EN2090

Laboratory Practice II

Project Mid Review Report

LEAD ACID BATTERY CHARGER

Group 06

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PWM Generation

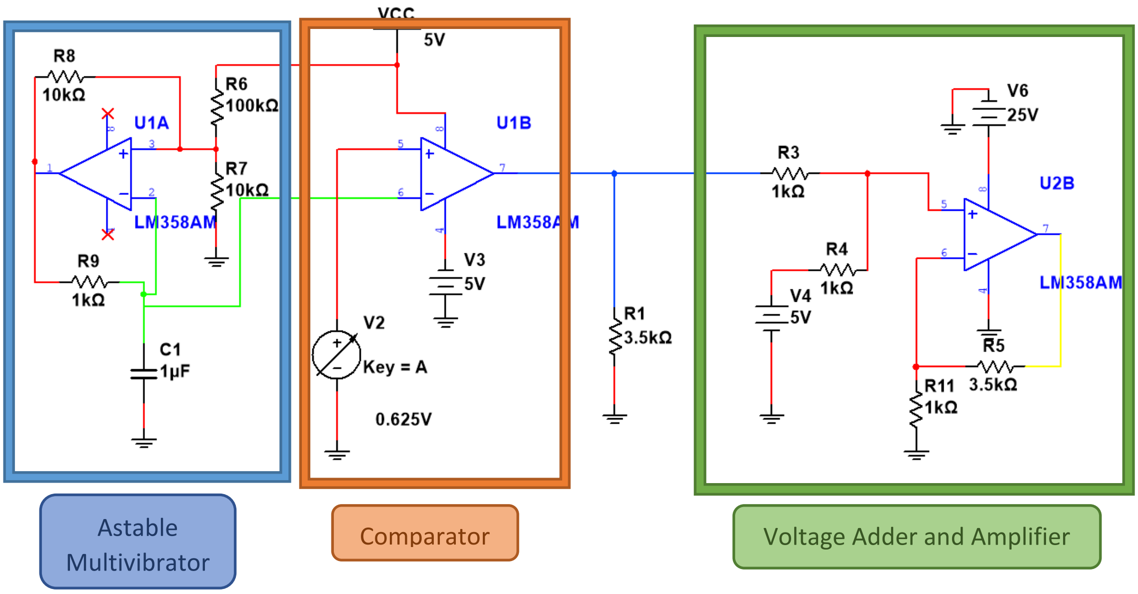
For the PWM generation a near triangular wave and a comparator is used since the duty cycle of the PWM can be easily controlled by changing the input voltage of the comparator.

To generate the near triangular waveform Astable Multivibrator is used and the voltage across the capacitor is taken as the near triangular waveform.

According to the given voltage to the comparator, PWM duty cycle can be changed with ease.

After generating the PWM, it is used to switch on/off a MOSFET, for that purpose the PWM needs to be amplified and also the negative voltage part of the PWM must be removed. In order to do that Voltage adder and Amplifier is being used.

Controlling the PWM duty cycle can be done using a input voltage to the comparator ranging from -2V to +2V corresponding to 0% duty cycle and 100% duty cycle respectively, since the near triangular waveform lies between -2V to +2V.



For calculating the frequency of oscillation (f) of the astable multivibrator following formula is used,

$$T = 2RC\ ln\left(\frac{1+\beta}{1-\beta}\right)$$

Here $\beta = \frac{R_2}{R_1+R_2}$ where $R_1 = R_2 = 10k\Omega$ and $R = 1k\Omega$

$$\therefore T = 2 \times 1k\Omega\ \times 1\mu F\ ln\left(\frac{1+\frac{1}{2}}{1-\frac{1}{2}}\right)$$

$$T = 2.197 \times 10^{-3}$$

$$f = {}^{1}/_{T} = {}^{1}/_{2.197\times\ 10^{-3}} = 455.16Hz$$

Selecting Required Op AMP for the waveform generation,

Slew Rate for the Astable Multivibrator and comparator = $2\pi f V$

$$= 2 \times \pi \times 455.16Hz \times 10V$$

$$= 0.0286\ {}^{V}/_{\mu s}$$

Slew Rate for the Astable Multivibrator and comparator = $2\pi f V$

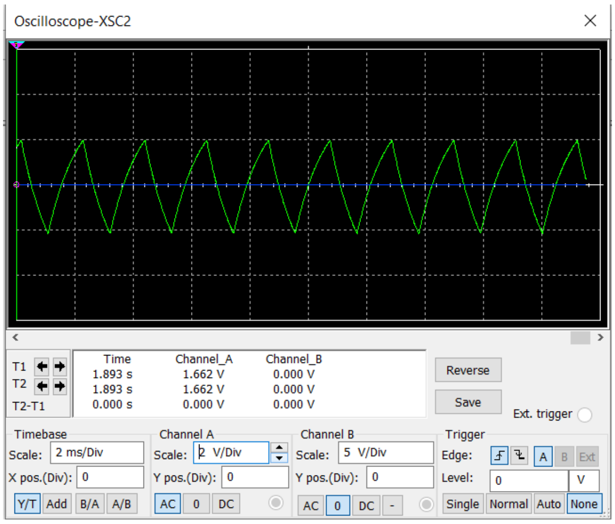
$$= 2 \times \pi \times 455.16Hz \times 20V$$

