

# 3A BATTERY CHARGER HAS AUTOMATIC OVERCHARGE PROTECTION

## ABSTRACT

This article describes a 3A battery charger that senses the temperature rise of the battery to cut off the charging current and prevent overcharge.

## CIRCUIT CONCEPT

This battery charger was developed specifically for applications using either **Nickel-Cadmium (Ni-Cd)** or **Nickel-Metal Hydride (Ni-MH)** batteries that will accept a 3A fast-charge rate, and provides automatic shutoff of the high-current charge when the battery is full.

After shutoff, a continuous (low level) charge current is used to "trickle charge" the battery which keeps it topped off and prevents charge loss due to any internal leakage.

The trickle charge rate used must always be low enough that the amount of gas developed within the cell is small enough that it can recombine, thus preventing pressure build-up and venting (opening of the cell's internal vent to release pressure). The maximum safe trickle charging rate is determined by the size and type of battery (this is covered later in the paper).

The critical specification for a battery is its **Amp-hour (A-hr) rating**, which is numerically equal to the maximum amount of current the battery can supply to a load for one hour before the cell reaches its **end-of-life voltage** (usually taken as 1.0V/cell for Ni-Cd and Ni-MH batteries).

When a battery is charged or discharged at a current that is equal to its A-hr rating, **this is known as the "c" rate**.

Most Ni-Cd and Ni-MH batteries can be safely charged at a 1c rate, as long as they are not overcharged. Also, the battery temperature must be within a range of about 15°C to 45°C (the reasons are detailed later in this paper).

## OVERCHARGING: THE SILENT KILLER

The nemesis of all rechargeable batteries is overcharge, although some battery types tolerate it better than others, the results of overcharge range from minor damage to catastrophic failure.

In the case of Ni-Cd, which is the most popular rechargeable battery type presently in use, sustained overcharge causes increasing pressure within the battery that eventually causes the cell's vent to open and release oxygen. This has a detrimental effect on the battery, although it may still retain some useful capacity.

If Ni-MH batteries are overcharged, they will also build up pressure and release gas: **however, the gas released will be hydrogen**. As demonstrated at the Hindenberg's final landing, hydrogen gas is **extremely explosive** near spark or flame. One battery manufacturer created an interesting euphemism for some of the unfortunate accidents in cases where Ni-MH batteries were overcharged: **Rapid Spontaneous Disassembly**.

## DETECTING END-OF-CHARGE

There are several ways to detect end-of-charge for Ni-Cd or Ni-MH batteries, but one way that is both simple and reliable is called a  $\Delta T$  detector. It measures both the ambient temperature and the battery temperature and cuts off the high current charger when the battery rises a pre-set amount above ambient. This design uses a 10°C rise as the cutoff point (which is recommended by most battery makers), but can be easily adjusted by changing resistor values.

Ni-Cd cells are perfectly suited for  $\Delta T$  cutoff techniques, because their charge process is **endothermic** (they get slightly **cooler** when a discharged battery is being recharged). Even at very high charge rates, the battery will not begin to heat until it is fully recharged. At that point, the battery is no longer converting the electrical current into a chemical reaction, so it must be dissipated as heat. This resulting increase in temperature provides a very accurate indicator that it is time to stop charging.

The Ni-MH battery is not quite as accommodating: the recharge cycle is **exothermic** (the battery gets slightly **warmer** during recharge) but still shows a fairly well defined increase in temperature when the battery is fully charged. Using a 10°C  $\Delta T$  detection point will give good results in most cases, and is recommended by the battery makers.

## NOTE: WARNINGS ABOUT FAST CHARGING NI-MH AND NI-CD BATTERIES

Since the Ni-MH battery normally gives off heat during recharge, the 10°C "window" may have to be adjusted to suit the characteristics of the specific cell: The window must be wide enough to prevent premature cutoff from "normal" heating, but narrow enough to detect the temperature rise which occurs at full charge (and execute charge termination).

Any new design that uses Ni-MH batteries should be carefully evaluated to verify accurate end-of-charge termination because of the potential for battery explosion if hydrogen is released.

**IMPORTANT:** With Ni-Cd or Ni-MH cells, the 1c (fast) charge rate can only be safely used if the battery temperature is in the range of about 15°C to 45°C.

At **low temperatures**, gas recombination within NiCd and NiMH batteries does not occur as easily, which limits the amount of charging current that can be safely used before venting will occur. If low-temperature (< 15°C) recharging is required, consult the battery maker for safe charging current levels.

A battery that is recharged at **elevated temperature** will retain substantially less energy than a battery recharged at 25°C. At high temperatures (> 35°C) gas generation within the cell occurs at a much lower state of charge, meaning that the cell will not accept as much charge (compared to 25°C) for a given amount of cell temperature rise.

The poor charging efficiency seen at high battery temperatures means that extremely long recharge times (at low charging currents) are required to deliver full (25°C) capacity of charge to a "hot" battery.

### **TRICKLE CHARGE CURRENT**

All batteries lose charge internally due to leakage paths through the insulators. The amount of leakage is dependent primarily on battery type and age, with leakage increasing dramatically in batteries that are aged or have completed many cycles of charge and discharge.

Trickle charging is a continuous low-level charging current that tops off the total charge in the battery, and prevents any energy loss that would occur due to leakage.

The **maximum safe trickle charging current for a typical Ni-Cd cell is about 0.1c**, this being the maximum charge rate at which all of the gas developed internally is able to recombine (so there is no internal pressure buildup that would cause venting).

