Charging a three-cell nickel-based battery pack with a Li-Ion charger

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Introduction

One thing common to all portable devices is the need for a portable energy source to power the device. Many portable devices use lithium-ion (Li-Ion) polymer cells, which have a high energy density that allows them to be light and small in size. This has led to the design of numerous low-cost, highly integrated Li-Ion charger ICs to charge the batteries of such devices. For any device requiring high current, nickel-based cells are still very popular due to their low impedance, low cost, and availability. They are also considered safer than Li-Ion cells, which require many safety features.

Most systems require at least 3 V to operate, which dictates using one Li-Ion cell or three series (3S) nickel cells. Either type of cell chemistry can power portable devices, but each requires a different "fast-charge" method and thus a completely different charger IC. Due to the emphasis on Li-Ion cells and the need for nickel-charger ICs to have several external components, there are few modern, integrated, and easy-to-use nickel-charger ICs available today. This article shows the justification for using a highly integrated, low-cost, Li-Ion single-cell charger IC to charge nickel-cell packs and discusses the benefits and trade-offs.

Charge profiles of nickel and Li-Ion batteries

All nickel cells require a constant-current (CC) fast-charge rate greater than 0.3C and less than 3C to have a detectable termination signal. Discharging a full cell in one hour takes 1C of current. For example, a 2300-mAh cell is completely discharged if loaded at 2300 mA for one hour. The nickel-charger IC uses a peak-voltage-detection algorithm to monitor the nickel pack's voltage. When the pack reaches a peak voltage and then drops from that voltage by typically 3 to 6 mV per cell, the fast charge is terminated. Once the cell becomes full, the excess energy is dissipated as heat in the cell and the voltage drops, since the cell's internal impedance has decreased due to the increase in temperature. A very precise sampling circuit is required to detect the small voltage change that indicates fast-charge termination. Figure 1 is an example of a 3S NiMH-pack charge profile during one complete charge cycle at a 1-A (1C) constant-current (CC) fast charge.

Figure 1. Charge profile of 3S NiMH pack

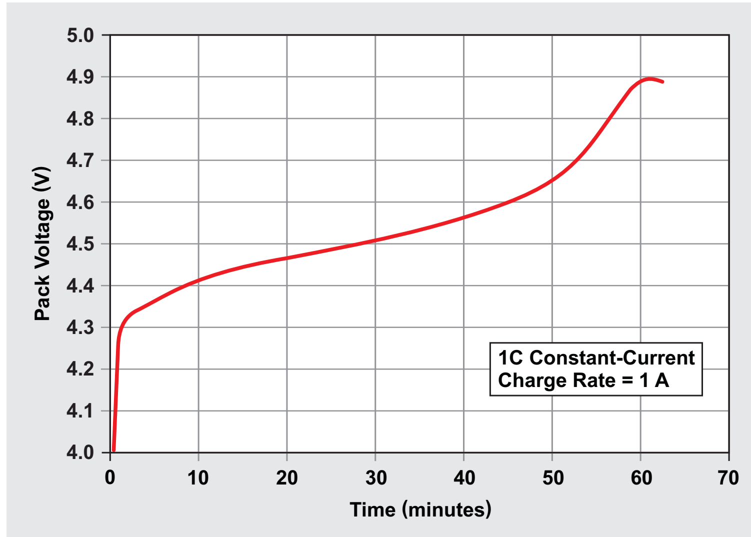
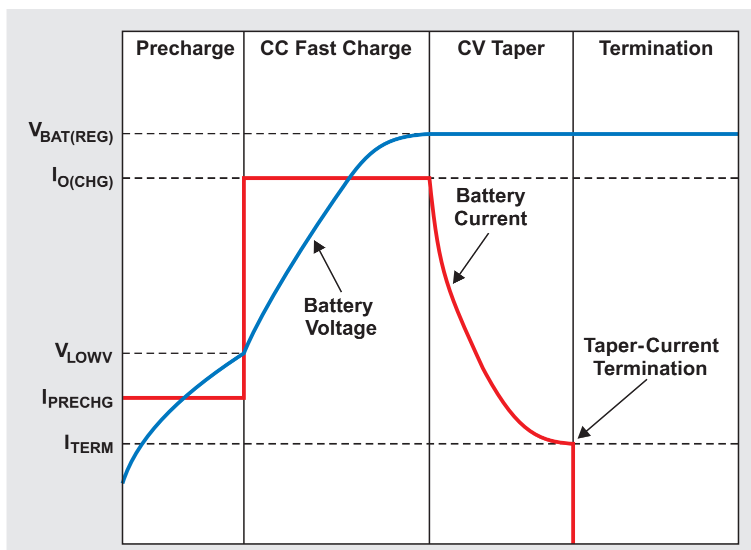


