

# Extending Battery Life With Low Quiescent Current and Dynamic Voltage Scaling



Milos Acanski

## ABSTRACT

When designing a battery powered system, maximizing battery life is often one of the most important design goals. This is especially true in applications such as smart and IoT sensors or wireless medical equipment where some parts need to operate continuously at a low power level and the cost of replacing the battery is high. Selecting the right converter to obtain a fixed system voltage in such a case is often based on the quiescent current parameter  $I_Q$ . Lower quiescent current translates to higher efficiency at light loads, which results in longer battery life. This application report shows that besides having low quiescent current, the battery life is further extended by dynamically scaling the output voltage.

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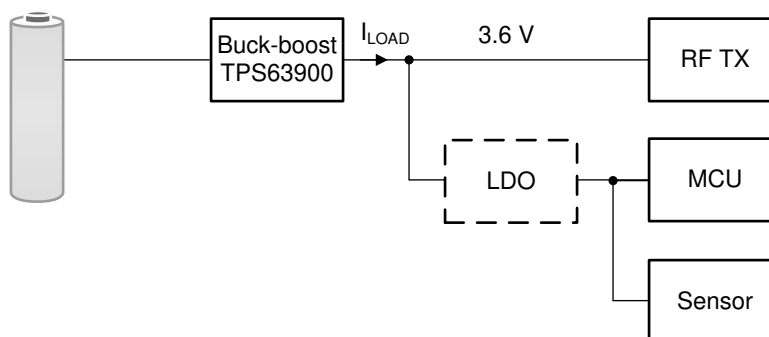
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## 1 Introduction

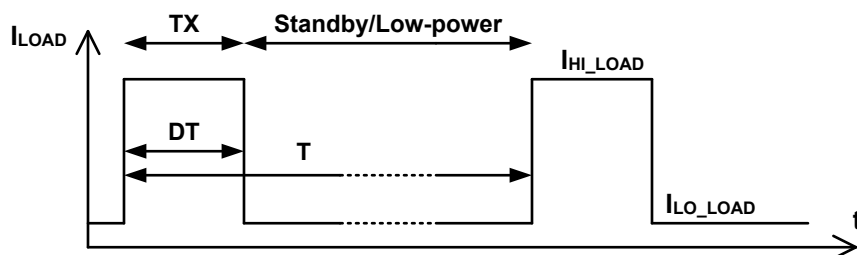
In many applications, it is necessary to continuously power a system, or at least some parts within a system. An example is a wireless sensor that needs to take continuous measurements, and periodically transmit them. A power tree of one such system is shown in [Figure 1-1](#). Often in such applications the battery current is very low for most of the time, in orders of  $\mu\text{A}$ . Periodically, the system wakes up and the current consumption rises up to hundreds of mA during data transmission.

To accommodate the wide range of battery operating voltage, a switching converter typically provides stabilized voltage for the system. If all the parts share the same voltage rail, the voltage is determined by the part that requires the highest minimum voltage to operate properly or with the required performance. In the example from [Figure 1-1](#), it is the wireless transmitter that requires 3.6 V to achieve the required range for data transmission. The other parts can be powered from the same rail, or via a secondary smaller linear regulator if their operating voltage is lower.



**Figure 1-1. Power Tree of a Wireless Sensor**

Often, the transmission takes place sporadically and most of the time the system is in low-power mode with the converter operating with very light load. [Figure 1-2](#) shows an example of such a load profile with very low duty cycle  $D$ .



**Figure 1-2. Typical Current Consumption in Wireless Sensors**

To maximize the battery life, it is important that the converter has high efficiency so that the amount of power lost during conversion is as small as possible. Moreover, the efficiency has to be high at both high and low load currents, which are often two contradicting requirements when designing a converter. However, if the duty cycle  $D$  is sufficiently low, the efficiency at light loads becomes more important. For more details, see [Selecting a DC/DC Converter for Maximum Battery Life in Pulsed-Load Applications](#).

When assessing the converter performance at very light loads, an often used parameter is the quiescent current, or  $I_Q$ .  $I_Q$  is defined as the current drawn by the device in a no-load and non-switching but enabled condition. In general, smaller quiescent current means that the converter is more efficient at very light loads. For a detailed explanation of the quiescent current and how it relates to the efficiency, see the [I<sub>Q</sub>: What It Is, What It Isn't, and How to Use It Technical Brief](#).