$$= 0.0572\ {}^{V}/_{\mu s}$$

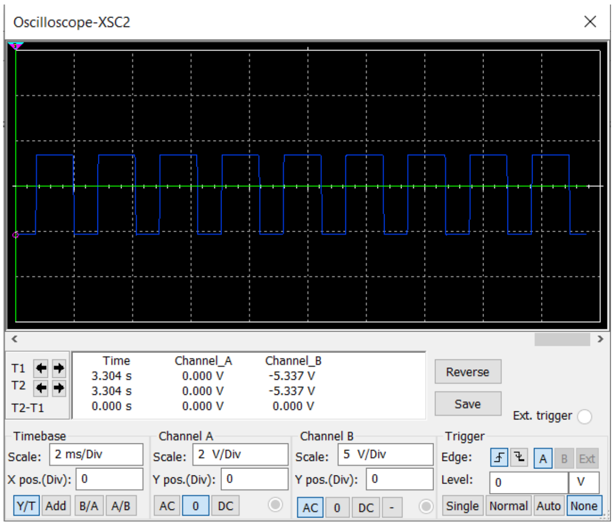
Therefore, LM358 which has the slew rate of $0.3\ {}^{V}/_{\mu s}$ was selected; for the ease of finding components for Astable multivibrator, Comparator and Voltage Adder same Op Amp was used.

Simulation Results of PWM generation

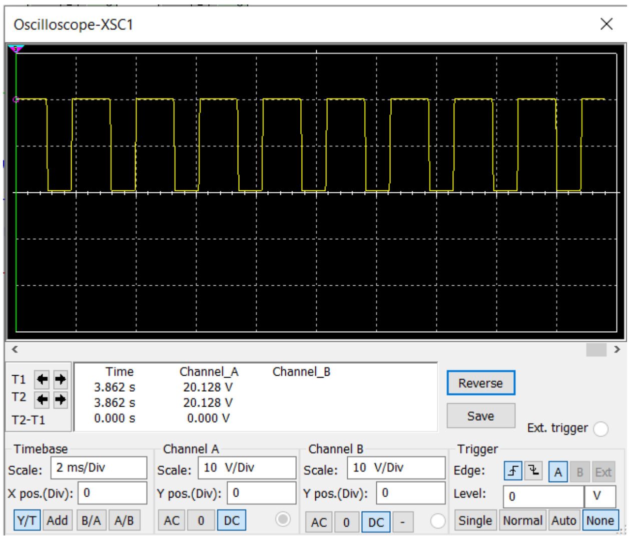
Astable Multivibrator Output



Comparator Output



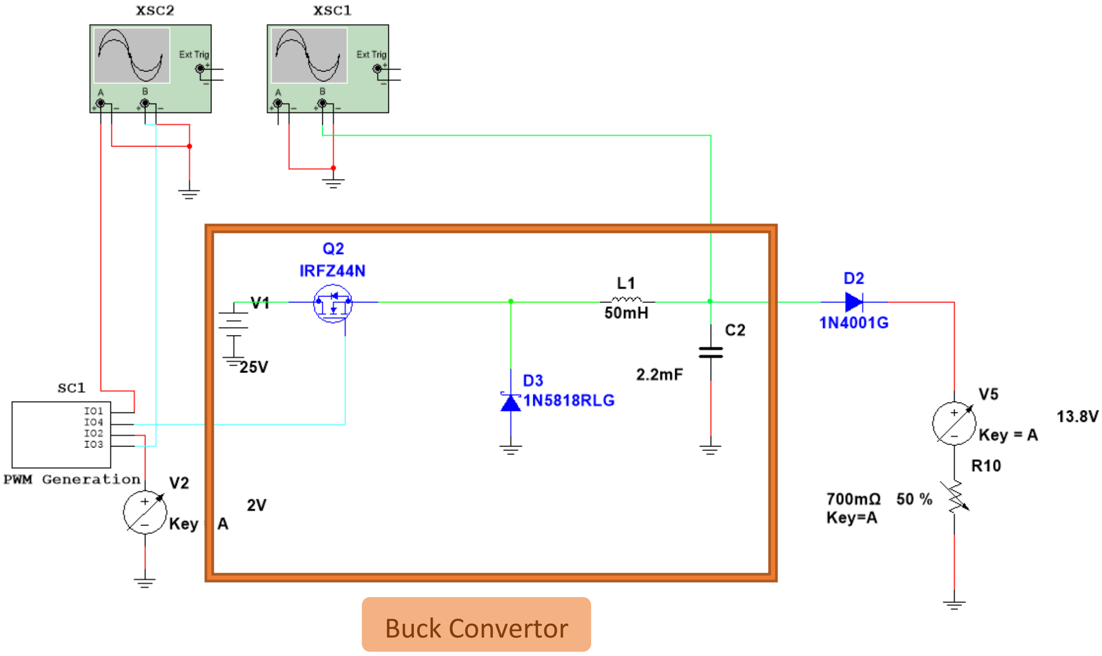
After Amplification Output



Smoothing Circuit

For the smoothing circuit Buck convertor design has been selected due to the convenience of stepping down DC-DC using PWM signal which is widely used in electronics.

Buck convertor regulates voltage using Switch on/off method. Therefore, the power loss of the Buck convertor is way less than in a linear voltage regulator.



In a buck convertor there are four main components need to be considered.

- Inductor
- Capacitor
- Rectifier Diode
- Switch

Inductor Selection

For the selection of inductor following parameters were considered.

- ✓ Maximum input Voltage
- ✓ Output Voltage
- ✓ Switching frequency
- ✓ Maximum Ripple Current
- ✓ Duty Cycle

Since the charging battery voltage around 13V the output voltage needed around 15V because of the back-current preventing diode and the resistors in the battery path.

