Don’t Overdesign Your Battery

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When developing an industrial grade wireless device intended for long-term deployment, design engineers must strike a balance between two inherently competing goals: long-term product performance versus price.

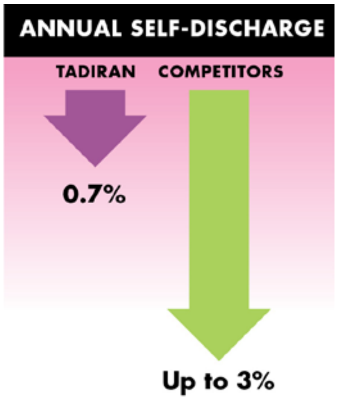
For remote battery-powered devices, this can lead to compromise solutions involving unnecessarily large and heavy batteries that carry unforeseen expenses, including more frequent battery replacements and the cost of transporting these oversized batteries to remote, hard-to-access locations.

In order to make a more informed product specification decision, the following parameters should be considered:

Operating voltage affects number of cells - Basic math tells you that it takes more than twice as many 1.5v cells to deliver the same voltage as 3.6v cells. Selecting the battery with a higher voltage could reduce size and weight while also saving money by requiring fewer cells.

Extreme temperatures affect voltage – Exposure to extreme temperatures reduces battery voltage under pulse. If a battery with a limited temperature range is deployed in a harsh environment, oversized batteries may be required in order to compensate for an expected voltage drop under pulsed load. One solution may be to utilize a specially modified bobbin-type lithium thionyl chloride ($LiSOCl_2$) battery that features extremely high energy density along with the ability to handle high pulses at extreme temperatures, thus eliminating the need for all that extra capacity and/or voltage.

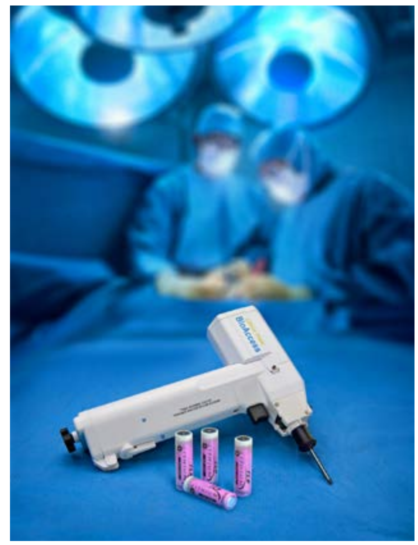
Self-discharge rate affects capacity – Certain battery technologies suffer from high self-discharge rates of up to 8% per month, thus requiring a larger battery to compensate for the expected capacity losses. Choosing a battery with a low annual self-discharge rate could enable the use of a smaller battery while possibly eliminating the need for future battery replacements over the life of the device.



A bobbin-type LiSOCl$_2$ battery featuring a 0.7% annual self-discharge rate can operate up to 4x longer than a competing cell that has a 3% annual self-discharge rate.

For example, superior quality bobbin-type LiSOCl2 batteries feature a self-discharge rate of 0.7% per year, able to retain over 70% of their original capacity after 40 years. By contrast, a lesser quality battery made with the exact same chemistry could have a much higher self-discharge rate of 3% per year, thus exhausting 30% of its original capacity every 10 years, making it impossible to achieve 40-year battery life.

Power or energy – Commonly confused are the need for power (a measure of short-term energy consumed) and the total amount of energy required (battery capacity). Certain wireless devices are designed for infrequent use, requiring high pulses for short bursts without exhausting a large amount of energy. Prime examples include surgical power tools, which may operate for a few minutes, and guided munitions, which may remain airborne for seconds. For example, a surgical power drill powered by four AA-size lithium metal oxide batteries can replace a much bulkier device powered by 12 alkaline cells, resulting in a significantly lighter and ergonomic device for use by surgeons. (see photo at right)



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

Another illustrative example is a missile guidance system, where a small pack of lithium metal oxide batteries were able to replace a much larger and costlier custom battery pack made with silver zinc batteries. (see photo below)

Air-to-ground missile systems can use lithium metal oxide batteries to replace larger silver-zinc batteries, shortening design/production cycles and reducing costs with COTS components.

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Be aware that most commercially available battery technologies are not designed to deliver a high power-per-energy ratio, thus demanding the use of a large number of cells in order to compensate for their low pulse design, resulting in compromise solutions that require added space and unneeded battery capacity.

Pulse size – Remote wireless devices increasingly require high pulses to power advanced two-way communications and remote shut-off capabilities.

