Application Note 37
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Fast Charge Circuits for NiCad Batteries

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Safe, fast charging of NiCad batteries is attractive in many applications. Short charge time requires high current. A potential difficulty with high current charging is battery heating. Excessive internal heating degrades the battery and can cause gas venting to the outside atmosphere. Fast charge schemes based on monitoring cell voltage during charge suffer because cell voltage is not necessarily indicitive of the battery's charge state. Additionally, the battery's charge-voltage relationship may alter over life and temperature. Similarly, open loop charging techniques involving high charge rates for a fixed time do not account for battery charge state or characteristic shifts over life and temperature.

One way to charge batteries without abuse is to measure cell temperature and taper the charge accordingly. This method is based on the fact that a discharged battery converts charging current to stored electrochemical energy, with relatively little heat produced. When the battery arrives at full charge the cell is saturated and cannot hold any more energy. As such, heat is produced, raising battery temperature. One way to detect this point is to measure cell surface temperature referred to ambient. An absolute temperature measurement is undesirable because cell temperature represents the summation of excess charging energy and ambient temperature. Additionally, the ambient and battery temperatures must be measured in phase. The thermal time constant of a battery pack can easily exceed one hour. If battery temperature is referred to a quickly responding ambient temperature poor charging characteristics can result. Consider the case of a portable computer retrieved from a locked automobile on a summer day. Passenger compartment temperature can exceed 120°F. The computer is brought inside, where the ambient temperature sensor quickly settles to 73°F. The battery pack temperature is sitting at 120°F looking through a one hour thermal time constant. Under these conditions the system is fooled into believing the battery has just received a full charge, and no charge is delivered. The opposite effect occurs if the computer is in a car parked overnight in Minneapolis in January. These effects are avoidable by lagging the ambient temperature information with a time constant similar to the battery packs. Figure 1 shows a simple analog. The resistors represent thermal resistance while the capacitors correspond to thermal capacitance. Ambient temperature appears as a common mode term, while charger energy affects the battery only. Note that the ambient and battery

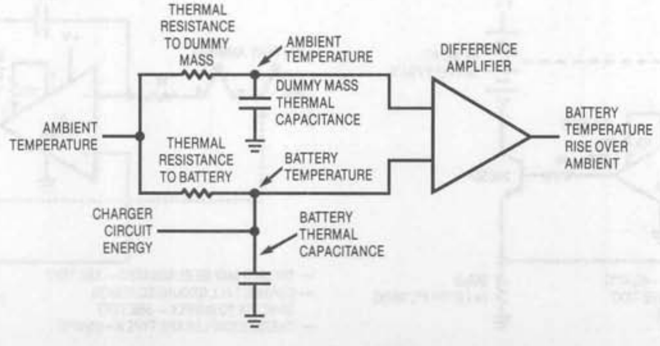


Figure 1. Simplified Thermal Analog. Matched Thermal RC Terms Provide Immunity to Ambient Temperature Shifts.

temperatures do not require the same individual R-C values to present phased information to the difference amplifier. Rather, their RC *products* must be matched. A massive battery pack with relatively low thermal resistance to ambient can be matched by the time constant of a well insulated (e.g., high thermal resistance) small thermal mass.

Practical Thermally Based NiCad Charger

Figure 2 shows a practical circuit. Thermocouples sense cell and ambient temperatures. The LT1006 amplifier furnishes the low level capability necessary to work with the microvolt level thermocouple signals. To understand the circuit's operation, assume a discharged battery pack in the transistor collector line. The battery and ambient thermocouples are at the same temperature. The battery thermocouple is directly mounted to one of the cells in the pack. The ambient thermocouple is thermally insulated and mounted to a mass, perhaps a frame member of the equipment. Under these conditions the sensors are phase matched, their outputs cancel and A1 sees 0V. The offset adjustment deliberately introduces enough input offset for A1 to swing positively, turning on the transistor. Current flows from the supply, through the battery pack and to ground via the 250$\mu\Omega$* shunt. The low impedance shunt minimizes losses, cost, and complexity. The voltage across the shunt rises to about 625μV (the amount of offset forced by the potentiometer), and the amplifier servo controls about 2.5A through the battery pack. As the battery charges, it heats. This heat is picked up by the battery-mounted thermocouple. The temperature difference between the two thermocouples determines the voltage which appears at the amplifier's positive input. As battery temperature rises, this small negative voltage (1°C difference between the thermocouples equals 40μV) becomes larger. The amplifier gradually reduces the current through the battery to maintain its inputs at balance. The effect of this action is shown in Figure 3. The battery charges at a high rate until heating occurs and the circuit then tapers the charge. The values given in the circuit limit the battery surface temperature rise over ambient to about 15°C.

