A VERSATILE GEL CELL CHARGER

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1. INTRODUCTION

A charger that is based on the TI/Unitrode UC3906 IC is described. The unit features switched charge rates, proper charge status feedback and 6V (3-cell) or 12V (6-cell) battery options.
Proper detail on these facilities have been lacking or poorly implemented at least in non-commercial designs published in hobby electronics literature.
As sealed lead-acid batteries are not cheap, it pays to give proper attention to optimizing battery life and the return of maximum capacity after each charge.
Capacity and life are critical parameters that are strongly affected by charging methods.
The UC3906 manages the charge cycle suitable to typical sealed lead-acid cell chemistry and also compensates for its temperature coefficient. Battery performance is measured in two ways: cycle life and standby life.
Cycle life refers to the number of charge and discharge cycles a battery can go through as a stand-alone unit. Standby or float life is a measure of how long a battery can be maintained in a fully charged state permanently on a charger and able to provide proper service when called upon.
In the following text, the author has borrowed heavily from notes in the data sheet[1] and application note[2] U-104, which are extensive, but lack the real practical implementation detail to construct a fully functional unit. The latter gap is filled by this article and is a very worth while project.

2. CHEMISTRY

During the charge cycle of a typical lead-acid cell, lead sulphate $PbSO_4$, is converted to lead on the battery's negative plate and lead oxide on the positive plate. Once the majority of lead sulphate has been converted, an overcharge reaction begins which generates hydrogen and oxygen gas. In sealed cells these recombine as opposed to unsealed batteries which will dehydrate.
The onset of the overcharge reaction depends on the rate of charge. For the overcharge point to coincide with 100% return of capacity, charge rates must typically be C/100. As this takes a very long time, a compromise at C/8 to C/10 will return approximately 85-90% capacity at the onset of overcharge and return 100% after proper control.
Once a cell is fully charged, its voltage at 25°C is typically 2,3V but has a temperature dependence of typically –4mV/°C. Translating this to a 6-cell 13,8V battery this amounts to 0,24V for every 10°C which results in bad undercharging at 15°C and heavy overcharging at 35°C. Such errors can drastically reduce service life. The best way to maintain proper charge is to apply a precise temperature compensated constant (float) voltage that tracks the cell temperature coefficient.

3. DESCRIPTION

The unit is designed as a dual level float charger with three temperature compensated states and some safety features. A battery will be treated thus:

a) Validation of condition better than a set threshold V_T: If less, an alarm indicator will come up automatically and the unit will attempt to trickle charge the battery at 25mA to try and bring it up. If there is a shorted cell or other reason it will not go into its normal charge sequence so as to prevent battery overheating etc. If the applied battery is $>V_T$ the bulk charge state will be initiated.
b) Bulk charging is at maximum constant current where the current in this design is C/8. The battery voltage is monitored to a threshold V_{BO} where it switches over to the overcharge state.

c) During overcharge, the voltage per cell is increased by 0,1V to 2,4V per cell and the current is now monitored until it slowly drops to one tenth (C/80) after which a switchover to the float condition V_F occurs.

d) In the float state the charger is a voltage regulator with a precise temperature compensated output voltage onto which the battery can remain indefinitely.

e) If the battery has to give service when connected to the charger, a discharge beyond 90% of the float voltage will reset the system to bulk charge.

f) If the battery had service elsewhere and is reconnected in any condition, the unit will sense and self-initiate to the correct charging state at the instant of charger switch-on.

g) Connecting a 12V battery with a 6V setting will bring up the float indicator as the unit considers it to be a full battery.

h) Connecting a 6V battery with a 12V setting will bring up the alarm condition as the unit considers it as a very flat battery. In the extreme, a short-circuit will do the same.

i) The unit is safeguarded against reverse battery connections in the sense that safety diodes prevent the controller to experience full polarity reversal below ground. The battery can however be damaged if no fused leads are used.