Alkaline batteries are ideal for delivering high rate energy, but have major limitations, including low voltage (1.5v), a limited temperature range (0°C to 60°C), a high self-discharge rate that reduces life expectancy, the inability to deliver high pulses, and crimped seals that may leak. Alkaline batteries may also need be replaced every few months, causing long-term maintenance costs to skyrocket, especially for devices located in remote, hard-to-access locations.

A 3.0v LiMnO2 battery such as the popular CR123A can deliver twice the voltage of an alkaline cell, potentially reducing the total number of batteries required. However, CR123A batteries can only deliver moderate pulses, making them ill-suited for powering two-way wireless communications.

Comparison of primary (non-rechargeable) battery chemistries

Primary Cell	**LiSOCL2** Bobbin-type with Hybrid Layer Capacitor	**LiSOCL2** Bobbin-type	**Li Metal Oxide** Modified for high capacity	**Li Metal Oxide** Modified for high power	**Alkaline**	**LiFeS2** Lithium Iron Disulfate	**LiMnO2** 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

Standard bobbin-type $LiSOCl_2$ batteries are not designed to handle periodic high pulses as they can experience a temporary drop in voltage when first subjected to a pulsed load: a phenomenon known as transient minimum voltage (TMV). One way to minimize TMV is to use supercapacitors in tandem with lithium batteries. While popular for consumer applications, supercapacitors have major drawbacks for industrial grade applications, including bulkiness, a high annual self-discharge rate, and an extremely limited temperature range. Solutions involving multiple supercapacitors also require the use of expensive balancing circuits that draw additional current.

Industrial grade Li-ion batteries can operate up to 20 years and 5,000 recharge cycles, able to operate and be recharged at extremely cold temperatures.

An alternative solution is to combine a standard bobbin-type $LiSOCl_2$ cell with a patented Hybrid Layer Capacitor (HLC). The battery and HLC work in parallel: the battery supplies long-term low-current power in the 3.6 to 3.9 V nominal range, while the single-unit HLC acts like a rechargeable battery to deliver periodic high pulses, thus avoiding the need for supercapacitors. This hybrid LiSOCl2 battery design also features a unique end-of-life voltage curve plateau that can be interpreted to deliver low battery status alerts.

Rechargeable battery cycle life – If the application calls for rechargeable batteries, then the design engineer must be mindful that consumer grade rechargeable Lithium-ion (Li-ion) cells have a limited life of approximately 5 years and 500 full recharge cycles. If the rechargeable device is intended to operate for more than 500 recharge cycles, then extra cells may need to be incorporated to reduce the average depth of discharge per cell.

Choosing a battery with a higher cycle life could reduce the total number of cells needed. Industrial grade rechargeable Li-ion batteries are available that can operate for up to 20 years and 5,000 recharge cycles. Unlike consumer batteries, these industrial grade cells can also deliver the high pulses (15 A pulses and 5 A continuous current) while also featuring an extended temperature range (-40°C to 85°C). (See battery comparison next page)

Cheaper is often more expensive – Application-specific requirements dictate the need to think long-term, comparing the total cost of ownership over the lifetime of the wireless device versus achieving low initial cost.

If a wireless device is intended for long-term deployment in a highly remote and inaccessible location, then you need to factor in all expenses associated with frequent battery replacement, which invariably will eat up any initial savings achieved by specifying a less expensive battery.

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).

Comparison of consumer and industrial grade Li-ion rechargeable batteries

		TLI-1550 (AA) Industrial Grade	**Li-ion 18650**
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 Continuos Discharge Current	[A]	5	5
Capacity	[mAh]	330	3000
Energy Density	[Wh/l]	129	627
Power [RT]	[W/liter]	1950	1045
Power [-20C]	[W/liter]	> 630	< 170
Operating Temp	deg. C	-40 to +90	-20 to +60
Charging Temp	deg. C	-40 to +85	0 to +45
Self Discharge rate	[%/Year]	<5	<20
Cycle Life	[100% DOD]	~5000	~300
Cycle Life	[75% DOD]	~6250	~400
Cycle Life	[50% DOD]	~10000	~650
Operating Life	[Years]	>20	<5

The costs associated with excessive size and weight can also be important considerations. For example, a compact and lightweight power supply could be especially valuable to research scientists conducting experiments in extremely frigid conditions. Battery size and weight also factor into transportation costs, especially to remote places.

For remote industrial applications, it pays to think long-term, and assess the total cost of ownership when specifying a battery-powered solution.

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