NC2000 Charge Controller for Nickel-Cadmium and Nickel-Metal Hydride Batteries

General Description

The NC2000 is a device designed to intelligent charge either nickel-cadmium (NiCad) or nickel-metal hydride (NiMH) batteries. The charge process is controlled by a microprocessor that uses a pulse current charging technique, together with voltage slope and/or temperature slope termination. The NC2000 employs a four stage charge sequence that provides a complete recharge without overcharging. The NC2000 has four user selectable charge rates and five user selectable programs. A selected charge rate is automatically adjusted to one of four user selectable battery capacities.

The NC2000 monitors for the presence of a battery and begins charging when a battery is installed. Voltage and temperature are measured to ensure a battery is within fast charge conditions before charge is initiated.

Applications

- Battery charging for:
- Model aircraft
- Children’s toys
- Power tools
- Communication equipment
- Audio/Video equipment

Features

- Multiple charge termination methods include:
  - Voltage slope (delta peak)
  - Temperature slope
  - Maximum temperature
  - Charge timer
- Four stage charge sequence:
  - Soft start charge
  - Fast charge
  - Topping charge
  - Maintenance charge
- Reverse pulse charging (reflex charging) available in all stages
- Four programmable charge rates between 15 minutes (4C) and four hours (C/4)
- Out of temperature range detection:
  - Hot battery: charge shutdown
  - Cold battery: low current charge
- Continues polling mode for battery detection
- Five programs:
  - Topping charge only (C/10)
  - Discharge and fast charge
  - Discharge only

  - Fast charge only
  - Maintenance charge (C/40) only
- Open circuit (No battery) detection.

Charging stages

The charging sequence consists of four stages. The application of current is shown graphically in figure 1. The soft start stage gradually increases current levels up to the user selected fast charge rate during the first two minutes. The soft start stage is followed by the fast charge stage, which continues until termination. After termination, a two hour C/10 topping charge is applied. The topping charge is followed by a C/40 maintenance charge.

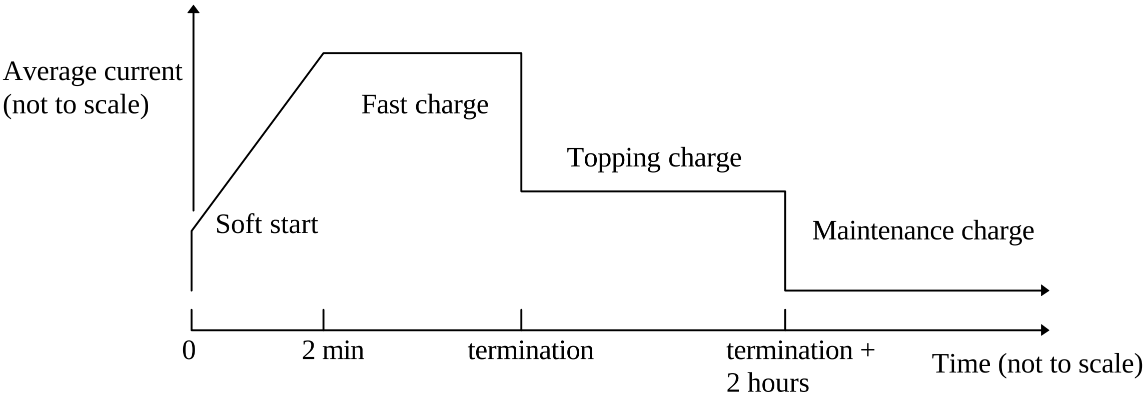


Figure 1: Graphical representation of average current levels during the four charge stages

Soft Charge Stage

Some batteries may exhibit an unusual high impedance condition while accepting the initial charge current, as shown in figure 2. Unless dealt with, this high impedance condition can cause a voltage peak at the beginning of the charge cycle that would be misinterpreted as a fully charged battery by the voltage termination methods.

The soft start charge eases batteries into the fast charge stage by gradually increasing the current to the selected fast charge rate. The gradual increase in current alleviates the voltage peak. During this stage, only positive current pulses are applied to the battery. The duty cycle of the applied current is increased to the selected fast charge rate, as shown in figure 3, by extending the current pulse on every cycle until the pulse is about one second in duration. The initial current pulse is approximately 200 ms. The charge indicator is lit continuously during this stage.

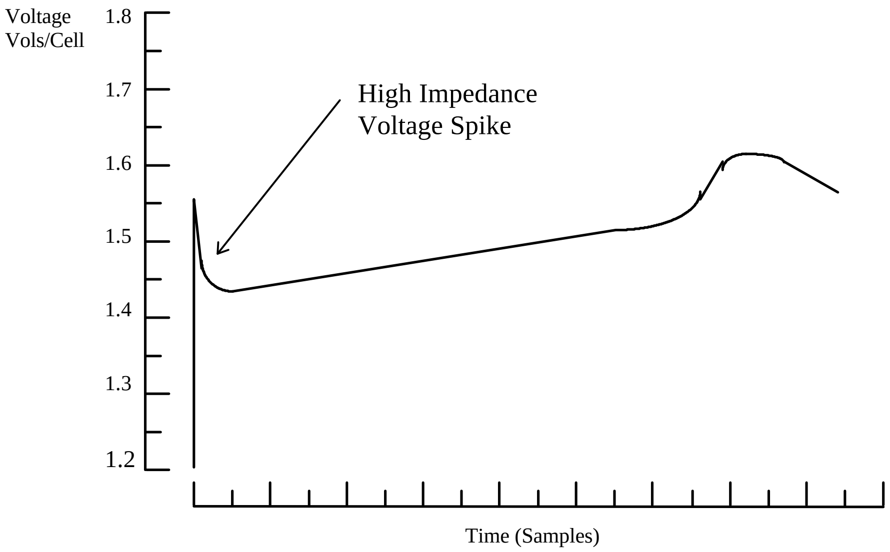


Figure 2: High impedance voltage spike at the beginning of charge

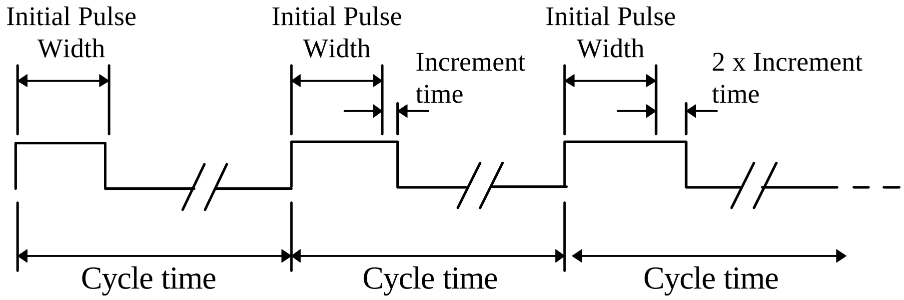


Figure 3: Cycle-to-cycle increase of the soft-start current pulse widths

Fast charge

In the second stage, the NC2000 applies the charging current in a series of charge and discharge pulses. The technique consists of a positive current charging pulse followed by a high current, short duration discharge pulse. The cycle, shown with charge, discharge, rest and data acquisition periods in figure 4, repeats every second until the batteries are fully charged.

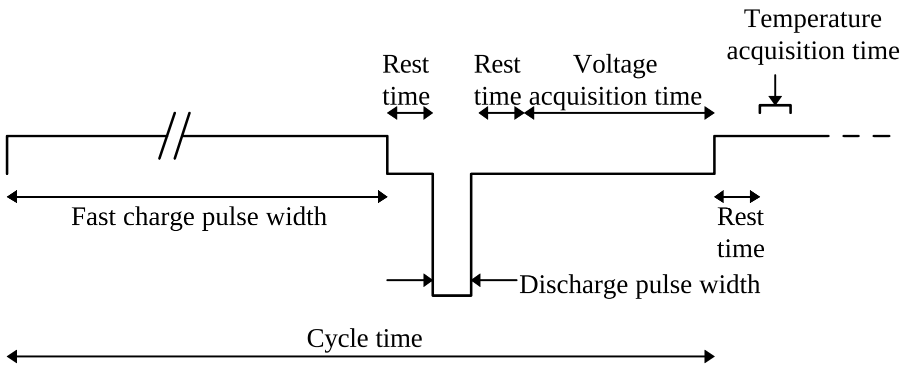


Figure 4: Charge cycle showing charge and discharge current pulses

The amplitude of the current pulse is determined by the user selected charging method and user selected battery capacity and the ability of the cell to accept the charging current. The NC2000 can be set to four different charge methods ranging from 15 minutes (4C) to four hours (C/4) and to four different battery capacities; 500 mAh to 2000 mAh. Charge pulses occur approximately every second. The charge indicator is lit continuously during this stage.

The discharge current pulse is amplitude is set to about 2.5 times the charging current. For example, if the charge current is set at about 4 amps, then the discharge current is about 10 amps. The energy removed during the discharge pulse is a fixed ratio to the positive charge rate. The amplitude of the discharge pulse does not affect operation of the charger as described in this section.

A voltage acquisition window immediately follows a brief rest time after the discharge pulse. No charge is applied during the rest time or during the acquisition window to allow the cell chemistry to settle. Since no current is flowing, the measured cell voltage is not obscured by any internal or external IR drops or distortions caused by excess plate surface charge. The NC2000 makes one continues reading of the no-load battery voltage during the entire acquisition window. The voltage that is measured during this window contains less noise and is a more accurate representation of the true state of charge of the battery. If temperature termination is selected, the thermistor voltage is sampled after a brief rest time once the current supply to the battery is turned on.

Topping Charge

The third stage is a topping charge that applies current at a rate low enough to ensure a full charge.

The topping charge applies a C/10 charging current for two hours. The current consists of the same pulse technique used during the fast charge stage; however, the duty cycle of the pulse sequence has been extended as shown in figure 5. Extending the time between charge pulses allows the same charging current used in the fast charge stage so that no changes to the current source are necessary. For example, the same charge pulse that occurs every second at a 2C fast charge rate will occur every 20 seconds for a topping charge rate of C/10. The “trickle charge / discharge” indicator is lit continuously during this stage.