**For Ni-MH batteries, the trickle charge current must be limited to a maximum value of c/20.** This is a critical difference between Ni-Cd and Ni-MH batteries.

In this design, the trickle charge current is provided by the resistor labeled R<sub>TR</sub> (see schematic). This current flows any time V<sub>IN</sub> is present, regardless of operation of the high-current charger. When the high-current charger is operating, the total charging current is the **sum** of the trickle current and the current provided by U1.

Once the input voltage V<sub>IN</sub> and the desired trickle charge current I<sub>TR</sub> are known, the value for R<sub>TR</sub> is found using Ohm's Law:

$$R_{TR} = (V_{IN} - 7 - 0.7) / I_{TR}$$

The power dissipation in R<sub>TR</sub> must also be calculated:

$$P_{DISS} (R_{TR}) = (V_{IN} - 4 - 0.7)^2 / R_{TR}$$

Note that the power dissipation in the resistor is dependent on the battery voltage. As the battery voltage increases, the voltage drop across  $R_{TR}$  decreases (causing the power dissipation to decrease).

In the above equation, a battery voltage of 4V is assumed as a worst-case minimum value for battery operating voltage (which would provide the maximum power dissipation for  $R_{TR}$ ).

A **good** 5-cell Ni-Cd or Ni-MH battery which is being trickle charged (after being fully recharged) will read about 7V, which will give much less power dissipation in  $R_{TR}$  than when the battery is discharged (and the battery voltage is below 5V).

## DETAILS OF CIRCUIT FUNCTION (REFER TO SCHEMATIC)

The 3A of charging current used by the fast-charger is obtained from an LM2576, which is a buck regulator that switches at 52kHz. Because it is a switcher, it allows the user the option of using a wider input voltage range and still retaining high power conversion efficiency (about 80% @ 3A with  $V_{IN}$  in the 10-14V range).

The LM2576 IC (U1) is used to provide a charging current that is independent of the battery voltage. Whenever the ON/OFF pin is held low, U1 will source current into the battery through D3. A current-control feedback loop is established using U5B, R12, and associated components.

R12 is used as a current shunt, and it provides a voltage to the input of U5B that is proportional to the charging current. U5B functions as an amplifier with a gain of 8.5, which causes the output of U5B to be 1.23V when the current through R12 is about 2.9A. The 1.23V signal on the feedback pin of U1 will "lock" the loop at this value of charging current.

A fast-charge current value other than 2.9A can be set by adjusting the values of R7, R9, or R12. These values (which set the overall gain of the stage) should be adjusted so that the output of U5B is 1.23V at the desired amount of fast-charge current.

## AUTOMATIC SHUTDOWN AT FULL CHARGE

The crucial part of fast charging a battery (especially if it is Ni-MH) is **knowing when to stop**. This design uses a  $\Delta T$  detector that measures **both** the battery temperature and the ambient temperature, and shuts down the fast-charge current source when the battery is +10°C **above ambient**.

This method is superior to techniques which sense only battery temperature. Single-ended temperature sensing may not accurately measure charge: a "cold" battery will have to heat up too much before the detection point is reached (overcharging it), while a "hot" battery will terminate charge long before full charge has been delivered to the battery (because its temperature starts out too near the detection level).

Two LM35 temperature sensors (U3 and U4) provide output voltages of 10mV/°C (proportional to their temperature). U3 is used to measure the ambient, while U4 measures the battery temperature.

Note: U4 must be in contact with the metal case of the battery to accurately measure its temperature. The plastic sleeve around the battery may have to be opened up to allow flush contact. Best results are obtained if the sensor is located **between two batteries** (touching both).

Monitoring more than one battery virtually eliminates the possibility that the sensor happens to be reading a bad (shorted) cell which will not heat up and provide charge termination. In some laptops, multiple sensors are used so that all battery cells are monitored, with charge termination occurring when **any** cell temperature reaches the trip level.

The 78L05 regulator (U2) is used to provide a 5V source to power the LM35 sensors and also acts as a reference point for resistive divider R2 and R3. Resistors R1 and R11 are used to sink current (since the LM35 can not).

### **CONTROLLING THE FAST-CHARGE CURRENT SOURCE**

U5C acts as a comparator which controls the on/off pin of the high-current charging source (U1). When the output of U5C is low, the 3A current source is turned on. When the output of U5C is high, U1 is turned off and LED 1 is lit which indicates that the charger has completed the high-current charge phase and is now trickle charging.

Hysteresis is built into U5C (see R13), which effectively "latches" the output of U5C high after it completes the fast-charge portion of the cycle (it stays latched until the input power is cycled on and off). Without hysteresis, the charger would again turn on the 3A charger after the fully-charged battery had cooled during trickle charging.

### **DETECTING AN END-OF-CHARGE CONDITION**

The signals that are sent to U5C are derived from the temperature sensors. They can not be compared directly, since detection must occur when the signal coming from U4 (the battery sensor) is 100mV above the signal coming from U3 (the ambient sensor).

In this design, the signal from U3 is DC level shifted up about 0.1V by U5A and its associated components. R2 and R3 set a 0.1V reference point for U5A, whose output voltage is the voltage at the output of U3 added to the 0.1V reference.

With the signal from U3 level shifted by an amount that is equal to 10°C, U5C can be used to compare the level-shifted signal from U3 to the signal from U4. When these two are equal, the temperature sensed by U4 (the battery) will be 10°C above the temperature sensed by U3 (the ambient). This is the point where shutdown of the 3A charger occurs, and trickle charging continues.