

Use of Low Resistivity Surface Mount PPTC in Li-ion Polymer Battery Packs

Introduction to Li-ion Battery Technology

Lithium-ion batteries (LIB) have now become part of the standard battery pack of choice used in most notebook, smartphone, e-reader, and tablet designs. The LIB chemistry produces optimal characteristics with regard to high energy density, low self-discharge, light weight, long cycle life, lack of memory effect, and low maintenance. LIBs are now gaining popularity in other market segments such as electric vehicles, power tools, and military/aerospace applications. Since the technology was developed in the 1970s, LIBs have improved dramatically in terms of energy density, cost, durability, and safety.

The three main functional components in a lithium-ion battery cell are the anode (typically graphite), the cathode (typically lithium cobalt oxide), and a non-aqueous electrolyte (typically a lithium salt or organic solvent containing complexes of lithium ions). The material choices affect a cell's voltage, capacity, life, and safety.

Li-ion cells are available in a cylindrical solid body, prismatic semi-hard plastic/metal case, or pouch form, which is also called Li-polymer. Although pouch cells and prismatics have the highest energy density, they require some external means of containment to prevent an explosion when their State of Charge (SOC) is high (see Figure 1).

Overheating is the main safety concern for lithium-ion cells. Overheating causes thermal runaway of the cells, which can lead to cell rupture, fire, or explosion. A deep discharge event could cause internal shorts in the cell, which would cause a short circuit upon charging.

Over-charging and deep discharge/short-circuit events create heat (generated by the anode of the cell) and oxygen (created by the cathode). Both of these effects can be dangerous to the cell and cause bloating (in the case of Li-polymer pouch cells), rupture, fire, or even an explosion.

This is why LIBs have several levels of fail-safe internal cell level and external protection circuitry, which shuts down the battery pack when parameters go out of range. The addition of this protection circuitry takes up useful space in the battery pack and cell, thereby reducing the available capacity. It also causes a small current drain on the pack and contributes to potential points of failure, which can permanently disable the cell or pack.

Internal cell protection consists of a shut-down separator (for over-temperature), tear-away tab (for internal pressure), vent (pressure relief), and thermal interrupt (over-current/over-charging) (Figure 1).

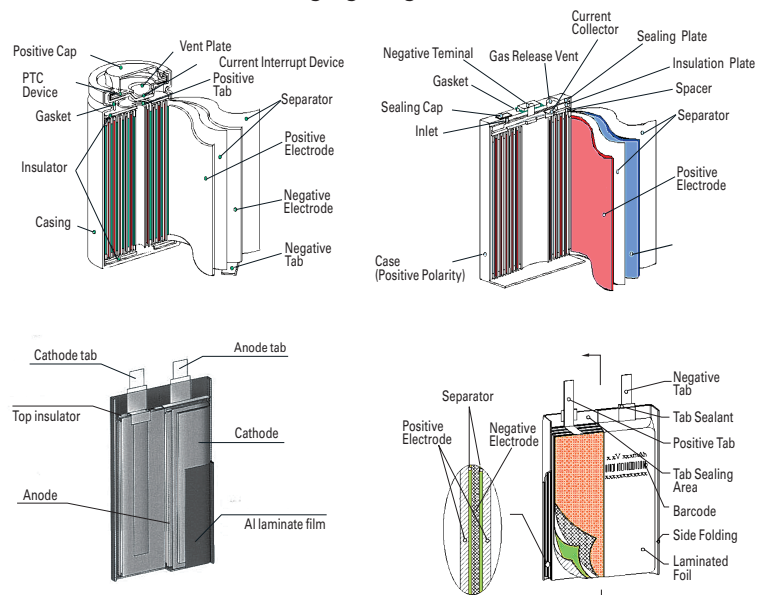


Figure 1. Various Li-ion cell configurations

Over the last five years, LIBs have been the subject of highly publicized recalls of notebook and cell phone battery packs, as a result of instances of overheating, fire, and rupture. Several new standards from IEC, UL, and the DOT/UN have emerged to specify required safety measures and testing.