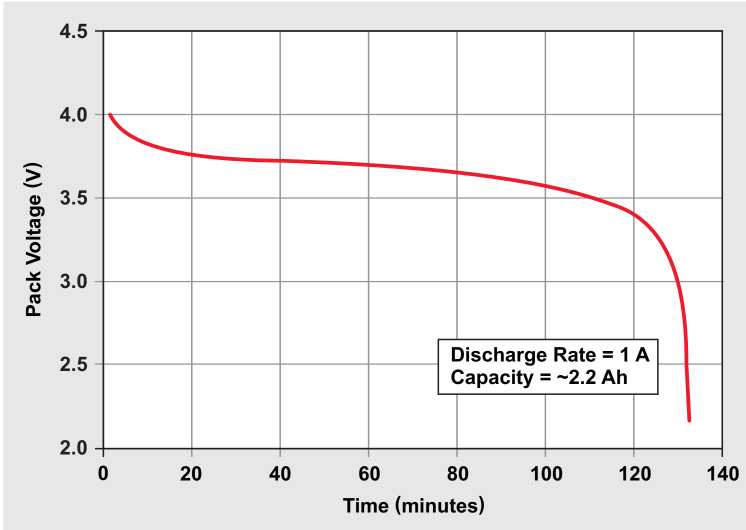
Figure 2. Charge profile of typical Li-Ion battery



By contrast, a Li-Ion charger has a constant-current and constant-voltage (CC-CV) charge algorithm (Figure 2). During fast charge, the charge current is constant until the pack voltage reaches 4.2 V. At this point, the voltage loop takes over and holds the voltage constant as the current tapers, typically to one-tenth of the fast-charge current. When the charge current decreases to this level, termination occurs. The precharge mode is a safety feature for Li-Ion cells with internal shorts and will be discussed later. The taper curve is nothing more than a slow RC time constant. The pack has internal resistance and capacitance. As the cell's voltage increases, the voltage drop across the cell's internal resistance decreases, which means less charge current.

A typical Li-Ion charger detects only the taper-current termination (I_{TERM}), which presents some design challenges when it is used as a nickel-cell charger. With the standard CC method, a typical NiMH cell charges up to ~1.55 V prior to termination. After termination, it relaxes to ~1.45 V. A NiCd cell terminates at ~1.45 V and relaxes to ~1.35 V. So the total voltage for a 3S NiMH pack is 4.65 V/4.35 V, and for a 3S NiCd pack, 4.35 V/4.05 V. Since the "relaxed" voltages are very close to the Li-Ion cell's termination point of 4.2 V, this article investigates using a Li-Ion single-cell charger to charge a 3S nickel pack. As the nickel cells charge to full capacity, the pack's voltage approaches 4.2 V, which causes the Li-Ion charger's current to taper to a very low level.

Figure 3. Discharge profile of 3S NiMH pack after traditional CC charging



Safety concerns

There are no real safety concerns with the Li-Ion CC-CV method of charging a 3S nickel pack up to 4.2 V, since the current naturally tapers toward 0 A as the pack reaches full capacity. Thus, there is little energy being applied to the pack once it is full. Termination of the Li-Ion charger should be disabled, since it is not necessary and reduces the charged capacity of the nickel cells if set too high. For example, with the Texas Instruments bq24040/50/90 families, the termination threshold can be programmed to a fairly low level if desired.

There is some possibility that one of the 3S nickel cells may become shorted and the fast charge may not reach voltage regulation where the current tapers toward zero. This concern can be addressed by placing a thermistor in the battery pack so the charger IC can monitor and limit the maximum temperature during this and other fault conditions. The Li-Ion charger's precharge mode is not needed or used for typical charging of a nickel pack. However, this mode can be a safety benefit that reduces the charge current if the pack voltage drops to the precharge threshold (2.5 to 3 V) due to a shorted pack. Another way to mitigate the risk of a shorted cell is to reduce the fast-charge current to C/5. This approach reduces the temperature rise at the expense of moderately increasing charging time.

