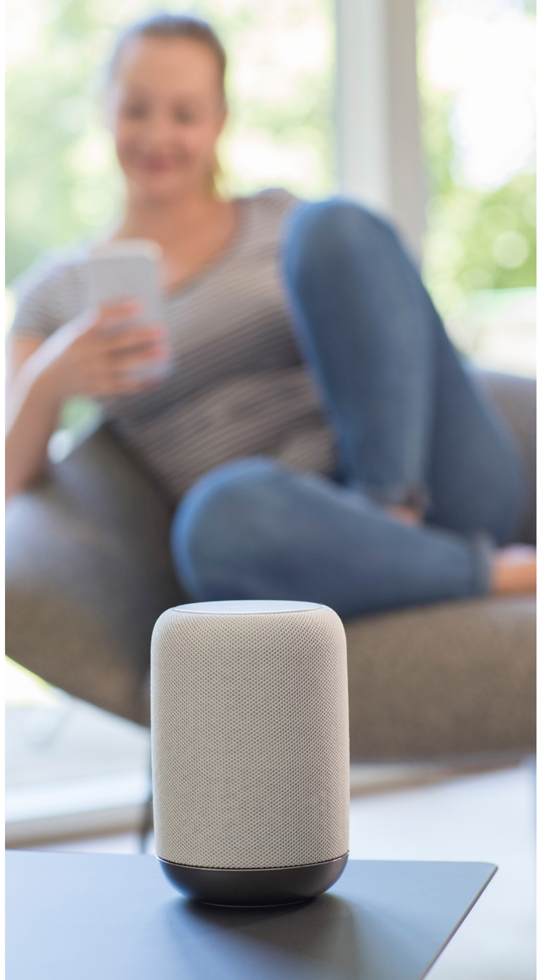

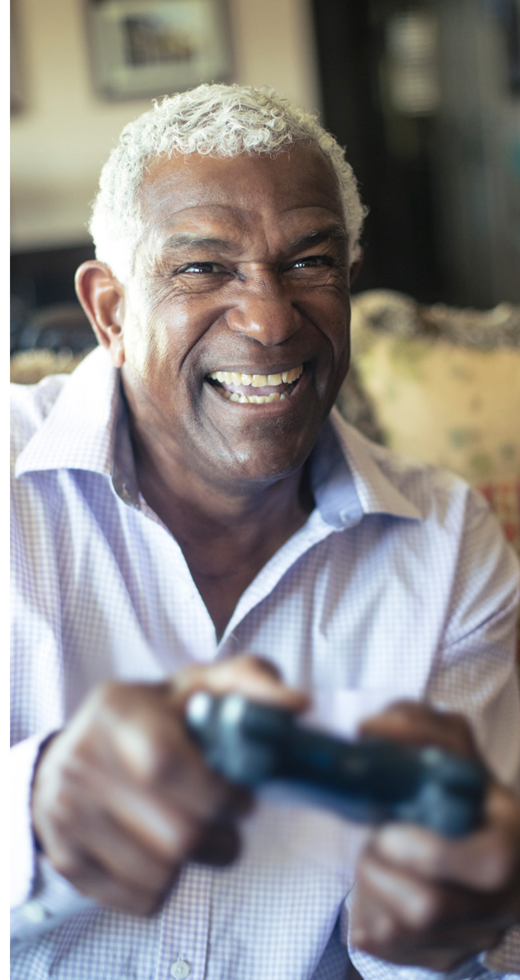

Generating Greater System Efficiency for Single- to Multi-Cell Battery-Powered Designs

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Abstract

Consumers want their electronics, including small, battery-powered devices, to operate for long periods between charges. The growing prevalence of devices powered by 1-, 2- and 3-cell lithium-ion batteries has placed a spotlight on the importance of efficient power conversion in the power supplies for these applications' hard-working processors. This white paper examines how dynamic power management capabilities in buck, or step-down, converters—key components of power supplies—can generate greater energy efficiency for the entire system. The paper also highlights how enhanced energy efficiency contributes to the extended battery runtime as well as battery life that consumers have come to expect from their electronic gadgets.