Maintenance Charge

The maintenance charge is intended to offset the natural self discharge of NiCad or NiMH batteries by keeping the cells primed at peak charge. After the topping charge ends, the NC2000 begins this charge stage by extending the duty cycle of the applied current pulses to a C/40 rate. The maintenance charge will last for as long as the battery voltage is greater than 0.5 V per cell, or, if the ten hour timer mode is enabled, until the timer stops the NC2000. The “trickle charge / discharge” indicator is lit continuously during this stage.

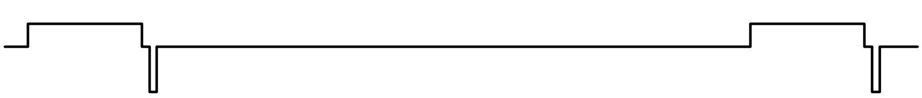


Figure 5: Representative timing diagram for topping and maintenance charge

Charge Termination Methods

Several charge termination schemes, including voltage slope, temperature slope, maximum temperature, and two overall charge timers are available. The voltage slope and negative voltage slope methods may be used with or whiteout the temperature slope and the maximum temperature method. Maximum temperature and the fast charge timer are available as backup methods.

Voltage Slope termination

The most distinctive point on the voltage curve of a charging battery in response to a constant current is the voltage peak that occurs as the cell approaches full charge. By mathematically calculating the first derivative of the voltage, a second curve can be generated showing the change in voltage with respect to time as shown in Figure 6. The slope will reach a maximum just before the actual peak in the cell voltage. Using the voltage slope data, the NC2000 charger calculates the point of full charge and accurately terminates the applied current as the battery reaches that point. The actual termination point depends on the charging characteristics of the particular battery.

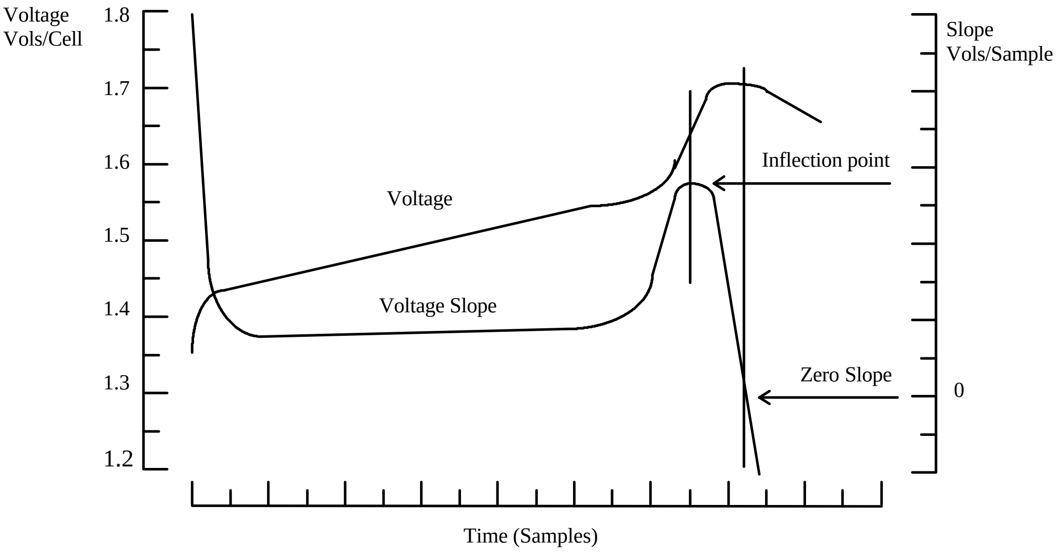


Figure 6: Voltage and slope curves showing inflection and zero slope points

Cells that are not thoroughly conditioned or possess an unusual cell construction may not have a normal voltage profile. The NC2000 charger uses an alternate method of charge termination based on a slight decrease in the voltage slope to stop charge to cells whose voltage profile is shallow. This method looks for a flattening of the voltage slope which may indicate a shallow peak in the voltage profile. The zero slope point occurs slightly beyond the peak voltage and is shown on the voltage curve graph.

Temperature Slope Termination

Temperature slope termination is based on the battery producing an accelerated rate of heating as the amount of readily chargeable material diminishes at full charge, An increase in battery (cell) heating due to the charging reaction will occur at a much faster rate than a change due to a warming ambient temperature. Note the effect of 0.5C fluctuations in ambient temperatures resulting in slight variations in the temperature slope as shown in figure 7. However, the increase in cell temperature near the end of charge causes a much larger change in the temperature slope that can be easily detected and used as a trigger for fast charge termination.

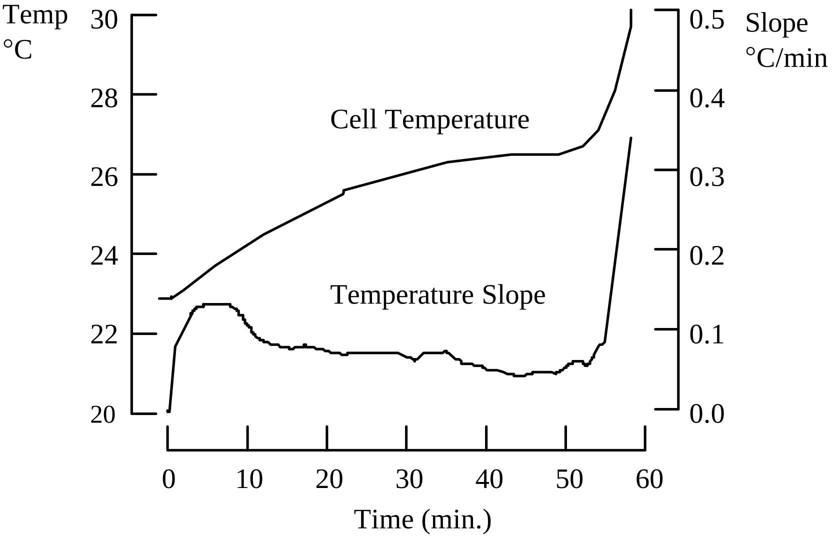


Figure 7: Cell temperature and temperature slope

The rate of change in a cell temperature can be determined by measuring the change in voltage across a negative temperature coefficient thermistor as shown in figure 8. The resistance of an NTC thermistor changes in proportion in the change in temperature of the thermistor. The NC2000 measures the decreasing resistance as a drop in voltage and calculates the thermistor voltage slope, shown in Figure 8. The charger terminates fast charge based on the selected rate and the calculated slope.

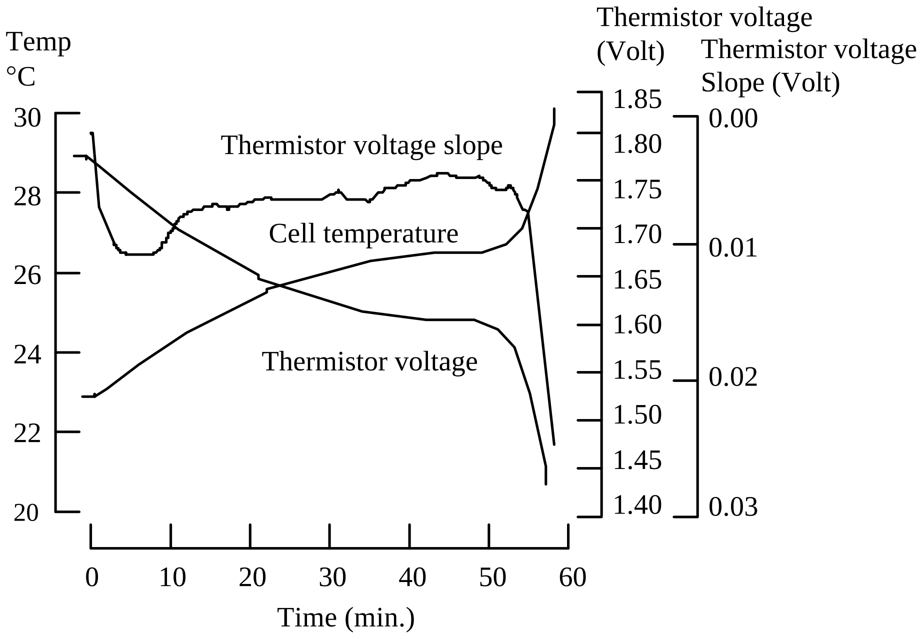


Figure 8: Cell temperature and thermistor voltage slope

Table 1 shows the decrease in thermistor voltage the last minute before full charge required by the NC2000 at various charge rates. The thermistor voltage slope should not exceed the listed value to ensure charge termination. Note that changes in thermistor location, cell size or large ambient temperature fluctuations can affect the slope to some degree. Refer to the Application Information section for more information on thermistor mounting.

Table 1: Slope vs. Charge rate

Charge rate	Thermistor Voltage Slope (-V/min.)
1C, 2C & 4C	0.040
C/4	0,018

To determine the required thermistor characteristics for proper temperature slope termination, the battery temperature rise must be known or determined for the last minute prior to full charge. Maximum temperature termination is also enabled when temperature slope termination is used.

Maximum Temperature Termination

Maximum temperature can be sensed using either a NTC thermistor or a thermal switch. Maximum temperature termination can be bypassed by short circuiting the thermistor input if desired, although it is strongly recommended that some form of temperature termination be used.

If an NTC thermistor is used, an internal voltage threshold determines when the battery is too hot to charge. As temperature increases, the voltage across the thermistor will drop. This voltage is continually compared to the internal voltage threshold. If the thermistor voltage drops below the internal threshold, the “too hot” indicator is lit and the NC2000 shuts down. The NC2000 must be reset once the hot battery fault condition has cleared to restart the charge sequence.

If a thermal switch is used, a 45°C open circuit switch is recommended. When the thermal switch opens, an internal pull-up at the sensor input results in a logic high which shuts down the NC2000 and activates the “too hot” indicator. The NC2000 must be reset once the hot battery fault condition has cleared to restart the charge sequence.

Maximum temperature termination can be disabled by grounding the sensor input. The NC2000 model type presented later in this document employs a sensor jack that automatically grounds the temperature input when the sensor plug is removed.

