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Designing smarter for single-battery applications

DESIGNS USING ONE BOOSTED BATTERY CAN REDUCE A PROJECT'S OVERALL COST AND SIZE.

The vast market for battery-powered systems lends itself to a multitude of products in the consumer, medical, personal-care, and entertainment markets. Successful battery-powered products in these markets require intelligent control, maximized battery life, and minimal size and weight to support device portability. Rechargeable batteries can work well in devices that undergo frequent usage and operate at higher drain rates. For many applications, however, primary—that is, disposable, nonrechargeable—batteries can be the best fit because they support simpler and lower-cost implementation options that enable truly portable devices. Each iteration of battery-powered products, including blood-glucose meters, computer accessories, cameras, and wireless headphones, continues to become smaller.

A number of popular batteries are available to developers designing disposable batteries into their projects. Each battery option targets different devices and use cases (**Table 1**). Lithium-coin batteries—typically comprising lithium and manganese dioxide—feature packages in 13 sizes that fit within small, lightweight devices, such as timers and watches, which use relatively low amounts of energy and need a shelf life on the order of seven to 10 years.

Disposable alkaline and lithium-iron-sulfide batteries are available in cylindrical form factors. Alkaline batteries suit use in a variety of portable devices that exhibit a low to moderate drain rate. These batteries are more readily available and less expensive than other disposable batteries, and they are available in compact AA, AAA, and AAAA form factors. Lithium batteries are available in AA and AAA form factors and suit use in applications that exhibit medium to high drain rates or that must operate in cold temperatures. They provide highly reliable operation, are 33% lighter than alkaline batteries, and have shelf lives as long as 15 years—two to three times longer than that of alkaline batteries.

Although portable, battery-powered products continue to shrink, the size and shape of the battery cavity, which may house two or more batteries, is placing limits on the size of the batteries themselves. Therefore, to reach even smaller form factors, the ability to operate a microcontroller on one 1.5V battery is becoming increasingly valuable. Using a battery-boost converter in a design makes it possible to operate the system with one battery, whereas earlier designs relied on two or more batteries. A battery-boost converter, such as the Microchip MCP1640 power supply, boosts an input voltage up to a higher, regulated voltage, such as 2 to 5V.

By incorporating a battery-boost converter, a device can start up with an input voltage that is significantly lower than the operating voltage. For example, many microcontrollers cannot operate with a voltage that is lower than 2V, and

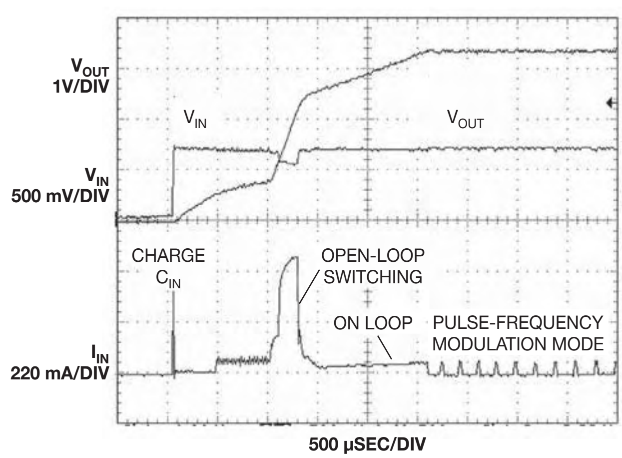

Figure 1 In a typical start-up waveform, the low-voltage start-up begins to charge the output voltage up to the input voltage. Once the output voltage is charged, the N-channel begins to switch, pumping up the output voltage, after which the internal bias switches from the input to the output.

