**Date: 12.01.2018**

# MIDDLE EAST TECHNICAL UNIVERSTY

# DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

# EE213 ELECTRICAL CIRCUITS LABORATORY

# 2017-2018 FALL

# TERM PROJECT

# SOLAR TRACKING SYSTEM

# FINAL REPORT

Menduh Kesici

# TABLE OF CONTENTS


1. Introduction ............ 2

2. Basic Design Diagram ............ 3

3. Circuit Schematics ............ 4

   A. Sensing Unit ............ 4

   B. Light Intensity Indicator Unit ............ 5

   C. Control Unit ............ 7

   D. First Light Emitter Unit ............ 9

   E. Second Light Emitter Unit ............ 10

   F. Pulse Width Modulator Unit ............ 12

   G. Angle Adjustment Unit ............ 14

4. Overall Schematic of The Project ............ 18

5. Power Analysis and Budget ............ 19

6. Conclusion ............ 20

7. References ............ 21

# 1. INTRODUCTION

As our EE213 term project, we designed a solar panel rotating to specific angles taking into consideration the light intensities coming from three different directions. To achieve this, we obtained a servo motor rotating to different angles according to the signal it is obtaining. Also, 3 RGB's are used to indicate whether these three light intensities are low, medium or high; and another 2 RGB's are used to show which one is the highest among them and which one is the lowest. Because some bonus parts are also included in this new design, now it composes of seven parts as below:

- Sensing Unit
- Light Intensity Indicator Unit
- Control Unit
- First Light Emitter Unit
- Second Light Emitter Unit
- Pulse Width Modulator Unit
- Angle Adjustment Unit

