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Power for Extreme Environments

Two options emerge for powering remote wireless devices in extreme environments: lithium thionyl chloride batteries and energy harvesting devices coupled with extended-temperature-range rechargeable lithium-ion batteries.

Specifying the ideal power management solution for remote wireless devices found in extreme environments and hard-to-access locations requires more ruggedized solutions. Fortunately, two viable options are now available: lithium thionyl chloride ($LiSOCL_2$) chemistry that can operate for 40+ years, and energy harvesting devices coupled with special rechargeable lithium-ion batteries designed for extreme environments that can deliver up to 20+ years of battery life. Lithium thionyl chloride chemistry is proven for use in extreme environments.

When recharging or replacing a battery is not an option, the preferred choice is bobbin-type $LiSOCL_2$ chemistry due to its intrinsic negative potential, which exceeds that of all other metals. Lithium is the lightest non-gaseous metal, offering the highest specific energy (energy per unit weight) and energy density (energy per unit volume) of all available battery chemistries.

Lithium cells, all of which use a non-aqueous electrolyte, have normal open-circuit voltages (OCVs) of between 2.7 and 3.6V. The absence of water also allows certain lithium batteries to operate in extreme temperatures (–55 °C to 125 °C), with certain models adaptable to cold-chain temperatures down to –80 °C. $LiSOCl_2$ cells were placed in a cryogenic chamber and subjected to progressively lower temperatures down to –100 °C, and the batteries remained operational.

Bobbin-type $LiSOCl_2$ batteries have been field-proven to last more than 28 years, with plenty of unused capacity to last up to 40 years. However, bobbin-type $LiSOCl_2$ batteries are not created equal, as superior-grade $LiSOCl_2$ batteries are constructed using high-quality materials and advanced manufacturing techniques that reduce the potential for electrolyte leakage or short circuits. Use of inferior raw materials or non-standardized battery manufacturing techniques can lead to batch-to-batch inconsistency, which severely limits battery service life.

As a result, design engineers need to be leery of battery manufacturer's claims regarding low annual self-discharge at ambient temperatures, as these claims may not be valid depending upon the size of the battery, its method of construction, or the application-specific temperature requirements; a difference of just a few microamps in annual self-discharge rate can translate into years of reduced battery life expectancy.

Matching Performance to Applications

Increasingly, remote wireless devices feature two-way RF communications and/or remote shut-off capabilities that can reduce battery life expectancy. To maximize battery life, these devices typically operate in a "dormant" mode with nominal average daily power consumption, periodically requiring high pulses for data acquisition and transmission that range from hundreds of milliamps for short-range RF communications, up to a few amps for certain GPRS protocols.

Every application has unique power requirements based on application-specific parameters, such as:

- Energy consumed in dormant mode (the base current)
- Energy consumption during active mode (including the size, duration, and frequency of high-current pulses)
- Storage time (as normal self-discharge during storage diminishes capacity)
- Thermal environments (including

Bobbin-type lithium thionyl chloride ($liSOCL_2$) batteries are preferred for remote wireless applications because they deliver high energy density with up to 40+ years of service life and the widest possible temperature range, making them ideal for use in extreme environmental conditions.

storage and in-field operation)
- Equipment cut-off voltage (as battery capacity is exhausted, or in extreme temperatures, voltage can drop to a point too low for the sensor to operate)
- Battery self-discharge rate (which can be higher than the current draw from average sensor use)

If the application involves dormant periods at elevated temperatures, alternating with periodic high current pulses, then lower transient voltage readings can result during initial battery discharge. This phenomenon, known as transient minimum voltage (TMV), is common to bobbin-type $LiSOCl_2$ batteries due to their low-rate design. One alternative solution is to use supercapacitors in conjunction with lithium batteries. However, supercapacitors have performance limitations related to high self-discharge rates, their need for balancing circuits, and limited temperature range, which is not ideal for extreme environments.