Fast Charge Timer Termination

The NC2000 uses a timer to limit the fast charge duration. These times are pre-programmed, and are automatically adjusted in time duration according to the charge rate selected. Fast charge timer termination is best suited as a safety backup feature to limit the duration of the fast charge stage. The fast charge timer is always enabled and cannot be disabled. See table 4 in the charge rate section for more information.

Battery Detection

Upon power-up or after a reset, excess charge from output filter capacitors at the charging system terminals is removed with a series of discharge pulses. After the discharge pulse sequence is complete, the voltage at the battery terminals must be greater than 0.5 V per cell when a battery is present. If the voltage at the battery terminals is less than 0.5 V, the NC2000 assumes no batteries are present, and the polling detect mode is initiated. No indicator is active during the discharge pulses.

The NC2000 enters the polling detect mode and applies a 100 ms charge pulse. During the pulse, the NC2000 monitors the battery terminals to determine if the voltage is above 1.87 volt per cell. If a battery is present, the voltage will be clamped below 1.87 volt per cell while the current pulse is applied. If a battery is not present, the voltage at the battery terminals will rise above 1.87 volt per cell.

The charge pulse will repeat at one second intervals until the battery is reinstalled. The “No batteries” indicator is the only one lit while the NC2000 is in polling detect mode. Once a battery is installed, the NC2000 will turn off the “No batteries” indicator and enter the soft start stage. The NC2000 will automatically re-enter the polling detect mode if the battery is removed.

Battery Removal

During the application of a charge pulse, the voltage at the battery terminals is compared against 1.87 volt per cell. If the voltage at the battery terminals is greater than 1.87 volts per cell during the application of the current pulse, then the battery is assumed to have been removed and the NC2000 enters polling detect mode. If the voltage at the battery terminals is below 1.87 volt per cell. the charging mode continues.

When in the topping charge or maintenance charge stages, a charge pulse may nor occur for several seconds. During the period between charge pulses, the voltage at the battery terminals must be greater than 0.5 volts per cell if batteries are attached. If the voltage at the battery terminals is less than 0.5 volts per cell., the NC2000 assumes the battery has been remove, and the polling detect mode is initiated.

Modes of Operation

The NC2000 allows six user selectable modes of operation. Except for the discharge-to-charge mode, another mode can only be enabled by resetting the NC2000 after the new mode has been selected.

Discharge-to-Charge Mode

The time required for discharge depends on the energy in the battery and the selected discharge rate. The discharge is not limited by a timer. This allows the user to set the discharge rate. The batteries are drained to 1 volt/cell under load and the NC2000 enters soft start at a charge rate set by the user. The discharge cycle is about 400 ms every second. Since the discharge circuit is designed to discharge at 2.5 times the charge current this duty cycle results in an average discharge current equal to the selected charge current.

The NC2000 enters the discharge-to-charge mode at initial power up or a reset after the mode has been selected by the user. The discharge mode occurs first, to be followed by the selected fast charge mode. During discharge the “trickle charge / discharge” indicator flashes at a one second interval rate, while during soft start and fast charge stages the charge indicator is lit.

Discharge only mode

The time required for discharge depends on the energy in the battery and the selected discharge rate. The discharge is not limited by a timer. This allows the user to set the discharge rate. The batteries are drained to 1 volt/cell under load. The NC2000 shuts down after the discharge sequence is finished and a reset must be performed to reactivate the device. The discharge cycle is about 400 ms every second. Since the discharge circuit is designed to discharge at 2.5 times the charge current this duty cycle results in an average discharge current equal to the selected charge current. The “trickle charge / discharge” indicator flashes at a one second interval rate.

Direct Maintenance Mode

The NC2000 can enter directly into C/40 maintenance mode for cells that require a maintenance charge only. The direct maintenance mode is enabled by selecting this mode prior to a reset or a power-up of the device. The C/40 direct maintenance mode assumes a correct setting of the battery capacity. The delay time, shown in figure 5, depends on the setting of the charge rate. Regardless of the charge rate setting the maintenance charge averages to C/40, see table 4. The maintenance charge is applied until the battery is removed, upon the NC2000 will enter the polling detect mode. The NC2000 will enter the direct maintenance mode upon initial power up or after a reset. The “trickle charge / discharge” indicator will be continuously lit during this mode.

Conditioning Mode

The NC2000 can enter a conditioning mode which applies a C/10 charge for a 10 hour period, followed by an indefinite C/40 maintenance charge until batteries are removed.

The conditioning mode is enabled by selecting this mode prior to a reset or a power-up of the device. The C/10 conditioning mode assumes a correct setting of the battery capacity. The delay time, shown in figure 5, depends on the setting of the charge rate. Regardless of the charge rate setting the conditioning charge averages to C/10, see table

4. The “trickle charge / discharge” indicator will be continuously lit during the 10 hour conditioning charge and the maintenance charge that follows. The NC2000 enters the polling detect mode if the battery is removed

Ten Hour Timer Mode

The ten hour timer mode limits the total charge, including the maintenance charge, to approximately ten hours for a battery that is completely discharged before fast charge is initiated. The ten hour limit is based on the assumption that the charge terminates due to the fast charge timer as shown in table 2.

Table 2: Ten Hour Timer Information

Charge Rate	Fast Charge Timer Cut-off	Maintenance Timer Cut-off (after fast charge termination)	Charge Time Limit (from reset)
4C	0.3 hrs	9.7 hrs	10 hrs
2C	0.6 hrs	9.4 hrs	10 hrs
1C	1.2 hrs	8.8 hrs	10 hrs
C/4	4.6 hrs	5.4 hrs	10 hrs

Cold Battery Charging

Cold battery charging is activated if the voltage at the battery terminals is in the cold battery range as shown in figure 9. The NC2000 checks for a cold battery before initiating fast charge. If a cold battery is present before initiating fast charge begins, the NC2000 begins a two hour C/10 topping charge (the pulsed duty cycle is based on the selected charge rate). If the battery is still cold after the two hour topping charge is complete, the NC2000 begins a C/30 maintenance charge. The maintenance charge will continue for as long as the battery remains cold unless the ten hour time mode is selected. The thermistor voltage is checked every second to see if the battery has warmed up. If so, the NC2000 stops the topping or maintenance charge and begins a fast charge at a rate selected by the user. A cold battery does not interfere with the condition mode, direct maintenance mode, the discharge portion of the discharge-to-charge mode, or the charge-only mode as selected by the user. See the section on Temperature Sensing, for more information.

The “trickle charge / discharge” and the hot battery indicators are both lit continues while the cold battery condition exists.

Interface description

The NC2000 requires an external component for temperature measurement and must be interfaced with an external power source that will provide the current required to charge a battery pack.

Output

The battery terminals are intended to interface directly to a battery pack. Care must be taken to wiring resistance and inductance. The wiring must be capable of carrying up to 8 amps continuously. Due to the discharge pulse and the discharge mode no diodes may be part of the external circuit, they prevent the batteries from being discharged. Under no circumstance may the fast charge method be applied on battery packs that have a build in diode to prevent accidental exchange of wiring. The NC2000 has a ten amps fuse to protect the internal circuits from accidental battery polarity exchange.

Fan control

Charging two or discharging eighth high capacity cells may under certain circumstances overheat the transistors of the charge and discharge constant current sources. The heat sink has been designed to cope with ambient temperatures up to 50 °C. With ambient temperature is meant the temperature of the air surrounding the heat sink. If the NC2000 is mounted in a cabinet or tote or on very hot summer days the heat sink may not receive enough cold air.

The fan control output allows a 12 volt fan to be controlled. It is switched on when the heat sink temperature rises above 45 °C provided a NTC thermistor of 10K ohm @ 25 °C is mounted against the heat sink and connected to the fan control circuit.

Input

The NC2000 has one optional input for a temperature sensor that provides for cold battery detection and for temperature slope termination when a NTC thermistor is used. The temperature sensor input also provides for hot battery and maximum temperature termination when used with a normally closed thermal switch. If no temperature sensor is used the input must be short circuited. Many off-the-shelf bulkhead connectors provide a contact that is closed when the plug is removed. This type of connector can automatically short the temperature sensor input when the temperature sensor is removed.

Several internal voltage thresholds are used internally by the NC2000 depending on whether a thermistor or a thermal switch is used. Figure 9 shows the internal thresholds over laid on a typical thermistor curve.

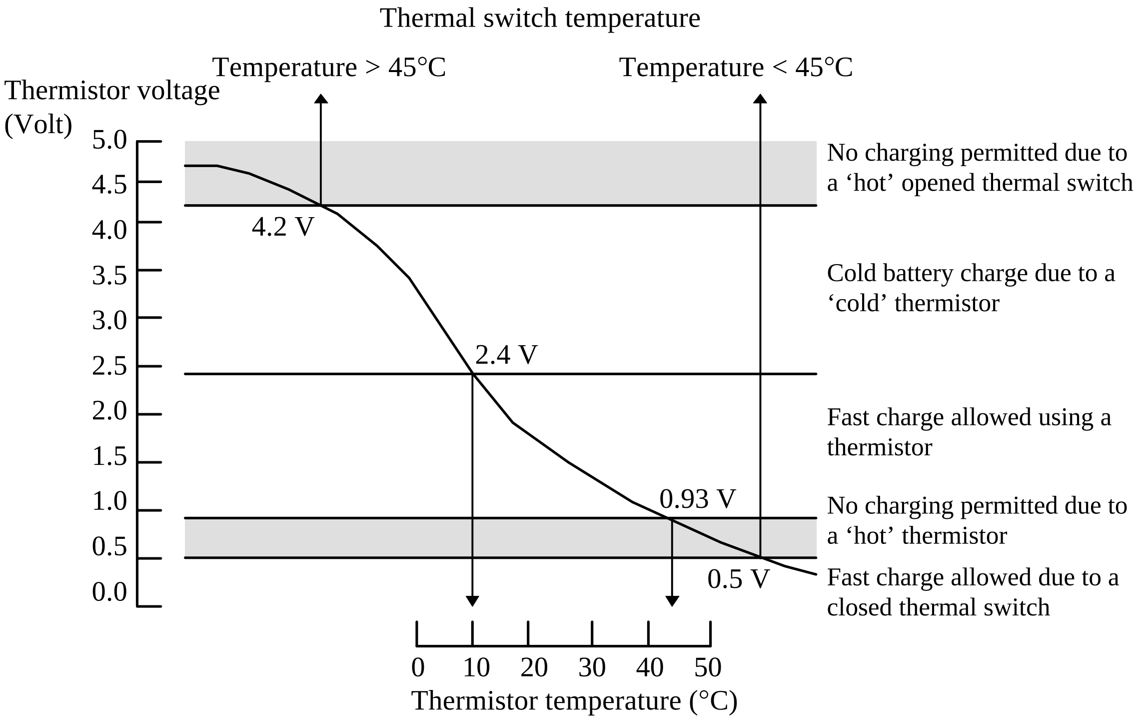


Figure 9: Voltage levels for temperature sensing with a thermistor or thermal switch

