Sealed Lead Acid Battery Charger Mk II

Revision : 1.3

21st November 2000

Disclaimer

This battery charger may cause serious harm, even if used correctly. It could over charge your batteries and cause a fire, burning your house to ashes and making your wife/girlfriend/mum or husband/boyfriend/dad pretty pissed off. In fact, I don't recommend using it myself. I suggest you spend $300 on a commercial one, then take them to court when it stuffs up. This project is offered in good faith for non commercial purposes only. If you build this project, you agree that it is entirely your responsibility if something does go wrong and no damages in any way are the responsibility of VK3EM. If after all this you still want to sue me, don't bother...I don't have any assets (I spend all my time designing battery chargers you see...)

This project is offered under the Open Hardware scheme. All relevant design and manufacturing details are included. You may not, in any way, shape or form use the information in this project for commercial purposes.

Revision History

Rev 1.0 - New development of MkII battery charger. New documentation and schematics. First build of Rev C PCB.

Rev 1.1 - Added document sections on construction and testing.

Rev 1.2 - Modified circuit for "LED Current Monitor". Added documentation on heat sink calculation.

Rev 1.3 - Modified circuit to fix reset problem. Updated schematic and BOM. Added wiring diagram. Fixed some documentation errors. Change schematic revision to match documentation revision. Added documentation to locate track to cut for reset circuit modification.

Thanks go to :

As with most projects, they don't happen without help. I have been very fortunate and received a lot of help from the following people. They deserve a very very big thank you.

- John Wright , VK3AJL for countless hours of technical conversation which inspired this project.
- Bryan Ackerley, VK3YNG for his help manufacturing the PCB's and supplying UC3906's.
- Adrian Hatherley, VK3LK for organising the kit orders, making kits up and soldering of surface mount bits.
- Robyn (my girlfriend) for her patience!

This project is dedicated to Harold Hepburn, VK3AFQ who was one of the most proliferic amateur radio home brewers I have been privelidged to meet. R.I.P.

Contents

Section 1 - Introduction

This section details why you should build and use a Sealed Lead Acid Battery Charger based on the UC3906 IC from Unitrode.

Section 2 - Design Notes

This section details how the charger was designed, what was considered and why it was done. This section would be helpful if you intend to modify the charger to suit your own needs (i.e.: change the voltage to 6 volts). This section is more for my own reference than anything else.

Section 3 - Construction Notes

This section details how to construct the charger with a MkII PCB and the appropriate components. It also contains hints and tips if you are building your own charger on vero-board or by some other means.

Section 4 - User Manual

This section details how the charger works and what those funny lights mean.

Section 5 - Appendices

This section details : (1) Schematics and wiring diagram, (2) PCB Layout, (3) PCB Overlay, (4) Bill of materials and (5) Design Calculations.

Please Note : I have spent many hours documenting as much information as possible. If this documentation does not answer a question or concern, try reading the "Frequently Asked Questions" on the website. If that does not help, e-mail me at VK3EM@HOTMAIL.COM. All information, intellectual property, circuits and circuit boards documented are (c) 2000 VK3EM. They are for non-profit use only. Refer to the website for up to date information. This project has been placed in the public domain for the purposes of education.

1.Introduction - Why use a special charger?

A lot of people have their own view on charging batteries. A lot of people get it wrong. What do I mean by wrong? If you spend big dollars on batteries (or you obtain good batteries for free) you want to get two things : maximum life and maximum capacity. A significant influence on these two factors is the way the battery is re-charged, especially seal lead acid cells with gel electrolyte. Get it wrong, and your getting less life and capacity than your battery can offer. Sealed lead acid batteries are quite expensive, so building a good charger is a worthwhile investment. (Buying one is the next best option, but good ones are very expensive).

The VK3EM Sealed Lead Acid Battery charger is based around a UC3906 integrated circuit from Unitrode (Now owned by Texas Instruments) specifically designed for charging SEALED lead acid batteries. It is not a cheap and nasty battery charger. It is an accurate battery charger designed specifically to get maximum life and capacity from your batteries. It can also be built for a modest price.

Some key points about recharging sealed lead acid cells can be detailed here :

1.) The chemistry of sealed lead acid cells with a gel electrolyte is different to a standard lead acid cell (as used in automotive applications)

2.) The use of a controlled "over-charge" is required to force chemical reactions to occur that lead to maximum battery capacity and life.

3.) The use of temperature tracking is required as the battery voltage varies with temperature.

4.) A slow controlled charge gives maximum battery life

In my opinion, the following are the three biggest factors that cause a dramatic reduction in useful battery life and capacity (not in order of preference).

1.) The failure to use an over-charge cycle during the charging process (i.e.: under-charging the battery).

2.) The failure to temperature track a float charger

and,

3.) The excessive discharging of a battery.

Where to find further information ?

One of the best sources of information is the "Gates Energy Products" applications manual for sealed rechargeable batteries. As Murphy's law dictates, it's out of print and not available in PDF form. It should be, because there are many hours of informative reading to be had with this book.

The next best source is Unitrode Application Note U-104. This application note can be downloaded at the VK3EM website. It is also available via Texas Instruments (who now own Unitrode).

Please Note : It is impossible to detail exactly how to recharge a sealed lead acid battery. It will vary with different manufacturers, materials, constructions, electrolytes, discharge cycles, etc. All I wish to point out with this project is that using a UC3906 based charger is a few orders of magnitude better than a voltage regulator set at 13.8 volts.

2. Design Notes

Introduction : Please make sure you have a copy of Mk II schematics and design calculations in front of you when you read this section. You will find them in the Appendices. This section of the manual should give you a fair idea of what's going on inside my head when I designed this charger. As always, I might have done some things differently with hindsight. I encourage constructive criticism, but remember, there are a lot of trade-offs that one goes through as a designer. At some point in time, you have to trade off performance, reliability, manufacturability against cost. Otherwise, who would want to build a $200 charger? (OK NASA would, but who else?) Soapbox dis-engaged....

Power Supply : J1 is the power input to the charger. The AC transformer required should ideally be 18v AC RMS. It can be higher, but the power dissipated by Q1 (the main pass regulator) will increase. Please be careful with the unloaded voltage on the Electrolytic capacitors. They can go pop and are 35v rated for a good reason. The input power can also be DC should you already have a DC plug pack lying around. The best source of power for this charger are plug packs from old laptops (Almost always 18v AC @ 3Amps).

The rectifier diodes are type 1N5404. They are 3 Amp 400 v PIV type. If you are only building a 250 ma bulk current charger, you could replace them with common (and cheaper) 1N4004 diodes. If you have a diode bridge of a suitable rating, you could also use that, but you might not be able to easily fit it onto the PCB. 3 Amp diodes were chosen (even though the bulk current maximum is 1 Amp) because of input current rush into the electrolytic filter caps at turn on and they were just as cheap as 1N4004 (From my source of parts anyway). These diodes do get warm at 1 Amp, they would be egg frying temperature at 3 amps.

The value of the main electrolytic capacitors will vary with the loaded AC voltage of your transformer. In the case of DC input power supply, they do not need to be fitted, although fitting a small value would be recommended. So long the DC voltage across the capacitors is never less than 17v at your lowest mains supply voltage, you should be safe. I make particular mention of this because designers sometimes forget that 240v AC mains does not mean you will have 240v AC RMS at all times. I've seen the voltage at my power points vary from 260v AC RMS to 222v AC RMS. When designing, also ensure your electronics will cope with the change in transformer secondary voltage due to change in primary voltage.

U4 provides a regulated 12v output for the operation of the other circuitry. This is required due to the possibility of many and varied input supply voltages. It became too hard to try and limit the current through the leds with a wildly varying power supply. Unfortunately, this regulator is a source of heat and thus will contribute to the temperature sensing error of the UC3906 battery temperature compensation. U4 is located close to the rear edge of the PCB so it can be mounted on a heatsink or have a small heatsink added. It is recommended that you mount this device on the heat sink and run some short leads back to the PCB. Be careful though as long leads might cause the regulator to oscillate.

Charger Control Circuitry :

The exact operation of the UC3906 battery charger is a bit complex to detail here. Not only that, but it's detailed to the nth degree in the data sheet and application note (See links on the VK3EM web page).

