Increase Your Battery Life With Nano Quiescent Current LDO

ABSTRACT

With the increase in battery powered applications like metering, wearables, building automation and other internet-of-things (IoT) systems, one of the major challenges that is faced by the power design industry is to design an efficient power supply circuit that reduces the overall power consumption of the system and prolongs battery life. One common solution to this problem is to sub regulate the power supply of the system using a power IC like a low-dropout regulator (LDOs), that provides a stable DC supply converted down from the battery voltage. This document explains how the power consumption of a low-power nano I_Q LDO like TPS7A02 will impact the overall battery life of the system compared to one using a traditional LDO.

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1 Description

For this analysisa simple system is used in which a low-power MCU is being powered by an LDO. Next, an assessment of the impact of current consumption from the individual components in the circuit on battery life is made. The LDO is used to sub-regulate the battery power supply voltage down to a fixed DC voltage needed for the MCU.

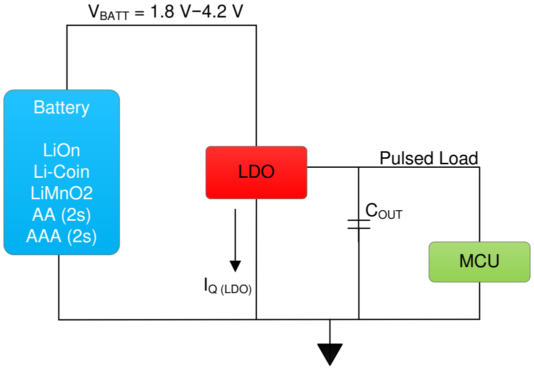

Figure 1. System Block Diagram

For a system like this, there are 4 main components that contribute to the total power consumption; the quiescent current consumption of the LDO, the current consumption of the MCU, the self-discharge of the battery, and the leakage of the output capacitor. The total current consumption of the system therefore can be calculated using Equation 1:

$$I_{Total} = I_{Q(AVG,\,LDO + MCU)} + I_{BL} + I_{CL} \tag{1}$$

The total battery life in years can be calculated with Equation 2:

$$\text{Battery Life} = \frac{\text{Battery Capacity}}{I_{Total}} \tag{2}$$

2 Components of the System

2.1 MCU

Modern low-power MCUs are designed to maximize battery life by spending most of the time in standby or sleep mode (T_S) and wake up periodically or with interrupts to perform specific software operations in active mode and then return to standby mode once completed. This creates a pulsed current load behavior on the supply and is illustrated in Figure 2.

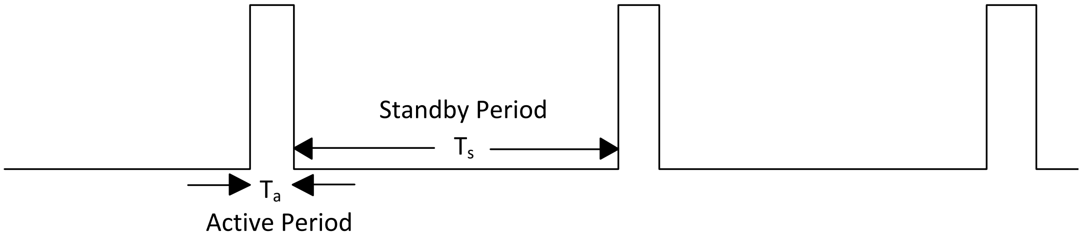

Figure 2. MCU Timing Diagram

Typically during the active mode the MCU consumes a current that is a function of its internal clock frequency. Calculate this using Equation 3.

$$\text{Active Current, } I_{QA} = \left(\frac{I_Q}{\text{Hz}}\right) \times \text{Frequency} \tag{3}$$

In standby mode, the current consumed ($I_{QS(MCU)}$) of the MCU is much lower compared to the active current to save power.

2.2 LDO

The LDO powering the MCU is an important component of the total current consumed in the system. Most traditional LDOs are designed to consume low quiescent current. This means that they will typically have low bandwidth and demonstrate slow dynamic response to fast current load changes.

Modern low I_Q LDOs like the TPS7A02 device use novel biasing techniques which allow the LDO to dynamically increase its bandwidth (and current consumption) based on its instantaneous load current. Furthermore, the TPS7A02 device achieves this while maintaining high current efficiency with respect to the current load. Current efficiency is defined in Equation 4:

$$\text{Current Efficiency } (\eta_i)\% = \frac{I_{OUT}}{I_{OUT} + I_Q} \times 100\% \tag{4}$$

Figure 3 shows how the TPS7A02 device maintains a current efficiency of ≥ 98% for loads higher than 10 µA.

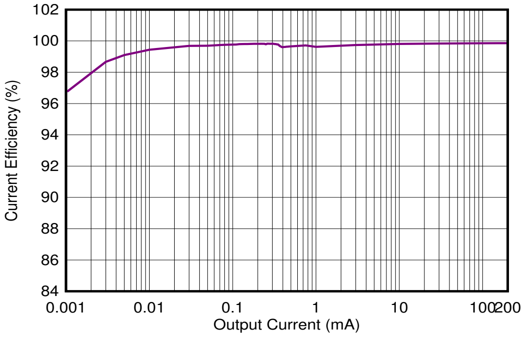

Figure 3. TPS7A02 LDO Current Efficiency

In active mode, the MCU would consume current in the order of several 100 s of µA. As Figure 3 shows, at this level of current load the TPS7A02 operates at close to 100% efficiency. So we can assume that in active mode, most of the current consumed by the system is due to the MCU and the impact of the current consumption of the LDO on the total I_Q is negligible.