TABLE 1 COMPARISON OF BATTERY TYPES

Battery	Key attributes
Cylindrical alkaline	Inexpensive; widely available; moderate drain rate; available in AA, AAA, and AAAA sizes
Cylindrical lithium	High performance, 15-year shelf life, high drain rate, extreme-temperature tolerant, high reliability, lightweight, available in AA and AAA sizes
Lithium coin	Small, lightweight, low drain rate, seven- to 10-year shelf life, available in 13 sizes

the battery-boost converter can provide the voltage that the microcontroller requires, with a start-up voltage as low as 0.65V (**Figure 1**). This feature enables an application using a boosted alkaline battery to start up at any point in its discharge curve, provided that it has enough remaining capacity to operate the device. Although a battery-boost converter may be able to deliver a consistent output voltage from input voltages as low as 0.35V, battery manufacturers do not recommend discharging alkaline or lithium batteries at voltages lower than 0.8V because doing so can damage the battery.

Using a single-battery implementation offers advantages that depend on which alternative-battery configuration you are comparing it with. The most straightforward approach is to compare one alkaline battery with two alkaline batteries. The most obvious differences are the volume and weight savings achieved by eliminating one battery. Using a battery-boost converter also maximizes the system power efficiency by providing regulated power over the battery's entire operating range. This regulated voltage can make the microcontroller more efficient by enabling it to run at a lower and flatter voltage. For example, reducing the microcontroller's operating voltage from 3.3V to 2.2V provides 1.8-times-lower power consumption on the microcontroller side. The boost converter also provides short-circuit protection through current limiting.

The OEM cost for implementing the boost converter with one battery is slightly higher than the cost of two alkaline batteries, but the cost to the consumer for this approach is similar to that of using two batteries if the boost converter is operating at high efficiency. A single-alkaline-battery approach enables developers to make their product smaller without switching between battery chemistries from a legacy multibattery alkaline design. Working with one battery also simplifies the mechanical considerations of the battery housing and reduces the risk that the user will install the batteries incorrectly.

Designers comparing the pros and cons of implementing one alkaline battery versus a rechargeable lithium-ion-polymer battery will find similar but different reasons for selecting the single-battery approach. Because the boost converter provides a regulated power output, it allows you to tune the voltage to maximize system efficiency. Similar to the alkaline example, the boost converter provides short-circuit protection through current limiting. The 352-mm^2 AAAA alkaline battery is smaller than a 650-mm^2, or 31×21×3.5-mm, lithium-ion-polymer battery, even though the two battery types have the same volume, 2.3 cc, assuming a two-sided board design.

Using an alkaline implementation versus the lithium-ion-polymer device simplifies logistics because it avoids the need for charging circuitry and conforming to the regulations for shipping products containing lithium. For those applications in which using a replaceable battery is more convenient, implementing a boost converter with a single AAAA alkaline battery can cost 50 to 70% less for the battery portion of the system than that of a single lithium-ion-polymer battery plus a charge controller and a charger.

Comparing a single-alkaline-battery implementation with a lithium-coin battery demonstrates yet another advantage of the one-battery approach. This example compares an AAAA alkaline battery with a 600-mAhr capacity and a CR2032 lithium-coin battery with a 225-mAhr capacity. As in the lithium-ion-polymer example, using a single boosted alkaline battery avoids the need to conform to the shipping regulations for lithium batteries. Consumers are more familiar with cylindrical batteries, such as the AAAA, than they are with

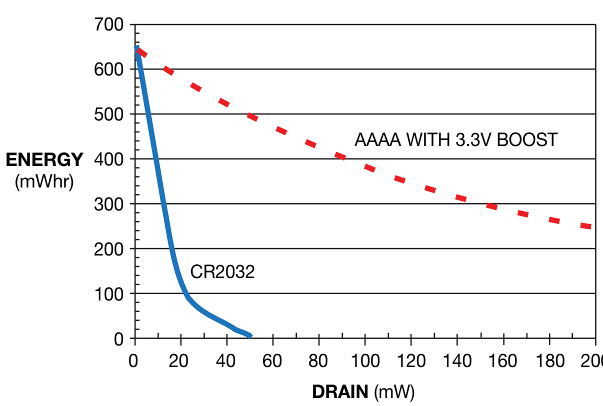

Figure 2 A single AAAA battery with boost delivers higher continuous-current draw than a lithium-coin battery when the current draw is higher than a few microamps.

