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BATTERY CHARGING

Introduction

The circuitry to recharge the batteries in a portable product is an important part of any power supply design. The complexity (and cost) of the charging system is primarily dependent on the type of battery and the recharge time.

This chapter will present charging methods, end-of-charge-detection techniques, and charger circuits for use with Nickel-Cadmium (Ni-Cd), Nickel Metal-Hydride (Ni-MH), and Lithium-Ion (Li-Ion) batteries.

Because the Ni-Cd and Ni-MH cells are similar in their charging characteristics, they will be presented in a combined format, and the Li-Ion information will follow.

NI-CD/NI-MH CHARGING INFORMATION

In the realm of battery charging, charging methods are usually separated into two general categories: Fast charge is typically a system that can recharge a battery in about one or two hours, while slow charge usually refers to an overnight recharge (or longer).

Slow Charge

Slow charge is usually defined as a charging current that can be applied to the battery indefinitely without damaging the cell (this method is sometimes referred to as a trickle charging).

The maximum rate of trickle charging which is safe for a given cell type is dependent on both the battery chemistry and cell construction. When the cell is fully charged, continued charging causes gas to form within the cell. All of the gas formed must be able to recombine internally, or pressure will build up within the cell eventually leading to gas release through opening of the internal vent (which reduces the life of the cell).

This means that the maximum safe trickle charge rate is dependent on battery chemistry, but also on the construction of the internal electrodes. This has been improved in newer cells, allowing higher rates of trickle charging.

The big advantage of slow charging is that (by definition) it is the charge rate that requires no end-of-charge detection circuitry, since it can not damage the battery regardless of how long it is used. This means the charger is simple (and very cheap).

The big disadvantage of slow charge is that it takes a long time to recharge the battery, which is a negative marketing feature for a consumer product.

Slow Charge Rates

NI-CD: most Ni-Cd cells will easily tolerate a sustained charging current of c/10 (1/10 of the cell's A-hr rating) indefinitely with no damage to the cell. At this rate, a typical recharge time would be about 12 hours.

Some high-rate Ni-Cd cells (which are optimized for very fast charging) can tolerate continuous trickle charge currents as high as c/3. Applying c/3 would allow fully charging the battery in about 4 hours.

The ability to easily charge a Ni-Cd battery in less than 6 hours without any end-of-charge detection method is the primary reason they dominate cheap consumer products (such as toys, flashlights, soldering irons).

A trickle charge circuit can be made using a cheap wall cube as the DC source, and a single power resistor to limit the current.

NI-MH: Ni-MH cells are not as tolerant of sustained charging: the maximum safe trickle charge rate will be specified by the manufacturer, and will probably be somewhere between c/40 and c/10.

If continuous charging is to be used with Ni-MH (without end-of-charge termination), care must be taken not to exceed the maximum specified trickle charge rate.

Fast Charge

Fast charge for Ni-Cd and Ni-MH is usually defined as a 1 hour recharge time, which corresponds to a charge rate of about 1.2c. The vast majority of applications where Ni-Cd and Ni-MH are used do not exceed this rate of charge.

It is important to note that fast charging can only be done safely if the cell temperature is within 10-40°C, and 25°C is typically considered optimal for charging. Fast charging at lower temperatures (10-20°C) must be done very carefully, as the pressure within a cold cell will rise more quickly during charging, which can cause the cell to release gas through the cell's internal pressure vent (which shortens the life of the battery).

The chemical reactions occurring within the Ni-Cd and Ni-MH battery during charge are quite different:

The Ni-Cd charge reaction is endothermic (meaning it makes the cell get cooler), while the Ni-MH charge reaction is exothermic (it makes the cell heat up). The importance of this difference is that it is possible to safely force very high rates of charging current into a Ni-Cd cell, as long as it is not overcharged.

The factor which limits the maximum safe charging current for Ni-Cd is the internal impedance of the cell, as this causes power to be dissipated by $P = I^2R$. The internal impedance is usually quite low for Ni-Cd, hence high charge rates are possible.

There are some high-rate Ni-Cd cells which are optimized for very fast charging, and can tolerate charge rates of up to 5c (allowing a fast-charge time of about 15 minutes). The products that presently use these ultra-fast charge schemes are cordless tools, where a 1 hour recharge time is too long to be practical.

The exothermic nature of the Ni-MH charge reaction limits the maximum charging current that can safely be used, as the cell temperature rise must be limited.

At present, there are no makers of Ni-MH batteries that recommend charging rates faster than 1.2c (and the chances of that changing are not very good).

Fast Charge: Possible Cell Damage

Caution: Both Ni-Cd and Ni-MH batteries present a user hazard if they are fast charged for an excessive length of time (subjected to abusive overcharge).

When the battery reaches full charge, the energy being supplied to the battery is no longer being consumed in the charge reaction, and must be dissipated as heat within the cell. This results in a very sharp increase in both cell temperature and internal pressure if high current charging is continued.

The cell contains a pressure-activated vent which should open if the pressure gets too great, allowing the release of gas (this is detrimental to the cell, as the gas that is lost can never be replaced). In the case of Ni-Cd, the gas released is oxygen. For Ni-MH cells, the gas released will be hydrogen, which will burn violently if ignited.

A severely overcharged cell can explode if the vent fails to open (due to deterioration with age or corrosion from chemical leakage). For this reason, batteries should never be overcharged until venting occurs.

In later sections, information is presented which will enable the designer to detect full charge and terminate the high-current charge cycle so that abusive overcharge will not occur.

Fast Charge Current Source

Both Ni-Cd and Ni-MH are charged from a constant current source charger, whose current specification depends on the A-hr rating of the cell.

For example, a typical battery for a full-size camcorder would be a 12V/2.2A-hr Ni-Cd battery pack. A recharge time of 1 hour requires a charge current of about 1.2c, which is 2.6A for this battery.