Whereas during the standby mode the I_Q consumed by the MCU is much lower in magnitude. At lower current loads the LDO's current efficiency also decreases. So the quiescent current of the LDO can become a significant portion of the total system current consumption in standby mode.

$$I_{QS(total)} = I_{QS(MCU)} + I_{QS(LDO)} \tag{5}$$

Considering that this system runs a majority of the time in the standby mode and turns on only for a small duration of the time, the average quiescent current it consumes can be calculated using Equation 6:

$$I_{Q(AVG)} = \frac{\text{Active Current} \times \text{Active Time} + \text{Standby Current} \times \text{Standby Time}}{\text{Total Time}}$$

$$I_{Q(AVG)} = \frac{I_{QA(Total)} \times T_A + I_{QS(Total)} \times T_S}{T_A + T_S} \tag{6}$$

2.3 Battery Leakage

As batteries age over their lifetime, they start experiencing higher leakage currents and undergo self discharge even when they are not connected to any electrodes. The amount of self discharge the battery undergoes is a function of the battery type and chemistry and can be elevated by the aging and temperature of operation. As an example, consider that the self-leakage of the battery is I_L% per year. This means for a battery of capacity Q mAh, the total current consumed due to its self-leakage is calculated using Equation 7:

$$I_{BL} = \frac{Q \times I_L \%}{24 \times 365} \tag{7}$$

2.4 Output Capacitor Leakage

Most LDOs require an output capacitor for stability. The leakage current consumed by this output capacitor is also a component of the total system current consumption. The TPS7A02 LDO can be stabilized with a very small ceramic capacitor which helps to reduce this effect. The leakage current of the ceramic capacitor is usually specified in insulation resistance (Ω) and the leakage current can be estimated by the ratio of the rated capacitor voltage and insulation resistance (I = V/R). This parameter is defined as I_{CL}. This capacitor leakage varies by manufacturer, temperature, charging profile, and product family so the actual part measurement over operating conditions is strongly recommended.

3 Conclusion

All the components discussed in this application report contribute to the total current consumed by this system. So as Equation 1 shows, the total current consumption of the system therefore can be calculated with Equation 8:

$$I_{Total} = I_{Q(AVG)} + I_{BL} + I_{CL} \quad (8)$$

The total battery life can be calculated as a function of the capacity of the battery and the total current consumed in the system and can be shown to be the same as Equation 2:

$$\text{Battery Life} = \frac{\text{Battery Capacity}}{I_{Total}} \quad (9)$$

Use these equations to calculate and compare the battery life of a nano power LDO like the TPS7A02, which consumes current of only 25nA with a traditional low I_Q LDO like the TPS7A05 device, which consumes current of 1 µA. Observe that the battery life of a system can be increased from 5 years to 8.7 years by using a nano-I_Q LDO compared to a traditional low I_Q LDO.

Table 1. Battery Life Comparison

Parameter	**LDO (1) TPS7A02**	**LDO (2) TPS7A05**
LDO I_Q (µA)	0.025	1
MCU active mode µA/MHz	100	100
MCU frequency (MHz)	16	16
Active MCU current (µA)	1600	1600
Standby MCU current (µA)	1	1
Time ratio (Ts, standby/ Ta, active)	10000	10000
Average active current (µA)	1.18	2.16
Battery capacity (mAh)	100	100
Battery leakage % per year	1%	1%
Battery leakage - µA	0.11	0.11
LDO output capacitor leakage - µA	0.01	0.01
Total hours	76392	43784
Total years	8.7	5.0

A plot can be made using the same equations that shows how the battery life of the system is impacted by varying quiescent current. Figure 4 shows how using an LDO with low I_Q in standby mode can significantly affect the battery life of the system.

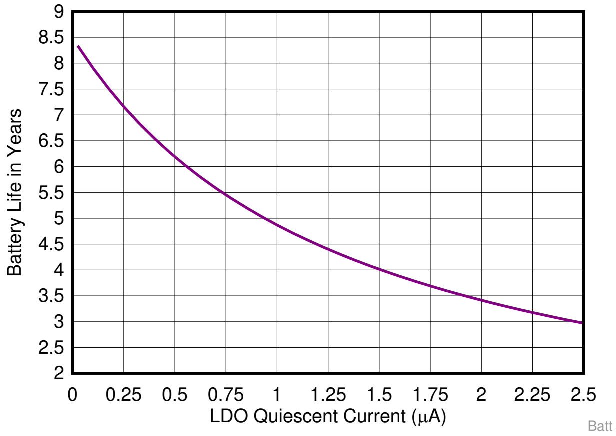

Figure 4. Battery Life in Years vs LDO Quiescent Current

This demonstrates the impact of the quiescent current of the LDO on the battery life of the system and the benefit that the ultra low I_Q LDO like the TPS7A02 device provides. For a duty-cycled system where the system stays in standby mode for most of the duration and turns on only for a small amount of time, the battery life of the system can be doubled using a 25-nA I_Q LDO vs a 1.5-µA I_Q LDO.

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