Reducing battery size and cost

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As modern wireless electronic devices become increasingly miniaturized, there is growing demand to reduce the size and cost of the battery wherever possible. Achieving these two goals simultaneously is an ideal objective, especially when it can be achieved without compromising product performance.

The route to saving size and expense differs depending upon whether the application calls for a primary (non-rechargeable) batteries or some form of energy harvesting device combined with a rechargeable battery to store the harvested energy.

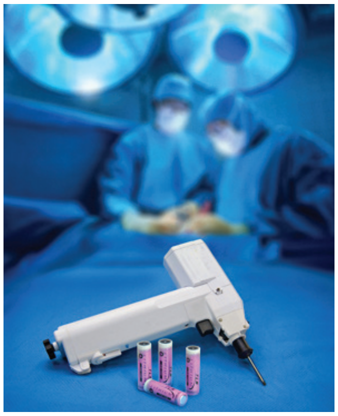
Choosing among primary batteries

The vast majority of remote wireless devices are powered by a primary battery, with choices that include lithium thionyl chloride, lithium metal oxide, alkaline, lithium iron disulfide, and lithium manganese oxide. Each chemistry offers different performance characteristics, so trade-offs are common (see Table 1 below).

Primary Cell	**$LiSOCl_2$** Bobbin-type with Hybrid Layer Capacitor	**$LiSOCl_2$** Bobbin-type	**Li Metal Oxide** Modified for high capacity	**Li Metal Oxide** Modified for high power	**Alkaline**	**$LiFeS_2$** Lithium Iron Disulfate	**$LiMnO_2$** CR123A
Energy Density (Wh/1)	1,420	1,420	370	185	600	650	650
Power	Very High	Low	Very High	Very High	Low	High	Moderate
Voltage	3.6 to 3.9 V	3.6 V	4.1 V	4.1 V	1.5 V	1.5 V	3.0 V
Pulse Amplitude	Excellent	Small	High	Very High	Low	Moderate	Moderate
Passivation	None	High	Very Low	None	N/A	Fair	Moderate
Performance at Elevated Temp.	Excellent	Fair	Excellent	Excellent	Low	Moderate	Fair
Performance at Low Temp.	Excellent	Fair	Moderate	Excellent	Low	Moderate	Poor
Operating Life	Excellent	Excellent	Excellent	Excellent	Moderate	Moderate	Fair
Self-Discharge Rate	Very Low	Very Low	Very Low	Very Low	Very High	Moderate	High
Operating Temp.	-55°C to 85°C, can be extended to 105°C for a short time	-80°C to 125°C	-45°C to 85°C	-45°C to 85°C	-0°C to 60°C	-20°C to 60°C	0°C to 60°C

When specifying primary (non-rechargeable) batteries, numerous variables can contribute to reducing the size and expense of the battery, including:

- Reducing the number of cells and the size of each cell in a pack
- Battery voltages
- Battery energy densities
- Battery self-discharge rates
- Operating temperature effects on battery technologies
- Power (pulse) or energy (capacity)?
- Battery costs over the desired operating life of the device



Surgical power drills use lithium metal oxide batteries to achieve a 64% weight reduction and a 60% volume reduction compared to alkaline batteries .

High cell voltage can mean fewer cells

Battery voltage differs depending on the chemistry: Alkaline cells – 1.5v each; Lithium iron disulfide cells – 1.5v each; Lithium Manganese dioxide – 3.0v each; Lithium Sulphur Dioxide cells – 3.0v each; Lithium Thionyl Chloride cells – 3.6v each, TLM (Lithium Metal Oxide) cell – 4.1v each.

For example, a surgical drill manufacturer was able to replace 12 alkaline AA cells with 4 TLM (Lithium Metal Oxide) AA cells, resulting in reduced size and weight while also enabling greater torque and faster drilling speeds.

Converting to PulsesPlus battery packs reduced the size of a device that monitors the size and location of icebergs. The larger battery pack (left) used 380 D-size alkaline cells while the far more compact battery pack (right) used 32 lithium D-cells and 4 AA-sized hybrid layer capacitors (HLCs).

Wider temperature ranges affect battery size and cost

Low temperatures can reduce cell voltage, thus requiring the use of more cells to offset the expected loss in voltage. Prolonged exposure to high temperatures increases a battery's annual self-discharge rate, thus shortening battery operating life (see Table 1). Bobbin-type lithium thionyl chloride cells ($LiSOCl_2$) batteries are least affected by exposure to severe temperatures.

