# Using NiMH and Li-Ion Batteries in Portable Applications

## Introduction

Lithium Ion (Li-Ion) batteries are becoming more available in the marketplace, allowing system designers to use both nickel metal-hydride (NiMH) and Li-Ion battery types to power their portable equipment. The batteries, however, require different charge schemes. NiMH batteries are usually fast-charged at a constant current and terminated by either peak voltage detection, PVD, or the increasing rise in temperature at the end of full charge, $\Delta T/\Delta t$. Li-Ion batteries are usually charged at a constant voltage with a 1C current limit. Charge is usually terminated by time or when the charging current drops to a very low rate, typically less than $^{C}\!/_{30}$, indicating that the battery is full.

In addition to battery charging, the designer has the task of battery monitoring and capacity reporting. NiMH batteries are typically monitored for end-of-discharge voltage, battery temperature, and charge and discharge current. With a fairly flat discharge voltage over about 80% of its capacity, capacity gauging for NiMH is done by determining the Amp-hour capacity removed during discharge and replaced during charge. NiMH batteries loose capacity due to self-discharge, which is determined by the temperature of the battery and is about 1.5 to 2 percent at 25°C.

Li-Ion batteries also require monitoring for capacity and state of charge. Li-Ion batteries using coke electrodes have a sloping discharge as shown in Figure 1. In some cases, the voltage during discharge can be used as an indicator of state of charge, but the voltage must be corrected for charge/discharge rate and ambient temperature. Voltage is acceptable for full or empty indication, but the better approach would be to monitor the capacity removed and the capacity replaced to determine the battery state of charge. This method would be more applicable to the other type of Li-Ion battery, which uses graphite electrodes. The graphite Li-Ion battery has a much flatter discharge profile making voltage-based gauging much less accurate than the coke Li-Ion batteries. The self-discharge for both types of Li-Ion batteries is about $^{1}\!/_{10}$th of that for NiMH batteries.

Benchmarq Microelectronics is developing charge controllers, battery protectors, and capacity gauging ICs specifically tailored for the Li-Ion battery. Today, however, Li-Ion batteries can be charged and monitored using existing Benchmarq products. The purpose of this paper is to describe how a subsystem can be developed that will support both NiMH and Li-Ion batteries using existing Benchmarq ICs and easily transition to the new IC developments.

