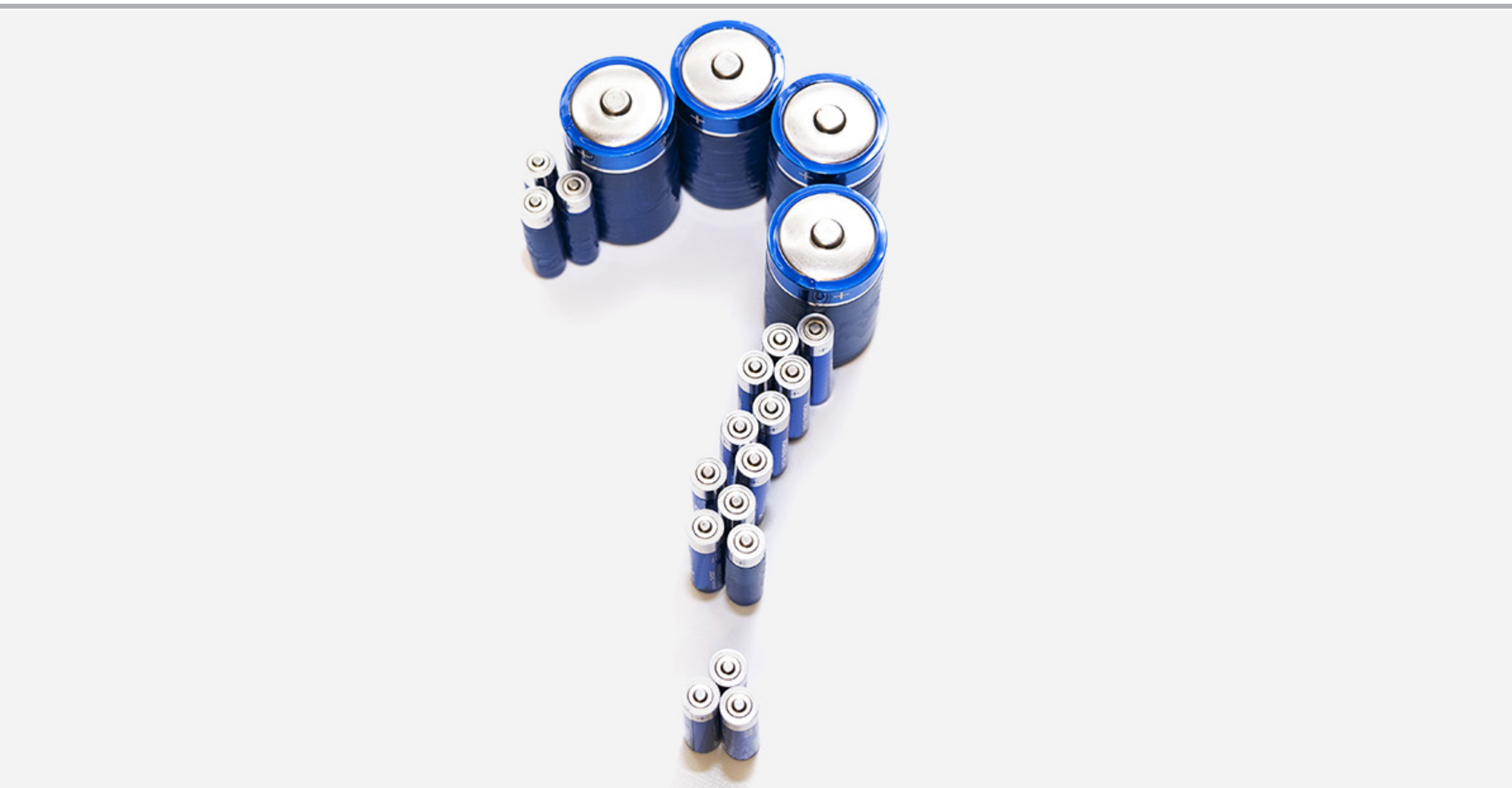
Whitepaper February 2022



Lithium Thionyl Chloride Battery Selection Considerations

Meet your application performance, physical size, and economic goals

DEVICE BATTERY REQUIREMENTS

Non-rechargeable Lithium Thionyl Chloride (also known as ER or Li/SOCl2) cell or battery packs provide reliable DC power that is long-lasting due to long shelf-life and high energy density.
All Li/SOCl2 cells are unique so, to select the best one for your needs, consider:

- ✓ Cell or pack level battery
- ✓ Operating temperature range
- ✓ Voltage
- ✓ Electrical current rate needed
- ✓ Capacity
- ✓ Cell sizes and rates
- ✓ Space available
- ✓ Safety
- ✓ Shipping regulations
- ✓ Certifications and quality
- ✓ Cost
- ✓ Availability

CELL OR PACK LEVEL BATTERY

Early on, decide whether to use a single cell battery or a battery pack. This can be influenced by voltage, packaging and reliability requirements. ER cells are all 3.65V Open Circuit Voltage (OCV) and about 3.3V to 3.4V Closed Circuit Voltage (CCV) at nominal currents. So if you need to power CMOS digital logic, which is at 3V or lower, consider using a single cell. Packaging the cell with a connector and/or other insulation or structural packaging will make it a single cell battery pack. Cell or pack size determines the voltage and/or capacity and max. current you can draw from it.

OPERATING TEMPERATURE RANGE

Most ER cells operate in a range from well below 0°C to +85°C (eg. figure 1); but some are designed for very high temperature use (+200°C max).

Make sure the cell covers, with some tolerance margin, the min. and max. temperatures your application will face. Also focus on storage temperature specifications (eg. figure 2).

As ER batteries are an electrochemical device, operating temperature affects their ability to generate electricity.

Generally, the warmer it is, the more robustly the cell can generate electrical current without its voltage drooping. The colder it is, the less current it can generate to meet application load demand.

In terms of capacity, warmer operation tends towards more capacity delivered before empty (less capacity if colder).

Therefore, ensure the battery meets application current load needs, especially at cold temperatures.

Plan expected worse case capacity and application run times based on cold temperatures.

ER cell datasheets provide load profile examples of tested delivered capacity at different continuous current discharge rates at varied cold to warm temperature points (eg. figure 3).

Using this data, determine/extrapolate your use case performance expectation at appropriate worse case application temperature.

OPERATING TEMPERATURE
-55°C to +85°C

Figure 1 - from an Ultralife technical datasheet (TDS)

STORAGE TEMPERATURE
30°C max., store at ≤ 20°C to minimize passivation and self-discharge

Figure 2 - from an Ultralife TDS

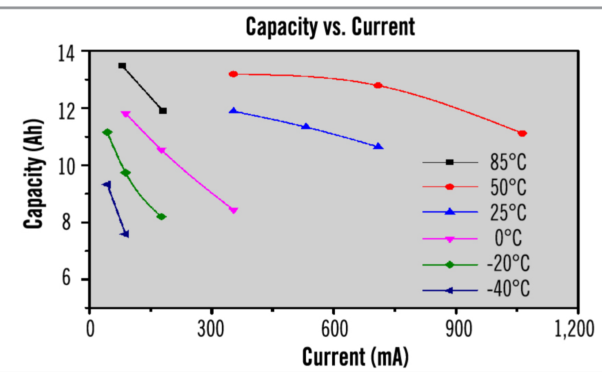


Figure 3 - Capacity vs. Current @ Temperature - from an Ultralife TDS

VOLTAGE

Li/SOCl2 cells chemically have a 3.65V Open Circuit Voltage (OCV). They deliver about 3.3V to 3.4V Closed Circuit Voltage (CCV) at nominal currents. So to get higher voltages, configure a series of cells connected positive to negative and so forth. Each cell step in the series contributes about 3.6V OCV to the battery pack (see figures 4 and 5). This is achieved by loading batteries in series into a battery cell holder or canister, making contacts at the negative and positive end of the battery cells in a series string. This is OK for consumer devices but can be unreliable for continuity in industrial devices where failure results in expensive downtime. In industrial applications, multi-cell batteries are best built into a battery pack, where inter-cell connections are made with permanent welds and/or soldering of connectors. Welding/soldering gives much higher continuity reliability than friction touch point only.

NO. OF CELLS	VOLTAGE
1 cell in series	3.6V
2 cells in series	7.3V

Figure 4 - example data

NO. OF CELLS	VOLTAGE
4 cells in series	14.6V
8 cells in series	29.2V

Figure 5 - example data

ELECTRICAL CURRENT RATE NEEDED

Continuous or constant current is the load that the application will put on the battery for a sustained or continuous period of time. This can be quiescent current levels of digital circuits or any other ongoing level of current demand based on the application's regular operating level. It is specified as MAX continuous or constant current (eg. figure 6) that a cell can support with minimal voltage droop/internal damage.