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Li-ion and Li-ion polymer chemistry has specific energy of 400Wh/L at 20°C, which is approximately two times the specific energy of NiMH (nickel metal hydride) and four times that of the old NiCd (nickel cadmium) chemistry. Li-ion chemistry also operates at higher voltages of 3.0–4.2V versus 1.0–1.2V for the older chemistries. The older chemistries had a moderate-to-high tolerance to over-charging events, whereas the newer Li-ion chemistry has a very low tolerance to over-charging

There are a variety of reasons for battery pack failures: poorly designed cells, lack of over-current/over-voltage protection, lack of thermal protection, no tolerance to swelling, no venting methods for gas, and use in high temperature environments.

Over-discharge and over-charge are two externally created events that can cause problems in LIBs. During over-discharge, if the cell voltage drops lower than approximately 1.5V, gas will be produced at the anode. When voltage drops to less than 1V, copper from the current collector dissolves, causing internal shorting of the cell. Therefore, under-voltage protection is required and is provided by the battery protection IC. Over-charge creates gassing and heat buildup at the cathode when cell voltage reaches approximately 4.6V. Although cylindrical cells have internal protection from pressure, activated CIDs (current interrupt devices) and internal PTCs (positive temperature coefficient discs that increase in resistance when heated), Li-polymer cells do not have internal CIDs and PTCs. External over-voltage, over-gas, and over-temperature protection is especially critical for Li-polymer cells

Li-ion Battery Safety Standards

Several safety agency standards apply to lithium-ion battery packs. These are the key standards that govern the performance, safety testing, and transportation of lithium-ion battery packs:

- UL 1642-2005, Standard for Lithium Batteries—Requirements are intended to reduce the risk of fire or explosion when lithium batteries are used in a product.

- IEC 62133:2002, Secondary cells and batteries containing alkaline or other non-acid electrolytes—Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications.
- IEC 62281, Safety of primary and secondary lithium cells and batteries during transport—These requirements cover portable primary (non-rechargeable) and secondary (rechargeable) batteries for use as power sources in products.
- UL 2054, Standard for Household and Commercial Batteries—These requirements are intended to reduce the risk of fire or explosion when batteries are used in a product.
- UN/DOT (Dept of Transportation) Manual of Tests and Criteria 4th Revised Edition Lithium Battery Testing Requirements – Sec 38.3.
- IEEE 1625 - IEEE Standard for Rechargeable Batteries for Multi-Cell Mobile Computing Devices
- IEEE 1725 - IEEE Standard for Rechargeable Batteries for Cellular Telephones
- IEC/UL 60950-1, Information Technology Equipment Safety—Limited Power Source, Sec 2.5, Table 2B, requirements to limit current to less than 8A within 5sec ; this specification would apply to most battery systems used for notebook computers, cell phones, and tablet devices.

These standards guide manufacturers/suppliers in planning and implementing the controls for the design and manufacture of lithium-ion (Li-ion) and lithium-ion polymer (Li-ion polymer) rechargeable battery packs.

The typical safety-related tests in these standards, which involve the use of external and internal battery pack protection, will include the following (standards will each have their own specific requirements and this is just a brief summary of the types of tests conducted):

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1. Short-Circuit tests and Forced Discharge tests: These tests are conducted by discharging the battery with a low resistance load and then allowing the battery to protect itself or fail by fire or explosion; the latter being a test failure. A test pass is when battery returns to a safe temperature. Tests are done at room temperature and elevated temperatures.
2. Abnormal Charging test, Overcharging test, High Charging Rate test: These tests are conducted by subjecting the battery pack to several times more than the normal charging current or charging at an abnormally fast rate. When there is a non-resettable over-current device present, the test is repeated at a current below which the device activates.
3. Heating and Temperature Cycling tests. These tests are conducted by raising and cycling the battery pack to high temperature and then checking to see if the pack responds safely. Fire, explosion, and venting would be considered failures.

The purpose of the safety standards is to ensure the battery pack and cells have protection mechanisms designed into the overall system to prevent rapid thermal runaway, fire, explosion, rupture, venting, or even gas bloating of the battery packs. All of these events can create a hazard to the user or any equipment used with the battery pack.