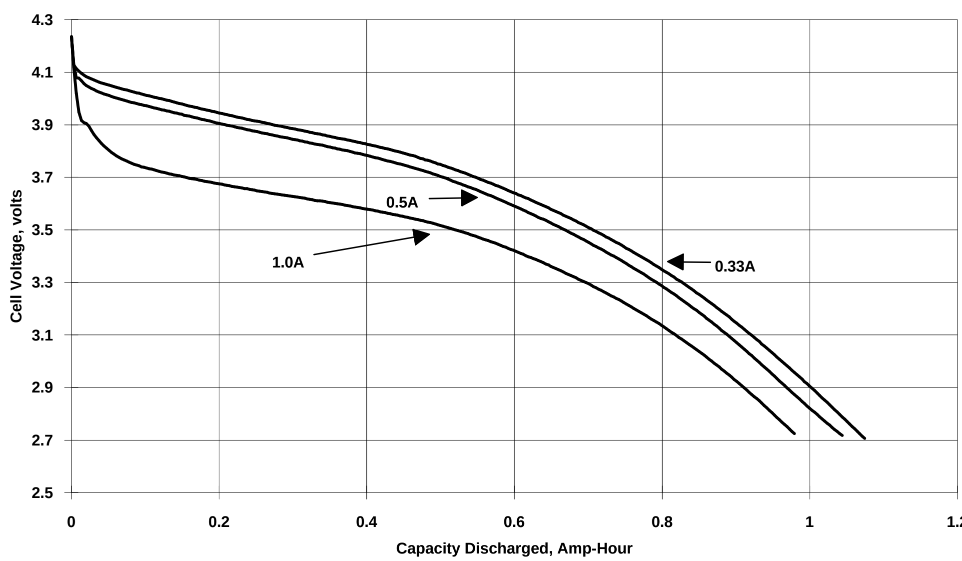


**Figure 1. Li-Ion Battery Discharge Curve (Coke Electrodes)**

## Charger

The charger is based on the bq2004 operating in the switch-mode topology as shown in Figure 2. The charger can be controlled by either a bq2004 or a bq2004E. The charger is operated in a buck configuration where BAT+ is the battery pack positive contact and BAT– is the battery pack negative contact. When the battery is a NiMH pack, the SELC connection is not connected. When the battery is a Li-Ion battery, then the SELC contact is tied to the BAT+ contact within the battery pack. The battery also provides a thermistor contact so that charging can be qualified by the battery temperature and $\Delta T/\Delta t$ can be used for charge termination.

L1 is made using a composite core, MICROMETALS PN ST50-267, in a toroid geometry (see attached data sheet). The toroid is wound with 70 turns of 22 gauge copper magnet wire. The initial inductance is about 3mH. Because the inductance is a function of the current, the greater the current, the lower the inductance. This property allows for a greater range of current with smaller changes in switching frequency. The current range is needed for the lithium battery where the charge current decreases during charging as the battery EMF approaches the maximum allowable charging voltage. The switching frequency is about 30KHz.

When the SELC contact is floated, the charge selection is made for NiMH. In this mode, the bq2004 is configured for 1C charging with top-off and pulse trickle. The charge current is set to 2.25A. In this example, the battery divider is configured for nine cells. The $\Delta T/\Delta t$ sensitivity is configured using R8 and R9, and the maximum charge temperature is set by the resistors R5 and R6. The bqCharge disk provides a program to calculate the proper values for these resistors depending on the application requirements and the thermistor choice. The

