Electronic Design Lab - EE 344

Group - 33

Solar-powered Street Light: LED intensity control

Team Details

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Faculty Mentor

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Problem Statement

At times due to cloudy sky or rain the solar panel present in the street light cannot produce the required amount of energy required to charge the battery. Full load is applied to this uncharged battery and hence the working time of the street light is low. Using battery at full load when it is low on charge, can damage it.
To address the above mentioned problem, we were expected to design a LED intensity control based on the state-of-charge (SoC) of the battery.

Figure 1

1 Design Approach

One of the possible solutions to vary the intensity of the LED lights is by varying the PWM's duty cycle of the input voltage to the load LED's. The proposed solution uses 555 Timer to vary the pulse width from 100% to 50% depending upon the battery voltage, hence increasing the discharge time of the battery and reducing the LED intensity by half. Using this, the street lights can be used for prolonged duration.

1.1 Proposed circuit

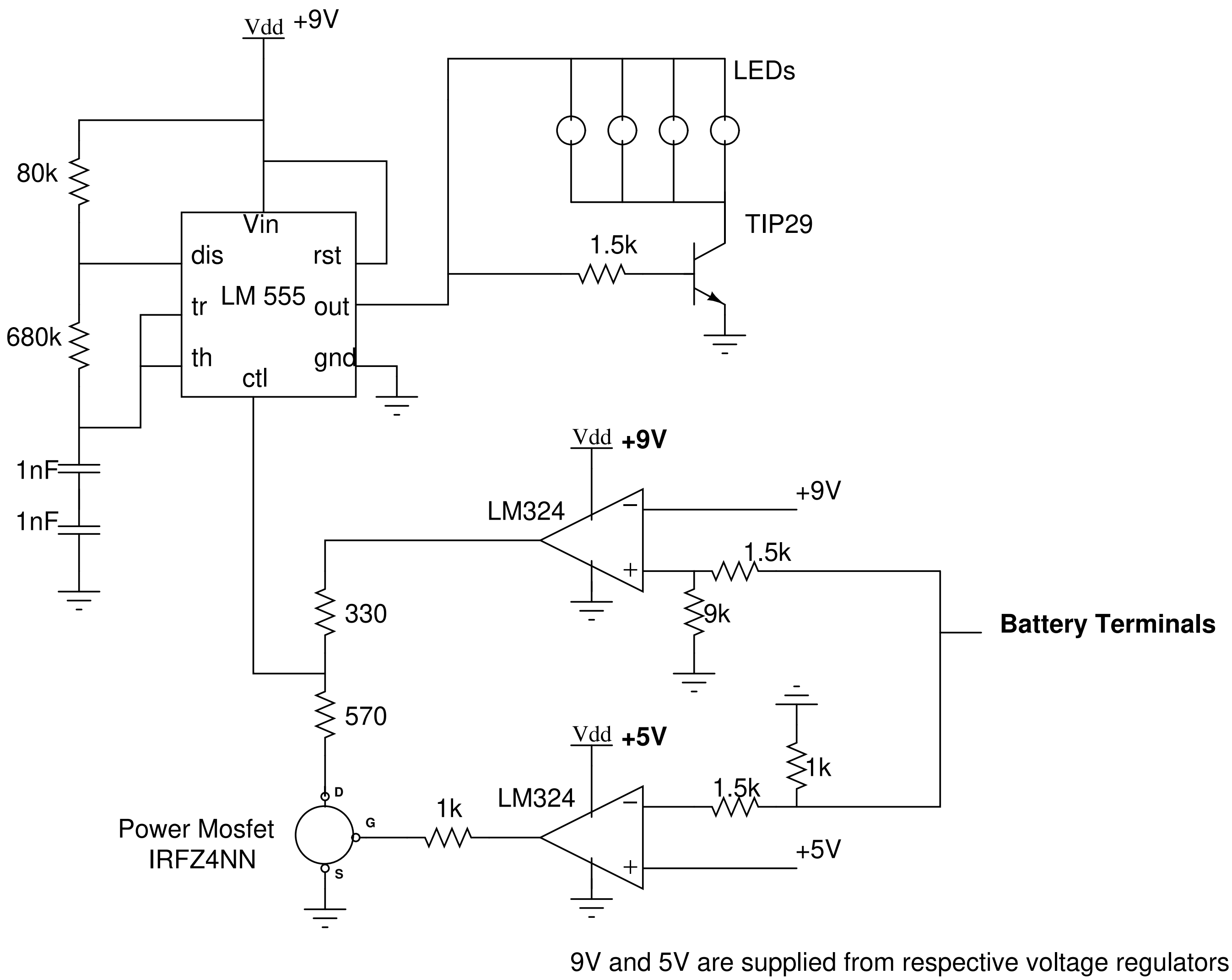


Figure 2

Battery

1. The battery used is **Panasonic UP-PW1245P1**.
2. The Voltage when full charged is 12.7V
3. The battery has 50% charge at 11.6V.
4. The battery charge is below 10% or dead when no load voltage is 10.5V
5. Internal resistance of the battery is $20m\Omega$.