Q1 is the main pass device. It is a TIP32C PNP pass transistor. The data sheet is provided website on the website for those who want to substitute another transistor. When looking for a substitute, pay careful attention to the maximum Ic and minimum Beta and Ft. Too low a Beta at the UC3906 will be unable to sink enough base current at 1 Amp collector current. Too high Ft and you'll end up with a free running RF oscillator. Q1 will need to be mounted on a heat sink. It is suggested that you use some medium gauge hook-up wire to run from the circuit board to the transistor mounted on a heat sink. I've seen too many solder joints fail due to constant expansion/contraction of hold/cold metalwork. See the construction notes (Section 3) for details on calculating the size of the heat sink.

R2 and R3 are the current sense resistors. These are the resistors that set the bulk charge current. As mentioned before the charger tries to maintain 250mV across these resistors when in the bulk charge state. 1 Ohm will give you a bulk charge current of 250mA, and 0.25 Ohms will give you a bulk charge current of 1 Amp. Just ensure that the value chosen is never lower than 0.25 Ohms. Remember "RESISTORS HAVE A TOLERANCE AND YOUR RESISTOR MIGHT FALL OUTSIDE THIS RANGE". It's best to check it first by making up simple circuit and measuring the voltage drop across the resistor.

J6 allows the current sense resistors to be selected using a switch. If you want both 1 Amp and 0.25 Amps (or whatever current sense resistor you choose), make sure you use a DPDT switch and parallel both sides of the switch. Even good DPDT switches have enough switch contact resistance to effect the bulk charge current. Poor quality (yum cha brand) and rotary switches are not recommended. Don't use them.

Q1 Base current is sinked by Pin 16 of U2 (the UC3906) and added back to the charger output via Pin 15. R45 sets the trickle bias current (when the battery is below the trickle bias threshold of 10v in this case). Pin 14 has two capacitors to ground that provide loop stability. 100nF is the main compensation capacitor, 100p helps with RF by-pass. C11 gives some noise protection to the over-charge state terminate input. Too high a value causes the charger to start up in the over change state. Too low a value causes the charger to prematurely trip to the float voltage state.

The calculation of RA,RB,RC and RD are shown in the Design Calculations (see ***Appendix A).*** Print it out for future reference or tweaking. Each resistance value is made of up two resistors in parallel and then two of these parallel combinations in series. In other words, it is highly unlikely potentiometers are required. You can use potentiometers if you want to, but good ones are expensive. Yum Cha potentiometers are cheap, but they are yuck. Horrible, nasty, hideous little creatures that go open and short and change their value depending on the day of the month. Don't use them and don't complain to me if you do. Remember, you don't need to tweak a pot...If you feel like you do, consult your doctor.

RT limits the amount of trickle current when the charger detects a very low battery that may have a shorted cell. You defiantly don't want to bulk charge a battery with a shorted cell. Ensure that at the maximum supply voltage 25mA is never exceeded. The formula for calculating this resistor value is in the appendices.

D5 stops you letting the smoke out of your pass device and UC3906 IC when you connect the charger up backwards to a battery (Hey once bitten, twice shy). For a 1 Amp bulk charger, the 1N5404 3 amp diode provides sufficient headroom. Always factor in the idiot factor. Even designers are idiots sometimes....Usually after 1am....and too many beers.

Charge Current Monitor Circuitry :

This is basically a differential amplifier that drives a transistor that varies the current through a led which varies its light intensity (Take a Breath). The problem is most op-amps won't work with inputs above their supply rails. Subsequently, R48 and R49 in combination with R50 and R51 divide the differential DC voltage down to a level acceptable for the inputs on the op-amp. U1A is the classic differential amplifier circuit. It's best if you use 1% or better resistors. Extra gain is provided by U1B which is a standard non-inverting DC coupled amplifier. any jelly bean op-amp that can run from 12v should work. For best results, match all the resistors in this circuit. Even matched, the circuit is only a very rough indication of charge current. How rough...well, very rough so don't be too alarmed if it lights slightly even with no battery connected or if its off with over charging no complete. It's just a cheaper alternative to a ammeter.

Note : The charge current monitor circuitry really does not work well. It's a total pain in the arse to get right. The reason is due to the common mode rejection of the diff amp (your trying to detect a 250mV difference down to a 25mV difference) on a 24 volt DC signal. In the partial kit version, this circuitry is not loaded due to the time it takes to match resistors. If you have the time to match them, then it does work and is a lot cheaper and easier (in terms of metal work) than an analogue ammeter. However, for most people, the use of an analogue meter will be easier (due to access to SMT parts).

Float Charge Indicator Circuitry :

This is a fairly simple circuit that uses a LM393 or similar comparitor and "observes" the status of PIN 10 of the UC3906 (U2). When bulk or over charging, Pin 10 is low (close to ground), thus Pin 2 of U3 is lower (in voltage) than pin 3, which causes the output of the comparitor to be open-circuit (go high) and thus the PNP transistor Q3 is off (Led off). When Pin 10 of U2 turns off (which occurs when the float state has been entered), Pin 2 of U3 is now higher than Pin 3, Pin 1 (output) goes low drawing base current from Q3 turning it and the LED on. Thus the green LED turns on when in the float state.

Elevated Charge (Over Charge) Indicator Circuitry :

The only indication that the charger has changed from State 1 (Bulk Charge) to State 2 (Over Charge) is the fact that Pin 9 of U2 (UC3906) goes low. There is no other electrical change. When Pin 9 goes low, base current is drawn from Q4 (PNP) which turns on the orange LED.

Reseting the UC3906 :

Many IC's that look fantastic often have one or two problems that are just waiting to appear. The reset problem of the UC3906 is one of those! The reasoning behind it is quite simple. Turn the charger on with no battery connected and the UC3906 defaults to the float charge state, because the "open circuit" load appears to be a fully charged battery accepting no current. When you then connect the charger to a battery with a battery voltage above V_{13} (The state where the battery voltage is low enough for the charger to swap from float state to bulk charge state), the charger remains in the float the charge state. To properly charge the battery, the UC3906 needs to be reset to the bulk charge state.

As with many designs, there are always things you over-look or fail to test completely. My earlier design has a fairly simple two transistor circuit that pulled V_{sense} and OCTRM low which reset the UC3906 into the bulk charge state. This solution had one major drawback. By fooling the UC3906 into thinking battery volts are low, the UC3906 tries to turn the pass device Q1 on harder. In other words, the current from the charger defaults to the bulk charge current.

This side effect has two problems. If the battery you're trying to charge is close to V_{oc}, the instant charge of bulk charge current causes the battery voltage to rise above V_{oc}, thus keeping the UC3906 in the float state. In practice, it causes erratic resetting of the UC3906. The device will eventually reset, but not if your finger is a bit slow. The second problem with the above mentioned side effect is a bit more serious. Imagine if you the reset switch accidentally locked on. The user would never suspect anything was wrong yet the charger would be locked onto the bulk charge state, never able to terminate. What a mess that would make. Yum cha brand designers wouldn't care, since cost is everything. If you can, always design fail safe systems especially when it involves batteries which can potentially release an enourmous amount of power in a very short time scale.

It turns out that the solution was really simple, but I never thought of it because of the way I developed my original prototype PCB. Just break the input power path between the main filter capacitors and the UC3906. This causes the UC3906 to reset into the bulk charge mode. The way to implement this is shown in the new system wiring diagram which can be found in the Appendecies at the back of this manual. Sometime simple solutions are just staring you in the face and often your blind to them. This is where it is really handy to give you work to a college or friend and get his suggestions. This modification is now standard and forms part of schematic revision 1.3.

Note : You might ask why can't you use the on/off switch? The problem with that simple solution is the filter capacitors. It does take a considerable time for the charge to bleed off, so its not really an elegant solution.

Modification Note : Please be aware this modification requires the removal of a PCB track on the Rev 1.3 PCB.

3. Construction Notes

Interface Information :

The designator "J" is used to describe a connection from/to the MkII charger. The following connections are used :

J1 - 18v AC RMS Supply Input : This is the main power supply input for the charger. The power supply should be fused (for safety purposes) with a 3 Amp or other appropriate sized fuse. Do not short either side of the AC supply to (chassis ground).

J2 - Regulated Charger Output : The is the regulated charger output that should be connected to some flying leads (preferably using flexible heavy gauge wire with large alligator clips). If you intend to use the charger near RF fields, the use of ferrite beads on these leads, inside a shielded box is recommended. This output does not need to be fused. The square pad is goes to the positive terminal of the battery and the round pad to the negative terminal.

J3 - Float Charge Indicator LED (Green) : An external green LED can be connected to this point. When the LED is on, the charger is in the *Float* state. The square pad connects to the Anode(long lead) of the LED and the round pad to the cathode(short lead). Current is limited to 10mA.

