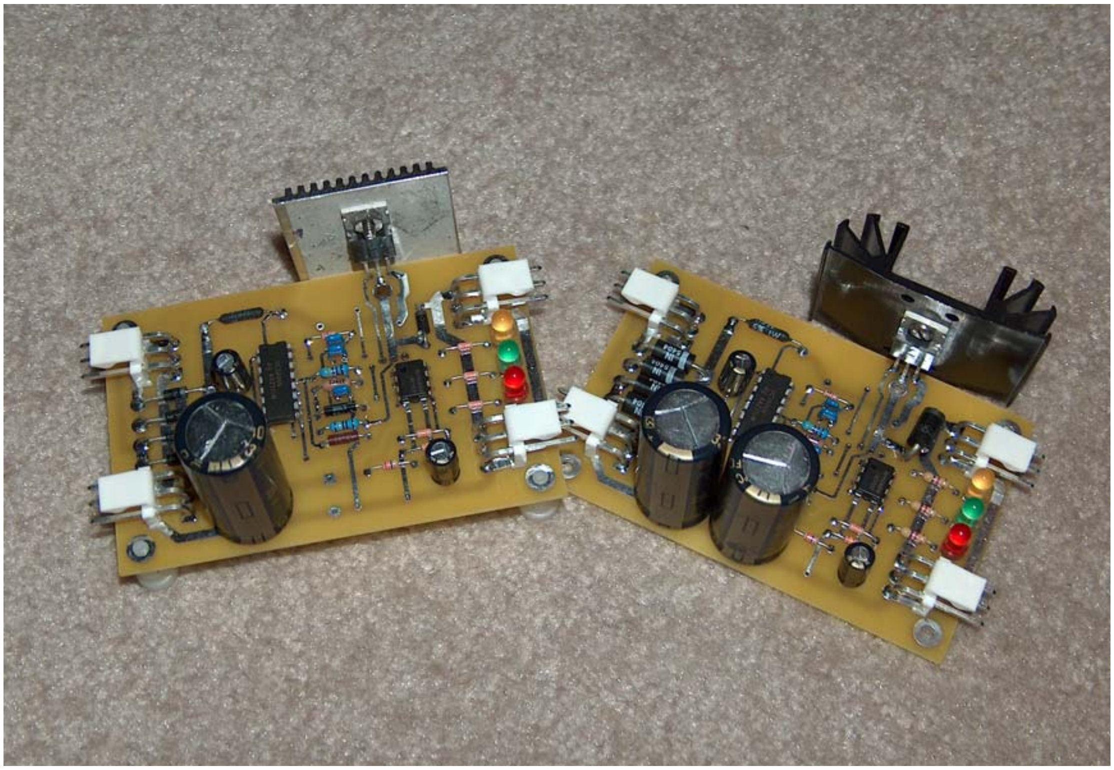
Lead-Acid Battery Charger Kit



Bill Buoy

N5BIA

16214 Hollow Rock

Houston, TX 77070
website: n5bia.com

Table of Contents

Introduction

Lead-acid cells are a reliable power source for operating radios and supporting equipment. Characteristics of the lead-acid family of cells include prolonged standby capability, high capacity, and high current discharge capability.

A key factor in obtaining optimum performance from this battery technology is a proper charging environment. Charge voltage and current must be accurately controlled and matched to battery temperature to obtain maximum energy return and long life. This charger uses a charge controller IC designed to accomplish this.

The board is designed to mount conveniently in a variety of enclosures. It can be built it into a stand-alone charger or in an enclosure with the battery. Input power can be supplied by a transformer or a DC supply. Connectors enable removing the board for service or modification.

Circuit Description

The charging circuit is designed around an IC specifically designed to provide the proper charging voltage and current determined by the temperature and state of charge of the battery. A pass element carries the high current charge current under control of the charge controller.

Three indicators show the charge state. The charge controller drives the overcharge mode indicator directly. The power indicator and the float state indicator are driven by voltage comparators. This keeps dissipation within the charge controller to a minimum so as not to influence the internal temperature sensor or affect the output voltage programming divider.

