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How Ultra-Low I_Q Boost Converters Extend IoT Device Runtime

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Common characteristics in internet of things (IoT) devices include small form factor and the need to operate for long periods of time without consuming too much power. For smart sensors deployed in the field, for example, it's not practical to have to change the batteries frequently, nor is it feasible to implement them with any kind of bulky power source. A similar situation holds for electronic gadgets like earbuds and smart watches.

A good user experience dictates that these devices run for a long time in between charges. What's more, the "green energy" drive toward reducing wasted power and moving to renewable energy generation sources reinforces the importance of finding ways to extend battery runtime.

In consumer electronics, boost converters are commonly used to raise and stabilize the sagging voltage of their lithium-ion batteries under load. In this article, we'll discuss a typical IoT power management solution for small, portable gadgets, as well as its shortcomings. We will then introduce a boost converter, the MAX17222, which addresses these shortcomings while also providing the ability to operate practically on fumes down to minimal amounts of residual battery energy.

We will begin by discussing an application example—a wearable heart monitor—that illustrates the runtime limitations imposed by the battery and the voltage regulator used to power it. The impact of the regulator's leakage current and quiescent current will be highlighted. Then we will explain how the features and performance capabilities of the MAX17222 serve to extend the run time of the application example.

To demonstrate the benefits of the regulator's low quiescent current, we'll go through the simple calculations of input quiescent current to show how that translates into longer shelf time. We'll also discuss some design tradeoffs made in the regulator to achieve its low I_Q. Finally, we'll look at the high efficiency of the boost converter over its load range as a means to extend operating time.

Fig. 1. IoT devices need highly efficient energy sources for long battery runtime.

Example: A Wearable Heart-Monitoring Patch

As an example of an IoT device, let's consider a wearable heart monitoring patch (Fig. 2). Such patches are typically very small and must last a long time, so it's essential to minimize both size and power dissipation.

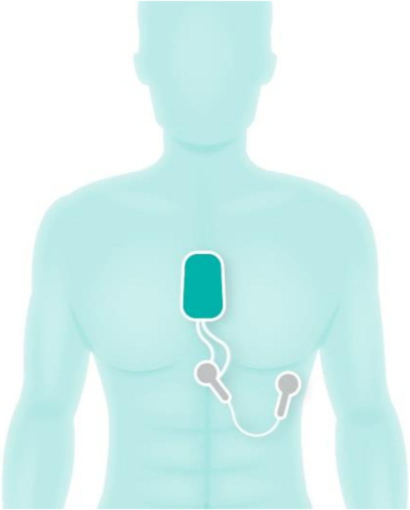

Fig. 2. Patient wearing a heart-rate monitor.

A heart-monitoring patch powered by a 100-mAh alkaline button cell and consuming 100 µA in operation can be expected to last three weeks. However, when in shutdown mode, the device may need to last up to three years; in this case, the leakage current must be 4 µA or less. The dilemma is, a typical switching regulator won't support these parameters. With a leakage current of 0.2 µA and a total quiescent current of 10 µA, a typical voltage regulator will rob 1.8 months from the device's shelf life and two days of operation.

Indeed, it's definitely a challenge to achieve both high efficiency and small size from an electronic device. One way to address the size requirement is to increase the frequency of operation, which will reduce the size of passives; however, this approach also increases losses, thereby reducing efficiency.

A proven method to address power efficiency and extend battery runtime is to lower the quiescent current, or standby power. Battery life is calculated based on active, sleep, and hibernate currents of the central controlling unit, such as a microcontroller. Active current consumption is certainly an important factor in extending battery life, but runtime is ultimately influenced by how long the device spends in each power mode.

Considering that sleep and hibernate functions occupy longer periods of time with many IoT devices, the standby current of each component has become quite critical. The device power supply's quiescent current is the biggest contributor to a system's standby power consumption.

With the proliferation of portable IoT devices, there's an emerging need for multiple customized versions of voltage regulators, especially when it comes to output voltage and current specifications. Accordingly, an IoT device manufacturer may be forced to maintain a sizeable and costly inventory of different regulators and the passives required to support them.

A New Class Of Boost Converters

What if you had a voltage regulator that addresses all of these shortcomings? Today, there are new options. As an example Maxim's nanoPower ICs have <1 µA of quiescent current. The MAX17222 nanoPower synchronous boost converter is a voltage regulator that addresses the shortcomings of more traditional power supply solutions.

The MAX17222 provides a 400-mV to 5.5-V input range, a 0.5-A peak inductor current limit, and an output voltage that is selectable using a single standard 1% resistor. Its novel True Shutdown mode yields leakage currents in the nanoampere range, making this a true nanoPower device.

Why Low Shutdown Current Matters

In Fig. 3, you can see the basic elements of the MAX17222 regarding shutdown and quiescent currents.