4. DESIGN

The accompanying circuit diagram depicts all necessary components except the raw DC supply. The internal workings of the IC are adequately described in the data and four main parameters can be set with user defined components:

4.1 Bulk charge current rate. Here C/8 was considered a good compromise. The IC current-sense input is referenced to 250mV and there must thus be 250mV across R1-R8 to maintain maximum constant current at any Ah setting. A rotary switch selects the required resistors as calculated below:

Capacity Ah	C/8 mA	R at 250mV	Nearest practical implementation
1	125	2,000	R1= 2x1,00Ω = 2,000
2	250	1,000	R2= 2x1,00Ω // R1 = 1,000
3	375	0,667	R3= 1x1,00Ω // R1 = 0,667
4	500	0,500	R4= 1x0,68Ω // R1 = 0,507
5	625	0,400	R5= 1Ω//1Ω // R1 = 0,400
6	750	0,333	R6= 1x0,39Ω // R1 = 0,326
7	875	0,286	R7= 1x0,33Ω // R1 = 0,283
8	1000	0,250	R8= 1x0,27Ω // R1 = 0,237

These values need not be exact and the above results are within 5% give or take another 5% for resistor tolerances. The use of 5W WW types is recommended for values below 1Ω to ensure stability with temperature rise as these carry the higher currents.

Additional unwanted series resistance can be experienced in the rotary switch. This was minimized by using three wafers in parallel.

4.2 Enable threshold and alarm/trickle charger. This is also not critical but must detect one bad cell at least. A normally flat cell is approximately at 1,75V. Thus for 3-cell and 6-cell batteries the threshold V_T can be 5V and 10V respectively. This is done with the voltage divider on pin 12 according to R_{bottom}= 2,3xR_{top} /(V_T-2,3). Choosing R15=R_{top}=75k yields 63,88k and 22,40k respectively. These can conveniently be made up with a common 18k=R19 in series with switched 47k=R20 and 4k7=R21 with good accuracy.

To effect constant-current trickle charging for any load below V_T (including a short circuit), a simple LM317L regulator configured as a 25mA constant current source fed from pin 11 is employed. Pin 11 is derived from the main positive supply and can thus rise much higher than V_T to take up the voltage drops across D7, U2 and D8 and much more.

4.3 Float voltage (V_F). This is set by the voltage divider on pin 13 that needs to be exactly at 2,3V at 25°C. For a 3-cell and 6-cell battery this ratio is simply 1/3 and 1/6 of the float voltage. It is easily seen that the circuit with R16,17,21,22 can accurately effect this with standard values.
Using stable metal film resistors with 1% tolerance adequately covers requirements.

4.4 Bulk and overcharge voltage (V_{OC}). For both these states the open collector output at pin 10 connects R18 to ground changing the float divider ratio slightly down so that more voltage is required at the terminals to reach 2,3V at pin 13. Overcharge is well on the way after 2,4V per cell and climbs very steeply as a function of the charge rate used. For C/8 the actual overcharge voltage should preferably be kept below 2,5V. For the case of 2,4V, the required $R18=2,3xR_{top}/N(V_{OC}-V_F)$ which in this design is conveniently a constant $57,5/(V_{OC}-V_F) =$ 575k. Using a 560k value increases V_{OC} only to 2.4027V per cell which for 3-cell and 6-cell batteries translates to 7,208V and 14,416V respectively. Add to this cumulative tolerances of the divider network as say, 1% and a maximum internal reference error specifications of 1%, then a worst case of +2% can be expected to 2,45V/cell or 7,35V and 14,7V respectively with standard components at 25°C. The aforementioned temperature coefficient compensation will of course contribute to safe limits and optimum charging conditions.

5. STATUS INDICATION

The UC3906 does not have very useful status indication outputs. A circuit was devised that makes use of the available collector outputs at pins 1,9,10 which can only sink small external currents for low saturation voltages. To complicate matters, pins 1 and 10 must be isolated when off; else normal operation is affected. The status indicator block comprises Q1, Q2 and associated components. Stimuli and outputs are as tabled below:

Condition at 25°C Voltages below apply to a 6-cell battery.	Pin1 O.C.T	Pin9 O.C.I	Pin10 State	Bulk LED	O.C. LED	Float LED
Unit on after flat battery connected I=Imax	0	1	0	on		
Bulk–O.C transition $0,95(V_{OC}=14,4V)=13,68V$	0	0	0		on	
O.C. current down to Imax/10	1	1	1			on
Float condition $V_F=13,80V$	X	1	1			on
Float condition loaded down to $0,9V_F=12,42V$	0	1	0	on		
Unit on with no battery	1	1	1			on
Unit on and subsequent battery connection	X	1	1			on

Once the float condition is reached the internal logic is latched to fix the output at 13,8V. None of the above logic stimuli can now change its state. Only the terminal voltage can reset the logic and has to fall 10% for unlatching to take place. This means that a falling voltage in the float condition will not go through an O.C indication as it traverses the overcharge threshold. This latching also isolates the indeterminate state of the low current sense comparator output at pin 1 which can be in any state either due to battery fluctuations or actual use of the battery when remaining connected. Hence the X in the truth table.

