# Designing Low-Cost Single/Multi-Cell Li-ION Battery Chargers

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Li-ION rechargeable batteries, with a projected yearly market growth rate of approximately 20%, are widely used in smart phones, portable media players, and digital still cameras. This battery type is widely adopted because of its high energy density on both gravimetric and volumetric basis, low self discharge rate, and low maintenance. Li-Ion batteries are also lighter in weight than NiCad and NiMH batteries. On the other hand, the material nature in the Li-ION cell also introduces higher safety risk: the LiNiO2 layer in the battery cell introduces high voltage and high energy during decomposition. Therefore, safety has always been the focus of Li-ION battery chargers design, and the batteries are usually assembled with a built-in thermistor and protective circuit.

The Li-ION charger design is known for its simplicity, low cost, and small size, and there are highly-integrated charger ICs offered by various vendors in the market. The particular charging algorithm, charging protection, board space, and complexity are the decisive factors governing Li-ION battery charger design.

Figure 1 shows the typical charging profile of Li-ION batteries. There are three charging phases: precharge, fast-charge/constant current, and constant voltage[1] . Li-ION batteries exhibit flat discharge characteristics and are free from memory effects. If the starting voltage of these batteries is initially too low, a small constant current is applied until the battery reaches a certain threshold specified by the manufacturer (V_{FULL}). The battery is charged with constant voltage when this threshold is crossed. Charging is terminated when the charging current drops below the threshold (I_{TERM}).
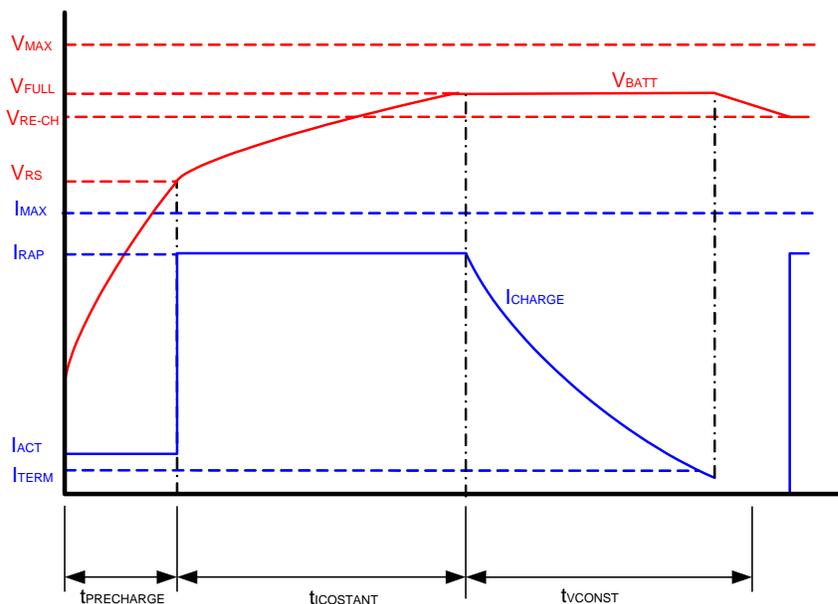
Figure 1: This chart shows the typical charging profile for a Li-ION battery across its three charging phases: precharge, fast-charge/constant current, and constant voltage. Charging is terminated when the charging current drops below the threshold (I_{TERM}).

From a safety perspective, the constant current and voltage charging stage must be protected by a timeout, which is usually implemented by a timer in the charging IC. The constant current time is estimated to provide 100-120 percent of the battery charge because during this mode the battery is charged up to 70-80 percent. The constant voltage charge time is limited to 2 hours, according to manufacturer recommendations [2]. The built-in thermistor and protective circuit in Li-ION battery are used to protect the battery from overcharge and overdischarge and limit the charger current/voltage to stay within safe values. The

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charge source voltage-limit accuracy must be more than 1 percent. The charge process cannot be activated unless the battery temperature is within the predefined limit. Typical temperature values are +2 to +40 C [2].

The advantages of Li-ION battery come with higher complexity of the charging profile, protection and temperature control to ensure that the battery does not explode under adverse conditions. These characteristics demand the charging IC to grant designers more control over the timing accuracy and voltage/current/temperature feedback model. To take it one step further, the variation of charging parameters (V_{FULL}, I_{TERM}, etc) from battery manufactures requires engineers to adapt the design of one charging IC to other platforms on the fly to catch the next wave of new product releases in the fast-changing consumer electronic industry.