Ensure that your application will not exceed the specified continuous or constant discharge curve on the battery. If it does, you need to find a bigger size cell or a higher rate cell that can support it. Or you can utilize one or more parallel strings in your battery design to share the current load among the parallel strings, making each string endure a lower relative current load than it would if standalone. Parallel strings will also increase rated capacity of the battery pack (discussed below).

Peak pulse current (eg. figure 7) refers to the load that the application may submit to the battery as pulses of demand at intermittent time periods; but not on a continuous basis. Besides amplitude in mA or Amps of the peak current pulse, you also need to pay attention to duration of the pulse. Battery cells will fatigue more the longer they are discharged at high rates, and thus cause more voltage droop and possible cell damage the longer in time that they are discharging a high current pulse.

With your device's peak current pulses (mA rate and duration), it may be hard to assess if the datasheet data covers your use case load profile. So test run against a specific candidate battery.

MAX. CONSTANT DISCHARGE CURRENT
666mA

Figure 6 - from an Ultralife TDS

PULSE CAPABILITY
Up to 2,000mA, 1.0 second pulse

Figure 7 - from an Ultralife TDS

CAPACITY

Battery capacity determines the runtime of your application before you run out of power. Measured in Amp Hours (Ah), it is calculated as current rate (Amps) multiplied by time (hours). Different cell types have different capacities. Larger size cells have more capacity due to more volume for active ingredients. Think of it like the size of the gas tank in a vehicle… a bigger tank holds more gas. Therefore, the bigger the battery size, the greater the capacity and longer the runtime.

However, capacity can also be affected by cell rate. Eg. low rate cells can have more capacity than high rate cells of the same size, as the low rate cell contains more active Lithium metal ingredients.

Capacity is also affected by the rate at which current is drawn from the cell. Higher rates typically cause lower capacity. Voltage droop caused by an excessive current rate application load on a battery can cause the tool electronics to "Cut Off" due to under-voltage, implying an empty battery. Yet, capacity could still remain in this battery if delivered at more moderate current load rates.

Additionally, temperature affects the delivered capacity from a battery. Lower temperatures often beget lower capacity. Higher temperatures, not exceeding specification, usually avail more complete utilization of rated capacity.

Capacity will vary from the same battery cell based on how hard you drive it (current) and at what temperature. There should not be a single specified value for capacity, as it depends on current rate and temperature, but a range (e.g. figure 8). Given such current rate and temperature impacts on delivered capacity, a battery pack with parallel strings can be used to add available battery capacity if larger battery cells will not accomplish the capacity goal. For instance, two strings in parallel will provide roughly twice the capacity of the single string, and so on.

To estimate required capacity, determine average current load (e.g. figure 9). Then consider what the lowest typical operating temperature may be and ensure the cell or pack provides more Ah than required at that temperature. This can be estimated from test data that shows different capacities at varied current rates and temperatures. In figure 10, at the 600mA X-axis value, this example cell could supply 600mA load at +25°C temperature for about 11 Ah capacity (blue curve), or at +50°C temperature for about 13Ah capacity (red curve). But, it may not be able to supply much capacity, if any, at 0°C or colder when attempting a 600mA continuous load (other color curves). This would call for closer investigation and likely require parallel cell strings.

CAPACITY RANGE
10-14Ah 0-60°C temp. & rate dependent

Figure 8 - from an Ultralife technical datasheet (TDS)

EXAMPLE AVERAGE CURRENT LOAD
600mA (0.6 of an amp)
EXAMPLE APPLICATION RUNTIME
8 hours (at current load above)
Ah TO MEET RUNTIME TARGET
600mA x 8 hours = 4800mAh (4.8Ah)

Figure 9 - example data

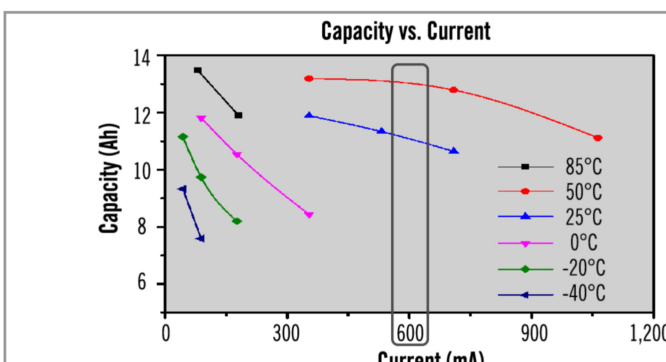


Figure 10 - Capacity vs. Current @ Temperature - from an Ultralife TDS

CELL SIZES & RATES

Li/SOCl2 cells are often 1/2AA, AA, C, D and DD size (custom sizes in-between). Larger cells tend to have higher current rate (continuous and pulse) and more capacity. If chosen cell size does not give sufficient current rate or capacity, add strings of cells in parallel into a battery pack. For rate information, see figure 11.

