Improving battery life in wearable patient monitors and medical patches

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Introduction

The market for wearable patient monitors is growing fast. The two main attributes for wearable monitors are portability (or size) and operating time (or battery life). Today's wearable medical products not only measure vital signs but can also act as personal emergency-response systems.

Portable and wearable applications are typically battery powered, and for consumers, battery life is one of the key purchasing considerations. The life of the battery is critical because most patient monitors measure and monitor continuously.

Battery-powered systems require careful partitioning, tight space utilization and efficient use of the available charge. It is important to enable more functionality while delivering power more efficiently in a tight space for a longer time. Functions like standby, sleep, power save, hibernate and shutdown are critical for designers to reduce power consumption and extend battery life.

Low-power microcontrollers (MCUs) and analog integrated circuits are available, but it won't be possible to leverage most of the latest technologies in the design without optimizing power management. It is important to choose the right power architecture for the application to be more efficient and get extended battery runtimes. This article highlights different power schemes to improve battery life in wearable patient monitors and medical patches.

Types of batteries used in medical applications

Devices like heart-rate monitors, multiparameter patches, blood glucose monitors, blood-pressure monitors, pulse oximeters, fitness monitors and activity monitors can be portable and wearable. Many of these devices are disposable or use batteries that need replacing. However, their connections to smart devices are making them more power-hungry. Disposable batteries (nonrechargeable primary cells like the CR2032 or CR3032) may not be sufficient, and thus contribute to the use of rechargeable batteries.

Lithium-ion (Li-ion), lithium-polymer (Li-poly), nickel metal hydride (NiMH), lithium iron phosphate, lithium manganese and zinc are popular battery chemistries in medical devices, and each type needs a different charging circuit. It is also important to note that rechargeable batteries have a self-discharge rate. To reduce overall bill of materials (BOM) and size, designers may connect batteries directly to the radio module and other peripherals, but running directly from the battery voltage is not the most efficient way to use the battery.

Choosing the right battery charger to improve battery life

Battery charging for wearables is challenging because batteries must be both small in size and capacity. Charge currents vary greatly depending on whether a 50-mAh, 100-mAh or 200-mAh battery is used, and whether to charge at 0.5 C-rate (C), 1 C or 2 C. The key is to include a programmable fast-charge current capability into the design.

While it is important to charge quickly, it is also important to get as much energy into the battery as possible. To do this, the termination current must be precise and be able to terminate reliably at very low current. See Reference 1 for an example of a charger with very-low termination and quiescent currents.

Figure 1 shows that it is possible to gain an additional 2 mAh (~5%) of battery life by reducing the termination current to 1 mA. Based on the application, the number of cells can vary. The battery charging solution will also change accordingly.

Figure 1. Benefits of a low-termination current
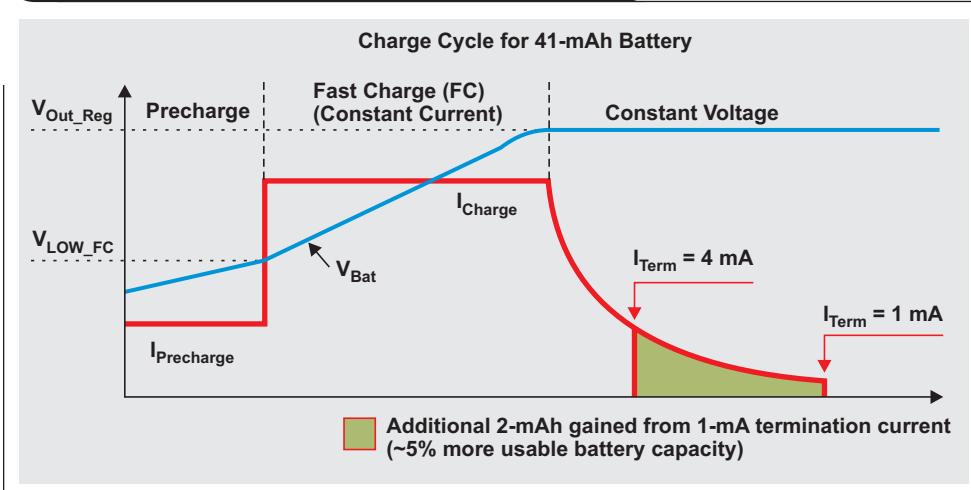
Powering with a buck, boost or buck-boost converter

Consider an example where a radio device from Texas Instruments is used in a wearable application. The CC254x device family operates between 2.0 V and 3.6 V. Internally, the supply is generally regulated down to 1.8 V using low-dropout regulators (LDOs). This means that for systems with high supply voltages, much of the energy is lost in the LDOs. To remedy this, an external DC/DC converter can be used to regulate down to ~2 V and increase the overall system efficiency.

