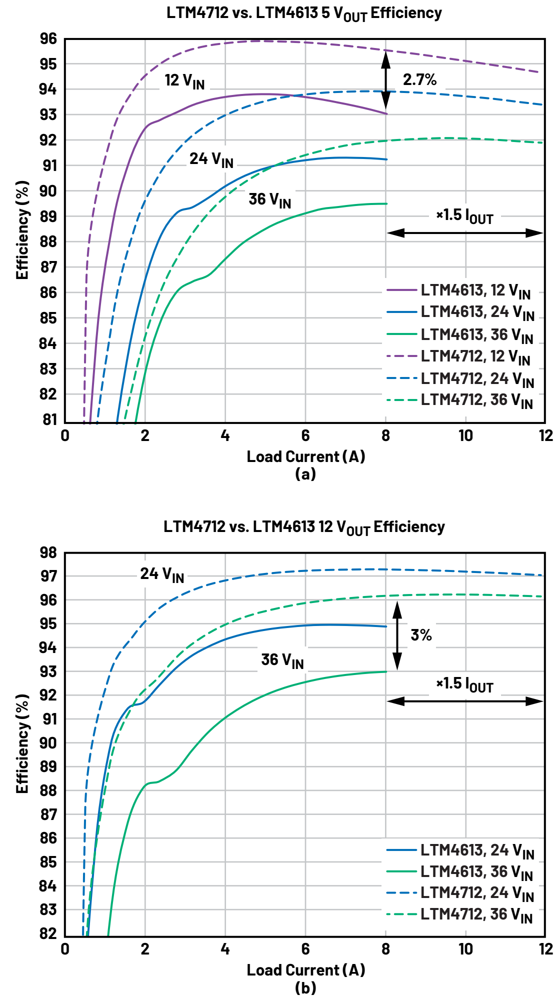

Figure 3. Buck mode efficiency and current capability comparison: (a) 5 V_{OUT} efficiency and (b) 12 V_{OUT} efficiency.

Table 1. Buck Mode Thermal Performance Comparison, TA = 25°C, No Forced Cooling

Operating Condition	Parameters	LTM4712	LTM4613
12 V_{IN}/5 V_{OUT}	Max I_{OUT}	12 A	8 A
	Efficiency at I_{MAX}	94.7%	93%
	Thermal at I_{MAX}	58°C	70°C
36 V_{IN}/12 V_{OUT}	Max I_{OUT}	12 A	6 A
	Efficiency at I_{MAX}	96.2%	93%
	Thermal at I_{MAX}	80°C	101°C

Utilize Four-Switch Buck-Boost as a Boost (Step-Up) Regulator

As shown in Figure 4, ADI has previously released one 40 V boost μModule regulator. While the LTM4656 supports a maximum current of 4 A, the newly released four-switch buck-boost converter can handle a higher load current when it functions as a step-up regulator.

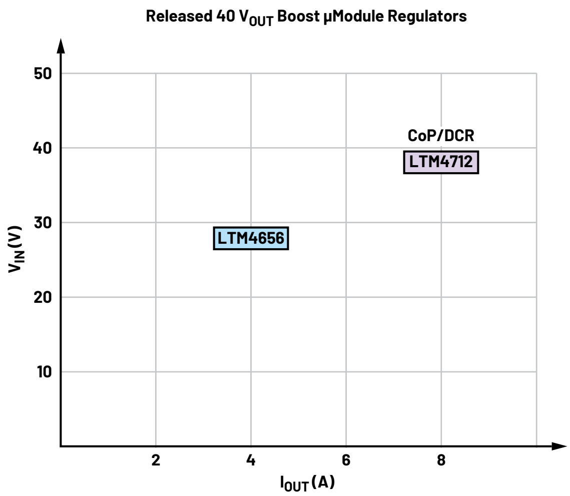

Figure 4. ADI 40 V boost regulator family.