- Using a NTC thermistor for hot and cold battery detection:

The NC2000 has an internal 20 kΩ pull up resistor which is intended for a typical 10 kΩ @ 25 °C NTC thermistor. Consider using the controller to prevent charging above 45 °C and reducing the current below 10 °C. At 10 °C, the resistance of the thermistor is 18 kΩ. At 45 °C, the resistance drops to 4.7 kΩ. The NC2000 has an internal voltage threshold of 2.4 V, and an internal voltage at 45 °C at 0.93 V as shown in Figure 9. At 25 °C the voltage at the sensor input is set at the midpoint of the thresholds: 1.67 V. Table 3 lists the internal thresholds for hot and cold battery detection. If the voltage across the thermistor drops below 0.93 V, the NC2000 will shut down due to a hot battery fault condition and will not restart unless reset. If the voltage dropped across the thermistor is above 2.4 V before fast charge is initiated, the NC2000 will begin reduced current charge. See *Cold Battery Charging* section for more information.

Table 3: Thermistor Voltage Thresholds

Parameter	Voltage	Battery temperature
Cold Battery Thermistor Voltage	> 2.4	< 10 °C
Hot Battery Thermistor Voltage	< 0.93	> 45 °C

- Using a NTC thermistor for temperature slope termination:

As a battery approaches full charge, its accelerated rate of heating can be used to terminate fast charge by detecting the large change in the temperature slope. The large change temperature slope is proportional to the thermistor voltage change per unit of time. If temperature slope termination is selected by the user, the NC2000 will calculate the thermistor voltage slope and terminate based on internally set thresholds as listed in table 1. The threshold is 40 mV per minute for selected charge rates equal or greater than 1C and 18 mV per minute when the C/4 charge rate is selected. The voltage across the thermistor must change at these rates or greater to terminate the selected charge rate.

These thresholds correspond to a set change in thermistor resistance when an external 10 kΩ (@ 25 °C) NTC thermistor is used.

- Using a thermal switch for hot battery detection:

A thermal switch that opens at about 45 °C is recommended. When the thermal switch is closed the voltage over the TERM input must be below 0.5 V for normal operation. When the thermal switch is opens, the NC2000 will shut down and will not restart unless reset.

- Using no temperature sensor:

If a temperature sensor is not used the TEMP input must be shorted. A simple way to do this is by connecting the TEMP input to a bulkhead connector with a plug operated switch. The switch is connected in such a way that the input gets shorted by the switch if the plug is removed. The prototype uses a two pole, 2.8 mm audio headset plug to interface thermistors. The 2.8 mm, female bulkhead of this type has a switch that opens if a plug is inserted. Normally this switch is used to disconnect a loudspeaker when a headset is plugged in.

Power supply

The NC2000 is designed to operate from a 12 V lead-acid car battery (14.8 V when fully charged). Any voltage, minimal 2 V larger than the voltage of the batteries to be charged, provided the voltage is larger than 6.5 V, will do. The minimal voltage is dictated by the internal 5V regulator that powers the micro-processor. The maximum voltage allowed is 32 V DC, which is defined by the maximum supply voltage of the operational amplifiers that drive the constant current sources. The Power supply must be capable of supplying the maximum charge current as selected without significant voltage drops. A 10 Amp fuse , build inside the NC2000 protects the battery from excessive current draining.

When 230 or 110 volt power supply is desired a simple transformer with bridge cell may be used provided a large capacitor limits the ripple voltage (10.000 µF or greater).
A more expensive solution is a switched mode power supply. Switched mode power supplies are more compact by design and generally have a neglectable ripple voltage. Both solutions must be capable of providing 12 V DC @ 8 A to allow charging batteries up to 9.6 V. The minimal power supply voltage is 6.5 V allowing batteries up to 4.8 V (4 cells) to be charged.

Indicators

The NC2000 has four LED indicators that denote fast charge stage, topping and maintenance stages, and the polling detect and out-of-temperature range modes as shown in table 3. A combination of lit indicators denotes the charger detected a fault condition.

The charge indicator is activated continuously during the soft start and fast charge stages. When the controller enters the topping charge stage, the indicator turns off.

The “trickle charge / discharge” indicator is on when the NC2000 is either in the topping charge, maintenance charge, direct maintenance mode, or in the condition mode. The “trickle charge / discharge” indicator is also lit in conjunction with the hot battery indicator when cold battery charging is in progress. The “trickle charge / discharge” indicator flashes at a one second rate when the NC2000 is in the discharge portion of the discharge-to-charge or the discharge-only mode.

The “No batteries” indicator is on when the NC2000 is in the polling detect mode. The charger applies periodic charge pulses to detect the presence of a battery. The indicator is a warning that these charge pulses are appearing at the battery terminals at regular intervals. When a battery is detected the indicator is turned off.

The out of temperature indicator is lit when ever the voltage at the temperature sense input enters a range that indicates that the attached battery is too hot to charge. The out of temperature indicator is also activated together with the “trickle charge / discharge” indicator if the charger is initialised with the battery in the cold battery charge region.

Table 4: Indicator description list

No Battery	Trickle charge / Discharge	Fast charge	Too Hot	Description
on				Polling detect mode

	on			Maintenance or topping charge, direct maintenance or condition mode
		on		Fast charge
			on	Hot battery shutdown
	on		on	Cold battery charge
	flash			Discharge portion of the discharge-to-charge or discharge only mode
		flash		Voltage detected at the battery terminals with no batteries and current source off
		on	on	Cold battery detected during fast charge.
	flash	flash		Battery disconnected during discharge-to-charge mode
	flash		on	Cold battery while discharging

The NC2000 indicates a fault status by lighting a combination of indicators.

When the fast charge indicator is flashing with no other indicator active, there is voltage present at the battery terminals with the current source off and no battery attached. Check the current source and ensure that it produces no more than the equivalent of 350 mV/cell when turned off with no battery. If the fast charge indicator flashes with a battery installed then the constant current source is producing more than the equivalent of 350 mV/cell when off and there is an open connection between the charger terminals and the battery. Check wires, connections, battery terminals and the battery itself for an open circuit condition.

If the fast charge and too hot indicators are active together, this is an indication that the battery temperature has dropped to below 10°C after a fast charge was initiated with battery temperature normal. If this condition is observed and the battery temperature did not drop after high charge was initiated, check the thermistor circuit mechanically for poor contact and electrically for excessive noise.

If the “trice charge / discharge” and fast charge indicators are alternately flashing, the likely cause is no battery with the NC2000 programmed in the discharge-to-charge mode. If the battery is present, check wires, connectors, battery terminals and the battery itself for an open circuit condition.

If the “trickle charge / discharge” indicator is flashing with the too hot indicator active, this is an indication that the battery is cold while in either the discharge portion of the discharge-to-charge mode or the discharge only mode. When in the discharge-to-charge mode, if the battery does not warm-up into the normal temperature range after the discharge is complete, the NC2000 will enter the maintenance charge stage. When the battery warms-up, the discharge-to-charge mode will repeat.

Charge Rate Selection Switch

The charge rate selection switch allows the user to inform the NC2000 of the desired charge rate. The charge rate selection determines the topping and maintenance charge pulse rate, the fast charge timer duration and in conjunction with the capacity selector, the charge and discharge currents.

Table 5: Charge Rate List

Rate switch position	Charge Rate	Topping Charge Pulse Rate	Maintenance Charge Pulse Rate	Fast Charge Timer Duration (after reset)
1	C/4 (240 min)	one every 2 sec	one every 10 sec	275 min
2	1C (120 min)	one every 10 sec	one every 40 sec	75 min
3	2C (60 min)	one every 20 sec	one every 80 sec	39 min
4	4C (15 min)	one every 40 sec	one every 160 sec	21 min

Battery Capacity Selection Switch

The capacity selection switch allows the user to select a charge and discharge current suitable for the batteries to be charged. The battery capacity switch determines the charge and discharge currents in conjunction with the rate selection switch.

Table 6: Current rate list

Capacity switch position	Rate switch position	average fast charge / discharge current	discharge pulse current during fast charge	average conditioning current	average maintenance current
1 - 2000 mAh	1 - C/4	500 mA	1.25 A	200 mA	50 mA
	2 - 1C	2 A	5 A	200 mA	50 mA
	3 - 2C	4 A	10 A	200 mA	50 mA
	4 - 4C	8 A	20 A	200 mA	50 mA
2 - 1500 mAh	1 - C/4	375 mA	937 mA	150 mA	37.5 mA
	2 - 1C	1.5 A	3.75 A	150 mA	37.5 mA
	3 - 2C	3 A	7.5 A	150 mA	37.5 mA
	4 - 4C	6 A	15 A	150 mA	37.5 mA
3 - 1000 mAh	1 - C/4	250 mA	625 mA	100 mA	25 mA
	2 - 1C	1 A	2.5 A	100 mA	25 mA
	3 - 2C	2 A	5 A	100 mA	25 mA
	4 - 4C	4 A	10 A	100 mA	25 mA
4 - 500 mAh	1 - C/4	125 mA	312 mA	50 mA	12.5 mA
	2 - 1C	500 mA	1.25 A	50 mA	12.5 mA
	3 - 2C	1 A	2.5 A	50 mA	12.5 mA
	4 - 4C	2 A	5 A	50 mA	12.5 mA

Mode Selection Switch

The mode selection switch allows the user to select on of six programs the NC2000 will execute.