A DC/DC converter, like the TPS62730, can convert an input in the range of 3.9 V down to a desired voltage of 1.9 V. (See Reference 2, where 2.2 V is the limit above which the DC/DC-converter switching frequency does not affect the radio-frequency performance of the CC254x.) When the supply voltage to the converter falls below 2.2 V, the converter automatically enters bypass mode, where its output is directly connected to the battery. This reduces current consumption during active mode, which ensures improved battery life. Figure 2 shows the reduction in battery current while using the TPS62730.

In case there is no pin control available from the micro-controller, other buck converters with extremely low I_Q like the TPS62743 or TPS62740 can be used.

Patient monitors that measure heart rate and oxygen saturation (SpO_2) have LED drivers that drive green, red and infrared LEDs. Based on the forward voltage of the LEDs, the driver should have a supply voltage higher than the coin-cell battery voltage (such as 3 V). To achieve this, a very low-I_Q boost converter can be used.

Insulin pump applications are becoming more compact now that they have an integrated injection needle. In such integrated cases, the load current will be very high because it has to power the pump as well as the interface circuit to the injection needle. A boost converter like the TPS610981 (shown in Figure 3) can operate directly from battery and has very low I_Q, which can help make the pump work well.

Often neglected, a buck-boost converter offers another technical advantage in small battery-powered applications compared to a buck or boost converter. In wearable applications, the rails do not require a voltage higher than 3 V; therefore, using a boost converter isn't necessary. Power rails for MCUs and wireless devices often require a low voltage, so a buck may be an obvious choice until all aspects of the design are evaluated.

While drawing current from the battery with a pulsating load profile, the battery voltage can drop below the required output voltage for a short period, which can cause instability in the regulation—more than

the manufacturer's specified voltage. The voltage drop on the battery is especially significant toward the end of the battery's life because of the internal resistance increasing in value over time. As the name implies, the key advantage of a buck-boost converter is to provide a higher voltage than the input voltage, ensuring an accurate and precise regulated voltage for pulsating load-current profiles and high-impedance batteries. A buck-boost converter provides the highest flexibility in battery and power-architecture choice over a buck converter.

Using LDOs to improve efficiency

There are general assumptions that switching controllers or converters contribute to highly efficient power schemes and that LDOs have bad efficiency. But LDO topologies have changed; they can provide very-low dropout voltages. A low-input low-output (LILO) LDO uses an N-channel metal-oxide semiconductor (NMOS) pass transistor and a