Calculation of the inductor

$$Maximum\ Duty\ cycle(D) = \frac{V_{out}}{V_{in(\max)} \times \eta}$$

$$V_{out} = Output\ Voltage$$

$$V_{in(\max)} = maximum\ input\ Voltage$$

$$\eta = efficiency\ of\ the\ convertor(estimated\ to\ be\ 90\%)$$

$$\therefore D = \frac{15V}{25V \times \frac{90}{100}} = \frac{2}{3}$$

$$Maximum\ load\ current = 1.5\ A$$

$$Ripple\ current(\Delta I_L) = 1.5\ A\ \times\ \frac{20}{100}$$

$$\Delta I_L = 300mA$$

$$L = \frac{D\ \times (V_{IN} - V_{out})}{\Delta I_L\ \times f}$$

$$L = \frac{\frac{2}{3} \times (25V - 15V)}{300mA\ \times 475Hz}$$

$$L =\ 46.78mH$$

Therefore, L was selected to be 50mH.

Capacitor selection

For the selection of Capacitor following parameters were considered.

- ✓ Ripple Output Voltage
- ✓ Ripple Output load current
- ✓ Switching frequency

Calculation of the capacitor

$$C_{min} = \frac{\Delta I_L}{8\ \times f\ \times\ \Delta V_{OUT}}$$

$$C_{min} = \frac{300mA}{8\ \times 475Hz\ \times\ 50mV}$$

$$C_{min} = 1.578mF$$

Therefore, C was selected to be 2.2mF

Rectifier Diode Selection

$$I_F = I_{OUT(max)} \times (1 - D) I_F = Average\ forward\ current\ of\ the\ rectifier\ diode$$

$$I_{OUT(max)} = maximum\ output\ current\ in\ the\ application$$

$$I_F = 1.5A \times \left(1 - \frac{2}{3}\right) = 0.5A$$

$$P_D = I_F \times V_F$$

Schottky diodes are selected to reduce losses and they have a higher peak current rating.

Selected diode was 1N5818 and for that diode,

$$I_F = 1A$$

$$V_F = 0.5\ V$$

$$P_D = 0.5W\ @\ 1A$$

$$P_D\ required = 0.5A \times 0.5V = 0.25W$$

Therefore, 1N5818 is suitable for the application.

Switch Selection

Since Mosfets have much lower switching losses and can result in overall efficiencies in the high 90 percentiles a suitable Mosfet was chosen as the Switch.

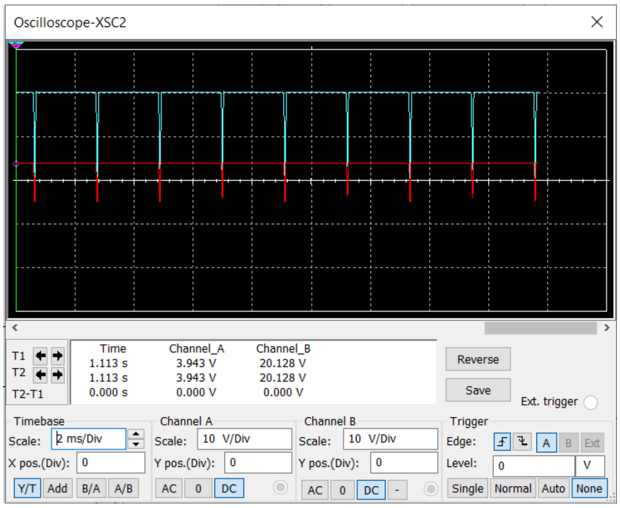
$$Power\ Dissipation_{Switching} = (C_{RSS} \times V_{IN}^2 \times f \times I_{LOAD})/I_{GATE}$$

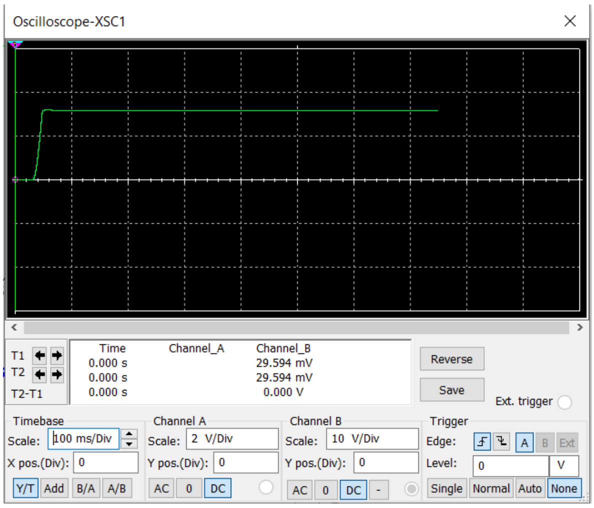
$$Power\ Dissipation_{Switching} = \frac{88pF \times (25V)^2 \times 475 \times 1.5A}{0.1A} = 0.4mW$$

Since the Mosfet is in the high side and it needs a adequate switching frequency, IRFZ44N was chosen since it has fast switching and Maximum Drain-Source voltage of 55V and a maximum gate source voltage of 20V and also a maximum power rating of 94W which is more than enough.

Simulation Results

After simulation it has been found that the smoothing circuit can provide up to 15.8V in the full duty cycle.