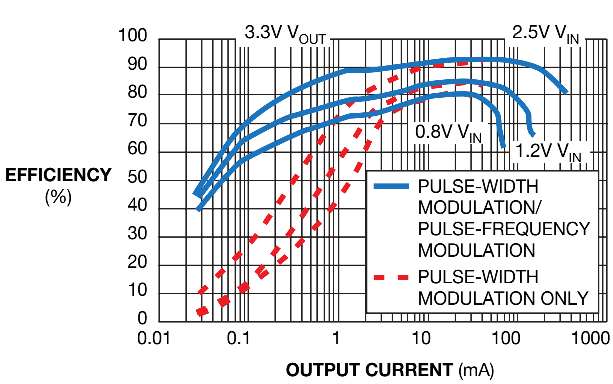

Figure 3 The efficiency of a boost converter depends highly on the current draw and the input and output voltages.

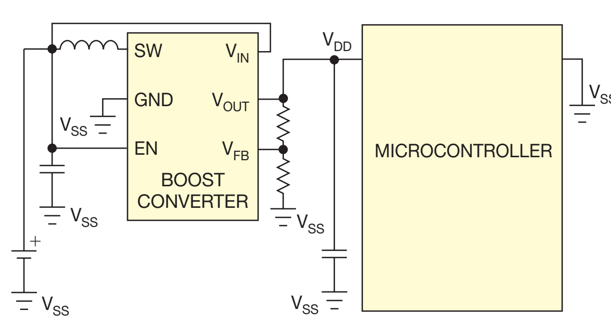

Figure 4 A typical battery-boost-converter configuration comprises a boost converter, two resistors, two capacitors, and an inductor.

coin batteries, increasing the chances of correct installation. The footprint of using either power source is similar, with the single alkaline AAAA battery taking approximately 352 mm^2, versus 314 mm^2 for the CR2032 lithium-coin battery, assuming a two-sided board.

The single alkaline battery continues to benefit from the tunable voltage to maximize efficiency and provide short-circuit protection through current limiting. However, the alkaline battery delivers a higher continuous current, whereas the CR2032 cannot. Specifically, the boosted alkaline battery can continuously source 150 mA, whereas the CR2032 can perform that task only for short pulses. Continuous current beyond 10 mA from the CR2032 battery dramatically decreases its usable capacity; even at 20 mA, it can deliver only one-fifth the energy that boosted AAAA batteries can (**Figure 2**).

TRADE-OFFS

Although using a battery-boost converter provides many advantages, such as enabling a microcontroller-based design to operate with a single battery, it is important to consider the system-level trade-offs between a boosted single-battery implementation and a multiple-battery design. The efficiency of the battery-boost converter highly depends on the current draw, as well as the input and output voltages. The dominant loss for a boost converter is resistance, so the efficiency of lower I/O voltages is lower than the efficiency of higher-I/O-voltage applications (**Figure 3**). Other factors that can affect the boost converter's efficiency are the resistive losses in the inductor and capacitors. Inductors with lower dc-series resistances and capacitors with low ESR (equivalent series resistance) allow higher efficiency; potential trade-offs are size and cost.

To support a lower system-current draw, the boost converter may include a low quiescent-operation mode, which typically draws 20 μA, and a shutdown mode, which draws less than 1 μA. With a microcontroller, a booster can provide a voltage to power the application in a sleep mode, using a "coast-down" method. The microcontroller turns on the boost circuit when the system voltage falls below a predetermined level and then shuts it off to eliminate the operating current of the booster and to continue to get power from the booster's output capacitor. Using this method, the total power consumption of the microcontroller and the boost regulator can decrease by as much as 87%.

