Select the Right Li-Ion and Li-Polymer Battery Charger

By
Qi Deng
Senior Product Marketing Engineer, Analog and Interface Products Division
Microchip Technology Inc.

Henry Lee
Senior Field Applications Engineer, Analog and Interface Products
Microchip Technology Inc.

Li-Ion and Li-Polymer Battery Advantages

Rechargeable batteries are widely used in portable electronic devices. It is important for portable device design engineers to select the right battery chemistry for each application, as well as the right charging solution for the chemistry they choose.

There are four mainstream rechargeable battery chemistries on the market – NiCd, NiMH, Li-Ion and Li-Polymer. The NiCd battery was the first mass-market rechargeable battery designed to replace the size-wise similar, yet non-rechargeable alkaline battery. The commercial success of the NiCd battery established the advantages of rechargeable over non-rechargeable batteries for most portable equipment and devices. This success also laid the market foundation for the more advanced rechargeable battery technologies to come – NiMH, Li-Ion and Li-Polymer batteries. The NiMH battery was received by the market as a higher energy density, and therefore longer run time, replacement of the NiCd battery (NiMH and NiCd batteries have the same operating and terminating voltages, as well as similar form factors).

Since the early 90s, there has been a proliferation of portable consumer devices with increasingly advanced features to enhance user experiences. These features rely upon sophisticated components such as high-performance embedded processors, high-density memories and high-resolution Thin Film Transistor (TFT) Liquid Crystal Display (LCD) panels to be fully functional and, therefore, appreciated. With these components, today’s portable consumer devices are more power-hungry than their predecessors.

The NiCd battery is not a good choice for today’s portable consumer devices because its energy density is not high enough to provide an acceptable run time. Although the energy density of the NiMH battery is higher than that of the NiCd battery, it is still rather marginal. As a result, NiMH batteries are typically found in larger and heavier portable devices, such as DVD players. In general, all Nickel-based batteries suffer from a condition called “memory effect,” which prevents them from being fully charged unless they are fully discharged prior to each recharging cycle. In addition, both NiCd and NiMH batteries must be fully discharged periodically to avoid long-term capacity loss. These factors make Nickel-based batteries inconvenient for most portable consumer electronic device users.

A new battery chemistry that offers high energy density and “low maintenance” (from a user’s perspective) is required, and the Li-Ion battery meets this requirement. Li-Ion batteries offer much higher energy density than NiCd and NiMH batteries, have no “memory effect” and do not require periodic discharging. Since first introduced in the early 90’s, Li-Ion batteries have established themselves as the battery of choice for portable electronic devices. They can be found in most of the latest consumer gadgets such as mobile phones, MP3 players, Personal Media Players (PMPs) and Digital Video Broadcast (DVB) devices.
However, Li-Ion batteries are not low maintenance from a designer’s perspective. The Li-Ion chemistry uses Lithium salt as the electrolyte, which is soaked in an organic solvent. Because the organic solvent is in a liquefied state, conditions such as polarity reversal, over voltage and overheat can occur during storage. Regular usage or charging can trigger rapid chemical reactions that produce Lithium, a volatile metal that may cause explosion and, consequently, inflict injuries upon the user. As such, a protection circuit must be used either internally on the battery or on the charger design. This is also the reason why Li-Ion batteries require that the charging voltage, and current and cell temperature closely follow a set of predetermined curves, which prevents potential damage to the core.

The Li-Polymer battery evolved from the Li-Ion battery. Today’s commercially available Li-Polymer batteries should really be called Li-Ion Polymer batteries, because they also use Lithium salt (hence ion) as the electrolyte. However, the electrolyte of the Li-Polymer battery is not soaked in an organic solvent -- rather, it is held in a gel-like polymer composite that eliminates the metal casing required by Li-Ion batteries. One positive effect of this more inert polymer composite is that Li-Polymer batteries are less likely to explode than Li-Ion batteries.

From a pure chemical-reaction standpoint, the energy density of Li-Polymer batteries is lower than that of the Li-Ion battery. However, because the metal casing is absent, the packing can be more dense and, therefore, Li-Polymer batteries can have a higher energy density than Li-Ion batteries. Also, elimination of the metal casing increases the cell’s flexibility and reduces its weight, making Li-Polymer batteries ideal for applications that require specific shaping and light weight. These benefits make Li-Polymer batteries the ideal choice for compact and long run-time devices such as laptop computers and hard drive based PMPs.

