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## DESIGN AND IMPLEMENTATION OF FAST THREE STAGES SLA BATTERY CHARGER FOR PLC SYSTEMS

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### ABSTRACT

New fast sealed lead acid (SLA) battery chargers must be able to charge the fully discharged batteries in a short time. In the same time, the charger must monitor the battery state of health in order to prevent over charge and to extend the battery life time.

In this paper a Fast charger was presented to charge SLA batteries in short time and monitor the battery voltage to prevent over charge. The design was implemented practically. And 150 charger of similar type was produced for commercial use. They are now in service in different Mobile base station sites around Baghdad. It can charge a fully discharged 12V, 4.5Ah battery in less than 5 hours. To supply PLC control system on DC power to about 24 hour of continuous operation during main electricity faults.

During one and half year of continuous operation three faults have been recorded in the 150 chargers. All of the three cases were because of bad components manufacturing.

150

150

12V, 4.5Ah

24

150

**Keywords:** SLA, VRLA, SoC, SoH, Battery Chargers, three mode charger, Fast charger, DC PLC backup system.

## 1. INTRODUCTION

In the introduction a brief discussion about the SLA batteries and charging algorithms will be presented.

### 1.1.VRLA Batteries

Lead-acid batteries, invented in 1859 by French physicist Gaston Planté[1]. VRLA stands for valve-regulated lead-acid and is the designation for low-maintenance lead-acid sealed rechargeable batteries. Because of their construction, VRLA batteries do not require regular addition of water to the cells.

These batteries are often called sealed lead-acid batteries, but they always include a safety pressure relief valve. As opposed to vented (also called flooded) batteries, a VRLA cannot spill its electrolyte if it is inverted.

The name "valve regulated" does not wholly describe the technology; these are really "recombinant" batteries, which means that the oxygen evolved at the positive plates will largely recombine with the hydrogen ready to evolve on the negative plates, creating water thus preventing water loss. The valve is strictly a safety feature in case the rate of hydrogen evolution becomes dangerously high.

Since VRLA batteries do not require (and make impossible) regular checking of the electrolyte level, they have been called Maintenance Free (MF) batteries. However, this is somewhat of a misnomer. VRLA cells do require maintenance. As electrolyte is lost, VRLA cells may experience "dry-out" and lose capacity. This can be detected by taking regular internal resistance, conductance or impedance measurements of cells.

### 1.2.Charging the lead-acid battery [2]

The charging algorithm for lead-acid batteries is to use voltage rather than current limiting. The charge time of a sealed lead-acid battery is 12-16 hours (up to 36 hours for larger capacity batteries). With higher charge currents and multi-stage charge methods, the charge time can be reduced to 10 hours or less.

It takes about 5 times as long to recharge a lead-acid battery to the same level as it does to discharge. A multi-stage charger first applies a constant current charge, raising the cell voltage to

a preset voltage (Stage 1 in Figure 1). Stage 1 takes about 5 hours and the battery is charged to 70%. During the topping charge in Stage 2 that follows, the charge current is gradually reduced as the cell is being saturated. The topping charge takes another 5 hours and is essential for the well being of the battery. If omitted, the battery would eventually lose the ability to accept a full charge. Full charge is attained after the voltage has reached the threshold and the current has dropped to 3% of the rated current or has levelled off. The final Stage 3 is the float charge, which compensates for the self-discharge.

Correct settings of the voltage limits are critical and range from 2.30V to 2.45V. Setting the voltage limit is a compromise. On one end, the battery wants to be fully charged to get maximum capacity and avoid sulfation on the negative plate. A continually over-saturated condition at the other end, however, would cause grid corrosion on the positive plate. It also promotes gassing, which results in venting and loss of electrolyte.

The voltage limit shifts with temperature. A higher temperature requires slightly lower voltages and vice versa. Chargers that are exposed to large temperature fluctuations should be equipped with temperature sensors to adjust the charge voltage for optimum charge.

The battery cannot remain at the peak voltage for too long; the maximum allowable time is 48 hours. When reaching full charge, the voltage must be lowered to maintain the battery at between 2.25 and 2.27V/cell. Manufacturers of large lead-acid batteries recommend a float charge of 2.25V at 25°C.

Car batteries and valve-regulated-lead-acid batteries (VRLA) are typically charged to between 2.26 and 2.36V/cell. At 2.37V, most lead-acid batteries start to gas, causing loss of electrolyte and possible temperature increases.

Large VRLA batteries are often charged with a float-charge current to 2.25V/cell. A full charge may take several days. It is interesting to observe that the current in float charge mode gradually increases as the battery ages in standby mode. The reasons may be electrical cell leakages and a reduction in chemical efficiency.

Aging affects each cell differently. Since the cells are connected in series, controlling the individual



cell voltages during charge is virtually impossible. Even if the correct overall voltage is applied, a weak cell will generate its own voltage level and intensify the condition further.

Lead-acid batteries must always be stored in a charged state. A topping charge should be applied every six months to avoid the voltage from dropping below 2.10V/cell on an SLA. Prolonged storage below the critical voltage causes sulfation, a condition that is difficult to reverse.

1.3.State-of-charge (SoC) reading based on terminal voltage

The state-of-charge of a lead-acid battery can, to a certain extent, be estimated by measuring the open terminal voltage[4] . Prior to measuring, the battery must have rested for 4-8 hours after charge or discharge and resided at a steady room temperature[4] . A cold battery would show slightly higher voltages and a hot battery would be lower. Due to surface charge, a brief charge will raise the terminal voltage and provide inflated state-of-charge reading. For example, a 30 minute charge could wrongly indicate 100% SoC if no rest is applied.

With sufficient rest and stable temperature, voltage measurements provide an amazingly accurate State of Charge (SoC) estimation for lead acid batteries. It is important that the battery is free of polarization. If connected in a system, such as in a car, there are steady auxiliary loads, not to mention frequent starting and driving.

Table 1 BCI standard for SoC estimation of a 12V flooded lead acid car battery [2]

Open circuit voltage	State-of-Charge in %
12.65V	100%
12.45V	75%
12.24V	50%
12.06V	25%
11.89V or less	Discharged

Proposed charger and backup system

A simplified block diagram of the system is shown in Fig. 2. This block diagram represents the functional blocks of the system. The first block is the SMPS, which is a standard SMPS. The output of the SMPS is DC voltage about 19V. This DC

voltage is transferred to the second block which is charging control and output conditioning circuit. This block is the main block of the system and the design of this block is the state of art, which contains the charging algorithms and output control circuits and contains all the protections.

2. DESIGN AND IMPLEMENTATION

In this section, the design and implementation of each block of Fig. 2 will be demonstrated.

2.1.SMPS

The first block is the SMPS. To implement this block a standard SMPS that is available commercially was used. Fig.4 shows the circuit diagram and Fig.3 shows the PCB picture of similar SMPS. The output of this power supply is set to 19V DC through the voltage divider R4 and R5. This value is limited by the MOSFET used. For the IRF3205, the max threshold voltage is 4V[13] . Since the max battery voltage during charging is 14.75, the total power supply voltage must be 14.75+4=18.75V. 19V was used for safe circuit operation. The TL431 is an Adjustable Precision Shunt Regulator. It is responsible for keeping the output voltage fixed by controlling the feedback loop. The max current that can be drawn from similar supply is 1A.

The operation of the SMPS can be summarized as follows:

- The 220V AC is converted to about 311V DC through the diode bridge D1 and high voltage chemical capacitor C3.
- The TOP224 is a Three-terminal Off-line PWM MOSFET switch. It chops the 311VDC at frequency of about 100 kHz. The chopping frequency is set by the internal oscillator of the TOP224. This high voltage signal will be reduced to low voltage through the ferrite step-down transformer TP.
- The high speed rectifier Diode D4 will rectify the output of the transformer into DC voltage. This DC voltage will pass through low pass power filter to reduce switching noise.
- The TL431 regulator is responsible of keeping the output voltage constant. The TL431 compare the voltage at the middle terminal with the internal Precision Reference Voltage of 2.495V. This voltage is the R4 and R5 divider voltage. If the voltage is less than the reference voltage, the TL431 will conduct and the optocoupler will pass current to the C terminal of TOP224. This current will increase the duty cycle of the

PWM signal generated and more power will be transferred to the output. If the divider voltage is larger than the reference voltage, the TL431 will not conduct and the optocoupler will not pass current to the C terminal of TOP224. This will decrease the duty cycle of the PWM signal generated and less power will be transferred to the output. For farther details on the operation please refer to the datasheet of TOP224[9] and TL431[10] ICs. The output voltage of this power supply is set to 19V DC through choosing appropriate values of the divider  $R_4$  and  $R_5$ .