J4 - Charge Current Monitor LED (Red) : An external red LED can be connected to this point. When the LED is glowing brightly, the battery is accepting a large charge current. When the LED is glowing slightly, the battery is accepting a small charge current. When the LED is off, the battery is accepting negligible current. The square pad connects to the Anode(long lead) of the LED and the round pad to the cathode(short lead). Current is limited to 20mA.

J5 - Over Charge Indicator LED (Amber) : An external orange LED can be connected to this point. When the LED is on, the charger is in the *Over Charge* state. The square pad connects to the Anode(long lead) of the LED and the round pad to the cathode(short lead). Current is limited to 10mA.

J6 - Current Sense Resistor Selection : An external switch which can select one out of two current sense resistors. Recommended values are 1 Ohm (For 250 mA amp bulk charge) and 0.27 Ohm (For 1 amp bulk charge). Ensure the switch has low contact resistance. It is recommended you use both sides (ie: parallel) of a DPDT switch.

J7 - Not Used : This connection is not used for Rev 1.3 and onwards.

Special Notes :

a.) It is recommended that you print out the bill of materials Rev 1.3 and mark off the items as you solder them on. If you are not familiar with the techniques of hand soldering surface mount components, download "A Guide to Prototyping with SMT" from the VK3EM website http://www.geocities.com/vk3em.

b.) It is recommended that you do not use the charge current monitor circuitry unless you can match resistor values. It may be easier to use an analogue meter and sense the voltage drop across the bulk charge setting resistors.

1.) First solder on all surface mount resistors. Remember to check and match 1% resistors.

2.) Solder on all surface mount capacitors, except the Tantalums.

3.) Solder the 2 surface mount IC's (U1 and U3). Pay careful attention to the index (Pin 1). The side that contains pins 1 to 4 is usually chamfered.

4.) Solder the SOT-23 transistors.

5.) Solder on the Tantalum capacitors.

6.) Bend and solder surface mount the 1N5404 power diodes. Pay attention to the orientation of the cathode. Bending is best achieved using a pair of needle nose pliers.

7.) Solder in the wire links. There are 9 of them.

8.) Solder U2, the UC3906 IC. You can use a quality IC socket if you wish.

9.) Solder the screw terminal blocks if your using them.

10.)Solder the current sense resistors R2 and R3.

11.)Solder the main electrolytic capacitor. Use a dab of hot melt glue to keep it firm on the PCB.

12.)Install and solder U4 the 7812 voltage regulator. The metal TAB should be facing outwards from the centre of the PCB. Make sure you install it in the right spot. U4 is located near the binding post and the battery charger output connector J2.

13.)Install binding posts in the four corner holes. It is suggested that you mount posts on both side of the pcb as shown in the front cover photo. This helps keep the PCB stable during testing.

14.)Solder diodes (temporarily) into place for D8, D9 and D10. You could use surface mount diodes or leaded ones. The anode is the chamfered end as shown on the silk screen.

15.)Install Q1, the TIP32C pass transistor. You should mount this transistor on the heatsink and use short length of hook-up wire (suitable gauge) to connect to the PCB. Make sure you get the pin out right. It is printed on the solder side of the board. If you substitute another pass transistor, it might have another pinout.

16.)Cut the track and lift it from the PCB as shown in the picture below. This is part of the charger reset modification described in the Design Documentation.

Smoke Test :

1.) Apply 18v AC with no battery connected to charger. Check for smoke. Did you see any? If so, bugger!

2.) Check that the green LED, D8 is on.

3.) Check for 18v AC across cathodes of D4 and D3.

4.) Check the DC voltage across the main electrolytic capacitor. (Meas : 24.8v)

5.) Check the PIN voltages as per the following table.

Pin Number	U2 - UC3906 (Volts)	U1 - LM358 (Volts)	U2 - LM393 (Volts)	Q1 - TIP32C (Volts)
Pin 1 (B)	0.7	0.05	0	24.4
Pin 2 (C)	24.8	6	2.15	14
Pin 3 (E)	24.8	5.96	1.05	24.8
Pin 4	24.8	0	0	
Pin 5	24.8	0.05	0.7	
Pin 6	0	0	0.6	
Pin 7	0.03	0.28	0	
Pin 8	0.7	11.94	11.94	
Pin 9	9.45			
Pin 10	2.15			
Pin 11	14.3			
Pin 12	3.2			
Pin 13	2.2			
Pin 14	14.7			
Pin 15	14.3			
Pin 16	24.4			

System Test :

1.) Connect a battery of terminal voltage between 11v and 12.5v to the charger output J2.
2.) Connect a momentary switch to J7.
3.) Apply power to the charger.
4.) The RED LED (D9) should light indicating charge current.
5.) Disconnect the battery.
6.) The RED LED should go off and the GREEN LED (D8) should light.
7.) Reconnect the battery.
8.) Check for 0.25 v drop across the current sense resistor.
9.) When the battery voltage reaches approximately 13.5 volts, the ORANGE LED should light.
10.)As the battery charges the RED LED should become DIM and go off.
11.)When the battery voltage eventually reaches 14.5 volts, the ORANGE LED should go off and the GREEN LED should come on, indicating a fully charged battery. More operational advice can be found in the next section.

But it doesn't work !! Suggestions :

- Are the 7812 and TIP32C devices in the right place?
- Did all voltage match the table?
- Are my diodes in the wrong way around? Have then been damaged if they are?
- Are all my power diodes in the wrong way around?
- With no battery connected, is anything getting HOT? The 7812 will get warm.
- Are all IC's in the right way?
- Have I mixed up the BC817 and BC857 transistors?
- Are the 1% resistors really 1%?

If the above suggestions do not help, please contact Luke (VK3EM@HOTMAIL.COM) for further assistance.

Calculating Dissipation of Heat Sink :

Emphasis within this project has been on the end user to take the "partial kit" to the fully completed stage. That mean, choose the required bulk charge rates, LED indicators, on/off switches, fuses, box, power supply, etc. However, choosing the right heat sink can always be a bit of a hit and miss affair if you simply choose based on the "This looks big enough" principle. The theory behind choosing the right heat sink is simple. Unfortunately, not all heat sinks (especially second hand or recovered heat sinks) have known thermal resistances. However, some suppliers such as Farnell Electronics supply pictures, dimensions and thermal resistance's of many heatsinks in their catalogue. Thus a heatsink of unknown specification can be matched with the pictures and dimensions to estimate the thermal resistance.

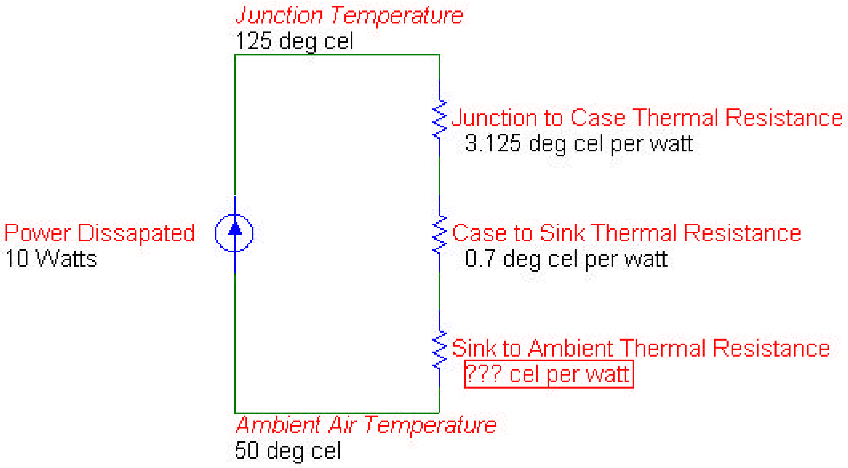


Fig A - Schematic Diagram for Power Dissipation of TIP32C pass device.

A thermal system such as a device dissipating heat into an environment can be drawn schematically as shown above. The power source is equivalent to an electrical current source. Temperatures are equivalent to electrical voltages, and thermal resistance's are equivalent to electrical resistance's. The designers problem in this projects case is "what is a safe value of thermal resistance for the heat sink". This depends on what you consider "a safe value is".

In this example, the power is being dissipated by the pass transistor (a TIP32C). The aim is to ensure the junction temperature of the TIP32C does not exceed a safe value. There are three things that limit the transfer of heat from the junction to the ambient air. The first is the "Junction to Case Thermal Resistance" or θjc. This thermal resistance is due to the internal construction of the TIP32C and there is nothing that can be done about it. θjc is quoted in the TIP32C datasheet as being 3.125 deg cel per watt. This means for each watt dissipated the junction temperature will be 3.125 deg hotter than the case.