When using the four-switch buck-boost converter in applications where $V_{IN} < V_{OUT}$, internal switch M1 remains on, while M2 stays off. M3 and M4 naturally regulate the output as a typical boost converter as shown in Figure 5. Unlike standard boost converters, which lack output short-circuit protection, the four-switch buck-boost offers inherent short-circuit protection. If the output is shorted to ground, M1 and M2 begin switching as a buck converter, limiting the current flowing from input to output. The maximum short circuit current is restricted by either the R_{SENSE} resistor placed in the input or output paths, or the peak inductor current limit, whichever is lower. In addition, during the initial fast V_{IN} ramping up stage, a conventional boost converter usually has uncontrolled, high inrush current through the boost diode to charge up C_{OUT}. As the four-switch buck-boost always starts in buck mode when V_{OUT} is low, its input inrush current is tightly controlled and limited by the soft start of the inductor current. In summary, the four-switch buck-boost offers a more reliable step-up converter than a conventional boost regulator.

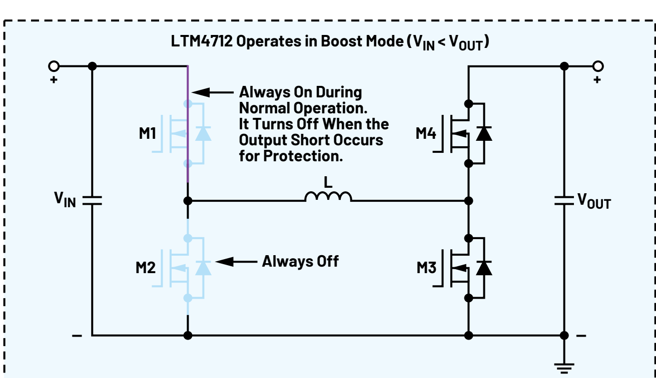

Figure 5. Utilizing as a boost regulator with inherent output short protection.

Figure 6 and Table 2 compare the efficiency, power capability, and thermal performance between the four-switch buck-boost μModule regulator and the buck μModule regulator. The first device demonstrates superior efficiency, extended current handling, and significantly better thermal performance. Both regulators share the same 16 mm × 16 mm footprint.

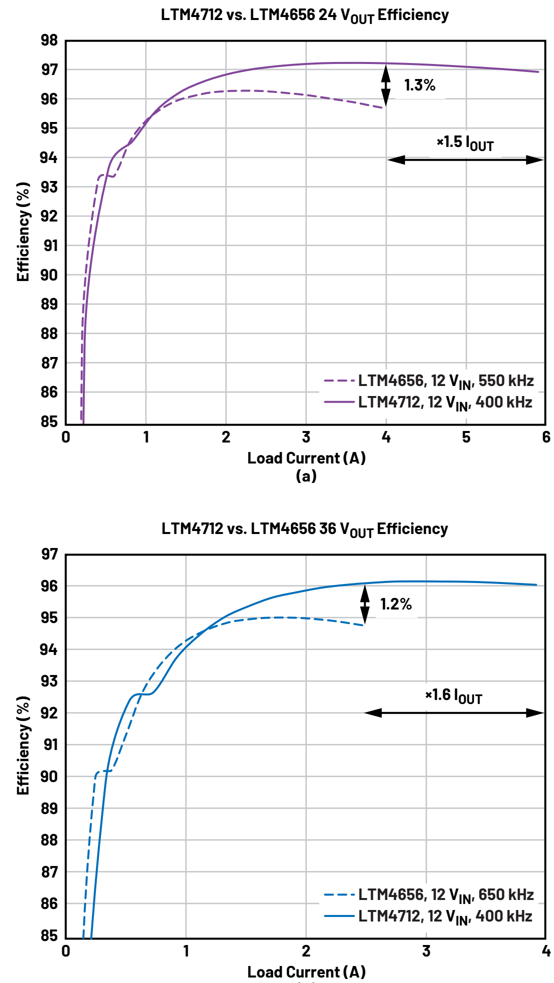

Figure 6. Boost mode efficiency and current capability comparison: (a) 24 V_{OUT} efficiency and (b) 36 V_{OUT} efficiency.