Constant Current Control

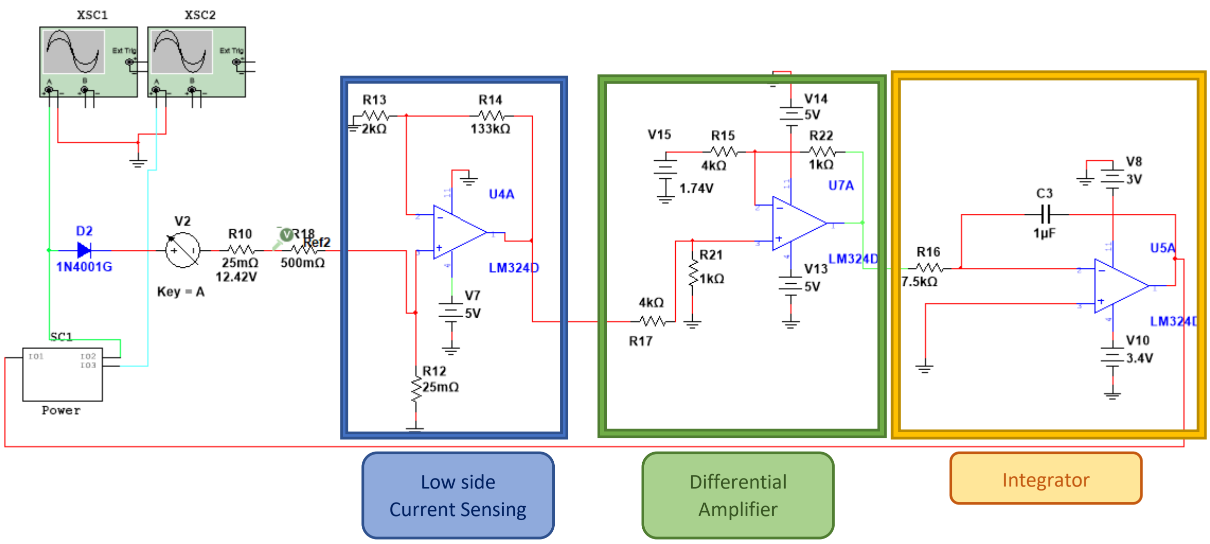
For the Constant current the battery must be fed 1A, for this purpose ways to measure the current, measure the error and adjusting the PWM had to be chosen.

For each task following have been used,

Measuring current - lowside current sensing

Measuring Error – Differential Amplifier

Adjusting PWM - Integrator



Measuring current

Lowside current sensing was chosen because it's inexpensive and fairly easy and straightforward to implement. If Highside current sensing had been chosen, the circuit would have been able to withstand high voltages and the shunt resistor should have been chosen very carefully. Therefore, Lowside current sensing was the obvious current sensing method.

$$V_{OUT(Current\ Measuring)} = I_{LOAD} \times R_{SHUNT} \times Gain$$

$$Gain = 1 + \frac{R_F}{R_G}\ where\ R_F = 133k\Omega\ and\ R_G = 2k\Omega$$

$$Gain = 1 + \frac{133k\Omega}{2k\Omega} = 67.5$$

$$V_{OUT(Current\ Measuring)} = 1A \times 25m\Omega \times 67.5 = 1.6875V \approx 1.7V$$

Measuring Error

For the measuring of error, a simple differential amplifier has been used and for the stationary voltage previously calculated voltage should be applied since it corresponds to 1A.

$$V_{OUT(Error)} = \frac{R_2}{R_1}(V_{IN} - 1.7V)\ where\ R_1 = 4k\Omega \text{ and } R_2 = 1k\Omega$$

$$\therefore V_{OUT(Error)} = \frac{1}{4}(V_{IN} - 1.7V)$$

Controlling PWM

For the controlling of PWM error must be accumulated, therefore an integrator is used for that purpose and the accumulated error is used to control the PWM.

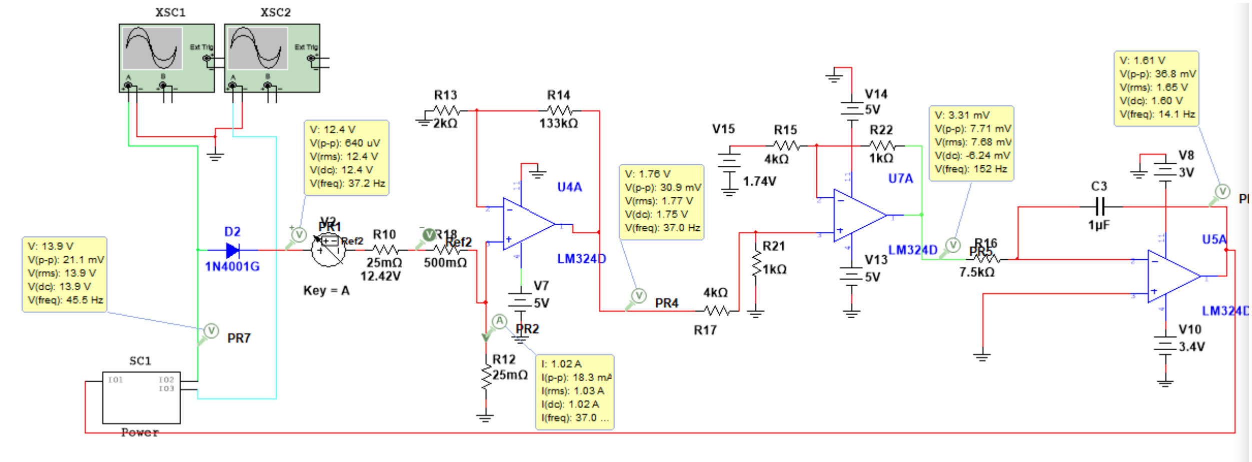
$$V_{OUT(PWM\ control)} = -\int_0^t \frac{V_{IN}}{RC} dt \quad where\ R = 7.5k\Omega \text{ and } \mathrm{C} = 1\mu\mathrm{F}$$