## 2.2. Charge Control

The charge control circuit consists of the following parts:

- Constant current charge circuit.
- Constant voltage charge circuit.
- Float charge circuit.
- Under voltage alarm circuit. This circuit will turn ON red LED when battery voltage is reduced under 10V. This indication means the battery is damage and must be replaced. Also there is an output control signal that will be activated with the red LED. This signal could be used to generate Battery LOW ALARM and to indicate that battery is completely discharged. The circuit will never disconnect the battery even if the battery is fully discharged.

These circuits are interconnected such that at each power ON of the supply voltage the charge controller will do the following sequence:

1. Start the constant current charging mode first. This represents the fast charge mode. During this mode the circuit will supply a constant current of about 0.7A to the battery and will continue supplying this current until the battery voltage reaches 14.5V.
2. When the battery voltage reaches 14.5V, the second charging stage is started. This stage is the constant voltage stage. In this stage, the circuit will behaves like a constant voltage source of 14.5V. This stage represents the slow charge mode. During this stage, the voltage will stay constant at 14.5V and the charging current will decrease gradually as the battery charge. When the charging current reduced to a specified value, the float charge stage is started.
3. The float charge stage is the final charging stage. In this stage the charger will provide a very small charging current. This small current will account for self discharge in the battery cells after the battery get fully charged. The

float charging is neither constant voltage nor constant current it is simple charging through resistor. The battery voltage and the exact charging current will depend on the battery state and battery rest.

**Fig. 5** shows the complete circuit diagram of the three charging modes and the low battery indication circuits. The Battery charging current will be designated by  $I_{BAT}$  and the Battery Charging voltage will be designated  $V_{BAT}$  in the next sections.

## 2.3. Constant Current Charging Circuit:

The circuit below (**Fig.6b**) is the constant current charging circuit. The OPAMP  $U_{1:A}$  is the core of this circuit. It always compares the SENS2 voltage with the 0.7V reference voltage. The voltage SENS2 is the voltage across the 1 ohm resistor  $R_1$  connected in series with the Battery to monitor the charging current (see **Fig.6a**).

$$SENS2 = I_{BAT} \times 1\Omega \quad (1)$$

When the charging current drop below 0.7A, SENS2 voltage will be less than 0.7V and the comparator output will be low this will turn off D5 which in turn, turns ON the power MOSFET to supply more power to the Battery.

When the charging current rise above 0.7A, SENS2 voltage will be greater than 0.7V and the comparator output will be high. This will turn ON Q5 and D5 which in turn, turns OFF the power MOSFET to reduce the Battery charging current. This negative feedback operation will maintain the Battery Charging current  $I_{BAT@CC}$  constant at 0.7A. If it is required to increase this current for larger batteries, the value of  $R_1$  must be reduced. The power dissipated inside  $R_1$  is:

$$P_{R1} = (I_{BAT})^2 \times R_1 \quad (2)$$

$$P_{R1} = 0.49 \times 1 = 0.49 \text{ W},$$

Choosing 1W resistor gives 50% safety margin.

The resistor  $R_4$  is used to limit the base current for  $Q_2$  to about 225 $\mu$ A:

$$I_{B2} = (3.65 - 1.4) / 10k = 225\mu\text{A} \quad (3)$$

Since the minimum value of  $\beta$  in the transistor datasheet is 100 for collector currents less than 100mA[6]. This  $I_{B2}$  will results in collector current of about 22.5mA, but since  $R_8$  is 4.7k then max  $I_{C2}$  will not exceed  $19/4700=4\text{mA}$ . Then  $Q_2$  will be heavily in saturation and the MOSFET gate voltage is zero. Also the resistor  $R_{22}$  is used to limit

$I_{B5}$  to  $70\mu A$  which will give about  $7mA$  at the collector to turn the  $LED_1$  ON.

$$I_{B5} = (1.4-0.7)/10k=70\mu A \quad (4)$$

The other function of  $R_4$  is to protect the OPAMP output stage when the output is high.  $D_5$  and  $Q_2$  will clipdown the opamp output voltage to about  $1.4V$ . This will provide low resistance path to the OPAMP output stage.  $R_4$  will prevent this short circuit.

The Capacitor  $C_2$  compensates the feedback control loop by adding integration function to the error amplifier output ( $U_{1:A}$ ).

### 2.4.Constant Voltage Charging Circuit

**Fig.7** is the constant voltage charging circuit. The OPAMP  $U_{1:C}$  is the core of this circuit.

It always compares the precisely adjusted reference voltage of  $RV_1$  with the battery voltage. The OPAMP  $U_{1:B}$  is subtraction circuit. It subtracts the voltage drop across the  $1\Omega$  resistor ( $SENS2$ ) from the Battery positive terminal voltage ( $SENS1$ ) to get accurate Battery voltage (see **Fig.6a**). The output of  $U_{1:B}$  is fraction of battery voltage.

$$V_{BAT} = SENS1 - SENS2 \quad (5)$$

$$V_{O U_{1:B}} = SENS1 \times R_3 / (R_2 + R_3) \times (1 + R_6 / R_7) - SENS2 \times R_6 / R_7 \quad (6)$$

$$V_{O U_{1:B}} = (SENS1 - SENS2) \times R_6 / R_7$$

Then:

$$V_{O U_{1:B}} = V_{BAT} \times R_6 / R_7 \quad (7)$$

When the voltage  $V_{O U_{1:B}}$  drop below the voltage at the moving terminal of  $RV_1$ , the comparator output will be low this will turn off  $D_4$  which in turn, turns ON the power MOSFET to supply more current to the Battery. When the Battery voltage rise above the voltage at the moving terminal of  $RV_1$ , the comparator output will be high. This will turn ON  $Q_6$  and  $D_4$  which in turn, turns OFF the power MOSFET to reduce the Battery charging current. This process will continue till the battery get fully charged and the charging current reduced greatly. At this point, the float charging will start.

The two fixed resistors  $R_9$  and  $R_{10}$  are added to  $RV_1$  to limit the max and min voltage at the moving terminal (terminal 3) of  $RV_1$ . The values are selected such that the voltage at terminal 2 of  $RV_1$  is:

$$V_{terminal 2} = 5 \times R_{10} / (R_{10} + R_9 + RV_1) = 5 \times (10/35) = 1.4285V \quad (8)$$

Similarly, the voltage at terminal 1 of  $RV_1$  is:

$$V_{terminal 1} = 5 \times (R_{10} + RV_1) / (R_{10} + R_9 + RV_1) = 5 \times (20/35) = 2.8571V \quad (9)$$

From Eq. (7), these voltages correspond to battery voltages of

$$1.4285V \times R_7 / R_6 = 9.7397V \quad \text{and} \quad (10)$$

$$2.8571V \times R_7 / R_6 = 19.4802V \quad (11)$$

It is required to set the value of constant Voltage to  $14.75V$ . This value will be in the middle range of the trimming pot. The trimming pot must be adjusted such that the charging voltage in this stage is near  $V_{BAT@CV} = 14.75V$ .

The resistor  $R_{13}$  is used to limit the base current for  $Q_3$  to about  $478.723\mu A$ , for  $+5V$  supply of the LM324, the comparator high level will be  $3.65V$  [8] :

$$I_{B3} = (3.65-1.4)/4.7k = 478.723\mu A \quad (12)$$

Since the minimum value of  $\beta$  in the transistor datasheet is 100 for collector currents less than  $100mA$  [6] . This  $I_{B3}$  will results in collector current of about  $47.872mA$ , but since  $R_8$  is  $4.7k$  then max  $I_{C3}$  will not exceed  $19/4700 = 4mA$ . Then  $Q_3$  will be heavily in saturation and the MOSFET gate voltage is zero. Also the resistor  $R_{24}$  is used to limit  $I_{B6}$  to  $70\mu A$  which will give about  $7mA$  at the collector to turn the  $LED_3$  ON.

$$I_{B6} = (1.4-0.7)/10k=70\mu A \quad (13)$$

The other function of  $R_{13}$  is to protect the OPAMP output stage when the output is high.  $D_4$  and  $Q_3$  will clipdown the opamp output voltage to about  $1.4V$ . This will provide low resistance path to the OPAMP output stage.  $R_{13}$  will prevent this short circuit.

The function of Capacitor  $C_3$  is similar to  $C_2$  in the last section, it compensates the feedback control loop.