Figure 4's circuit is arranged for use with batteries which are committed to ground. The common emitter output necessitates exchanging amplifier input assignments, but circuit operation is identical to Figure 2. In both circuits the trimpot may be eliminated by specifying an LT1006 set at manufacture to the desired offset value.

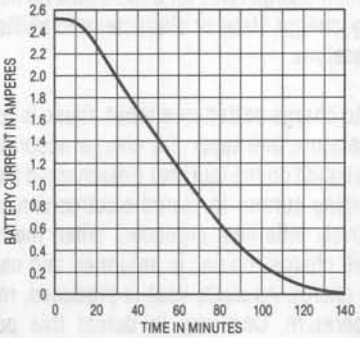
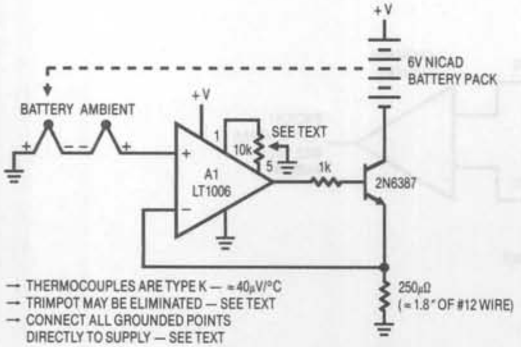
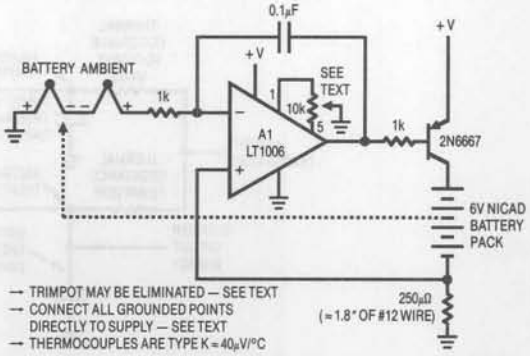


Figure 3. Figure 2's Charge Characteristics



→ THERMOCOUPLES ARE TYPE K — ≈40μV/°C
→ TRIMPOT MAY BE ELIMINATED — SEE TEXT
→ CONNECT ALL GROUNDED POINTS DIRECTLY TO SUPPLY — SEE TEXT

Figure 2. Thermally Controlled NiCad Battery Charger



→ TRIMPOT MAY BE ELIMINATED — SEE TEXT
→ CONNECT ALL GROUNDED POINTS DIRECTLY TO SUPPLY — SEE TEXT
→ THERMOCOUPLES ARE TYPE K ≈ 40μV/°C

Figure 4. Figure 2's Circuit Arranged for a Grounded Battery

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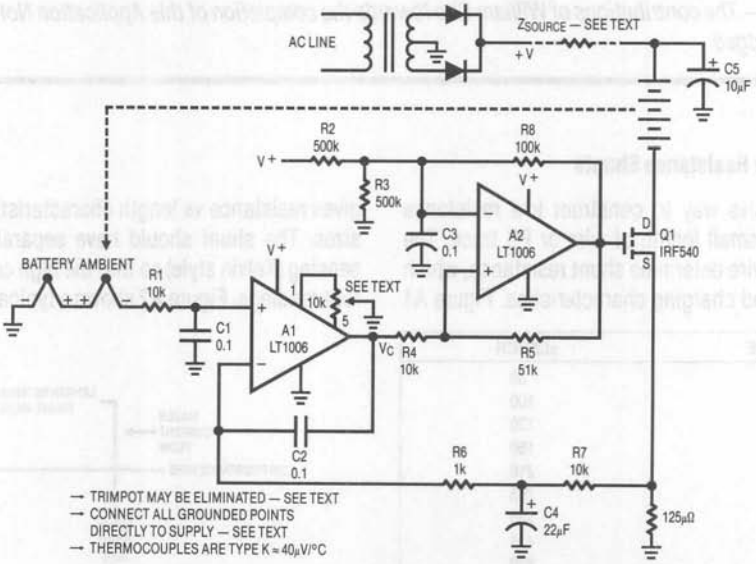
*See Appendix A for construction information on low resistance shunts.

