Keeping Higher Current Lithium-ion Battery Cells Safe with Effective Overtemperature Protection

WHITE PAPER

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INTRODUCTION

The explosion in use of consumer electronics is the result of multiple trends not the least of which is the global increase in a middle-class and an increasingly urbanized population that is eager to use the proliferation of internet services now available. This growing consumer base has helped to stimulate market suppliers to compete by offering more and more exciting products. The latest smartphones, tablet PCs and notebooks are attracting consumers with stunning new display technologies and powerful processors that do not compromise on performance versus power consumption, delivering wireless download speeds that are as fast as cable speeds and offer longer battery life in smaller and slimmer chassis.

The ability to power such high-end devices in ultra-thin form factors is the result of the steady evolution of the lithium-ion battery pack. These packs, first introduced in the early 1990s, have continued to improve with the development of new cathode, anode, electrolyte and separator materials. While lithium-ion battery technologies may not follow Moore's Law, they still have shown a relentless progression in improving energy capacity, power delivery and lifespan while costs have continued to decrease. The use of lithium-ion batteries has expanded from the traditional "3C" applications of computers, cameras and communications (mobile phones) to such diverse areas as automotive electric vehicles, power tools and electricity grid storage units.

While battery technology has evolved and the applications have expanded, the requirement for a safety circuit as part of their design into consumer electronics has remained. This white paper will present the basics of lithium-ion cell functionality, potential operational hazards and the need for a multi-layered protection design approach. It will show the advanced protection solutions available from Bourns, and the features they deliver that contribute to safer lithium-ion battery cell usage.

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LITHIUM-ION CELL FUNCTIONALITY

The basic function of the lithium-ion cell is to transform chemical energy into electricity where a cell is comprised of an intercalating lithium compound cathode, a carbon-based (typically graphite) anode as well as a liquated or gel-type electrolyte with lithium salts through which ions travel, and a polymer separator to act as an internal insulator to the electrons. The use of the two intercalation electrodes has led to the lithium-ion batteries being called “rocking-chair” batteries as ions shuttle back and forth between the electrodes and through the electrolyte in a lithiation/delithiation process. The separator plays a critical role in cell safety by ensuring there is no physical contact between the cathode and anode.

POTENTIAL LITHIUM-ION CELL HAZARDS

While separators have evolved from simple, single layer sheets to multilayer sheets with shutdown features, they alone cannot ensure complete cell safety. The lithium-ion cell is constructed with materials that are flammable and degradable and can cause mechanical and electrical shocks resulting in a destructive and dangerous thermal runaway condition. Another issue is that lithium-ion cell materials are stable at lower temperatures but start to breakdown when temperatures exceed 130 °C. If a cell starts to enter thermal runaway, the results can be catastrophic as seen in various news reports in recent years. Thermal runaway in a lithium-ion cell is a highly exothermic, self-propagating process that results in the venting of toxic and highly flammable gases, releasing significant energy in the form of heat (typically greater than 1000 °C). When cells are part of a larger networked battery pack, the risk becomes even greater as the failure can potentially daisy chain from one cell failure to the next.

LITHIUM-ION CELL SAFETY

In light of such obvious hazards, cell designers should take a multi-layer protection approach. Individual cells require mechanical, electrical and thermal protection, and designers have found that implementing this level of protection becomes more complicated when cells are networked into various battery pack arrangements.

There are numerous standards that help govern battery pack safety such as IEC 62133 for secondary cells and batteries containing alkaline or other non-acid electrolytes and UL 2054 for household and commercial batteries. These standards have helped guide designers into taking a layered approach to battery protection with multiple levels of redundancy built into a pack.

An integral part of maximizing battery pack efficiency and safe operation is the battery management system (BMS) that uses various primary and secondary protection devices as well as software and hardware elements to manage the state of charge, current, voltage and ambient battery temperatures. Mini-breaker thermal cut-off (TCO) devices are key elements in the BMS protection architecture and are increasingly being integrated into lithium-ion battery cell arrangements.