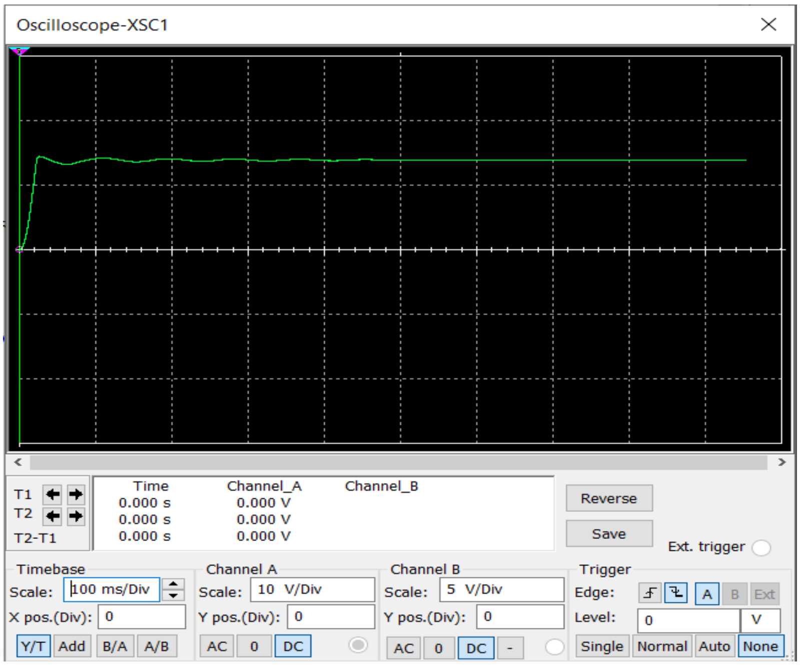
When $I_{LOAD} < 1A,\ V_{OUT(PWM\ control)}$ keeps increasing until it reaches the correct voltage needed for the PWM duty cycle.

When $I_{LOAD} > 1A,\ V_{OUT(PWM\ control)}$ keeps decreasing until it reaches the correct voltage needed for the PWM duty cycle.

Simulation Results

During the simulation it has been found that there is an oscillation before converging to the correct corresponding controlling voltage of PWM duty cycle because of the propagation delay.





Constant Voltage Control

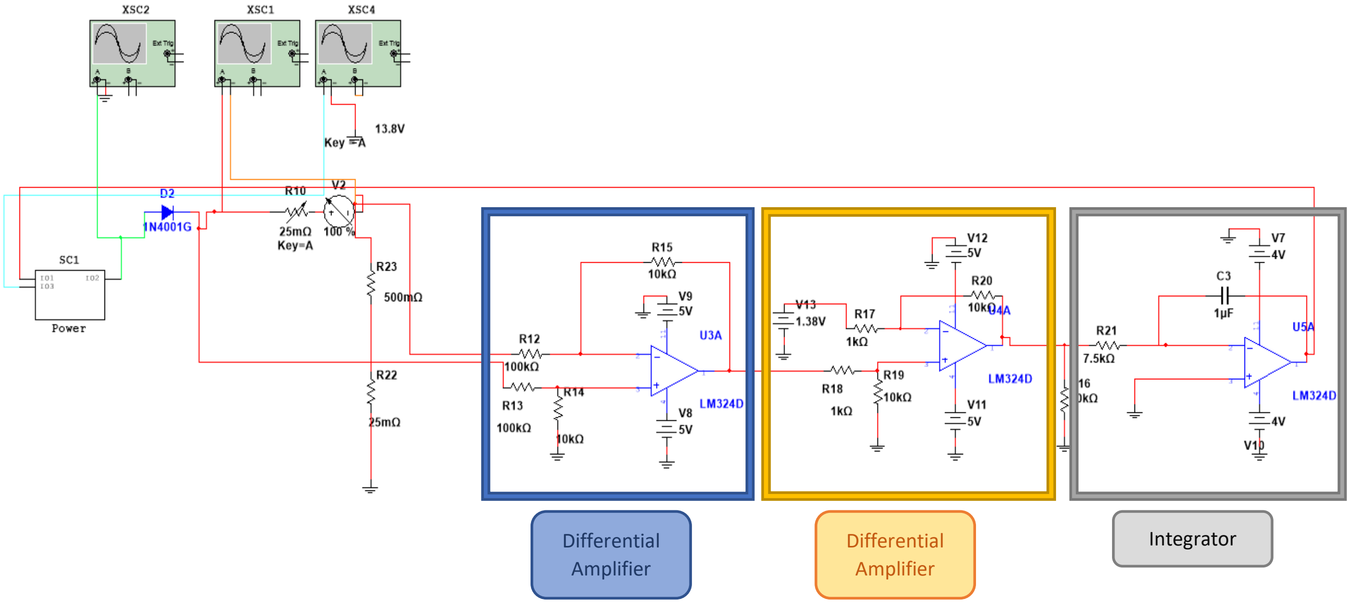
For the Constant voltage the battery must be kept under 13.8V, for this purpose ways to measure the voltage across the battery, measure the error and adjusting the PWM had to be chosen.

For each task following have been used,

Measuring voltage - Differential Amplifier

Measuring Error – Differential Amplifier

Adjusting PWM - Integrator



Measuring Voltage

For the measuring of the voltage across the battery differential op amp has been used with stepping down the voltage by 0.1 times.

$$V_{OUT(Voltage\ Measuring)} = \frac{R_2}{R_1}(V_+ - V_-)\ where\ R_1 = 10k\Omega \text{ and } R_2 = 100k\Omega$$

$$V_{OUT(Voltage\ Measuring)} = 0.1 \times (Voltage\ of\ the\ Battery)$$

For the voltage of 13.8V $V_{OUT} = 0.1 \times 13.8V = 1.38$

Measuring Error

For the measuring of error, a simple differential amplifier has been used and for the stationary voltage previously calculated voltage should be applied since it corresponds to 13.8V.