Typical Li-ion and lithium-polymer battery packs have several levels of protection in order to meet the required safety standards and to protect the user and equipment from battery failure hazards. In addition to internal cell level protection, external protection solutions are added to provide further safety measures. Some battery packs will use what is called a Battery Management Unit (BMU), which is a small print circuit board with several protection components (see Figure 2). The BMU will have a central processing device, which is usually an IC that controls the battery charge and monitors the pack for unsafe conditions. The battery controller IC controls two FETs, which act as the charge and discharge switches. The battery IC will turn these FETs off as the primary way to shut down the battery pack. The IC will use thermistors and

temperature cut-outs (TCO) to sense temperature, current sense resistors to monitor current, gas gauges to monitor gas buildup, and fuel gauges to monitor charge. Upon any unsafe condition, the IC will turn the FETs off to shut down the pack and stop the fault event. Because the Li-ion chemistry is so dangerous in certain conditions, there must be a secondary method for protection. This secondary protector can be a PPTC (polymeric positive temperature coefficient) resettable fuse, thermal fuse, or a controllable battery protector (see Figure 3).

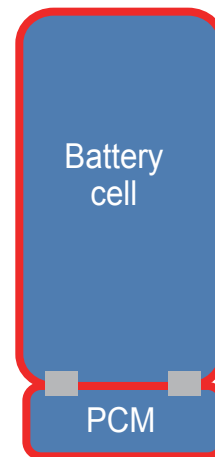


Figure 2. A typical Battery Management Unit (BMU) design

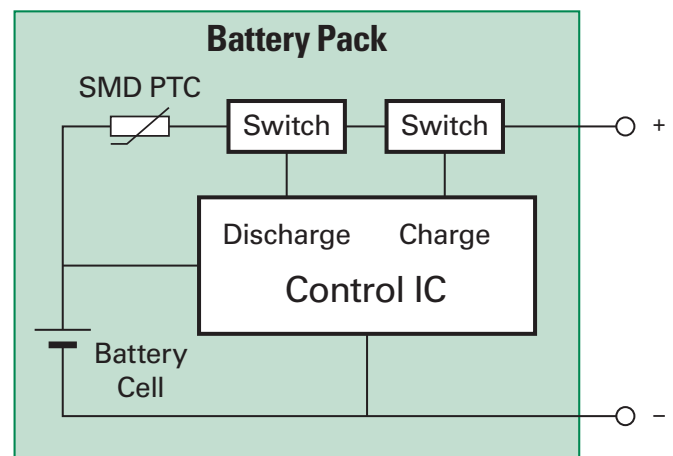


Figure 3. A secondary method of battery protection

General Safety Standard that Applies to Smartphones and Tablets

IEC/UL/EN 60950-1 - Information Technology Equipment Safety, Part 1: General Requirement

- The standard applies to battery operated devices that can be charged from AC mains supply.
- Sec 2.5 – Limited Power Source
 - Fire enclosure requirements in 4.7.2 are reduced or not required if the components/connectors are connected to a Limited Power Source.
 - This allows designer to reduce cost, use thinner materials, etc.
 - Limited Power Source spec has two tables:
- Table 2B – no OC protective device (so using PTC or electronic fuse)
 - Must limit current to 8A within 5 sec if using PTC
- Table 2C – OC protective device is used (fuse)
 - Fuse rating 5A or less (210% / 120sec overload gate)
 - Limit Short ckt current to less than 1000 / Vmax and 250VA within 60sec
- Where an overcurrent protective device is used, it shall be a fuse or a non-adjustable, non-autorest, electromechanical device

Agency Approvals: Littelfuse PPTCs are recognized under the Component Program of Underwriters Laboratories to UL Standard 1434 for Thermistors. The devices have also been certified under the CSA Component Acceptance Program.

Introduction to PPTC Technology

PTC stands for Positive Temperature Coefficient, which means the resistance of the device increases as its temperature goes up. PTCs increase in resistance as temperature increases due to increased current flow. Polymer PPTC (PPTC) devices are made of a polymer plastic material. Unlike a typical “one-time” fuse, a PPTC device (see Figure 4) will reset when cooled.

