Understanding battery self-discharge

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Ultra-long-life lithium batteries feature a low self-discharge rate while delivering the high pulses required to power two-way wireless communications.

Battery-powered remote wireless devices support virtually all IIoT applications, from asset tracking to SCADA, environmental monitoring, AI, M2M, and machine learning, to name a few.

Applications involving harsh environments and inaccessible locations are overwhelmingly powered by industrial grade lithium batteries instead of short-lived consumer grade batteries, as extended battery life can result in higher reliability, greater longevity, improved customer satisfaction, and a lower cost of ownership. Achieving extended battery life begins with a fundamental understanding about the causes of battery self-discharge.

Low-power devices conserve energy to run marathons

There are two types of low-power wireless device: those that draws average current that is measurable in microamps with high pulses in the multi-amp range, which are typically powered by industrial grade primary (non-rechargeable) lithium batteries; and low power devices that draw average current measurable in milliamps, enough to prematurely exhaust a primary lithium battery, typically requiring the use of an energy harvesting device in combination with an industrial grade rechargeable Lithium-ion (Li-ion) battery.

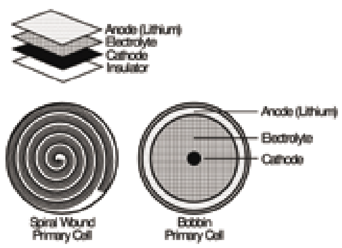
Specifying the right battery for a low-power application involves numerous considerations, including: the amount of current consumed while in active mode (including the size, duration, and frequency of pulses); the amount of energy consumed while in stand-by mode (the base current); storage time (as normal self-discharge during storage diminishes capacity); thermal environments (including storage and in-field operation); and equipment cut-off voltage, which drops as cell capacity is exhausted or during prolonged exposure to extreme temperatures. The most important consideration of all is the cell's annual self-discharge rate, which can exceed the amount of current required to actually operate the device.

Bobbin-type $LiSOCl_2$ batteries deliver proven 40-years operating life for certain low power applications.

Low-power wireless devices are predominantly powered by primary (non-rechargeable) chemistries, including iron disulfate ($LiFeS_2$), lithium manganese dioxide ($LiMNO_2$), lithium thionyl chloride ($LiSOCl_2$), alkaline, and lithium metal oxide chemistry.

Lithium stands apart as the lightest non-gaseous metal, with a high intrinsic negative potential that exceeds all others, resulting in the highest specific energy (energy per unit weight) and energy density (energy per unit volume) of all commercially available chemistries. Lithium cells operate within a normal operating current voltage range of 2.7 to 3.6V. These chemistries are also non-aqueous, preferable to water-based chemistries that can freeze.

Among these options, lithium thionyl chloride (LiSOCl2) chemistry stands apart by offering the longest operating life. These batteries are constructed in two ways: bobbin-type or spiral wound.



Spiral wound cells are specified for applications that require higher energy flow. Bobbin-type cells are better suited for low-power applications due to their higher capacity, higher energy density, as well as a wider temperature range (-80°C to 125°C). A key feature of bobbin-type $LiSOCl_2$ chemistry is its exceptionally low annual self-discharge rate (less than 1% per year for certain cells), permitting up to 40-year battery life.

Self-discharge shortens battery life

Battery self-discharge is common to all chemistries as chemical reactions sap energy even while the cell is inactive. Fortunately, you can modify the self-discharge rate of a bobbin-type $LiSOCl_2$ battery by controlling the passivation effect.

Passivation occurs only with $LiSOCl_2$ batteries, where a thin film of lithium chloride (LiCl) forms on the surface of the lithium anode, separating the anode from the electrode to limit the chemical reactions that cause self-discharge. When a load is placed on the cell, the passivation layer causes initial high resistance along with a temporary drop in voltage until the discharge reaction slowly dissipates the LiCl layer: a process that keeps repeating each time the load is removed.

Several other factors can influence cell passivation, including: current discharge capacity; the length of storage and storage temperature; discharge temperature; along with prior discharge, as partially discharging a cell and then removing the load can increase the amount of passivation relative to when the cell was new.