Because Li-Ion and Li-Polymer batteries are based on the same Li-Ion chemical reaction, they share the same charging and discharging profiles. As a result, all protection and charging circuit designs for Li-Ion batteries can also be used by Li-Polymer batteries. From a user’s perspective, they do not need to be differentiated.

<table>
<thead>
<tr>
<th></th>
<th>NiCd</th>
<th>NiMH</th>
<th>Li-Ion</th>
<th>Li-Polymer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Density by Weight (Whr/kg)</td>
<td>40 - 80</td>
<td>60 - 120</td>
<td>110 - 160</td>
<td>100 - 130</td>
</tr>
<tr>
<td>Nominal Operating Voltage (V)</td>
<td>1.2</td>
<td>1.2</td>
<td>3.6</td>
<td>3.6</td>
</tr>
<tr>
<td>Open Circuit Voltage (V)</td>
<td>1.25</td>
<td>1.25</td>
<td>4.2</td>
<td>4.2</td>
</tr>
<tr>
<td>End Voltage</td>
<td>0.9</td>
<td>0.9</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Load Current</td>
<td>&lt;10C</td>
<td>&lt;5C</td>
<td>&lt;2C</td>
<td>&lt;2C</td>
</tr>
<tr>
<td>Fast Charge Time (Hour)</td>
<td>1</td>
<td>2 - 4</td>
<td>2 - 4</td>
<td>2 - 4</td>
</tr>
<tr>
<td>Overcharge Tolerance</td>
<td>Moderate</td>
<td>Low</td>
<td>Very Low</td>
<td>Low</td>
</tr>
<tr>
<td>Charge/Discharge Cycles</td>
<td>1500</td>
<td>500</td>
<td>1000</td>
<td>500</td>
</tr>
<tr>
<td>Discharge Profile</td>
<td>Flat</td>
<td>Flat</td>
<td>Sloping</td>
<td>Sloping</td>
</tr>
<tr>
<td>Self-Discharge per Month</td>
<td>20%</td>
<td>30%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Internal Resistance (mΩ)</td>
<td>100 - 200</td>
<td>200 - 300</td>
<td>150 - 250</td>
<td>200 - 300</td>
</tr>
<tr>
<td>Operating Temperature Range (°C)</td>
<td>-40 - 60</td>
<td>-20 - 60</td>
<td>-20 - 60</td>
<td>0 - 60</td>
</tr>
<tr>
<td>Periodic Discharge Requirement</td>
<td>30 - 60</td>
<td>60 - 90</td>
<td>Not Required</td>
<td>Not Required</td>
</tr>
<tr>
<td>Typical Battery Cost</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

*, ** Table 1: Comparison of Rechargeable Battery Chemistries
Of course, there are certain areas in which Li-Ion and Li-Polymer batteries are not the best choice. Other than safety concerns, the most noticeable shortcoming for Lithium-based batteries is that the discharging (load) current cannot be much higher than 1C and, as a result, they are not particularly suited for applications that require very high current, either peak or continuous. For example, in portable hand tools that require high torque, and hence high current, NiCd is still the battery of choice. Also, Li-Ion and Li-Polymer batteries are still high cost items compared to the Nickel varieties, and may not be the best option for cost-conscious, low volume users.

**Li-Ion and Li-Polymer Battery Charging Algorithms**

Depending upon the power requirements of the end application, a “battery pack” can consist of up to 4 cells of Li-Ion or Li-Polymer battery in a variety of configurations (Table 2) with a handful of mainstream power-source types -- AC adapter, USB port or car adapter. Despite differences in the number of cells, cell configurations or power source types, these battery packs all follow the same charging profile, which is shown in Figure 1. This sameness is due to the commonality of the Li-Ion chemistry and, therefore, the charging algorithms.