How a PPTC Works

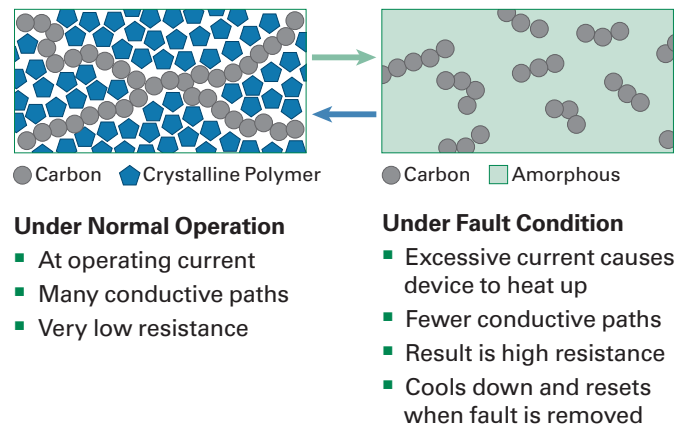


Figure 4. How a PPTC works

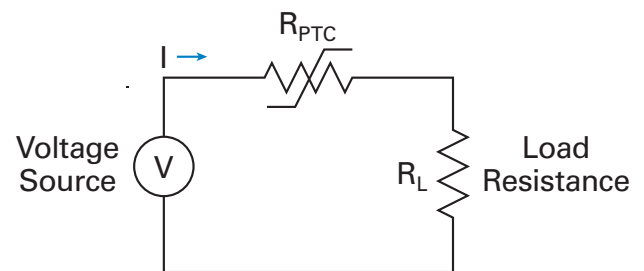


Figure 5. PPTC resistors

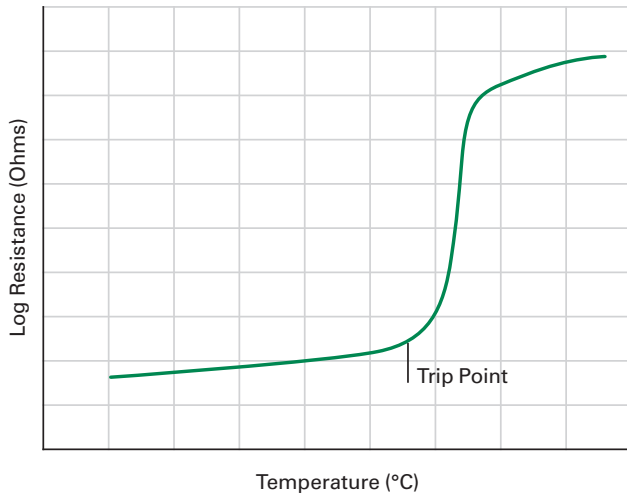


Figure 6. The effect of temperature on the resistance of a PPTC

PPTC resistors are over-current protection devices. Like fuses, they have two terminals and are placed in line with the circuit being protected (see Figure 5). Because they are ideal for situations where frequent over-current conditions occur or constant uptime is required, PPTCs are typically used in Li-ion battery pack applications. In order to limit unsafe currents while allowing constant safe current levels, their resistance will “reset” automatically when the fault is removed and temperature returns to a safe level.

Under normal conditions, PPTCs act as a low value resistor – dissipating little power and barely warm. Under fault conditions, they heat up due to I^2R (Ohmic heating; $>100^{\circ}\text{C}$) and their resistance increases 1000X or more, limiting the current to a small value (see Figure 6). When the current is removed, the PPTC will return to normal temperature and resistance, restoring the circuit (see Figure 7).

PPTC trip times are influenced by:

- Resistance of the device
- Ambient temperature and air currents
- PCB trace size and copper weight
- Proximity of other components

Other items that influence the effective heat transfer rate from the device to its surroundings can also impact performance.

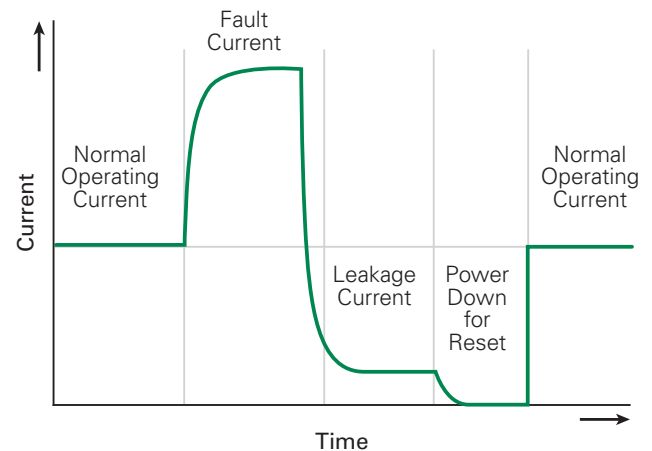


Figure 7. The effect of changing current levels on a PPTC’s temperature and resistance