A cost-effective method to design a current source for this application would be to use an AC-DC wall cube to provide a DC voltage to a switching converter that is set up to operate as a constant-current source.
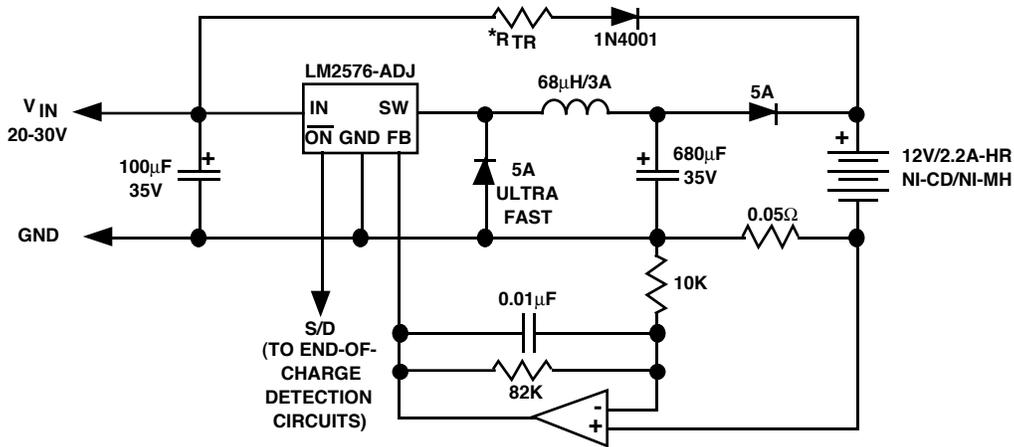
Figure 1 shows a schematic diagram of a circuit which will fast-charge a 12V Ni-Cd or Ni-MH battery at 2.6A and trickle charge it when the converter is shut off.

Note that the circuit must have a shutdown pin so that the end-of-charge detection circuit(s) can terminate the fast charge cycle when the battery is full (the LM2576 has a low-power shutdown pin built in).

A temperature sensing end-of-charge detection circuit suitable for use with this charger will be detailed later in this paper.

The LM2576 is a buck (step-down) switching regulator, used as a constant-current source set to 2.6A. It provides good power conversion efficiency (about 80%) and operates from a wide input voltage range.

A constant-current feedback loop is established by holding the voltage at the Feedback pin of the LM2576 at 1.23V.

$$R_{TR} = \frac{(V_{IN} - 15)}{I_{TR}}$$

FIGURE 1. 2.6A NI-CD/NI-MH CHARGER

The op-amp amplifies the voltage drop across the 50 mΩ sense resistor (with a gain of 9.2) which locks the loop at the value of charging current that causes the output of the op-amp to be 1.23V.

The resistor R_{TR} is included to provide a "trickle charge" current when the LM2576 is turned off. Current flows through this resistor any time the input voltage is present. The value of this resistor must be calculated based on the maximum allowable trickle charge current for the battery selected (equation shown in Figure 1).

The total charging current during fast charge is the sum of the current coming from the LM2576 (about 2.6A) and the trickle charge current provided by resistor R_{TR}.

The following section details end-of-charge detection information and provides a circuit example in Figure 3 which can be connected directly to the circuit shown in Figure 1 and provide end-of-charge shutdown.

End-of-Charge Detection for Ni-Cd/Ni-MH

Both Ni-Cd and Ni-MH batteries can be fast charged safely only if they are not over-charged.

By measuring battery voltage and/or temperature, it is possible to determine when the battery is fully charged.

Most high-performance charging systems employ at least two detection schemes to terminate fast-charge: voltage or temperature is typically the primary method, with a timer as the back-up in case the primary method fails to correctly detect the full charge point.
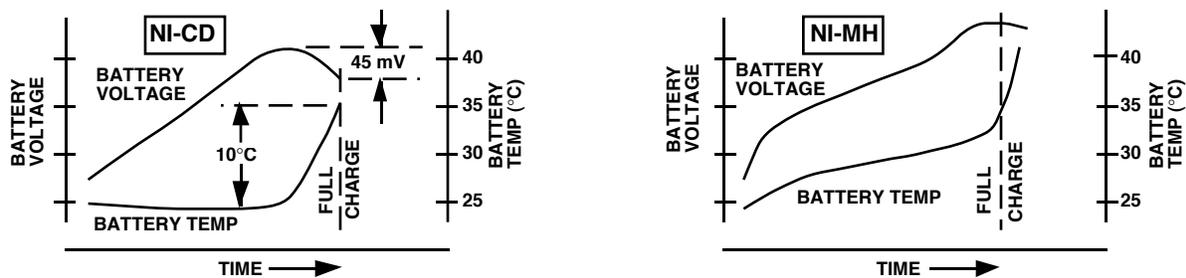
FIGURE 2. V/T PLOTS FOR 1C CHARGE RATE

The voltage/temperature plots in Figure 2 define the battery "signature" that shows when full charge has been reached (both Ni-Cd and Ni-MH are shown for comparison).

For both plots, the data was taken on a single cell that was charged from a constant current source at a rate of 1c, and the ambient temperature was 25°C.

As shown, the full charge point can be determined by sensing the cell temperature or cell voltage.

Temperature sensing is preferable to voltage sensing because the cell temperature gives the most accurate information about what is happening within the cell. However, if the cell temperature is to be accurately measured, the temperature sensor must be built into the battery pack which increases the manufactured cost of the battery.

Voltage sensing is easier, because the voltage leads are easily accessible and require no special assembly in the battery pack.

Temperature Detection Methods

The Ni-Cd cell shows no significant temperature increase until nearing full charge, as the internal charge reaction is endothermic (the Ni-Cd cell actually gets slightly cooler during the charging process).

As full charge is reached, the amount of energy used in the endothermic charge reaction decreases and the amount dissipated in heat increases (making the cell get hot).

The temperature in the Ni-MH cell increases all during the charge process, as its charge reaction is exothermic. However, as full charge is reached, the rate of temperature rise increases very sharply.

It can be seen that the cells have one important characteristic in common: both show a cell temperature rise of about 10°C above ambient when the cell is fully charged (assuming a 1c charge rate).

