

How to Apply DC-to-DC Step-Down/Step-Up (Buck/Boost) Regulators

by Ken Marasco

INTRODUCTION

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 application note focuses on how to successfully apply buck/boost dc-to-dc converters. Buck and boost converters are described individually in the [AN-1125 Application Note, How to Apply DC-to-DC Step-Down \(Buck\) Regulators](#), and the [AN-1132 Application Note, How to Apply DC-to-DC Step-Up \(Boost\) Regulators](#).

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. Whereas 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 (LDO) regulator can supply 1.8 V, as the battery discharges. A buck regulator or LDO can conceivably 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 drops below 3.5 V. Allowing the system to be turned off prematurely reduces the system's operating time before the battery must be recharged.

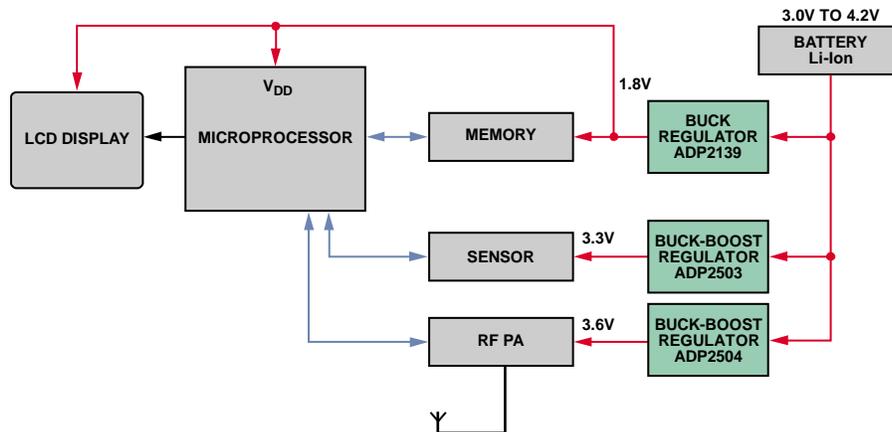


Figure 1. Typical Low Power Portable System

10542-001

TABLE OF CONTENTS

Introduction	1	Soft Start	6
Revision History	2	Switching Frequency	6
Buck/Boost Regulators.....	3	Thermal Shutdown (TSD)	6
Buck/Boost Regulators Improve System Efficiency.....	5	Buck/Boost DC-to-DC Switching Converters Operate at	
Buck/Boost Regulator Key Specifications and Definitions.....	6	5 MHz.....	7
Output Voltage Range Options.....	6	Conclusion.....	8
Ground or Quiescent Current	6	References.....	8
Shutdown Current	6		

REVISION HISTORY

4/12—Revision 0: Initial Version

BUCK/BOOST REGULATORS

Buck/boost regulators contain four switches, two capacitors, and an inductor, as shown in Figure 2. Current 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.

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

When V_{IN} is less than V_{OUT} , Switch B is open and Switch A is closed. Switch C and Switch 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 $V_{OUT} \pm 10\%$ 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.

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.

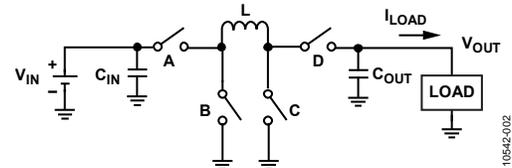


Figure 2. Buck/Boost Converter Topology

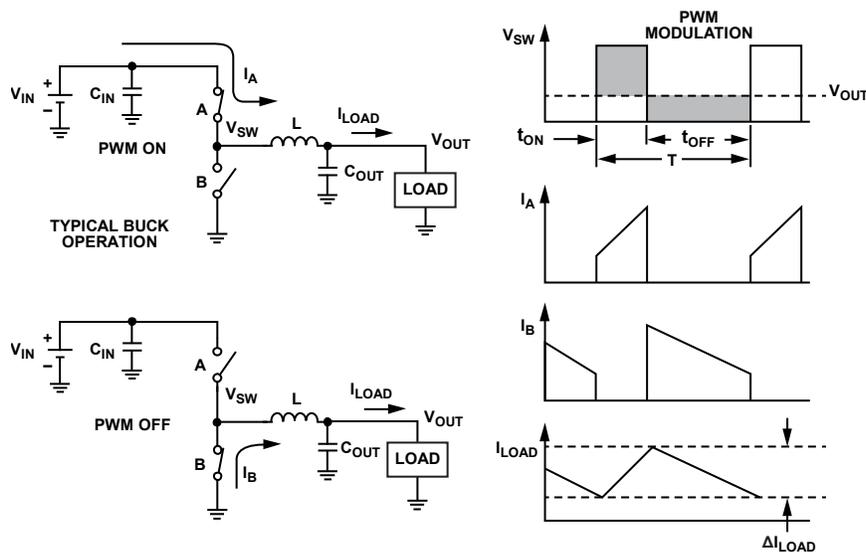
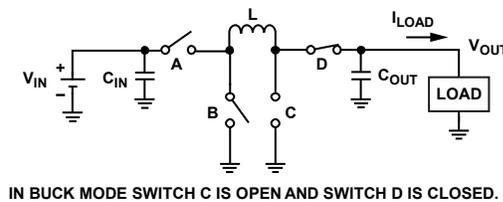