For example, a buoy that measured the location and thickness of icebergs in the Artic, formerly powered by a very large pack consisting of 380 alkaline D cells, was able to substitute a much smaller pack consisting of 32 lithium thionyl chloride D cells and 4 AA-sized HLCs. These batteries can be modified for use in the cold chain, enabling continuous monitoring of foods, medicines, and tissue samples at -80°C.

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Awarepoint medical asset tracking RFID tags contain bobbin-type $LiSOCl_2$ batteries that can withstand high temp. autoclave sterilization without having to remove the battery, saving labor and providing a continuous data stream.

Specially modified $LiSOCl_2$ cells can withstand 125°C, thus utilized in active RFID devices that track the location and status of medical equipment, allowing the equipment to undergo high temp. autoclave sterilization without having to remove the battery, which improves data reliability and cuts labor expense.

High energy density reduces battery size

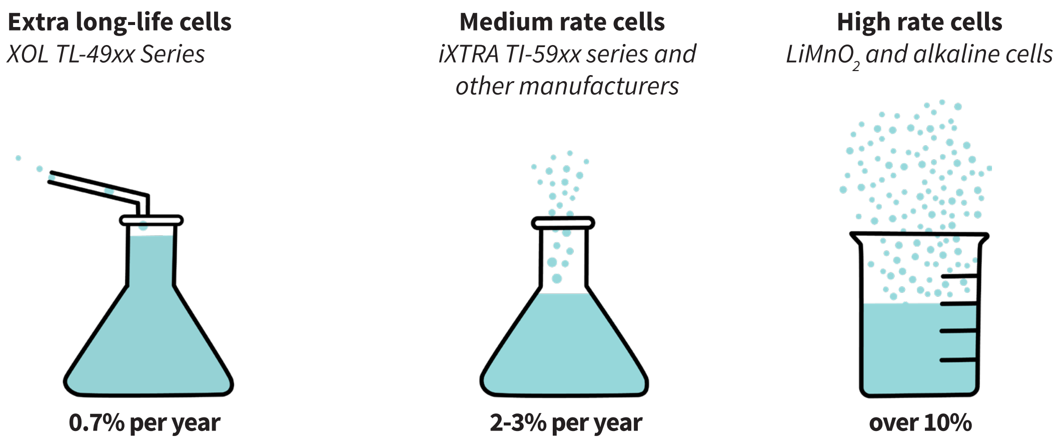
As Table 1 shows, the energy density of a primary battery can range from a high of 1,420 Wh/l for a bobbin-type lithium thionyl battery equipped with a patented hybrid layer capacitor (HLC) to 185 Wh/l for a lithium metal oxide battery.

For example, higher energy density permits one (1) AA-size bobbin-type $LiSOCl_2$ battery to be substituted for 3.5 alkaline or $LiMnO_2$ batteries to achieve a significant size and weight reduction.

In addition, using cells with less capability of producing high pulses can lead to the use of a greater number of larger size cells with higher energy capacity to produce the required pulse, leading to wasted battery capacity.

High self-discharge rates equate to larger batteries

Battery self-discharge rates vary considerably, with long-life cells featuring a self-discharge rate as low as 0.7% per year to permit up to 40-year battery life. By contrast, cells with higher drain rates can have a self-discharge rate of over 10% per year, which severely limits battery operating life to as little as 5 years. Use of extended life batteries can also help to reduce the total number of batteries required while also reducing the need for future battery change-outs over the expected lifetime of the device.



In certain cases, it is possible to use a smaller size cell with a lower self-discharge rate. For example, using a C-size cell instead of a higher self-discharge D-size cell.

Don't confuse price and cost

The price of a battery is the initial amount spent to purchase the battery. The cost of the battery is the total amount spent throughout the lifetime of the device. Here is a relative price comparison:

- X is the price of the lowest self-discharge lithium thionyl chloride cell
- 2/3X is the price of the cheaper, higher self-discharge lithium thionyl chloride cell
- 1/2X is the price of the lithium manganese dioxide cell
- 0.2X is the price of the alkaline cell
- 0.05X is the value-added price per cell to construct pack
- 5X is the price to replace a pack in a remote location
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Below is the comparative cost for a 3-4 V device with a 20-year battery life (at 25°C).