Voltage regulators

In the design we have used 9V and 5V which are to be produced using voltage regulators.

To produce 9V	**To produce 5V**
The IC used to generate 9V output is LM7809. It gives 9V for V_{in} upto 24V The peak current can go upto 2.2A	The IC used to generate 5V output is LM7805. It gives 5V for V_{in} upto 20V The peak current can go upto 2.2A

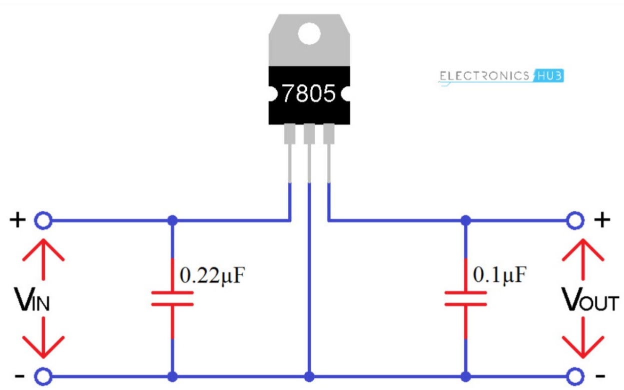


Figure 3: How to connect Voltage regulators

The above figure shows how voltage regulators must be connected in the circuit.
NOTE: This circuit is not shown in the above circuit, Voltages of 9V and 5V are shown independently to avoid unnecessary confusion.

Timers

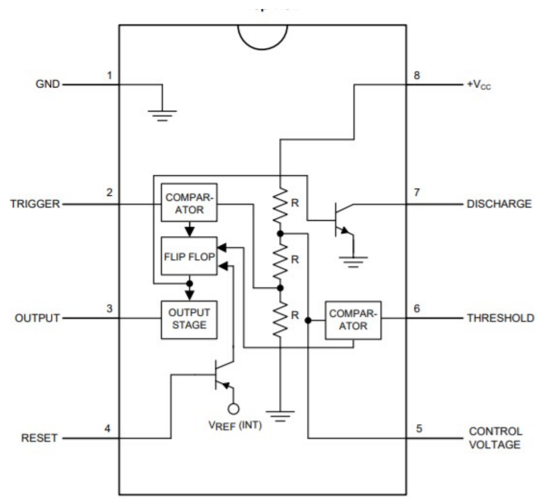


Figure 4

1. The 555-Timer used in the circuit is **LM-555**
2. V_{cc} can be from 5V-15V.
3. V_{ctl} is used to vary the PWM cycle of the timer.

1.2 Calculations for Load and it's specifications

The load that is being used is 5W LED strips.
The current required to be fed to the 5W load to operate it at full load is:

$$P_{load} = 5W$$
$$V_{out}\text{ (from 555 timer)} = 9V$$
$$I_{load} = \frac{P_{load}}{V_{out}} = 555.56\,mA$$

The resistor needed to maintain the current with the BJT used is derived as follows:

$$\beta = 100; \qquad V_B = 0.7\,V$$
$$I_C = I_{load} = 555.56\,mA; \qquad I_B = 5.56\,mA$$
$$R_B = \frac{9 - V_B}{I_B}$$
$$\therefore R_B = 1.49\,k\Omega \approx 1.5\,k\Omega$$

The NPN transistor BJT used is TIP29-BP, which has max collector current (I_c) =1A specifications.