### 2.5.Float Charging Circuit

The next figure (**Fig.8**) is the float charging circuit. The OPAMP  $U_{1:D}$  is the core of this circuit. It always compares the battery charging current with reference value. When the charging current

reduced below 167mA (see eq.14 below), the comparator output will be high to turn ON LED2 and Q3 which will turn off the Power MOSFET. This reference value is determined by R15 and R16, in this case with the resistor values shown in the Fig., the voltage at pin12 will be:

$$V_{12} = 0.7 \times R_{16}/(R_{16}+R_{15}) = 0.7 \times (4.7/19.7) = 0.167V \quad (14)$$

The resistor R<sub>11</sub> (in Fig.5) is used to limit the base current for Q<sub>3</sub> to about 478.723μA:

$$I_{B3} = (3.65-1.4)/4.7k = 478.723\mu A \quad (15)$$

Since the minimum value of β in the transistor datasheet is 100 for collector currents less than 100mA[6]. This I<sub>B3</sub> will result in collector current of about 47.872mA, but since R8 is 4.7k then max I<sub>C3</sub> will not exceed 19/4700 = 4mA. Then Q3 will be heavily in saturation and the MOSFET gate voltage is zero.

The circuit of Q4, C5, R18 and R20 is to turn off the comparator (make the output low) when there is no AC power. When the AC power is OFF, the base of Q4 is connected to ground through R19 and R18. Q4 will be ON and I<sub>B4</sub> is -215μA:

$$I_{B4} = (-5+0.7)/(10k+10k) = -215\mu A \quad (16)$$

Since the minimum value of β in the transistor datasheet is 100 for collector currents less than 100mA[7]. This I<sub>B4</sub> will result in collector current of about -21.5mA, but since R<sub>17</sub> is 2.2k, then max I<sub>C4</sub> will not exceed 5/2200 = -2.2727mA. Then Q4 will be heavily in saturation and the voltage at pin13 is +5V. When the AC power is ON, the transistor Q4 will be OFF because the base of Q4 will be connected to equivalent voltage of about +9.5V through equivalent base resistor of about 3.333k. This operation will not happen fast because of the charging time of C<sub>5</sub>. The initial value of C<sub>5</sub> voltage is:

$$V_{C5initial} = (5-0.7) \times R_{18}/(R_{18}+R_{19}) = 2.15V \quad (17)$$

The final value of C<sub>5</sub> is:

$$V_{C5final} = 19V/2 = 9.5V \quad (18)$$

The transistor will turn OFF when the capacitor value reaches 4.3V. The charging time constant is:

$$\tau = C_5 \times 5k \quad (19)$$

Using the capacitor charging equation to find the estimated time for the transistor Q<sub>4</sub> to turn OFF.

$$V_{C5} = V_{C5final} - (V_{C5final} - V_{C5initial}) \cdot e^{-t/\tau} \quad (20)$$

Solving for C<sub>5</sub> yield:

$$t = R_{eq} \cdot C_5 \cdot \ln\left(\frac{V_{C5final} - V_{C5initial}}{V_{C5final} - V_{C5}}\right) = 5k \cdot C_5 \cdot 0.346 \quad (21)$$

$$C_5 = \frac{t}{5k \cdot 0.346}$$

For 100ms delay, C5 must be 57μF. Select 47 μF as the nearest standard value. This delay is important at start-up, because the charging current initially rises from zero to its constant value gradually. This delay will disable the comparison circuit till the charging current exceeds the 167mA. This will insure that the constant charging will start first. The capacitor discharge when the power is off will be through the resistor R18, R19 and the base of transistor Q4. This discharge time has no effect on the circuit operation.

## 2.6.Low Battery indication Circuit

Fig.9 shows the Low Battery indication and alarm circuit. The OPAMP U<sub>3:A</sub> is the core of this circuit. It always compares the battery voltage with the reference voltage. The circuit is Schmitt Trigger circuit to prevent LED and alarm fluctuation. When the battery voltage drops under 10 volt the LED will be ON and it will stay ON until the voltage become larger than 11V. Consider the output of the OPAMP is low then the voltage at pin3 is:

$$V_3 = 5 \times R_{30}/(R_{26}+R_{30}+R_{31}) = 5 \times (4.7/15.7) = 1.4968V = V_{TL} \quad (22)$$

This voltage corresponds to battery voltage of:

$$1.4968V \times R_7/R_6 = 10.2054V \quad (23)$$

The output of the comparator will stay low unless the battery voltage reduced below the 11.7V. If the battery voltage reduced below this value, the comparator output will be high (about 5V-1.35V=3.65V [11]) and the current in D9 is about

$$I_{D9} = (3.65-0.7)/(100k) = 29.5\mu A \quad (24)$$

Referring to the diode Datasheet [12], V<sub>D9</sub> will be about 440mV. Then the reference voltage will be:

$$V_3 = 5 \times (R_{30}||R_{29})/(R_{26}+R_{30}||R_{29}+R_{31}) +$$

$$\begin{aligned} & \frac{(3.65V - V_{D9})}{(R_{30} \parallel (R_{26} + R_{31}) + R_{29})} \times \frac{(R_{30} \parallel (R_{26} + R_{31}))}{(R_{30} \parallel (R_{26} + R_{31}) + R_{29})} \\ & = 5 \times (4.489/15.7) + 3.21 \times \\ & 3.29299/(3.29299 + 100) = 1.449V + 0.10233V = \\ & 1.55133V = V_{TH} \end{aligned} \quad (25)$$

This voltage corresponds to battery voltage of:

$$1.55133V \times R_7/R_6 = 10.5772V \quad (26)$$

At the same time the red LED of the bicolour LED will be ON to indicate Low Battery ALARM. The comparator output will stay high till the Battery voltage exceeds the  $V_{TH}$  value. Practically the measured values are  $V_{TH}=1.573V$  and  $V_{TL}=1.518V$  and the transitions are at  $V_{BAT} = 11V$  and  $10.6V$  respectively.

This difference between the measured and the calculated voltages is due to the subtract circuit of U1:B non exact gain.

### 2.7. Output Power MOSFET Circuit

The Power MOSFET  $Q_1$  is the main power transistor in the circuit. It was fixed on heat sink to dissipate extra heat generated inside it.

$Q_3$  and  $Q_2$  are the driving transistors. Both of them must be OFF in order to make the MOSFET ON. If any one of them is ON, the gate of the MOSFET will be about zero and the MOSFET will be turned OFF see Fig.10.

$R_{12}$  will provide the float charging current to the Battery. Changing this value will change the float charge current. For steady battery voltage of  $12.8V$  and supply voltage of  $19V$ , the current will be:

$$\begin{aligned} I_{BAT@float} &= (19 - 12.8)/(220) \\ &= 28.1818mA \end{aligned} \quad (27)$$

This small current will count for the self discharge inside the battery cells and will prevent the battery from being over charged.

$D_1$  is the diode that supplies the DC voltage from the Battery to the system when the power is turned OFF. Therefore the output voltage will be  $0.7V$  less than the battery voltage in case of AC power failure.

### 2.8. The Voltage regulator circuit

In order to make the circuit operation and reference voltages independent of battery voltage, a 7805 voltage regulator was used to supply the OPAMP circuit. As shown in Fig.11.

### 2.9. The PCB

After passing all the primary tests, the circuit has been sent to PCB factory to produce the mass production. The circuit was printed on  $10cm \times 13cm$  double layer PCB to fit inside the plastic enclosure. See the figure below.

### 2.10. The enclosure

A standard industrial plastic enclosure was selected for the case. See the figure below. It has standard DIN rail fixing accessories and high current barrier terminal block.

## 3. Test and results

In the following sections a typical data taken from one of the chargers, it was charging a  $12V$   $4.5Ah$  Battery. The Battery was about 75% discharged when connected to the charger. The max charging current for the battery is  $1.3A$  in the battery Datasheets[3]. All charging current in the following figures was normalized to this max value. All voltage readings also normalized to the max allowable voltage of  $15V$ .

### 3.1. Constant Current stage

Fig. 14 shows the change in battery voltage during the constant current charging stage. As seen in the figure, the voltage change is non-linear.

In Fig. 15, the charging current is approximately constant. However there is a small change in the value of the charging current as the battery voltage increases. This small change represents the accuracy of the constant current source circuit that was implemented. The change is  $0.69A - 0.64A = 0.05A$ . This is about 4%.

### 3.2. Constant Voltage stage

Fig. 16 shows the charging current variations during the constant voltage stage. It is clear that the charging current in this stage is reduced in exponential form.