Table 2. Boost Mode Thermal Performance Comparison, TA = 25°C, No Forced Cooling

Operating Condition	Parameters	LTM4712	LTM4656
12 V_{IN}/24 V_{OUT}	Max I_{OUT}	6 A	4 A
	Efficiency at I_{MAX}	96.9%	95.7%
	Thermal at I_{MAX}	69°C	81°C
12 V_{IN}/36 V_{OUT}	Max I_{OUT}	4 A	2.5 A
	Efficiency at I_{MAX}	96.1%	94.8%
	Thermal at I_{MAX}	84°C	89°C

Utilize Four-Switch Buck-Boost as an Inverting Buck-Boost Regulator for Negative Output Voltage

Similar to standard buck converters, the four-switch buck-boost can also be configured in an inverting buck-boost topology for negative output applications. As shown in Figure 7, M1 and M2 switch complementary, with M3 off and M4 on during this operation. Note that the maximum voltage, $V_{MAX} = |V_{IN}|+|V_{OUT}|$, must be less than 40 V, which is the maximum voltage rating for the device. The magnitude of the DC through the inductor, I_L, is given by $I_L = I_{OUT}/(1-D)$, where D is the duty cycle of the phase leg with M1 and M2, and M1 is the primary switch.

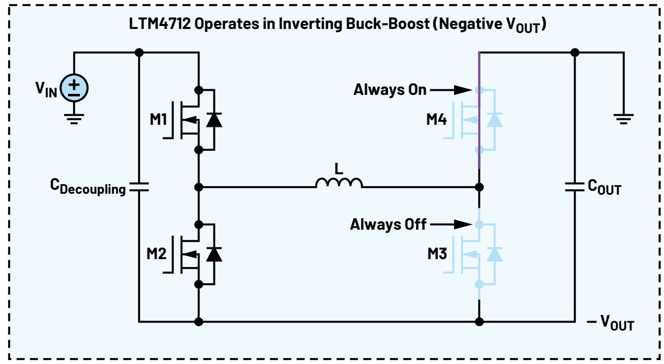

Figure 7. Configure as an inverting buck-boost regulator.

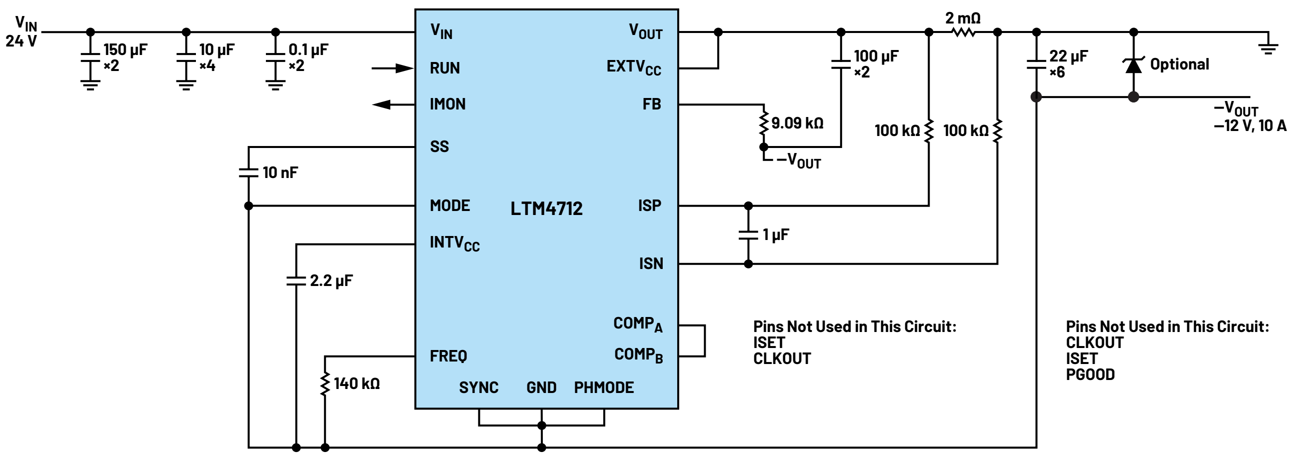

Figure 8. Example circuit of an inverting configuration.