6. PRACTICAL CONSIDERATIONS

Note that a front panel meter is not much use in this charger. Firstly it cannot tell the state it is in and secondly the current indication will be low most of the time.

A power-on or power-good indication (pin 7) was considered as unnecessary front-panel clutter as some or other LED is always on. A reset button to force the charge cycle to start (last entry in table needs a reset to get started)) was dumped in favour of just switching on the charger after the battery is connected (an operating instruction) and not before. If you wish to have one, arrange to ground pin 13 momentarily with a discharged 22nF capacitor.

In case of the supply failing, the battery is drained by approximately 200µA due to the resistor networks. Though this is pretty negligible, there is even a remedy for that by designing a single resistor chain with taps for both pin 12 and 13 and switching the underside either to ground or not with pin 7 (power-good). This resistor chain invariably uses complicated resistor values[4]. The separate dividers in the design used here can also be isolated from ground this way but in all cases the collector at pin 7 has some saturation voltage that will affect the resistor ratios.

7. OPERATING INSTRUCTIONS

The instructions can be derived from the table above but can appear on the unit's cover in simple words as follows:

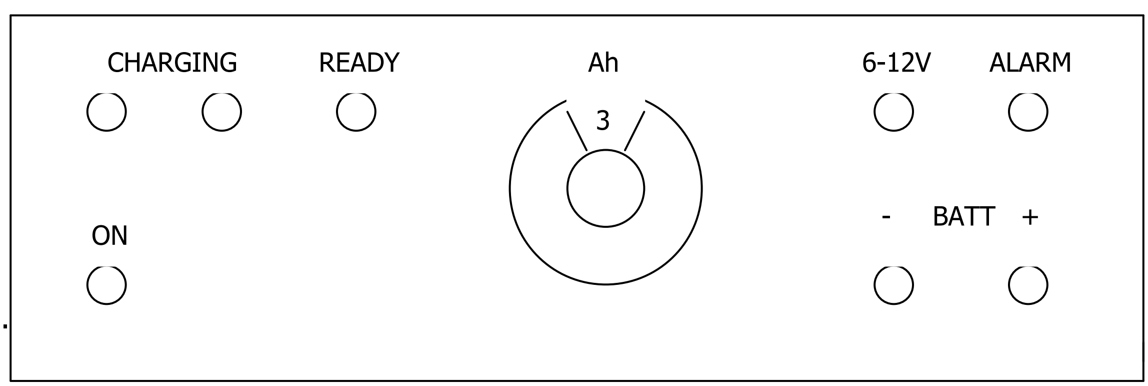
SWITCH OFF
SET CHARGE RATE –--------: NEVER EXCEED 2x BATTERY RATING
SET TO CORRECT VOLTAGE
CONNECT BATTERY
SWITCH ON
ALARM ON -------------------: Possibly faulty battery
RED OR AMBER ON -- ------: OK to charge
GREEN ON -------------------: Ready for use/removal

Note that at a setting of twice the battery rating the general safe limit of C/4 for gel-cells has been reached. For an efficient but longer charge the rate must be set to equal that of the battery or less.

There are cases where feedback can be deceptive. For instance a poor leaky battery may never get out of the overcharge (amber on) state as the current cannot fall below 10% of the maximum. A battery with high internal resistance will appear to charge faster by quickly skipping the bulk phase and yet gives poor service. Experience or battery test methods can bear this out. Working with the same batteries regularly will build up mental data and justify replacement of a particular unit.

8. CONSTRUCTION

Some thought should be given to the front panel layout. The author's version is as shown below.



The status display components were mounted on a small strip of vero-board which in turn was mounted directly onto the cathode pins of the three status display LED's. A 4-wire ribbon was taken from there to the main component board.
Components that need attention are the selector switch, which as mentioned should have two or three identical wafers. If an AC power source is used the transformer should be of reasonable quality and not build up heat when unloaded
In order to isolate the UC3906 completely from internal component heat radiation, it was mounted upside-down (in a socket on the main vero-board) over a rectangular hole made in the case bottom so that it was exposed only to upward ambient air. This is the first unit the author has built where an IC can be replaced without having to open the case!

9. CONCLUSION

Though a reasonably simple project, not many battery users appear to be motivated to use proper charging methods. Admittedly many sealed cells are in unattended float service but for portable power there is nothing more satisfying than knowing that you have maximum capacity. Putting a flat battery on a C/8 current limited 13,8V supply can only return 75% of capacity, so all the more reason to consider this project. In the long term you will have more reliability and save money.