1.3 Calculations Duty cycle and frequency

With control voltage applied at pin 5, we can control duty cycle and freq as follows:

1. Let voltage applied at pin 5 be V_{ctl} and $V_{ctl} <= 9$ V.

2. Then the voltages map as follows:

$$\frac{2}{3}V_{cc} \longrightarrow V_{ctl}$$
$$\frac{1}{3}V_{cc} \longrightarrow \frac{V_{ctl}}{2}$$

3. Calculating "On" (charging) time:
Taking the moment that the capacitor starts charging to be $t = 0$ we can state the charging equation for the capacitor as:

$$V(t) = (V_{cc} - 0.5V_{ctl})(1 - e^{\frac{-t}{\tau_c}}) + 0.5V_{ctl}$$

where, charging time constant $\tau_c = (R_A + R_B)C$
Now, $V(t_{on}) = V_{ctl}$ gives:

$$t_{on} = \tau_c \ln\left(\frac{V_{cc} - 0.5V_{ctl}}{V_{cc} - V_{ctl}}\right)$$

4. Calculating "Off" (discharging) time:
Now we will show that the "off" time is not dependent on V_{ctl}. We know that a discharging capacitor can be modeled with the following relation:

$$V(t) = V_0 e^{\frac{-t}{\tau_d}}$$

where, $V_0 = V_{ctl}$ i.e initial voltage and discharging time constant $\tau_d = R_B C$
Now, $V(t_{off}) = 0.5V_{ctl}$ gives:

$$t_{off} = \tau_d \ln(2)$$

5. Duty cycle is given as follows:

$$D = \frac{t_{on}}{t_{on} + t_{off}} = \frac{\tau_c \ln(\frac{V_{cc} - 0.5V_{ctl}}{V_{cc} - V_{ctl}})}{\tau_c \ln(\frac{V_{cc} - 0.5V_{ctl}}{V_{cc} - V_{ctl}}) + \tau_d \ln(2)}$$

6. Frequency is given as:

$$f = \frac{1}{t_{on} + t_{off}} = \frac{1}{\tau_c \ln(\frac{V_{cc} - 0.5V_{ctl}}{V_{cc} - V_{ctl}}) + \tau_d \ln(2)}$$

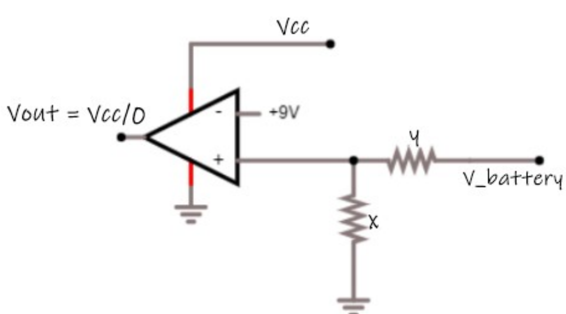
To maintain the clock frequency around 1kHz, we choose $R_A = 80\,k\Omega$, $R_B = 680\,k\Omega$ and $C = 0.5\,nF$.
So, in our case when $V_{cc} = 9V$, for achieving 100% duty cycle, V_{ctl} should be **9V** and for achieving 50% duty cycle, V_{ctl} should be **5.68V**. As we can observe that the frequency varies as V_{ctl} varies. Hence for 100% PWM the frequency is around 1kHz, for 50% it is 2kHz.

1.4 Switching Circuit

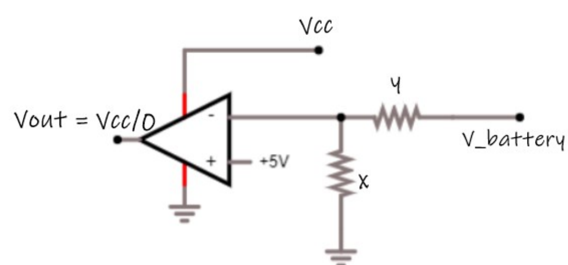
The OPAMP used for the circuit as a comparator is LM324.The supply voltage can be of 3V-32V. The maximum output current is of 20mA
The switching logic creates the output such that,