<table>
<thead>
<tr>
<th>Application</th>
<th>Battery Capacity (mAh)</th>
<th>Cell Configuration</th>
<th>Power Source</th>
<th>Charger Normal Input Range</th>
<th>Suggested Charging Topology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bluetooth® Headset</td>
<td>90 - 150</td>
<td>1 Cell</td>
<td>AC Adapter, USB</td>
<td>5V</td>
<td>Linear</td>
</tr>
<tr>
<td>Wireless Handset</td>
<td>70 - 200</td>
<td>1 Cell</td>
<td>AC Adapter, USB</td>
<td>5V</td>
<td>Linear</td>
</tr>
<tr>
<td>Mobile Phone, PDA</td>
<td>700 - 1500</td>
<td>1 Cell</td>
<td>AC Adapter, USB</td>
<td>5V</td>
<td>Linear</td>
</tr>
<tr>
<td>MP3</td>
<td>700 - 1500</td>
<td>1 Cell</td>
<td>AC Adapter, USB</td>
<td>5V</td>
<td>Linear</td>
</tr>
<tr>
<td>PMP (HDD)</td>
<td>1200 - 2400</td>
<td>1 Cell</td>
<td>AC Adapter, USB, Car Adapter</td>
<td>5V, 9V – 16V</td>
<td>Linear, Switcher (Buck)</td>
</tr>
<tr>
<td>PDVD/P-TV</td>
<td>1800 - 3600</td>
<td>2 Cells (2 in Series, Multiple Parallel)</td>
<td>AC Adapter, Car Adapter</td>
<td>9V - 16V</td>
<td>Switcher (Buck)</td>
</tr>
<tr>
<td>Notebook PC</td>
<td>1800 - 3600</td>
<td>3 - 4 Cells (3 – 4 in Series, Multiple Parallel)</td>
<td>AC Adapter, Car Adapter</td>
<td>9V - 16V</td>
<td>Switcher (SEPIC)</td>
</tr>
</tbody>
</table>

*Table 2: Li-Ion/Li-Polymer Battery Applications and Associated Charging Power Sources*

The preferred charging algorithm Li-Ion/Li-Polymer batteries can be broken up into three stages -- trickle charge, fast charge and constant voltage.
1. **Trickle Charge** – Trickle charge is used to restore charge to deeply depleted cells. When the cell voltage is below approximately 2.8V, the cell is charged with a constant current of 0.1C.
2. **Fast Charge** – When the cell voltage rises above the trickle-charge threshold, the charge current is raised to perform fast charge. The fast-charge current should be less than 1.0C.
3. **Constant Voltage** – Once the cell voltage reaches 4.2V during the fast charge stage the constant-voltage stage starts. Charging is terminated by either minimum charging current or a timer, or a combination of the two. The minimum-current approach terminates charging when the charge current diminishes below approximately 0.07C. The timer method terminates charging when a preset timer expires.

Advanced battery chargers incorporate additional safety features. For example, charging is suspended if the cell temperature is outside a specified window, typically 0°C to 45°C.

Except for some very low-end applications, all Li-Ion/Li-Polymer battery-charging solutions in the market now, either integrated or built with discrete components, follow the above charging profile closely, not only for better charging results, but for safety reasons, as well.

![Li-Ion and Li-Polymer Battery-Charging Profile](image)

**Li-Ion and Li-Polymer Battery-Charging Topologies**

Although the charging profile for Li-Ion/Li-Polymer batteries is universal, the charging topologies vary for different numbers of cells, cell configurations, and power-source types. There are three major charging topologies for Li-Ion/Li-Polymer batteries:

1. Linear Topology
2. Buck (step-down) Switching Topology
3. SEPIC (step-up and step-down) Switching Topology
The linear topology is preferred when the input voltage to the charger is higher than the fully charged open-circuit voltage of the cells with sufficient headroom, especially when the 1C fast-charging current is not much higher than 1A. For example, there is typically one Li-Ion battery cell in a MP3 player, with capacity ranging from 700 mAH to 1500 mAH and a fully charged open circuit voltage of 4.2V. Since the power source for the MP3 player is either an AC/DC adaptor or a USB port with a well-regulated 5V output, a battery charger with a linear topology offers the simplest and most cost-effective solution. The basic structure of the linear topology is the same as that of a linear voltage regulator (see Figure 2).

![Figure 2: Li-Ion and Li-Polymer Linear Charger Topology](image)

The buck, or step-down, topology is a better choice when the 1C charging current is higher than 1A, or when the input voltage is much higher than the fully charged open-circuit voltage of the cells. For example, in a hard drive-based PMP, a one-cell Li-Ion battery with a 4.2V fully charged open-circuit voltage and a capacity of 1200 mAH to 2400 mAH is typically used. PMPs are now frequently charged by car kits, which output a voltage between 9V and 16V. The high voltage differential (at least 4.8V) between the input voltage and the battery voltage makes the linear topology very inefficient for this application. This inefficiency, coupled with more than 1.2A 1C fast-charging current, can create heat-dissipation problems. To avoid this, the buck topology needs to be adopted. The basic structure of the buck topology is the same as that of a buck (step-down) switching voltage regulator (Figure 3).