A circuit which can cut off the high current charge at this 10°C rise point can be used with either battery type: this circuit is called a ΔT detector.
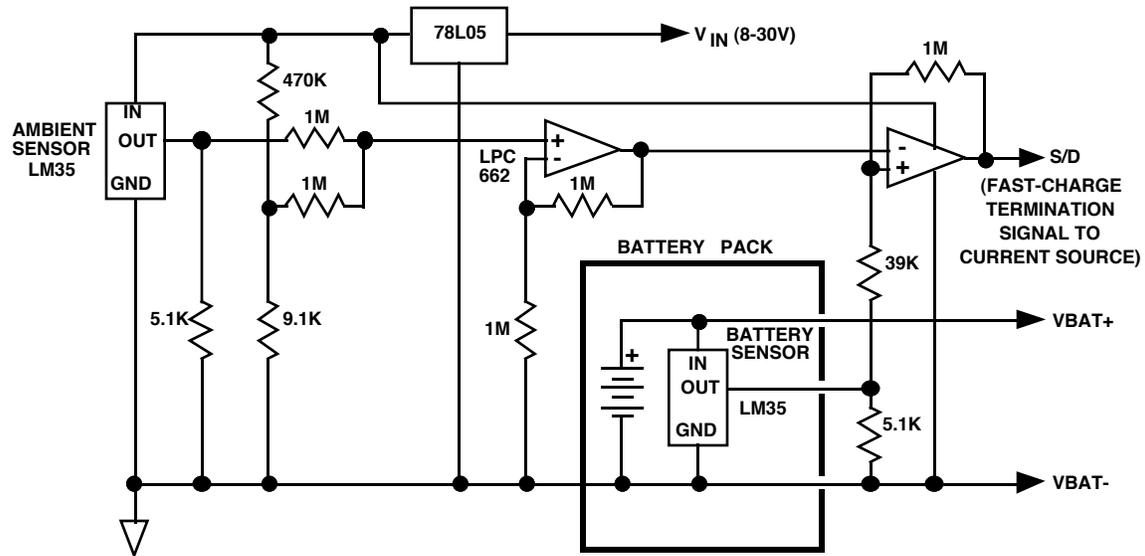
FIGURE 3. ΔT DETECTOR CIRCUIT

ΔT DETECTOR

Figure 3 shows a schematic diagram of a circuit which measures both the ambient temperature and the battery temperature and produces a high signal when the cell temperature is 10°C above ambient.

The signal coming from the ambient sensor (10 mV/°C) is level shifted up 100 mV by a unity-gain buffer stage (the 100 mV shift corresponds to 10°C).

The signal from the battery sensor is compared to the level-shifted ambient signal by the second amplifier, which is connected as a comparator.

When the two signals are equal, the battery temperature is 10°C above ambient, and a high signal is provided on the S/D line which can be used to shut off the high current charger shown in Figure 1.

TEMPERATURE SLOPE DETECTION

During fast charge, the temperature of both Ni-Cd and Ni-MH cells starts increasing very rapidly when full charge is reached (see Figure 2).

A circuit which measures the rate-of-change (slope) of the cell temperature can be used for end-of-charge detection with both Ni-Cd and Ni-MH batteries. This type of circuit is referred to as a ΔT/Δt detector, because it measures the change in battery temperature with respect to time.

Temperature slope detection is typically used in μP-based systems: temperature readings are taken at timed intervals, and stored in memory. The present temperature reading is compared to the previous value, and the difference (which is the temperature increase) during that time period is calculated.

Once the temperature change over a timed interval is known, the rate-of-change (slope) of the cell temperature is calculated and compared to a target value. When the target is reached, the fast charge is terminated (because the battery is fully charged).

Unlike the ΔT detector shown in the previous section, it is not necessary to measure the ambient temperature in a $\Delta T/\Delta t$ system, because only the cell temperature is required.

Voltage Detection Methods

The voltage of a Ni-Cd and Ni-MH cell during fast charge can be used to determine when it is fully charged (see Figure 2): not by the magnitude of the voltage, but by the amount (or rate) of voltage change.

The two techniques that will be discussed in this paper are $-\Delta V$ and Slope Detection.

$-\Delta V$ Detection

A definitive signal that a Ni-Cd cell is fully charged can be seen when the cell voltage begins to dip (see Figure 2). This drop in battery voltage is used to terminate fast charge in a $-\Delta V$ Detector, which continuously monitors the battery voltage and shuts off the charger when the voltage drops by a pre-set amount.

The voltage of the Ni-Cd cell used to generate the data in Figure 2 dropped 45 mV when the cell temperature was $10°C$ above ambient (a $10°C$ rise is typically used as the full charge cutoff for a Ni-Cd cell that is charged at 1c). Battery makers typically recommend a $-\Delta V$ detection threshold of 10-20 mV/cell in charging systems that are dedicated to Ni-Cd only.

The Ni-MH cell also exhibits a dip in voltage, but it is much smaller (typically a few mV). This means that detecting the drop in Ni-MH requires circuitry that is about one order of magnitude more accurate (and noise immune) than is needed for Ni-Cd.

It follows that a detector which is accurate enough to detect $-\Delta V$ in Ni-MH can always be used with Ni-Cd, but the reverse is not true.

Some relief is provided by the fact that the voltage dips in a multi-cell (series-connected) pack tend to be additive if the cells are well matched, which increases the signal that the $-\Delta V$ detector circuit will see.

Voltage Slope Detection

A μP-based system that can measure, store and compare battery voltage readings taken at timed intervals can accurately detect end-of-charge by using a method called voltage slope detection.

This method of charge termination can be used with either Ni-Cd and Ni-MH, as long as the system accuracy, resolution, and noise immunity are adequate for the job.

A μP-based system can use digital signal processing to attain higher levels of performance than is possible using strictly analog circuits.

For example, improved noise margin and accuracy can be obtained by using a time-averaging technique, where multiple readings are taken in a narrow time interval and then averaged to get the data value to be stored for comparison. This greatly reduces the probability of a noise "hit" giving a false reading, thereby improving the noise figure of the overall system.

