Top 10 Tidbits of Battery Wisdom

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By avoiding common design errors, designers can extend the runtime of their battery-powered portable products.

In spite of accomplishing amazing feats of technology, many products still frustrate and disappoint consumers for the simple reason that they run out of power. Often, the consumer's experience could be significantly better if the product designer just avoided common mistakes that unduly decrease battery life. What follows is a short list of guidelines (not necessarily in order of importance) to help designers avoid battery-draining errors and extend the runtimes of their products.

Although much of my contact with portable devices comes from a design perspective, I have compiled most of the items on my list by viewing products from a consumer's point of view. On some occasions, the noted design flaws are unavoidable. But more often than not, they occur because they, or their consequences, are not considered.

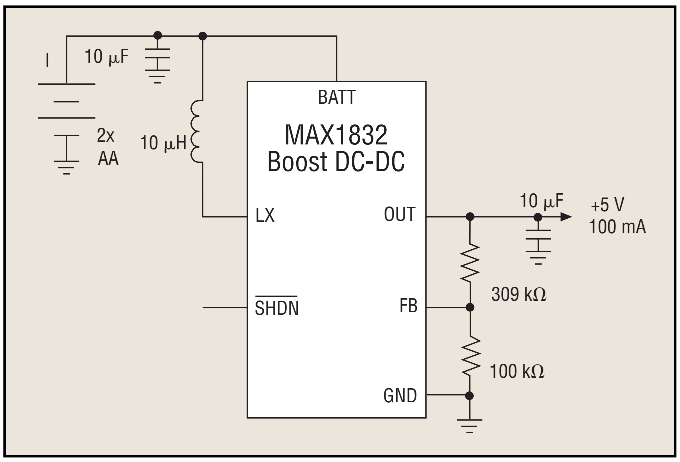

Fig. 1. *A 6-pin SOT device turns two AA cells into 5 V with 90 % efficiency, doubling the time between battery changes compared to that for expensive 9-V batteries.*

1. Friends Don't Let Friends Use AAA or 9-V Batteries

AAA and 9-V alkaline "transistor radio" batteries have significant disadvantages compared to AA cells. Both have poor output impedance; therefore, their already limited capacity is made even worse as losses increase with load peaks. From typical manufacturer data, AA capacity is 2.5 times that of AAA. Except in cases where mechanical design prohibits their use, AAA cells should be avoided. Admittedly, AAA batteries are smaller than AAs, but frequently they are used even though there is room for larger cells.

Nine-volt transistor radio batteries have some justification, because they allow a 5-V system to be powered with a cheap linear regulator. For low-current loads, 9-V capacity is comparable to AA. However, 9-V batteries are made from six tiny series connected cells, so output resistance is high and capacity is dependent on load current.

This situation is fine for a smoke alarm where the battery is replaced twice a year. However, with larger loads, frequent battery replacement is expensive for the user, and the cell's poor output resistance compounds this problem. When comparing the capacity of AA and 9-V batteries, keep in mind that, for consumers, 9-V cells typically cost four times as much as AAs.

Due to modern low-cost dc-dc converters, it is easy to efficiently generate a 5-V supply from two AA batteries. An example circuit depicted in **Fig. 1** includes useful features such as reverse battery protection, which is built into the IC. The connection shown typically doubles the time between battery changes and costs one-fourth as much for the user to operate, compared to 9-V batteries.

2. No Off-State Load Current

Alkaline batteries excel because of their low self-discharge rate and low cost of implementation (no charger or ac power jack is needed). If power requirements are low, alkaline is a great choice. However, to be used properly, quiescent load, or sleep current, must be reduced with religious conviction.

A common power-system design mistake is focusing only on a product's operating efficiency while ignoring "off" or "sleep" current. Even tens of microamps of wasted current can drain cells, causing intermittently used products to require frequent cell replacement. Ironically, this design mistake is more common today than it was years ago because "software switches" have replaced the mechanical switches that completely disconnected the battery.