One way that engineers simplify charger design is to use a single cell charger design that can be easily adapted to multi-cell. The fixed functional charging ICs are easy to drop into such an implementation, but this does not offer designers flexibility of tuning and controlling. Alternatively, a programmable IC implementation takes longer to develop but provides with much more control and an easy migration path to support various types of battery chargers covering low- to high-end applications. The early investment of developing such firmware pays off in the long run.

When evaluating a programmable charging IC implementation, firmware development should take greater weight. To offer designers the path with least resistance to success, many IC vendors offer functional codes in the format of user modules, allowing designers to select components based on the particular function required for a particular battery charger. For example, the current and voltage control circuit in a battery charger uses a Pulse Width Modulator (PWM), as shown in the Regulation Circuit shown in Figure 2.[1] The signal from the PWM goes to a low pass RC-filter (R8 and C1). The output of the RC filter is a constant voltage signal proportional to the PWM duty cycle value.
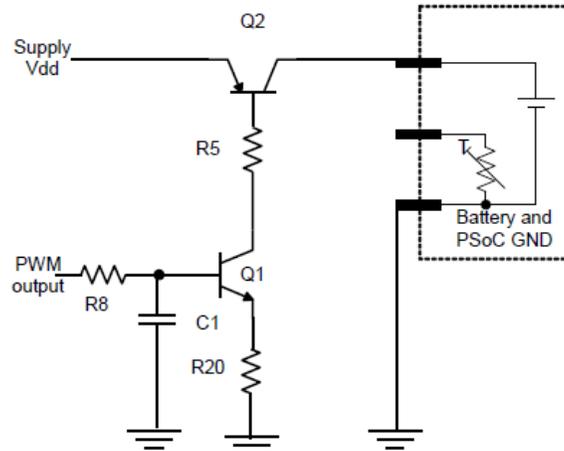
Figure 2: The regulation circuit for an Li-ION battery charger controls both the current and voltage in the charger using a Pulse Width Modulator (PWM). The signal from the PWM goes to a low pass RC-filter (R8 and C1) and the output of the RC filter is a constant voltage signal proportional to the PWM duty cycle value.

Figure 3 shows how the PWM module can be configured using parameters to establish the optimal pulse width and duty cycle to correspond to a particular application. Application programming interfaces (API) enable developers to allow high-level functions to control and respond to hardware events and interrupts at run time.

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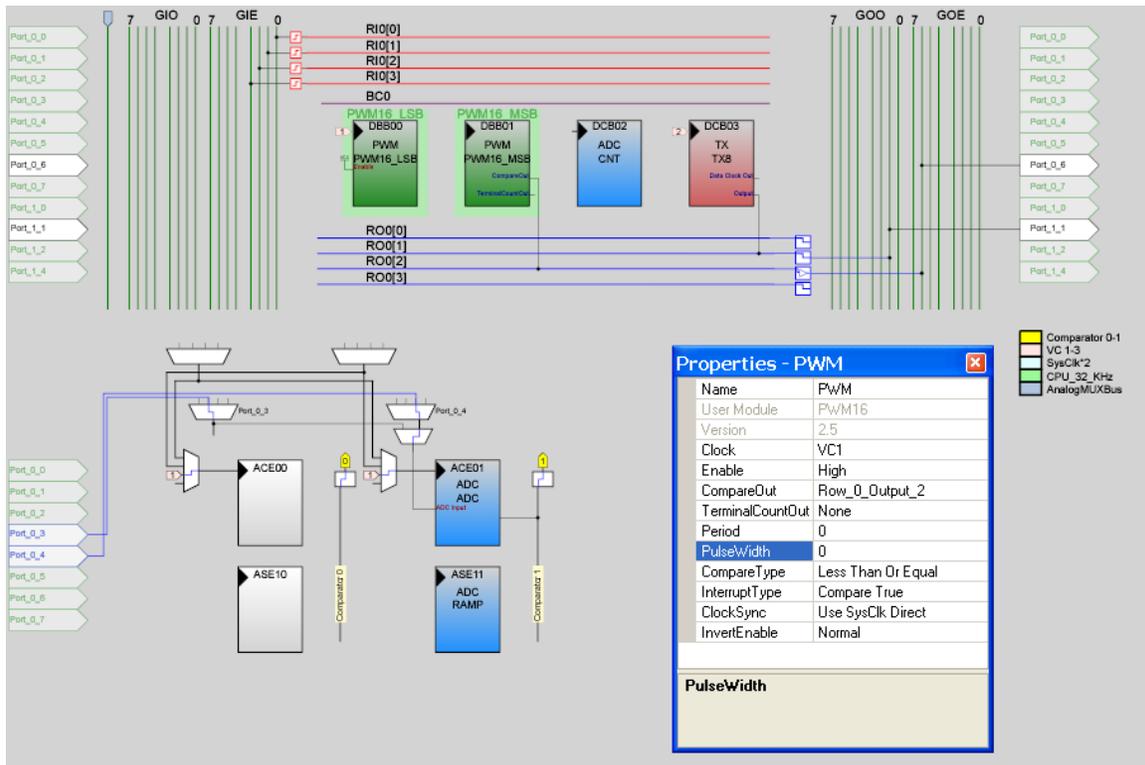
Figure 3: The parameters of the PWM component can be configured to correspond to a particular application using tools from IC manufacturers. For example, Cypress' PSoC Designer enables developers to establish the optimal pulse width and duty cycle for the PWM, as well as allows high-level functions to control and respond to hardware events and interrupts at run time.