Figure 2. Efficiency improvement and battery-current reduction using the TPS62730
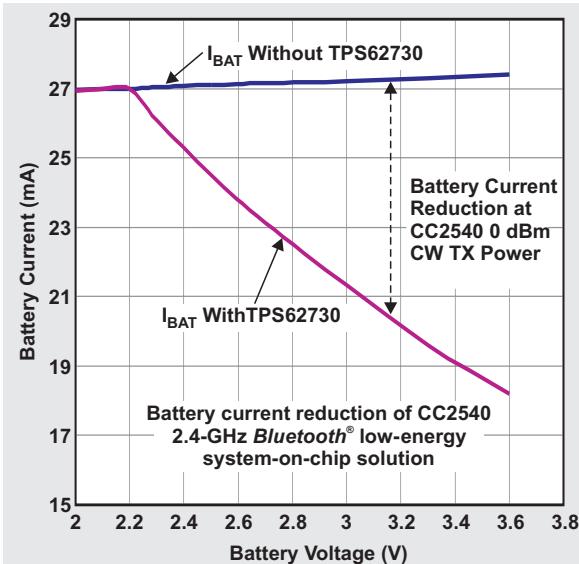
Figure 3. Insulin delivery-patch application
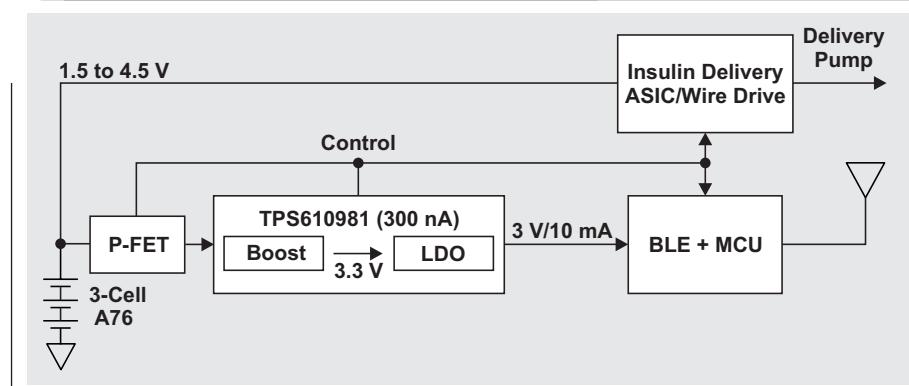
bias rail to achieve low dropout. As a result of this topology, there is a higher voltage that supplies the bias rail and powers most of the LDO's internal circuitry, so the LDO can operate at lower input voltages.

The decreased dropout voltages enable an increase in efficiency that is comparable to that of switch-mode power supplies. In portable electronics, it is very common to have LDO-powered sensors because a switching converter generates too much noise. Designers may use low-I_Q LDOs with the assumption that they increase the battery life of the system as the load is being pulsed. This is not necessarily the most efficient solution, however, as large power dissipation during the time when the load is on can drastically decrease efficiency.

Figure 4 shows two common power configurations for implementing a portable system. One uses a generic low-I_Q LDO and the other uses a low-I_Q LILO LDO. Comparing the power dissipation between the two solutions, the generic low-I_Q LDO dissipates 2.7 mW while the LILO LDO dissipates 1.8 mW (see Table 1). Using the LILO LDO increased efficiency from 55% to 82%, even though the total I_Q is higher on the LILO LDO.

As shown in Table 1, there is a clear benefit to implementing LILO LDOs in portable applications if battery life and efficiency are the main concerns.

Using load switches to further enhance battery life

After optimizing the front-end power path of the battery charger and mid-rail DC/DC converters and LDOs, there is still a way to use a load switch to reduce the shutdown current of any load. A radio module might consume over 10 µA in deep sleep or hibernation mode. A load switch reduces the shutdown current to just 10 nA (see Figure 5).

If there are multiple sensors and wireless transmitters in a single product, more than one load switch can be used to disable the load.

Figure 4. A low-IQ LDO versus a LILO LDO

a) Generic low-I_Q LDO

b) Low-input, low-output (LILO) + low-I_Q LDO
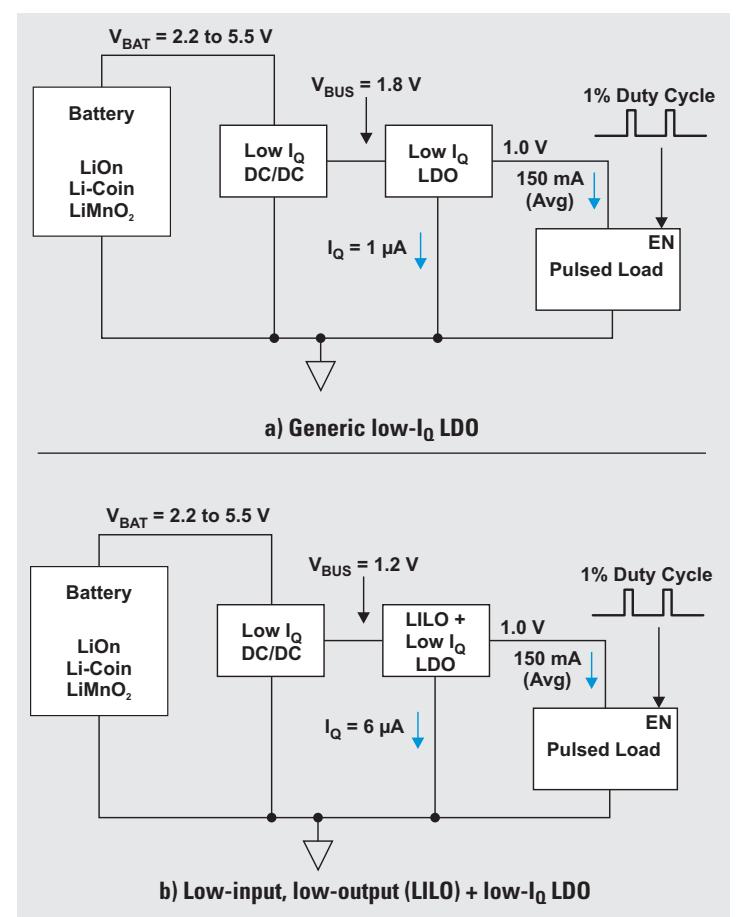
Table 1. Efficiency calculations