If voltage slope detection is to be used with Ni-MH or Ni-Cd batteries, any one of three methods is typically used (refer to Figure 2):

Decreasing Positive Slope: This termination method looks for the part of the voltage curve where it is rising more slowly, but still has positive slope. This point on the curve is just prior to the voltage peak.

$0\Delta V$: In this case, fast-charge is terminated at the point on the voltage curve with zero slope, which is the peak of the curve. The detector system would identify zero slope when two successive voltage readings were the same over a timed interval.

$-\Delta V$: The part of the curve which has negative slope (just past the peak of the curve) is denoted by successive voltage readings that reduce in value.

3A Battery Charger with Logic-level Controls

The current source that charges a battery must often be integrated into a μP-based system that controls the charging current applied to the battery.

Also, it is often desirable to have more than one charging current available to accommodate different size batteries.
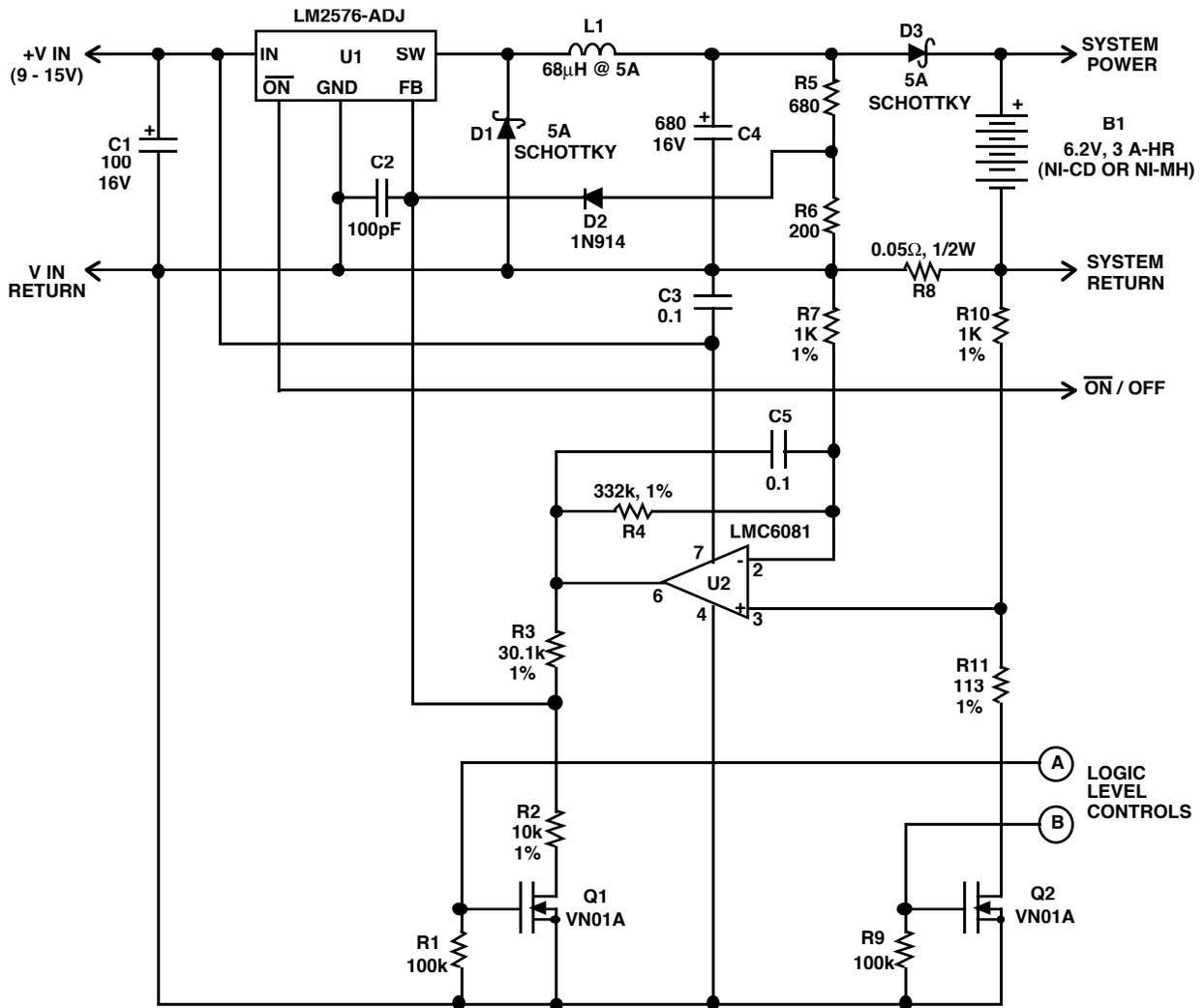
An example of how a 3A charger can be implemented with four selectable charging rates is shown in Figure 4.

General Description

The circuit shown in Figure 4 is a 3A (maximum) battery charger that uses a 52kHz switching converter to step down the input DC voltage and regulate the charging current flowing into the battery. The switching regulator maintains good efficiency over a wide input voltage range, which allows the use of a cheap, poorly regulated "DC wall adaptor" for the input source.

The key feature of this circuit is that it allows the μP controller inside the PC to select from one of four different charging currents by changing the logic levels at two bits. The various charge levels are necessary to accommodate both Ni-Cd and Ni-MH type batteries, as they require slightly different charge methods.

Both Ni-Cd and Ni-MH batteries can be charged at the high-current "c" rate up until the end-of-charge limit is reached, but the two batteries must be trickle-charged at different rates. The recommended trickle-charge rate for a Ni-Cd is typically c/10, but for Ni-MH, most manufacturers recommend that the trickle charge rate not exceed c/40.

