

Extending battery life in smart locks



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New smart lock power architectures greatly increase battery life by reducing system standby power consumption.

Power management is a key design challenge in every Internet of Things (IoT) and connected home product. If the consumer experiences product downtime due to dead batteries or gets tired of changing the batteries too frequently, they will likely choose to not use the product. This is especially true for smart locks. When a lock malfunctions, the result is frustration from being locked out of the office or hotel room.

In addition to the relatively high peak current demands of the radio, common in all IoT applications, smart locks have an additional high peak current demand from the motor which turns the lock itself. Also, smart locks sit idle for the vast majority of every day—the time when they are actively locking or unlocking the door is very small. This combination of high peak current demands and very lengthy, low-power system standby time demands new power architectures to extend the battery life.

System overview

While smart lock systems may contain many integrated circuits (ICs) such as light-emitting diode (LED) drivers, Wi-Fi® communications, and so on, this paper focuses specifically on these three ICs:

- 1) microcontroller with wireless connectivity, such as *Bluetooth*® low energy;
- 2) a motor driver; and
- 3) power management.

Throughout this paper, the term “events” refers to the door locking or unlocking when the motor is active. For example, locking the front door and then unlocking the front door counts as two separate events. Twenty-four events per day is commonly used for comparing the performance of different smart locks.

Wireless microcontroller

In a smart lock product, the wireless microcontroller (MCU) device communicates with the phone to lock and unlock the door wirelessly. In order to do this without any noticeable lag, the wireless microcontroller needs to be powered on to send an advertising event signal periodically, and then be put back into its standby state. Current consumption is much lower in standby—usually around the single-digit micro-amp (μA) range. Such a low current enables long battery life.

Advertising events (not to be confused with the locking/unlocking events) occur when the wireless microcontroller periodically wakes up to briefly transmit identifying information and listen for incoming connection requests from peer devices (e.g., a smart phone). The period of advertising events is programmable on most Bluetooth low energy devices from 20 ms to 10.24 seconds.

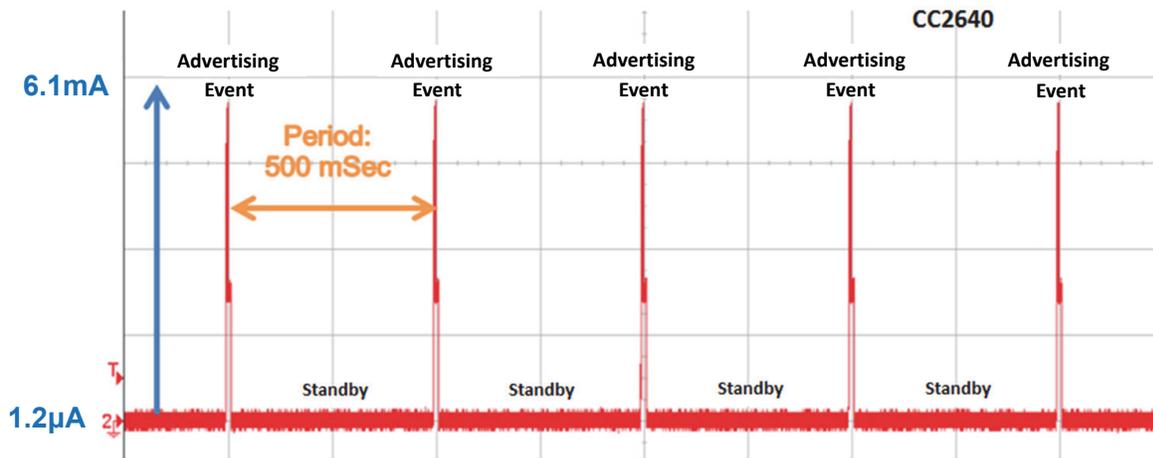


Figure 1. Current consumption versus time during a Bluetooth low energy advertising event.

The longer the period, the longer it takes for a connection but the lower the power consumption. A period of 500 ms between advertising events is a good balance between power consumption and connection speed. **Figure 1** shows the current consumption waveform of a typical wireless microcontroller with Bluetooth low energy communication ^[1]. Default values for the [CC2640](#) current consumptions are shown in **Figure 1**. The pie graphs and plots in **Figure 6** and **Figure 7** (see page 6) use the worst-case scenario of 9.1 mA of active current and 2.5 μA of standby current. These values are used for maximum output power.

Since the advertising event period is programmable, the two most important values to look for when choosing a Bluetooth low energy radio, in terms of power consumption, are active (during an advertising event) and standby currents. The supply voltage range of the SimpleLink™ Bluetooth low energy CC2640 wireless MCU is 1.8 V to 3.8 V. In this application note 2.5 V will be used to allow easy comparison between the different configurations.

