Keywords: charger, fast charger, Li-ion battery, NiMH Battery, NiMH battery charger, Li-Ion battery charger, rechargeable batteries, NiCd battery, NiCd battery charger, stand-alone charger, stand-alone fast charger, alkaline battery detect

Mar 26, 2007

APPLICATION NOTE 3999

Overview of Rechargeable Batteries and Fast Stand-Alone Chargers

Abstract: This application note provides an overview of nickel-cadmium (NiCd), nickel-metal-hydride (NiMH), and lithium-ion (Li-Ion, Li+) rechargeable batteries, discussing their characteristics and explaining how to safely fast charge NiMH and Li-Ion rechargeable batteries in a stand-alone configuration, without the use of a supervising microcontroller.

Introduction

Rechargeable batteries are the standard power source for today's products, especially for portable appliances such as notebook computers, mobile phones, and digital cameras. Even as power levels are falling, the absolute amount of power consumed by rechargeable batteries is rising. The reasons are several: an ongoing integration of functions (such as a mobile phone with a digital camera), the higher computing speed in notebook computers, and the convenience of large color displays. As a consequence of this high level of power consumption in portable devices, the use of a rechargeable battery has become more cost effective than using a standard battery. Even more important are the environmental benefits of rechargeable batteries. Using rechargeable batteries tremendously reduces the amount of hazardous materials dumped into our environment, the consumption of materials, and the energy required to produce the equivalent in nonrechargeable batteries.

This application note provides an overview of rechargeable battery chemistries; it details their typical characteristics and important considerations for selecting a battery type. The article then describes how to safely fast charge NiMH and Li-Ion rechargeable batteries in a stand-alone configuration, without using a microcontroller or a power-surge-protected mains adapter.

Rechargeable Battery Types

Portable appliances in the mid-1980s—such as DECT phones, cassette players, and electric shavers—were powered mainly by nickel-cadmium (NiCd) rechargeable batteries. Nickel-metal-hydride (NiMH) and lithium-ion (Li-Ion) rechargeable batteries came later, appearing on the mass market toward the end of the nineties.

NiCd batteries were especially popular in low-cost applications because they were cheaper than NiMH and Li-Ion batteries. Because NiCd's provide the highest level of discharge current, they were also used in applications that required high levels of power for short periods of time.

On the other hand, NiCd batteries once suffered from the so-called memory effect (modern NiCd's seldom do), which reduces battery capacity. If such a NiCd battery is recharged before being fully discharged, some active material (as much as 100µm on the anode's cadmium side) remains unused and begins to crystallize, thereby removing itself from the chemical action. (Cadmium crystals at the anode of a fresh battery are approximately one micrometer thick.)

The resulting memory effect yields a battery with lower capacity and a lower terminal voltage, causing the NiCd battery to reach the minimum usable terminal voltage (shutoff point) sooner than desired (**Figure 1**). Another disadvantage of NiCd batteries is the poisonous cadmium (Cd) in its active material. These early types of NiCd batteries turned out to be an ecological as well as an economical burden when disposing of defective batteries. As a consequence, European Regulation 2000/53/EG forbids the sale of NiCd rechargeable batteries, effective December 31, 2005.

NiMH batteries are more environmentally friendly than NiCd's, but they also cost more. Their discharge currents are lower, but they suffer from the lazy effect, which is a weaker version of the memory effect in NiCd batteries. The lazy effect results from the crystallization of a portion of the nickel. Like the memory effect, the lazy effect prevents full use of the capacity in a rechargeable battery; both effects, however, can be avoided by using chargers with a discharge function.