HIGH RATE CELLS (high continuous/pulse current Amp load capability at lower Ah capacity)
More surface area between the anode and cathode (less lithium content)
MEDIUM RATE CELLS (higher rate capability than low rate; more capacity than high rate)
In-between high and low rate cells
LOW RATE CELLS (higher Amp hour capacity but lower Amp current rating)
More anode/cathode volume (max lithium anode and thionyl chloride/carbon cathode mass)

Figure 11 - differences between cell rates

SPACE AVAILABLE

As many electronic devices get smaller and lighter, the space available for a battery reduces. Physical space consumed by the battery is determined by the cell size times the number of cells in the battery pack (with pack configuration, connectors , mounting, cases and other overhead factors contributing). It is wise to consider battery size requirements early on in your product design. You do not want to end up having voltage, capacity and/or current load dictated by an application performance requirement that cannot be achieved due to limited battery space.

You can estimate the number of cells required in a battery pack using figure 12.

STEP ONE - VALUES NEEDED FOR ESTIMATE
No. of cells in series to get required voltage to create battery string = S (for series)
No. of strings in parallel to meet capacity/ current rate needed at worse case operating temperature = P (for parallel)
Size of the unit battery cell selected with approx. 10% adder for pack mechanical and interconnect overhead = V (for volume)
STEP TWO - CELL COUNT CALCULATION
S x P = C (cell count within battery pack)
STEP THREE - ESTIMATE SIZE OF PACK
C x V
STEP FOUR - PACK SIZE/VOLUME
C x Vcell x 110%

Figure 12 - example data

After the estimate, you may have room to spare, or have exceeded your limit. So iterations may be needed to tune pack size versus performance (eg. sacrificing capacity or runtime to make space).

SAFETY

When it comes to safety, avoid crushing cells or subjecting Lithium metal based cells to excessive heat or short circuits that could see internal cell temperature approaching +180°C. This is because, at +180°C, Lithium metal in the cell melts to a liquid state and mixes with the liquid Thionyl Chloride catholyte, causing an immediate uncontrolled exothermic chemical reaction that includes fire and/or high pressure vents or explosions. Do not exceed max. operating temperatures and avoid approaching +180°C during cell use or storage.

Crushing cells exposes Lithium metal and catholyte to the atmosphere. Lithium metal is highly reactive with water or moisture, so this can make it fizzle or catch on fire. The catholyte is an acid that is corrosive.

Safety Data Sheets (SDS) should be given to whomever uses Li/SOCl2 cells or packs, as these provide instructions for first responders regarding the particular battery cell ingredient exposure safety and recovery response.

Li/SOCl2 cells are primary cells, designed to be dissipated one cycle only (not recharged). Attempting to recharge a primary Lithium cell can cause reverse voltage, which can lead to dangerous pressure venting or explosion. Consequently blocking diodes are installed in Lithium primary battery packs.

Another safety consideration, for batteries that use Lithium primary cells of 3 or more in series, is the use of a bypass or shunt diode around each cell. With the bypass diode, a damaged cell does not experience current drive through it internally from any remaining cells in the string, thus it does not heat up and possibly overheat or reverse voltage.

SHIPPING REGULATIONS

Li/SOCl2 cells are regarded as Class 9 Hazardous Materials by the United Nations/Department of Transportation, and classified under UN3090 Lithium Metal Batteries or UN3091 Lithium Metal Batteries Contained Within Equipment. Therefore, tests are required to Section 38.3 of the UN Manual of Tests and Criteria (i.e. Altitude, Thermal, Vibration, Shock, Short Circuit, Impact, Overcharge, and Forced Discharge).

Packaging must also be compliant with trained shippers following compulsory UN/ DOT 49 CFR 173,185 procedures (which allow for Air Cargo shipment).