$$V_{OUT(Error)} = \frac{R_2}{R_1}(V_{IN} - 1.7V)\ where\ R_1 = 1k\Omega \text{ and } R_2 = 10k\Omega$$

$$\therefore V_{OUT(Error)} = 10 \times (V_{IN} - 1.7V)$$

Controlling PWM

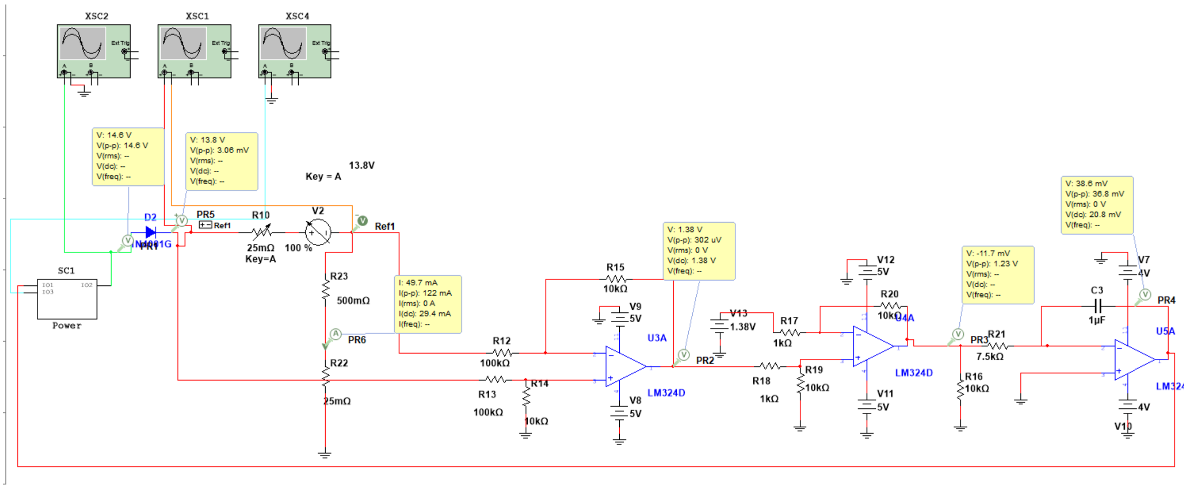
For the controlling of PWM error must be accumulated, therefore an integrator is used for that purpose and the accumulated error is used to control the PWM.

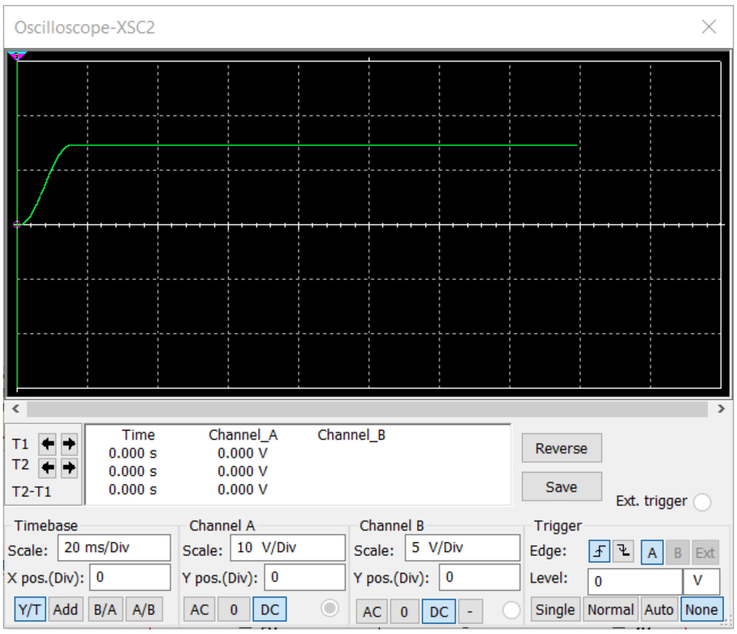
$$V_{OUT(PWM\ Control)} = -\int_0^t \frac{V_{IN}}{RC} dt \ \ where\ R = 7.5k\Omega \text{ and C} = 1\mu\text{F}$$

When $V_{Battery} < 13.8\ V$, $V_{OUT(PWM\ Control)}$ keeps increasing until it reaches the correct voltage needed for the PWM duty cycle.

When $V_{Battery} > 13.8\ V$, $V_{OUT(PWM\ Control)}$ keeps decreasing until it reaches the correct voltage needed for the PWM duty cycle.