Figure 8 illustrates an example circuit of the inverting configuration, designed for a 24 V input and –12 V output, capable of delivering up to 10 A of load current. Figure 9 presents the efficiency curves obtained from bench testing.

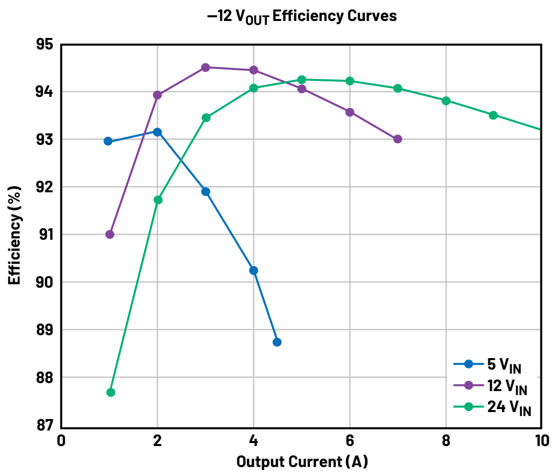

Figure 9. Bench tested efficiency curves for –12 V_{OUT}.

In the inverting buck-boost converter, the output voltage may rise slightly above zero during startup. This same behavior is observed when configuring the four-switch buck-boost regulator in inverting mode.

Figure 10 illustrates the mechanism behind the reversal of the output voltage during startup. When the input supply is turned on, but before all four MOSFETs begin switching, the input current starts charging the output capacitor in reverse through two paths: via the C_{IN} decoupling capacitors placed across M1 and M2, and through the $INTV_{CC}$ capacitor path. If C_{IN} or C_{INTVcc} are significantly larger than C_{OUT}, a higher reverse output voltage is likely to occur.

However, an inherent clamping circuit is present inside of the µModule regulator, as shown in Figure 11. V_{SD3} and V_{SD4} represent the source-to-drain voltages of M3 and M4, respectively. When $-V_{OUT} > V_{SD3} + V_{SD4}$, the body diodes of M3 and M4 conduct, taking over the charging current. These two body diodes create a natural clamping circuit. In other words, the maximum reverse output voltage is $V_{SD3} + V_{SD4}$.

Figure 12 displays the bench-tested reversed output voltage waveforms during startup. In Figure 12a, the magnitude of reversed $-V_{OUT}$ is approximately +0.75 V, with a limited C_{IN} (50 µF) presented in the circuit compared to C_{OUT} (330 µF). When increasing C_{IN} to 350 µF, a higher reserved $-V_{OUT}$ of +1.5 V is observed, as shown in Figure 12b.

The ratio of C_{IN} to C_{OUT} can be adjusted to minimize the positive output voltage. A smaller ratio results in a lower positive output voltage before reaching the internal clamping voltage, $V_{sd3} + V_{sd4}$. Additionally, an external low forward drop clamping Schottky diode can be added at the output to limit the positive voltage to a desired level, as shown in Figure 8.

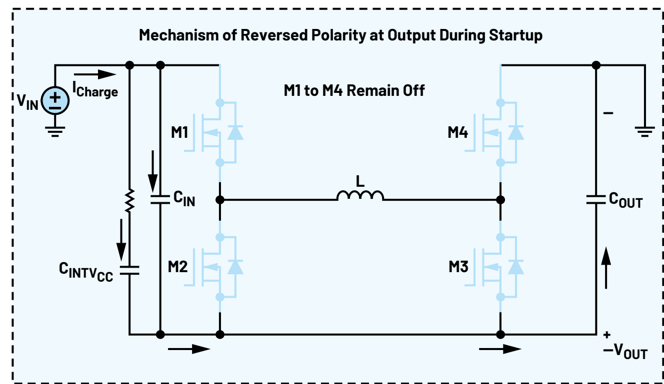

Figure 10. Charging current flow paths during startup.