The charger requires 18 to 22 volts DC input. This voltage may be obtained from an 18-volt laptop computer adapter. Optionally, populate the rectifier and the filter components and provide 16 to 20 volts AC in the bridge configuration or 32 to 40 volts AC in a full-wave configuration.

Charge Controller

The UC3906 charge controller is an IC designed specifically to charge sealed lead acid or lead calcium batteries. The IC is configured to provide three charge states:

- Bulk charge – the charger operates in a constant-current charge mode until the battery reaches the programmed full-charge voltage.
- Overcharge – when the voltage reaches the programmed full-charge voltage, the charger switches to overcharge mode to 'top-off' the battery. Charging voltage is held constant while the charge current is permitted to decrease until it is approximately one-tenth the bulk charge current.
- Float charge – when the current decreases to the minimum overcharge current, the charger enters the float charge mode. The voltage is reduced slightly below the full charge voltage, but the full bulk charge current is available. The battery may be left on the charger in the float mode indefinitely without damage.

A fourth state protects the battery, charger, and pass element if power is applied and the battery is severely discharged, has a shorted cell, or if a battery is connected with reverse polarity. Current is limited to $1/10^{th}$ the maximum charge current until the voltage rises to a minimum safe threshold. When the minimum threshold voltage is reached, the charger switches to the bulk charge mode to begin a full charge cycle.

The voltages and currents are programmable. See the *Design Equations* section of this guide for details.

Pass Transistor

The pass element drive current must be kept below 25 mA to minimize heating in the UC3906 which would cause influence the internal temperature sensor. At the maximum charge current of 2 A, the transistor must have a dc gain (h_{fe}) of 80 or more. The transistors supplied with the kit have adequate reserve gain for all operating conditions that are less than or equal to the kit rating.

The transistor must always be attached to a suitable heat sink. Refer to the *Thermal* section in this guide for typical operating conditions. Determine the heatsink requirements based on the charge current and the input voltage available. Good engineering practice is to provide adequate cooling in at least a 100-degree ambient temperature environment.

Indicators

Three LEDs indicate the operational state of the charger. Two of the LEDs are driven from the LM2902 comparator. Loading the UC3906 outputs with LED current would contribute to inaccuracies in the voltage divider. The third LED is driven directly from the overcharge indicator pin of the UC3906.

Power Source

A minimum of 18 volts DC is required to provide proper regulation. A DC input connector location is available on the circuit board if a suitable power source is available. A convenient and frequently available source of DC for charging the battery is to use a laptop computer power pack to charge the station battery when it is not connected to the laptop. Most current laptop power packs deliver 18 to 20 volts DC at 2 to 5 A, depending on the make and model of the laptop.

Circuit board mounting locations for rectifier diodes are also provided so that the charger can be powered from a transformer. The rectifier and power input connector is configured to enable either full wave rectifier or bridge rectifier topology. This permits maximum flexibility when selecting a transformer. Refer to the *Specifications* section of this guide for more information on transformer selection.

Assembly

Board assembly time is approximately 1 to 2 hours. Start assembly by identifying all of the components from the parts list. Assemble and solder each group of components before proceeding to the next group of components.

Resistors

All resistors are mounted flush with the circuit board. All resistor lead spacing is 0.4 in.

	ID	Value	Remarks
□	R1	22	Red-red-black-gold
□	R3	33K	Orange-orange-orange-gold
□	R4	1K	Brown-black-red-gold
□	R5	2400	Red-yellow-red-gold
□	R9	4.7K	Yellow-violet-red-gold
□	R10	4.7K	Yellow-violet-red-gold
□	R11	4.7K	Yellow-violet-red-gold

Turn the board component side down and solder the resistor leads. Clip the leads flush with the board.

Note that the 1% resistors may have a color code or have the value designated on the body, depending on the manufacturer. R2 lead spacing is 0.7 in. All remaining resistor lead spacing is 0.4 in.