Table 7: Mode selection list

Mode Switch Position	Mode selected	Mode operation
1	Ten hour timer	Limits total charge including maintenance charge to 10 hours
2	Condition	Timed C/10 topping charge followed by a C/40 maintenance charge
3	Discharge-to-charge	Battery discharge to 1 V/cell followed by the selected charge mode
4	Discharge-only	Battery discharge to 1 V/cell
5	Fast charge	Fast charge only
6	Direct maintenance	Indefinite C/40 maintenance charge

Termination Selection Switch

The NC2000 has the capability of either temperature slope termination, voltage slope termination or both methods simultaneously. The termination selection switch allows the user to select the termination method. If another termination method is desired the NC2000 must be reset after the selection is made.

Table 8: Termination selection list

Termination Switch Position	Result
1	Temperature slope termination only
2	Voltage slope termination only
3	Voltage slope and temperature slope termination

Number of Cells Selection Switch

Batteries are charged and/or discharged by a constant current source. The voltage selection is irrelevant for charging or discharging. However, the low battery detection circuit and an open battery terminal detection circuit operate by measuring the battery voltage. Further more the internal electronics can not handle voltages over 5 volt. The battery measurement voltage is normalised to a single cell level by a voltage divider. This process is not automated for shorted cells would not be detected. A number off cells detection circuit would assume a battery pack with one cell less than really is the case. The number of cell selection switch ensures battery measurements are correct under all circumstances.

Because of the voltage drop across the constant current source the minimum number of is two and the maximum is eight cells connected in series when using a 12 volt power supply.

Table 9: Number of cells selection list

Number of cells Switch Position	Number of cells	Total battery voltage
1	8	9.6
2	7	8,4
3	6	7,2
4	5	6,0
5	4	4.8
6	3	3.6
7	2	2.4

Reset Push-button

A user selection is recognised only when the NC2000 powers up. To simplify this procedure a reset push-button allows the restart of the controller without powering down. Since some ports of the circuit remain powered when a battery is connected, even when the power supply is disconnected, the reset button provides the only sure way to initiate a new program.

Data tables

Table 10: Absolute Maximum Ratings

Supply Voltage	20	V
Ambient operating temperature	0 to 50	°C
Storage temperature	-10 to 80	°C

Stresses above those listed under Absolute Maximum ratings may cause permanent damage to the device. This is a stress rating only. Functional operation of the device at the Absolute Maximum Rating conditions for extended periods may affect product reliability.

Table 11: DC characteristics

PARAMETER	MIN	TYP	MAX	UNIT
Supply Voltage	7	14.8	32	V
Max. supply current		8		A
Max. charge / Discharge current (average)		8		A
Peak charge current		8		A
Peak Discharge current		20		A

Note: The maximum current ratings may be extended under certain conditions as described in the modifications chapter.

Table 12: DC Voltage thresholds

PARAMETER	TYP	UNITS
Minimum battery voltage	2.4	V
Discharge limit	1	V/cell
Thermistor - Cold Temperature	2.4	V
Thermistor - Hot temperature	0.93	V
Thermal switch - open	4.2	V
Thermal switch - closed	0.5	V

Table 13: Timing characteristics

PARAMETER	SYMBOL	REFERENCE	TYP	UNITS
Clock Frequency			1.0	MHz
Reset Pulse Duration	t_{reset}	see Figure 11	700	ms
Charge Pulse Width	t_{CHG}	see Figure 10	1048	ms
Discharge Pulse Width	t_{DCHG}	see Figure 10	5.0	ms
Rest Time	t_R	see Figure 10	4.0	ms
Data Acquisition Time	t_{DA}	see Figure 10	16.4	ms
Cycle Time	t_{CYCLE}	see Figure 10	1077	ms
Capacitor Discharge Pulse Width			5.0	ms
Capacitor Discharge Pulse Period			100	ms
Polling Detect Pulse Width			100	ms
Polling Detect Pulse Period			524	ms
Soft Start Initial Pulse Width			200	ms
Soft Start Increment Pulse Width			7.0	ms
Discharge Mode Pulse Width			400	ms
Discharge Mode Pulse Period			1050	ms
Program Initialisation Period after Reset	t_{RSA}	see Figure 11	1160	ms

Figure 10:

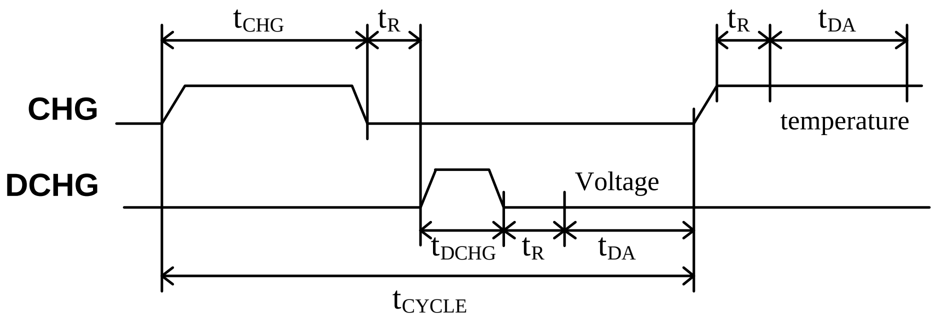
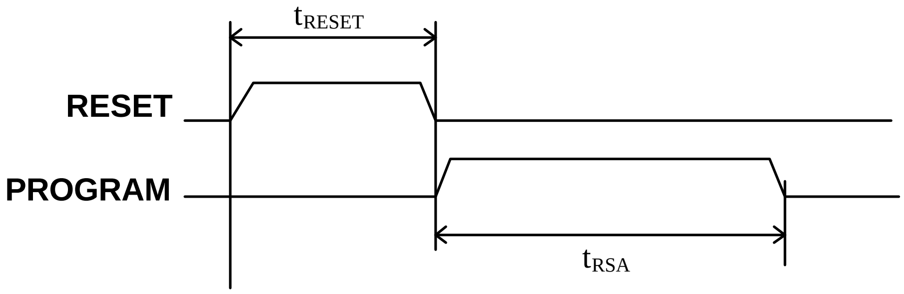


Figure 11:



Temperature Slope and Maximum Temperature

The use of Temperature slope and/or maximum temperature termination as a back up termination method may prove the best approach. Temperature termination methods require that the thermal sensor be in intimate contact with the battery. A low thermal impedance contact area is required for accurate temperature sensing. The area and quality of the contact surface between the sensor and the battery directly affects the accuracy of temperature sensing. Thermally conductive adhesives may have to be considered in some applications to ensure good thermal transfer from the battery case to the sensor.

The thermal sensor should be placed on the largest surface of the battery for the best accuracy. The size of the battery is also a consideration when using temperature termination. The larger the battery the lower the surface area to volume ratio. Because of this, larger batteries are less capable in dissipating internal heat.

Additional considerations beyond the basics mentioned above may be involved when using temperature slope termination where sudden changes in ambient temperature occur or where forced air cooling is used. For these applications, the surface area of the thermal sensor in contact with the battery compared to the surface area of the sensor in contact with the ambient air may be significant. For example, bead type thermistors are relatively small devices which have far less thermal capacity compared to most batteries. Insulating the surface of the thermistor that is in contact with the ambient air should help minimise heat loss by the thermistor and maintain accuracy.

may have to be used for

Design Considerations

This design is an answer to a need for a simple, cheap yet reliable battery charger. Although most modern chargers use some micro controller with a Liquid Crystal Display this solution was quickly dismissed because it would make the design more expensive while the information supplied on a display has little value in comparison to its cost. The only real benefit of a LCD is the option to display the rest capacity of a battery after discharging it. A job that can also be done with some common sense and a wrist watch. The capacity of a battery is seldom tested since it requires full charging it followed by a completely discharging it. If needed there are other simple ways of doing that.

The ready-to-use charge controllers offer almost all control requirements at far less cost than a micro computer. Another reason to use an off-the-shelf charge controller is that it does not require someone to program it, a great threshold for hobbyists to use a design is when a pre-programmed micro controller is required, available at only one place in the world.

The ISC 1702 charge controller came up as a controller that would fulfil the requirements and it is affordable. The ICS 1702 supports reverse pulse charging, although the effectiveness of this charge method is questionable, it is sure it does not harm the battery. This reverse pulse charging method is therefore acceptable.

An important reason for choosing the ICS 1702 lies in is very good termination algorithms. It truly differentiates the voltage and temperature signal and is thus capable of detecting not only the charge voltage peak but also the inflection point, the point on the voltage curve where it changes from rising to falling (The first derivative peaks). A more safe way to stop a fast charge process and switch to a more moderate charging method.

Unlike most charge controllers the ICS 1702 has both temperature and voltage slope termination, Most others support only one of these. Last it supports all functions required such as fast charging, discharging, conditioning, trickle charging and several safety timers as a last defence against over charging.

The other parts used are all chosen with price and availability in mind. Instead of more sophisticated voltage converters this design uses a simple NE 555 driven switched capacitor voltage doubler and it uses a very common Operational Amplifier.

Programming is done by widely available rotary switches. The (relative) most expensive and hard to get parts are the precision resistors used to control the constant current sources. When configured for large battery capacities, the heat sink will be the most expensive part. A handy hobbyist may replace it with a home build heat sink or use an aluminium case as heat sink.

Description of the Schema

The NC2000 charger schema consists of two pages, one page shows the control electronics and the other the power stages of the charger.

Constant current sources

The power stage consists of two constant current sources, one for charging and one for discharging the battery. The basic configuration of the current sources is shown in figure 12.