1. The OP-AMP-1 outputs 1 (high=9V) when the battery voltage is more than 10.5V.
2. The OP-AMP-2 outputs 1 (high=5V) when the battery voltage is less than 11.6V
3. Then the output of OP-AMP -2 decides whether the MOSFET is supposed to turn on or off.
4. The V_{DD} is 0V (output low of OM-AMP1) when battery is dead.

$$\begin{aligned} &OPAMP1/2 = ON/OFF \qquad MOSFET = OFF, \quad V_{out} = V_{ctl} = 9V \\ &OPAMP1/2 = ON/ON \qquad MOSFET = ON, \quad V_{out} = V_{ctl} = 5.68V \approx 5.7V \\ &OPAMP1 = OFF \qquad V_{out} = V_{ctl} = 0V \end{aligned}$$



(a) Opamp 1



(b) Opamp 2

Figure 5

OP-AMP-1 Calculations
We want output high for $V_{Battery} > 10.5$, I have put a $V_{-} = 9V$, hence,

$$\begin{aligned} V_{-} = 9V > V_{+}; \quad V_{battery} \leq 10.5 \\ 9 \geq V_{battery} \times \frac{x}{x+y} \\ 9x + 9y \geq 10.5x \\ 9y \geq 1.5x \\ Chosen\ resistor\ values\ are \quad x = 1.5k\Omega; \quad y = 9k\Omega \end{aligned}$$

OP-AMP-2 Calculations

We want output low for $12.7 > V_{Battery} > 11.6$, I have put a $V_+ = 5V$, hence,

$$V_+ = 5V > V_-; \quad 11.6 \leq V_{battery} \leq 12.7$$
$$11.6 \times \frac{x}{x+y} \leq 5 \leq 12.7 \times \frac{x}{x+y}$$
$$11.8x \leq 5x + 5y \leq 12.7x$$
$$6.8x \leq 5y \leq 7.7x$$
$$1.36x \leq y \leq 1.54x$$
$$Chosen\ resistor\ values\ are \quad x = 1k\Omega; \quad y = 1.5k\Omega$$

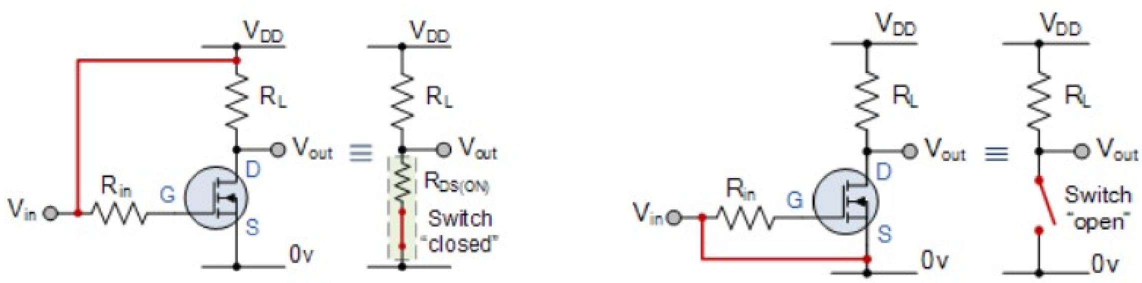
MOSFET Calculations

The MOSFET we decided to use is **IRFZ44N**. It has a max Gate threshold of 4V.The V_{GS} can go upto 20V. It has a max current rating of 49A.

$MOSFET = ON$	$V_{GS} = 5V$	$V_{th} = 4V$	$V_{DD} = 9V$
$MOSFET = OFF$	$V_{GS} = 0V$	$V_{th} = 4V$	$V_{DD} = 9V$

As noted in the above section for 50% cycle we need to have $V_{out} = 5.68 \approx 5.7V$

Functioning of the MOSFET as a switch can be denoted by the following figure.



(a) switch on

(b) switch off

Figure 6

1. The internal resistance of the MOSFET R_{DS} is of $19m\Omega$ and hence is neglected.
2. We need to drop the potential of 9V to 5.7 volts and give it as input to 555 timer.
3. This is achieved by using 570Ω $(470 + 100)$ and 330Ω resistors.
4. The max current through OMAMP and MOSFET is of 10mA which is well below the max rated current.