LM2576-ADJ

+V IN (9 - 15V)

U1 — IN, ON, GND, SW, FB

L1 68µH @ 5A

D3 5A SCHOTTKY

SYSTEM POWER

C1 100 16V

C2 100pF

D1 5A SCHOTTKY

D2 1N914

C4 680 16V

R5 680

R6 200

B1 6.2V, 3 A-HR (NI-CD OR NI-MH)

V IN RETURN

C3 0.1

0.05Ω, 1/2W R8

R7 1K 1%

R10 1K 1%

SYSTEM RETURN

$\overline{ON}$ / OFF

C5 0.1

332k, 1% R4

LMC6081 U2

R3 30.1k 1%

R11 113 1%

A — LOGIC LEVEL CONTROLS

B

R2 10k 1%

Q1 VN01A

R1 100k

R9 100k

Q2 VN01A

NOTES (UNLESS OTHERWISE SPECIFIED):
1) ALL RESISTORS ARE IN OHMS, 5% TOLERANCE, 1/4W
2) ALL CAPACITORS ARE IN µF
3) Q1 AND Q2 ARE MADE BY SUPERTEX
4) FOR 3A CURRENT, U1 REQUIRES SMALL HEATSINK (RTH ≤15°C/W)

BENCH TEST DATA:

LOGIC INPUT "A"	LOGIC INPUT "B"	NOMINAL BATTERY CHARGING CURRENT (A)	MEASURED BATTERY CHARGING CURRENT (A) WITH V IN = 10V	POWER CONVERSION EFFICIENCY (%) WITH V IN = 10V
1	1	3.0 (C RATE)	3.06	77
0	1	0.75 (C/4 RATE)	0.78	79
1	0	0.30 (C/10 RATE)	0.30	
0	0	0.075 (C/40 RATE)	0.077	

FIGURE 4. 3A CHARGER WITH LOGIC-LEVEL CONTROLS

The primary objectives of the design was to charge a 3A-hr Ni-Cd or Ni-MH battery with high efficiency, using logic-level signals to control the charging current.

The four selectable charge rates are 3A, 0.75A, 0.3A, and 0.075A which correspond to charge rates of c, c/4, c/10, and c/40 for the 3A-hr battery used in this application.

Circuit Operation (See Figure 4)

The unregulated DC input voltage is stepped down using an LM2576 3A buck regulator, providing up to 3A of current to charge the battery.

In order to regulate the amount of charging current flowing into the battery, a current control loop is implemented using op-amp U2. The voltage drop across the sense resistor R8 provides a voltage to U2 that is proportional to the charging current.

The 0.05Ω value for R8 was specified by the customer in this application to minimize the power dissipated in this resistor. If a higher Ohmic value is used (more resistance), a larger sense voltage is developed and a less precise (cheaper) op-amp can be used at U2, since the input offset voltage would not be as critical (of course, increasing the value of R8 also increases its power dissipation).

When the current-control loop is operating, the voltage at the feedback pin of U1 is held at 1.23V. The battery charging current that corresponds to this voltage is dependent on the overall gain of U2 and the attenuators made up of Q1, Q2 and the resistors R10, R11, R2 and R3.

Turning Q1 on (by putting a "1" on logic input "A") provides an increase of 4:1 in load current. The load current is higher with Q1 on because R2 and R3 divide down the output of U2 by 4:1, requiring U2 to output a higher voltage to get the 1.23V on the feedback line of U1. Higher voltage at the output of U2 means that more charging current is flowing through R8 (also the battery).

The operation of Q2 is similar to Q1: when Q2 is turned on by putting a logic "1" on input "B", the load current is increased by a factor of 10:1. This is because when Q2 is on, the sense voltage coming from R8 is divided down by R10 and R11, requiring ten times as much signal voltage across R8 to get the same voltage at the non-inverting input of U2.

Although both attenuating dividers could have been placed on the input side of U2, putting the 4:1 divider at the output improves the accuracy and noise immunity of the amplifier U2 (because the voltage applied to the input of U2 is larger, this reduces the input-offset voltage error and switching noise degradation).

R5, R6, and D2 are included to provide a voltage-control loop in the case where the battery is disconnected. These components prevent the voltage at the cathode side of D3 from rising above about 8V when there is no path for the charging current to return (and the current control loop would not be operational).

Capacitor C2 is included to filter some of the 52kHz noise present on the control line coming from U2. Adding this component improved the accuracy of the measured charging current on the breadboard (compared to the predicted design values).

Performance data measured on the breadboard is listed in Figure 4.

LI-ION CHARGING INFORMATION

A Li-Ion battery is unique, as it is charged from a fixed voltage source that is current limited (this is usually referred to as constant voltage charging).

Constant Voltage Charging

A constant voltage (C-V) charger sources current into the battery in an attempt to force the battery voltage up to a pre-set value (usually referred to as the set-point voltage or set voltage).

Once this voltage is reached, the charger will source only enough current to hold the voltage of the battery at this constant voltage (hence, the reason it is called constant voltage charging).

At present, the major Li-Ion cell manufacturer recommends 4.200 +/- 50 mV as the ideal set point voltage, and 1c (a charging current rate equal to the A-hr rating of the cell) as the maximum charging current that can be used.

The accuracy on the set point voltage is critical: if this voltage is too high, the number of charge cycles the battery can complete is reduced (shortened battery life). If the voltage is too low, the cell will not be fully charged.