![Figure 3: Li-Ion and Li-Polymer Buck (Step-Down) Charger Topology](image)
In certain applications where 3 or even 4 Li-Ion/Li-Polymer cells are connected in series, the input voltage to the charger might not always be higher than the battery voltage. For example, a laptop PC uses a 3-cell Li-Ion battery pack, with a 12.6V (4.2V x 3) fully charged open-circuit voltage and 1800 mAH to 3600 mAH capacity. The input power source can be either an AC/DC adaptor with an output voltage of 16V, or a car kit with an output voltage between 9V and 16V. As such, the input voltage can be either lower or higher than the battery voltage. Obviously, neither a linear nor a buck topology is capable of charging a battery pack under this circumstance. This leaves the Single-Ended Primary Inductance Converter (SEPIC) topology, which is capable of outputting a voltage that is either higher or lower than the input voltage. The basic structure of the SEPIC topology is the same as that of a SEPIC switching voltage regulator (Figure 4).

*Figure 4: Li-Ion and Li-Polymer SEPIC (Step-Up & Step-Down) Charger Topology

**Additional Features of Li-Ion and Li-Polymer Battery Chargers**

Many of the latest battery chargers offer a variety of additional features to differentiate themselves from the competition. For the consumer market, two of the most popular features are:

1. Adapter and USB Switch-Over
2. Load Sharing

**Adaptor and USB Switch-over**

Increasingly, for many portable consumer devices, in addition to the conventional power sources such as an AC/DC wall adapter or a car kit, a USB-power option is added. The USB port is capable of delivering a charging current up to 500 mA. The conventional power sources are now used to provide large current for both battery charging and system load. As such, some battery chargers allow automatic switchover between the USB-power port and the adapter, without external control.

**Load Sharing**

There are two load-sharing approaches: the simpler charging-and system-load switchover, and the more advanced intelligent load sharing.

The charging-and system-load switch-over approach senses the presence of a high-current adapter. When the adapter is present, it powers the system directly and charges the battery pack. When the adapter is removed, the system is powered by the battery pack.

The intelligent load-sharing approach, or dynamic power-path management, allows current to be dynamically shared between the system load and battery charging. For most battery chargers that offer this feature, the system load is prioritized over the battery-charging current. This allows the user to fully utilize the portable device during battery charging.
There are two types of intelligent load sharing used in today’s advanced battery chargers:

1. Current-based Load Sharing
2. Voltage-based Load Sharing

In current-based load sharing, both the total system current and the charging current are monitored. If the system-and battery-charging currents exceed the power-source current limit, the battery-charging current is reduced to remove the over-current condition. As the system current decreases, additional current can be directed to battery charging.

In voltage-based load sharing, the output voltage (system voltage) is monitored. Once the output voltage drops below a pre-determined value, due to power-source current limit, the charging current is reduced until the output voltage recovers. When the output voltage stabilizes and the system-load current requirement is satisfied, the battery is charged with the remaining current.

Conclusions

There are four mainstream rechargeable battery chemistries – NiCd, NiMH, Li-Ion, and Li-Polymer, with the Li-Ion and Li-Polymer chemistries sharing the same charging profile. The Li-Ion and Li-Polymer chemistries are superior to the NiCd and NiMH chemistries in portable devices, especially in the consumer space.

While charging Li-Ion and Li-Polymer batteries, the chargers must closely follow a set of charging algorithms in order to obtain the best charging result, as well as to prevent damages.

There are three steps during Li-Ion/Li-Polymer battery charging -- trickle charge, fast charge and constant voltage. Also, depending upon the number of cells used, cell configuration, and power source type, there are three popular charging topologies among the latest Li-Ion/Li-Polymer battery chargers -- linear, buck (step-down) and SEPIC (step-up and step-down).

Some advanced features are offered in the latest battery chargers, including automatic adapter, USB switchover and load sharing. There are two types of intelligent load sharing in use -- current-based load sharing and voltage-based load sharing.

References:

* = Microchip MASTERS Conference 2005, Class 965BCH

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