With a software switch, the system remains alive but goes into a (hopefully) low current state where only an ON/OFF key is scanned. Such systems can have excellent "off" current drain because the static (unclocked) current drain of CMOS logic is essential zero. Nevertheless, these systems often still drain the battery while off because of sloppy design, where pull-up resistors continue to draw battery current or inactive system blocks are not powered down.

Rarely is there a legitimate reason for the off-state current of such systems to exceed a few microamps. Even 1- or 2-cell AA designs, where a boost dc-dc converter must run full time to maintain a logic supply, can now consume less than 2 µA with devices such as the MAX1722 boost converter IC. With AA cells, this level of operating current usually is less than the internal discharge rate of the cells themselves.

3. No Diode-ORing

The world needs a perfect diode with a 10-mV forward voltage drop and no reverse leakage. To date, Schottky diodes are the best we have, with a forward voltage drop between 300 mV and 500 mV. Unfortunately, for many voltage selection designs, even a Schottky is not good enough. It makes little sense to use a cutting-edge, high-efficiency voltage converter only to waste the power saving in a steering diode's forward voltage drop.

If conserving battery energy is a priority in a low-voltage system, power MOSFET switches should be used instead of diodes. Given SOT devices with on-resistances in the tens of milliohms, MOSFET forward drops are negligible at portable product current levels.

The way to determine if MOSFETs are needed for power steering is to compare the (diode or MOSFET) voltage drop to the battery voltage and treat this ratio as an efficiency loss. If a Schottky diode with a 350-mV forward drop steers the output of a (nominally 3.6 V) Li-ion battery, the loss is 9.7%; with 2 AA cells (nominally 2.7 V), the loss would be 13%. In a low-cost design, these losses may be acceptable, but the cost of a high-efficiency dc-dc converter should be weighed against the cost of the 13% or 9% improvement gained from a steering-diode-to-MOSFET upgrade.

In some cases, steering diodes and MOSFET switches can be avoided with careful system design. In **Fig. 2**, system power is handed off between a single AA cell and a USB input without using MOSFET switches. When USB power is plugged in, no current is drawn from the AA cell. The MAX1675 boost converter's shutdown (SHDN) input does not need to be activated to prevent AA drain when USB power is connected, because the MAX8511 LDO pulls the boost output from 3 V up to 3.3 V in this situation. This stops the boost converter from draining the battery.

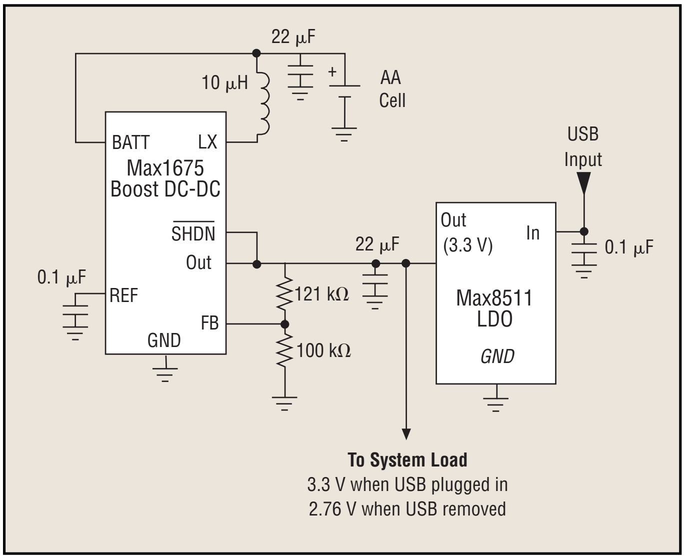

Fig. 2. *Power hand-off between a AA cell and USB power is managed without diode losses or MOSFETs. The MAX8511 LDO "pulls up" the output to 3.3 V when USB is connected. The MAX1675 boost converter then automatically stops draining the battery.*

4. No 10-kΩ Pull-ups

Most portable products (PDAs, cameras, etc.) are so complex that their design is spread over many engineering groups. These groups focus on their immediate goals and may not fully consider the impact on other parts of the design. Most digital designs contain pull-up resistors. Taken individually, the current flowing in a pull-up resistor likely would not have a huge impact on power consumption. However, a system full of pull-up resistors can waste significant battery energy.