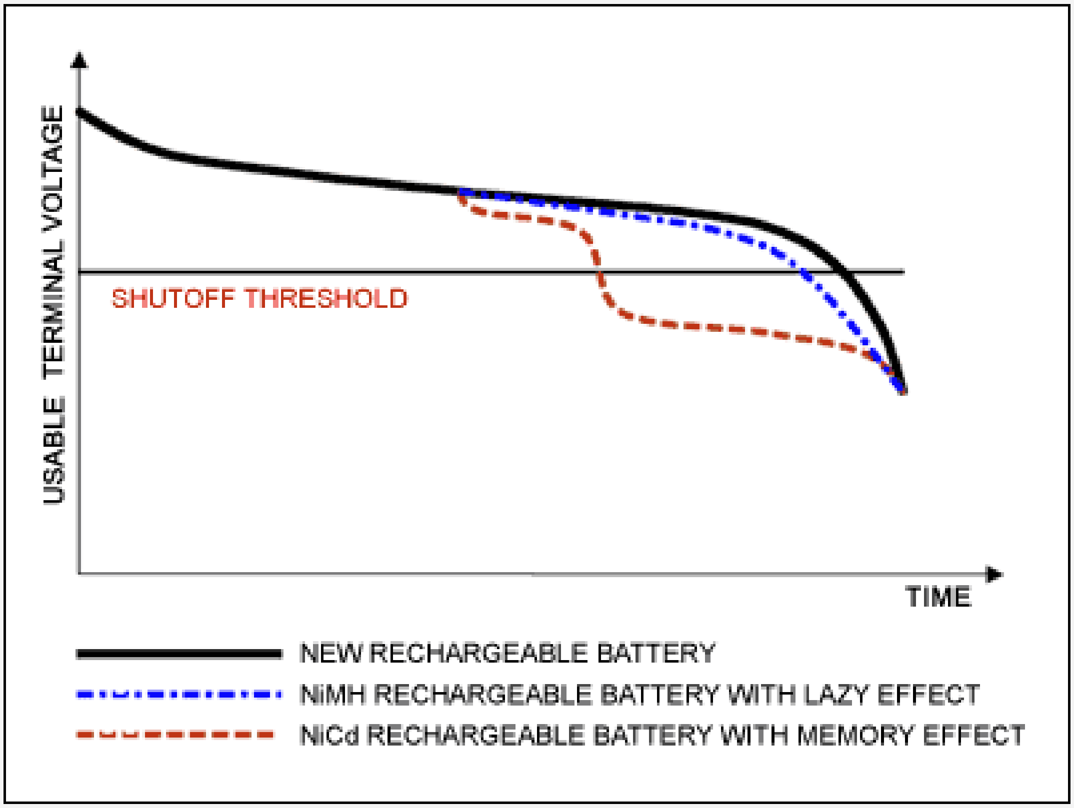

Figure 1. Comparison of the memory effect in NiCd's and the lazy effect in NiMH's.

Li-Ion rechargeable batteries are more expensive, but they have a substantially higher energy density and can, therefore, deliver more performance for a given size. In turn, this capability makes them suitable for small, highly portable appliances.

Table 1 provides an overview of the key characteristics of each battery type.

Table 1. Overview of Rechargeable Battery Types

	NiCd	NiMH	Li-Ion
Energy Density	Average	Average	High
Memory Effect or Lazy Effect	Memory effect	Lazy effect	No
Costs	Cheap	Average	Expensive
Self-Discharge, % per Month*	~ 25	~ 25	~ 8
Maximum Discharge Current	> 5C	< 3C	< 2C

* at room temperature
C = battery capacity

Stand-Alone Fast Chargers for NiMH Rechargeable Batteries

Even for those who prefer Li-Ion batteries, NiMH batteries are popular because they are substantially cheaper than Li-Ion batteries, and they are available in the standard AA and AAA sizes often found in equipment such as MP3 players, flash attachments, and cycle lamps.

The temperature and terminal voltage of a NiMH rechargeable battery rise steadily as the battery charges, then change abruptly after the battery is fully charged (**Figure 2**). The main task of an NiMH charger, therefore, is to recognize this inflection point and interrupt the charging, or it can switch from fast charging to trickle charging. In addition, a constant, independent (secondary) monitoring of temperature and voltage enhances safety during the charging process.

