

How to Apply DC-to-DC Step-Up (Boost) Regulators Successfully

By Ken Marasco

Power for portable electronic devices such as smartphones, GPS navigation systems, and tablets can come from low-voltage solar panels, batteries, or ac-to-dc power supplies. Battery-powered systems often stack cells in series to achieve higher voltages, but this is not always possible due to a lack of space. *Switching converters* use an inductor's magnetic field to alternately store energy and release it to the load at a different voltage. With low losses they are a good choice for high efficiency. Capacitors connected to the converter's output reduce output voltage ripple. *Boost*, or *step-up* converters—covered here—provide higher voltage; *buck*, or *step-down* converters—covered in a [previous article](#)¹—provide lower output voltage. Switching converters that include internal FETs as switches are called *switching regulators*,² while devices requiring external FETs are called *switching controllers*.³

Figure 1 shows a typical low-power system powered from two series-connected AA batteries. The battery's usable output varies from about 1.8 V to 3.4 V, whereas the ICs require 1.8 V and 5.0 V to operate. Boost converters, which can step up the voltage without increasing the number of cells, power the WLED backlights, micro hard disk drives, audio, and USB peripherals, while a buck converter powers the microprocessor, memory, and display.

The inductor's tendency to resist changes in current enables the boost function. When charging, the inductor acts as a load and stores energy; when discharging, it acts as an energy source. The voltage produced during the discharge phase is related to the current's rate of change, not to the original charging voltage, thus allowing different input and output voltage levels.

Boost regulators consist of two switches, two capacitors, and an inductor, as shown in Figure 2. Nonoverlapping switch drives ensure that only one switch is on at a time to avoid unwanted shoot-through current. In Phase 1 (t_{ON}), Switch B is open and

Switch A is closed. The inductor is connected to ground, so current flows from V_{IN} to ground. The current increases due to the positive voltage across the inductor, and energy is stored in the inductor. In Phase 2 (t_{OFF}), Switch A is open and Switch B is closed. The inductor is connected to the load, so current flows from V_{IN} to the load. The current decreases due to the negative voltage across the inductor, and energy stored in the inductor is discharged into the load.

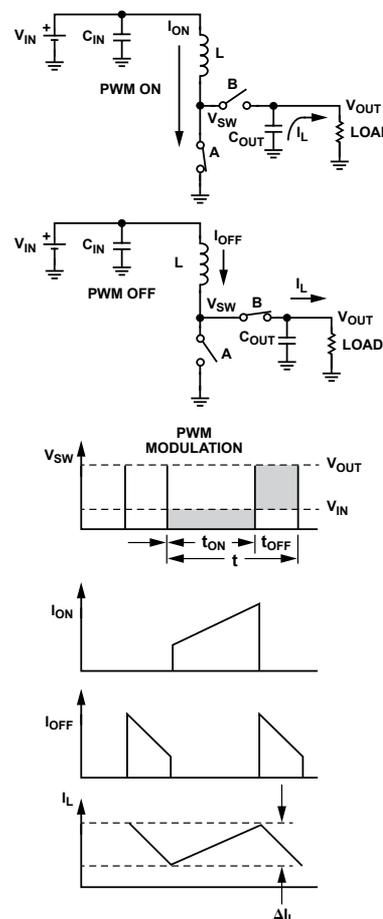


Figure 2. Buck converter topology and operating waveforms.