In many cases, pull-up resistors can be eliminated by using logic that is active in both states. But even when resistors are needed, they can often be raised to 1 MΩ or more if speed is not a concern. Be sure to consider the most common state of the pull-up (is it high impedance or drawing current) and reduce the pull-up current to the lowest possible value (highest possible resistance).

5. No Iron-core 60-Hz "Wall Warts"

Although not really a battery issue, this is sufficiently related to warrant mention. From the viewpoint of a consumer of portable devices, nothing deflates a product's value like packing a large heavy ac adapter with a portable product that pitches small size and weight as a feature. A manufacturer could not send a more conflicted message.

Small, light switchmode ac adapters are now commonplace. They cost somewhat more than iron-core 60-Hz "wall warts," but their advantage to the customer justifies the expense in all but the cheapest applications.

6. Use the Right Battery

All portable devices have a pattern of use that customers tend to follow as a result of their interaction with the device. Customer satisfaction (or dissatisfaction) depends largely on how the product fits or conflicts with this pattern. For example, it is a distraction when a product requires a user to be hyper-aware of the battery.

The best products make the battery "disappear" with either infrequent cell replacement (e.g., TV remote controls) or charging, or with unobtrusive charging (e.g., electric toothbrushes). It is important to match the battery (most commonly alkaline, NiMH and Li-ion) to a product's use pattern so customers are not forced to think about batteries more than the device's intended function.

As mentioned previously, alkaline cells are not rechargeable but feature a very low self-discharge rate and low cost of implementation (no charger or ac power jack is needed). If power requirements are low, alkaline is a good choice. When operating loads are too great for alkaline batteries, rechargeable batteries are required. The trick is to make the rechargeable battery as unobtrusive as possible.

Of the two main rechargeable choices, NiMH or Li-ion, the lower cost of NiMH can make sense when the product's use pattern is not unhealthy for the cells. This consideration is especially important in low-cost products where sophisticated charging is not affordable. NiMH cells prefer full charge/discharge cycles and hence fit best in products frequently used to exhaustion, such as power tools.

Another use pattern that sometimes fits NiMH is as alkaline "replacements," where cells are removed from the device when depleted and then charged in an external charger. This is common in digital cameras, but still has the disadvantage of requiring a lot of attention from the consumer.

Products such as cell phones do not conveniently fit the full charge-discharge pattern. Cell phones are charged regularly (over night) but drained sporadically. These products need Li-ion's higher power-to-weight ratio, low self-discharge and affinity for small charge-discharge cycles. Thus, consumers devote little effort to "battery management" and instead focus on the product.

7. Don't Skimp on Bypassing—Especially at Low Voltage

Low-voltage battery systems incorporate boost converters to supply system voltages. These converters take constant power from the battery, so when the battery voltage falls, input current rises, which exacerbates problems caused by source resistance. In addition, dc-dc converters take power from the input source in pulses, even when the load is constant.