Time Current (TC) curves present the average values of the trip time at a given current for every part number (see Figure 8). PPTC trip times will be distributed above and below the curve. Lower percentage overloads produce greater variations in trip time. Customer verification tests need to be done for actual applications to ensure proper component selection.

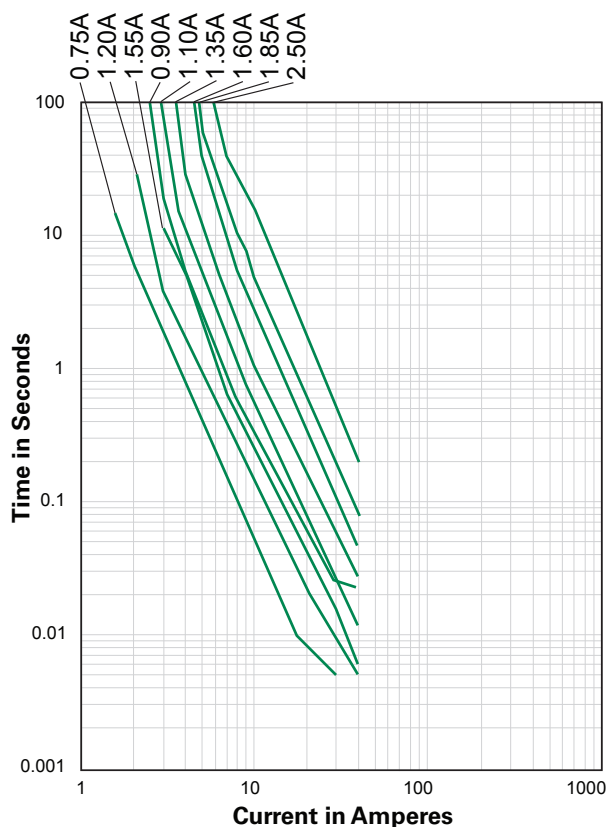


Figure 8. Time Current (TC) curves

Resistance of the PPTC device changes directly with temperature. The rating of the PPTC is influenced by ambient temperature, as shown at the temperature de-rating chart (Figure 9). The heat required to trip the device may come from several sources, such as:

- Resistive heating from the electrical current
- Ambient environment
- Adjacent components

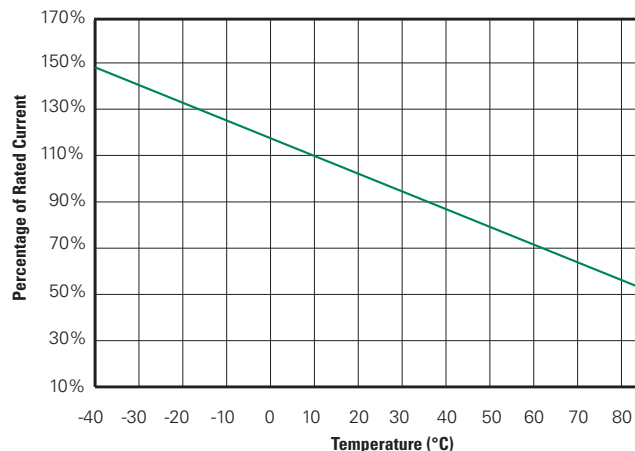


Figure 9. A PTC (or PPTC) de-rating chart

Key Considerations in Selecting a PPTC

1. Determine the circuit's operating parameters:
 - Application temperature
 - Hold current requirement
2. Select the PPTC device that will accommodate the circuit's maximum ambient temperature and normal operating current.
 - Compare the selected device's maximum electrical ratings with the circuit's maximum operating voltage and interrupt current.
 - Determine time-to-trip.
 - Verify ambient operating conditions.
 - Verify the PPTC device dimensions.
3. PPTC resistances do shift during operation.
 - Repetitive tripping/reset cycles will cause slight changes in resistance.