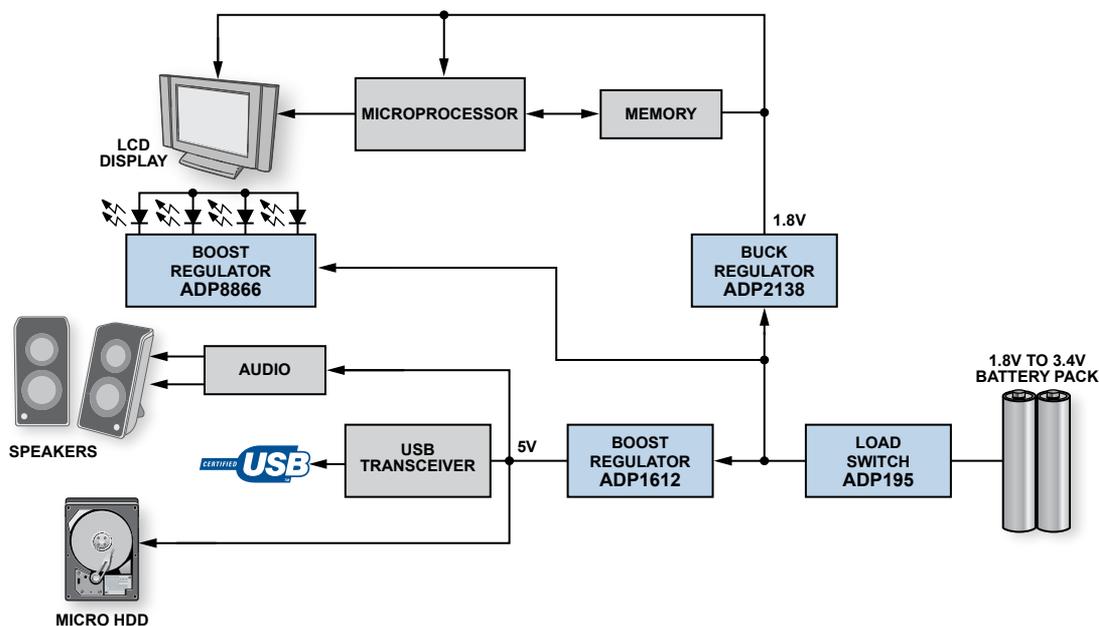


Figure 1. Typical low-power portable system.

Note that the switching regulator operation can be continuous or discontinuous. When operating in *continuous conduction mode* (CCM), the inductor current never drops to zero; when operating in *discontinuous conduction mode* (DCM), the inductor current can drop to zero. The *current ripple*, shown as ΔI_L in Figure 2, is calculated using $\Delta I_L = (V_{IN} \times t_{ON})/L$. The average inductor current flows into the load, while the ripple current flows into the output capacitor.

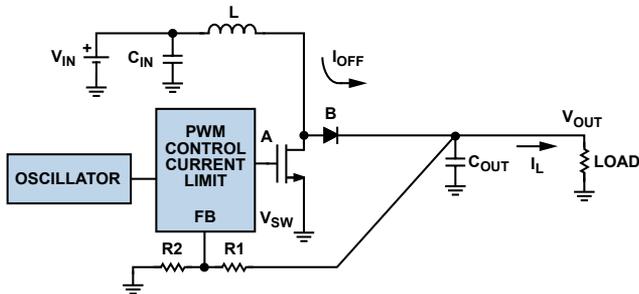


Figure 3. Boost regulator integrates oscillator, PWM control loop, and switching FETs.

Regulators that use a Schottky diode in place of Switch B are defined as *asynchronous* (or nonsynchronous), while regulators that use a FET as Switch B are defined as *synchronous*. In Figure 3, Switches A and B have been implemented with an internal NFET and an external Schottky diode, respectively, to create an asynchronous boost regulator. For low-power applications requiring load isolation and low shutdown current, external FETs can be added, as shown in Figure 4. Driving the device's EN pin below 0.3 V shuts down the regulator and completely disconnects the input from the output.

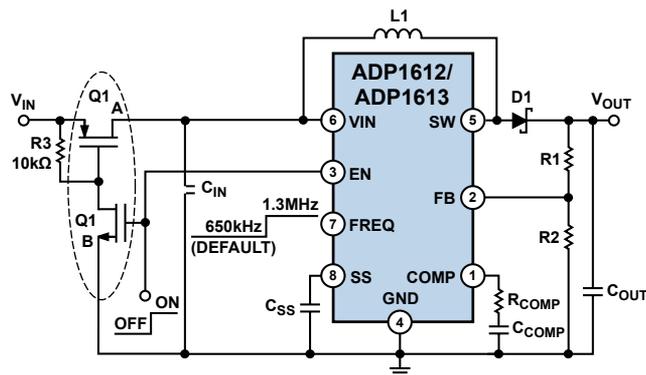


Figure 4. ADP1612/ADP1613 typical applications circuit.