	ID	Value	Remarks
□	R6	732K 1%	Violet-orange-red-orange-brown 7323F
□	R7	205K 1%	Red-black-green-orange-brown 2053F
□	R8	140 1%	Brown-yellow-black-black-brown 1400F
□	R12	17.4K 1%	Brown-white-brown-red-brown 1742F
□	R13	44.2K 1%	Yellow-yellow-red-red-brown 4422F
□	R2	0.13 (2A) .25 (1A) 0.5 (.5A)	Value printed on the resistor body (note – only 1 resistor supplied)

Turn the board component side down and solder the resistor leads. Clip the leads flush with the board.

Integrated Circuits and Blocking Diode

Be sure to align each IC pin 1 identification mark with the square pad on the circuit board. Turn the board over and solder one pin to hold the IC in position. Before soldering the remaining pins, be sure the IC is fully seated in the board. Momentarily heat the soldered pin and press the IC fully into the pattern to reposition the IC. Solder each pin, then turn the board component side up.

Bend the leads on D8 to fit the holes – lead spacing is 0.45 in. Insert the diode, leaving about 1/8 in space between the diode body and the board. Solder one lead, then recheck the spacing – the diode should not touch the board. Solder the remaining lead.

	ID	**Value**	**Remarks**
□	U1	LM2903	8-pin DIP
□	U2	UC3906	16-pin DIP
□	D8	IN5404	Axial lead

Ceramic Capacitors

Insert each of the ceramic capacitors into the board. Turn the board component side down on the workbench and solder one lead of each capacitor. Turn the board over and ensure that the capacitors have not slipped out of position. If one or more have slipped, heat the soldered lead and adjust as necessary, then turn the board component side down and solder the remaining lead of each capacitor. Trim the leads flush with the pad.

	ID	**Value**	**Remarks**
□	C2	.1 μf 50V	104M
□	C4	.01μf 50V	103M
□	C7	.1 μf 50V	104M
□	C8	.1 μf 50V	104M

Electrolytic Capacitors

Insert C1 and C3 into the board. Observe the polarity – these little parts make a big mess if reverse polarity power is applied. Turn the board component side down on the workbench and solder one lead of each capacitor. Turn the board over and ensure that the capacitors have not slipped out. If one or more have slipped, heat the soldered lead and adjust as necessary, then turn the board component side down and solder the remaining lead of each capacitor. Trim the leads flush with the pad.

	ID	**Value**	**Remarks**
□	C1	47 μf 35V	Observe polarity
□	C3	47μf 35V	Observe polarity
□	C5	3300μf 35V	Observe polarity
□	C6	3300μf 35V	Provided on 2A models only

Transistor and LEDs

Mount Q1 on a heatsink. Mount the transistor using an insulator and heatsink compound. Two sites are provided on the circuit board to facilitate mounting the transistor to a convenient heat sink arrangement.

If the transistor is mounted on a heatsink and connected to the circuit board with wire, observe the following precautions:

- Keep the leads as short as possible.
- Do not bundle the leads with other wiring.
- Connect the leads to the proper points on the board.

LEDs may be mounted vertically or the leads bent to enable mounting them facing the edge of the circuit board. Two-pin 0.100 connectors (not supplied) may also be used to facilitate mounting the LEDs on a panel instead of on the board. Observe polarity – the flat side of the base denotes the cathode.

Optional Components

Optional components include the full-wave rectifier or bridge (D4 through D7). If 18 to 22 volts DC is available and it is not necessary to provide a dual power option, it is not necessary to populate these component sites.

If a bridge rectifier is required, populate all four diode sites. If a full-wave configuration is necessary, populate D6 and D7.

Connectors

Install the output and battery connectors J3 and J4. If the AC power option is chosen, populate J1. If the DC power option is preferred, populate J2.

Cleanup

After assembly is complete, remove the flux from the soldering operations from the circuit board. Commercially available flux removal solvents are available from most electronic parts sources such as Mouser or Digikey.

WARNING: Most flux solvents are toxic and many are flammable. Use with extreme caution, adequate ventilation, and in an area free of accidental ignition sources. Always read and follow all label directions and warnings.

An alternative technique, though not as effective, is to use alcohol and an old toothbrush to loosen the flux. The toothbrush is used to scrub the flux off.