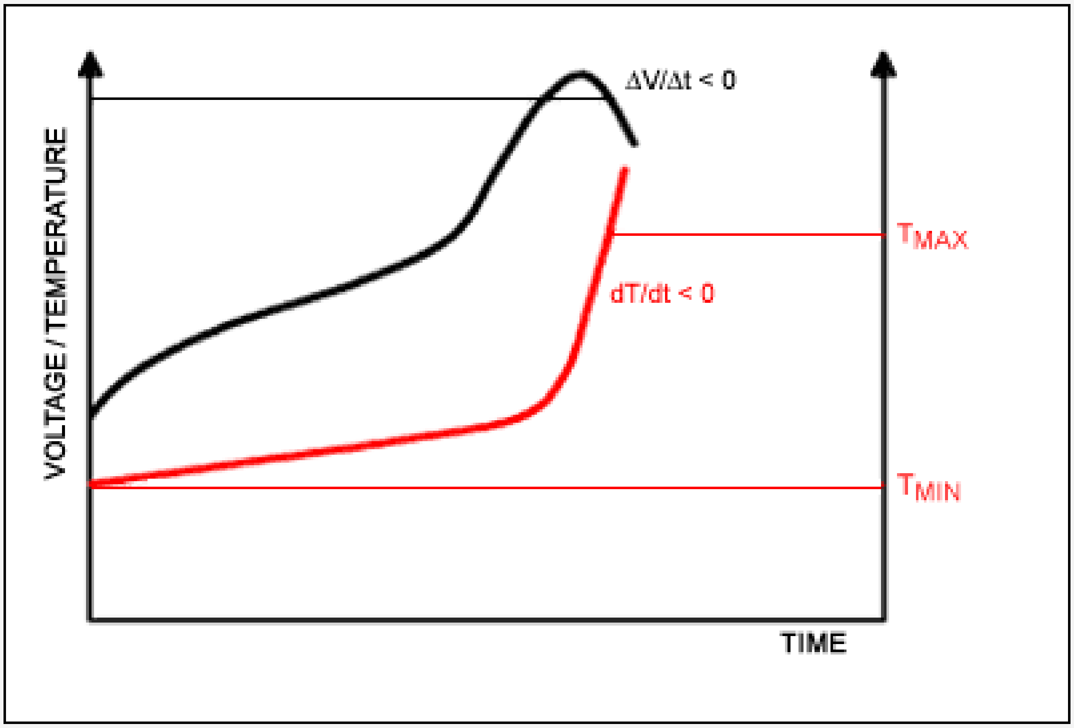

Figure 2. These curves show the typical time variations of voltage (top) and temperature (bottom) while charging a NiMH rechargeable battery.

Chargers in the DS2711/DS2712 family have these functions. In addition, they work independently and therefore do not need the oversight of a microcontroller or microprocessor. They are designed to charge a single standard AA or AAA rechargeable battery, or a pair of batteries in serial or parallel configuration. The DS2711 operates as a linear controller, and the DS2712 as a switching controller. To maximize their operating life and spare the batteries, these chargers have four charging modes: precharge, fast charge, top-off charge, and maintenance (trickle) charge. In top-off mode, for instance, the charging rate is switched to a lower rate (to 25% for the DS2711) soon after the battery is fully charged.

In addition to the monitoring functions already mentioned, the DS2711/DS2712 chargers have an internal timer that lets you set the maximum charging time (0.5 to 10 hours in fast-charge mode, for example) by connecting an external resistor to the TMR pin. The top-off charging time (0.25 to 5 hours) is then half the length of the maximum charging time already set. The resistor value in terms of the approximate desired charging time (T_{APPROX}) is

$$R = 1000T_{APPROX}/1.5 \quad \text{(Eq. 1)}$$

If the maximum charge time is exceeded in fast-charge mode, the charger switches from fast charge to top-off charge and resets the timer. The timer then counts down the top-off charge time. If that is exceeded, the charger switches from top-off mode to maintenance (trickle-charge) mode (**Figure 3**).