When the TIP32C is mounted on a heatsink, some sort of insulating washer is usually used due to the metal tab of the TIP32C being electrically connected to the collector. You don't have to use an insulating washer (you can insulated the heat sink instead), but it is usually easier to insulate the transistor with an insultating washer. Unfortunately, this adds more thermal resistance to the system. This is known as "Case to Sink" thermal resistance's or θcs. Using thermal grease and good mechanical compression with a flat surface heatsink helps to minimise θcs. Using a good thermal conducting rubber washer, compression and thermal grease would result in a thermal resistance close to 0.7 deg cel per watt. θcs will depend on the type of washer you use, so if your unsure use 1 deg cel per watt to be on the safe side.

The final thermal resistance in the system is the heatsink itself, known as "sink to ambient" thermal resistance or θsa. To determine what heat sink we need to use, the maximum value of θsa for the heat sink needs to be calculated. Before this can be calculated, the parameters of the system must first be defined.

When it comes to component lifetime, it is always wise to err on the side of caution. For instance, according to the TIP32C datasheet, the maximum operating junction temperature is 150 deg cel. However, it would be logical to assume that keeping the junction temperature to a maximum of 125 deg cel would result in less stress on the transistor and thus a longer lifetime. Similarly, your choice in heatsink might be fine at room temperature, but what about when accidentally you sit something on top of the charger or use it in a tin shed where the ambient temperature could reach 50 deg cel on a hot day.

Obviously, these are extreme circumstances that are not likely to happen. But they can, so you should always way up the consequences. If you can afford it, design in the safety margin. If you can't, be aware of what the limits are. The general procedure for calculating heatsink size is as follows :

1.) Calculate the maximum power dissipation of the pass device.

> a. Maximum dissipation occurs at maximum bulk charge current with minimum battery voltage.
> b. Connect a temporary heatsink to the pass device, and with the charger bulk charging a battery at the maximum rate, measure the DC voltage across the main filter capacitor (ie: 20v input to the pass device).
> c. Since the charger will trickle charge a battery with a terminal voltage less than 10v, the maximum voltage differential across the pass device will be 20v (Input) - 10v (Battery Voltage) = 10v (Differential). Thus if P=IV then power dissipated by the pass device is 10 Watts.

2.) Determine what the maximum safe operating junction temperature will be

> a. Read the datasheet. The maximum possible operating junction temperature is 150 deg. Use a value 25 deg lower (125 deg) for safe reliable operation. Thus Tj = 125 deg worst case.

3.) Determine what the maximum ambient temperature will be.

> a. Worst case ambient should be based on environment. Normal environments can have ambient temperatures up to 50 deg cel. Harsh environments could get as high as 70 deg cel. Ta = 50 deg.

4.) Determine what the known thermal resistance's are in the system.

> a. θjc = 3.125 deg cel per watt (From Datasheet)
> b. θcs = 0.7 deg cel per watt (From other research)

5.) Calculate the maximum thermal resistance of the heat sink, θsa. Refer to Fig A.

> a. First note all known parameters.
>
> Pd = 10 Watts
> Tj = 125 deg cel (max)
> Ta = 50 deg cel (max)
> θjc = 3.125 deg cel per watt
> θcs = 0.7 deg cel per watt
>
> b. Now remember V=IR, well I guess you do. So, using the same principles, write a system equation
>
> $(Tj - Ta) = Pd * (\theta jc + \theta cs + \theta sa)$
>
> With a bit of manipulation :
>
> $$\left\{ \frac{(Tj - Ta)}{Pd} \right\} - \theta jc - \theta cs = \theta sa$$
>
> Now fill in the real values to calculate θsa. Thus, θsa = 3.675 deg cel per watt.

4.User Manual

Status Lights

RED LED (Charge Current) - The "Charge Current" LED represents the amount of battery charge current. When glowing brightly, charge current will be at or near the bulk charge current (1A or 250mA). As the battery is charged, the LED will gradually become dim, indicating that battery charge current is tapering off. When the LED is off, charge current is negligible. This LED is only a rough indication of charge current.

ORANGE/AMBER LED (Over Charge State) - The "Over Charge" LED indicates the battery charger is in the *Over Charge State*. In this state, the battery terminal voltage will slowly rise to 14.5 volts. As the battery approaches this voltage, charge current decreases and the charge current will dim. The charger attempts maintain 14.5v at the battery terminals until the charge current decreases to B/25 where B is the bulk charge current(40mA or 10mA). When the charge current reduces this value the charger will change to the *Float State* and the green LED will light.

GREEN LED (Float State) - The "Float State" LED indicates the battery charger has entered the *Float State*. This state maintains the battery voltage at 14 v (@ 25 deg cel) which is suitable for long term battery storage.

Operation

(1) Firstly, calculate the appropriate maximum charge current (Bulk Charge Current). The maximum safe charge current for most sealed lead acid batteries can be calculated by dividing the capacity of the battery (in Ampere Hours) by six. This is referred to as the C/6 charge limit. However, the maximum capacity of a battery is returned at a charge rate somewhat lower than C/6. When charging time must be kept to a minimum, use C/6.

(2) Select the appropriate charge current with the charge current selection switch.

(3) Turn the charger on. When power is applied and NO battery is connected the battery charger enters the *float state* and the green LED will turn on. If the green LED does not turn on, the battery charger is faulty and you should contact your network administrator.

Connecting the charger to a battery may cause one of several things to happen. If the battery voltage is less than 12.6 volts, the charger will enter the bulk state and the charge current LED will turn on. If the battery voltage is greater than 12.6 volts, the charger will remain in the float charge state (green LED on) but the charge current LED may turn on.

To reset the state of the battery charger, the reset switch must be depressed. This will cause the battery charger to return to the bulk state or the over charge state. In either case, the battery charge cycle will begin and the charge current LED (RED) will glow brightly.

As the battery is charged the terminal voltage increases. When the battery voltage reaches 13.7 volts the "Over Charge State" LED will turn on. As the battery continues to charge, the terminal voltage will rise to 14.5 volts and the charge current will decrease. When the battery is fully charged, the charger will switch to the float state which is appropriate for long term maintenance of the battery. The battery can be left permanently connected the battery charger and is ready for use when required.

Special Notes

(1) You can connect the charger to the battery, then turn the charger on. The charger will enter bulk charge state and the charge cycle will begin. In most cases, the charger will already be on when connected to a battery. In this case, simply push the reset switch.

(2) The charger may never finish in the over-charge state (Amber LED on). If this occurs, it is a good indication that your battery health is not good and the battery should be replaced or used for low power applications. NEVER USE THE CHARGER WITH A LOAD CONNECTED. It will cause inaccuracies in charging cycle.

(3) The charger may never enter the bulk charge state. If the battery connected to the charger is only partially discharged, the charger may skip the bulk charge state. This doesn't really matter as the charge cycle will still be completed.

(4) The charger may be affected by RF fields. This does not seem to be a problem at HF, mainly VHF and above. If this is causing problems, use ferrite beads to help suppress RF interference.

(5) The charger may swap states at a voltage other than quoted in this manual. Firstly, don't forget that the charger temperature tracks the battery and this will naturally causes states to change at different voltage with different temperatures. Component tolerance will also cause some errors in these voltages.