Motor

All smart lock products need a motor and motor driver in order to turn the lock in either direction (lock and unlock) wirelessly and without a physical

key. The current profile of the motor is different for each type of door lock, because the amount of torque needed to turn the lock differs between different brands of door locks. On many locks, the current through the motor ramps up and peaks at around one amp. There are a number of sources of power dissipation in a motor driver, but the biggest source is the on-resistance of its MOSFETs. When choosing a motor driver, the highest efficiency is achieved with a very low on-resistance. The motor driver, such as a [DRV8833](#), must work with the smart lock's power source and the specific motor used. Considering both of these, the motor driver voltage is typically around 5 V.

Power management

Power management is required to convert the varying battery voltage to the voltages required by each of the loads: wireless microcontroller, motor driver and any other sub-systems. Power management adds cost, size and inefficiency to the system. Thus, it is important to design the entire system with the power management in mind—the power management must work together with each sub-system.

The power management's efficiency is critical to the performance of the overall system, especially in an

IoT application such as a smart lock. This efficiency is important at the full system load with motor turning and wireless microcontroller connecting, but critical when the system is in standby-mode—drawing micro amps (μA) of current. Being efficient at both light and heavy loads is challenging and requires specially-designed ICs.

The power management must ultimately run off of the user-installed batteries. The choice of battery type, number and configuration goes hand-in-hand with the system’s power architecture and power management selection. AA-size alkaline batteries are widely used in smart locks due to their wide availability to consumers and low cost. The average per-cell voltage of an AA cell is around 1.25 V, though their voltage varies from under 1 V when fully discharged to 1.6 V when brand new. With four AA cells, over four years of battery life is achieved [2].

Whereas many existing smart locks focus on achieving lowest-cost power management with low drop-out (LDO) linear regulators—at the expense of efficiency—newer, cost-effective power management more than doubles the battery life with minimal added cost. Switching DC/DC converters, both boost (sometimes called a step-up) and buck (sometimes called a step-down) converters, offer higher efficiency and a corresponding longer battery life compared to LDO implementations.

Linear regulator

The four AA batteries are connected as 4s1p (four series cells and one parallel cell) to create a 5-V supply voltage to power the motor. Now, only a simple motor driver is needed to turn the motor on or off without any added power management. Because of this, the motor sub-system operates at nearly 100 percent efficiency.

LDOs step down the higher battery voltage to lower voltages. An LDO is used to convert the 5-V battery to the 2.5 V required by the wireless microcontroller.

Any LDO converting 5 V to 2.5 V is 50 percent efficient at best, with much lower efficiency obtained in standby-mode due to the LDO’s quiescent current (sometimes called ground current) [3]. For example, the [TPS76625](#) is suitable to convert four AA batteries to 2.5 V. This device achieves 50 percent efficiency at higher loads, but only two percent efficiency at the 1.2 μA standby load due to its 35- μA quiescent current. The very low efficiency results in relatively high power consumption when the smart lock is in standby—this reduces battery life. **Figure 2** shows a typical block diagram of an LDO-based system.

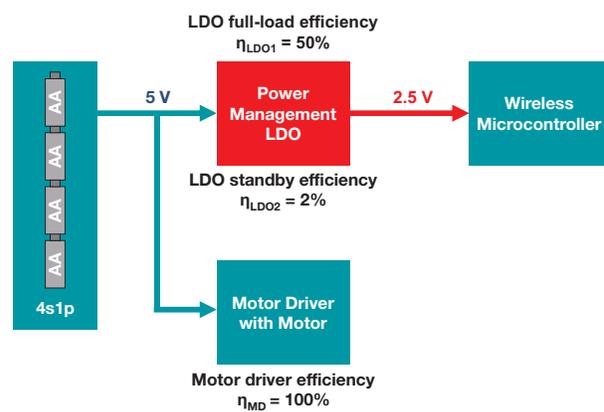


Figure 2. Smart lock block diagram using an LDO and four AA cells connected in series.

Boost converter

To overcome the LDO’s low efficiency in standby-mode, the battery configuration is rearranged and a boost converter is used instead. In this power architecture, the wireless MCU connects directly to the battery pack, which is arranged as a 2s2p (two series and two parallel cells). Since four cells are still used, the cost and energy are the same as the previous case. But since there are only two cells in series, the total battery pack voltage is just 2.5 V—a perfect match for the wireless MCU. Now, this connection is 100 percent efficient.

However, the motor still requires 5 V to operate. From the 2.5-V battery, a boost converter must

be used. A typical boost converter, such as the [TPS61030](#), has around 85 percent efficiency when boosting to drive a motor. Due to the efficiency and boost ratio (where the output voltage is greater than the input voltage), the boost converter draws very high currents from the battery which increases the losses. **Figure 3** shows a typical block diagram of a boost-based system.