The positive attribute of higher passivation is its ability to minimize battery self-discharge. The downside of higher passivation is the potential to overly restrict energy flow.

Self-discharge is also influenced by the cell's current discharge potential, the method of manufacturing, and the quality of the raw materials. In fact, the highest quality bobbin-type $LiSOCl_2$ cell can feature a self-discharge rate as low as 0.7% per year, retaining 70% of its original capacity after 40 years. Conversely, a lower quality bobbin-type $LiSOCl_2$ cell can experience a self-discharge rate of up to 3% per year, losing 30% of its initial capacity every 10 years, making 40-year battery life impossible.

Unfortunately, it can take years to see the full impact of an elevated self-discharge rate along with prolonged exposure to extreme temperatures. Theoretical models tending to under-estimate these effects, so thorough due diligence is required in situations where the original battery must last for the entire lifetime of the device.

PulsesPlus™ batteries combine a standard bobbin-type $LiSOCl_2$ cell with a patented hybrid layer capacitor (HLC) to generate the high pulses required to power two-way wireless communications.

High pulses power two-way wireless communications

Many remote wireless devices require periodic high pulses to power two-way wireless communications. To conserve energy, these devices utilize a variety of strategies, including the use of a low-power communications protocol (e.g., WirelessHART, ZigBee, or LoRa), low-power chipsets, and proprietary techniques designed to conserve energy during 'active' mode.

Standard bobbin-type $LiSOCl_2$ cells deliver the longest operating life but cannot deliver the high pulses required for two-way communications. This challenge that can be easily overcome with the use of a patented hybrid layer capacitor (HLC). This hybrid solution uses the bobbin-type $LiSOCl_2$ cell to deliver nominal background current during 'standby' mode while the HLC generates high pulses of up to 15A. The HLC also features a unique end-of-life voltage plateau that enables 'low battery' status alerts.

Supercapacitors provide a similar function for consumer electronics but are not well suited for industrial applications due to numerous limitations, including: short-duration power; linear discharge qualities that do not permit full discharge of available energy; low capacity; low energy density; and a very high self-discharge rate of up to 60% per year. Supercapacitors linked in series require cell-balancing circuits that are bulky, expensive, and draw additional energy to further shorten battery operating life.

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Understanding battery self-discharge using the Runner analogy:

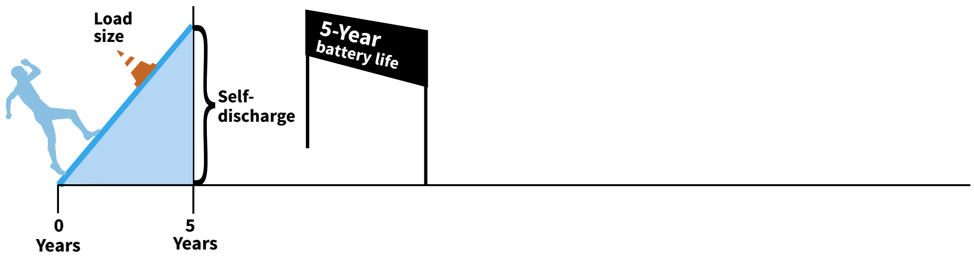
*Each application has varying power requirements that are analogous to running vavarious types of races, including considerations for **distance**, **incline**, and jumping **hurdles**.*

The Distance *– is equivalent to the battery/device operating life. The farther a runner can travel, the more years a device will be able to operate.*

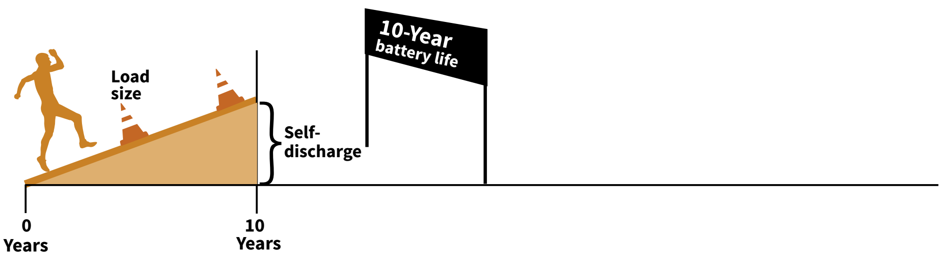
The Incline *– is equivalent to the battery's self-discharge rate. The higher the self-discharge rate, the larger the incline, which draws more power and shortens the duration of the run. Similarly, the battery with higher self-discharge consumes more energy to shorten the cell's operating life.*

