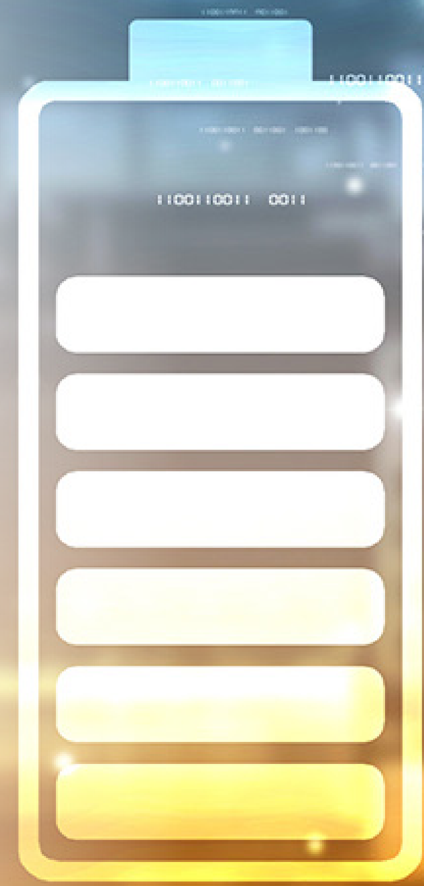
Powering Remote Wireless Devices to Run a 40-year Marathon



Low-power remote wireless devices can operate for up to 40 years on a single battery while powering two-way communications.

By Sol Jacobs, Tadiran Batteries

The Industrial Internet of Things (IIoT) is exploding, resulting in the dramatic growth of remote wireless devices being powered by primary (non-rechargeable) lithium batteries. Often, these devices need to operate maintenance-free for decades without having to replace the batteries.

To achieve such extended battery life, energy losses must be minimized. This is especially true for low-power devices that draw average current measurable in micro-amps while operating mainly in an energy-saving "standby" state, fully awakening only to sample or transmit data.

Battery-powered wireless devices deployed in extreme environments and hard-to-access locations are generally ill-suited for consumer grade alkaline cells that are extremely short-lived, primarily due to a high self-discharge rate of up to 60 percent per year. Lithium chemistries can last much longer.

Lithium features a high intrinsic negative potential that exceeds all other metals, functioning within an operating current voltage (OCV) ranging from 2.7 V to 3.6 V. Lithium chemistries are also non-aqueous, able to endure extreme temperatures with less risk of freezing. Chemistries such as iron disulfate ($LiFeS_2$) and lithium manganese dioxide ($LiMNO_2$) can deliver medium to high rates of energy discharge. However, there is a trade-off, as these chemistries feature annual self-discharge rates that are far lower than alkaline but far greater than lithium thionyl chloride ($LiSOCl_2$) (Table 1).

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	$LiFeS_2$ Lithium Iron Disulfate (AA-size)	$LiMnO_2$ Lithium Manganese Oxide
Energy Density (Wh/Kg)	700	730	370	185	335	330
Power	Very High	Low	Very High	Very High	High	Moderate
Voltage	3.6 to 3.9 V	3.6 V	4.1 V	4.1 V	1.5 V	3.0 V
Pulse Amplitude	Excellent	Small	High	Very High	Moderate	Moderate
Passivation	None	High	Very Low	None	Fair	Moderate
Performance at Elevated Temp.	Excellent	Fair	Excellent	Excellent	Moderate	Fair
Performance at Low Temp.	Excellent	Fair	Moderate	Excellent	Moderate	Poor
Operating life	Excellent	Excellent	Excellent	Excellent	Moderate	Fair
Self-Discharge Rate	Very Low	Very Low	Very Low	Very Low	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	-20°C to 60°C	0°C to 60°C

Table 1. Bobbin-type $LiSOCl_2$ batteries are preferred for use in remote wireless applications. These cells deliver higher capacity and energy density, up to a 40-year operating life, and the widest possible temperature range, which is ideal for hard-to-access locations and extreme environments.

Not all batteries can handle a 40-year marathon

Among all commercially available lithium chemistries, bobbin-type $LiSOCl_2$ batteries are preferred for long-term deployments in remote locations and extreme environments due to their ruggedness and ultra-long-life potential. Bobbin-type $LiSOCl_2$ cells deliver the highest capacity and highest energy density of any lithium chemistry, along with an extremely low annual self-discharge rate (less than 1 percent per year), enabling certain low-power devices to operate for up to 40 years on their original battery. Bobbin-type $LiSOCl_2$ batteries also offer the widest possible temperature range (-80°C to 125°C), along with a glass-to-metal hermetic seal that resists battery leakage. Common applications for $LiSOCl_2$ cells include AMR/AMI metering, machine-to-machine (M2M), supervisory control and data acquisition (SCADA), tank-level monitoring, asset tracking, and environmental sensors, to name a few (Figure 1).