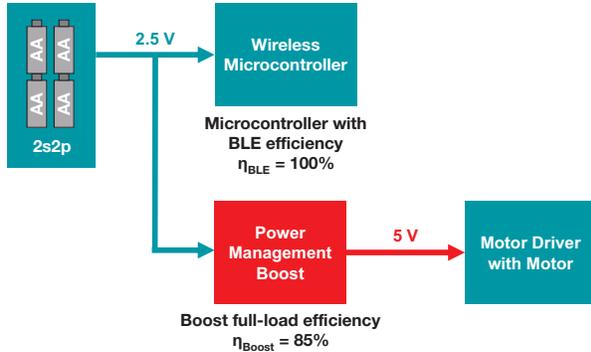


Figure 3. Smart lock block diagram using a boost converter and four AA cells connected as 2s2p.

Buck converter

Taking the same power architecture as the LDO system, a buck converter is used in place of the LDO to dramatically increase the efficiency. At the wireless microcontroller's full load, the buck converter, such as a [TPS62745](#), is 90 percent efficient. The motor sub-system remains at nearly 100 percent efficiency because it is connected

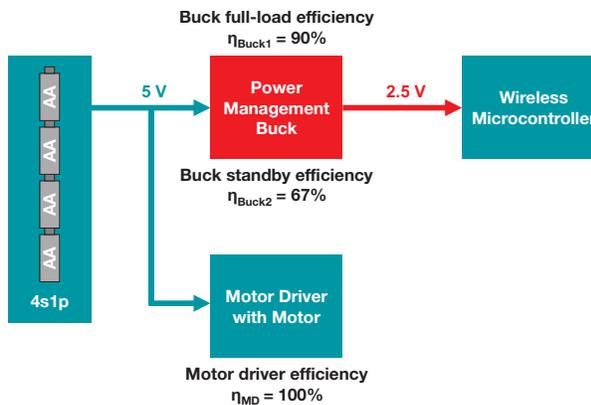


Figure 4. Smart lock block diagram using a buck converter and four AA cells connected in series.

directly to the battery pack. **Figure 4** shows a typical block diagram of a buck-based system.

A standard buck converter has a relatively large quiescent current (I_Q). The high I_Q dramatically decreases efficiency in standby-mode as it did with the LDO [3]. However, the ultra-low power buck converter used in this example has ultra-low I_Q specifically designed for IoT applications, which have higher peak currents and long system standby times. **Figure 5** shows that the ultra-low I_Q enables over 67 percent efficiency at the typical standby-mode load currents with a 2.5-V output voltage.

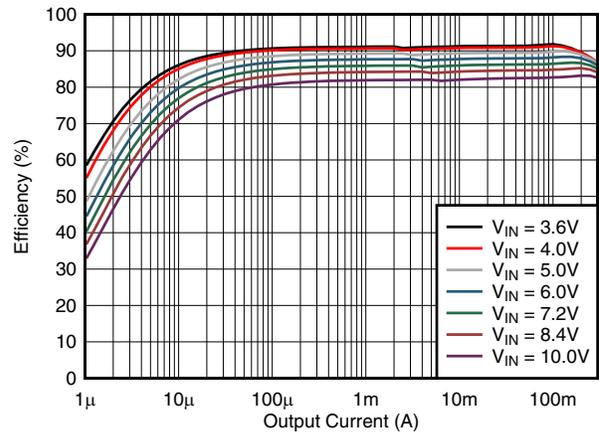


Figure 5. An ultra-low power buck converter's efficiency remains high, even at very light loads.

Power management architecture comparison

The efficiency of the power architecture is critical for extending the smart lock's battery life. Power management is necessary to convert the battery voltage to what is required by each sub-system, but it consumes some of the battery's energy to function.

Figure 6 on the following page shows three pie graphs of the power consumption of all three system blocks in a real smart lock for one day of operation. The percentages show how much of the total system power budget is used for each of the three sub-systems, and the bar charts show the total power consumption in each

Daily power consumption with 24 lock/unlock events and 500-ms Bluetooth® low energy advertising period