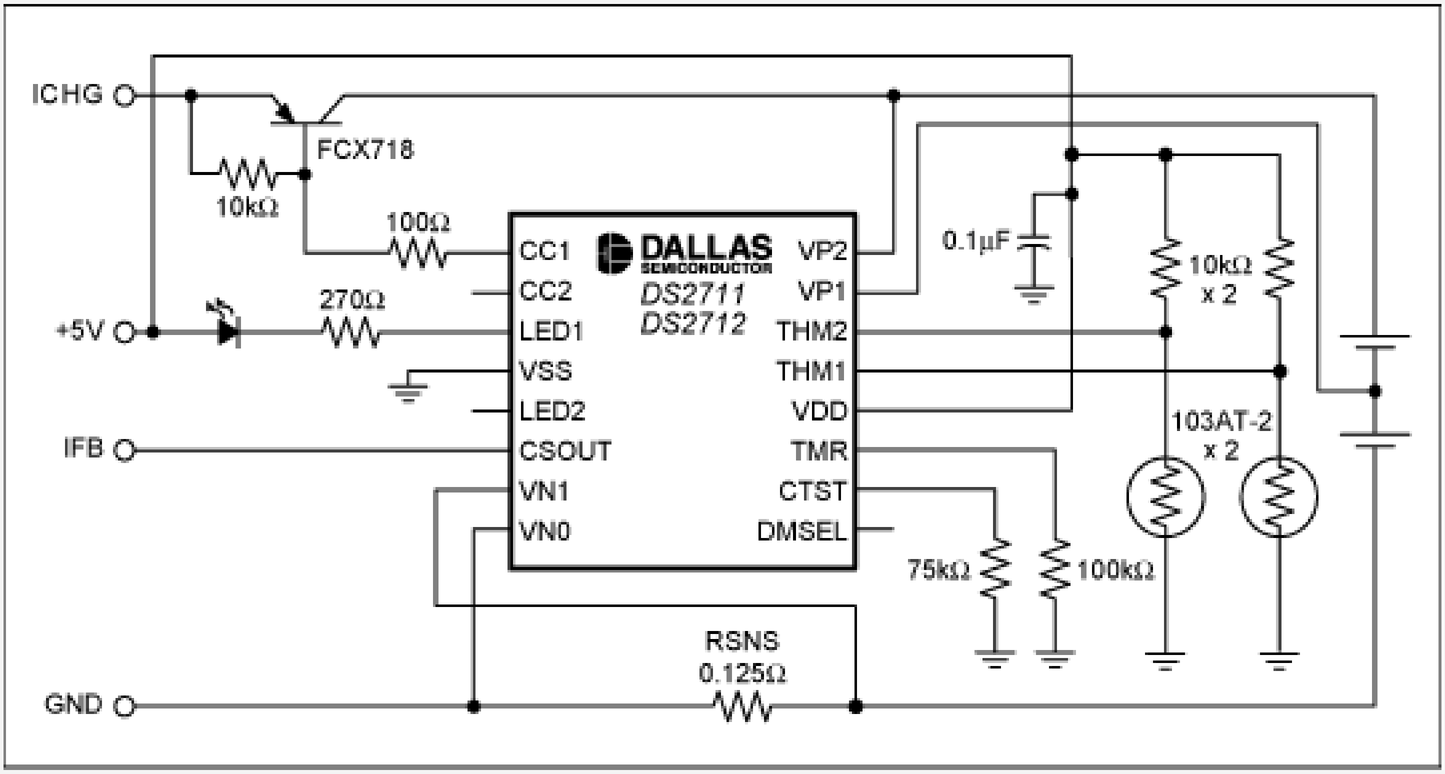

Figure 3. In this standard application circuit, a DS2711 battery-charger IC charges two NiMH rechargeable batteries in series.

Connectors VP1 and VP2 monitor the voltage; and THM1 and THM2 (with the help of thermistors) monitor the charging temperature of each rechargeable battery. Terminals TMR (timer) and R_{SNS} (sensor resistor) are used in setting the charging time and the charging current. One other feature of the DS2711/DS2712 chargers detects whether the battery to be charged is faulty, or whether you have accidentally installed primary alkaline instead of rechargeable battery types in the charger. If so, the charger shuts down. This is an important feature because the charging of an alkaline battery can result in battery leakage, producing hazardous fluids and/or gases. The gases are toxic, and the fluids react with the surroundings, often damaging circuitry and/or equipment enclosures.

How Are Alkaline Batteries Detected?

The typical internal resistance for new high-capacity NiMH rechargeable AA batteries is between 30mΩ and 100mΩ, and for an alkaline battery it is usually between 200mΩ and 300mΩ (but as high as 700mΩ, depending on its charge status). Faulty rechargeable batteries have a much higher internal resistance. The DS2711/DS2712 chargers therefore calculate the internal resistance of batteries to be charged, using the measured battery voltages (VP1 and VP2) and the charging current that has been set.