References

1. UC2906/3906 data sheet – TI/Unitrode Revised version Jan 2002
2. UC2906/3906 application note – Unitrode U-104
3. Various battery manufacturer's data
4. http://www.arrl.org/qexfiles/0205evans.zip
   Excel spreadsheet to design R values for a single chain of resistors.
   (Ra+Rb=Rsum=R16)
   Junction of Ra and Rb to pin 12.
   Junction of Rb and Rc to pin 13.
   As the rest of the circuit configuration differs from the one published here, the last 5 calculations are not applicable.

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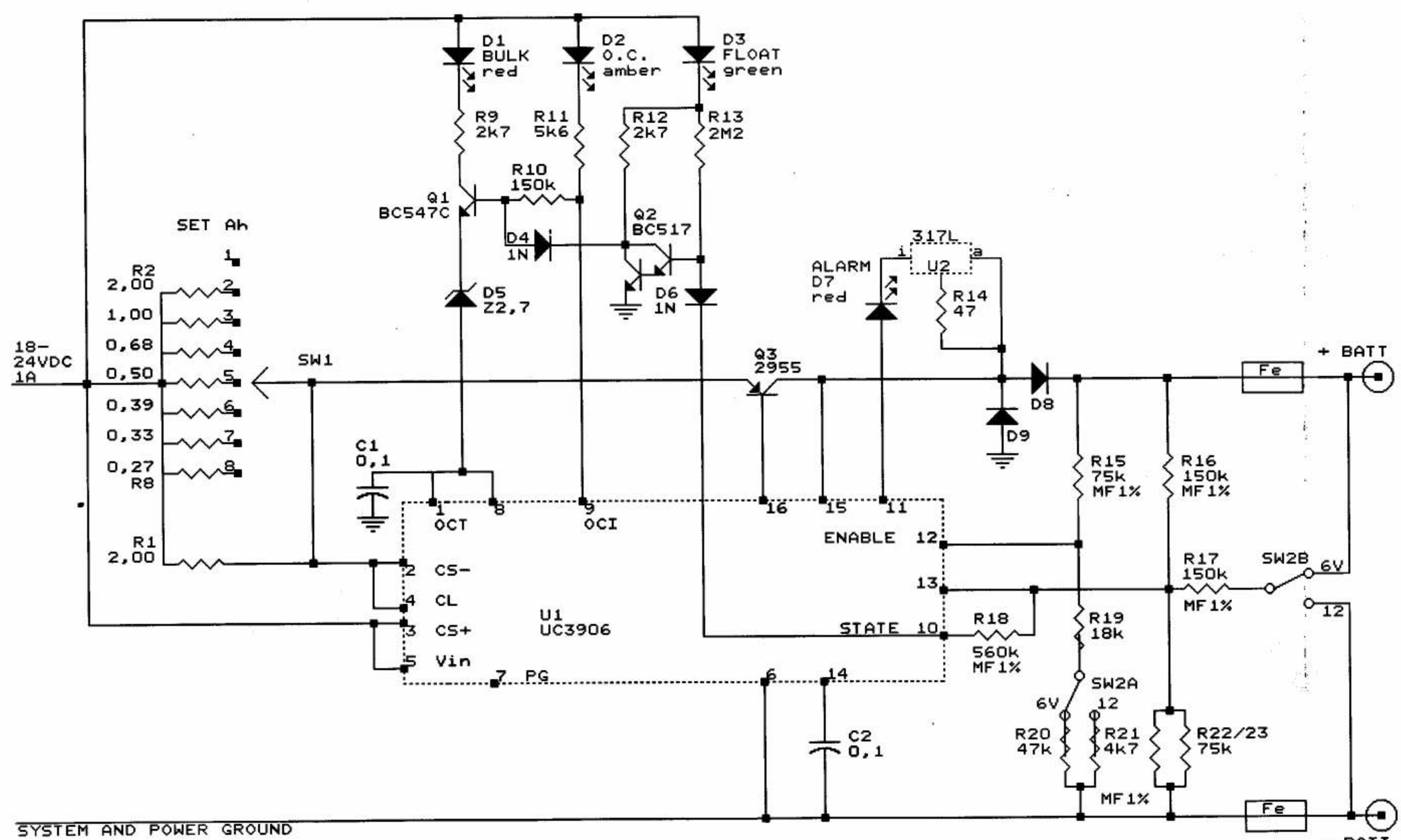
Diagram follows on next page.



Pins 12 and 13 can be
RF decoupled with 1nF
(C3 and C4)

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