Heatsink

A significant amount of heat is developed in the transistor during normal operation, particularly when the charger is connected to a deeply discharged battery. This is the time when the greatest power is dissipated in the pass transistor. Dissipation in the output diode is at maximum throughout the bulk charge period.

Thermal design is a very important component of this project. Adequate heat sink area must be provided to keep from destroying the series pass element transistor.
Typical thermal operating conditions are provided in the following table. Substitute measured values when possible.

Input parameters				Note - all temps in C
Input volts	18.00	V	Vin	Depends on power source
Min output volts	12.49	V	Vmin	
Pass transistor voltage	4.81	V	Vce	Vce=Vin-Vmin
Max current	2.00	A	Ic	
Pass transistor diss	9.63	W	P	
Pass thermal resistance	3.125	degC/W		From transistor data sheet
Case - heatsink	0.7	degC/W		No insulating washer
Max allowed die temp	125	deg C		
Ambient	37.8	deg C		
Diode drop	*0.70*	V		For reference – not part of heatsink calculations
Diode diss	1.40	W		
Diode thermal resistance	20	degC/W		
Case - heatsink	2	degC/W		

To select a suitable heat sink, complete the following steps:

1. Calculate the maximum power dissipation expected in the pass transistor:
   $P = Vce \times Ic$
2. Obtain the maximum junction temperature (T_j) for the transistor (125°C).
3. Estimate the maximum surrounding air temperature (T_a).
   If the heat sink is going to be outside the case, 25°C is reasonable. Inside an enclosure, 40°C is reasonable. For most accurate results, actual measurement is best.
4. Calculate the maximum permissible thermal resistance (R_{th}) for the heat sink:
   $Rth = (Tj - Ta)/P$
5. Subtract 2°C/W for the thermal resistance of the insulator between the transistor case and the heat sink.
6. Choose a heat sink with a thermal resistance that is less than the value calculated.

Packaging

This kit is supplied without a case or housing. It is designed to be incorporated into a package that includes the battery and connectors required. It may also be built into an enclosure that houses a power transformer and suitable input and output connectors for AC power, battery, and load.

Select the enclosure before assembling the charger board – the choice of enclosure affects the transistor mounting arrangement, especially when building the charger into a small enclosure.

Circuit Protection

Include adequate short-circuit protection in the event of component failure. Provide an input fuse for the DC input to the charger. The fuse should be no more than 1.5 to 2 times the maximum charge current. If a transformer supplies the input current to the charger, fuse the mains AC input with a slow-blow fuse type to allow for the startup surge current when the charger is first powered up.

Operating Notes

The UC3906 is the heart of an advanced battery charger. Because it is a complex device, misinterpretation of the charge state of the battery is possible.

If the charger is powered up before connecting the battery, the charger enters the float mode immediately. Because the charger is designed to be permanently connected to the battery, this mode should not be encountered. If the battery voltage is above 12.2 volts, the bulk charge mode will not start until the battery is discharged below this point.

If the battery voltage is below approximately 10.2 volts, the charger supplies a small charging current designed to prevent damage to the charger or battery in the event of a deeply discharged battery, shorted cell, or reverse connected battery. If the battery is deeply discharged, the low charge current will bring the battery voltage up to a safe level before entering the bulk charge mode. Only the power LED is illuminated when the charger is in this mode. The low initial current automatically switches to the programmed bulk charge current when the voltage rises above the 10-volt threshold.

If the battery voltage is between 10.2 and 12.2 volts when input power is applied to the charger, charging begins at the programmed bulk charge current and continues until the voltage rises to 14.0 volts. Only the power LED is illuminated during this state.

When the voltage exceeds 14.0 volts, the overcharge LED illuminates, indicating that the charger has entered the overcharge mode to complete the charge. The charge current remains at the programmed bulk charge rate. This state continues until the battery voltage reaches 14.7 volts.

When the battery voltage reaches 14.7 volts, the charging current begins to taper off. When it decreases to $1/10^{th}$ of the bulk charge current, the overcharge LED extinguishes and the float LED illuminates to indicate that the charger has entered the float charge mode. In the float charge mode, the voltage is maintained at 13.9 volts. The programmed bulk current is available from the charger in this mode. Typically, the current will slowly decrease to a few ma if there is no load on the battery.