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STRUCTURE OF LITHIUM-ION POUCH CELLS

Lithium-ion pouch cells have all of the standard features of a lithium-ion battery: cathode, anode, liquated electrolyte as well as a polymer separator that are all encased in a flexible foil-based enclosure. These pouch-type cells are soft and malleable compared to the rigid metal cases of cylindrical cells. Pouch cells are typically lighter than their cylindrical equivalents making them very desirable for portable applications such as notebook PCs. The simple laminate structure of the lithium-ion polymer cells is inherently easier to produce in various shapes and sizes, enabling them to be designed to spread across the full shape of any notebook PC[1]. While one electric vehicle manufacturer has become famous for its cylindrical cell GigaFactory facility, lithium-ion polymer laminates can also be produced in vast quantities, giving rise to multiple gigafactories around the world.

Lithium-ion pouch cells can boast many desirable features such as low cost, ease of large scale manufacturing, lighter non-universal sizes and high-energy densities. However, the technology still has the same limitations as other types of lithium-ion cells. The requirement for protection circuits to maintain voltage and current within safe limits is one of the primary limitations of a lithium-ion battery. The soft foil cell design also adds a further disadvantage by allowing the cells to visibly inflate (sometimes called pillowing) during overcharging because of internal delamination.

One of the most effective approaches for providing a safety circuit to lithium-ion battery packs is the use of one or more TCO devices. TCO devices are designed to provide accurate and repeatable overcurrent and overtemperature protection.

[1] However, in reality, notebook PCs use multiple cells in series and parallel to attain higher voltages and capacity. The most common is a six-cell lithium polymer that uses four cells in series with two cells positioned in parallel (3S2P).

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IMPLEMENTING EFFECTIVE LITHIUM-ION PROTECTION

Meeting the changing protection demands in next-generation lithium-ion battery packs has led to the evolution of TCO device technology as well. Today's TCO devices combine two common circuit protection technologies – a PTC and a bimetal switch. Bourns, as one the leading suppliers of TCO devices, has leveraged its extensive experience in precision metal stamping, plastic injection molding and high-end assembly, allowing the company to innovate these ubiquitous technologies into effective circuit protection solutions.

Figure 1 provides a simple schematic of the construction of a Bourns® miniature TCO device. The two terminals (arm terminal and base terminal) are connected in a normally closed position to allow current to flow through the device. The contact point between both terminals serves a critical function in supporting high precision contact resistance, which can be as low as 2 mΩ (max.) in some model families.

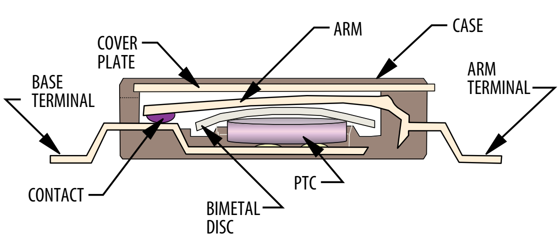

Figure 1. | *Construction of Bourns® Mini-breaker TCO Device*


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HOW TCO DEVICES WORK

Figures 2 and 3 illustrate how miniature TCO devices mechanically provide protection to the circuit. Under normal conditions, current flows through the arm terminal, down through the very low resistance contact point and out through the base terminal. Key to any battery application is low resistance, hence, the need for the right contact resistance between the arm terminal and the base terminal.