Figure 3. Buck Mode When $V_{IN} > V_{OUT}$

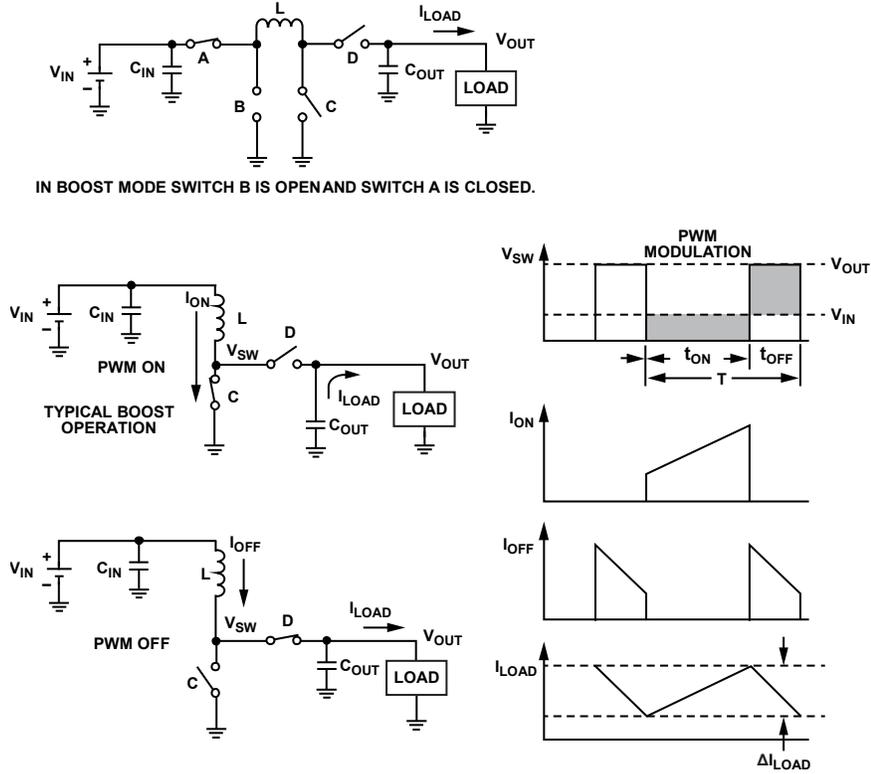


Figure 4. Boost Mode When $V_{IN} < V_{OUT}$

10542-004

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. The battery starts from a fully charged 4.2 V and slowly discharges down to 3.0 V. When the battery output drops below 3.0 V, the system turns 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 shuts down at

$$V_{INMIN} = V_{OUT} + V_{DROPOUT} = 3.3 \text{ V} + 0.2 \text{ V} = 3.5 \text{ V}$$

using 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 the minimum practical battery voltage. The [ADP2503](#) and [ADP2504](#) (see the Buck/Boost DC-to-DC Switching Converters Operate at 2.5 MHz section) are high efficiency, low quiescent current, 600 mA and 1000 mA, step-down/step-up (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 thus reducing 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 and 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 power-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 low battery warning, causing the system to turn off before the battery is completely discharged. The buck/boost solution tolerates 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

Ground current is the dc bias current not available for the load (I_Q). The lower the I_Q is, the better the efficiency, but I_Q can be specified under many conditions, including switched off, zero load, pulse frequency modulation (PFM), and pulse-width modulation (PWM) operation. It is, therefore, best to examine operating efficiency at specific operating voltages and load currents when determining the best boost regulator for the application.

SHUTDOWN CURRENT

Shutdown current is 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 does not return to normal operation until the on-chip temperature drops below the preset limit.

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

a 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.

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 [ADP2503/ADP2504](#) data sheet with design calculations available, the [ADIsimPower™](#) design tool simplifies the task for the end user. Regulator selection guides, data sheets, and application notes can be found at www.analog.com/power-management.

For help, visit EngineerZone™ at <http://ez.analog.com>, or phone or email an application engineer at Analog Devices.

REFERENCES

Marasco, Ken. AN-1125 Application Note. *How to Apply DC-to-DC Step-Down (Buck) Regulators*. Analog Devices, Inc., 2011.

Marasco, Ken. AN-1132 Application Note. *How to Apply DC-to-DC Step-Up (Boost) Regulators*. Analog Devices, Inc., 2011.

Marasco, Ken. AN-1072 Application Note. *How to Successfully Apply Low-Dropout Regulators*. Analog Devices, Inc., 2010.

<http://www.analog.com/ADIsimPower>

<http://www.analog.com/power-management>

http://www.analog.com/switching_controllers

<http://www.analog.com/switching-regulators>