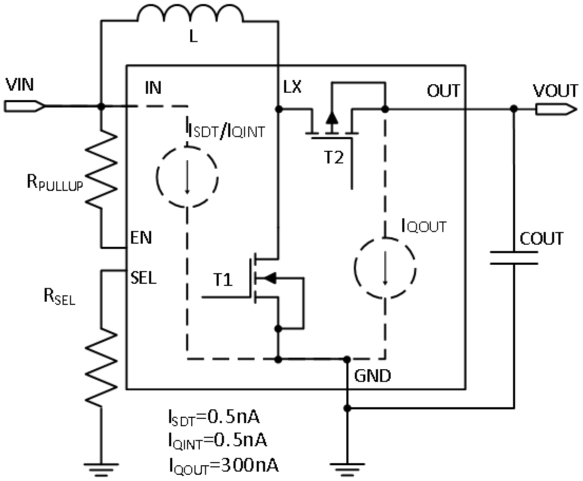

Fig. 3. MAX17222 shutdown and quiescent currents.

The True Shutdown feature disconnects the output from the input with no forward or reverse current, resulting in very low leakage current. With the True Shutdown mode, which uses only 0.5 nA current, there's no need to use external switches. The higher switching frequency also allows the use of a smaller external inductor, further contributing to a smaller overall solution size.

Going back to our heart-monitoring patch example with the typical voltage regulator, we had calculated a reduction in shelf life of 1.8 months out of three years for a 100-mAh cell. With the 0.5-nA leakage current of the nanoPower boost converter, the reduction in shelf life for the same cell over three years is reduced to only three hours.

If a pullup resistor is used to enable/disable operation, you'll also need to account for the pullup current in True Shutdown mode. Alternatively, if the enable (EN) pin is driven by a push-pull external driver, which is powered by a different supply, then there is no pullup current and the shutdown current is only 0.5 nA.

Benefits Of Low Quiescent Current

Looking at Fig. 3, the input quiescent current (I_{QINT}) for the MAX17222 is 0.5 nA (enable open after startup) and the output quiescent current (I_{QOUT}) is 300 nA. To calculate the total input quiescent current, add to I_{QINT} the additional input current needed to feed the output current (I_{QOUT_IN}). Since the output power is related to the input power by the efficiency ($P_{OUT} = P_{IN} \times \eta$), it follows that:

$$I_{QOUT\_IN} = I_{QOUT} \times (V_{OUT}/V_{IN})/\eta$$

If V_{IN} = 1.5 V, V_{OUT} = 3 V and efficiency η = 85%, we have:

$$I_{QOUT\_IN} = 300 \text{ nA} \times (3/1.5)/0.85 = 705.88 \text{ nA}$$

Adding the 705.88 nA to the input current of 0.5 nA yields a grand total input quiescent current of 706.38 nA (I_{QINGT}). This calculation is 14x better than the typical case previously discussed. With 0.7 µA of quiescent current, the two days of reduced operation calculated for the typical solution becomes only 3.5 hours.

The MAX17222 includes an option for enable transient protection (ETP) mode. When activated by the presence of a pullup resistor, extra on-chip circuitry powered by the output capacitor assures that EN stays high during short transient disturbances at the input. In this case, the quiescent current calculated above increases by a few tens of nanoamps.

The MAX17222 trades off the traditional resistor-divider that is used to set the output voltage value with a single output-selection resistor (RSEL), as depicted in Fig. 3. At startup, the chip uses up to 200 µA to read the

RSEL value. This occurs only during the select resistor detection time (typically lasting 600 µs), which virtually eliminates the contribution of RSEL to the quiescent current.

A single standard 1% resistor sets one of the 33 different output voltages, separated by 100-mV increments between 1.8 V and 5 V. As a result, you get a small reduction in bill of materials (BOM), with one less resistor, as well as lower quiescent current.

The Importance Of High Efficiency

The MAX17222 features low R_{DSON}, on-board powertrain MOSFETs, resulting in high efficiency even when operating at frequencies high enough to warrant a small overall PCB size. In Fig. 4, you can see the efficiency of the MAX17222, with V_{OUT} = 3.3 V at various values for V_{IN}. The low-quiescent-current design extends the outstanding efficiency performance down to a few microamps of load current.

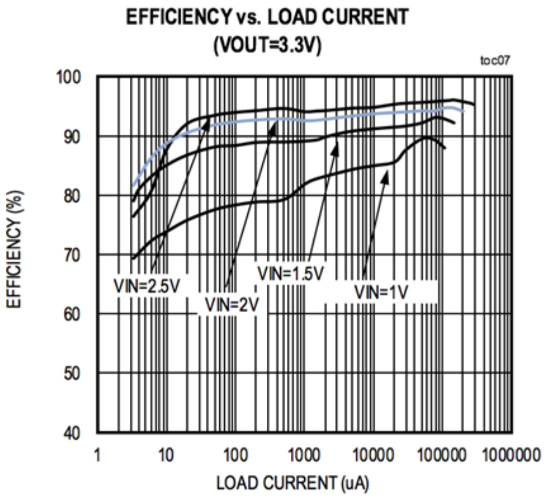

Fig. 4. MAX17222 efficiency curves.

Summary

As the IoT takes hold in our everyday lives, the market is experiencing an abundance of small, wirelessly connected, battery-operated electronic devices. One of the keys that these devices require in order to thrive is a significant reduction in power loss boundaries for operation (efficiency) and shutdown (leakage current). With the ultra-low quiescent current and high efficiency available in a nanoPower synchronous buck converter, designers have the means to increase the shelf and operating life that is expected of IoT devices.

About The Authors

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For more information on designing power converters for IoT applications, see How2Power's Design Guide, locate the Application category and click on "Battery Powered & Portables".