CERTIFICATIONS & QUALITY

Quality design, development, manufacturing and testing is important for any component in your product (eg. the battery). Certifications, such as ISO 9001 and/or ISO 13485, should be strongly considered as evidence of the quality built-in to your battery product.

COST

Analyzing cost versus benefit is typical in product selection; but you should also consider total cost of ownership, including engineering and technical support costs.

AVAILABILITY

Finally, it is important to consider availability. You cannot ship your product if components (eg. battery) are not delivered on time, within a reasonable lead time from purchase. Lead time availability of quality cells has been an issue in the Li/SOCl2 market in recent years so this is worthy of attention.

CHECKLIST COMPLETE, NOW SEE HOW ULTRALIFE'S CELLS CAN MEET YOUR NEEDS...

ER GENERATION X CELLS

For past, present and future commerical and industrial applications:

- ✓ Utility metering
- ✓ Asset tracking
- ✓ Internet-of-things
- ✓ Medical devices
- ✓ Military technology
- ✓ Security devices
- ✓ Radio communications
- ✓ Pulse discharge
- ✓ LED lighting
- ✓ GPS and transmitters
- ✓ Sensors

and many more...

WHY CHOOSE ULTRALIFE'S CELLS?

Ultralife's 'Generation X*' family of Li/SOCl2 products are one of the most rugged, energy dense lithium chemistries available on the market today.

* -X products are a new range, -H legacy cells are still available

- ✓ Up to 30% more capacity performance (average across temperatures versus competition)
- ✓ More than 400 Whr/Kg
- ✓ Off-the-shelf availability of low quantities and short lead times for volume quantities of production units**
- ✓ Cell sizes and rates to meet many application needs
- ✓ 100% battery use case fit confidence

** Location dependent

- ✓ Responsive technical service and support direct from the manufacturer (with worldwide locations, see below)
- ✓ Spiral and bobbin versions available
- ✓ Competitive prices for the best value of quality cells (contact us to learn more or request samples)
- ✓ ISO 9001 and ISO 13485 certified quality development and manufacturing
- ✓ UN 38.3 transportation certified

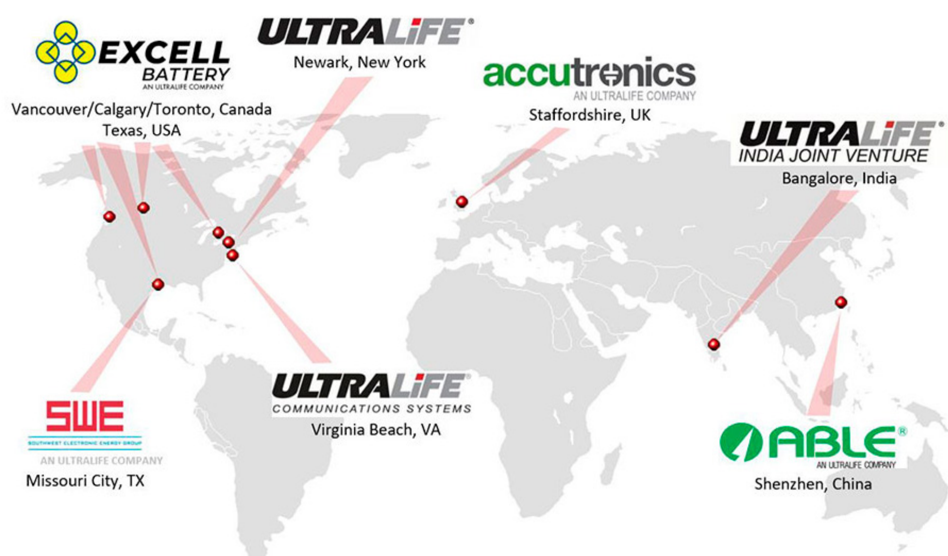
NEXT-GEN ENHANCEMENTS

- ✓ High and stable operating voltage
- ✓ Superior current capabilities
- ✓ < 2% self-discharge per year

ATTRIBUTE	GEN H	NEW - GEN X
Operating Temperature	-55°C to +70°C	-55°C to +85°C
Service Life	5 - 7 years	10 years
Improved Capacity	X	✓
Better Cell-to-Cell Consistency	X	✓
Better Passivation Performance	X	✓
Better Horizontal Discharge Performance	X	✓

- Specification details are correct at the time of printing.
- For the latest data please refer to published specifications which are available on our website at www.ultralifecorp.com

GLOBAL NETWORK OF COMPANIES



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