A typical charge profile for a Li-Ion cell using 1c constant voltage charging is shown in Figure 5.
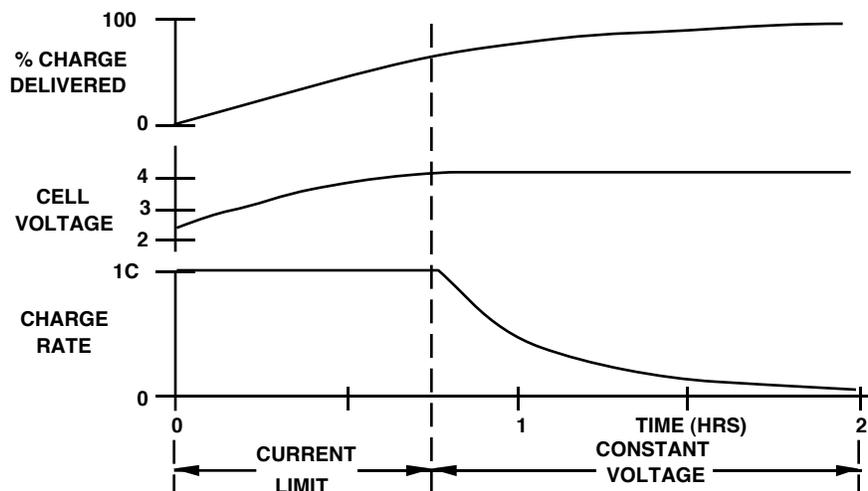

FIGURE 5. TYPICAL C-V CHARGE PROFILE

The constant voltage charging cycle is divided into two separate segments:

The current limit (sometimes called constant current) phase of charging is where the maximum charging current is flowing into the battery, because the battery voltage is below the set point. The charger senses this and sources maximum current to try to force the battery voltage up.

During the current limit phase, the charger must limit the current to the maximum allowed by the manufacturer (shown as 1c here) to prevent damaging the batteries.

About 65% of the total charge is delivered to the battery during the current limit phase of charging. Assuming a 1c charging current, it follows that this portion of the charge cycle will take a maximum time of about 40 minutes.

The constant voltage portion of the charge cycle begins when the battery voltage sensed by the charger reaches 4.20V. At this point, the charger reduces the charging current as required to hold the sensed voltage constant at 4.2V, resulting in a current waveform that is shaped like an exponential decay.

The constantly decreasing charge current during the constant-voltage phase is the reason that the Li-Ion charge time is nearly two hours, even though a 1c (maximum) charging current is used (this means that delivering the final 35% of the charge takes about twice as long as the first 65%).

To understand why this is true, it must be remembered that every real cell contains an internal ESR (Equivalent Series Resistance), and the voltage that the charger senses across the battery is influenced by the ESR (see Figure 6).

The voltage measured at the terminals of the battery is the sum of the voltage drop across the ESR and the cell voltage. The battery is not fully charged until the cell voltage is 4.2V with only a minute current flowing into it (which means the drop across the internal ESR is negligible, and the actual cell voltage is 4.2V).

During the 1c current limit charge phase, the battery reaches 4.2V with only about 65% of charge capacity delivered, due to the voltage drop across the ESR. The charger must then reduce the charging current to prevent exceeding the 4.2V limit, which results in the decreasing current as shown in Figure 5.
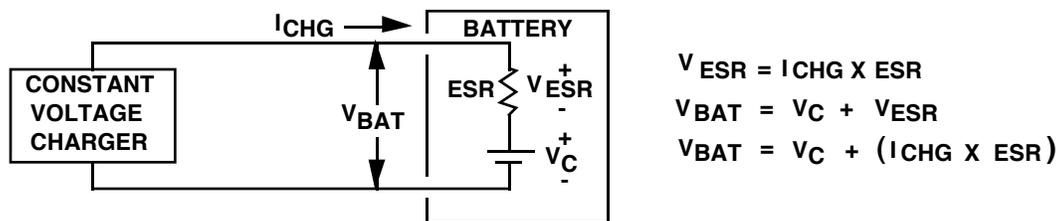

$$V_{ESR} = I_{CHG} \times ESR$$
$$V_{BAT} = V_C + V_{ESR}$$
$$V_{BAT} = V_C + (I_{CHG} \times ESR)$$

FIGURE 6. BATTERY EQUIVALENT CIRCUIT

Single-Cell 150 mA Charger

While a maximum charging current of 1c is allowed for Li-Ion, charging at a lower rate is also possible (with a correspondingly longer charge time). The design example presented next shows a simple solution for slow charging a single Li-Ion cell.

Figure 7 shows the schematic of a battery charger that was designed to recharge the Li-Ion battery in a portable stereo. The customer specification for the charger was 150 mA (minimum) charging current in the current-limit charge mode, and a voltage set point of 4.200V +/- 0.025V in the constant voltage charge mode.

An LP2951 regulator was selected because it has an output voltage that is very stable over temperature. Also, the LP2951 has built-in current limiting that prevents the output current from exceeding 160 mA (typical), and the part is fully protected with thermal shutdown and short-circuit protection.

The LP2951 is set for an output voltage of 4.20V using the resistors shown (the trimpot is required because of the tight tolerance specification).

When the battery voltage is below 4.2V, the LP2951 will source maximum current (typically 160 mA) in an attempt to force the battery voltage up to 4.2V (this is the current limit phase of the charge cycle).

Once the battery reaches 4.2V, the LP2951 will cut back the charging current as required to hold the battery voltage at 4.2V (this is the constant voltage portion of the charge cycle).

The large resistor values used in this design are necessary to keep the "OFF" current drain below 2μA, and a 330pF capacitor is needed to prevent instability due to noise at the high-impedance feedback node.

A blocking diode is used at the output of the LP2951 to prevent battery current from flowing back into the LP2951 output pin if the input power source is removed.
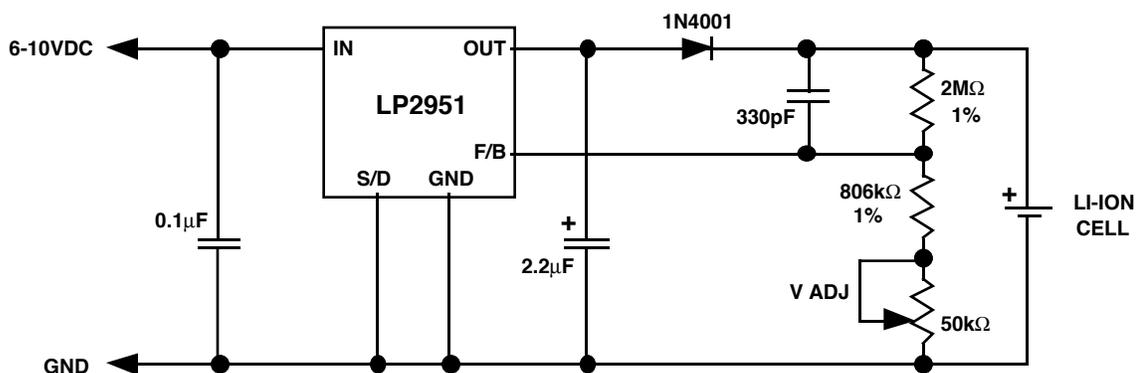

FIGURE 7. SINGLE CELL LI-ION CHARGER

3-Cell, 3A Charger Using the LP2952

Figure 8 shows a design which was developed for a customer who needed to charge a 3-cell Li-Ion battery with a maximum of 3A.

