AnalogDialogue

How to Apply DC-to-DC Step-Up/Step-Down Regulators Successfully

by **Ken Marasco**

DC-to-dc *switching converters* are used to change one dc voltage to another efficiently. High efficiency dc-to-dc converters come in three basic topologies: *step-down* (buck), *step-up* (boost), and *step-down/step-up* (buck/boost). The buck converter is used to generate a lower dc output voltage, the *boost* converter is used to generate a higher dc output voltage, and the buck/boost converter is used to generate an output voltage less than, greater than, or equal to the input voltage. This article focuses on how to successfully apply buck/boost dc-to-dc converters. Buck and boost converters have been covered individually in the June 2011 and September 2011 issues of *Analog Dialogue* and will not be reviewed in this article.

Figure 1 shows a typical low-power system powered from a single-cell *lithium-ion* (Li-Ion) battery. The battery's usable output varies from about 3.0 V when discharged to 4.2 V when fully charged. The system ICs require 1.8 V, 3.3 V, and 3.6 V for optimum operation. While the lithium-ion battery starts at 4.2 V and ends at 3.0 V, a buck/boost regulator can supply a constant 3.3 V, and a buck regulator or *low-dropout regulator* (LDO) could supply the 1.8 V, as the battery discharges. Conceivably a buck regulator or LDO could be used for the 3.3 V while the battery voltage is above 3.5 V, but the system would cease to operate when the battery voltage dropped below 3.5 V. Allowing the system to be turned off prematurely reduces the system's operating time before the battery needs to be recharged.

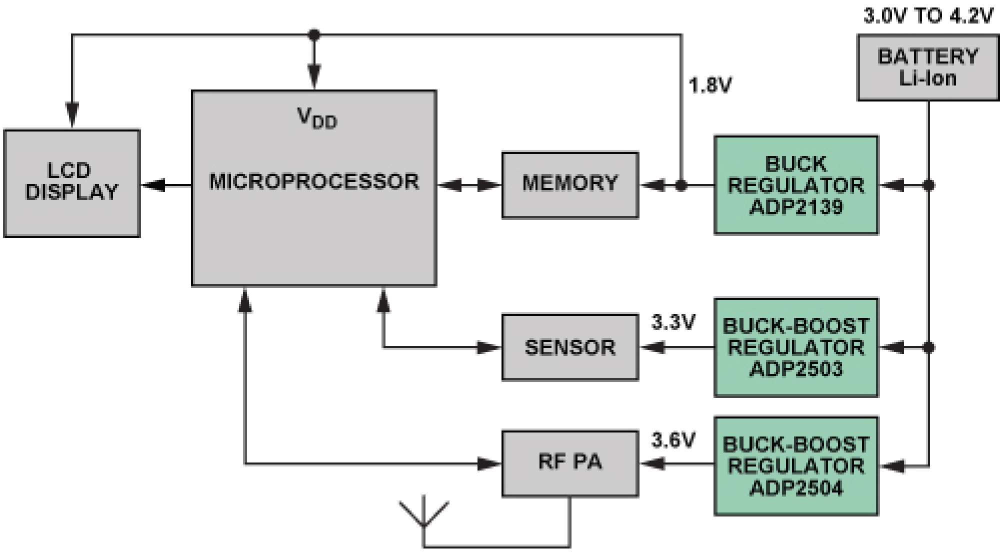

Figure 1. Typical low-power portable system.

Buck/boost regulators contain four switches, two capacitors, and an inductor, as shown in Figure 2. Today's low-power, high-efficiency buck/boost regulators reduce losses and improve efficiency by actively operating only two of the four switches when operating in buck- or boost mode.

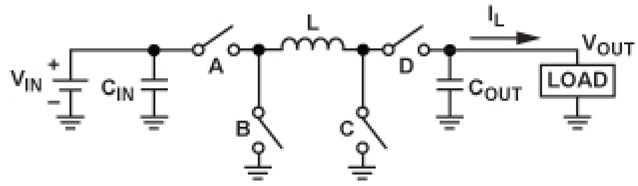

Figure 2. Buck/boost converter topology.

When V_{IN} is greater than V_{OUT}, Switch C is open and Switch D is closed. Switches A and B operate as in a standard buck regulator—as shown in Figure 3.