Fig. 17 shows the charging voltage in this stage. It is clear that the voltage is approximately constant. However there is also a small change in the battery voltage. This change is clearer in the first 1000 points of the curve. This small change represents the limit of the constant voltage source circuit used. It is  $14.42V - 14.53V = 0.11V$ . This is about 1%.

### 3.3. Float charge stage

Fig. 18 and 19 show the charging current and voltage variations during the float charge stage



respectively. At the start point of this stage, the charging current reduced sharply to about few milli amperes. The battery voltage will drops gradually until reaches the battery steady state voltage. The charge current will increase for decreasing battery voltage.

#### 4. CONCLUSION

Fast three stages SLA battery charger was designed, implemented and tested. This charger was able to charge 12V, 4.5A/h SLA Battery in about 2 hours and 23minutes. The three stages charger can charge the SLA batteries in short time while protecting the battery from over charge and self discharge. In the Constant Current Source the deviation was about 4% while the deviation for the constant voltage source is about 1% as seen in the results section. The control circuit is completely analogue electronic circuit. No digital parts were used. This will reduce time to fault and the system will be less sensitive to noise.

The main disadvantage of this design is that we need power supply of about 19V to supply the required power. It is about 4V above the maximum Charging voltage (15V). This is because of the MOSFT gate threshold voltage.

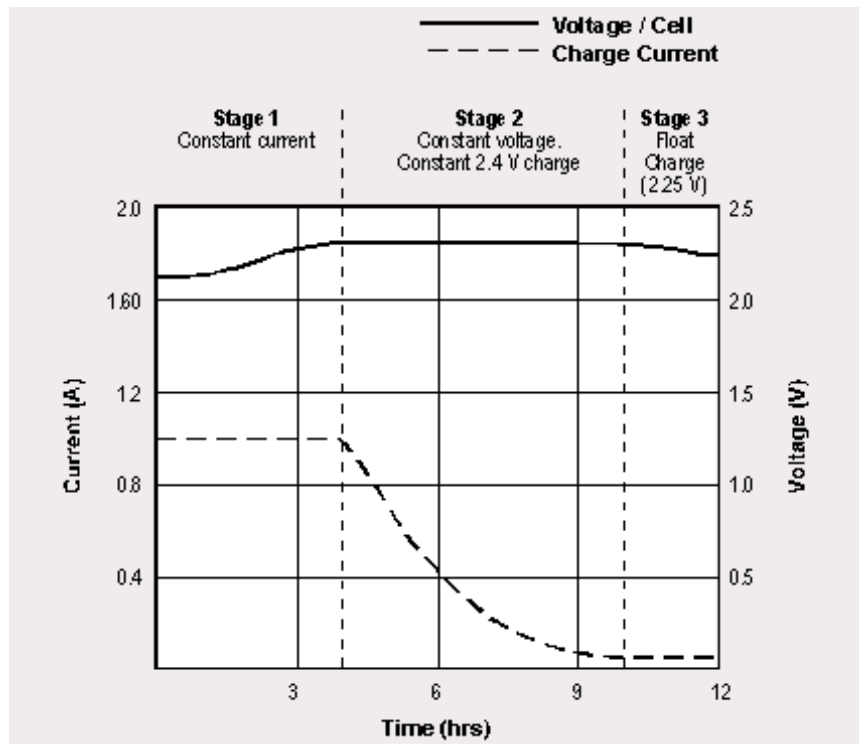
Better designs could use a supply voltage that is slightly above 15V to perform the same tasks without reducing the charging performance. The ambient temperature could be used to make the transition voltages between the stages more precise, also the Battery temperature could be used to monitor the Battery health and preventing over charge.

#### 5. ACKNOWLEDGEMENT

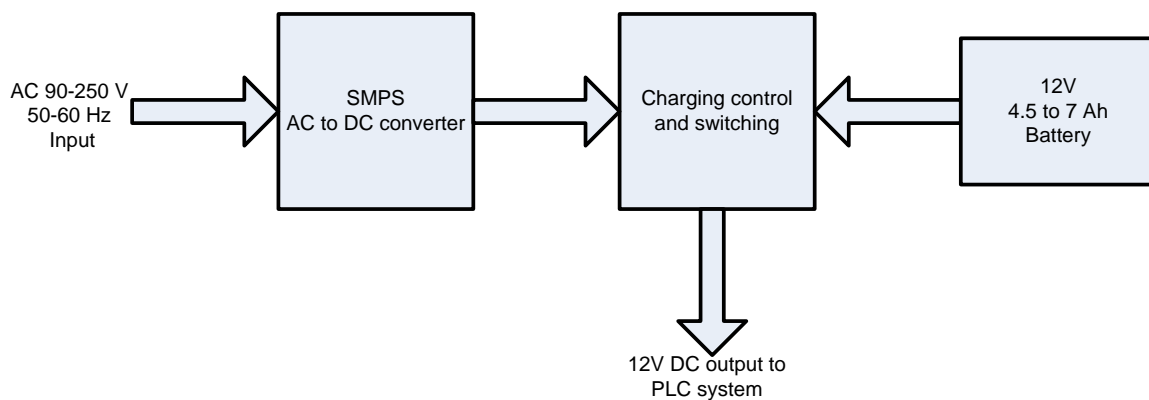
This work was under the supervision and funding of Integrated Engineering Services Company. It was done under the project of installing 128 mobile Base transceiver station (BTS) around Baghdad.

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**Figure 1: Charge stages of a lead-acid battery. The battery charges at a constant current to a set voltage threshold (Stage 1). As the battery saturates, the current drops (Stage 2). The float charge compensates for the self-discharge (Stage 3).**