The set point voltage for the charger was specified as 12.60V, with a required precision of better than +/-1% over temperature.

The design topology selected was a Low Dropout (LDO) regulator using the LP2952 as the controller and a D45H5 pass transistor to supply the 3A of current.

The LP2952A is a precision LDO regulator which is rated for up to 250 mA of load current, and has a reference voltage specification limit of +/- 1.2% (room temperature) on "A" grade parts.

In this design, U1 is used as a current sink for the base drive current of Q1. This base current flows through U1 (to ground) through R2.

The current through U1 drives the base of Q1, which will source as much current as it can to try to bring the output up to the set voltage. This means the DC input source must be current limited so that the maximum charging current does not exceed the limit that the battery can safely handle (3A in this design).
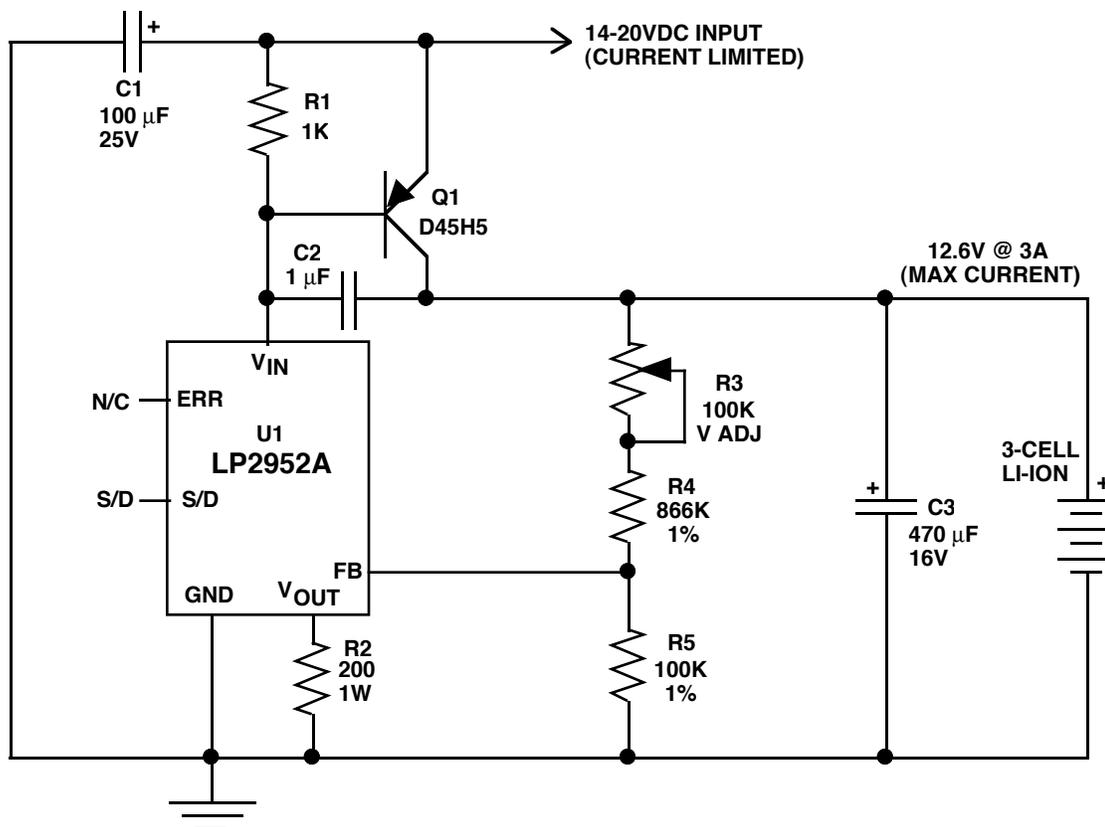

FIGURE 8. 3-CELL, 3A CHARGER USING THE LP2952

The output voltage is set by the resistive divider made up of R3, R4, and R5. Since an absolute accuracy of better than +/-1% is specified on the set voltage, a voltage trimmer (R3) is required.

C2 is used for compensation.

A heatsink must be used with Q1, sized as required by the ambient temperature and input voltage used to power the circuit.

Improving the Design

The circuit in Figure 8 works well, but has two "features" which are not optimal from the users standpoint.

A voltage trim is required, because the cumulative tolerances of the components will exceed 1% before you even get started:

If 1% resistors are used in a divider, they will contribute about 1.4% total error to the set voltage. 0.1% resistors are available (but they're expensive and nobody stocks them).

Adding to the resistor-induced error, the tolerance on the reference voltage of the best precision regulators is > +/-1%.

Although sometimes necessary, voltage trims are not user-friendly, as they require hand labor in the manufacturing process.

Another unpleasant feature of this design is that this circuit will continuously drain the battery through the R3, R4, and R5 divider if the power to the charging circuit is removed.

Even though the drain is only 12 μA, it does reduce standby time for the portable product (and customers don't like that).

The next design presented will highlight a new product developed for Li-Ion charging which overcomes both of these drawbacks.

LM3420 Battery Charger Controller

Developed specifically for Li-Ion charging, the LM3420 provides a simple way to build a charger for one, two, or three Li-Ion cells.

The LM3420 is a regulator (see Figure 9) which sources current from its output when the regulated voltage is applied from the input to ground.