Designers are putting tremendous efforts to decrease  $I_Q$  and improve the converter efficiency at light loads. At  $\mu\text{A}$  load current levels, often an LDO has an advantage over a switching converter, unless the voltage needs to

be boosted. Not having a sufficiently low  $I_Q$  sometimes requires combining a switching converter with an LDO as shown in the [Adding an LDO for Increased Standby Mode Efficiency Reference Design](#), or using a switching converter with an integrated LDO. This approach comes with the price of increased solution size and cost.

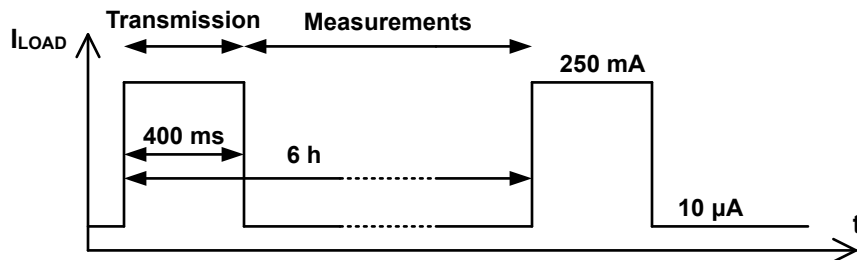
Now looking at the required external components, there is often a resistive feedback divider used to set the output voltage. When the load is in the range of a few  $\mu\text{A}$ , the current consumption of this feedback divider alone can take a significant portion of the total current consumption. To overcome this, some devices, such as the TPS63900, use set resistors to set the output voltage during start-up. This together with other design improvements leads to the extremely small  $I_Q$  of only 75 nA. Therefore, this switching converter can compete against linear regulators even in the  $\mu\text{A}$  current range.

As the next step in increasing the system efficiency, the supply voltage can be dynamically scaled to accommodate different power needs. Looking back at [Figure 1-1](#), the voltage rail is set to 3.6 V due to the transmitter power requirements for achieving a reliable data transmission. The same voltage is kept during standby, even though the rest of the system can operate at lower voltages. This is an unnecessary waste of power. Instead, the voltage rail can be lowered to a level that is just enough for the sensor and the microcontroller to operate. The TPS63900 has an additional feature that the output voltage can be dynamically switched between two user-configurable levels. This can lead to significant improvements in the system efficiency, as will be shown in the following case study.

## 2 Case Study

Consider a wireless sensor system shown in [Figure 1-1](#), with a load profile shown in [Figure 2-1](#). In reality, the load profile is usually more complex, with a sequence of different pulses. For the sake of simplicity and without significantly affecting the results, here the load profile is represented with a single rectangular pulse.

The system performs measurements or detection continuously, and transmits the data four times per day. The battery used is a 3-V Li-MnO<sub>2</sub> type, which is often the choice in long-life applications due to high energy density and low self-discharge. The converter provides the 3.6-V rail to power the system. In this case, the duty cycle  $D$ , defined as the time spent in high-power mode divided by the time spent in low-power mode, is close to  $2 \cdot 10^{-7}$ .



**Figure 2-1. Load Current Consumption for the Case Study**

With such a load profile, the energy consumption of the measurement period is more than two times larger than the energy consumption of the transmission period. This means that the efficiency at light loads, therefore, a low  $I_Q$  is more important than the efficiency at heavy loads.

Compare the TPS63900 with a closest competing device and see the difference in battery life. First, [Table 2-1](#) shows the main parameters of these two devices.

**Table 2-1. Main Parameters of the TPS63900 and the Competitor Device**

	TPS63900	Competitor	
Quiescent current	75 nA	300 nA	
Input voltage range	1.8 V - 5.5 V	1.8 V - 5.5 V	
Output voltage range	1.8 V - 5 V	1.6 V - 5.2 V	
Maximum output current	> 400 mA	250 mA	at $V_{OUT} = 3.6$ V
Adjustable output voltage	Yes, 100-mV step	No	
Dynamic voltage scaling	Yes, 2-level	No	
Adjustable input current limit	Yes, 8 presets	No	

Compare the two devices in case the voltage rail is fixed. [Table 2-2](#) shows that the 4 times lower  $I_Q$  of the TPS63900 decreases the total charge per load cycle by 8%, which increases the battery life by 9% when compared to the competitor's device.