1.5 Proposed method for SOC calulations

To calculate the SOC,

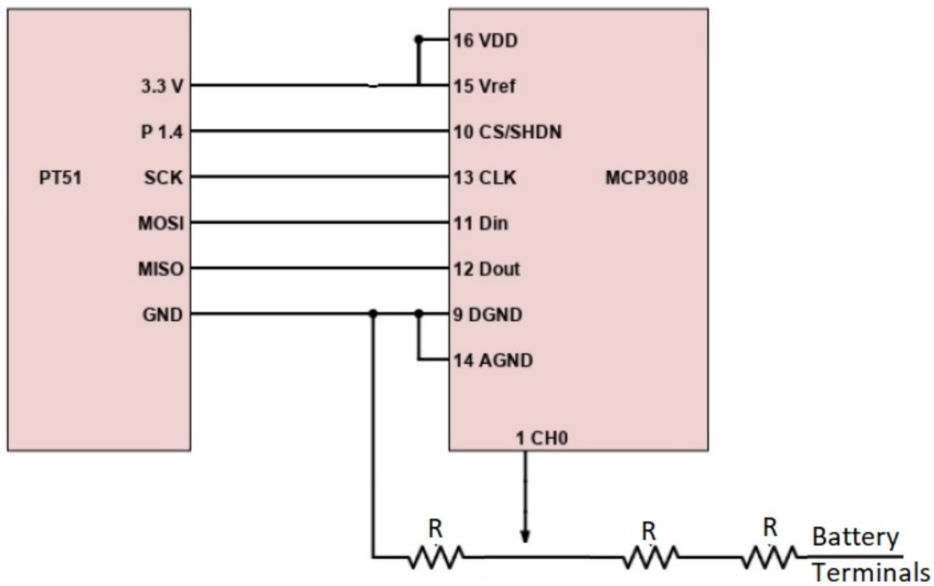


Figure 7: connections for pt-51

1. We are using IC MCP3008 (10-bit Analog-to-Digital converters (ADC) with SPI) to calcuate the voltage across the battery.
2. The circuit is connected as shown above.
3. The output of the IC is in the format: XXXXX mV, hence even after using the voltage divider we have not compromised much on the precision.
4. The range of output will be

$$10.5V \leq 3V_{measured} \leq 12.7V$$
$$3.5V \leq V_{measured} \leq 4.23V$$

5. We measure the 10 instances of the battery voltage and take the minimum voltage. This voltage will correspond to when LEDs are on (given the measured voltage is more than 10.5V).

6. Because we want open circuit voltage we make the following calculations (done by micro controller)

$$
\begin{aligned}
V_{battery} - I_{total}R_{internal} &= V_{measured} \\
Vmeasured &= (\text{measurement made by ADC}) \times 3 \\
I_{total} &\approx 560mA \quad (\text{when LED's are on}) \\
R_{internal} &= 20m\Omega \\
V_{battery} &= I_{total}R_{internal} + V_{measured} = 0.0112V + V_{measured}
\end{aligned}
$$

The link to the codes for the above method is, `https://github.com/Meeta14/EDLproject`

1.6 Cost of Billing

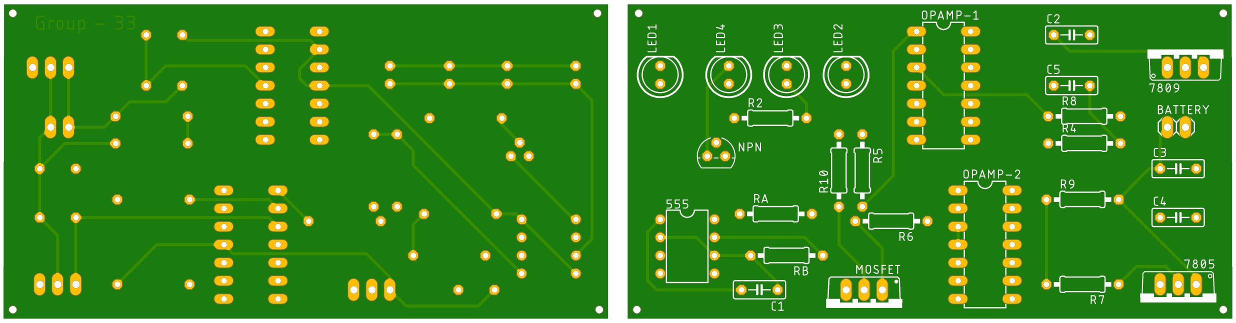
The total cost is shown below,
NOTE: Panasonic UP-PW1245P1 of worth Rs. 2252 and LED load is taken as given.

