APPLICATION NOTE

Overtemperature Protection for Smartphone Lithium-ion Cells

SA Series

SC Series

CB Series

INTRODUCTION

The rapid rise in consumer electronics usage is the result of multiple trends. The global increase in a middle-class and increasingly urbanized population as well as the proliferation of internet services are just a few of these trends. This growing consumer base has helped to stimulate the market to offer an abundance of exciting products. The latest smartphones, tablet PCs and notebooks are attracting consumers with stunning new display technologies, IC processors that do not compromise in performance versus power consumption and longer battery lives 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 that first arrived on the market 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 life span while costs have continued to decrease.

Overtemperature Protection for Smartphone Lithium-ion Cells

SA Series

SC Series

CB Series

LITHIUM-ION CELL FUNCTIONALITY

The basic function of the lithium-ion cell is to transform chemical energy into electricity. The individual lithium-ion 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 mechanical and electrical shocks can lead to thermal runaway. The lithium-ion cell materials that are stable at lower temperatures start to breakdown when the temperature exceeds 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 and releases significant energy in the form of heat greater than 1000 ˚C. Some of the newest smartphones on the market now use multiple cells so 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 take a multi-layer approach to protecting against various potential hazards. Individual cells require mechanical, electrical and thermal protection and this becomes more complicated when cells get networked into various battery pack arrangements. There are numerous standards that help govern battery pack safety but for rechargeable batteries in smartphones, the IEEE 1725 standard (IEEE Standard for Rechargeable Batteries for Cellular Telephones) is a solid starting point.

This standard and the standards it references has helped guide designers into taking a layered approach to battery protection with multiple levels of redundancy being 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 Cutoff (TCO) devices are key elements in the protection architecture that is being increasingly used in lithium-ion battery cell arrangements.


SA Series


SC Series


CB Series

LITHIUM-ION POUCH TYPE CELLS

Lithium-ion pouch cells have all 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 smartphones. 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 smartphone. While Tesla has become famous for its cylindrical cell GigaFactory facility, these laminates can also be produced in vast quantities. Hence, the rise of multiple GigaFactories around the world.

While lithium-ion pouch cells boast many desirable features such as low cost, ease of large scale manufacturing, lighter non-universal sizes and high-energy densities, the technology still has the same limitations of other types of lithium-ion cells. The requirement for protection circuits to maintain the 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, causing the cells to visibly inflate (sometimes called pillowing) during over-charge because of internal delamination.

One of the latest approaches for providing a safety circuit to lithium-ion battery packs is the use of the miniature resettable Thermal Cutoff devices (TCOs). TCO devices are designed to provide accurate and repeatable overcurrent and overtemperature protection.

SA Series

SC Series

CB Series

EFFECTIVE BATTERY PROTECTION SOLUTIONS

Meeting the changing protection demands in next-generation lithium-ion battery packs has led to the evolution of TCO 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 below provides a simple schematic of the construction of a Bourns® miniature TCO devices. 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.

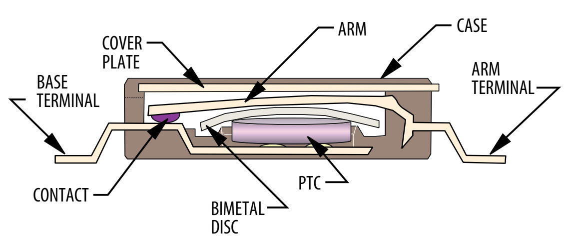

Figure 1. | *Construction of Bourns® Mini-breaker TCO Device*

SA Series

SC Series

CB Series

HOW TCO DEVICES WORK TO PROTECT A BATTERY CELL

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.

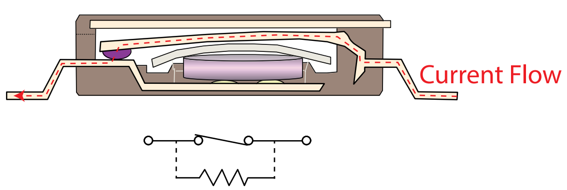

Figure 2. *Miniature TCO Device in the Normally Closed Position*

The TCO devices 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 a Bourns® miniature TCO device 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 device's arm. Instead, 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. As part of UL 60730 testing, the opening and closing mechanism of most of Bourns® miniature TCO devices are tested up to 6000 cycles.