A load can be connected to the battery, and as long as the load current drain does not exceed the charger bulk current, the charger will supply the operating current to the load. Once the charger enters the float mode it will remain in this mode as long as the voltage remains above 12.2 volts. If the load exceeds the charger bulk current capacity, the battery makes up the difference.

Because most loads are intermittent, the battery will be maintained in a charged state as long as input power to the charger is maintained. The charger will remain in the float charge state unless the load discharges the battery below approximately 12.2 volts.

The charger may not enter the overcharge state if a load is drawing current greater than $1/10^{th}$ of the bulk charge rate. Failure to enter the overcharge state may also occur if the battery is drawing too much leakage current. Excessive leakage current may be an indication that the battery is nearing the end of its useful life.

Modifications

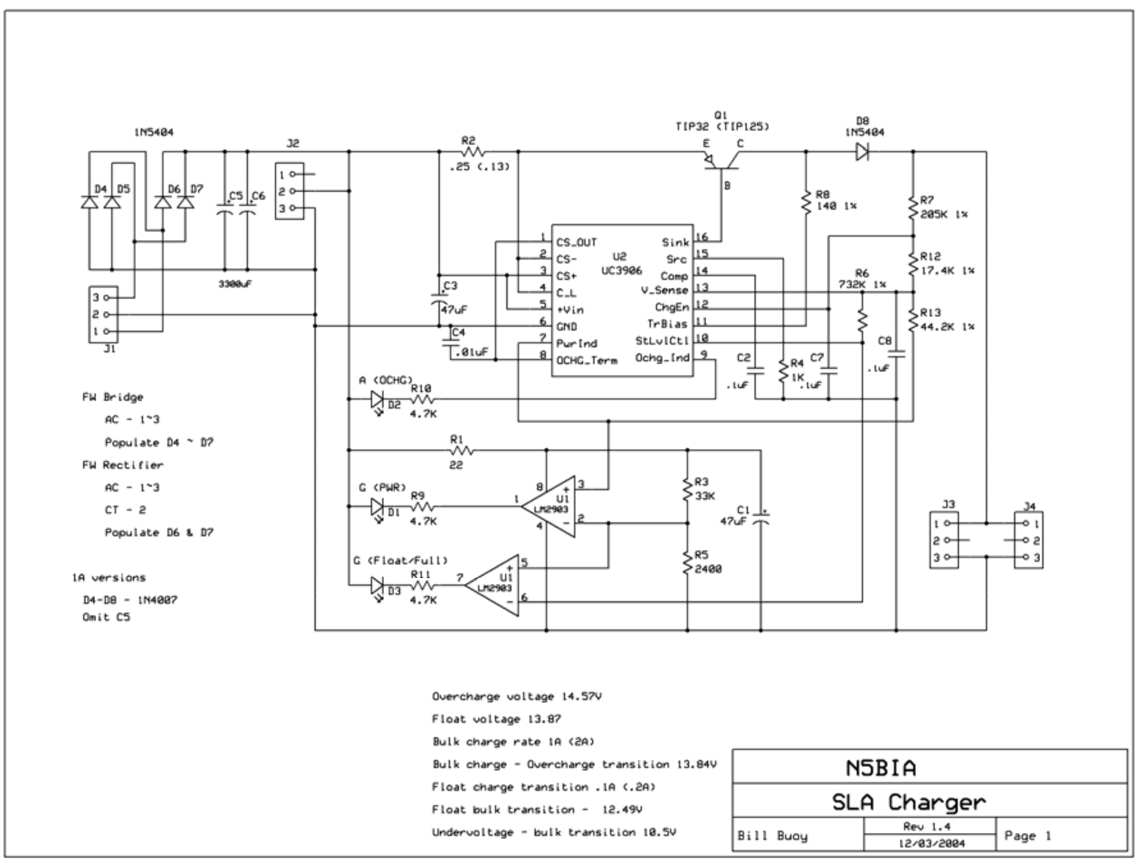
The design described in this document can be modified to charge 6 to 18 volt batteries at currents ranging from ½ A to 3 A. With the circuit board supplied, currents above 3 A may result in destruction of the traces on the board.