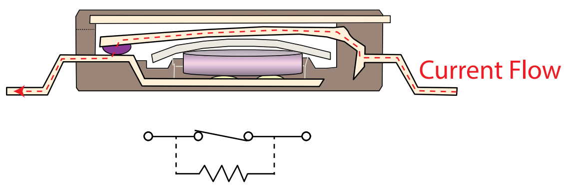

Figure 2. | *Miniature TCO device in the Normally Closed Position*

The TCO device can be triggered by either an increase in the environmental temperature or by excessive current flows. Once the trip temperature has been reached, the bimetal disc heats and flexes and this motion causes the arm to open (see Figure 3). If the TCO device used only a bimetal disc for its protection, the arm would quickly close as the temperature cooled. However, the benefit to the design of Bourns® miniature TCO devices is that the PTC operates in parallel with the arm terminal. When the bimetal disc causes the arm to open, current flows through the bimetal disc and into the PTC. This current causes the PTC to act like a current-limiting heater, which provides sufficient heat to keep the bimetal disc flexed and the arm open. The combination of the bimetal disc and the PTC prevents oscillating opening and closing of the TCO arm. A distinct advantage, this design allows the arm to remain open until a lower and safer temperature level is reached (between 40 °C and 10 °C below the lower specification limit of the TCO device), at which point the arm will reset to its normal position. As part of UL 60730 testing, the opening and closing mechanism of most of Bourns® miniature TCO devices are tested up to 6,000 cycles.

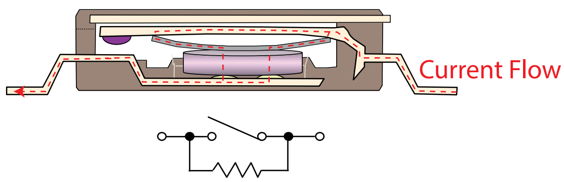

Figure 3. | *Mini-breaker Triggered Open*


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EVOLUTION OF BATTERY PACK PROTECTION

Typically, traditional 18650 cylindrical lithium-ion cells have incorporated protection by embedding overcurrent polymer PTCs and mechanical circuit interrupt devices (CIDs) within the cell head. However, as these cells have evolved from cylindrical to prismatic and more recently to pouch-type formats, this has facilitated the need for protection methods to evolve in tandem. Today, flat-type lithium pouch cells have become the de facto standard in notebooks and tablet PCs because of their physical dimensions and specific power ratings.

For these types of cell structures, protection cannot be embedded internally requiring protection to be attached externally to each cell. For that reason, TCO devices are usually manufactured in an axial leaded format to allow the device to be welded to the positive terminals of the battery cells. Terminals are typically made from aluminium tabs so the TCO devices need to be welded to nickel tabs before those nickel tabs are welded to the battery cell terminals. The advantage of the TCO devices being welded so close to the battery tabs is that they can be situated in intimate contact with the individual battery cell terraces, enabling them to react quickly to any unusual rises in cell temperature.