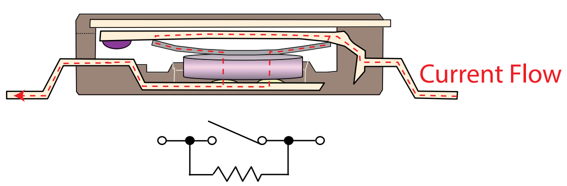

Figure 3. *Mini-breaker Triggered Open*

SA Series

SC Series

CB Series

THE NEED FOR RELIABLE BATTERY PACK PROTECTION

The traditional 18650 cylindrical cells have incorporated protection by embedding overcurrent polymer PTCs and mechanics Circuit Interrupt Devices (CIDs) within the cell head. However, as these cells have evolved from cylindrical to prismatic and more recently pouch type formats, the protection methods had to evolve in tandem. The flat type lithium pouch cells have become the de facto standard in smartphones because of the physical dimensions and specific power ratings. For these types of cell structures, the protection could not be embedded internally and hence require 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.

The battery cell terminals are typically made from aluminum tabs and the TCO device can be welded to nickel tabs prior to the nickel tabs being 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. The newest addition to the Bourns TCO product line is the CB series. This is the smallest TCO device on the market and is specifically designed for very small battery cells such as those used in smartphones. With a body width of just 2.5 mm and a height of 0.8 mm, the CB series is ideal for such battery cells and does not compromise current carrying capability. Other TCO component models such as the Bourns® SC series and SA series are surface mount devices that can be mounted on the smartphone BMS circuit board. The SC series, released in 2019, has a low profile option (Model SCxxAAB), with a height of just 0.94 mm ± 0.05 mm, making it ideal for smartphone BSM circuit boards.

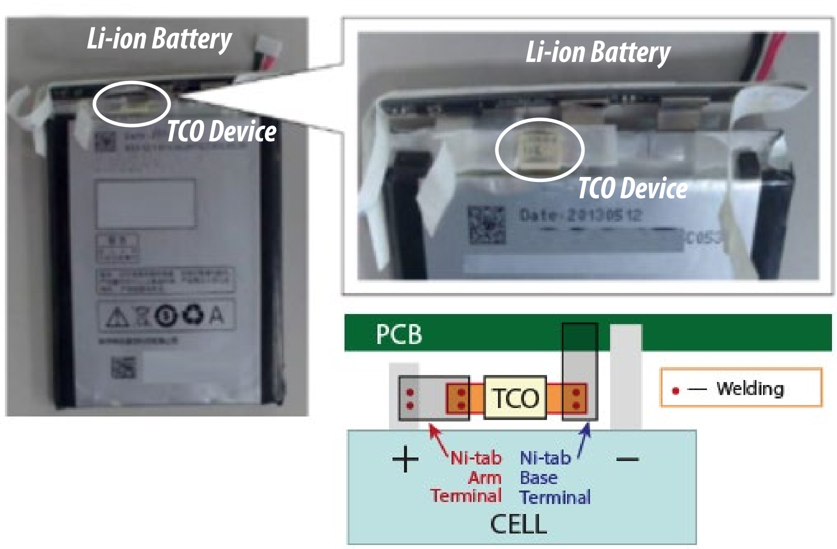

Figure 4. Mini-breaker TCO Devices in Battery Cell Protection Circuit

SA Series

SC Series

CB Series

IMPORTANT TCO SPECIFICATIONS

To ensure battery safety, designers try to mitigate against cell thermal runaway, whereby the increase in cell temperature may cause fire or harmful gas exhaust. 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. Therefore, 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 with ±5 °C accuracy. When a Bourns® TCO device trips, it immediately cuts the power to the cell and allows the cell to cool.

As many battery packs try to deliver greater levels of current to power some of the latest features in smartphones, the TCO devices must be able to handle greater levels of current without consuming precision real estate. The Bourns® Mini-breaker TCO portfolio is consistently being enhanced with TCO products that maximize current, minimize size and provide lower resistances. Fast charging smartphone batteries have become a desirable feature, so the reduction of TCO device impedance has become a an important focal point. Both the CB and the SC series combine a small footprint, a low-profile height and values of under 5mΩ.

APPLICATION NOTE

Overtemperature Protection for Smartphone Lithium-ion Cells

SA Series

SC Series

CB Series

CONCLUSION

Lithium-ion cells first arrived on the market in the early 1990s have risen to be one of the most ubiquitous technologies in the present era especially in smartphone devices. 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, the suspicions about their safety still persists hence it becomes a critical requirement that safety circuits match this evolution. Bourns' broad line of Mini-breaker TCO products provides recognized premium battery protection with more than 3.0 billion units sold. Bourns is committed to designing and manufacturing the highest level of quality proven with its history of no field returns received. This level of performance and quality is the foundation that ensures Bourns' customers continued innovation as the company prepares to meet the demand for higher currents, smaller sizes and surface mount formats.

BOURNS®

Americas: *Tel* +1-951 781-5500
Email americus@bourns.com

EMEA: *Tel* +36 88 885 877
Email eurocus@bourns.com

Asia-Pacific: *Tel* +886-2 256 241 17
Email asiacus@bourns.com