Significant changes to the input voltage will affect operating points of the charging circuit. Refer to the charger design equations for additional information.

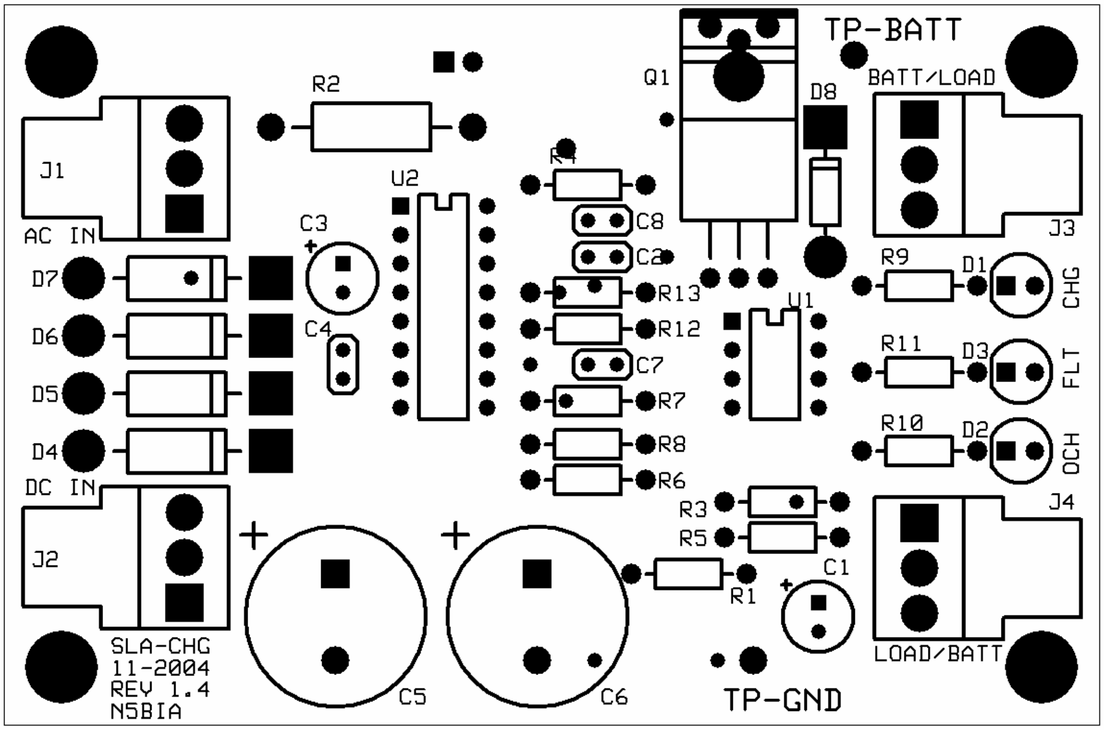
To change the charger operating voltages and currents to use it with a different battery voltage or to provide a different input voltage, it is necessary to adjust some of the resistor values. The following considerations apply to all modifications:

- The circuit board is designed to carry a maximum of 5 amps. Application of this circuit board in chargers designed to charge at rates above 5 amps is not recommended.
- The supplied rectifiers are designed to deliver a maximum of 3 A (1N5404). Exceeding these values will cause these components to fail. At currents above 2 A, the rectifiers should be provided with a heatsink to avoid damage to the diodes and the board.
- The pass transistor maximum current rating is 4 A. Exceeding this value will cause the transistor to fail, regardless of heatsink.

Schematic



Layout



Specifications

Input voltage – one of the following:

- DC input voltage – 18—20V
- AC input voltage (Bridge) 16—20V
- AC input voltage (FW-CT) 32—40V

Threshold voltage – 10.2 V
Float → bulk charge – 12.2 V
Bulk → overcharge – 14.0 V
Overcharge → float – 14.7 V
Float voltage – 13.9 V
Overcharge transition current – 0.2 A (.1A)
Bulk charge current – 2 A (1 A)

Electrical Design Equations

To change the voltage transition points, refer to the following design equations. All resistors must be 1%.