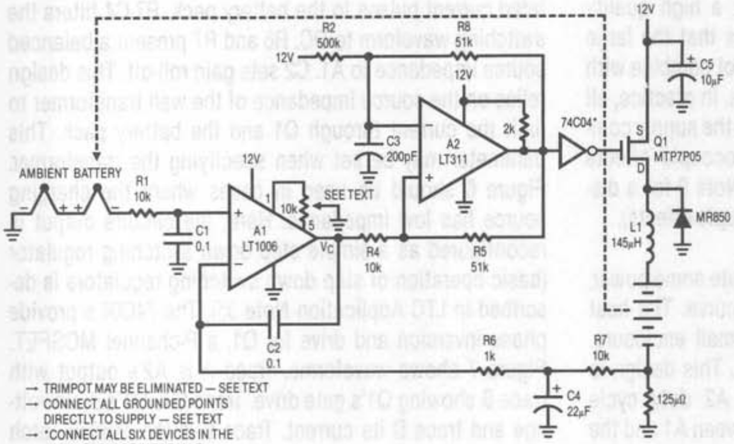
The small shunt sense voltage requires a high quality ground for accurate results. This ensures that the large current flow through the transistor does not combine with ground return impedances to create errors. In practice, all returns should be brought directly back to the supply common terminal. Similarly, parasitic thermocouple effects should be avoided (see LTC Application Note 9 for a discussion on minimizing parasitic thermocouple effects).

Both circuits force the transistor to dissipate some power, particularly in the middle of the charge curve. The heat produced may be a problem in a very small enclosure. Figure 5's circuit eliminates this problem. This design is similar to the others, except that the A2 duty cycle modulator configuration is interposed between A1 and the output transistor. The transistor, in this case a power FET, operates in switched mode, delivering duty cycle modulated current pulses to the battery pack. R7-C4 filters the switching waveform to DC. R6 and R7 present a balanced source impedance to A1. C2 sets gain roll-off. This design relies on the source impedance of the wall transformer to limit the current through Q1 and the battery pack. This parameter may be set when specifying the transformer. Figure 6 should be used in cases where the charging source has low impedance. Here, the circuits output is reconfigured as a simple step down switching regulator (basic operation of step down switching regulators is described in LTC Application Note 35). The 74C04's provide phase inversion and drive for Q1, a P-channel MOSFET. Figure 7 shows waveforms. Trace A is A2's output with trace B showing Q1's gate drive. Trace C is Q1's drain voltage and trace D its current. Trace E is the MR850 catch diode current. Trace F is L1's current. L1 smooths current flow, resulting in low loss operation.



→ TRIMPOT MAY BE ELIMINATED — SEE TEXT
→ CONNECT ALL GROUNDED POINTS DIRECTLY TO SUPPLY — SEE TEXT
→ THERMOCOUPLES ARE TYPE K ≈ 40µV/°C

Figure 5. Switched Mode Thermal NiCad Charger



→ TRIMPOT MAY BE ELIMINATED — SEE TEXT
→ CONNECT ALL GROUNDED POINTS DIRECTLY TO SUPPLY — SEE TEXT
→ *CONNECT ALL SIX DEVICES IN THE 74C04 PACKAGE IN PARALLEL
→ L1 = PULSE ENGINEERING #PE-92105
→ THERMOCOUPLES ARE TYPE K ≈ 40μV/°C

Figure 6. Switched Mode Thermal NiCad Charger

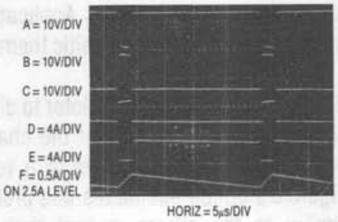


Figure 7. Figure 6's Switching Waveforms

Note — *This application note was derived from a manuscript originally prepared for publication in EDN magazine.*
Acknowledgement — *The contributions of William Cho towards the completion of this Application Note are gratefully acknowledged.*

APPENDIX A

Construction of Low Resistance Shunts

A simple, inexpensive way to construct low resistance shunts is to use a small length of wire or PC trace. The type and length of wire determine shunt resistance, which will vary with desired charging characteristics. Figure A1 gives resistance vs length characteristics for various wire sizes. The shunt should have separate connections for sensing (Kelvin style) so that the high current does not corrupt readings. Figure A2 shows a typical configuration.

WIRE GAUGE	μΩ/INCH
10	83
11	100
12	130
13	160
14	210
15	265
16	335
17	421
18	530
19	670
20	890
21	1000
22	1300
23	1700
24	2100
25	2700

Figure A1. Resistance vs Size for Various Copper Wire Types

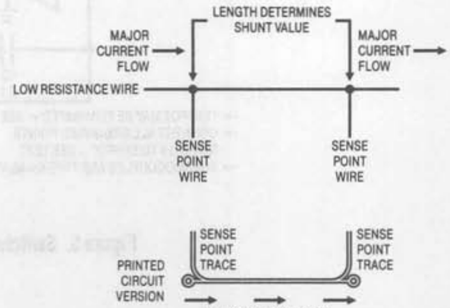


Figure A2. Detail of a Low Resistance Current Shunt