PROTECTING RECHARGEABLE LITHIUM BATTERIES

As battery technology and form factors for electronic devices expand beyond traditional cylindrical cells, Lithium based batteries are in increased demand due to their high energy density, small form factors and design flexibility. Although some Li-ion cylindrical cells contain a PTC as a basic protection against current surges, popular Lithium polymer (Pouch and Prismatic type) cells do not contain PTCs, and as such, additional consideration must be applied in order to prevent premature failure caused by misuse and or improper handling.

Need for Battery Protection

Battery packs containing Li-ion cells require a mandatory protection circuit or CID (circuit interrupt device) to assure safety. In addition to cell level safeguards, an external protection circuit or what is commonly known as PCM (Protection Circuit Module) is often implemented on battery packs to prevent thermal runaway resulting either from Overcharge, Over-discharge, Over-voltage, Over-current, and Short-circuit condition. Since Lithium based batteries contain very high specific energy per volume, an unprotected cell or battery pack can potentially result in costly and irreversible damage.

Overcharge Conditions

Various battery chemistries require specific charging profiles to optimize performance and prevent safety issues during charge. Generally, almost all Li-ion battery chargers use a constant current/constant voltage charging algorithm. Once the charger enters constant voltage mode it is important to ensure the charge does not exceed the maximum level allowed to avoid exposing them to overcharge conditions as it can cause excessive internal temperature rise and lead to premature failure.

A cell/battery pack overcharge condition is often caused by:

- Faulty charger**:** Charger fails to stop or limit the supply current once it is fully charged
- Improper Use**:** Cell or battery is charged using non-compatible charger

Over-current Conditions (charge or discharge)

Over-current conditions occur when Li-ion cell or battery pack is charged or discharged at a much higher current than its design set by cell a manufacturer. For example, if the manufacturer states a Li-ion 18650 cell is only rated for 2.0A maximum continuous discharge current but the user decides to neglect this warning and applies a continuous load of 4.0A. The cell has now gone into what is known as over-current condition and can causes the internal temperature to rise from chemical reaction and may lead to swelling or rupturing of cells and risk of damaging the battery. To help prevent this condition the end-user must always adhere to the manufacturer's cell or battery specification.

Short Circuit Conditions

Accidental short circuits can occur when exposed positive and negative terminals come into contact with metal object such as a keychain or poorly handled lead wires, which will lead to rapid rise in the cell internal temperature and result in performance degradation as well as swelling of cells. Test results on unprotected lithium cell, from testing laboratories such UL and Intertek, has shown that temperatures can reach in excess of 600^{o}C or 1112^{o}F during this type of event and may lead to venting of toxic and highly flammable gases. Once ignited, it can propagate to other cells or flammable objects and lead to irreversible damage.

Short circuit condition is often caused by:

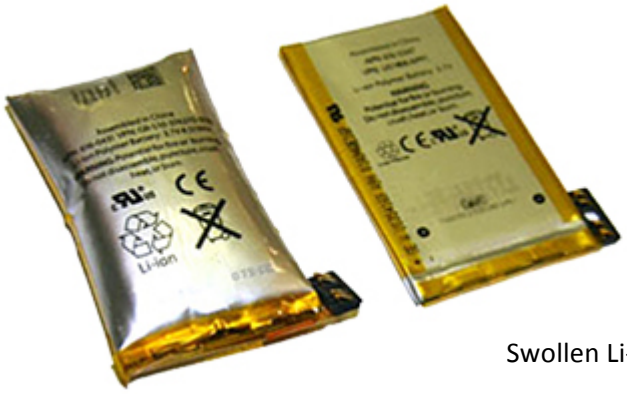
- Exposed positive and negative terminals come into contact with metal objects
- Reversed polarity
- Poor manufacturing or assembly

Before thermal runway

After thermal runaway

Over Discharge Conditions

Typical rechargeable lithium cells can safely operate down to 2.75V/cell. However, when an unprotected lithium cell is discharged past the minimum voltage level you run the risk of damaging the cell and ultimately lead to degraded cycle-life, unstable voltage characteristics and swelling of cells from internal chemical reaction. Generally, a protection circuit is designed with some extra buffer, usually in the +0.25~0.40V range from the cell manufacturer's minimum voltage, in order to prevent prematurely triggering the discharge cut-off voltage.