Hurdles *– are equivalent to pulses. The higher the hurdle, or obstacle, the higher the pulse required to support two-way wireless communications and other advanced functionality.*

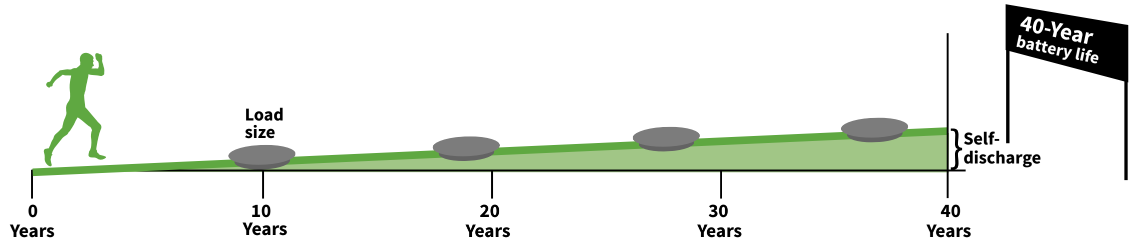
High Rate Alkaline and Lithium Manganese Dioxide



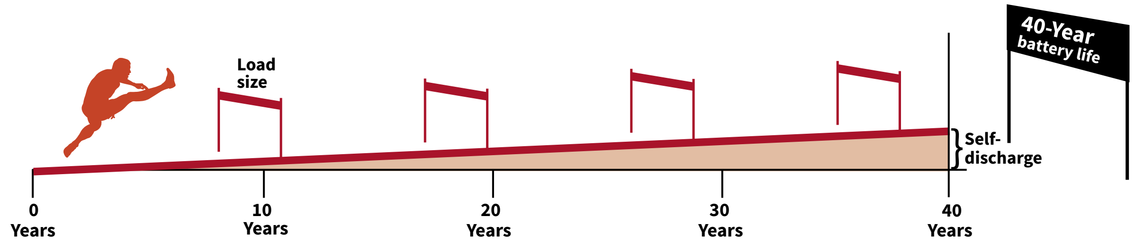
Medium Rate Bobbin-type Lithium Thionyl Chloride



Low Rate / Low Self-Discharge Bobbin-type Lithium Thionyl Chloride



High Rate / Low Self-Discharge Bobbin-type Lithium Thionyl Chloride with Hybrid Layer Capacitor



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Hard running devices often require energy harvesting devices

While primary batteries continue to predominate for most most low-power applications, we are seeing a dramatic rise in applications that draw milliamps of current, enough to quickly exhaust a primary lithium battery. Returning to our runner analogy, these applications burn up more calories, thus requiring the use of an energy-harvesting device in tandem with an industrial grade rechargeable Lithium-ion (Li-ion) battery to replace the calories burned.

For example, Cattlewatch combines small solar (PV) panels and Li-ion batteries to create a mesh network that tracks the location, health, and safety of animal herds. Similarly, solar/Li-ion hybrids power smart meters that collect parking fees and are equipped with AI-enabled sensors to communicate when open parking spots become available.

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 Continuous 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	~500
Cycle Life	[75% DOD]	~6250	~600
Cycle Life	[50% DOD]	~10000	~1000
Operating Life	[Years]	>20	<5

Low-cost, consumer-grade rechargeable Li-ion cells cannot power such applications because of their relatively short operating life (5 years and 500 recharge cycles), a limited temperature range (0-40° C), and their inability to deliver high pulses. By contrast, industrial grade Li-ion batteries can operate up to 20 years and 5,000 full recharge cycles, feature an expanded temperature range (-40° to 85° C), and deliver the periodic high pulses required to power two-way wireless communications.

In the long run it pays to specify an extended life battery that will increase product reliability while reducing your total cost of ownership.