**Figure. 2 simplified block diagram of the system**

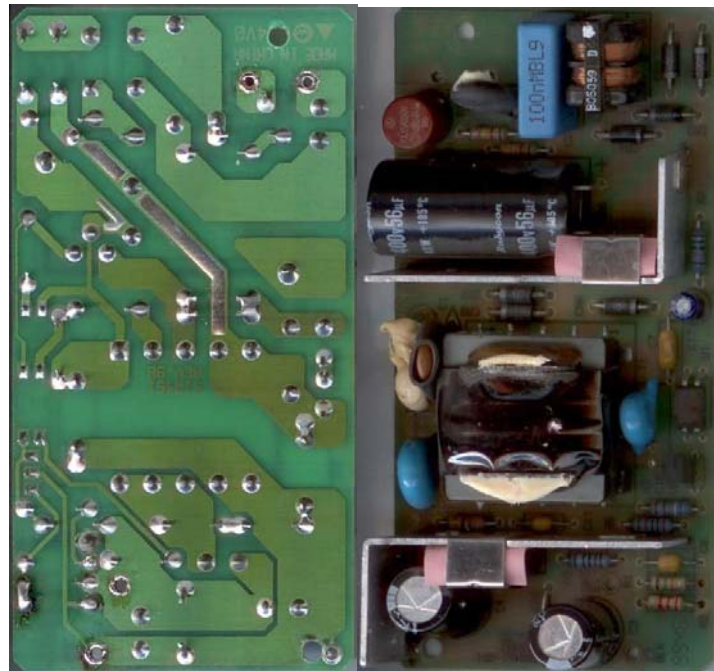


Figure. 3 SMPS board component side and solder side

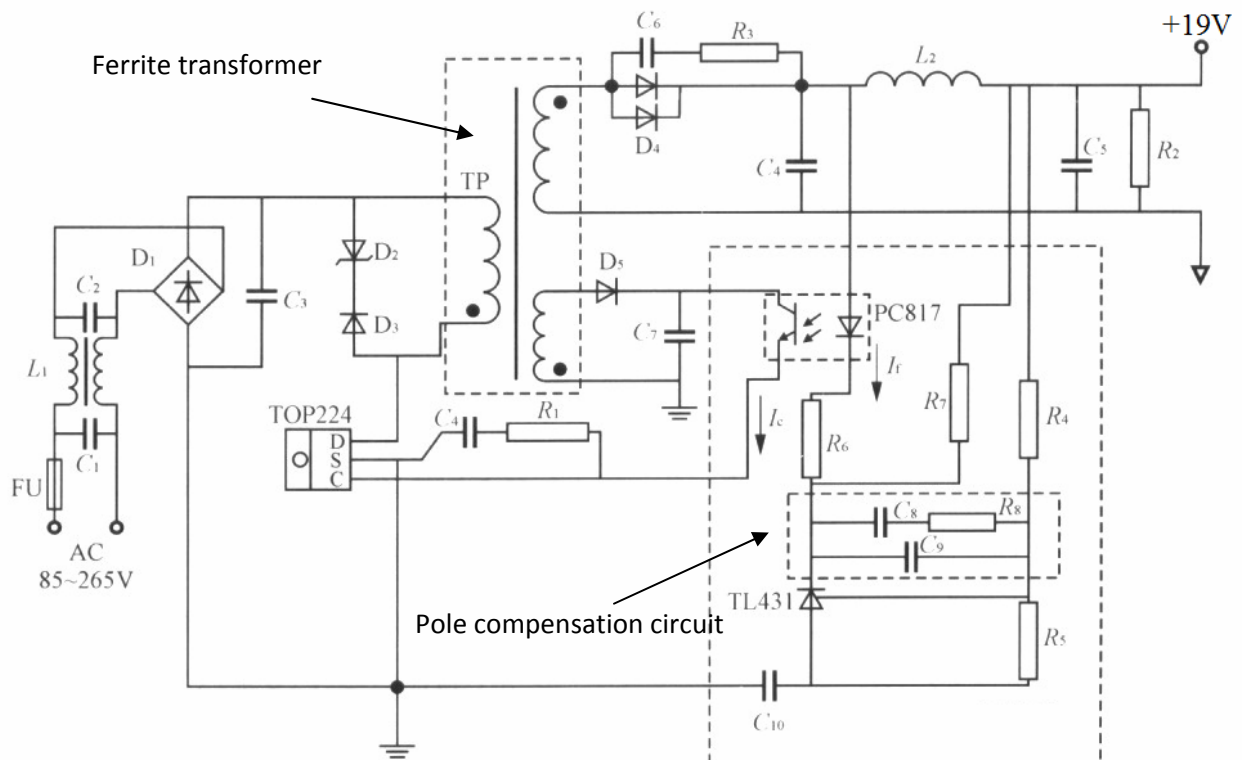


Figure. 4 Standard SMPS circuit diagram [5]