<u>Simulation results</u>

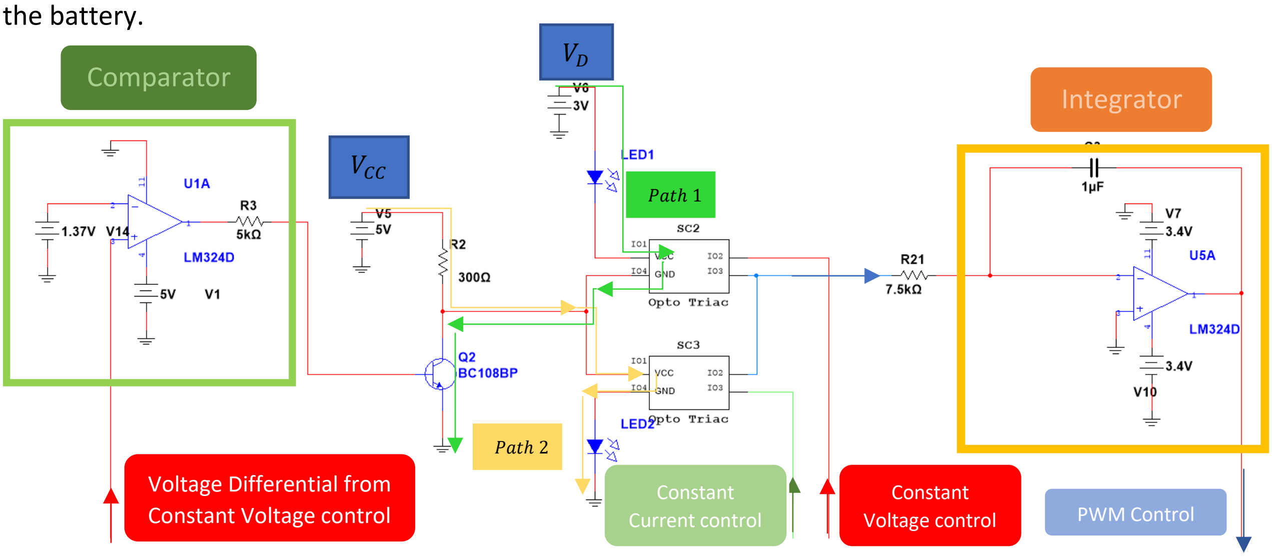




In both Constant current and constant voltage control LM324 Op Amps have been used since some packages can have dual power supplies and one package can be used to each task accordingly. Again, any kind of normal Op Amp which are being used for normal operations in +5V/-5V can be used for the both Constant Current and Constant Voltage control operations.

Switching Between Constant Current stage and Constant Voltage Stage

Since in both constant current and constant voltage controlling same integrator is used, two error signals can be directed into the same integrator while switching the stages at the suitable voltage of the battery.



To activate the transistor a comparator is used because it is difficult sometimes to find the required Zener for that specific voltage, also it provides a better control of the switching voltage. The comparator is directly connected to the Op Amp output of the Voltage Differential in the Constant voltage control which gives the stepped down voltage of the Battery. When the battery voltage is greater than 13.8V the comparator gives out 5V saturating the transistor. When the battery voltage is less than 13.8V the comparator gives out 0V cutting off the transistor.

As for the transistor BC108BP has been selected which has $V_{CE(Sat)} = 0.2V$ in fact there is no special requirement for selecting BC108BP and any transistor with $V_{CE(Sat)}$<0.7V and can conduct adequate current for the LED should be sufficient.

Here the Opto Triacs have been used because the error can be either negative or positive voltage and if a Diode Opto Isolator had been used the negative error wouldn't have been able to reach the integrator.

When selecting the V_D it should be carefully selected that only one Opto triac can be activated at a time. Two LEDs have been used to indicate in which stage the charging is happening.

When the transistor is in saturation, Path 1 can conduct current since,

$$V_D > 0.2V + 0.7V(Forward\ Voltage\ of\ the\ diode\ in\ the\ opto\ triac) + Forward\ Voltage\ of\ the\ LED$$

This allows Constant Voltage Control to connect to the integrator.

When the transistor is in cutoff, Path 2 can conduct current since,

$V_{CC} > 0.7V(Forward\ Voltage\ of\ the\ diode\ in\ the\ opto\ triac) + \ Forward\ Voltage\ of\ the\ LED$ and diode in above Opto Triac blocks the current. This allows Constant Current Control to connect to the integrator.

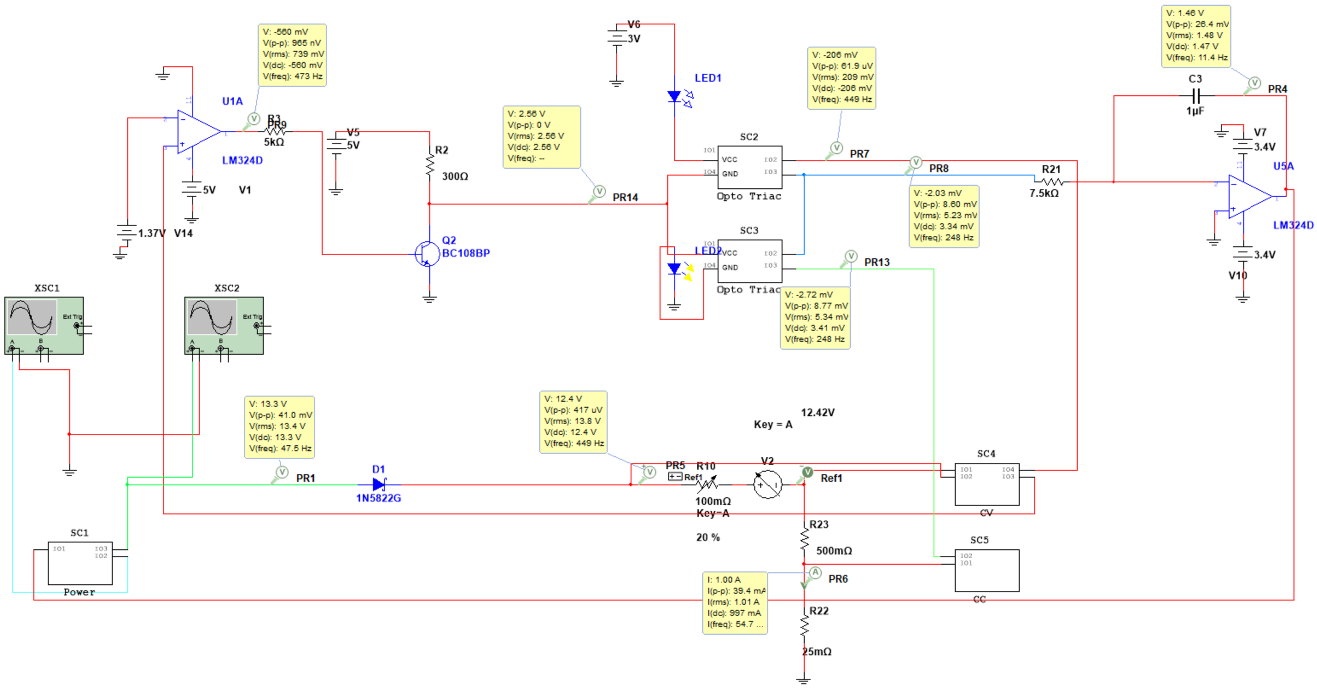
Therefore, using this a Solid State SPDT switch has been implemented for switching stages between constant current and constant voltage.