Cost for an alkaline pack, 20 cell pack lasting 5 years –

- 4 packs, 3 change outs   4[20(0.2X+0.05X)]+3(5X)= **35X**

Cost for an lithium manganese pack, 4 cell pack lasting 10 years –

- 2 packs, one change out   2[4(1/2X+0.05X)]+5X= **9.4X**

Cost for a higher self-discharge thionyl pack, 1 cell pack lasting 14 years –

- 2 packs, one change out   2[1(2/3X +0.05X)]+5X = **6.4X**

Cost for a lower self-discharge thionyl pack, 1 cell pack lasting 40 years –

- 1 pack = **X**

Cost for a SMALLER lower self-discharge thionyl pack, 1 cell pack lasting 20 years –

- 1 pack = **2/3X**

A real-life example showing the value of lower annual self-discharge

A recent article published in Water and Waste Digest, "*Determining the economical optimum life of residential water meters*", concluded that based on the costs on water loss and mechanical meter price and installation, "**Replacement (of mechanical water meters) at the end of year 16 will guarantee a minimum annual cost** under the conditions specified in the presentation."

While battery-powered electronic automatic read meters cost more than twice as much as mechanical meters, they can operate economically for over 30 years. A battery life of only 15 years would mean that meters would be replaced half way through their economic life.

New ULTRASONIC water meters do not wear out and could make use of battery lives up to 40 years.

Rechargeable batteries

Certain remote wireless applications exhaust enough average daily current that would prematurely exhaust a primary battery, making them well suited for some form of energy harvesting coupled with a rechargeable lithium-ion (Li-ion) battery to store the harvested energy, with a choice between consumer grade and industrial grade Li-ion batteries (see Table 2 on next page).

Industrial grade TLI Series rechargeable Li-ion batteries operate up to 20 years and 5,000 recharges, delivering high pulses and an extended temperature range.

If a consumer type application requires 2-3 year operating life at 25°C, the higher capacity of the consumer grade battery (3000 mAh vs. 330 mAh) is extremely advantageous. However, industrial applications often have far different requirements, including size constraints, exposure to extreme temperatures (-40°C to 85°C), and expected operating life often ranging for 5-20 years, commonly in remote locations where battery replacement is difficult or impossible.

The ability of an industrial grade TLI-1550 (AA-size) to discharge and recharge at -40°C to 85°C serves to reduce the size of the pack while improving the reliability of the device.

The higher recharge cycle life of the industrial grade TLI-1550 rechargeable Li-ion battery (5000 cycles @ 100% depth of discharge (DOD) is also preferable to consumer Li-ion cells (500 cycles @ 100% DOD), serving to extend operating life while also helping to reduce the size of the cell. This difference in battery life cycle expectancy grows exponentially when the DOD is reduced, reaching as high as 50,000 recharge cycles at 50% DOD.

A Comparison of Rechargeable Li-ion Cells		**TLI-1550 (AA)** Industrial Grade	**18650 Li-ion** Consumer Grade
Diameter (max)	[cm]	1.51	1.86
Length (max)	[cm]	5.30	6.52
Volume	[cc]	9.49	17.71
Nominal Voltage	[V]	3.7	3.7
Max Discharge Rate	[C]	15C	1.6C
Max Continuous Discharge Current	[A]	5	5
Capacity	[mAh]	330	3000
Energy Density	[Wh/l]	129	627
Power [RT]	[Wh/liter]	1950	1045
Power [-20°C]	[Wh/liter]	>630	<170
Operating Temperature	deg. C	-40 to +90	-20 to +60
Charging Temperature	deg. C	-40 to +85	0 to +45
Self Discharge Rate	[%/Year]	<5	<20
Cycle Life	[100% DOD]	~5000	~300
Cycle Life	[75% DOD]	~35000	~400
Cycle Life	[50% DOD]	~50000	~650
Operating Life	[Years]	>20	<5

Compared to consumer grade cells, industrial grade Li-ion batteries can achieve a higher maximum discharge pulse rate (15C max/ 5 A continuous vs. 1.6C/ 5 A max AT 25°C) and a lower self-discharge rate, with both features contributing to a possible size reduction of the rechargeable pack as well as longer battery operating life, including the need for fewer battery change-outs over the expected lifetime the device.

6 industrial Lithium Ion AAs replace 18 D size super-caps.

Consumer electronic devices often rely on supercapacitors (often in combination with a primary battery) to deliver high pulses, with performance features that include high cycle life and rapid recharge. However, supercapacitors are rarely used in industrial applications due to several notable limitations, including lower voltage, the need for balancing circuits which have inherent self-discharges, lower energy storage, very high capacity (4x less by energy, 5X less by volume), a maximum operating life of 10 years, and very high self-discharge rates (up to 10-20% per day).

Every application is unique and trade-offs are common, so due diligence is required to identify the ideal battery that performs well while serving to reduce cost and aid in product miniaturization.