System Details		Low I_Q LDO	LILO LDO	Unit
Voltage Rails	V_{BATT}	3.6	3.6	V
	LDO V_{IN}	1.8	1.2	V
	LDO V_{OUT}	1	1	V
Duty Cycle	Duty Cycle	1	1	%
Load Current + I_Q	I_{LOAD}	0.15	0.15	A
	I_Q V_{IN}	1	1.6	µA
	I_Q Bias	0	6	µA
Power Dissipation	P_{DISS}, Load	1.5	1.5	mW
	P_{DISS}, LDO	1.2	0.3	mW
	P_{DISS}, Off	0.002	0.023	mW
	P_{DISS}, Total	2.702	1.823	mW
Efficiency	Eff, Total	55.5	82.3	%

Figure 5. Reduce shutdown current by adding a low-leakage load switch

Now consider an example of a wireless patch (with *Bluetooth*® low energy) using a standard 4.2-V Li-ion rechargeable battery with 100 mAh of capacity. In order to last at least seven days before charging, certain vital-sign sensors can remain powered, but the radio module can be shut down.

Table 2 shows that if the radio module draws 10 µA when disabled, it is contributing to at least 10 µA × 24 hours × 7 days = 1.68 mAh of the 100-mAh budget. In other words, this one module contributes at least 1.68% (1.68 mAh/100 mAh) to overall loss of battery-life. Note that there are also other losses like minimum/maximum specs over temperature, efficiency loss through the power components, and other radio modules leaking current.

Using a load switch will cut that shutdown leakage current to just 10 nA. The radio module will have virtually no effect (0.00168%) on battery life when disabled.

Conclusion

There are multiple ways to improve battery life in wearable patient monitors and medical patches. The key to long battery life is operating with the lowest current consumption by reducing system activity when it is not needed. The power architecture plays a significant role in achieving longer battery life.

Table 2. Percentage loss of battery capacity while using a load-current switch

Input Source	Capacity	Shutdown Period	Shutdown Current for Radio Module	Loss of Capacity	Loss
Li-ion battery (4.2 V)	100 mAh	7 days	10 µA	0.00168 mAh	1.68%
			10 nA	0.00000168 mAh	0.00168%

References

1. Janice Escobar, "The future of wearable biosensors and linear chargers," TI E2E™ Community blog post, Dec. 4, 2017.

2. Abhishek Chattopadhyay, "Current Savings in CC254x Using the TPS62730," Application note (SWRA365B)

Related Web sites

TI E2E Community blog posts:

How LILO LDOs increase system efficiency

How can a load switch extend your device's battery life?

Reference designs:

Wearable, Wireless, Multi-Parameter Patient Monitor Reference Design (TIDA-01580)

Light Load Efficient, Low Noise Power Supply Reference Design for Wearables and IoT (TIDA-01566)

Product information:

***Bluetooth*® low-energy products**

Low-dropout linear regulators (LDOs)

Load switches

TPS62730, TPS62743, TPS62740, TPS610981

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