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Introduction

Higher Energy Efficiency Yields a Better User Experience

High voltage accuracy and high load transient performance are essential for the power supplies of portable designs

CPUs, field programmable gate arrays (FPGAs), digital signal processors (DSPs), and other processors are now taking on heavy computational loads in portable devices. This results in higher power consumption and heat dissipation. Adding to the challenge for designers is the fact that this hardware must fit in the small form factors of these applications, which makes it difficult to dissipate the heat. In order to perform reliably, these processors need power supplies with high voltage accuracy, high load transient performance, and high efficiency.

Imagine exploring a new place while on vacation or watching your kid's soccer game, and capturing the experience through photographs or video. The last thing you'll want to have happen is for the battery in your digital single-lens reflex (DSLR) camera (Figure 1) to drain out during an important and singular moment. Digital cameras along with drones, portable speakers, and factory automation and medical equipment are among the 2- and 3-cell battery-powered designs with multiple power rails that would benefit from small, highly efficient DC-DC power converters in their power supplies. So would the 1-cell battery-powered versions of these devices. And let's not forget that USB-C Power Delivery is emerging as a portable charging power source, with computing devices and smartphones as early adopters. In portable electronic applications, voltage regulator efficiency is essential as higher efficiency benefits the entire system and results in the longer untethered operation that consumers demand.

Figure 1. DSLR cameras are among the 2- and 3-cell battery-powered devices that call for small, highly efficient power conversion devices.

Small, Efficient Buck Converters for Longer Battery Life

Portable electronic devices are becoming more function-rich while shrinking in size. Today's DSLRs not only take still photographs but also capture 4K video and connect to the internet for instant transferring and sharing of image and video files. Gaming consoles provide another example, as modern consoles offer rich features like capacitive touchscreens, 3D visuals, and dual screens, while supporting game-playing on-the-go or on a TV. Packing an already compact product with more features (requiring more processing power) means less room for the battery, along with increased power-supply demand for higher output current with more efficiency. The formula lies in a solution that supports the right power peaks when needed by the device, while providing proper thermal management without wasting too much power.

Remember when handheld electronics required no or just one step-down converter to power their different functional blocks? Instead, a designer might have used several low-dropout (LDO) linear regulators. Popular processors at the time were typically at the 3V-3.3V range, for which an LDO works with reasonable efficiency using a single-cell lithium-ion battery input. But core voltages have been dropping as processing power demands continue to go up and IC process technology moves to submicron geometries. Also going down are typical I/O voltages. At low output voltages (as low as 0.8V these days), LDOs are inefficient and also dissipate a lot of heat when operating from single- or multi-cell lithium-ion batteries. That's why buck converters have emerged as viable solutions to the efficiency challenge. By comparison, LDOs do have a smaller size advantage over buck converters. However, buck converters have also decreased in size, which is critical for the portable devices discussed in this paper.

Single-cell lithium-ion batteries provide 3.6V-4.2V at full charge. Two- and 3-cell lithium-ion batteries provide 4V-9V and 6V-13.5V at full charge, respectively. Their end applications have various functions with multiple input power rails at lower voltages. Key features to consider when evaluating power management solutions like buck converters for small consumer electronics include:

- High conversion efficiency for maximum battery power to the load. Low quiescent current contributes to this, too, while also enabling longer standby time.
- Skip/light load mode to reduce switching losses at low output current.
- Voltage scaling and positioning to optimize the output voltage operating point.
- Multi-phase support for lower input and output capacitance (multi-phase devices reduce the number of input and output capacitors). For designs based on microcontrollers, multi-phase designs deliver faster transient responses that are important for microcontroller operations.
- Multi-channel support, where a single device can supply multiple rails.

Another beneficial feature to consider in a step-down converter is the converter's ability to be dynamically controlled to optimize its various parameters. The integration of an I^2C serial interface in the converter is one method to enable dynamic voltage scaling, which allows more granular control in order to optimize device performance in a system. With an I^2C bus, buck converters can still be configured and controlled in software before it is enabled. An alternate means to enable configuration and control to achieve the desired efficiency levels would be to rely on multiple I/Os and other

Dynamic voltage scaling optimizes system efficiency without requiring additional buck converters

external components. But this approach would significantly increase the system's footprint. For example, say you've got a system with a sensor requiring a 3.3V power rail and a Bluetooth component that also requires only a 2.5V rail. The buck converter for the system will support the highest voltage requirement, but this is inefficient for the lower voltage components, especially if the higher voltage component only operates from time to time. Dynamic voltage scaling solves this dilemma by dynamically lowering the voltage of the buck converter to meet the requirements of the lower voltage components when the higher voltage component (the main sensor, in this example) is off. This approach optimizes the efficiency of the entire system and also eliminates the need to utilize additional buck converters for the two lower voltage components.