3. Appendices

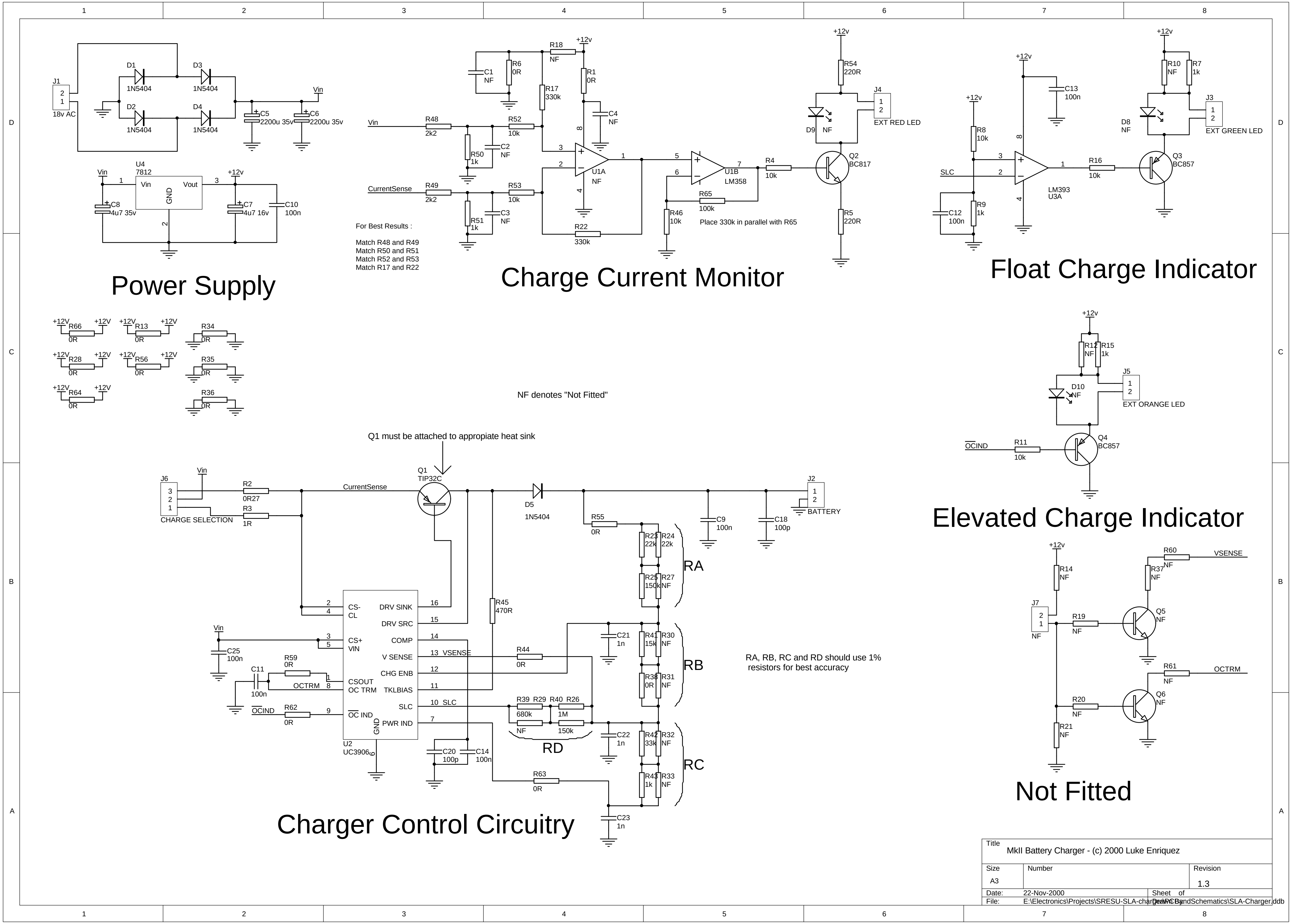
(1) Schematics and Wiring Diagram

(2) PCB Layout

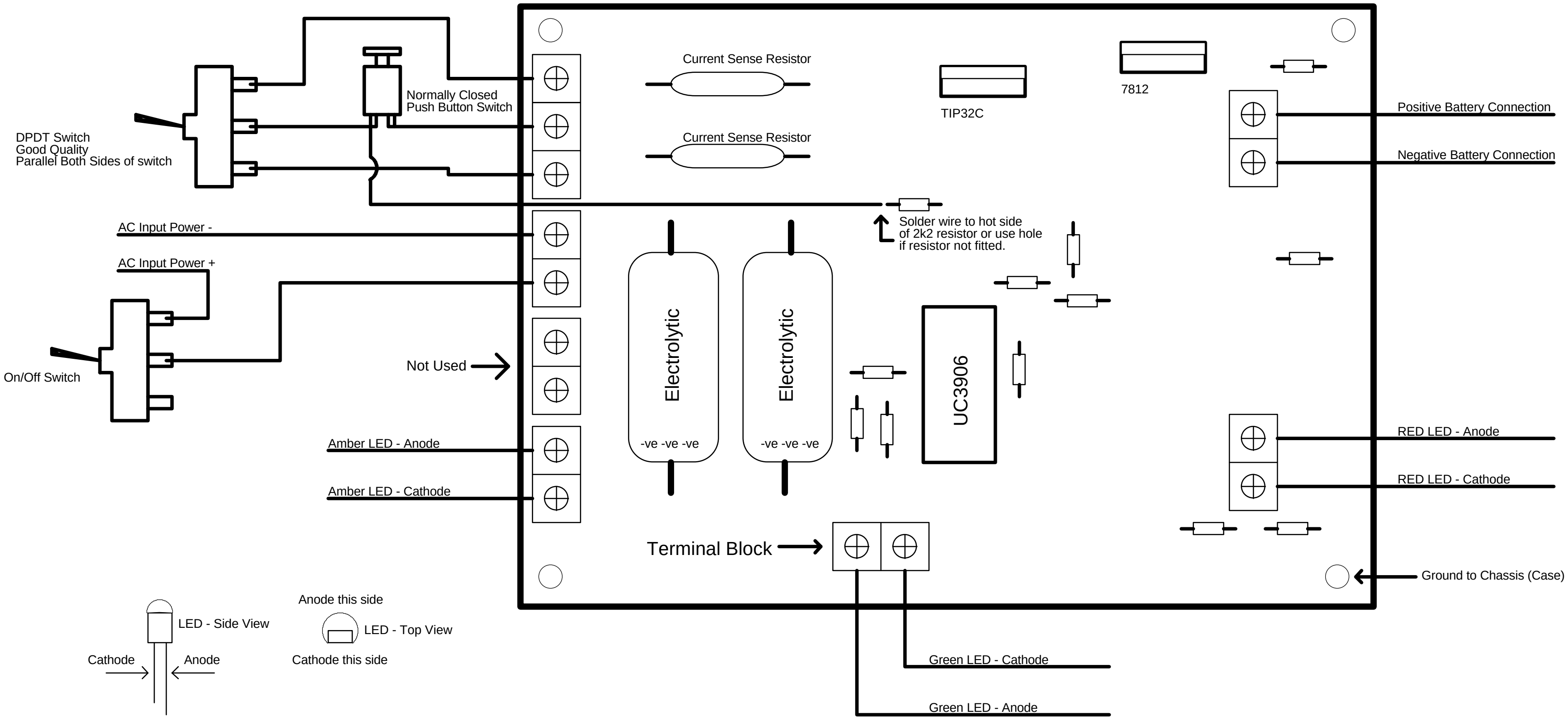
(3) PCB Overlay

(4) Bill of Materials

(5) Design Calculations


Power Supply
Charge Current Monitor
Float Charge Indicator
Elevated Charge Indicator
Charger Control Circuitry
Not Fitted
For Best Results :
Match R48 and R49
Match R50 and R51
Match R52 and R53
Match R17 and R22
Place 330k in parallel with R65
NF denotes "Not Fitted"
Q1 must be attached to appropiate heat sink
RA, RB, RC and RD should use 1% resistors for best accuracy
RA
RB
RC
RD
J1 18v AC
U4 7812
J6 CHARGE SELECTION
Q1 TIP32C
D5 1N5404
J2 BATTERY
U2 UC3906
U1A NF
U1B LM358
LM393 U3A
J4 EXT RED LED
J3 EXT GREEN LED
J5 EXT ORANGE LED
Title
MkII Battery Charger - (c) 2000 Luke Enriquez
Size A3
Number
Revision 1.3
Date: 22-Nov-2000
Sheet of
File: E:\Electronics\Projects\SRESU-SLA-charger\PCB and Schematics\SLA-Charger.ddb
Drawn By:

Battery Charger Wiring Diagram for a Typical Application



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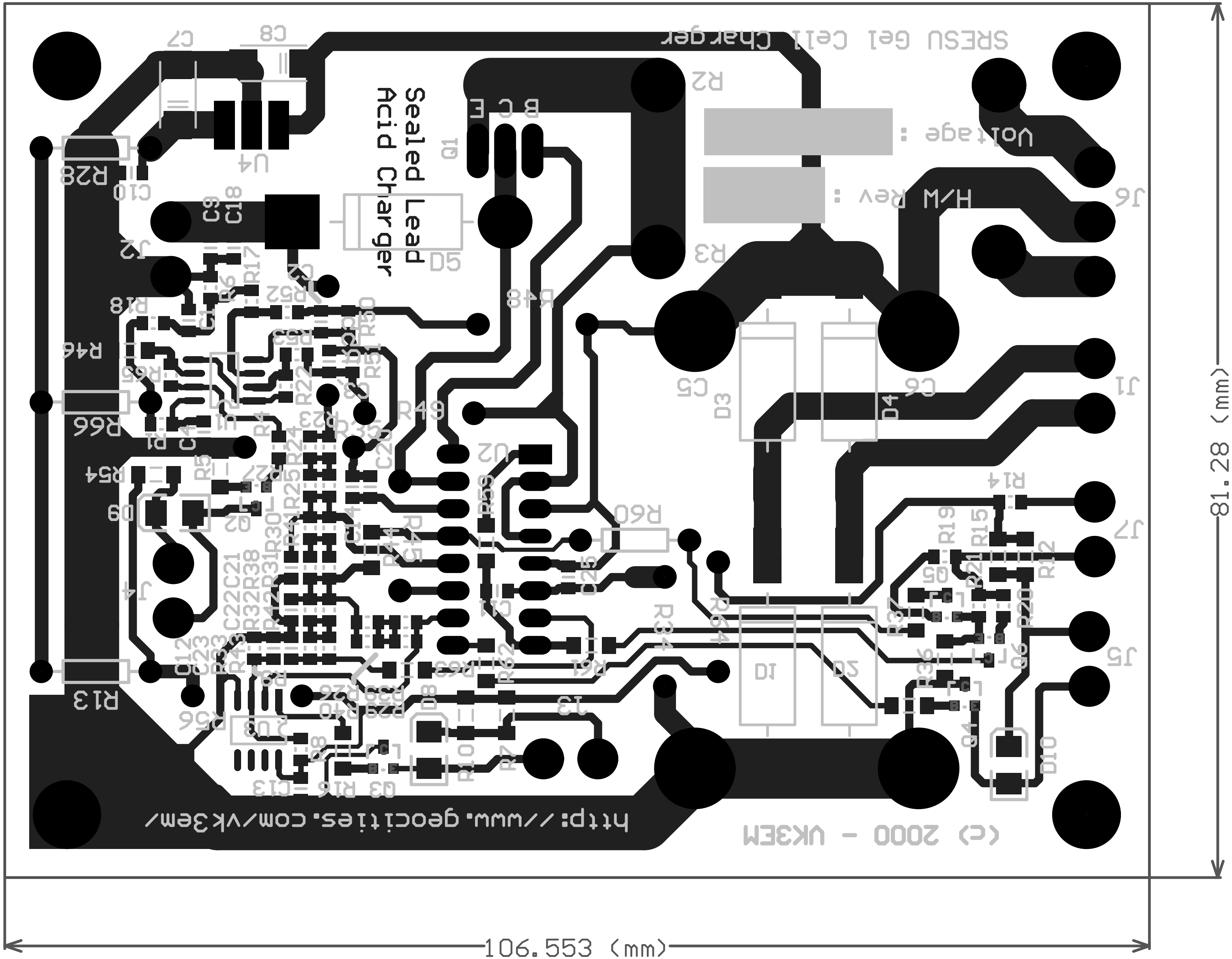
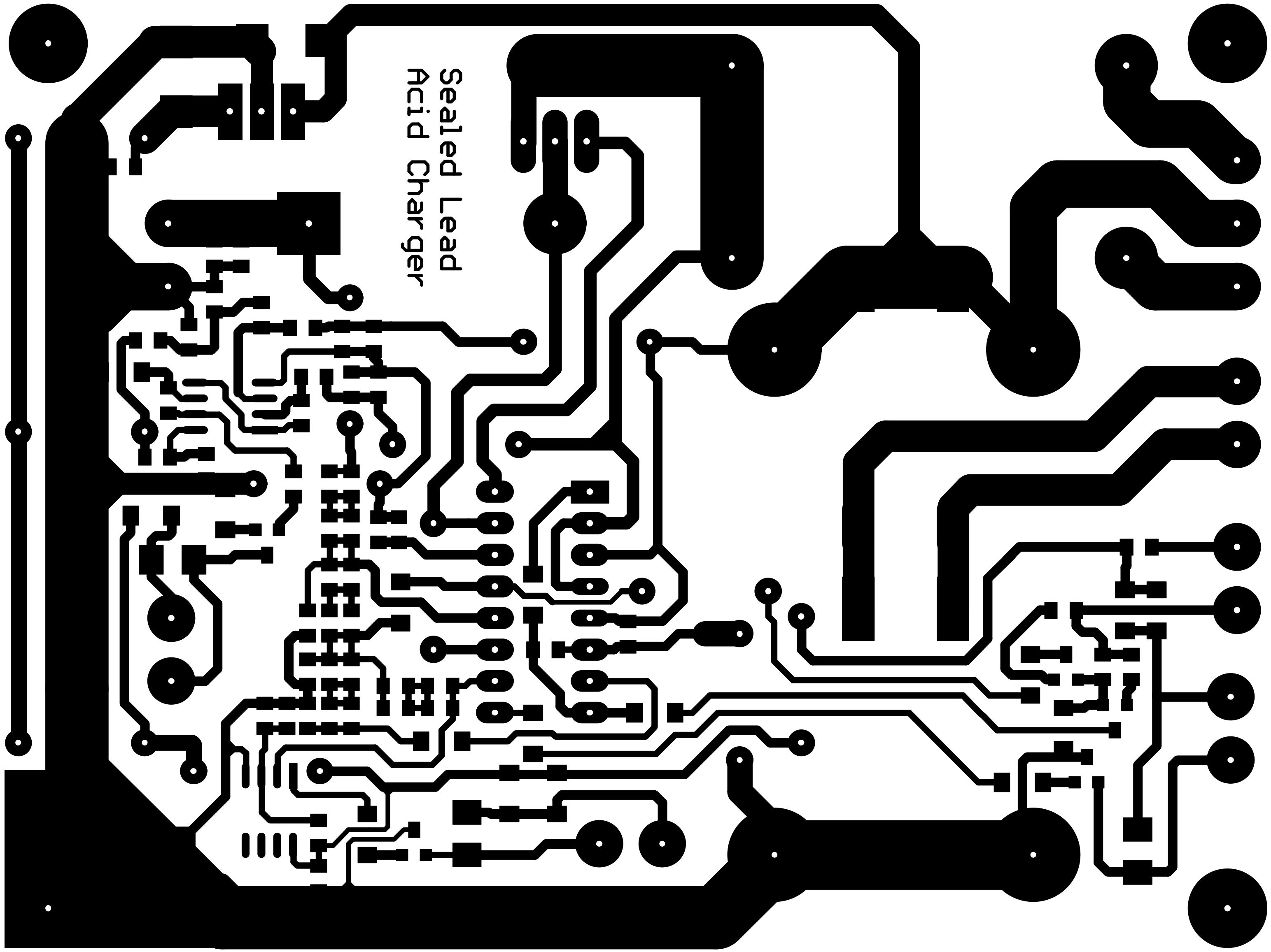
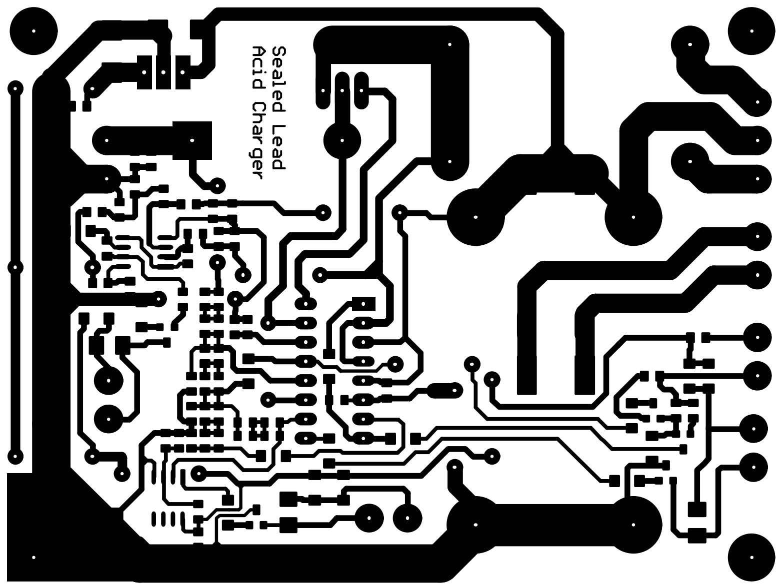
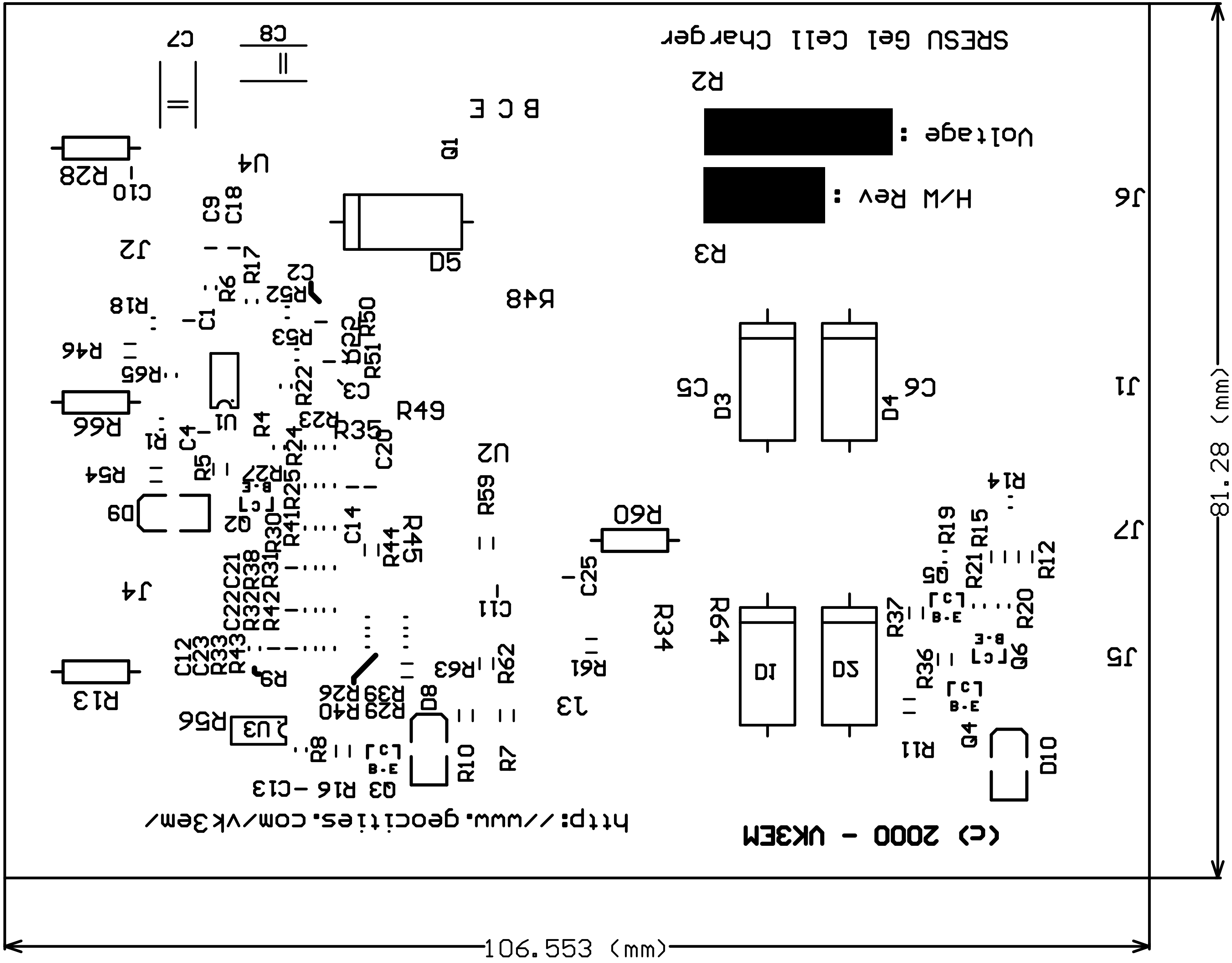