The CTST pin (for cell test, set threshold) controls measurement of cell impedance. V_{CTST} is the difference between the cell voltage during charge minus the open-circuit voltage (OCV) of the cell with no charge current. This value is equal to the product of the charge current multiplied by the cell impedance. Unless the sensing pins (VP1, VP2, and VN1) are Kelvin connected to the battery, the contact resistance is also measured and must be accounted for when setting V_{CTST}. The formula for calculating the value for the external resistor R_{CTST} is:

$R_{CTST} = 8000\ [V^2/A]/V_{CTST}$, where $V_{CTST} = I_{Charge} \times R_{CELL}$ (Eq. 2)

For instance, when charging a 2200mAh NiMH cell at a C/2 rate (1.1A) and choosing R_{CELL} = 150mΩ as the cell rejection-resistance threshold, V_{CTST} will be:

$V_{CTEST} = I_{CHARGE} \times R_{CELL} = 1.1A \times 150m\Omega = 0.165V$

Or:

R_{CTST} = 8000 [V²/A]/0.165V = 48,485Ω
(The nearest standard 1% value is 48.7kΩ)

If the V_{CTST} level (in this case > 0.165V) is exceeded, indicating the internal battery resistance plus contact resistance is higher than 150mΩ the IC asserts a logical or optical error message (LED1, LED2) and stops the charging procedure (**Figure 4**).