## 2. BASIC DESIGN DIAGRAM

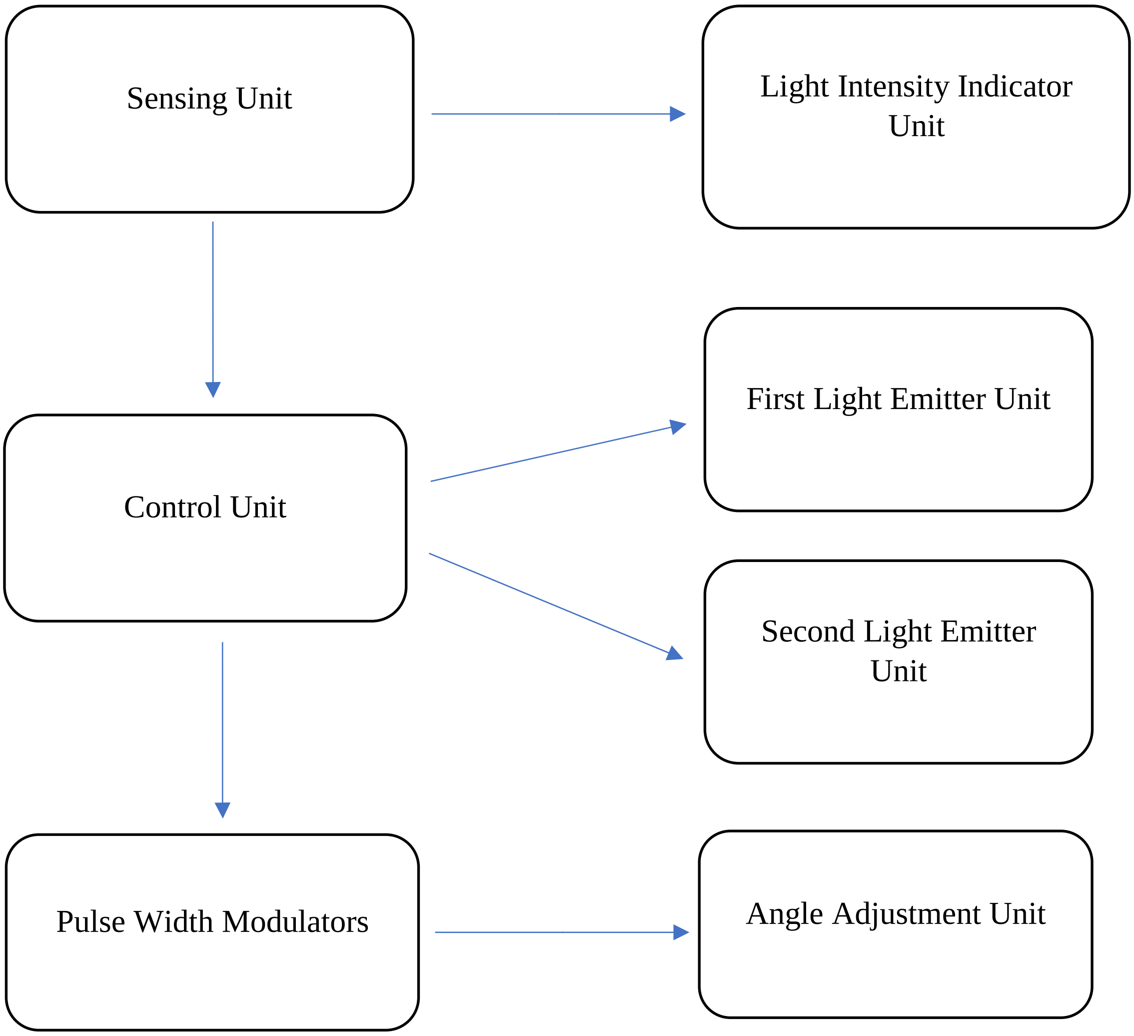


Figure 1: The block diagram of the project

As can be seen from the block diagram of the project (Figure 1), it compromises of six parts. At first, the sensing unit produces three different voltage values according to the light intensities coming from three different directions. Afterwards, the light intensity indicator, by comparing these three voltages by some reference voltages, decides if it has a low, medium or high voltage value and causes three RGB's for each three voltages to emit a different color of light accordingly. Then, the control unit, by comparing the voltages obtained from the sensing unit, decides which voltage value is the highest. Also, in the first light emitter unit, an RGB emits a different color of light according to which voltage is the highest, and in the second light emitter unit, another RGB emits a different color of light according to which voltage is the lowest. Then, with the help of pulse width modulators, three square waves which rotates the servo motor to three different angles are produced, but only one of them works because the control unit supplies the necessary voltage to only one of those which makes the motor take the desired angle. At last, in the angle adjustment unit, these square waves are added up and sent to the motor input.

## 3. CIRCUIT SCHEMATICS

### A) SENSING UNIT

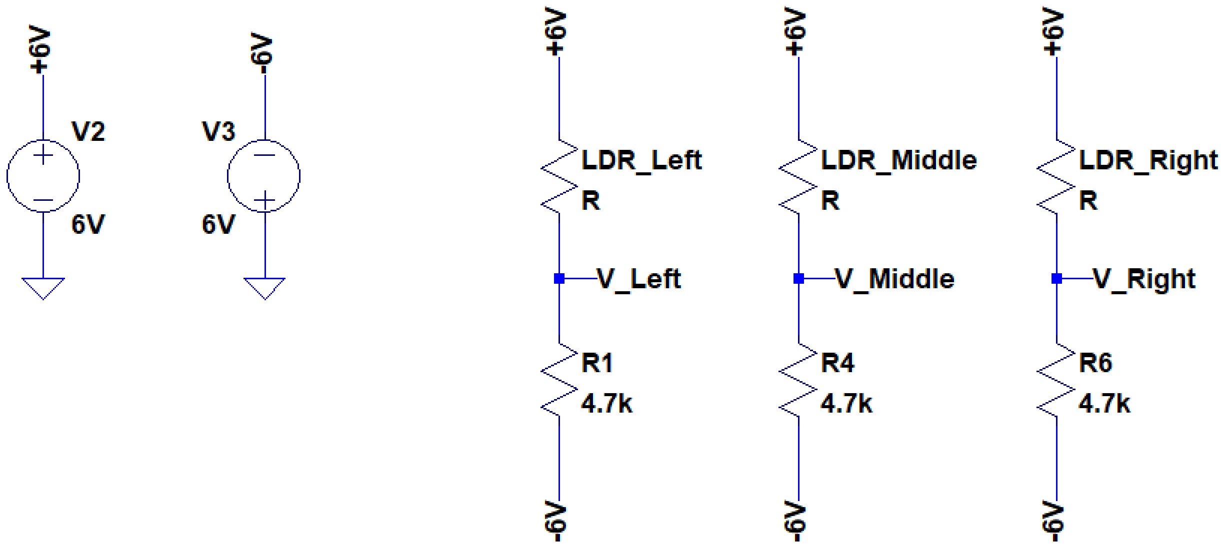


Figure 2: The circuit schematic of the sensing unit

As light is shone onto the LDR, its resistance decreases, and voltage values read from the V_Left, V_Middle and V_Right increase as more current passes through the other resistors. In our preliminary design, the other resistances were connected to the ground, but in order to obtain a voltage over a greater range, we replaced it with -6V as can be seen from the schematic of this part (Figure 2). LDR's resistance value is between 100k and 1k. When the light source is farther than 20cm, the voltage value read from the node is approximately +1V, and as it gets closer, the voltage goes up to +5V.