Sealed Lead
Acid Charger
SRESU Gel Cell Charger
Voltage :
H/W Rev :
http://www.geocities.com/vk3em/
(c) 2000 - VK3EM
81.28 (mm)
106.553 (mm)


Sealed Lead
Acid Charger


Sealed Lead
Acid Charger


SRESU Gel Cell Charger
Voltage :
H/W Rev :
(c) 2000 - VK3EM
http://www.geocities.com/vk3em/
106.553 (mm)
81.28 (mm)

SLA Charger Mk II - Bill of materials Rev 1.3

Part Type	Qty	Designators	Notes
0R25 2W Resistor Leaded	1	R2	Axial Style
1R0 2W Resistor Leaded	1	R3	Axial Style
0R Wire Link	8	R13,R28,R34,R35,R55,R56,R64,R66	Axial Style
0R Resistor 5%	3	R1,R6,R38	0805 SMD
0R Resistor 5%	5	R36,R44,R59,R62,R63	1206 SMD
1M Ohm Resistor 5%	1	R40	0805 SMD
1N5404 Diode	5	D1,D2,D3,D4,D5	4 x SMT Pre Bent
1K Ohm Resistor 1%	4	R9,R43,R50,R51	0805 SMD
1K Ohm Resistor 5%	2	R7,R15	1206 SMD
1nF Capacitor	3	C21,C22,C23	0805 SMD
2k2 Ohm Resistor 1%	2	R48,R49	Axial Style
10k Ohm Resistor 1%	4	R4,R8,R52,R53	0805 SMD
10k Ohm Resistor 5%	3	R11,R16,R46	1206 SMD
4u7 35v Tantalum	1	C8	C Case SMD
4u7 16v Tantalum	1	C7	C Case SMD
15k Ohm Resistor 5%	1	R41	0805 SMD
22k Ohm Resistor 5%	2	R23,R24	0805 SMD
33k Ohm Resistor 5%	1	R42	0805 SMD
100k Ohm Resistor 5%	1	R65 (parallel with 330k)	0805 SMD
100nF Capacitor 35v	7	C9,C10,C11,C12,C13,C14,C25	0805 SMD
100pF Ceramic Cap	2	C18,C20	0805 SMD
150k Ohm Resistor 5%	2	R25,R26	0805 SMD
470R Resistor 5%	1	R45	Axial Style
220R Resistor 5%	2	R5,R54	0805 SMD
330k Ohm Resistor 1%	3	R17,R22,R65 (parallel with 100k)	0805 SMD
680k Ohm Resistor 5%	1	R39	0805 SMD
2200uF 35v Electrolytic	2	C5,C6	Axial Style
7812 +12v 1Amp Regulator	1	U4	TO-220
BC817	1	Q2	SOT-23
BC857	2	Q3,Q4	SOT-23
LM358	1	U1	SO-8
LM393	1	U3	SO-8
TIP32C	1	Q1	TO-220
UC3906	1	U2	DIP-16
2 WAY Screw Terminal Block	6	J1,J2,J3,J4,J5,J7	0.2" Pin Spaced
3 WAY Screw Terminal Block	1	J6	0.2" Pin Spaced

Design Documentation : The UC3906 has a well defined design process for determining the battery charging characteristics. This is a fancy way of saying they were not plucked out of the air. Individual requirements might vary, so here is the design process I used for the VK3EM Sealed Lead Acid Charger. The voltages used in this design process were chosen after careful consultation with the UC3906 datasheet, applications note, the Gates Energy Products sealed lead acid applications handbook and discussions with engineering friends over a few beers. Regards - Luke VK3EM (20/8/2000)

The "Float Voltage" defines the long term maintenance voltage. This voltage is temperature dependent and tracked by the UC3906. There is *NO* one correct float voltage. Often an acceptable range of float voltages is printed on the side of the battery. Use the value appropiate for 25 deg cel.

Float Voltage $Vf := 14V$

The "Over Charge Voltage" defines when the charger swaps from State 2 (Over Charge) to State 3 (Float). When this voltage is reached, the battery is fully re-charged and ready for use.

Over Charge Voltage $Voc := 14.5V$

The "Reference Voltage" refers to the on board voltage reference of the UC3906 that temperature tracks with the battery. Use the value at 25 deg cel.

Reference Voltage $Vref := 2.3V$

The "Threshold Voltage" defines when bulk charge can begin. Remember, your battery might have a shorted cell, be connected reverse polarity or even be 6 volts, so 10 volts is a good voltage to choose. The charger will trickle 25 mA until the battery terminal voltage reaches 10 volts. The minimum input supply voltage is also needed for these eqn.

Threshold Voltage $Vt := 10V$
Threshold Trickle Current $It := 25mA$
Input Supply Voltage $Vin := 16.5V$

The "Divider Current" refers to the current flowing through the resistor divider string, that essentially defines the voltage sensing of the UC3906. The value of this current is very flexible (ie : it doesn't matter too much), but values between 50uA and 100uA are reconmended. If you find you can't easily make up the final resistor values with the combination of E12 resistors offered, change this value and try again. You should eventually find a combination of Id and Ra,Rb,Rc,Rd that will utilise E12 resistor values.