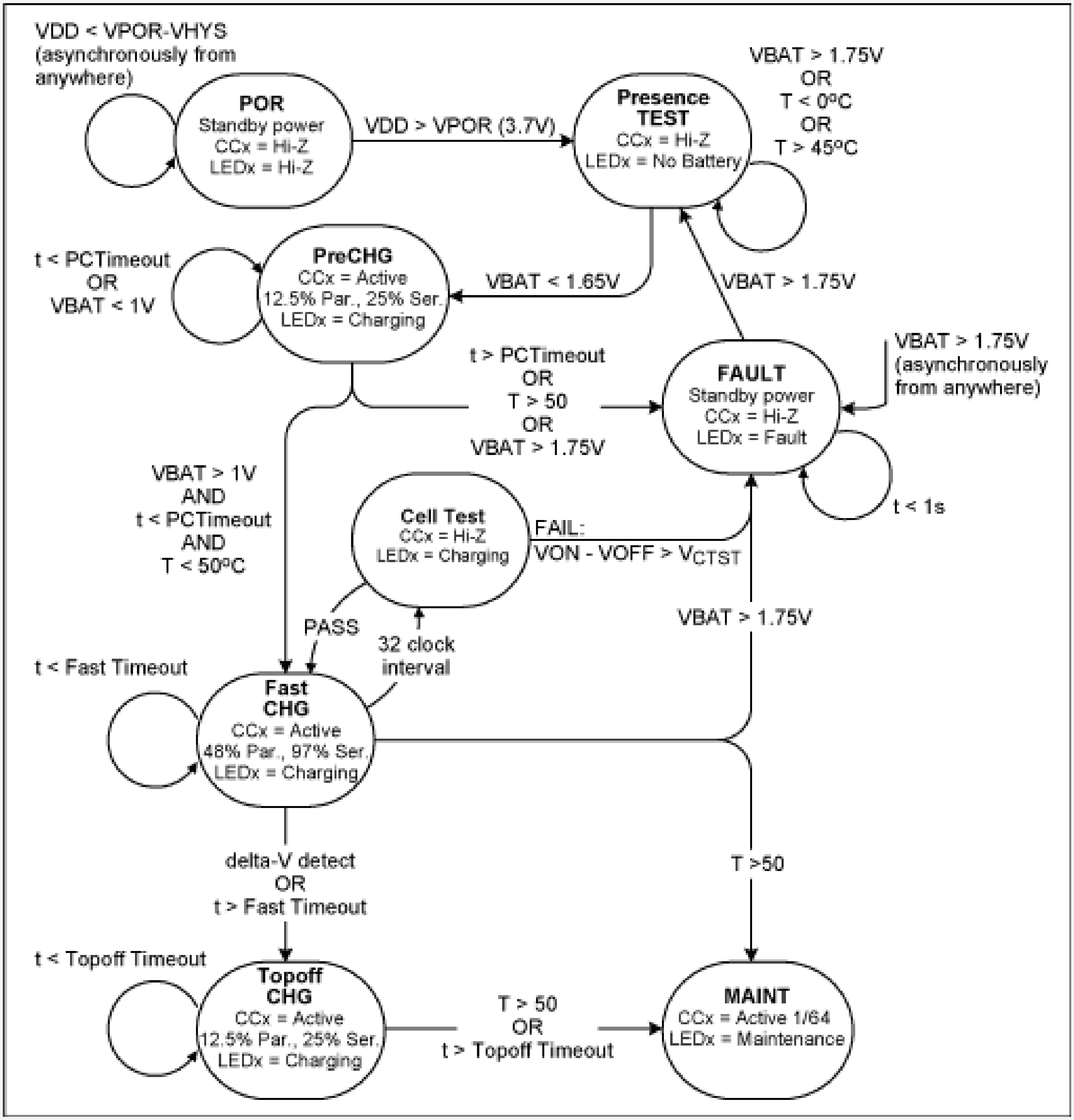

Figure 4. This flow diagram illustrates the charging procedure implemented by the IC in Figure 3.

Stand-Alone Fast Charger for Li-Ion Rechargeable Batteries

Charging Li-Ion rechargeable batteries is simpler than charging NiMH batteries because it is not necessary to monitor the rate of voltage change (dV/dt). Additionally, because Li-Ion rechargeable batteries react sensitively to excess voltage, the charging process requires a precise power source of 4.2V ± 50mV, with constant charging current. For NiMH batteries, the charger should have secondary monitoring functions (temperature, timer) as well as the primary voltage-monitoring function.

The MAX8601, a stand-alone charger for Li-Ion rechargeable batteries, has an internally controlled voltage source called V_{BATT}, which measures 4.2V ± 0.021V at +25°C, or 4.2V ± 0.034V over the range 40°C < T < 85°C. The charger can maintain constant output current while charging a Li-Ion battery through the V_{BATT} connection (**Figure 5**). An external resistor (on the SETI pin) and an external capacitor (on the CT pin) set the charging current and internal timer. The charger also uses an NTC resistor to monitor the temperature of the rechargeable battery.

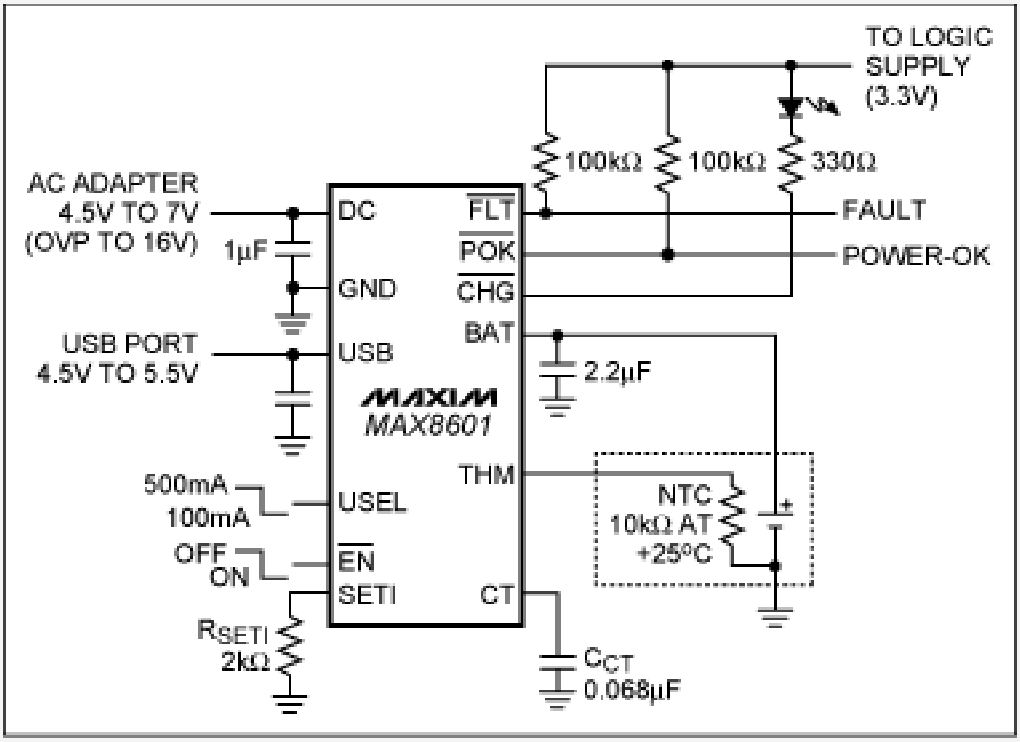

Figure 5. Standard application circuit for the MAX8601 stand-alone charger for Li-Ion batteries.