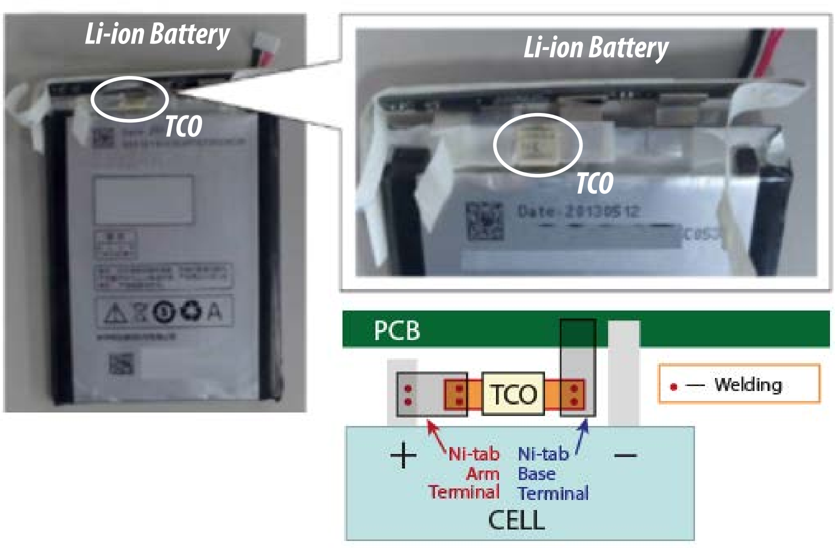

Figure 4. | *Mini-breaker TCO Devices in Battery Cell Protection Circuit*

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ABILITY TO TARGET SPECIFIC TRIP TEMPERATURES

As previously stated, consumer electronics designers try to mitigate against cell thermal runaway which can lead to a dangerous increase in cell temperature and could cause a fire or harmful gas exhaustion. Thermal runaway will occur above 150 °C. In multiple cells, the failure in one cell can quickly cause a chain reaction to the rest of the cells in the pack. To safeguard against this hazard, the trip temperature of a TCO device is a key specification to battery pack manufacturers. Bourns has developed the ability to target specific trip temperature values. The combination of both the composite bimetal material and the precision forming of the bimetal disc allows Bourns® TCO devices to target trip temperatures from 72 °C to 90 °C within ±5 °C accuracy. When a Bourns® TCO device trips, it immediately cuts the power to the cell and allows the cell to cool. Figure 5 demonstrates this function using a Bourns® Model NR72AB0 72 °C TCO device.

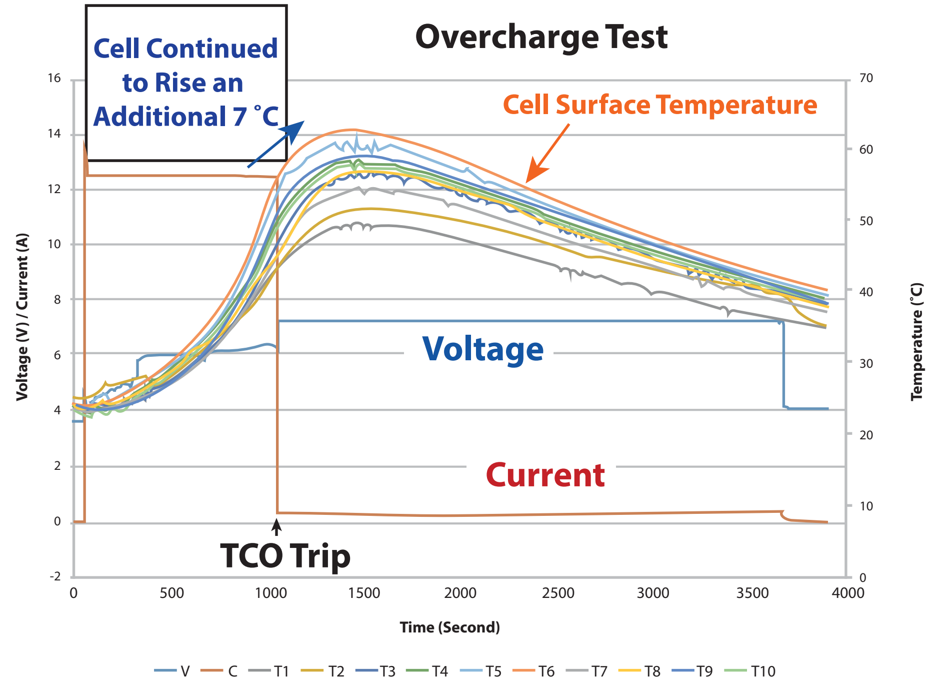

Figure 5. | *Mini-breaker TCO Device in Battery Cell Protection Circuit*


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HANDLING HIGHER CURRENTS

As many battery packs try to deliver greater levels of current to power some of the latest features in smartphones, notebooks PCs and tablets, TCO devices must be able to handle greater levels of current without consuming precious real estate.

The latest addition to Bourns' mini-breaker TCO device portfolio is the Model AC Series. The Model AC Series builds on the success of the existing Model AA Series released in January 2017 by offering up to 20 A of current carrying capability at 60 °C. The new Model AC series is 0.12 mm thinner and 16 percent lighter than the existing Model AA Series. Going beyond the features offered in the Model AA Series' four trip temperature options, from 72 °C to 85 °C, the new Model AC Series offers a fifth option of 90 °C.