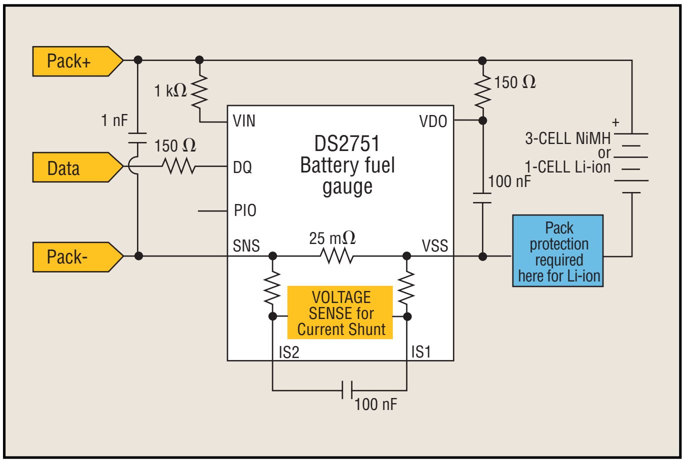

Fig. 3. *A 1-chip battery fuel gauge provides a cost-effective solution to the nearly useless "4-bar" display found on most devices.*

This dynamic loading aggravates the losses due to battery resistance and other factors that add to input resistance. Because losses through resistors are proportional to the square of current, "peaky" loads waste more power than continuous ones. That is why battery bypassing (with capacitance) is so important in systems that include dc-dc converters. If the current passing through input resistance can be made as close to dc as possible, the savings in consumed battery energy can be as much as 5%.

8. Don't Fear Dropout

Batteries are not perfect and have significant voltage variation during discharge. Li-ion cells vary from 4.2 V down to 2.7 V. When generating a 3.3-V output, it might seem necessary to step up the battery voltage when it is low. However, many "buck-boost" power supplies add significant system cost and may not add to battery life because their overall efficiency is not comparable to simpler buck-only dc-dc converters.

With buck-only designs, the question is how far down can the battery be run. The lower the battery can go, the longer the useful life. When the input and output of the regulator are nearly the same, the regulator is said to be in dropout. In the past, the dropout state was presented as a condition to be avoided. But when the economic advantages of simple buck designs are considered, it is worth considering a system's true minimum operating voltage.

Many contemporary LDOs and buck dc-dc converters are designed to operate in dropout with no ill effects. This allows the battery to operate down to the minimum possible voltage and thus permits the maximum energy to be drawn from the battery. The limits on this are determined by the minimum allowed system logic voltage as well as the dropout specs of the LDO or dc-dc converter. In most 3.3-V systems, logic devices allow a ±5% (or perhaps ±10%) tolerance. That means a minimum of 3.15 V for a 5% system. If the system is not clocked at the maximum rate, the minimum operating voltage may be allowed to be even lower.

9. Don't Skimp on the Battery Door

Again, this is not related to battery technology, but is an important issue with consumers and a weak spot on many products. If battery replacements will be frequent, the battery door needs to be up to the task of many operational cycles without breaking. Furthermore, it should not be difficult to operate. The need for good design here varies in proportion to the frequency of battery changes, particularly in products such as digital cameras where NiMH cells are charged outside the camera and swapped in and out as they are charged.

10. Accurate Battery Gauges are Not a Waste of Money

Products where accurate gas gauging is especially valuable are those with batteries that might not be fully discharged in one use. This, of course, could be true of nearly any battery-powered product, but is especially true for digital cameras, cell phones and PDAs.

Cameras in particular have a unique distinction because they are used irregularly (thus, it is easy to lose track of the battery charge), but are considered critical when they are used. Without good gas gauging, a digital camera has a greater risk of running out of power and a higher likelihood of doing so at an important moment.

Most designers of portable devices do not budget significant money for "gas gauges" because they don't think consumers value the feature. This thinking is flawed because although battery-powered devices have been around for a while, consumers don't know what they can expect and thus have not seen the benefit of an accurate gas gauge. This thinking, combined with the fact that many "so-called" gas gauges are so poorly implemented that they don't really work, has clouded the view of the real market and has "programmed" consumers to expect the worst from battery gauges.

This need not be the case, because now there are integrated solutions to battery gauging whose cost is low enough to add real value to portable devices. One such device is the DS2751 shown in **Fig. 3**. This device contains an internal current-sense resistor, has a 2-μA standby current and communicates with the system over a 1-wire serial interface. **PETech**

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