A main advantage of the MAX8601 charger is its ability to charge the battery through an external mains adapter (DC pin) or a USB port (**Figure 6**). The USB port gives a charging current of 100mA or 500mA (typical USB output current), depending on the setting of the USEL pin. The chip automatically selects the external source (mains adapter or USB), and if both sources are available it charges the battery through the mains adapter. Either source must have a minimum voltage of 4.5V. The ability to charge through a USB port saves the cost of an external power brick. Power bricks are often bulky and energy inefficient.

The MAX8601 optimizes charging for Li-Ion cells by using a control algorithm that includes low-battery precharging, voltage- and current-limited fast-charging, and top-off charging. It also features power-on reset, and it continuously monitors the battery for overvoltage, over/undertemperature, and charging time. An overvoltage, overtemperature, or undertemperature condition while charging can permanently damage a rechargeable battery, resulting in reduced battery capacity and life, and even a dead battery. Worst-case conditions can cause leakage or bursting of the battery case. The MAX8601 ensures that no damage occurs while charging, thus maximizing battery life and eliminating potential hazardous conditions.

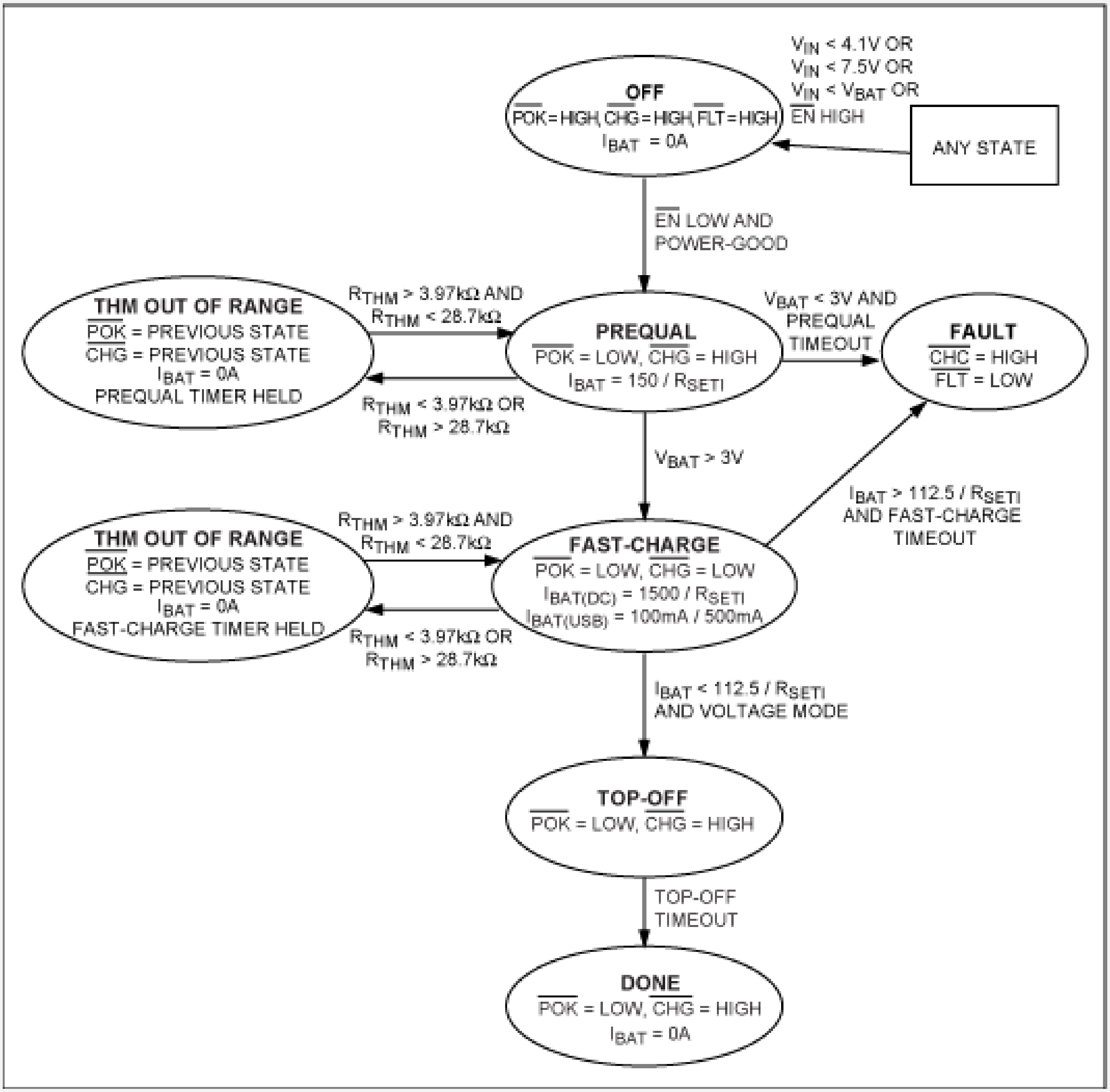

Figure 6. This flow diagram illustrates the charging procedure implemented by the IC in Figure 5.

Summary

The DS2711/DS2712 and MAX8601 are stand-alone chargers whose multiple monitoring functions (voltage, power, temperature, and timer) require neither a microcontroller nor a power-surge-protected mains adapter. Both devices provide clear and simple external switching.

General Questions and Answers

1. Can you charge NiCd batteries with a NiMH battery charger?
   Answer: With only moderate success, because rechargeable batteries have different shutoff characteristics. NiCd batteries should be shutoff when $dV/dt = 0$, and NiMH batteries should be shutoff when $dV/dt < 0$.

2. Can you install rechargeable batteries of different capacities, or install a mixture of old and new batteries in an appliance?
   Answer: That can be done but is not recommended because the appliance's performance is determined by the weakest battery.