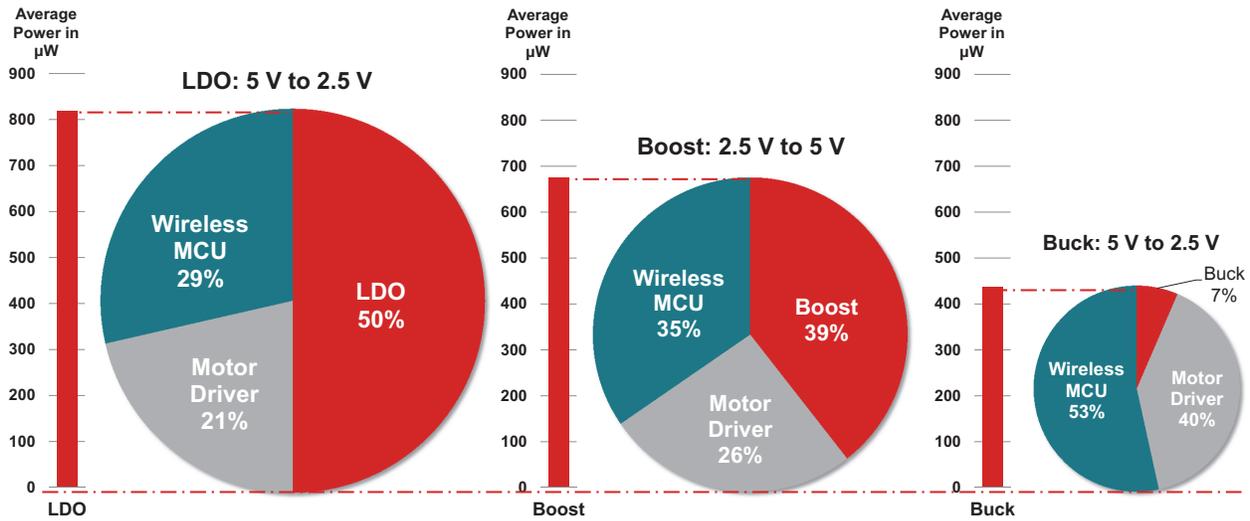


Figure 6. Total and sub-system-level daily power consumption of the three power architectures.

power architecture. A 500-ms advertising period and 24 lock/unlock events per day are used in the calculations. For visual representation, the overall size of each pie chart is proportional to the total power used for each of the three power management architectures—the bigger the pie chart, the greater amount of power consumed. The height of each pie chart also shows the total power consumption.

Figure 7 compares all three power architectures with the number of lock/unlock events on the x axis and the number of years of battery life on the y axis. For many applications, which have less than 36 events per day, both the buck and boost architectures offer an improvement in battery life compared to the LDO architecture. For higher lock/unlock event systems, the buck architecture is still best, but the boost architecture becomes worse than the LDO architecture due to the higher amount of motor power required for more events.

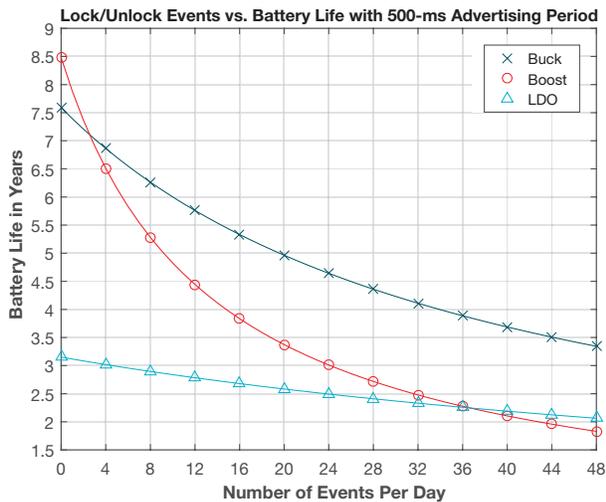


Figure 7. Battery life versus power architecture and number of events per day.

Conclusion

New power architectures in connected devices, such as smart locks, enable much higher battery life compared to the current LDO-based implementations. A switching power converter, either a boost or buck, increases battery life for smart locks with less than 36 lock/unlock events per day. An ultra-low power buck converter more than doubles the battery life for lower event systems, while nearly doubling the battery life for higher event systems. The ultra-low I_Q of such a buck converter

is critical to the battery life extension by vastly increasing the efficiency during the lengthy standby-modes of such systems. Designers of connected and IoT products should take another look at their power management architectures to make sure their products achieve optimal battery life.

References

1. Joakim Lindh, Christin Lee, and Marie Hernes. [Measuring Bluetooth Low Energy Consumption](#), Texas Instruments Application Report (SWRA478), December 2016
2. [Smart Lock Reference Design Enabling 5+ Years Battery Life on 4x AA Batteries](#), TI Design (TIDA-00757)
3. Chris Glaser. [I_q: What it is, what it isn't, and how to use it](#), TI Application Note (SLYT412), 2Q11
4. Product folders: [CC2640](#), [DRV8833](#), [TPS76625](#), [TPS61030](#), [TPS62745](#)

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