**Table 2-2. Case Study Comparison With Fixed System Voltage**

Load Profile			TPS63900			Competitor		
$I_{OUT}$ [mA]	t [s]	$V_{OUT}$ [V]	Eff [%]	$I_{IN}$ [mA]	$Q_{IN}$ [As]	Eff [%]	$I_{IN}$ [mA]	$Q_{IN}$ [As]
0.01	21600	3.6	92.5	$1.3 \times 10^{-5}$	0.281	82.1	$1.46 \times 10^{-5}$	0.316
250	0.4	3.6	92.3	0.325	0.130	91.7	0.327	0.131
					Total $Q_{IN}$ [As]			0.411
					Battery life extended [%]			9
							0.447	

A 9% increase is not negligible when taking into account all the benefits of a longer battery life, such as the user experience or associated costs to replace the battery. Moreover, if the duty cycle is further decreased, or in this case if the transmission takes place less frequently, the advantage of having low  $I_Q$  becomes more apparent.

Go a step further and see the benefits of having the option to dynamically change the system voltage. The TPS63900 has the possibility to switch between two user-configurable output voltages that are loaded into the device during startup. If the standby voltage is decreased to 2.1 V, the power consumption is cut to almost a half of the power consumption at 3.6 V. [Table 2-3](#) shows the resulting battery life increase when compared to the competitor's device that cannot dynamically change the output voltage.

**Table 2-3. Case Study Comparison With DVS**

Load Profile			TPS63900			
$I_{OUT}$ [mA]	t [s]	$V_{OUT}$ [V]	Eff [%]	$I_{IN}$ [mA]	$Q_{IN}$ [As]	
0.01	21600	2.1	90.8	$7.71 \times 10^{-6}$	0.167	
250	0.4	3.6	92.3	0.325	0.130	
					Total $Q_{IN}$ [As]	0.297
					Battery life extended [%]	51

It should be noted that in the above case it is assumed that the load current remains the same if the load voltage is scaled. This may be true for constant current types of load, such as LDOs. Many loads, such as microcontrollers or operational amplifiers for example, behave resistive-like, and will show lower power consumption at lower operating voltages. If in the previous case, it is assumed that the load current scales with the load voltage, [Table 2-4](#) shows that the battery life can be extended by 86%, compared to the competitors device. Compared to the fixed system voltage case, dynamic voltage scaling can significantly extend the battery life.

**Table 2-4. Case Study Comparison With DVS and Scaled Load Current**

Load Profile			TPS63900		
I <sub>OUT</sub> [mA]	t [s]	V <sub>OUT</sub> [V]	Eff [%]	I <sub>IN</sub> [mA]	Q <sub>IN</sub> [As]
0.0058	21600	2.1	80	5.1x10 <sup>-6</sup>	0.110
250	0.4	3.6	92.3	0.325	0.130
			Total Q <sub>IN</sub> [As]		0.240
			Battery life extended [%]		86

Besides the ultra-low quiescent current, one of the main features of the TPS63900 is the input current limiting. The TPS63900 can limit the current drawn from the input supply to protect the batteries that do not support high peak currents, such as coin cell batteries. The input current limit is active both during normal operation and during start-up. This is shown in more details in the [Extend Battery Life Using a DC-DC Converter with Programmable Input Current Limit Technical Brief](#).

Estimating battery life for a specific scenario can be time consuming, especially when taking into account various parameters such as the battery characteristics, converter efficiency and load profiles. The “Battery Lifetime Calculator” tool can speed up and ease this process. [Figure 2-2](#) shows the interface of the tool. Various scenarios can be tested by selecting the built-in or importing custom battery discharge curves, converter parameters and load profiles. Moreover, different converter topologies are compared to determine which one is the best match for the given case.



**Figure 2-2. Tool for Estimating Battery Life**

### 3 Summary

Low quiescent current is crucial when selecting a converter to maximize battery life in low-power applications. Beside the quiescent current, one should also consider additional device functions. This application report shows that significant improvement in battery life can be achieved if dynamic voltage scaling is used.

### 4 References

- Texas Instruments, [TPS63900 1.8-V to 5.5-V, 400-mA, 75-nA Quiescent Current Buck-Boost Converter Data Sheet](#)
- Texas Instruments, [Selecting a DC/DC Converter for Maximum Battery Life in Pulsed-Load Applications](#)
- Texas Instruments, [I<sub>Q</sub>: What It Is, What It Isn't, and How to Use It](#)
- Texas Instruments, [Adding an LDO for Increased Standby Mode Efficiency](#)
- Texas Instruments, [Extend Battery Life Using a DC-DC Converter with Programmable Input Current Limit](#)

### 5 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

<b>Changes from Revision * (April 2020) to Revision A (October 2020)</b>	<b>Page</b>
• Updated quiescent current I <sub>Q</sub> from 200 nA to 75 nA throughout document.....	2

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