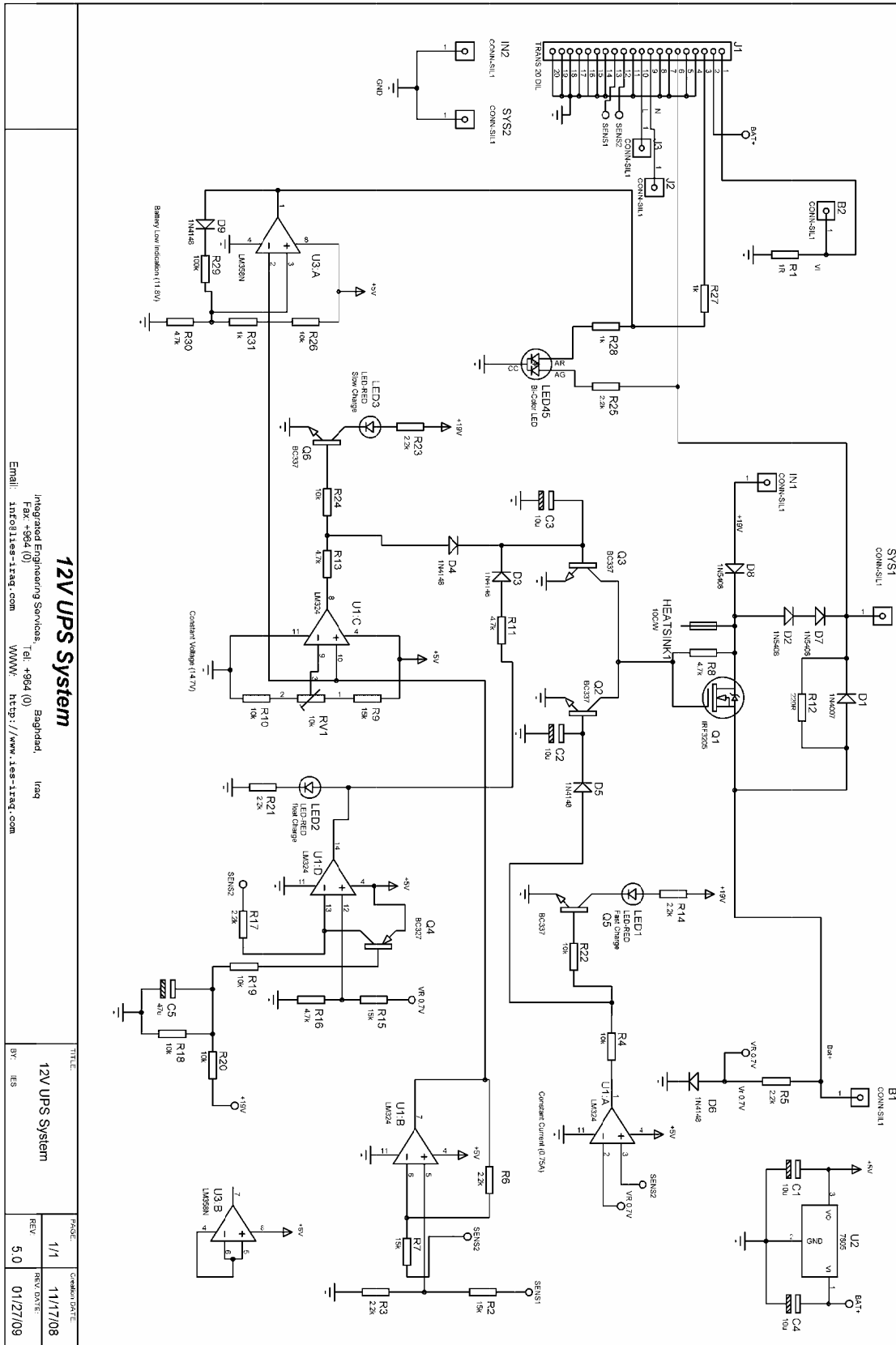


Figure. 5 Charge control circuit Diagram

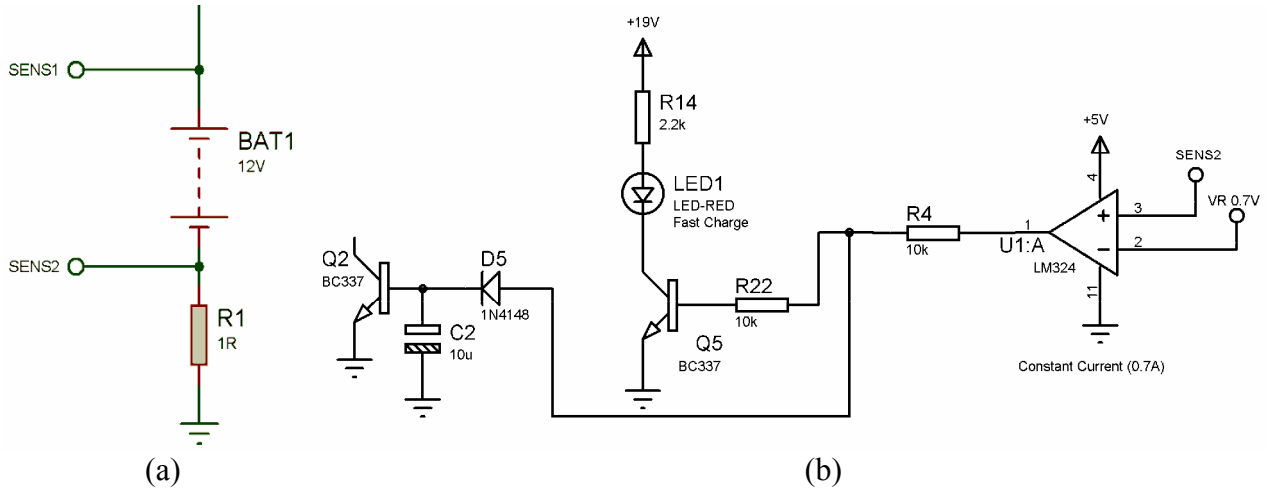


Figure. 6 (a) SENS1 and SENS2, (b) Constant Current Charging Circuit

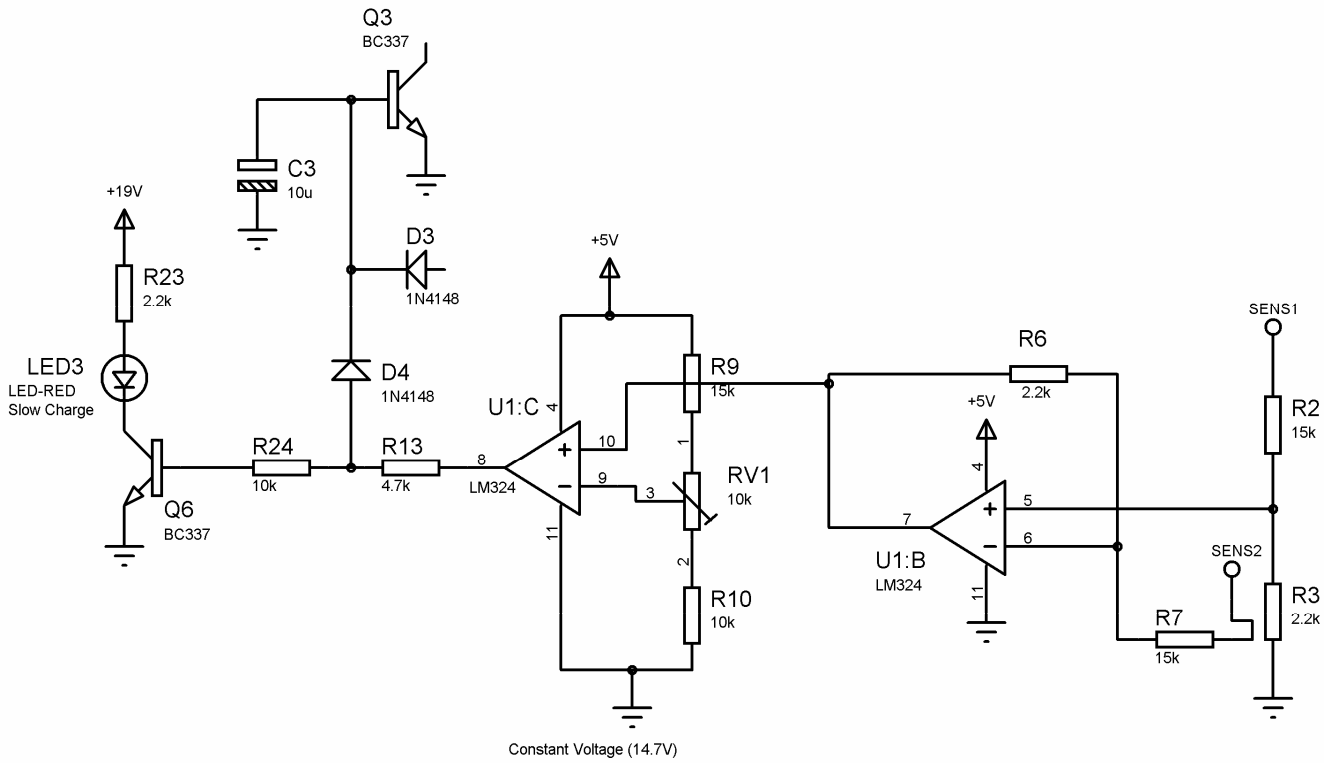


Figure. 7 Constant Voltage Charging Circuit

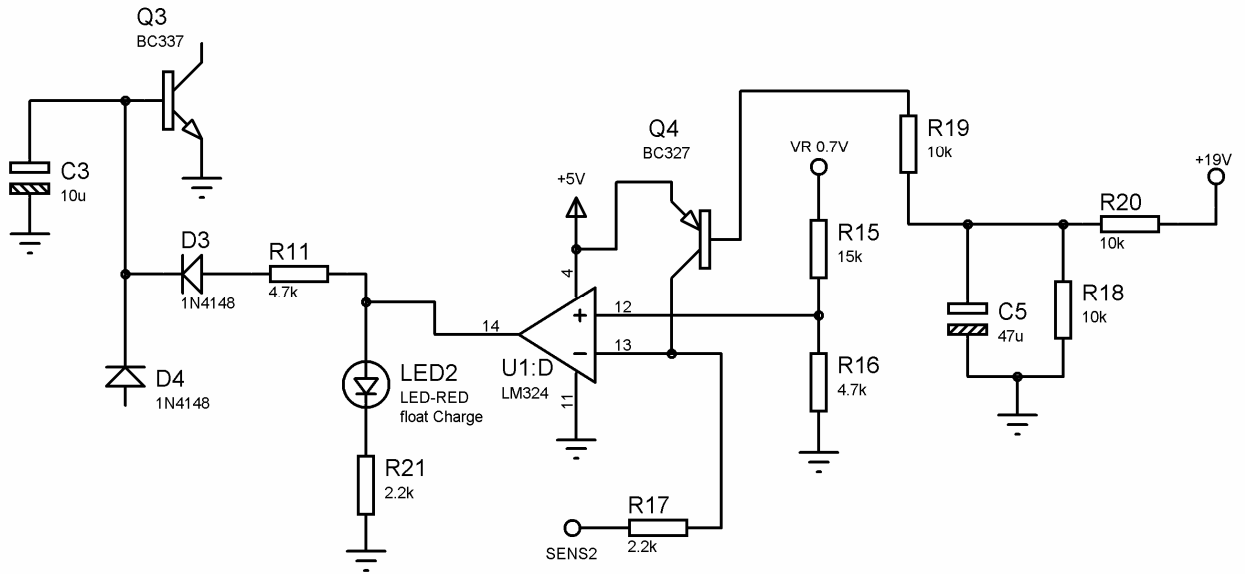


Figure. 8 Float Charging Circuit

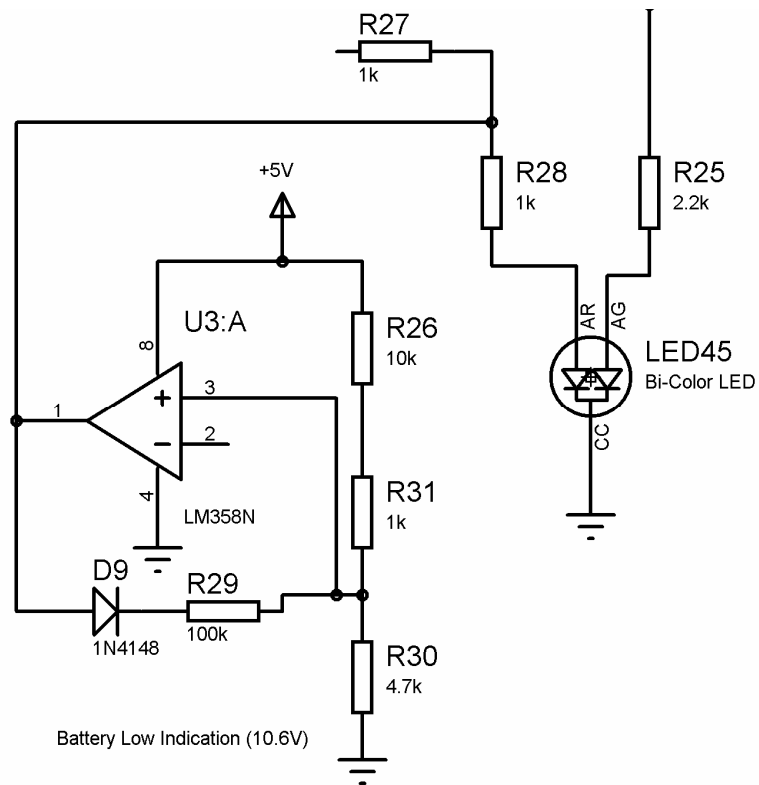


Figure. 9 Low Battery indication Circuit

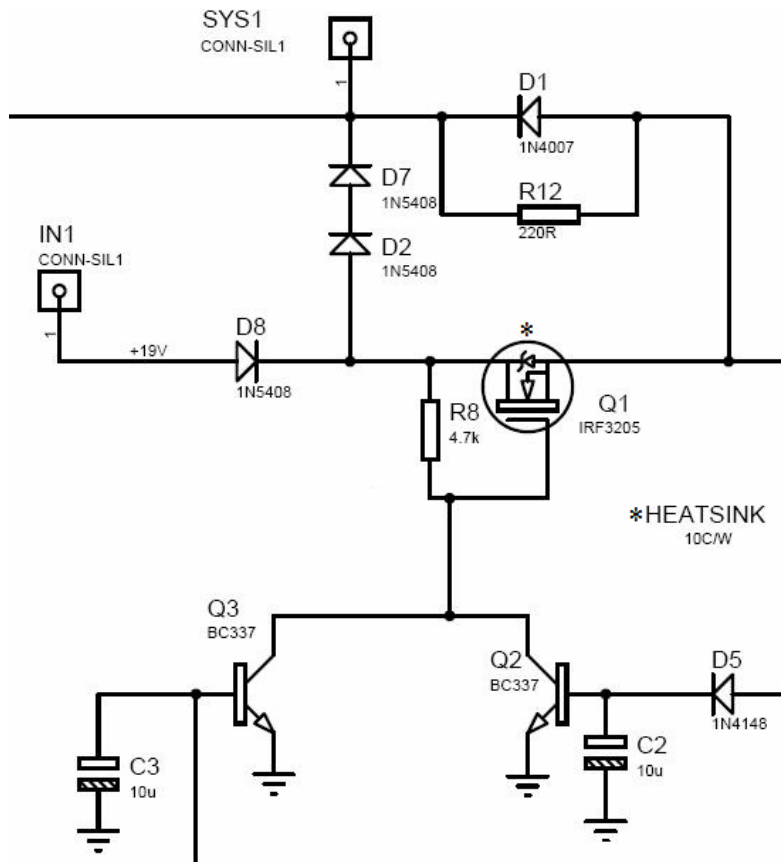