Select the following voltages from the battery data sheet:

Vt = threshold voltage

Vfloat = float voltage

Voc = overcharge terminate voltage

Select the maximum charge current from the battery data sheet:

Ichg = peak charge current

If a battery is deeply-discharged, has a shorted cell, or is accidentally connected with reverse polarity, the charge current is limited to a safe value. Choose a safe value – about 100 ma or so for *It* – that will bring a deep-discharged battery up to a safe voltage before applying the peak charge current and that will protect the charger in the event of a shorted battery or reverse-polarity connection.

Pick divider current (Id). The recommended value is 50 µA to 100 µA. Replace the voltages and current in the following equations with the values chosen.

$$R13 = \frac{2.3V}{Id}$$

$$Rsum = R7 + R12 = \frac{(Vfloat - 2.3V}{Id}$$

$$R6 = \frac{2.3VxRsum}{Voc - Vfloat}$$

$$R7 = \left(Rsum + \left(\frac{R13xR6}{R13 + R6} \right) \right) + \left(1 - \frac{2.3V}{Vt} \right)$$

$$R12 = Rsum - R7$$

Compare the calculated values with a standard table of 1% values. Select the closest 1% values, substitute them in the equations and solve for the voltages. If these values are acceptable, the work is done. If not, change the divider current and repeat. Due to the number and interdependence of the values, a spreadsheet will help immensely.

The peak charge current calculation is much simpler:

$$R2 = \frac{.23V}{Ichg}$$

Calculate the value of the short circuit limiting resistor:

$$R8 = \frac{Vin - Vt - 2.5V}{It}$$

where *Vin* is the input voltage to the charger.

Parts List

C1	47μF 35V
C2	.1μF 50V
C3	47μF 35V
C4	.01μF 50V
C5	3300μF 35V
C6	3300μF 35V (>1A models only)
C7	.1μF 50V
C8	.1μF 50V
D1	Amber LED
D2	Green LED
D3	Red LED
D4	1N5404 3A Rectifier
D5	1N5404 3A Rectifier
D6	1N5404 3A Rectifier
D7	1N5404 3A Rectifier
D8	1N5404 3A Rectifier
J1	Connector (male)
J2	Connector (male)
J3	Connector (male)
J4	Connector (male)
Q1	TIP125 NPN Transistor
R1	22 Ω ¼ w 5%
R2	0.13 Ω 1 w 1% (2A), 0.25 Ω 1 w 1% (1A), 0.5 Ω 1 w 1% (0.5A)
R3	33K Ω ¼ w 5%
R4	1K Ω ¼ w 5%
R5	2400 Ω ¼ w 5%
R6	732K ¼ w 1%
R7	205K ¼ w 1%
R8	140 ¼ w 1%
R9	4.7K Ω ¼ w 5%
R10	4.7K Ω ¼ w 5%
R11	4.7K Ω ¼ w 5%
R12	17.4K ¼ w 1%
R13	44.2K ¼ w 1%
U1	LM2903 comparator
U2	UC3906 battery charger controller

	Connectors to mate with J1~J4
P101	Connector (female)
P102	Connector (female)
P103	Connector (female)
P104	Connector (female)

Bibliography

Fairchild Semiconductor TIP32 Series data sheet
Fairchild Semiconductor KSB707/708 data sheet
Fairchild Semiconductor TIP125 data sheet
Improved Charging Methods for Lead-Acid Batteries Using the UC3906, Unitrode application note U104
Unitrode UC2906/UC3906 data sheet
(K5OOR battery charger)
(A&A engineering article, QST)
Electus Distribution Reference Data Sheet: HEATSINK.PDF (1)

Disclaimer

Revision Record

Original release – December 2004
Rev 1 – July 2005
Expanded installation instructions for capacitors, added thermal design equations and information, general grammar cleanup, added parts list, table of contents, page numbering, and revision record section.
Second production run packaging – June 2006
Resistors placed on card in package
All kits capable of 2A current – difference between 2A and 1/0.5 A kits is sense resistor and an extra capacitor.
Rev 2 – February 2007
Added website information, edited descriptive narrative, clarified assembly procedures.