Figure 1. Researchers from Cardiff University studying water channels beneath glaciers use the Cryoegg, which monitors temperature, pressure, and electrical connectivity by transmitting data underwater via radio waves. Bobbin-type $LiSOCl_2$ cells were specified for their high capacity, high energy density, extended temperature range, and high pulse capabilities. *Courtesy: Cardiff University.*

$LiSOCl_2$ batteries can also be manufactured with a spiral wound construction that permits a higher rate of energy flow but also results in a higher annual self-discharge rate that limits their potential operating life.

Harnessing the passivation effect

All batteries experience some amount of annual self-discharge as chemical reactions occur even when the battery is disconnected or not in use. Self-discharge can be significantly reduced by harnessing the passivation effect, which is unique to $LiSOCl_2$ chemistry.

Passivation occurs when a thin film of lithium chloride (LiCl) forms on the surface of the lithium anode to impede the chemical reactions that result in battery self-discharge. Whenever a load is placed on the cell, the passivation layer causes high initial resistance, resulting in a temporary drop in cell voltage until the discharge reaction slowly dissolves the passivation layer—a process that repeats each time a load is applied.

The ability of a bobbin-type $LiSOCl_2$ cell to harness the passivation effect can vary significantly based on the quality of the raw materials and the method by which the battery is manufactured.

Passivation levels can be affected by several variables, including the current capacity of the cell, the length of storage, storage temperature, discharge temperature, and prior discharge conditions, as partially discharging a cell and then removing the load can increase the amount of passivation relative to when the cell was new. While passivation can serve to reduce a battery's self-discharge rate, too much of it can cause energy flow to be blocked.

The ability of a bobbin-type $LiSOCl_2$ cell to harness the passivation effect can vary significantly based on the quality of the raw materials and the method by which the battery is manufactured. For example, lower quality bobbin-type $LiSOCl_2$ batteries can lose up to 3 percent of their original capacity annually due to self-discharge, thus exhausting 30 percent of their initial capacity every 10 years, making 40-year battery life impossible. By contrast, the highest quality bobbin-type $LiSOCl_2$ batteries can feature a self-discharge rate as low as 0.7 percent per year, retaining 93 percent of their original capacity after 10 years, thus enabling up to 40-year operating life.

The analogy to marathon running

Distance. Distance is equivalent to the battery/device operating life. The farther a runner can travel equates to the more years a device can potentially operate (Figure 2).

Incline. An incline is equivalent to the rate of battery self-discharge. The larger the incline, the higher the rate of self-discharge (Figure 3). When athletes run up a steep incline, they expend greater amounts of energy, which shortens the maximum duration of the run. Similarly, higher rates of battery self-discharge expend greater amounts of energy to reduce battery operating life.

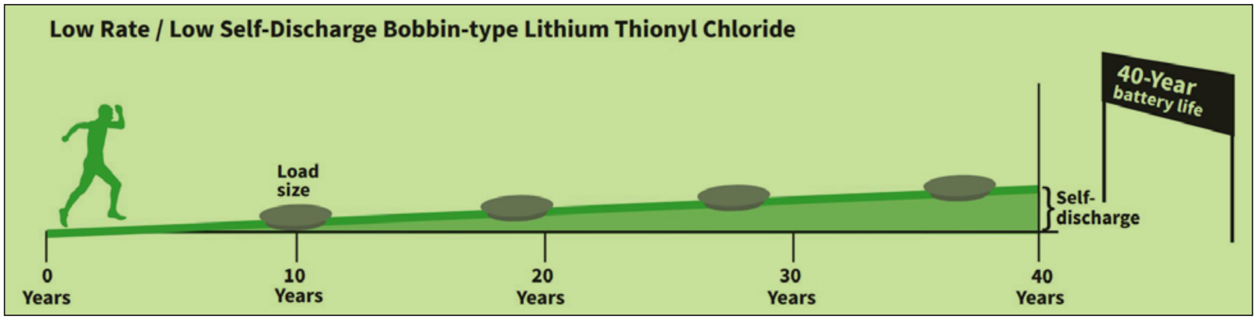


Figure 2. The farther a runner can travel equates to the more years a device can potentially operate.