Many designs for nickel chargers do have some inherent risks that are mitigated through circuitry that monitors the charging process, declares a fault condition, and stops the charge. In the typical CC fast-charge method, the IC looks for a –dV or dT/dt. One issue with this method is that after termination, if the device is removed and used for a minute and then reconnected to the charger, the pack will have to charge and heat up that much more to get a further dV drop or dT/dt increase. If the device is removed and replaced a few times, the impedance can drop only so much, and charging will not terminate. However, as previously stated, adding a thermistor will enable the charger IC to terminate the charge if the temperature fault threshold is reached. Using a Li-Ion charger does not have this recharging issue with the temperature unless a cell is shorted, which suggests an overall safer design.

Test results

A NiMH pack was charged and discharged to determine the difference in results between the CC and CC-CV charge profiles. Figure 3 shows the discharge profile and capacity of a typical 3S 2.3-Ah NiMH pack that was charged by the traditional CC method at 1C. The capacity measured ~2.2 Ah and was the reference point for judging the CC-CV charging method.

The first attempt at charging the pack with the CC-CV method yielded a surprise, since the termination was still set for 0.1C (230 mA). The battery did not charge long before termination was reached, and the capacity was measured at 0.76 Ah. Figure 4 shows the discharge profile of the partially charged cell. Obviously, the cells were undercharged due to the 0.1C termination. The fast-charge termination threshold was similar to a 0.1C "trickle"-charge rate, which means that a much higher capacity could have been obtained if the trickle charge had been allowed to continue. In order to store more capacity in the cells, the next step was to disable termination and see how the capacity changed.

Figure 5 shows the charge profile of the pack when it was charged without termination. The profile plots current instead of voltage since the battery current was changing and the battery was in voltage regulation 99% of the charging time. CC mode was seen for a few minutes at the start of the charge. The current data was integrated over the

Figure 4. Discharge profile of 3S NiMH pack after CC-CV charging with 230-mA termination

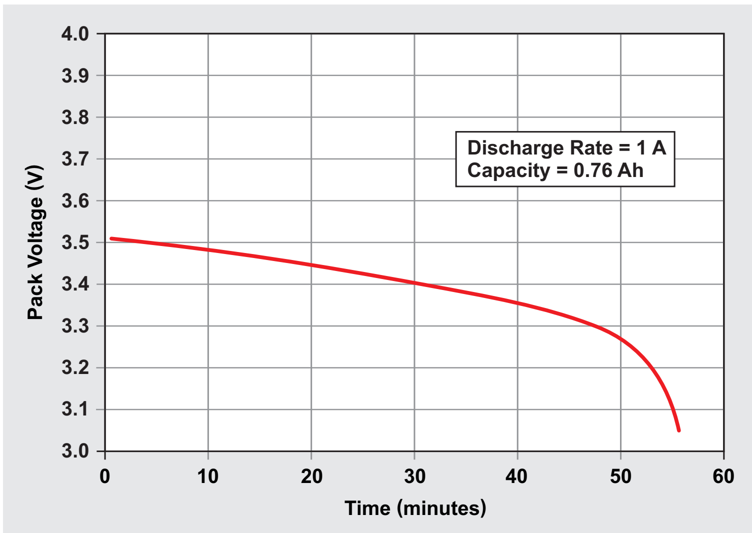
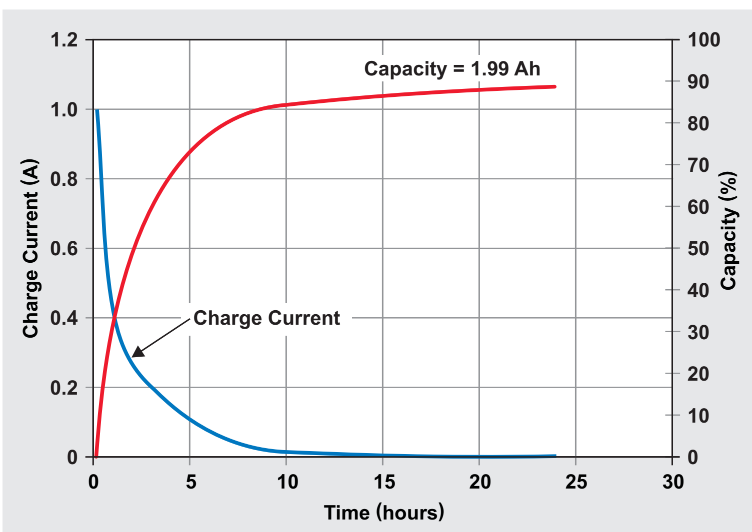