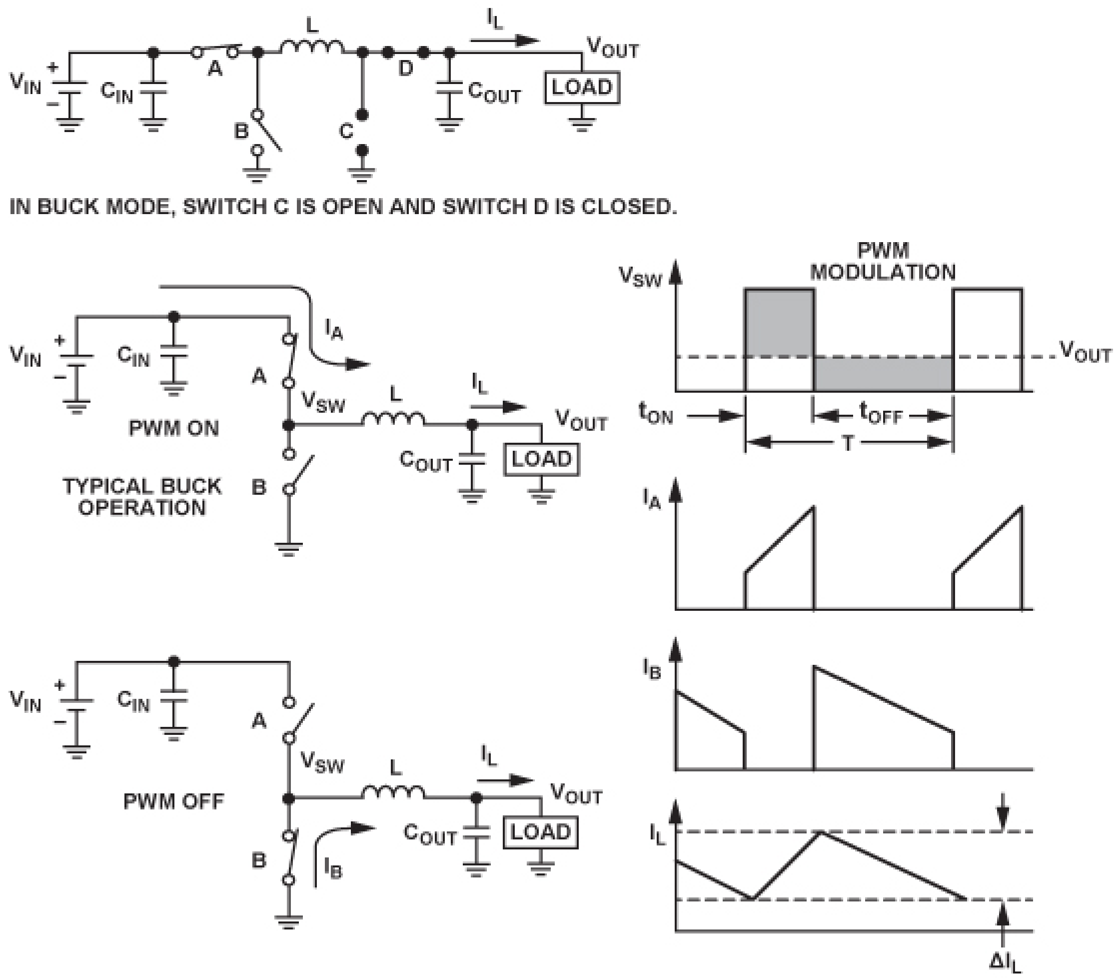

Figure 3. Buck mode when V_{IN} > V_{OUT}.

When V_{IN} is less than V_{OUT}, Switch B is open and Switch A is closed. Switches C and D operate as in a boost regulator—as shown in Figure 4. The most difficult operating mode is when V_{IN} is in the range of V_{OUT} ± 10%, and the regulator enters the *buck-boost* mode. In buck-boost mode, the two operations (buck and boost) take place during a switching cycle. Care must be taken to reduce losses, optimize efficiency, and eliminate instability due to mode switching. The objective is to maintain voltage regulation with minimal current ripple in the inductor to guarantee good transient performance.