Figure. 10 Output Power MOSFET Circuit

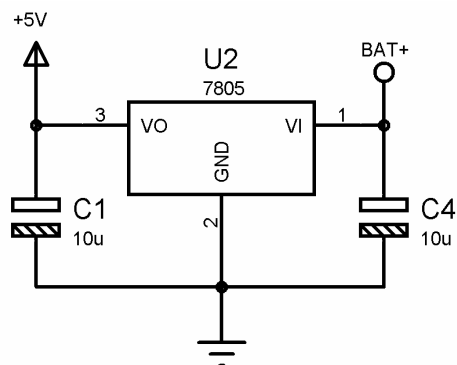


Figure. 11 Voltage Regulator Circuit

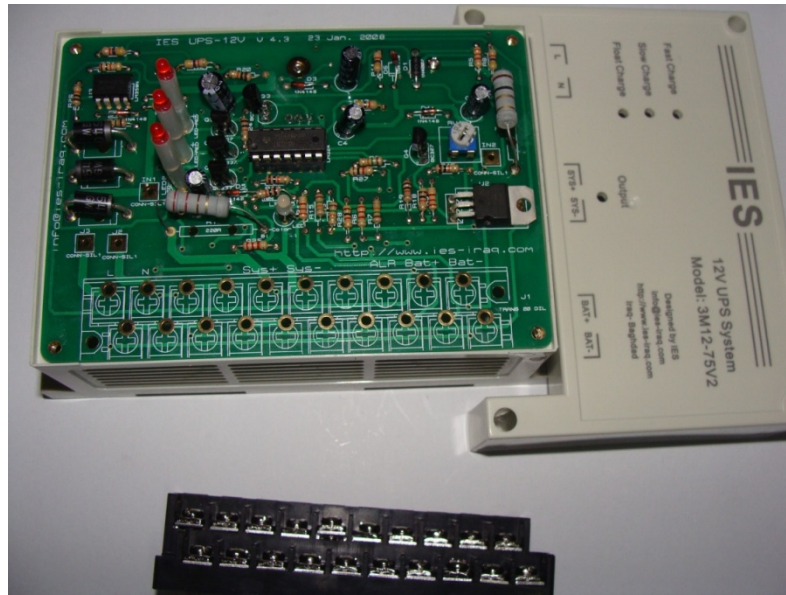


Figure. 12 PCB inside the enclosure

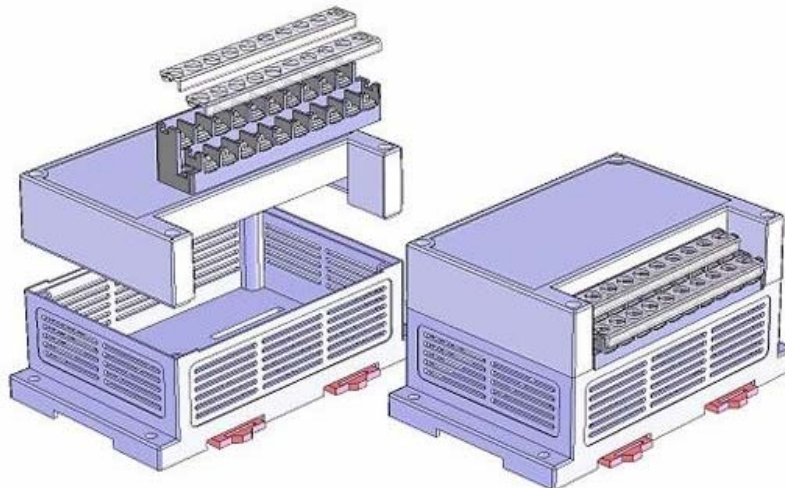


Figure. 13 the enclosure

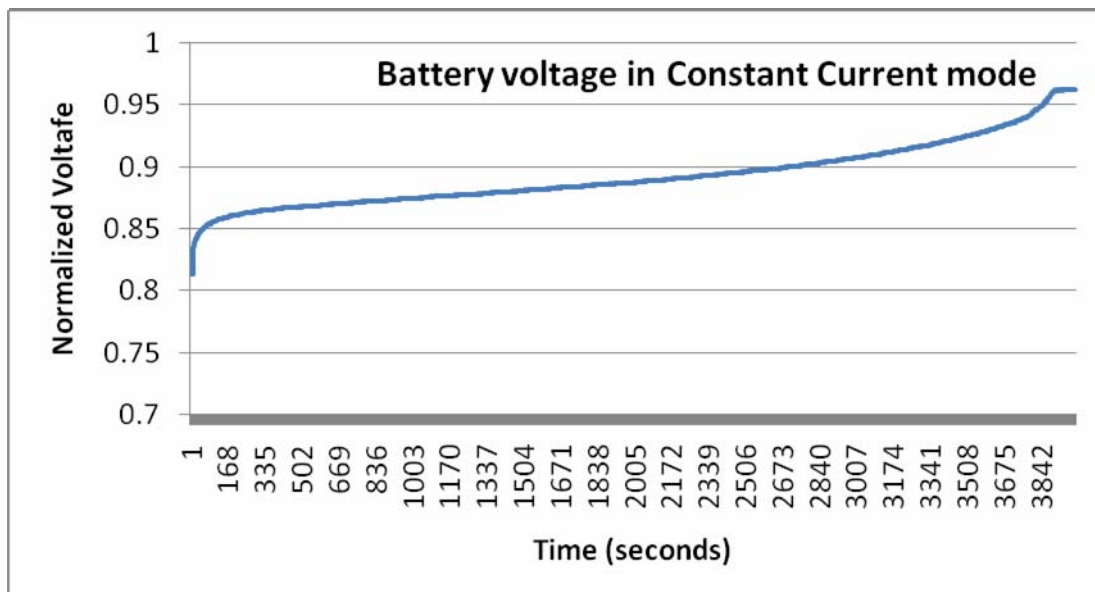


Figure.14 Battery voltage change during constant current stage



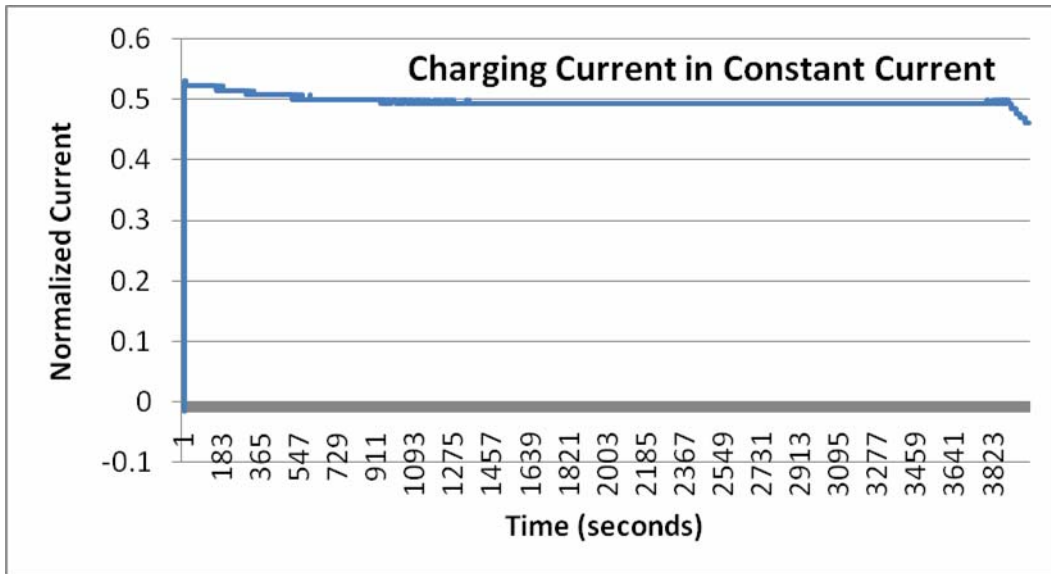


Figure.15 Battery Current change during constant current stage.