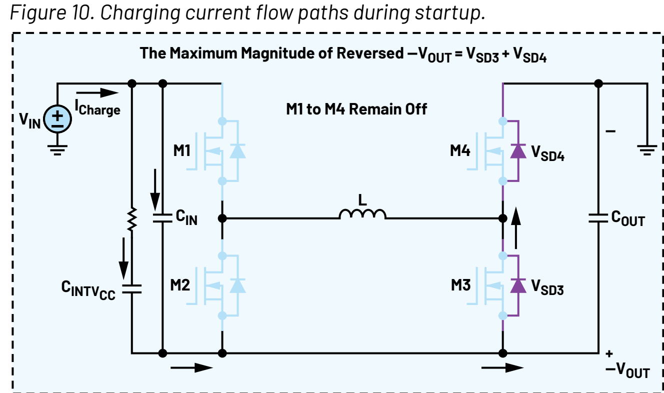

Figure 11. The natural clamping circuit in the four-switch buck-boost.

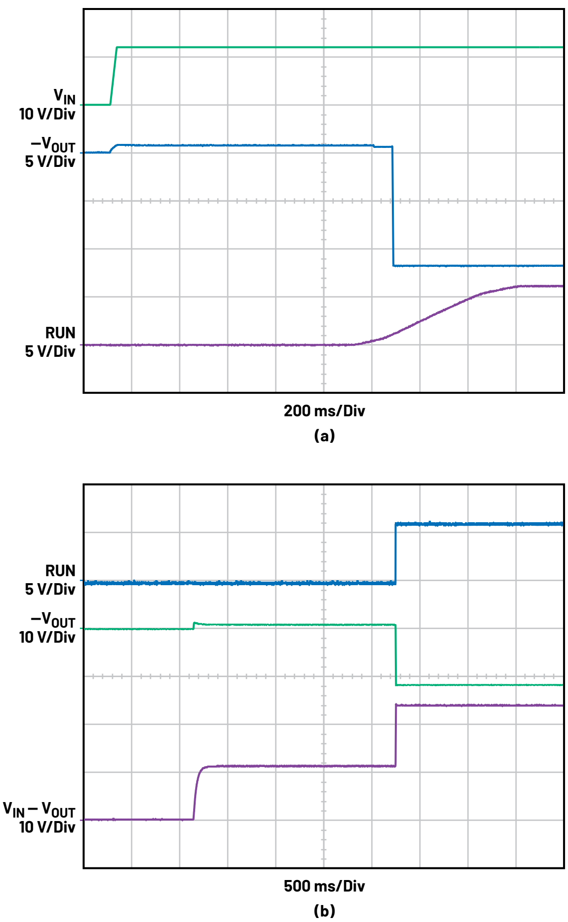

Figure 12. Reversed $-V_{OUT}$ waveforms during startup: (a) relatively small C_{IN} (50 µF) compared to C_{OUT} (330 µF) and (b) relatively large C_{IN} (350 µF) compared to C_{OUT} (330 µF).

Conclusion

The four-switch buck-boost regulator can naturally be used as either a step-down or step-up regulator without requiring any special configurations. Bench testing has verified that the newly released buck-boost µModule delivers the highest efficiency, best thermal performance, and extended current capability compared to other available buck or boost µModule regulators. Additionally, this four-switch buck-boost can be easily configured as an inverting buck-boost regulator for applications requiring a negative output. High efficiency has been confirmed through bench tests. This paper discusses the mechanism behind the momentarily reversed output voltage behavior, offering design guidelines and solutions to address it.

For comprehensive guidance on implementing the newly released four-switch buck-boost µModule regulator, it is recommended to refer to the data sheet and the associated evaluation kit design. It is also supported by the LTpowerCAD® design tool and LTspice® simulation tool. These resources provide valuable insights and specifications essential for optimizing the performance in diverse applications.

Reference

Jiang, Ling, Wesley Ballar, Anjan Panigrahy, and Henry Zhang. "µModule Regulator Achieves Highest Power Efficiency." Electronic Products, October 2024.

About the Authors

Ling Jiang received a Ph.D. degree in electrical engineering from the University of Tennessee at Knoxville in 2018. After graduating, she joined the Power Products Group at Analog Devices in the California Bay Area. Ling is currently an applications manager supporting μModule® products for multimarket applications.

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