Divider Current $Id := 66.5\mu A$

Everything that can be defined has been defined (well sort of). Now the calculation can begin. Get out your trusty pocket T-calculator, spend the next 4 hours looking for some batteries that will fit the bloody thing and continue when your ready.

Oh, yeah I kinda progressed from cave man calculator days and use a a mathematics program instead (A spreadhseet could be useful too). Either way, here we go :

Calculate the voltages for the state transistions V12 and V31. These formulas can be found on page 5 of the UC3906 datasheet.

$V12 := 0.95 \cdot Voc \qquad V12 = 13.775\,V$

$V31 := 0.90 \cdot Vf \qquad V31 = 12.6\,V$

Now calculate Rc :

$$Rc := \frac{Vref}{Id} \qquad Rc = 34.586\,K\Omega$$

Now calculate Rsum which gives us Ra and Rb :

$$Rsum := \frac{Vf - Vref}{Id} \qquad Rsum = 175.94\,K\Omega$$

Now calculate Rd :

$$Rd := \frac{Vref \cdot Rsum}{Voc - Vf} \qquad Rd = 809.323\,K\Omega$$

Now calculate Rx which gives us Ra :

$$Rx := \frac{Rc \cdot Rd}{Rc + Rd} \qquad Rx = 33.169\,K\Omega$$

Now calculate Ra :

$$Ra := (Rsum + Rx) \cdot \left(1 - \frac{Vref}{Vt}\right) \qquad Ra = 161.014\,K\Omega$$

Now calculate Rb :

$$Rb := Rsum - Ra \qquad Rb = 14.926\,k\Omega$$

Now calculate Rt :

$$Rt := \frac{(Vin - Vt - Vref)}{It} \qquad Rt = 168\,ohm$$

We now know all the theorectical resistor values for our battery charger. But why are they theorectical? Well, as Murphey's Law states, there is always something you don't factor in. In this case, its the Vce voltage drop across the open collector resistor at Pin 7 (Power Indicate). Huh? What do you mean?

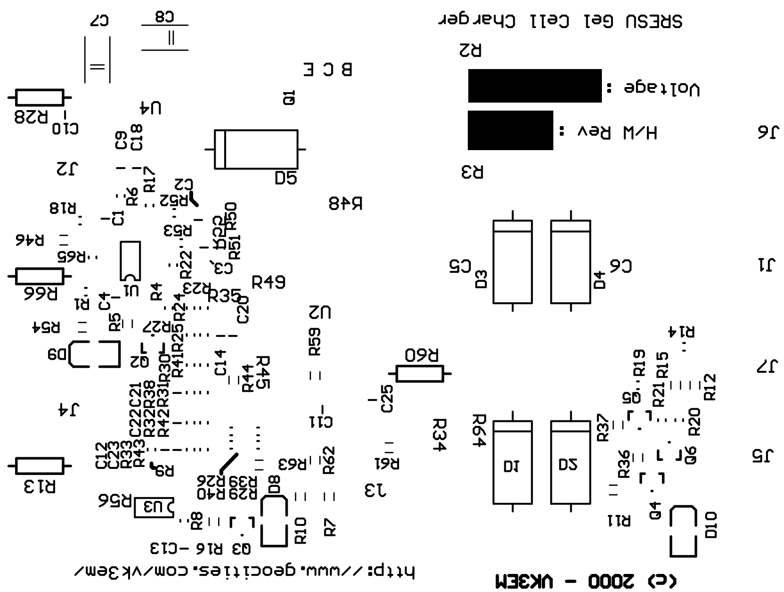
Remember, Pin 7 is being used as the ground reference instead of ground. This means the charger does not draw current (via the resistor divider string) when the battery charger is off (No supply). The problem is, Pin 7 is grounded via a Transistor. When turned hard on and with a collector current of 70uA, there is a voltage drop across the transistor. If this voltage drop is not factored into the equation, you will get an error in your battery charger transistion and float voltages.

The voltage on my prototype turned out to be 27mV. This may vary from unit to unit, but at 66uA equates to approximately 415 Ohms. Subsequently, the theorectical value of Rc and the real value of Rc differs by this amount.

So, the final theorectical values are :

Rc = 34.5 kOhm. So, this could be implemented as a 33k and 1k5.
Rd = 809 kOhm. This could be 680k + 150k // 1M
Ra = 161 kOhm. This would best be 150k + 22k // 22k
Rb = 15 kOhm. Well, obviously 15k is the best value.

Rt = 168 Ohms, so either 150 or 180 Ohms would suffice.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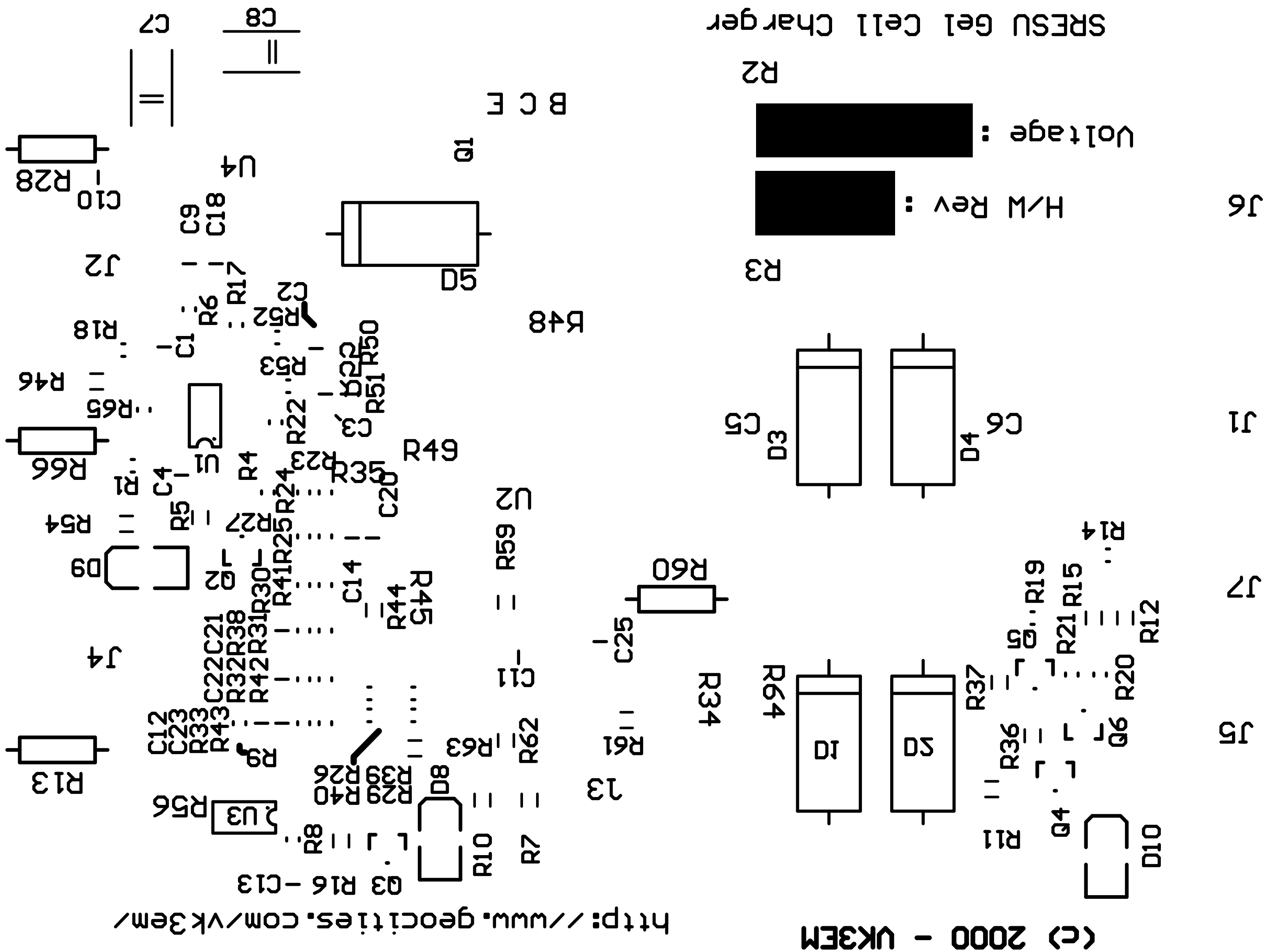
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