With voltage accuracy of 0.5% (room temperature) and 1% over the full temperature range for "A" grade units, external voltage trims are not required.

Minimum board space is used by the SOT23-5 package, and voltage options of 4.2, 8.4, and 12.6V are provided to accommodate 1,2, and 3 cell charger designs.
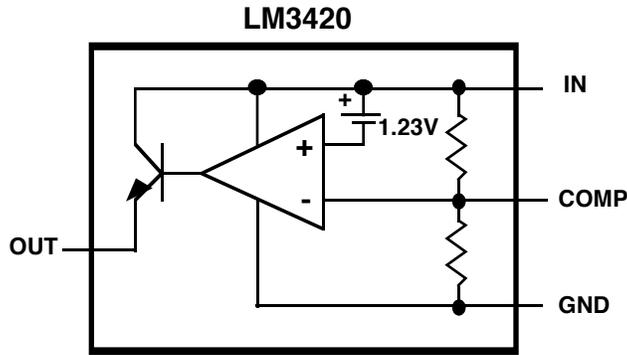
LM3420

FIGURE 9. BLOCK DIAGRAM OF LM3420

3-Cell, 3A Charger Using the LM3420

Use of the LM3420 for Li-Ion charging offers significant advantages, as highlighted in the charger design shown in Figure 10.

The customer's design specification called out 12.60V for the voltage set point (with an overall accuracy better than 1%). The maximum charging current is 3A (and must be limited by the DC input source).

The LM3420 has a factory-trimmed internal divider that is adjusted to 12.6V (tolerance better than +/-1%), so voltage setting resistors are not needed.

In the typical (constant-voltage) mode of operation, the LM3420 is the controller in a feedback loop that precisely regulates the voltage of the batteries.

The circuit has a built-in "on/off switch" made up of Q3, R4, and D3. When a DC input is present, D3 turns on Q3 which allows current to flow through the LM3420 and Q1, causing the circuit to operate.

If the DC input source is removed, Q3 will turn off and reduce the drain on the batteries to less than 1 μA (an important improvement over the previous design, as it prevents "off state" battery drain).

R1, R2, D1, D2 and associated components are used to set up a bias current through Q1. About 600μA will flow through D1, D2, and R2 to ground, forcing current to flow through R3, R5, Q1, and Q3 (assuming Q3 is turned on).

The current flowing through R5 is provided by the output of the LM3420 and the current flowing through Q1.

The 3A used for battery charging is provided by Q2, a P-FET which is turned on/off by Q1, D4, R5 and Q3.

In the current-limit mode of operation (where the battery voltage is below 12.6V), Q1 is fully turned on, which pulls down the gate of Q2 and turns it on to the maximum.

Since the FET Q2 is fully turned on, the charging current must be limited by the DC source which powers the circuit.
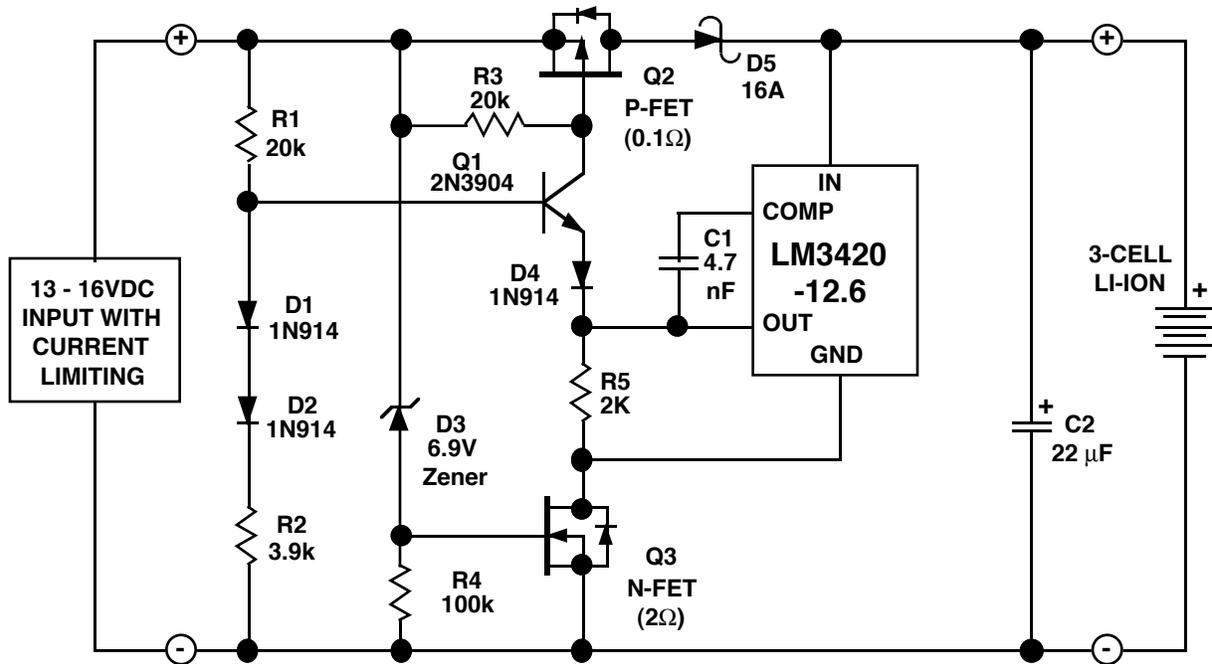
FIGURE 10. 3-CELL, 3A CHARGER USING THE LM3420

When the battery voltage reaches 12.6V, the LM3420 regulates the battery voltage by sourcing current, which adjusts the Q2 gate voltage as required to hold the battery voltage at 12.6V.

In this constant-voltage mode of operation, both Q1 and Q2 operate in their linear regions in response to the feedback from the output of the charger circuit (through the LM3420) to maintain this fixed battery voltage.

The Schottky diode used at D5 is necessary to prevent battery drain due to current flowing back through the internal diode of Q2 when the DC input is removed. A 16A diode was selected to minimize power losses, but a 6A could be used for cost savings.