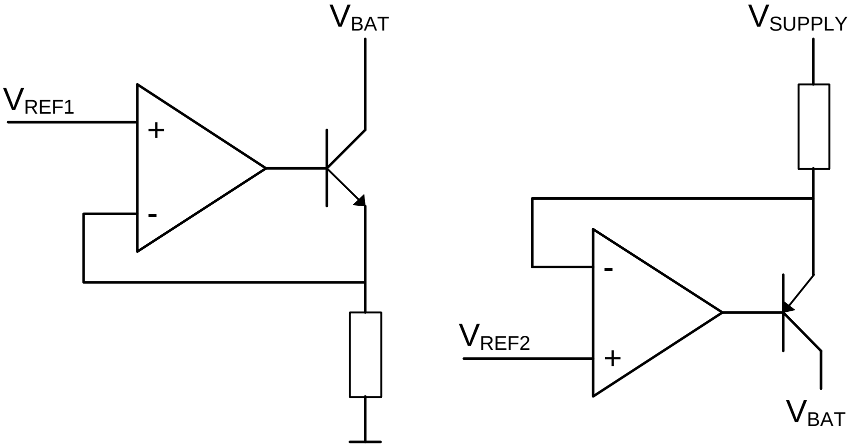


Figure 12: Basic Programmable Current Sources

The OpAmp will control the transistor in such a way that the voltage difference between its inverting and non-inverting inputs becomes zero volt. This means the voltage across the emitter resistor equals $V_{REF.}$ In other words, the circuit maintains a constant voltage across the emitter resistor. If the voltage across a resistor is constant, the current flowing through it must be constant too. The circuit is a constant current source.

Note that the reference voltage for the charge circuit (V_{REF2}) is relative to the supply voltage while the reference voltage (V_{REF1}) for the discharge circuit is relative to ground.

The discharge circuit of the NC2000 is build around power transistor Q6 and the U6A OpAmp. The OpAmp controls the power stage in such a way the voltage over the emitter resistor R33 is equal to the control voltage on the input of the OpAmp. At maximum discharge current the base current of Q6 is too much for the OpAmp to source, an intermediate stage Q10 amplifies the output current. Since the intermediate stage inverts the control current (A raise of the OpAmp output voltage causes a decrease of the Q6 base current) the reference voltage must be provided on the inverting input of the OpAmp, and the emitter resistor voltage is on the non-inverting input.

The charge portion is build around power transistor Q5 and OpAmp U10A. It operates similar to the discharge stage, since it is in the supply voltage line all signals are referenced to the supply voltage. If the function of the charge circuit has to be examined with a multi-meter one lead should be connected to the supply line instead of to GND.

Because the darlington transistors have a build-in clamping diode the NC2000 may be take its power supply from the battery through the clamping diode of Q5. The charger seems to be operational even with the power switched off. To avoid this feature a diode may be added between the collector of Q5 and the battery terminal. This diode can not be mounted in the battery connection for it would prevent the discharge of the battery.

This diode is not in the design for it would take away at least one volt of the supply voltage making it impossible to charge 2.4 volt batteries. If this diode is desired ensure it is capable of handling the maximum charge current. It should be mounted on the heat sink since it will dissipate, at 8 amp charge current, about 8 watts!
When the diode is not used the charger is capable of discharging the batteries without a power supply.

The current control voltages are generated from a reference voltage by OpAmp U10B and Q8. U10B, Q8 and R56 are, again, a constant current source. The voltage over the emitter resistor R56 is equal to the reference voltage. Since the voltage over the emitter resistor is constant, the current through R56 and R57 is constant too. The voltage over R57 follows the voltage over R56. In other words the voltage over R56 with reference to ground is mirrored to the voltage over R57 with reference to the supply voltage. By choosing a different value for R57 the voltage over R57 will be exactly 0.4 times the voltage over R56.

The discharge current equals the reference voltage divided by R33 and the charge current becomes 0.4 times that value because R38 is equal to R33.

The circuit parts around FET's Q1, Q3 and Q4 enables the current sources to be switched on and off by logic signals. Q1 puts +5 V on the input of OpAmp U6A, a level well above any possible reference voltage. When Q1 is conducting diode D1 prevents current flowing from the current resistor R33. This means the circuit around Q1 is virtually not there. A similar situation exists around Q3 and Q4. Since Q3 inverts the logic signal Q4 is needed (If Q3 conducts, Q4 does not). If Q4 is conducting the OpAmp's input is pulled to a voltage level that prevents Q5 from conducting. When Q4 is not conducting, it does not influence the current measurement by OpAmp U10A.

The two current sources may never be active at the same time. Since they are both connected to the same battery terminal all current will flow through Q5 and Q6 if enabled at the same moment, no current will flow from or to the battery.

OpAmp supply

Because of the common mode voltage range of the OpAmps they can not operate near their supply voltage. The supply voltage of the OpAmps must be at least 1.5 volts above the maximum input voltages. Since U10A has to handle voltages near the supply voltage a higher voltage is needed to supply the OpAmps.

The OpAmp supply is generated by a switched capacitor network around U11. The NE555 generates a square wave of about 10 kHz. When its output is low capacitor C18 is charged through D8. (Its negative lead is virtually connected to GND) When the output of the NE555 goes high the voltage between C18 and D8 is lifted about 5 volts and C18 will discharge over D9. (The negative lead of C18 is virtually connected to 5VDC). C19 is a buffer to stabilise the higher voltage (V++). In practise the V++ voltage will be about the supply voltage plus 3.8 V, enough to bring the input voltages of the OpAmps within their common mode range. The real value of V++ is not important as long as it is more than 2 V higher than the supply voltage and not higher than 32 V, the maximum supply voltage allowed for a LM358. If the NE555's supply is taken from the 12VDC supply V++ would raise to about 1.8 times the supply voltage, but since the NE555 has a supply limit of 16 V this would severely limit the supply voltage range.

The maximum voltage acceptable by the OpAmps is 32 V. This value limits the maximum supply voltage of the NC2000 to 32V.

Charge control

The control section of the schema is build around the ICS1702 battery charge controller. This controller does all the work. The only thing needed outside the controller are the voltage divider for the current sources and a voltage divider for the battery voltage. All other controls are directly connected to the charge controller and define how its program operates.

Battery Voltage Divider

The battery voltage divider simply divides down to a single cell voltage. D6 is added to prevent damage to the controller in case a wrong battery voltage is selected. The battery voltage divider is used only for scaling down the battery voltage to a level acceptable by the controller. The battery voltage is used only to determine the voltage slope and the discharge limit voltage of 1 V/cell. If a wrong number of cells is programmed by SW 4, it will not damage the batteries since constant current sources are used for charging and discharging the battery. A wrong number of cells may however cause bad voltage measurements during fast charge or discharge. If batteries are to be deeply discharged a the number of cells could be set one higher than the actual number of cells, causing the discharge to stop at a slightly lower voltage than 1 V/cell.

As long as the divided battery voltage is within the range of 0 - 1.6 V the batteries will charge correct since the first derivative of the voltage is determined. The first derivative will be the same regardless of the actual voltage present on the VIN input of the controller. When the VIN voltage becomes higher than 1.86 V the controller decides there is no battery connected. When the SW 4 switch is set correct this is the case when the supply voltage only feeds the battery voltage divider. A to low setting of SW 4 with batteries connected will cause the ICS1702 controller to decide no battery is present since its VIN voltage is above 1.86 V. If no battery is present the ICS1702 stop operation and must be reset to resume operations.

Current Source Voltage Divider

The current source is reference voltage divider is a little more complex. The circuit has to deal with two different aspects of the charge process. The charge/discharge currents are defined by both the charge method and the battery capacity. Changing the charge method not only requires different charge/discharge currents but also influences the timers of the ISC1702 charge controller, while changing the battery capacity only changes the charge/discharge currents. The current control reference voltage divider consists actually of two voltage dividers connected in series. The capacity defined current is set by SW3, R55, R54 and R52. The charge method defined current is set by SW5A, R44, R45, R46 and R47.

Other battery capacities

If other than the basic design charge/discharge currents are needed following procedure can be followed:

The circuit part around Q8 ensures the charge current is always 0.4 times the discharge current. The control voltage defines the discharge current. The following procedure describes how the current control voltage divider resistors are calculated. As an example the values of the basic design are used.

Create a two dimensional array with desired battery capacities in the leftmost column, as shown below.

Table 14: Current Control Voltage Divider Resistor Calculation

	Method															
Capacity (mAh)	4C				2C				1C				C/4			
	I	U	RA	RB	I	U	RA	RB	I	U	RA	RB	I	U	RA	RB
2000	20	2.4	2k6	2k4	10	1.2	3k8	1k2	5	0.6	4k4	600	1.25	0.15	4k8	150
1500	15	1.8	5k1	2k4	7.5	0.9	6k3	1k2	3.75	0.45	6k9	600	0.93	0.11	7k3	150
1000	10	1.2	7k6	2k4	5	0.6	8k8	1k2	2.5	0.3	14k4	600	0.62	0.07	9k8	150
500	5	0.6	17k6	2k4	2.5	0.3	18k8	1k2	1.25	0.15	19k4	600	0.31	0.04	19k8	150

Enter the required discharge currents at 4C this is 10 times the battery capacity (2.5 times 4 times the battery capacity). At 1C the discharge current should be 2.5 times the battery capacity, etc.

Next, calculate for each discharge current the control voltage using the formula:

$U_{REF} = I_{DISCHARGE} / R_{33}$ Formula I

Then decide on two resistor values (RA and RB) that will divide the 5 volt voltage down to the desired reference voltage, starting in the upper row of the table.

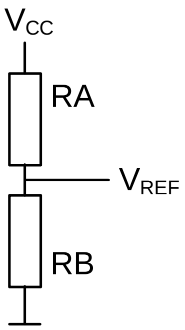


Figure 15: Generic Voltage Divider

$U_{REF} = 5\ V \times RB / (RA + RB)$ Formula II

By choosing a total resistance value of (RA + RB) of 5 kΩ calculation is greatly simplified. The RB value then equals the desired voltage in kΩ. E.g. 2.4 V requires a resistor of 2k4, etc. Once the RB values are established for the first row the RA values are easily calculated by subtracting the RB value from 5kΩ

Now copy all RB values to the other columns. And calculate the RA values for the other columns. Note that the sum of RA and RB is constant in each row. Once the voltage dividers are calculated they need to be transformed to real resistor values:
$R_{47} = RB_{column\ 4}$
$R_{46} = RB_{column\ 3} - R_{47}$

$R_{45} = RB_{\text{column 2}} - R_{46} - R_{47}$
$R_{44} = RB_{\text{column 1}} - R_{34} - R_{46} - R_{47}$

With the RA values from column 1 (4C) only, the rest of the resistors is calculated:

$R_{52} = RA_{\text{row 1}}$
$R_{53} = RA_{\text{row 2}} - R_{52}$
$R_{54} = RA_{\text{row 3}} - R_{53} - R_{52}$
$R_{55} = RA_{\text{row 4}} - R_{54} - R_{53} - R_{52}$

The last step is to round the values found to the nearest available real value from a 1% metal film resistor range. This establish the resistor values for the current reference voltage divider. Use only 1% metal film resistors for divider accuracy and temperature stability.