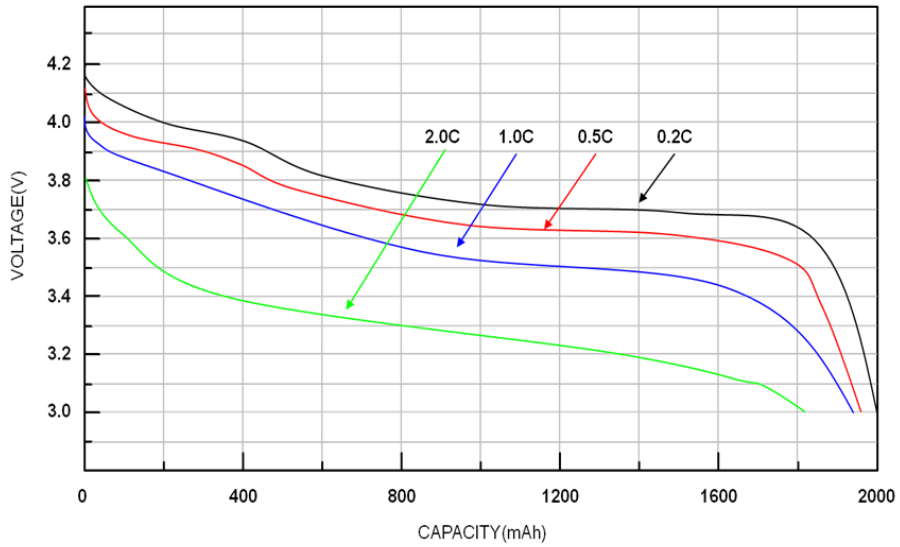


Swollen Li-ion cell

Common causes of over discharge conditions include:

- Host device minimum operating voltage is below cell's discharge cut-off Voltage
- Improperly set discharge cut-off Voltage
- Poorly implemented Protection Circuit Module

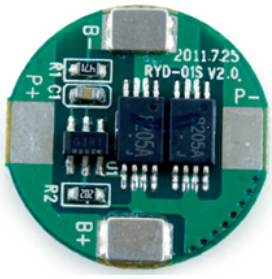
Voltage Characteristics at various loads. Cut-off Voltage=3.0V



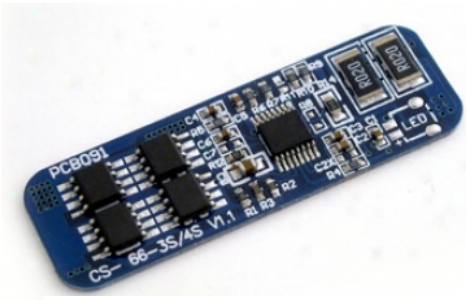
Key Elements of Protection Circuit Module

- Over charge: Protects against over charge condition
- Over current: Protects against over current condition
- Short circuit: Protects against external short circuit condition
- Over-discharge: Protects against over-discharge condition
- Temperature: Protects against high temperture
- Cell balancing: Balancing of cells in battery packs containing multiple cells connected in series

Various types of PCMs



PCM for 1S configuration



3S/4S application

Zeus Battery Products
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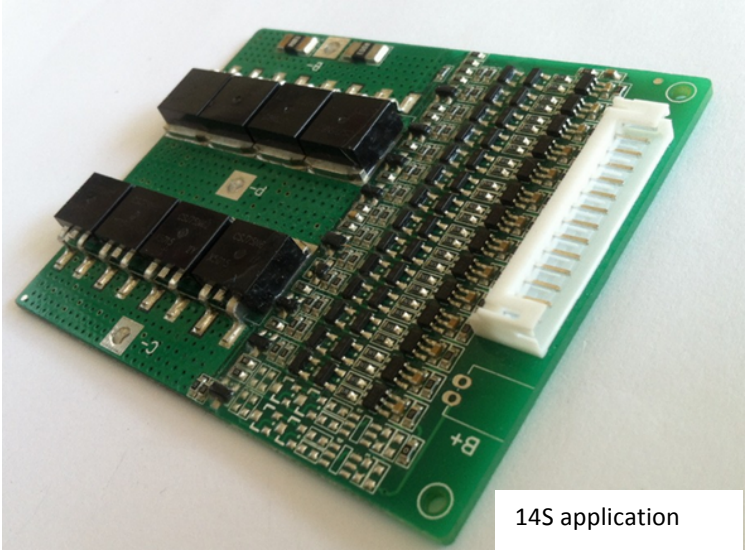

14S application

Common Signs of Damaged Lithium-ion/polymer cells

- Visible swelling or deformation
- Unstable Voltage characteristic during charge/discharge
- Significantly diminished run time
- Electrolyte leakage –distinct smell
- Fire from thermal runaway

Summary

Various considerations must be given prior to designing a device requiring rechargeable Lithium-ion batteries. It is always recommended to follow cell manufacturer's specific electrical parameters such as maximum discharge/charge current, operating Voltage, as well as operating temperature as they are some of crucial design elements to ensure battery safety, performance, and longevity.