Bobbin-type $LiSoCl_2$ chemistry has been successfully modified to address TMV issues. Tadiran's PulsePlus batteries combine a standard bobbin-type $LiSOCl_2$ battery with a patented Hybrid Layer Capacitor (HLC). The battery and HLC work in parallel, with the battery supplying long-term, low-current power while the HLC supplies pulses up to 15 A, thus eliminating the voltage drop that normally occurs when a pulsed load is initially drawn. The single-unit HLC works in the 3.6–3.9V nominal range to deliver high pulses and a high safety margin, thus avoiding the balancing and current leakage problems associated with supercapacitors. The batteries can also be programmed to deliver low battery status alerts.

For moderate pulse applications, Tadiran Rapid Response TRR Series batteries were developed to deliver high energy density and moderate pulses without the use of an HLC (or it can use a smaller HLC). When a standard $LiSOCl_2$ battery is first subjected to load (especially at cold temperatures or when the battery is nearing the end of its operating life), voltage can drop temporarily before returning to its nominal value. These batteries virtually eliminate the voltage drop as well as voltage drop under pulse (or transient minimum voltage level). They also use available capacity efficiently to extend battery operating life up to 15% in extremely hot or cold temperatures.

Solar-powered IPS parking meters utilize TLI Series rechargeable lithium-ion batteries for energy storage, ensuring 24/7/365 system reliability at extreme temperatures. (Photo courtesy of The IPS Group)

A Growing Opportunity for Energy Harvesting

The emergence of energy harvesting technology is closely linked to the development of low-power communications protocols such as ZigBee, Green Power, Bluetooth LE, and 6LowPan. These low-power protocols enable certain wireless sensor networks to operate within a peak power range of 10μW to 100mW, which is the sweet spot for energy harvesting devices that draw energy from sources such as light, heat, RF/EM, motion, or vibration.

Energy harvesting technology is rapidly evolving, so design engineers need to perform careful due diligence to specify the correct power management solution based on application-specific requirements, especially when high reliability is a concern.

Bobbin-type $LiSOCL_2$ batteries are ideal for applications such as electronic toll tags because they can operate maintenance-free for decades while handling the severe temperature cycles that characterize automotive interiors. According to SAE International, heat soak can hit 113 °C when a vehicle is parked, cooling down rapidly to room temperature. Conversely, in cold weather, the battery must handle cold soak and a rapid temperature rise.

Energy harvesting devices need to be coupled with rechargeable lithium batteries that store the harvested energy. Consumer-grade rechargeable lithium-ion batteries are not well suited for remote wireless applications, as these standard cells are limited by short operating life (maximum 5 years), low maximum cycle life (1,000 cycles), high annual self-discharge (up to 60% per year), and limited temperature range (0 to 60 °C) with no possibility of charging at low and high temperatures.

To address the limitations of consumer-grade rechargeable lithium batteries, Tadiran recently introduced TLI Series extended-temperature lithium-ion batteries that utilize the same technology found in the HLC, which stores the high current pulses required for wireless communications, and has been field-proven in millions of cells. The batteries modify this technology to deliver reliable, long-term performance under extreme environmental conditions.

Extended-temperature lithium-ion batteries offer unique performance features, including the ability to deliver high current pulses (up to 15A for AA cell), low annual self-discharge rate (less than 5%), up to 5 times more life cycles (5,000 full cycles), longer operating life (20 years), wider operating temperature (-40 to 85 °C, with storage up to 90 °C), charging possible at extreme temperatures (-40 to 85 °C), and a glass-to-metal seal (others use crimped seals that may leak). Available in AA and AAA diameters and custom battery packs, the batteries can be recharged using DC power or by energy harvesting devices. Energy harvesting devices supported by lithium-ion rechargeable batteries and bobbin-type $LiSOCL_2$ batteries provide a dynamic set of options for powering remote wireless devices.

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