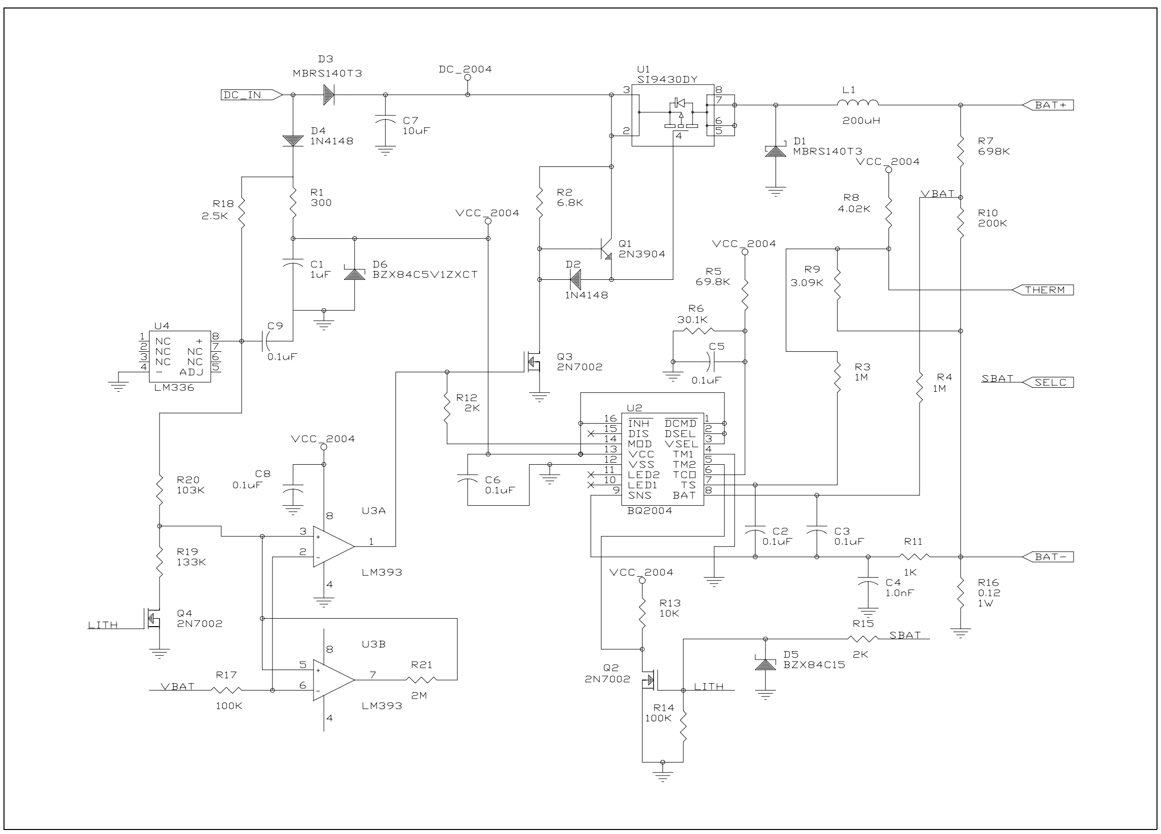


**Figure 2. Li-Ion/NiMH bq2004 Switch-Mode Charging System**

functional operation of the bq2004 and bq2004E is described in their respective data sheets.

When the SELC contact is at the BAT+ potential, the Li-Ion mode is selected. The battery pack is configured for three-by-three battery configuration, three strings of three cells in series connected in parallel. The TM1 and TM2 pins are set to provide a six-hour time-out with no top-off or trickle. The battery starts charging at the current limit set to 1.9A and is voltage-limited to 4.225V. For graphite Li-Ion cells, R19 and R20 are changed to limit charge voltage to 4.125V. During charging, the current varies as the battery EMF reaches the voltage limit. Full charge is indicated after the time-out of six hours.

## Capacity Gauging

Capacity gauging is an important user feature for both NiMH and Li-Ion. Capacity gauging is provided by the bq2014 for NiMH batteries and can be configured using the information in the bq2014 data sheet. The bq2014 can also be used for Li-Ion capacity gauging and is discussed in this paper.

Figure 3 shows the bq2014 monitoring an NiMH battery configured similar to that described in the above charger section. The application can identify the battery pack as NiMH by bit 4 of the PPU register. This bit is 0 for nickel-based chemistries. The bq2014 provides the proper compensation for charge and discharge rates with temperature compensation and self-discharge correction. The bq2014 provides software-adjustable end-of-discharge voltage selection. Battery voltage is also available. The capacity of the battery is reported in a 8-bit register pair. The typical application scales this value based on the sense resistor used to get the Amp-hour capacity. The application can also scale the capacity to Watt-hours by using the battery voltage. During discharge, the battery voltage is read from the bq2014 and averaged with the end-of-discharge voltage. This is the average available voltage for the remaining dis-