3. When should rechargeable batteries not be used?
   Answer: Do not use them in applications such as remote controls and smoke alarms, for which the power requirement is low and the appliance is not in constant use. Rechargeable batteries tend to have a higher rate of self-discharge than ordinary batteries. NiMH batteries, for example, lose 1% of their capacity every day. Their operating time is therefore substantially less.

4. Can I charge a nonrechargeable battery, like an alkaline battery?
   Answer: Do not charge alkaline batteries. Their chemistry and construct is not compatible for charging. The energy forced into an alkaline battery generates heat, and as internal temperatures rise, the case of the battery typically begins to leak and can sometimes burst. The material inside is toxic and harmful for most all environments.

5. Why is it important to monitor the temperature of a rechargeable battery?
   Answer: Even though a rechargeable battery's chemistry and construct are compatible for charging, there are limits to the amount of energy and the rate of that energy that the battery can handle. Too much energy too fast increases internal temperatures, and, as in the alkaline battery, the battery case can develop a leak or even burst. Once a rechargeable battery is fully charged, any additional charge forced into the battery creates heat. If the temperature is not monitored and the charge rate reduced or stopped accordingly, the same environmentally harmful results may occur. This is why the DS2711/DS2712/MAX8601 monitor so many parameters while charging. They ensure the longest battery life and the safest charging conditions possible.

Additional Resources
Maxim Integrated Products
VARTA
Duracell®
Battery University
Stiftung Gemeinsames und Rücknahmesystem Batterien [German common collection system for spent batteries]

A similar article appeared in the March 2006 issue of *Design and Elektronik*.

Application note 3999: www.maxim-ic.com/an3999

Related Parts

DS2711: QuickView -- Full (PDF) Data Sheet -- Free Samples

DS2712: QuickView -- Full (PDF) Data Sheet -- Free Samples

MAX8601: QuickView -- Full (PDF) Data Sheet -- Free Samples

AN3999, AN 3999, APP3999, Appnote3999, Appnote 3999