Implementing a battery-boost converter enables a design to reduce the overall system area by the size of the second battery, with the trade-off of including the boost converter, two resistors, two capacitors, and an inductor (**Figure 4**). The weight of the boost converter and its accompanying components is negligible for most designs. The area of a typical boost-converter circuit is approximately 60 mm^2, which is considerably smaller than the 450-mm^2 area of a second AAA battery or the 352-mm^2 area of a second AAAA battery and still yields a 290- to 390-mm^2 area reduction in the overall system, assuming a two-sided board design. The OEM's cost for implementing the boost converter and its accompanying

Figure 5 Reference designs can provide low-risk platforms for developers to more quickly understand how to use a boosted single battery in their designs.

components is approximately 20 cents, which may be offset by the alternative battery technology you are comparing.

Many semiconductor companies offer application notes, reference designs, or both for their boost converters. Microchip's MCP1640 single-AAAA-battery-boost converter reference design is one example (**Figure 5**). These reference designs help developers reduce their product's design cycle by providing a pre-engineered circuit that they can modify to meet their project's needs.

EXAMPLES

A boosted single-battery implementation not only enables differentiation through a smaller form factor for many applications but also provides a cost advantage over using coin or rechargeable batteries. The ability to minimize the width and weight of an electric toothbrush's handle, for example, enables the handle to feel more natural in a user's hand. Using a single battery also simplifies the mechanical-design effort to ensure that the user has correctly installed the battery.

Another benefit of boosted batteries is that the power supplied to the device is regulated, so it receives a flat voltage profile throughout the life of the battery. This approach enables the toothbrush to provide a consistent vibration throughout the life of the battery without a noticeable drop-off in vibration strength and, thus, performance as the battery discharges. The microcontroller can also modulate the vibration signal, such as generating pulsating vibration to signal to the user that the battery is approaching an end-of-life condition.

Flashlights, especially LED devices, can also benefit from a regulated supply voltage by using the boost converter to power a microcontroller, which in turn controls a more complex supply for the LEDs. The regulated supply can avoid a dimming of the flashlight as the battery discharges, hence providing consistent lighting through the battery's end of life.

Using one boosted alkaline battery can be appropriate in value-priced devices, such as a portable, wireless mouse. A value-priced mouse focuses on longer battery life by operating with low-frequency positioning updates appropriate for Web browsing and text editing, as opposed to higher-frequency updates for gaming. Wireless mice deliver a compact form factor with the single replaceable battery and have lower design and materials costs than do implementations that rely on a rechargeable battery. In addition to the cost difference among the battery technologies, using a replaceable battery means that the mechanical design avoids including an expensive connector for a recharging source.

Most consumers are familiar with and know where to acquire cylindrical AA, AAA, and AAAA batteries. Designs using these form factors can provide a simpler access hatch to replace the battery so that the user is confident the battery is installed correctly. Although other form factors, such as coin batteries, are not unusual, most consumers are less familiar with the notations for the coin devices' form factors and less familiar with how to install these batteries. The clear orientation for installing a cylindrical battery and the ease of acquiring replacement batteries provide an ease-of-use differentiation for a design.

An additional differentiation opportunity for boosted equipment is to incorporate RF connectivity in the volume gained from using only a single battery. Applications that can benefit include portable medical equipment, such as blood-pressure modules and blood-glucose meters, and beacons in industrial environments for tracking transportation containers.

The opportunities for delivering efficient energy through one battery span a range of applications. These applications demonstrate ways that a device using one boosted battery can enable a smaller form factor, lower weight, a lower cost of materials, and a simpler mechanical design than will a multiple-battery approach. Because consumers are more familiar with how to use cylindrical batteries, a single-battery system is more valuable. All of these benefits make it easier to consider migrating to a boosted single-battery implementation for the next iteration of your design. EDN

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