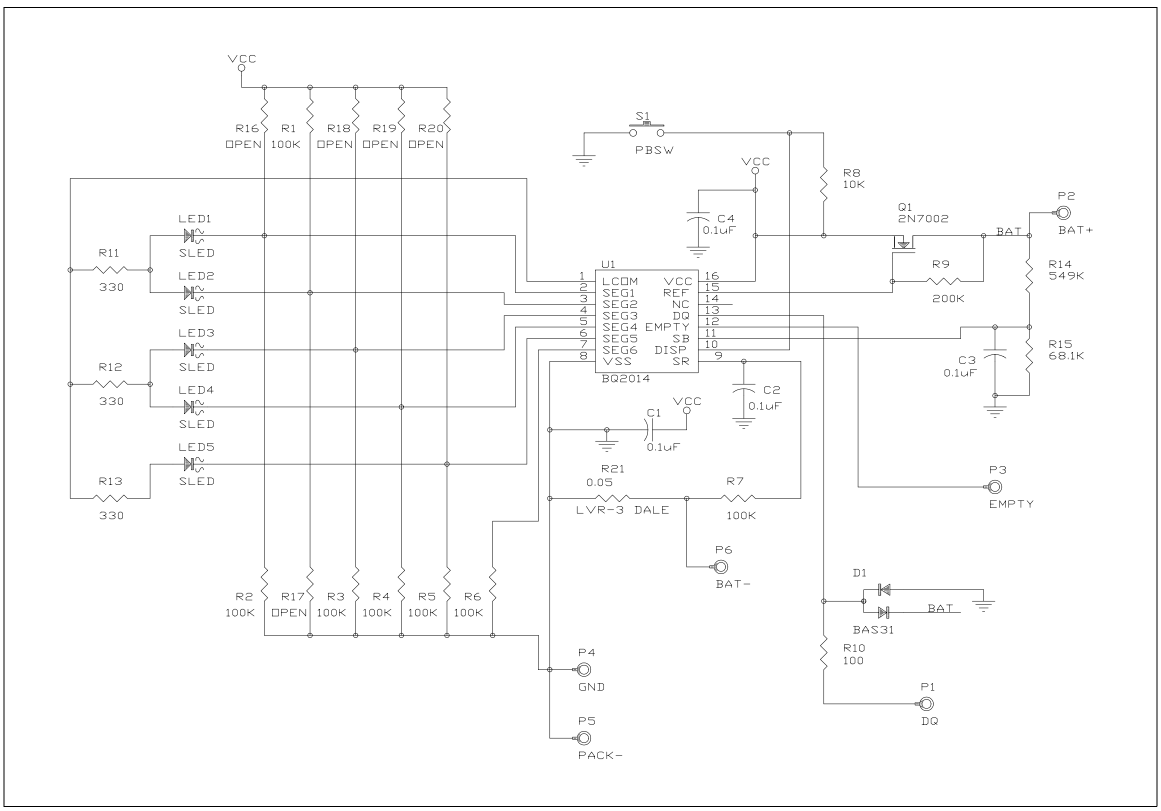


**Figure 3. bq2014 NiMH Battery Capacity Monitoring System**

charge at the current discharge rate. The average voltage is then multiplied by the remaining capacity to get the remaining Watthours. Although NiMH batteries are usually gauged in Amp-hours due to their relatively flat discharge profile, Watt-hour capacity can also be used for consistency with Li-Ion batteries.

Li-Ion battery capacity can be obtained using the bq2014 as shown in Figure 4. The primary difference is the configuration for the capacity and pulling PROG5 high to disable self-discharge compensation. The self-discharge for Li-Ion batteries is about $^1/_{10}$th of that for NiMH and can be neglected in most applications. For those applications that choose to compensate for self-discharge, the BATID register can be written with the week of the year so the time that the battery might have been exposed to self-discharge can be measured; however, in most applications, this correction is small enough to be neglected. Although the capacity for Li-Ion batteries is usually reported in Watt-hours, the capacity can be computed as described above. Figure 5 shows the cycle profile for a Li-Ion battery that has been discharged to 2.7 volts per cell after various levels of partial recharge. The battery capacity is determined properly, and the user can be comfortable with using the battery near the end of capacity.

# Summary

Benchmarq is developing a family of compatible Li-Ion chargers, protectors, and capacity gauges. Using existing products, manufacturers can go to market today with chargers from Benchmarq that support both NiMH and Li-Ion batteries. Battery capacity can be determined for both NiMH and Li-Ion batteries using the bq2014.