Figure 5. CC-CV charge profile of 3S NiMH pack with no charge termination



charging time and was used to determine that ~2 Ah were delivered to the cell. Figure 6 shows the discharge profile of the pack after it was charged without termination. The pack's measured capacity was 1.99 Ah.

As one can see, using the CC-CV method of charging a 3S NiMH pack results in charge capacity that approaches that of a standard CC fast charge, but the last 30% of that capacity takes longer to obtain.

Other applications

It is possible to apply the CC-CV method to a multicell Li-Ion charger to charge more than three series cells by adjusting the output voltage. If the regulation voltage is set by using the rule of thumb of 4.2 V/3 cells = 1.4 V per cell, this method should work fine. The design could be optimized by choosing a regulation voltage that is closer to the pack's full-capacity voltage with a 0.1C current level. This would give slightly more drive and would fully charge the pack quicker with a slightly higher capacity. The NiMH cells evaluated for this article had a pack voltage of 4.45 V at 0.1C (30°C) when full.

The CC-CV charging method can also be applied to a pack with NiCd chemistry. The NiCd pack has a specified voltage of 4.32 V at 0.1C (30°C) when full. The NiCd open-circuit voltage immediately after termination of a fast charge is ~1.4 V per cell times three, or 4.2 V, implying that the current goes to zero as the pack approaches full capacity.

When optimizing the maximum regulation voltage, the designer should take into account the characteristics of the cells to be used and whether or not they will be replaceable. To identify any system design issues, a charger application should always be tested over the full range of operation for all variables, plus a little more for some margin assurance.

The CC-CV charging method can be applied to adapters or USB sources, making the charging possibilities vast.

Conclusion

This article has shown that it is possible to charge a 3S NiMH pack safely and to nearly full capacity with a single-cell Li-Ion charger. The Li-Ion "nickel charger" can be classified as a hybrid fast/trickle charger, getting 70% of the bulk charge in 5 hours. The charge current tapers toward 0 A near the end of the charge, which reduces the chance of any thermal issues and possibly provides longer cell life. Most noteworthy is that the CC-CV method can be used to charge battery packs with either nickel-based or Li-Ion chemistry with no changes in hardware or firmware, making it a highly integrated solution at a low cost.

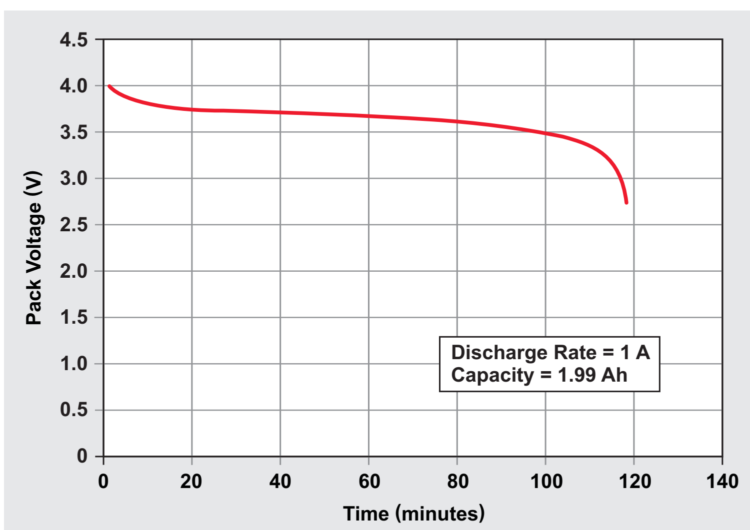
Related Web sites

www.ti.com/battery

www.ti.com/product/*partnumber*

Replace *partnumber* with bq24040, bq24050, or bq24090

Figure 6. Discharge profile of 3S NiMH pack after CC-CV charging for 119 minutes



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