Given the charging profile of Li-ON, the charging firmware can be built on a state machine to transfer between different charging phases. The state machine can be readily modified to support different charge profiles. By defining these different profiles in firmware, it becomes a straightforward process to add or modify profiles for different batteries.

Figure 4 shows the typical function blocks in a battery charger design. Each battery, however, has its own profile that requires adjustments to the various function blocks. And, with the growing popularities of Li-ON batteries, designers will need to be able to support a diversity of end applications that demand different charging profiles while providing higher levels of safety. With the increasing availability of low cost single-chip programmable devices with configurable analog and digital logic, developers will be able to implement flexible hardware to accommodate any charger configuration. As space and complexity are two key concerns in portable battery charger design, the ability to integrate functionality and high-precision peripherals not only simplifies designs but also decreases system size while reducing cost.

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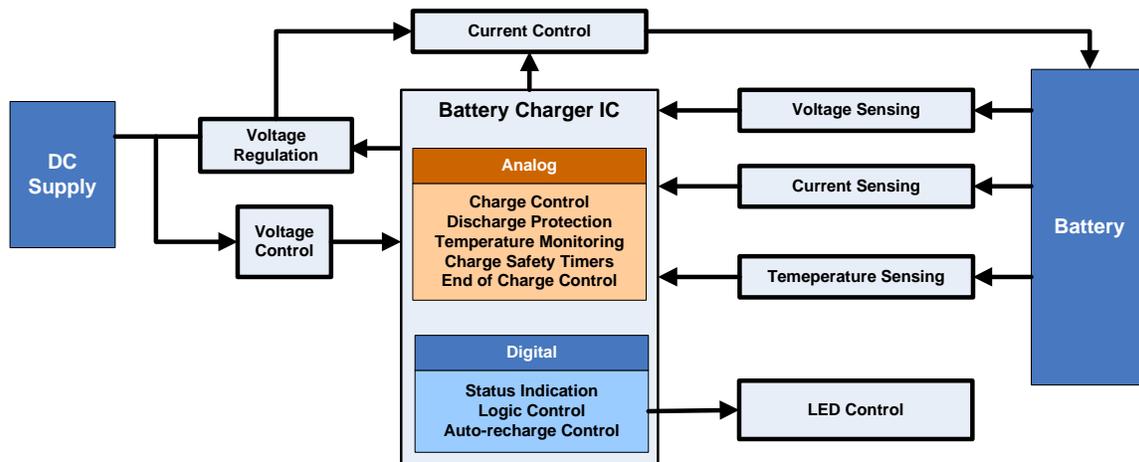
Figure 4: This diagram shows the typical functional blocks required to implement a Li-ION battery charger. As each end application demands a different charging profile, designers need programmable devices with configurable analog and digital functionality to implement these changes without requiring a separate hardware design for every application.

[1] Application Note: "Power Management - Single Cell Li-Ion Battery Charger with CY8C21x23" by Archana Yarlagadda, Cypress Semiconductor

[2] Application Note: "Power Management - Single Cell Li-Ion Battery Charger" by Svyatoslav Paliy, Cypress Semiconductor

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