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- Holding the device in a tripped state for long periods of time will cause an increase in resistance.
- Any hand soldering may have a significant effect if not performed properly and therefore is generally not recommended (particularly for SMT components)

4. PPTC devices have two distinct resistance ranges:

- RMIN: the minimum resistance of un-soldered devices
- R1MAX: the maximum resistance of a device at 20°C, measured one hour after tripping or reflow soldering at 260°C for 20 seconds.

When measuring resistance:

- Always perform the measurement at room temperature.
- Perform measurements at least one hour after any heating process to ensure that the device has cooled thoroughly (soldering, testing, etc.).
- Keep in mind that catalog specifications (trip time, hold current, etc.) assume the parts have been mounted on a PCB and the resistance shift has already occurred.

Other critical considerations for component selection include:

- Maximum circuit voltage
- Maximum available short circuit current
- Desired trip current and trip time
- Form factor
- Maximum ambient operating temperature
- Normal operating current
- Maximum operating voltage
- Maximum interrupt current

The use of a LoRho™ SMT PPTC in a Li-ion polymer battery pack

The SMT form factor is optimized for Li-ion polymer cell pack construction. Li-ion polymer packs are used for low profile smartphone and tablet applications. The SMT PPTC allows for more efficient high volume manufacturing because the PPTC can be surface mounted directly on the PCM (Protection Circuit Module). Also, in low profile designs, the PCM board is mounted flat in the same plane as the polymer pouch. This allows for the lowest profile thickness of the smartphone or tablet design. The low height capability of the LoRho™ SMT PPTC makes it a great choice for this application. The PPTC can be added to the PCM while maintaining a minimum height profile of the total assembly.

When using LoRho™ SMT PPTCs, some design and application testing aspects must be considered:

- The overall space allocated for SMT PPTC needs to be balanced against the total hold current required. The designer first needs to determine the maximum continuous current (this includes burst use or peak current use) and the maximum temperature that the PPTC can experience (ambient temperature in the PPTC's vicinity).
- So, the first step in selecting the appropriate PPTC is finding out how much current the device can hold at the maximum temperature. The advantage of using a LoRho™ PPTC is that the device can hold a large amount of current in a relatively small form factor and low profile device.
- Application testing is suggested to verify that the selected PPTC can hold the required current at temperature. Typically, the device is subjected to the required current for 15 minutes, which is enough time to reach thermal stability. If device can hold the current for 15 minutes, then this is one data point that can be used to verify the correct device has been selected.

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- It is highly suggested that the application testing be completed on the actual PCM board as the thermal effects can vary quite significantly when compared to a test board. The printed circuit board, traces, solder pads, and even adjacent components all have an effect on the thermal performance of the PPTC.
- The next step is to ensure the PPTC will trip or activate fast enough to meet safety requirements. Typically, smartphones and smaller tablets will need to meet the standards in UL/IEC 60950-1, Limited Power Source Sec 2.5. This standard will require the PPTC to trip in five seconds or less during an 8A fault condition. In other words, the PPTC must limit current to 8A or less in five seconds or less.
- The final critical aspect is the impedance of the PPTC device. The higher the impedance (PPTC are purely resistive components), the greater the drain on the battery and the lower the total capacity or battery "talk-time" energy available. Therefore, minimizing the impedance is critical. The main advantage of LoRho™ PPTCs is their very low resistance compared to standard PPTCs. However, all PPTCs undergo what is called "trip jump" after experiencing a thermal event or short circuit event. Trip jump is a permanent increase in resistance from initial resistance as delivered on tape/reel to post-reflow resistance. Therefore, it is very important to determine the typical and maximum trip jump associated with a given device and the process that it undergoes in manufacturing.
- The true worst-case maximum resistance of the PPTC needs to be determined. The suggested application test is for the PPTC to be reflowed onto the actual PCM using the reflow oven profile selected for the assembly. If there are multiple reflow passes and any dwell or cure times, then these should be applied as well. The PPTC resistance should then be measured one hour after the reflow process by using the four-wire method.

References

IEC/UL/EN 60950-1 - Information Technology Equipment Safety, Part 1: General Requirement