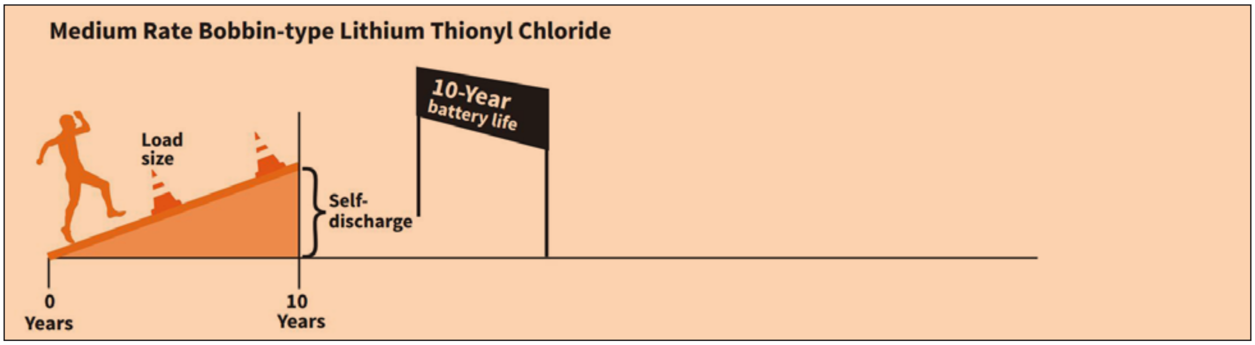


Figure 3. When athletes run up a steep incline, they expend greater amounts of energy, which shortens the maximum duration of the run.

Hurdles. High pulses of energy are similar to hurdles: the higher the hurdle, (obstacle) the higher the pulse being drawn by the battery (Figure 4).

Pole vault. Certain applications draw high rates of energy as well as high pulses (Figure 5). A prime example is a surgical power tool, which draws average current measurable in amps. As a result, these devices may be better suited to be powered by a lithium metal oxide battery.

Consumer devices with cell discharge rates measurable in the milli-amp to amp range, such as powering a flashlight or a consumer toy, are typically powered by an alkaline, LiFeS, $LiMNO_2$, or rechargeable Li-ion cell. By contrast, low-power remote wireless devices that draw average current measurable in micro-amps to conserve energy are typically powered by a bobbin-type $LiSOCl_2$ battery featuring an exceptionally low self-discharge rate.

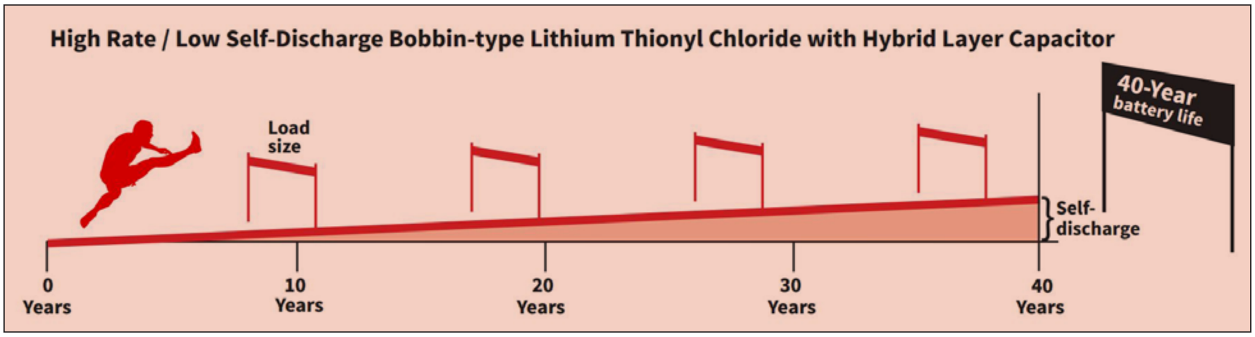


Figure 4. The higher the hurdle (obstacle), the higher the pulse being drawn by the battery.

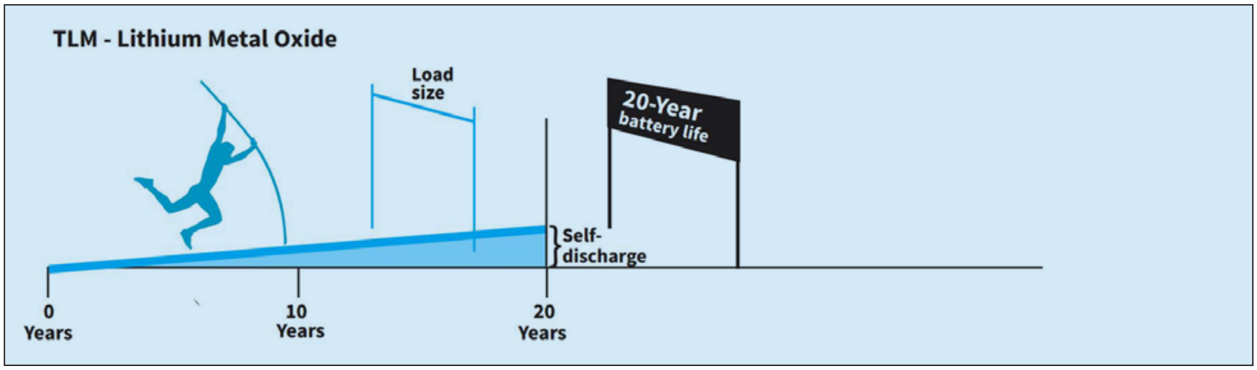


Figure 5. Certain applications draw high rates of energy as well as high pulses.