A buck converter is also useful for microcontroller-based portable designs, where the battery voltage is higher than the microcontroller supply. Minimum input voltage goes up as clock frequencies increase—this means more power consumption. The microcontroller would have to run on a high clock speed when it is performing computations or some other processing task. But when it's not in this mode, a buck converter with dynamic voltage scaling capability can bring down the input voltage to generate greater power efficiency. Additional I/Os can accomplish this as well, but with a footprint tradeoff. Portable designs also typically alter between standby mode and full-power operation.

As such, multiphase support enables the faster transient responses that are important for operational performance of the microcontrollers inside.

Flexible Point-of-Load Regulation

Many available multiphase buck converters either call for larger inductors and more silicon area or lack enough current capability to support the latest CPUs and GPUs. Maxim, however, offers a variety of highly efficient buck converters designed to meet the needs of application processors that require high current and low operating voltages.

For 1-cell battery-powered electronics, FPGAs, and digital signal processors (DSPs), the MAX77812 provides an example of a buck converter that provides flexible point-of-load regulation with fast transient response and internal power sequencing. Figure 2 highlights the efficiency of the MAX77812. The quad channel/quad phase (20A total) configurable buck regulator, available in a 3.408mm × 3.368mm 64-bump wafer-level package (WLP), provides:

- 2.5V-5.5V input range
- High efficiency: 91% peak efficiency (V_{IN} = 3.8V, V_{OUT} = 1.1V)
- 25µA (typ) standby current, 120µA quiescent current, and 2µA (typ) shutdown current
- 0.25V-1.525V output range (through I^{2}C/5mV steps); the range goes up to 2.7V with an external resistor
- 105mm^2 solution size

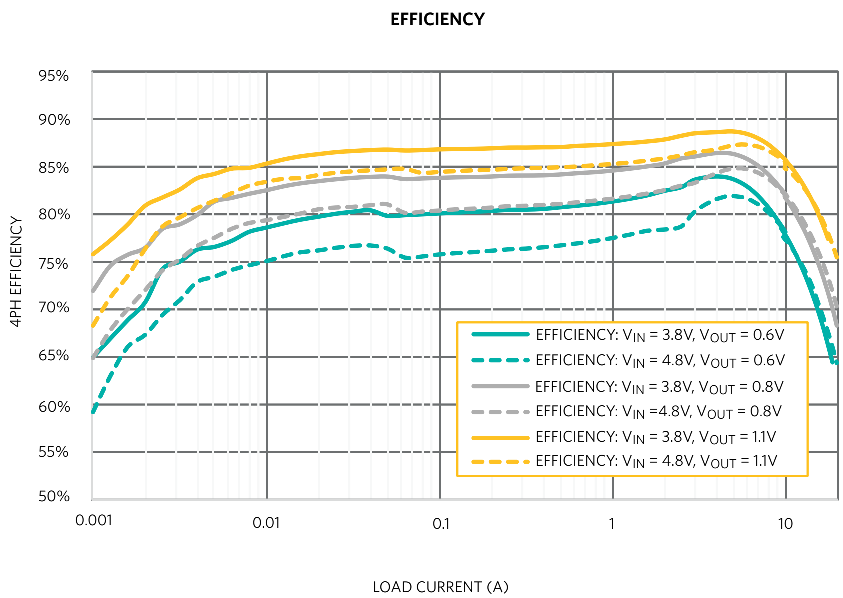


Figure 2. MAX77812 efficiency.