Modern low-power synchronous buck regulators use pulse-width modulation (PWM) as the primary operating mode. PWM holds the frequency constant and varies the pulse width (t_{ON}) to adjust the output voltage. The average power delivered is proportional to the duty cycle, D , making this an efficient way to provide power to a load.

$$D = \frac{t_{ON}}{t_{ON} + t_{OFF}} = \frac{V_{OUT} - V_{IN}}{V_{OUT}}$$

As an example, for a desired output voltage of 15 V and an available input voltage of 5 V,

$$D = (15 - 5)/15 = 0.67 \text{ or } 67\%.$$

Energy is conserved, so the input power must equal the power delivered to the load minus any losses. Assuming very efficient conversion, the small amount of power lost can be omitted from the basic power calculations. The input current can thus be approximated by

$$I_{IN} = (V_{OUT}/V_{IN}) \times I_{OUT}$$

For example, if the load current is 300 mA at 15 V, $I_{IN} = 900$ mA at 5 V—three times the output current. Therefore, the available load current decreases as the boost voltage increases.

Boost converters use either voltage- or current feedback to regulate the selected output voltage; the control loop enables the output to maintain regulation in response to load changes. Low power boost regulators generally operate between 600 kHz and 2 MHz. The higher switching frequencies allow use of smaller inductors, but the efficiency drops by approximately 2% with every doubling of the switching frequency. In the ADP1612 and ADP1613 boost converters (see Appendix), the switching frequency is pin-selectable, operating at 650 kHz for highest efficiency or at 1.3 MHz for smallest external components. Connect FREQ to GND for 650-kHz operation or to VIN for 1.3-MHz operation.

The inductor, a key component of the boost regulator, stores energy during the *on* time of the power switch and transfers that energy to the output through the output rectifier during the *off* time. To balance the trade-offs between low inductor current ripple and high efficiency, the ADP1612/ADP1613 data sheet recommends inductance values in the 4.7- μ H to 22- μ H range. In general, a lower value inductor has a higher saturation current and a lower series resistance for a given physical size, but lower inductance results in higher peak currents that can lead to reduced efficiency, higher ripple, and increased noise. It is often better to run the boost in discontinuous conduction mode to reduce the inductor size and improve stability. The peak inductor current (the maximum input current plus half the inductor ripple current) must be lower than the rated saturation current of the inductor; and the maximum dc input current to the regulator must be less than the inductor's rms current rating.

Key Boost Regulator Specifications and Definitions

Input Voltage Range: A boost converter's input voltage range determines the lowest usable input supply voltage. The specifications may show a wide input voltage range, but the input voltage must be lower than V_{OUT} for efficient operation.

Ground or Quiescent Current: The dc bias current not delivered to the load (I_q). The lower the I_q the better the efficiency, but I_q can be specified under many conditions, including switching off, zero load, PFM operation, or PWM operation, so it is best to look at operating efficiency at specific operating voltages and load currents to determine 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.

Switch Duty Cycle: The operating duty cycle must be lower than the maximum duty cycle or the output voltage will not be regulated. For example, $D = (V_{OUT} - V_{IN})/V_{OUT}$. With $V_{IN} = 5$ V and $V_{OUT} = 15$ V, $D = 67\%$. The ADP1612 and ADP1613 have a maximum duty cycle of 90%.

Output Voltage Range: The range of output voltages the device will support. The boost converter's output voltage can be fixed or adjustable, using resistors to set the desired output voltage.

Current Limit: Boost converters usually specify peak current limit, not load current. Note that the greater the difference between V_{IN} and V_{OUT} , the lower the available load current. The peak current limit, input voltage, output voltage, switching frequency, and inductor value all set the maximum available output current.

Line Regulation: Line regulation is the change in output voltage caused by a change in the input voltage.

Load Regulation: Load regulation is the change in output voltage for a change in the output current.

Soft Start: It is important for boost regulators to have a *soft-start* function that ramps the output voltage in a controlled manner upon startup to prevent excessive output voltage overshoot at startup. The soft start of some boost converters can be adjusted by an external capacitor. As the soft-start capacitor charges, it limits the peak current allowed by the part. With adjustable soft start, the start-up time can be changed to meet system requirements.

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, or high ambient temperature. The protection circuit includes hysteresis so that the device will not return to normal operation until the on-chip temperature drops below the preset limit after thermal shutdown occurs.

Undervoltage Lockout (UVLO): If the input voltage is below the UVLO threshold, the IC automatically turns off the power switch and goes into a low-power mode. This prevents potentially erratic operation at low input voltages and prevents the power device from turning on when the circuitry cannot control it.