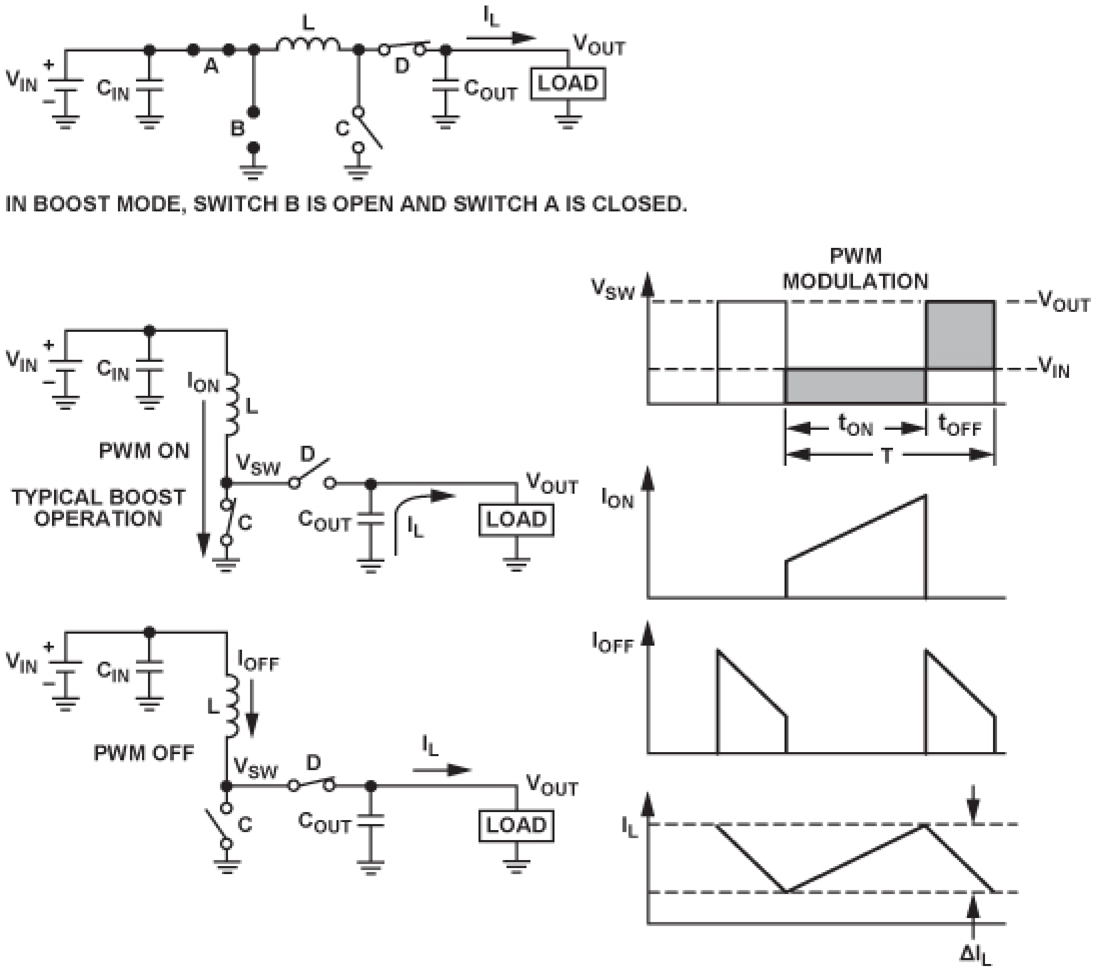

Figure 4. Boost mode when $V_{IN} < V_{OUT}$.

At high load currents, the buck-boost uses voltage or current-mode, fixed frequency pulse-width-modulation (PWM) control for optimal stability and transient response. To ensure the longest battery life in portable applications, a power-save mode reduces the switching frequency under light load conditions. For wireless and other low-noise applications, where variable-frequency power-save mode may cause interference, the addition of a logic control input to force fixed-frequency PWM operation under all load conditions is included.