Because the NC 2000 uses voltage and temperature termination the selectable battery capacities do not need to match the real battery capacity. To avoid stressing the batteries select the first lower value with SW3 or the first lower charge method with SW5. This ensures the charge and discharge currents will be less than the maximal allowable currents for the battery.
What ever charge method or battery capacity is selected, the voltage slope and/or temperature slope termination methods will prevent the battery from being overcharged.

Current and Supply Voltage Limitations

The previous paragraph showed how other battery capacities can be supported, there are however limits to the maximum current imposed by the power darlington transistors Q5 and Q6. Though the power darlington's may handle a voltage of 120V, the maximum supply voltage is defined by the components used U6 and U10 limit the supply voltage to 32 V.

When the charge darlington transistor (Q5) conducts a minimum voltage loss of 1.5 to 2 V remains over the transistor. This limits the maximum charge voltage to Vsupply - 2 V. Using a 12 V supply this means there can be a maximum of (12 - 2) / 1.2 = 8 cells in series charged. (9.6 volt battery). A fully charged car battery (14.8 V) allows 10 cells to be charged (12 V battery).

The discharge darlington transistor (Q6) also has this minimum of 2V, limiting the number of cells to be discharged to two (2.4 V).

The LM7805 voltage regulator that powers the charge controller requires a minimal voltage of 7 V for proper voltage regulation. This limits the minimal supply voltage to 7 V.

The constant current source darlington transistors have a maximum current rating of 30 A. The problem with the maximum current however is not in this rating but in the maximum power these transistors may dissipate.

Two extremes exist.

- Discharging the maximum number of cells of maximal capacity at 4C.

The power dissipated in Q6 is $V_{BAT} \times I_{DISCHARGE}$. Discharging a 2000 mAh, 9.6 V battery is done with an average current (duty cycle 40%) of 8 A. This dissipates $I^2 \times R$ => $8^2 \times 0.12 = 7.6$ watts in R33 and $(V_{BAT} - V_{R33}) \times I_{DISCHARGE}$ => $(9.6 - 8 \times 0.12) \times 8 = 69$ Watt in Q6. The maximal allowable junction temperature of Q6 is 200 °C. Its thermal conductance (TO-3, junction to case) is 1 K/W. Following formula is used to calculate the total thermal resistance of the heat sink to allow the power to be dissipated by Q6:

$R_{th\text{-}tot} = (t_j - t_a) / P$ Formula III

If the NC2000 is build in a tote the ambient temperature inside the tote will probably be higher than the open air ambient temperature. The ambient temperature for the calculation is therefore assumed to be 50°C which should supply enough safety margin. The total required thermal resistance becomes then:

$R_{th\text{-}tot} = (200 - 50) / 69 = 2.17$ K/W.

By subtracting the thermal resistance of the TO-3 case and the insulating wafer the maximal thermal resistance of the heat sink is established. (An average value of 0.4 K/W is used for the insulation wafer):

2.17 - 1 - 0.4 = 0.77 K/W

- Charging only 2 cells of maximum capacity at 4C

A similar problem exists when the minimum number of cells (2) are charged at maximum capacity using the 4C method. Then the charge darlington transistor has to dissipate 8 A.
At 12 volt supply, R38 dissipates $I^2 \times R \Rightarrow 8^2 \times 0.12 = 7.6$ Watts. The power darlington Q5 dissipates R38 and $(V_{SUPPLY} - V_{R38}) \times I_{CHARGE} \Rightarrow (12 - 8 \times 0.12) \times 8 = 88$ Watts, Using formula III the total thermal resistance required is:

$R_{th\text{-}tot} = (200 - 50) / 88 = 1.7$ K/W.

The heat sink must be better than:

1.7 - 1 - 0.4 = 0.3 K/W

With a 14.8 V supply voltage (a fully charged car battery) the power dissipation in Q5 is 110 W requiring a heat sink of 0 K/W !! This seams impossible, however the extremes are not expected, usually large capacity batteries are 7.2, 8.4 or 9.6 volts and never 2.4 volts. Assuming batteries of less than 7.2 volt are always low capacity a heat sink of 0.77 K/W is sufficient in all cases.

The prototype model uses a heat sink of 0.6 K/W, slightly better than required.

Increasing the Charge/Discharge Currents

Larger discharge currents are allowable when the heat sink is sufficiently enlarged or when the number of cells is limited.

When the charge/discharge currents need to be incremented be aware of the maximum average current of 30 A allowed to flow through the darlington’s Q5 and Q6. Always calculate, using the formulas from the previous paragraph, the maximum power to be dissipated in R33, R38, Q5 and Q6 and decide weather another type of resistor is needed. The types in the NC2000 design allow a maximum power dissipation of 9 Watts. Larger power types come in aluminium cans and can best be mounted on the heat sink using thick wires, instead of on the PCB. To limit the heat dissipation in the current source resistors smaller values may be used. In the 9W series values below 0.12 Ω are hard to get. In the 25W series values of 0.1 Ω or smaller are more easy to obtain.

The heat sink can be virtually enlarged by forced air. A fan control circuit around U6B switches the fan on when the temperature of the heat sink rises above 45 °C provided the

NTC thermistor (NTC 2) is mounted in a dead hole in the heat sink. R68 provides some hystereses, avoiding the fan to switch on and of all the time when the heat sink temperature is around 45 °C. A fan may also be connected directly to the power supply for continues run.

The air flow of the fan must be direct and equally spread over the heat sink. no obstacles may interfere with the air flow.

Using forced air allows the maximum current of 30 A to flow through the transistors. The charge current is 0.4 times the discharge current and becomes 12 A. Even larger currents are possible if the discharge pulse current is reduced by changing R57. The benefits of the negative pulse current is still a matter of debate amongst scientists. Note that when the discharge pulse current is reduced the discharge process will take longer, the 40% duty cycle while discharging a battery remains.

Practical Thermistor Mounting

Thermistor mounting, already discussed in the theoretical section of this document, must be very close to the battery. A thermistor probe can be used provided it is put in a thermally isolated box with the battery. A thermistor probe can be made of a plastic tube (e.g. a ball point part) and some epoxy resin. Make sure the thermistor us not fully encapsulated by the tube.

A more elegant method is to add a thermistor to each battery pack. Many battery packs are made of point welded cells covered by a heat shrunk sleeve. Remove the sleeve and glue the thermistor to the battery pack using some adhesive tape. Then cover the pack again with a new heat shrinkable sleeve. Make sure the thermistors leads are well isolated and the thermistor does not have electrical contact with the battery. A short piece of wire and a 2.3 mm ear-piece connector allow the thermistor to be connected while the battery is charged.

Component mounting and Testing

The PCB has copper traces on one side only, The trace width and the minimum space between traces is 0.32 mm. This makes the design more easy to copy for less experienced builders. The pitfall is that there are some 20 wire bridges that are best inserted before any components are mounted.

Its has shown good practise to start with the smallest components and leave the larger ones for later. The large components often are in the way when small components are to be mounted. Leave the ISC1702 charge control chip (U7) out until after the circuits have been tested. Also leave the LED’s out until the board is mounted against a front panel. The LED’s need to be mounted with long leads to have their heads sick into holes of the front panel..

Connect the power darlington’s, the power supply and the battery using minimal 2.5 mm^2 wires.

When all components are mounted temporary connect the gate of Q3 to Vcc and temporary connect the gate of Q1 to GND. When the unit is powered measure the voltages across R56 and R57. The Voltage across R56 must equal the voltage on Pin 1 of SW5 and must also equal the voltages calculated in table 14. The voltage across R57 should be 0.4 times the voltage across R56. If all this checks out well, connect an old battery and check if the voltage across R38 equals the voltage across R57.

Remove the temporary connection of the gates of Q1 and Q3 and connect these gates the other way around, gate Q3 to GND and gate Q1 to Vcc. With the old battery still connected the voltage over R33 which must equal the voltage over R56.

When these tests check out OK remove the power from the unit, the temporary gate connections of Q1 and Q3 and insert U7. The power up again and test the unit by discharging and charging an old battery. The charging process can be monitored by measuring the voltage over the battery. The charge and discharge phases show by a slight movement of the multi-meters needle. The currents can be checked by measuring the voltages over the resistors R33 (discharge current) and R38 (charge current).

Casing

The PCB is designed such that it can be mounted to a front panel using only the M10 nuts of the rotary switches. Many knob models will cover the nuts later. The size of the PCB equals the size of a common available heat sink, allowing the heat sink to be mounted behind the PCB. The heat sink used in the prototype is a Fisher Elektronik SK90/75 (0.6 K/W) which measures 190 x 75 x 50 mm. Many other manufacturers supply heat sinks with similar measurements.

The prototype case was build of four aluminium profiles screwed to the heat sink. A front and rear panel are mounted using four screws each. The screws go inside the head and tail end of the hollow aluminium profiles. Finally four cover plates close the case.

The prototype case also carries a 230 V AC supply described later. A relay disconnects the car battery terminal to prevent accidental “charging” of the car battery. The 230 V AC unit used is not capable of charging a car battery because it does not have any current limit.

Some extra pieces of aluminium were used to mount the parts of the 230 V AC supply as well as to optimise the fans air flow. The top lid is made of a punched aluminium plate the air flow is from the fan over the heat sink through the top plate. Some extra pieces of aluminium prevent the air from escaping early through the top plate.

To mount the TO-3 cased darlington power transistors a 40 mm aluminium angle profile is mounted against the heat sink. The transistors are then mounted horizontally on the profile. The heat sink thermistor is placed inside a dead hole in the heat sink. A plastic tube made of an old ball-point and some heat conducting paste isolate it from the heat sink. The aluminium angle profile also keeps the thermistor in place. All parts of the heat sink are treated with heat conducting silicon paste before they were mounted to ensure good thermal conductance from the transistors cases through the angle profile to the heat sink.