Item	Quantity	Single Unit Price (Rs)	Total Price (Rs)
LM324	2	11	22
LM555	1	10	10
IC 7805	1	9	9
IC 7809	1	10	10
IRFZ44N	1	20	20
TIP29 BJT	1	32	32
100Ω Resistor	1	0.5	0.5
330Ω Resistor	1	2	2
470Ω Resistor	1	1	1
1kΩ Resistor	2	0.5	1
1.5kΩ Resistor	3	1	3
9kΩ Resistor	1	1	1
40kΩ Resistor	3	1	3
80kΩ Resistor	1	1	1
680kΩ Resistor	1	2	2
1nF Capacitor	2	0.5	1
0.1uF Capacitor	2	0.5	1
0.22uF Capacitor	2	0.5	1
		Total Cost	120.5

NOTE: The cost of PCB printing is not included in it.

1.7 PCB Board

The link to the codes of PCB design, `https://github.com/Meeta14/EDLproject`



(a) bottom view (b) top view

Figure 8

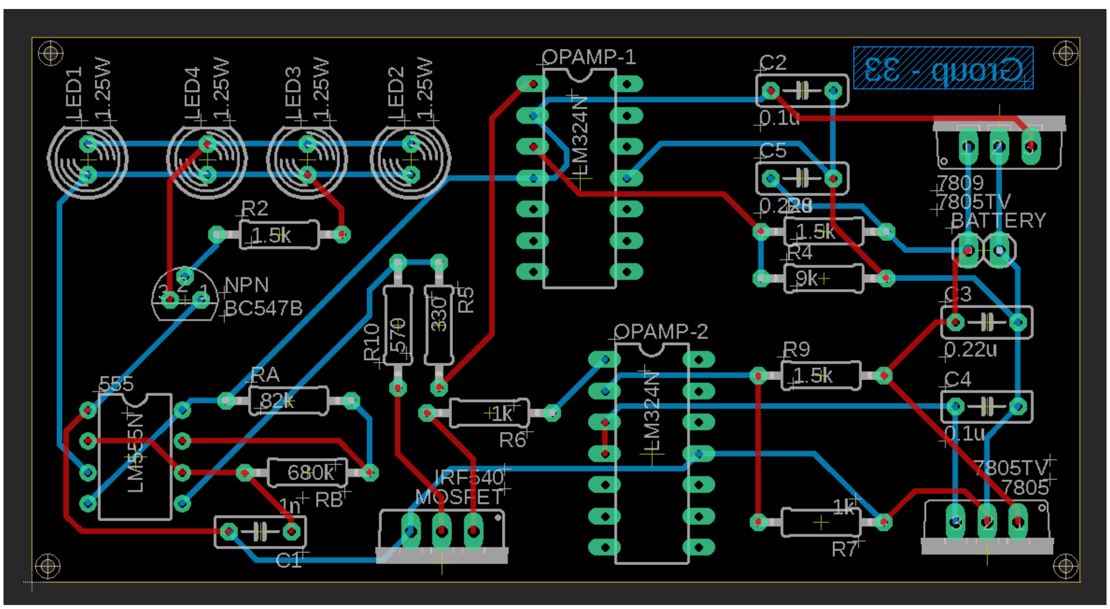


Figure 9: Board

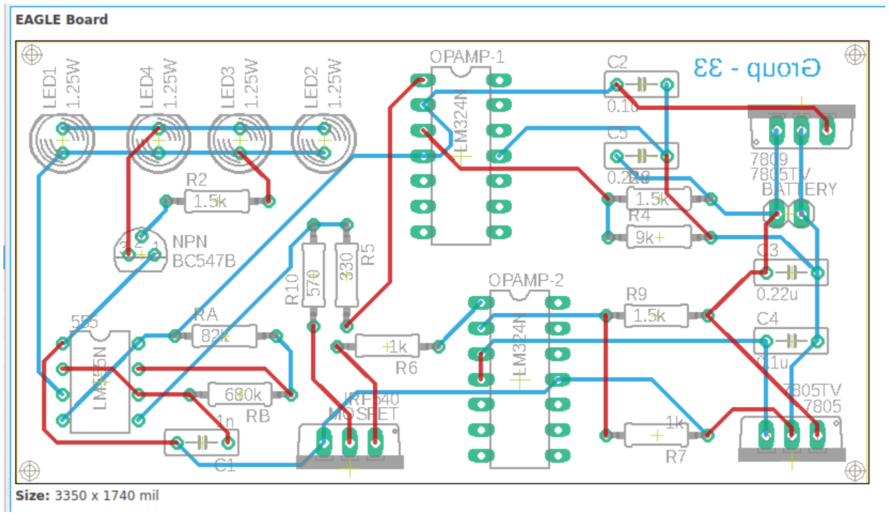


Figure 10: Board Preview

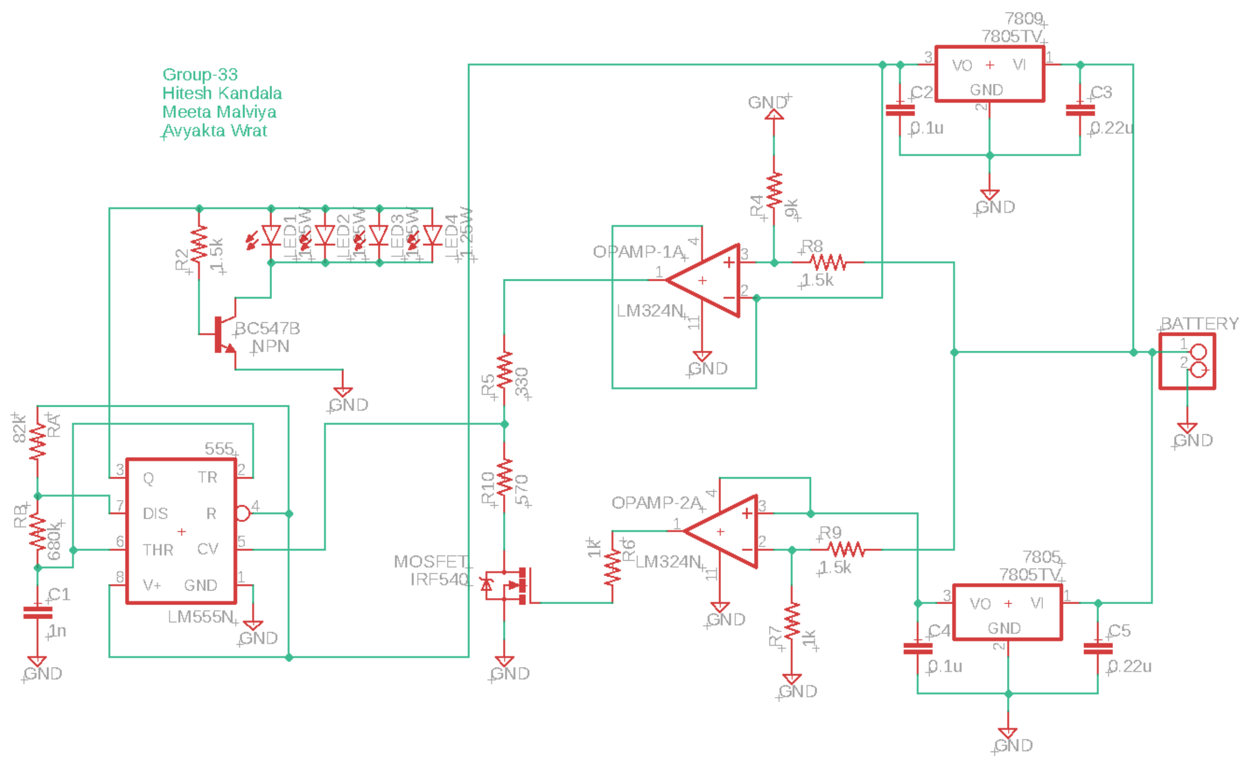


Figure 11: Schematic