Buck/Boost Regulators Improve System Efficiency

A large number of the portable systems in use today are powered by a single-cell rechargeable Li-Ion battery. As mentioned above, the battery will start from a fully charged 4.2 V and slowly discharge down to 3.0 V. When the battery’s output drops below 3.0 V, the system is turned off to protect the battery from damage due to extreme discharging. When a low-dropout regulator is used to generate a 3.3-V rail, the system will shut down at

$$V_{IN\,MIN} = V_{OUT} + V_{DROPOUT} = 3.3\text{ V} + 0.2\text{ V} = 3.5\text{ V}$$

employing only 70% of the battery's stored energy. However, using a buck/boost regulator, such as the ADP2503 or ADP2504, enables the system to continue operating down to minimum practical battery voltage. The ADP2503 and ADP2504 (*see* Appendix) are high-efficiency, low quiescent-current 600-mA and 1000-mA, step-up/step-down (buck/boost) dc-to-dc converters that operate with input voltages greater than, less than, or equal to the regulated output voltage. The power switches are internal, minimizing the number of external components and printed-circuit-board (PCB) area. This approach allows the system to operate all the way down to 3.0 V, using most of the battery's stored energy, increasing the system's operating time before a battery recharge is required.

To save energy in portable systems, various subsystems—such as the microprocessor, display backlighting, and power amplifiers—when not in use, are frequently switched between full *on* and *sleep* mode, which can induce large voltage transients on the battery supply line. These transients can cause the battery's output voltage to briefly drop below 3.0 V and trigger the *battery low* warning, causing the system to turn off before the battery is completely discharged. The buck/boost solution will tolerate voltage swings as low as 2.3 V, helping to maintain the system's potential operating time.

Buck/Boost Regulator Key Specifications and Definitions

Output voltage range options: Buck/boost regulators are available with specified fixed output voltages or in an option that allows the output voltage to be programmed via an external resistance divider.

Ground or quiescent current: DC bias current not available for the load (I_q). The lower the Iq, the better the efficiency, but I_q can be specified under many conditions, including switched *off*, zero load, pulse-frequency mode (PFM), or pulse-width mode (PWM) operation, so it is best to look at operating efficiency at specific operating voltages and load currents when determining the best boost regulator for the application.

Shutdown current: The input current consumed when the enable pin has been set to *off*. Low I_q is important for long standby times when a battery-powered device is in sleep mode. During logic-controlled shutdown, the input is disconnected from the output and draws less than 1 µA from the input source.

Soft start: It is important to have a *soft-start* function that ramps the output voltage in a controlled manner to prevent excessive output voltage overshoot at startup.

Switching frequency: Low-power buck/boost converters generally operate between 500 kHz and 3 MHz. Higher switching frequencies allow the use of smaller inductors and reduce the required PCB area, but efficiency is decreased by approximately 2% for every doubling of the switching frequency.

Thermal shutdown (TSD): If the junction temperature rises above the specified limit, the thermal shutdown circuit turns the regulator off. Consistently high junction temperatures can be the result of high-current operation, poor circuit-board cooling, and/or high ambient temperature. The protection circuit includes hysteresis so that, after thermal shutdown, the device will not return to normal operation until the on-chip temperature drops below the preset limit.

Conclusion

Low-power buck-boost regulators with proven performance and in-depth support take the worry out of designs using switching dc-to-dc converters. In addition to a comprehensive data sheet, with design calculations available in its applications section, the ADIsimPower design tool simplifies the task for the end user. Regulator selection guides, data sheets, and application notes can be found at http://www.analog.com/en/power-management/products/index.html.

For help, visit the Engineering Zone at http://ez.analog.com/index.jspa; or phone or email an application engineer at Analog Devices.

References

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Appendix

Buck-Boost DC-to-DC Switching Converters Operate at 2.5 MHz

The ADP2503 and ADP2504 are high-efficiency, low quiescent-current step-up/step-down dc-to-dc converters that can operate at input voltages greater than, less than, or equal to the regulated output voltage. The power switches and synchronous rectifiers are internal to minimize external part count. At high load currents, they use a current-mode, fixed-frequency pulse-width modulation (PWM) control scheme for optimal stability and transient response. To ensure the longest battery life in portable applications, the devices have an optional power-save mode that reduces the switching frequency under light load conditions. For wireless and other low-noise applications where variable frequency power-save mode may cause interference, the logic control input sync forces fixed-frequency PWM operation under all load conditions.

The ADP2503 and ADP2504 can run from input voltages between 2.3 V and 5.5 V, allowing a single lithium or lithium polymer cell, multiple alkaline or NiMH cells, PCMCIA, USB, and other standard power sources. Various fixed-output options are available, or using the adjustable model, the output voltage can be programmed through an external resistor divider. Compensation is internal to minimize the number of external components.

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