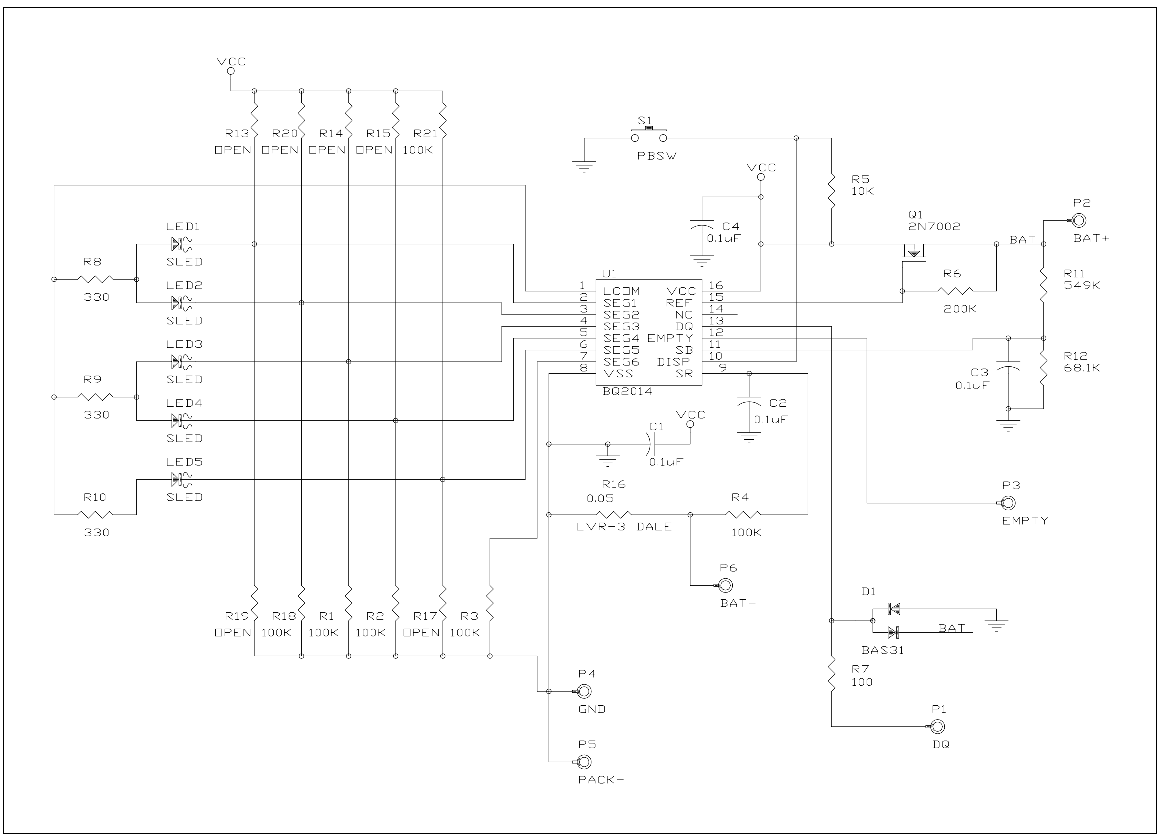


**Figure 4. bq2014 Li-Ion Battery Capacity Monitoring System**

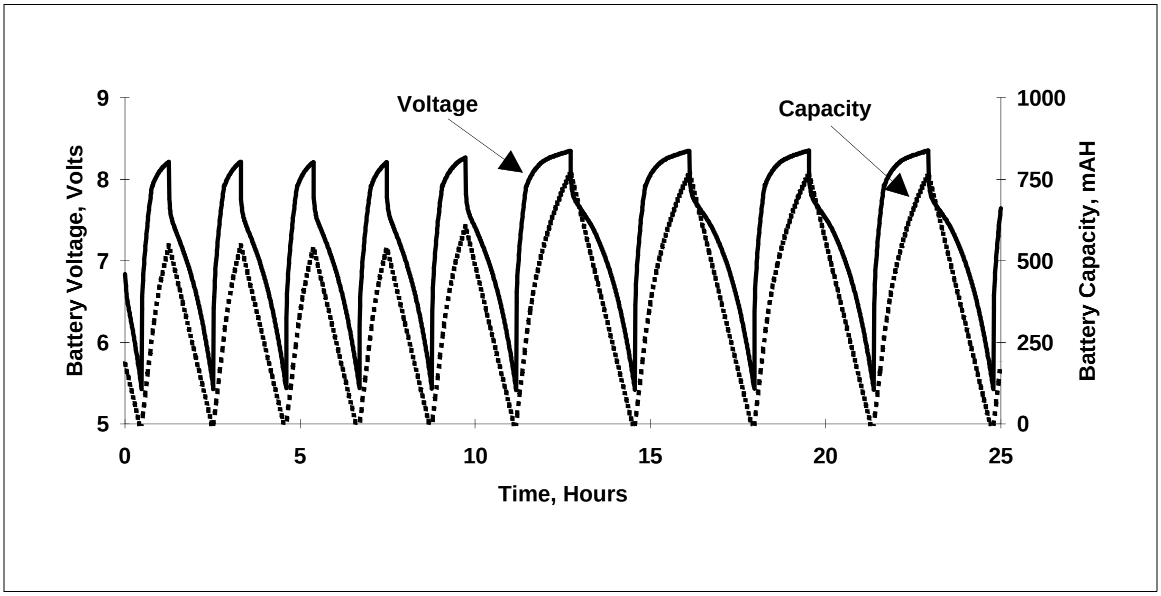


**Figure 5. Li-Ion Battery Discharge and Capacity Profile**

## IMPORTANT NOTICE