Figure 6. Bobbin-type liSOCl$_2$ batteries can be combined with a patented hybrid layer capacitor (HLC) to offer up to 40-year operating life while providing high pulses to power two-way wireless communications.

Standard bobbin-type LiSOCl$_2$ cells cannot deliver high pulses due to their low-rate design but can be modified with the addition of a patented hybrid layer capacitor (HLC) (Figure 6). With this hybrid approach, the standard bobbin-type LiSOCl$_2$ cell delivers low-level background current to power the device during stand-by mode while the HLC delivers the high pulses required to power two-way wireless communications (steeple jumping). The HLC also features a unique end-of-life voltage plateau that can be interpreted to deliver low-battery status alerts.

Many consumer devices use supercapacitors to deliver high pulses electrostatically rather than chemically. However, supercapacitors are rarely used in industrial applications due to performance limitations such as short-duration power, linear discharge qualities that prevent use of all the available energy, low capacity, low energy density, and high annual self-discharge rates (up to 60 percent per year). Supercapacitors linked in series also require the use of cell-balancing circuits that add expense, increase bulkiness, and consume additional energy to further accelerate their self-discharge rate.

Drawbacks of simulated tests

Long-term battery performance cannot be easily duplicated using short-term testing procedures. As a result, specialized test methods must be used to predict expected battery operating life. These testing methods include:

- **Long-term laboratory testing.** The ideal way to monitor long-term battery self-discharge is by continually testing random samples under various operating and environmental conditions. Over time, the accumulated data points can be used to accurately predict expected battery life based on cell size, temperature, load size, etc.

- **Accelerated testing.** The Arrhenius equation uses a two-fold increase of reaction rate for every 10°C rise in temperature to simulate long-term battery operation. Arrhenius tests are run at 72°C, which is equivalent to about 32 times the theoretical lifetime of a battery stored at 22°C. Unfortunately, the Arrhenius equation tends to yield inaccurate results with short-term tests.

- **Calorimeter testing.** An extremely accurate tool for predicting battery life is to measure the amount of actual heat energy being lost using a high-quality microcalorimeter. This device can detect small amounts of energy being dissipated as low as 0.1 W. This heat energy can be generated several ways: entropy change, often referred to as reversible heat; cell over-protection, often referred to as irreversible heat; chemical reactions that can affect self-discharge reactions and cell capacity; and side reactions that do not affect cell capacity. Calorimeter testing can be especially useful for measuring battery capacity losses resulting from long-term storage or device operation (including self-discharge), which can be measured using thermodynamic equations and cell voltage considerations. To ensure accuracy, prior to undergoing calorimetric testing, the battery needs to be stabilized for a minimum of one year as the self-discharge rate during the first year tends to be much higher than in subsequent years.

- **Lithium titration.** Lithium titration can also be used to measure available cell capacity. The battery is cut open, and then titration is used to dissolve the remaining lithium to determine its volume. High rates of self-discharge will accelerate the reduction of lithium found in the cell. Lithium titration techniques can be useful for measuring the effects of extreme temperatures or prolonged high pulses.

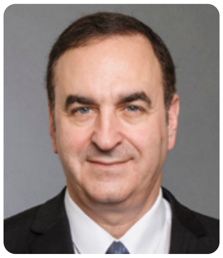
- **Field results.** Perhaps the best form of validation is to test a random sample of cells being deployed in the field. For this reason, Tadiran customers are asked to provide random samples of cells being used in the field to measure the real-life impact of long-term exposure to extreme environmental conditions. For example, AMR/AMI batteries deployed by Aclara (formerly Hexagram) in the mid-1980s were tested after more than 28 years in the field and were found to contain plenty of unused capacity after nearly three decades.

Another useful indicator is to calculate the number of failures in time (FITs) among a very large sample of batteries. Some batteries consistently achieve FITs ranging from 5 to 20 batteries per billion, which is extremely low compared to the industry average.

Final thoughts

Every application has unique power requirements. As a result, you must determine whether your device needs to be powered by a sprinter (a cell with high discharge potential), a medium distance runner (a cell capable of a moderate to high discharge rate with fairly low self-discharge), or a long-distance runner (a cell featuring an exceptionally low self-discharge rate while also being able to deliver high pulses).

ABOUT THE AUTHOR



Sol Jacobs is vice president and general manager of Tadiran Batteries. He has more than 30 years of experience in powering remote devices. His educational background includes a BS in engineering and an MBA.