Conclusion

Low-power boost regulators take the worry out of switching dc-to-dc converter design by delivering a proven design. Design calculations are available in the applications section of the data sheet, and the ADIsimPower⁴ design tool simplifies the task for the end user. For additional information, please contact the applications engineers at Analog Devices, or visit the EngineerZone at ez.analog.com for help. Analog Devices boost-regulator selection guides, data sheets, and application notes can be found at www.analog.com/power.

References

(Information on all ADI components can be found at www.analog.com.)

- www.analog.com/library/analogDialogue/archives/45-06/buck_regulators.html.
- www.analog.com/en/power-management/switching-regulators-integrated-fet-switches/products/index.html.

³ www.analog.com/en/power-management/switching-controllers-external-switches/products/index.html.

⁴ <http://designtools.analog.com/dtPowerWeb/dtPowerMain.aspx>

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APPENDIX

Step-Up DC-to-DC Switching Converters Operate at 650 kHz/1300 kHz

The ADP1612 and ADP1613 step-up converters are capable of supplying over 150 mA at voltages as high as 20 V, while operating, respectively, with a single 1.8-V to 5.5-V and 2.5-V to 5.5-V supply. Integrating a 1.4-A/2.0-A, 0.13-Ω power switch with a current-mode, pulse-width modulated regulator, their output varies less than 1% with changes in input voltage, load current, and temperature. The operating frequency is pin-selectable and can be optimized for high efficiency or minimum external component size: at 650 kHz they provide 90% efficiency; at 1.3 MHz their circuit implementation occupies the smallest space, making them ideal for space-constrained environments in portable devices and liquid-crystal displays. The adjustable soft-start circuit prevents inrush currents, ensuring safe, predictable start-up conditions. The ADP1612 and ADP1613 consume 2.2 mA in the switching state, 700 μA in the nonswitching state, and 10 nA in *shutdown* mode. Available in 8-lead MSOP packages, they are specified from -40°C to +85°C and priced at \$1.50/\$1.20 in 1000s.

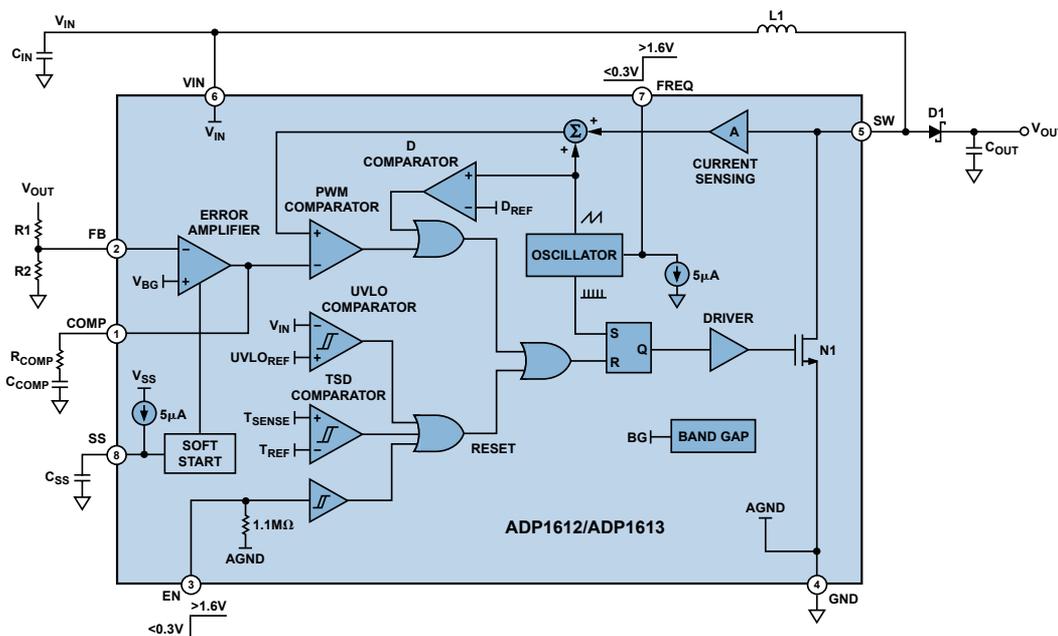


Figure A. ADP1612/ADP1613 functional block diagram.