Full Circuit Simulation

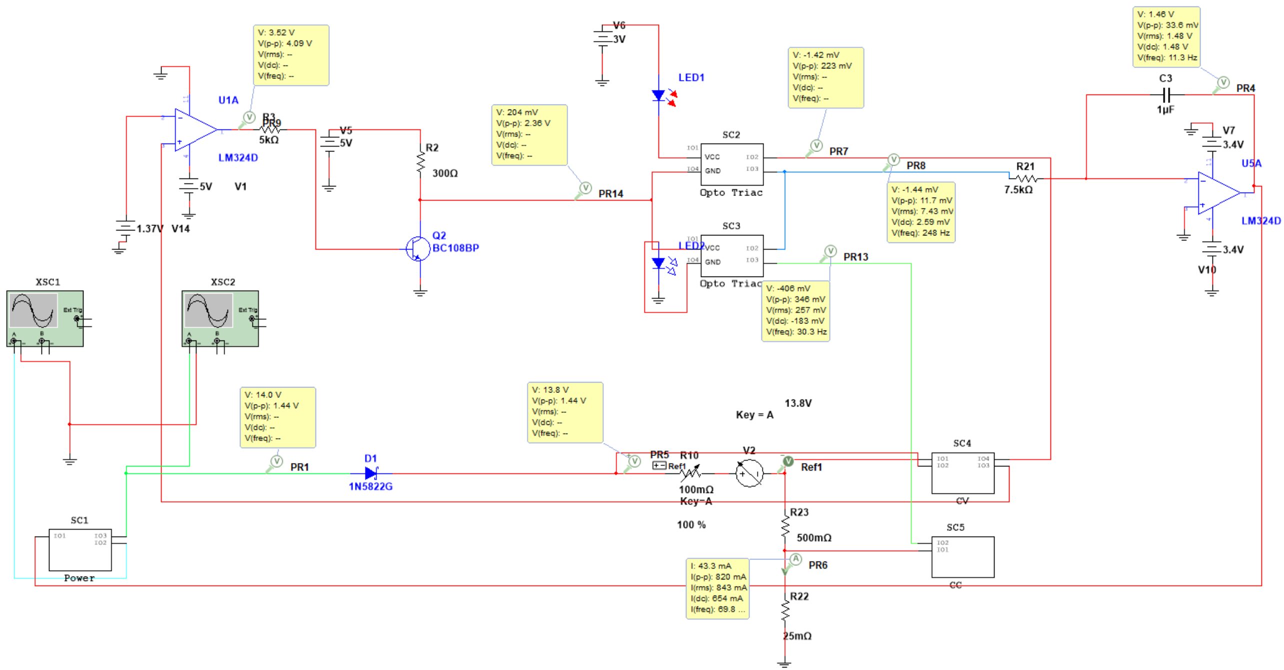
To simulate the battery, a variable DC voltage and a variable resistor have been used. Furthermore, for the prevention of back current 1N5822 Schottky diode has been used, which has a peak reverse voltage of 40V and average forward current of 3A with forward voltage of 0.9V.

To reduce the ripple current additional $500m\Omega$ has been added to the battery path.

<u>Constant Current stage</u>



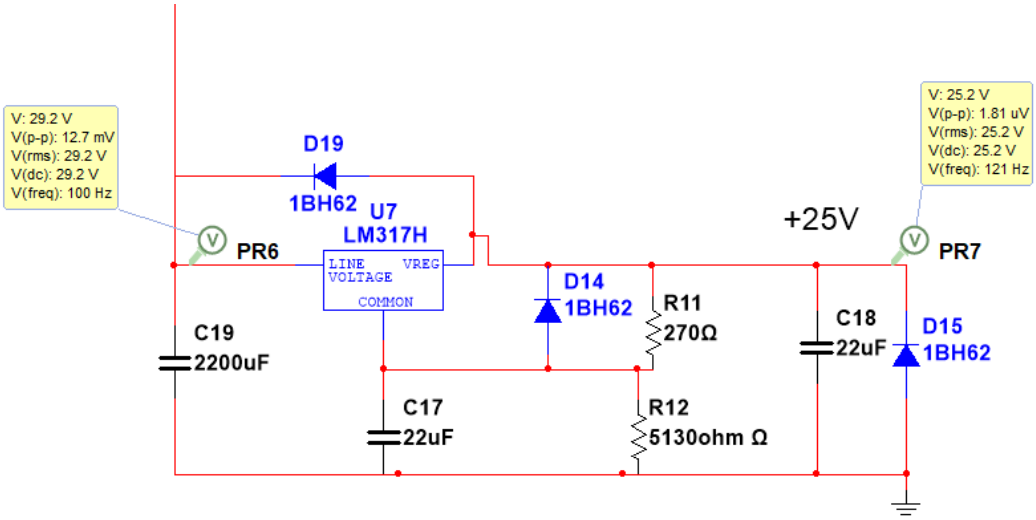
<u>Constant Voltage stage</u>



As shown above the Simulation was successful.

Voltage Regulation to power up the Main Circuit

For 25v



We have used an LM317 regulator to get 25V .

$$V_{out} = 1.25\,(1 + 270/R12)$$

So, R12 = 5130 ohm

For 5v

It is done by 7805 IC