The batteries are connected using two 4 mm banana plugs. After the photos were taken the plugs were replaced by an asymmetrical two terminal connector to avoid accidental exchange of the banana plugs.

PCB Etching

To keep things simple the PCB design uses only a single side and some wire bridges on the component side. This avoids problems aligning two sides, which can be a real pain for amateurs.

The PCB layout was printed to scale by an inkjet printer. The lay-out was copied from there to a piece of lithographic film. This was done by a local offset printing company.

They charge only a few dollars and the result has a much better quality than a print-out on an overhead sheet. Most printers posses a lithographic camera capable of handling large film sizes. In my case they did not charge me anything, I asked them to use scrap film and I did not specify a delivery time giving them a chance to do it in their lost hours.

The lay-out was then transferred on a piece of photo-sensitive PCB, lighted by a home build UV box. This UV box contains two UV-TL pipes and a timer. The PCB and film are pressed together by a piece of foam and the lid of the box. The PCB was developed using a NaOH solution (Sodium Hydroxide or sink de-choker). Use a low concentration and some patience, a high concentration works fast but also affects the un-exposed areas. Special PCB developers are safer but more expensive.

The PCB was etched in a aquarium pump driven bubble etching tank using FeCl (Ferri Chloride), available from every electronics shop. Less dirty but slower and more expensive are the specially developed fine etching crystals, but once solved into water they can not be kept very long and these chemicals can dissolve much less copper than FerriChloride can. By far the cheapest way to etch is by a mixture of hydrochloric acid and peroxide. This mixture can be used only once and gives unpredictable results.

After etching and carefully rinsing the PCB the remainder of the photosensitive lack needs to be removed either by sanding it of with steel wool or by exposing the PCB again with UV (without the film) and developing it again. When the PCB is carefully rinsed and dried an aerosol solder lack was applied that protects the copper from oxidation and ensures good solder flow in a later stage. After a few hours the lack is dry and the PCB can be drilled with a mini drill.

Front panel

Using the same process as described in the previous paragraph a film was made with the front panel text and symbols. This film is sandwiched between a fine sanded aluminium sheet and a transparent piece of polycarbonate (available from any do-it-yourself store). All holes are drilled in the aluminium and polycarbonate before the film is placed in between. The holes for the LED’s are drilled in the aluminium only and are widened by a countersink drill on the visible side of the sheet. The holes in the film are made by pressing the aluminium, the film and the polycarbonate together and sliding a hobby knife through the holes (not the LED holes). The three sheets of the Front panel are held together by the nuts that mount the switched to the front panel. Once the three parts are screwed together the access film is removed by sliding a hobby knife over the edges of the sheets. The end result looks very professional as shown on the pictures.

230 V AC Power Supply

Although designed for use by a car battery the NC2000 operated without problems from a simple transformer, bridge cell, and electrolytic capacitor. The prototype has a toroidial transformer simply because it was available in the old junk box. Not the best choice. because a toroidial transformer has no air gap its output voltage is not constant. It depends on the current drawn. A far better choice would be an old fashioned, square transformer. Because of their construction they have a much more stable output voltage. The greater magnetic stray field is not a problem (a charger is no a HiFi audio device).

A standard 35 Amp bridge cell rectifies the AC voltage of the transformer. For safe operation choose a bridge cell with a current rating at least 1.5 times larger than required.

The prototype uses a 8600 µF electrolytic capacitor which is a little small While charging at maximum capacity the ripple voltage is quite large but it never caused the charger to malfunction. Again, this value was chosen simply because it was in the old junk box. In its former life it served in the supply of a colour TV set.

The prototype is build in a RC-tote that houses amongst others, a 12 V, 10 Ah lead-acid battery. If 230 VAC is applied to the tote, a constant current charger charges the lead-acid battery. If the NC2000 were to take its power from the lead-acid battery it would drain it since the charge current to the lead-acid battery is far less than the current required by the NC2000, hence the relay.

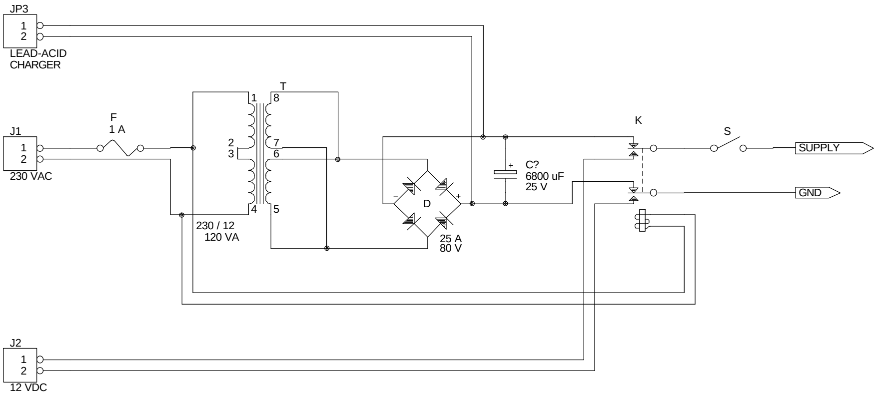


Figure 15: 230 V AC Supply

Bill of materials

2000 mAh DELTA PEAK REFLEX LOADER Revised: February 26, 1999
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Item	Quantity	Reference	Part
1	7	C2,C3,C4,C5,C6,C7,C10	100nF
2	1	C11	470uF 16V
3	4	C12,C13, C16, C17	10nF
4	1	C14	100pF
5	1	C15	1uF 16V
6	1	C18	10uF 35V
7	1	C1	1nF
8	1	C19	100uF 35V
9	4	D1,D7,D8,D9	1N4148
10	4	D2,D3,D4,D5	LED
11	1	D6	ZENER DIODE 3V9
12	2	F1,F2	FUSE HOLDER and FUSE 10A
13	1	H1	HEAT SINK Fisher SK 90/75
14	2	NTC1,NTC2	NTC Thermistor 10K @ 25 °C
15	3	Q1,Q3,Q4	BS170
16	1	Q5	MJ11015
17	1	Q6	MJ11016
18	1	Q7	BD234
19	1	Q8	BC547B
20	1	Q9	NPN
21	1	Q10	PNP
22	3	RN3,RN4,R31	10K
23	3	R32,R34,R39	2K2
24	2	R33, R38	0E12 - 9 W
25	1	R35	15K
26	1	R37	820E
27	1	R44	1K21 1% metal film
28	1	R45	604E 1% metal film
29	1	R46	453E 1% metal film
30	1	R47	150E 1% metal film
31	1	R52	2K61 1% metal film
32	1	R53	1K69 1% metal film
33	1	R54	3K32 1% metal film
34	1	R55	10K0 1% metal film
35	1	R56	560E
36	2	R57,R67	220E
37	2	R58,R59	390E
38	1	R60	16K
39	2	R61,R70	6K8
40	1	R62	3K3
41	1	R63	27K
42	2	R64,R65	22K
43	1	R66	4K7
44	1	R68	100K
45	1	R69	180E
46	2	R71,R72	1K

Item	Quantity	Reference	Part
47	1	S1	Push-button
48	3	SW1,SW3,SW4	LORIN-SK12 1 to 12
49	1	SW2	LORIN-SK12 2 to 6
50	1	SW5	LORIN-SK12 3 to 4
51	1	U4	LM7805
52	2	U6,U10	LM358
53	1	U7	ICS1702
54	1	U11	NE555

A Word About the Components

The components used are very common in Europe but might be less good available in other parts of the world. Since most components are not critical they can be exchanged with other types. To lessen the cost the author advises to check your electronics junk box first. Here are some remarks to keep in mind:

- Q5 and Q6 were selected because of their high DC gain (h_{FE}) and their high current rating (30 A). These darlington's have a h_{FE} of 2000 @ 20 A and still have a h_{FE} of >200 @ 30 A. Do not replace them with, for example a 2N3055 for this transistor has a far to low DC gain.
- The Drivers Q9 and Q10 are not critical and can be replaced by any other transistor. Just make sure they meet the current and power requirements (200 mA and 2 Watt). Their DC gain is not (h_{FE}) important. At full charge current Q5 and Q6 need 200 to 300 mA base current, a little to much for the OpAmps. The intermediate stages Q9 and Q10 bring down the current drawn from the OpAmps to below 20 mA. When other types are used for Q5 and Q6 the current and power requirements of Q9 and Q10 most likely will go up. Q9 and Q10 may be needing a small heat sink in that case or mount them with Q5 and Q6 on a large heat sink.
- Q8 can be replaced by any NPN transistor U10B will compensate a different characteristic of Q8.
- Q7 can be replaced with any ol' PNP power transistor. Just make sure it can handle the fan current.
- The diodes used are not critical any switch (or even rectifier) diode with a voltage rating of 35 V or more will do.
- The MOS-FETs Q1, Q3 and Q4 are not critical they are used in a switching mode only and may be replaced by any other N-channel enhancement type MOS-FET. Make sure their voltage rating is above 16 V.
- Most capacitors are in the prototype were taken out of an old colour TV set. They are used to short noise. C3, C4, C5, C6, C7 and C10 may have any value, the larger the better. C12 and C13 should not be made much larger for that would slow the switching characteristic of the current sources. The charger probably would work well without them. C1 should not be made too large for it will prevent correct voltage measurements by the charge controller. It is better to dismiss it than to increase its value.
  C14 is critical, with R60 it defines the clock rate of the controller. Use only the value shown in the schema.

- The value of the electrolytic capacitors used is not critical. Use what ever is available.
- The battery voltage divider is made of a Single In Line (SIL) resistor array. Althoug it has a tolerance of 5% the differences between individual resistors inside the SIL are much smaller. A SIL is therefore a cheap way of accurately dividing a voltage. The SIL may be replaced with 1% metal film resistors which are soldered together on one side. Their value is not critical as long as they are all the same.
- The rotary switches used in the prototype are by a British company called Lorlin. A number of other companies all over the world produce identical (pin compatible) switches. The PCB lay-out has extra holes for some brands do not remove unused pins.