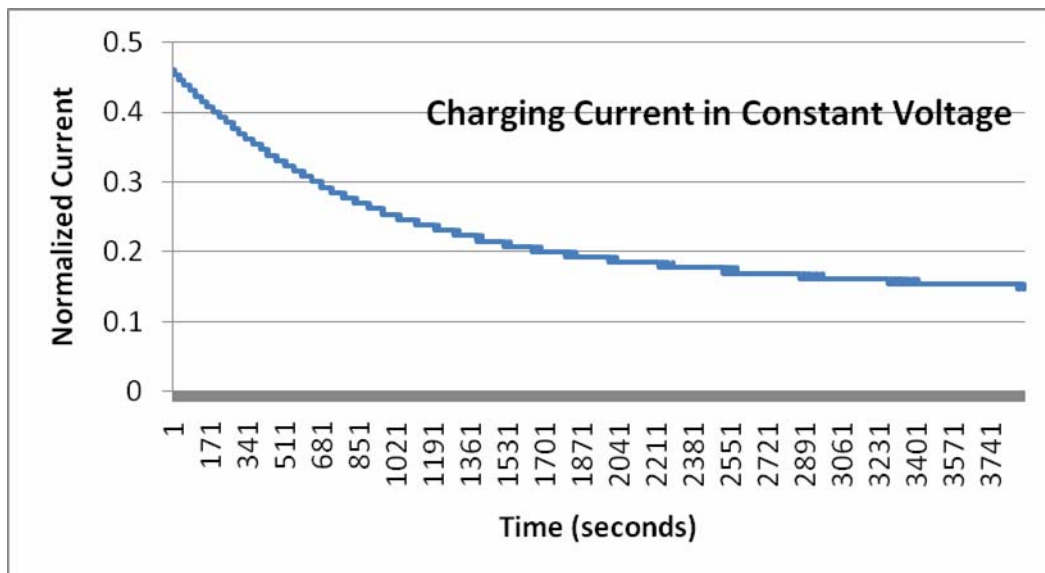


Figure.16 Battery Current change during constant voltage stage

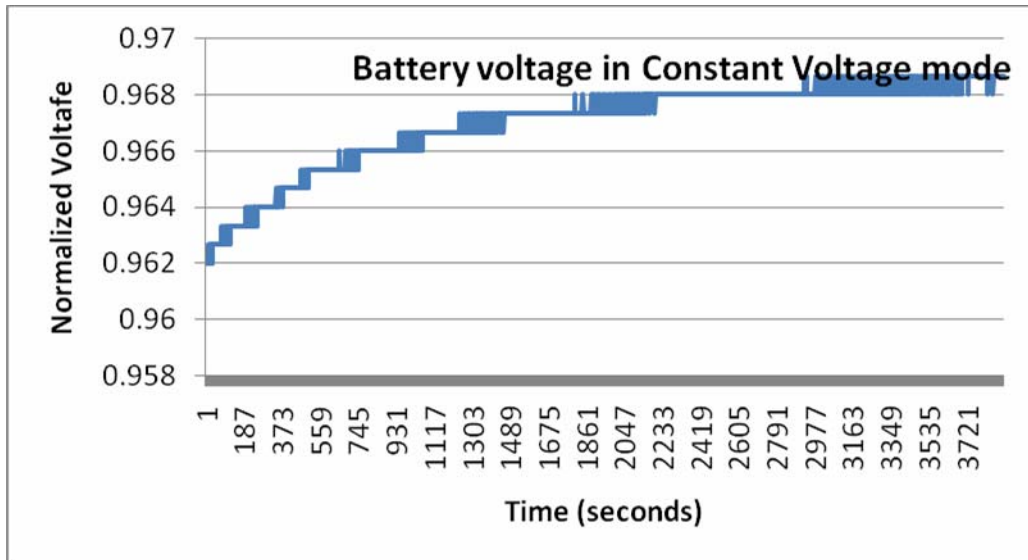


Figure.17 Battery Voltage change during constant voltage stage

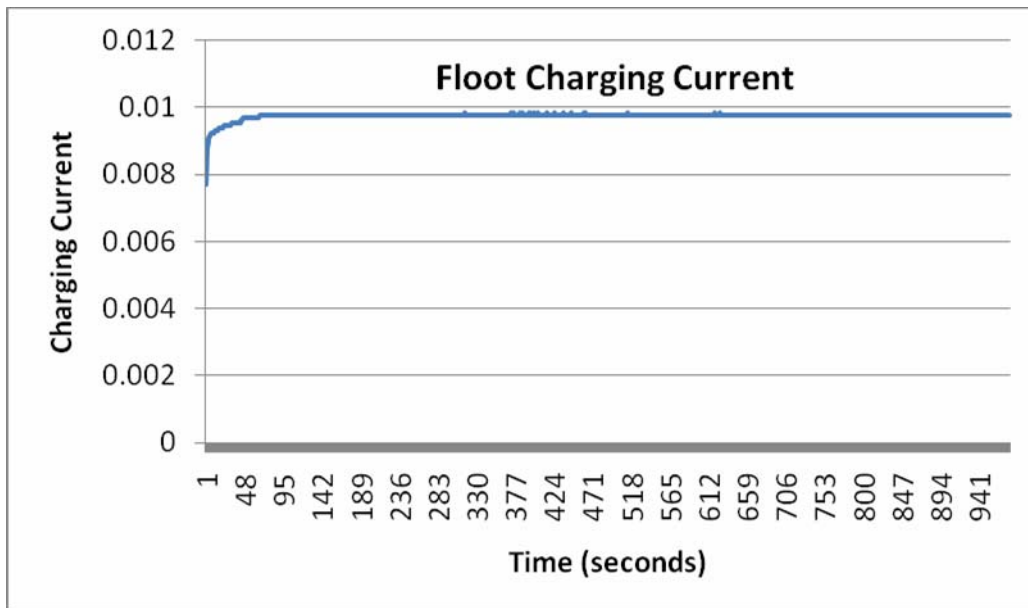


Figure.18 Battery Current change during float charge

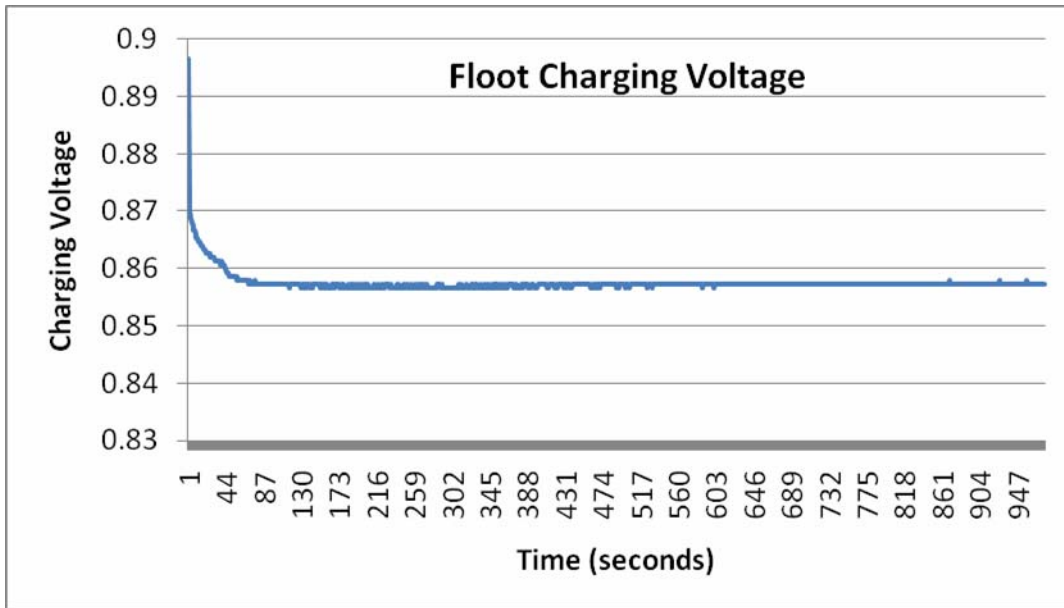


Figure.19 Battery Voltage change during float charge