TCO devices trigger from a combination of temperature and current. The ambient temperature will rise from the I^2R Joule heating (or resistive heating) caused by the interactions of the electrons from the electric current and the atomic ions in the terminals. Consequently, TCO devices at lower ambient temperatures can hold significantly higher currents than TCO devices at higher ambient temperatures. The graph in Figure 6 illustrates the ambient current impact of operating currents on various Bourns® TCO models – from low current to high current. The resistance of the welded nickel tabs also adds resistance to the circuit and impacts the current carrying capability of the TCO devices. Hence, individual application testing is always recommended when testing the performance of a TCO device coupled with individual cells.

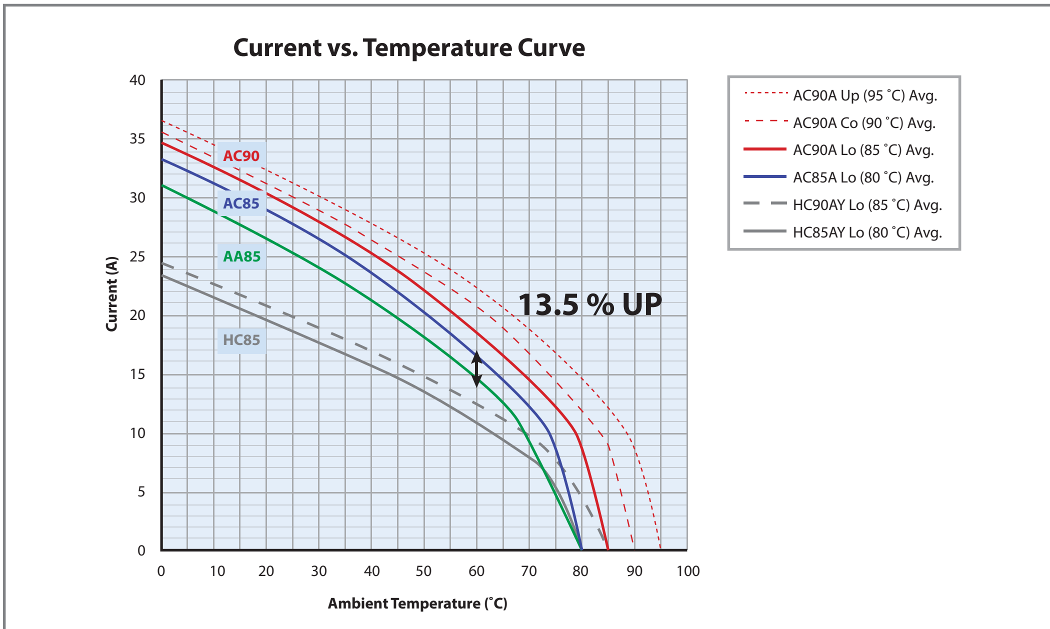

Figure 6. | *Ambient Temperature Impact on Bourns® TCO Device Operating Currents*


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CONCLUSION

Over almost 30 years, lithium-ion cells have risen to be one of the most ubiquitous technologies in the present era. Their long life and ability to scale means that they form an integral element for the future vision of a more renewable and sustainable world. However, potential safety hazards are still a concern. For greater usage peace-of-mind, it is a critical requirement that safety circuits continue to be part of lithium-ion designs. Offering proven protection for battery cells is Bourns' broad line of mini-breaker TCO products with more than 3.0 billion units sold. Bourns is committed to designing and manufacturing the highest level of quality, which is demonstrated with its history of zero miniature TCO device field returns received. This level of performance and quality is the foundation of Bourns' continued innovation as the company prepares to meet the ongoing protection demands for higher currents, smaller sizes and surface mount format solutions.

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