Another device ideal for portable electronics powered by single-cell batteries is the MAX77874 16A quad-phase, step-down buck regulator for multicore CPU and GPU processors. This device, available in a 2.22mm × 2.92mm WLP, has:

- Tight V_{OUT} accuracy: .28% (max) initial accuracy at $0.9V_{OUT}$, 1.5% (max) over line/temperature
- High efficiency: 89% peak efficiency at $3.7V_{IN}$, $0.9V_{OUT}$, $3.5A_{OUT}$
- Skip mode quiescent supply current: 275µA (typ) with V_{OUT} at 0.9V (no load, no switching)
- Turbo skip mode quiescent supply current: 475µA (typ) with V_{OUT} at 0.9V (no load, no switching)
- Input voltage operating range: 2.7V to 4.8V

The MAX77503 1.5A, $14V_{IN}$ high-efficiency buck converter operates from 2- and 3-cell batteries or USB-C Power Delivery for direct conversion to point-of-load voltages. Figure 3 shows efficiency versus load on the buck converter.

The MAX77503:

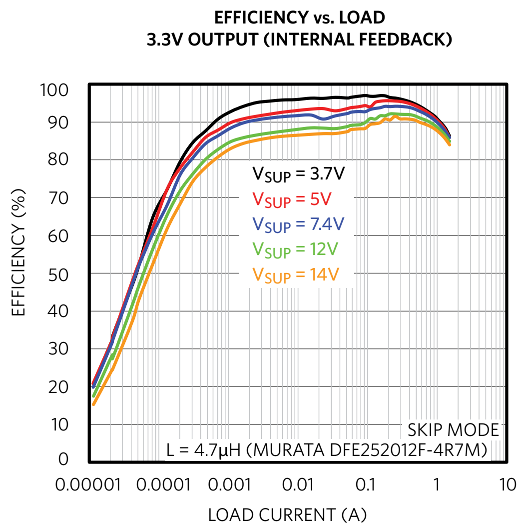
- Extends battery life and reduces power dissipation through:
  - 94% peak efficiency
  - As low as 9µA quiescent current
  - Selectable light load/skip mode efficiency enhancement
- Reduces solution size while allowing high power density in space-constrained equipment via: 1.85mm × 1.4mm WLP-12 package (14.3mm² solution size)

- Provides easy system integration, requiring no user intervention, via:
  - Direct hardware control with enable and power good flag
  - Optional I²C control for enable and dynamic voltage scaling, soft start control, peak current limit programming, and skip/forced pulse-width modulation (PWM) mode. An I²C interface has traditionally only been available in higher current devices.

The MAX8973A three-phase, step-down switching regulator is designed to meet performance and size requirements of next-generation smartphone designs. The device delivers up to 9A of output current in a compact WLP. Other key features:

- > 91% peak efficiency at $3.6V_{IN}$, $1.2V_{OUT}$
- 2.6V to 4.5V input voltage range
- Rotational Phase Spreading algorithm, which optimizes efficiency at low output currents
- Software-selectable forced-PWM mode for fixed-frequency operation or enhanced efficiency at light load with variable frequency in skip mode
- Triple-inductor architecture, which reduces the size of the external components while delivering ripple current cancellation

Maxim buck converters support application processors that require high current and low operating voltages



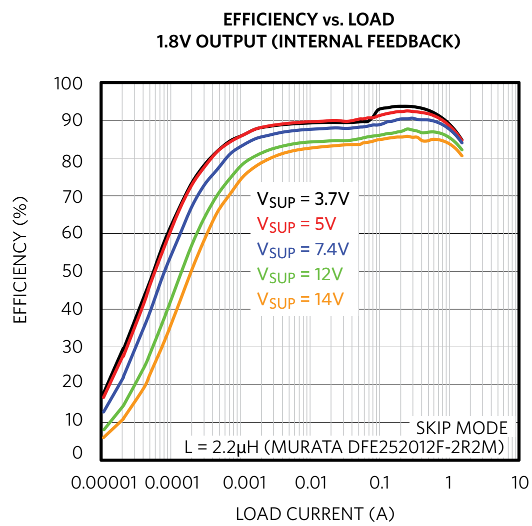


Figure 3. Low quiescent current of the MAX77503 results in higher efficiency.

Summary

As portable electronic gadgets shrink in size, their processors are being tasked with a greater computational workload. Generating a reliable level of high performance in these processors, while also extending battery life for a better user experience, calls for highly efficient power supplies. Efficient power conversion technology can encourage greater system efficiency and extend untethered operation in single- and multi-cell battery-powered products. This paper highlighted the role of buck, or step-down, converters with features like dynamic power management and low quiescent current.

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