## B) LIGHT INTENSITY INDICATOR UNIT

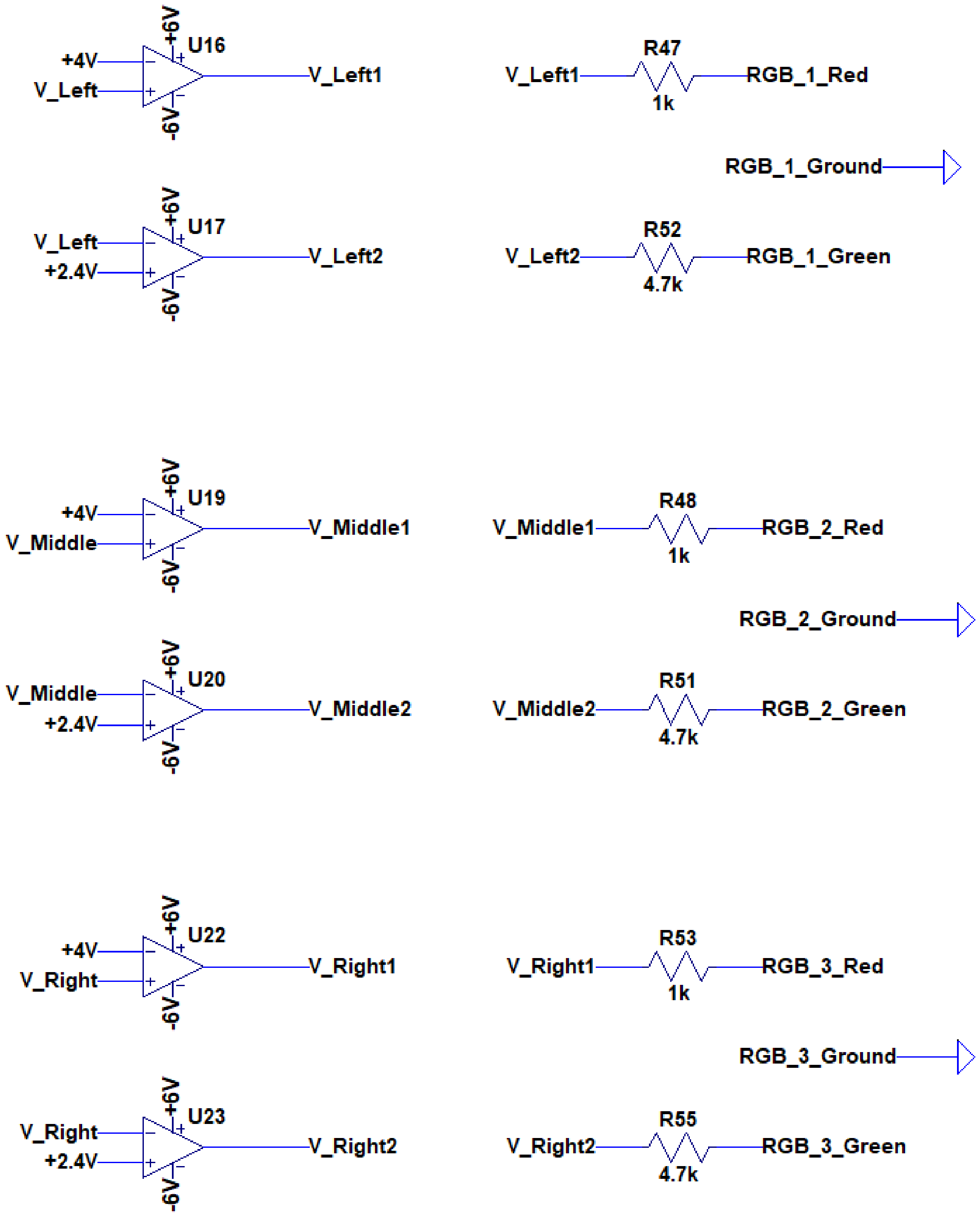


Figure 3: The circuit schematic of the light intensity indicator unit

In the light intensity indicator unit, three RGB's emit different colors of light according to different light intensities obtained from three directions. To do this, three voltage values obtained in the sensing unit part are compared with two other reference voltages chosen experimentally. As said in the previous chapter, in case of low intensity, the voltage is +1V, and it goes up to +5V as light gets more intense. Therefore, the reference voltages are chosen to be +2.4V and +4V. The objective was to obtain a red light in case of low intensity, a yellow light, that is red light plus yellow light in case of medium intensity, and a green light in case of high intensity from the RGB. If low intensity is defined as voltage values less than +2.4V, medium intensity is defined as voltage values between +2.4V and +4V, and high intensity is defined as voltage values more than +4V, then the RGB must emit red light when the voltage is less than +4V and yellow light when the voltage is more than +2.4V. Because common anode RGB's are used in this part, when the voltage is less than +4V, the red node of the RGB must be a negative voltage, and when the voltage is more than +2.4V, the green node of the RGB must be a negative voltage so that red, yellow and green colors of light will be obtained for different cases. Therefore, as can be seen from the schematic (Figure 3), six operational amplifiers are used to compare these three voltages with the reference voltages. If we look at the first comparator, it compares V_Left with +4V, and if V_Left is less than +4V, it gives a negative voltage and cause the RGB to emit red color. If we look at the second comparator, it compares V_Left with +2.4V, and if V_Left is more than +2.4V, it gives a negative voltage and cause the RGB to emit green color. The other four operational amplifiers are for the other two voltages obtained from the sensing unit for the same purpose. The resistors are used to prevent high current and to adjust the color tone. The resistance values used in the red nodes of the RGB's are higher than the ones in the green nodes due to different forward voltages and luminous intensities of different LED's in the RGB [1]. +2.4V and +4V voltage values are obtained by voltage dividing +6V with necessary resistors, and these voltages are connected to the according nodes of the op-amps.

## C) CONTROL UNIT

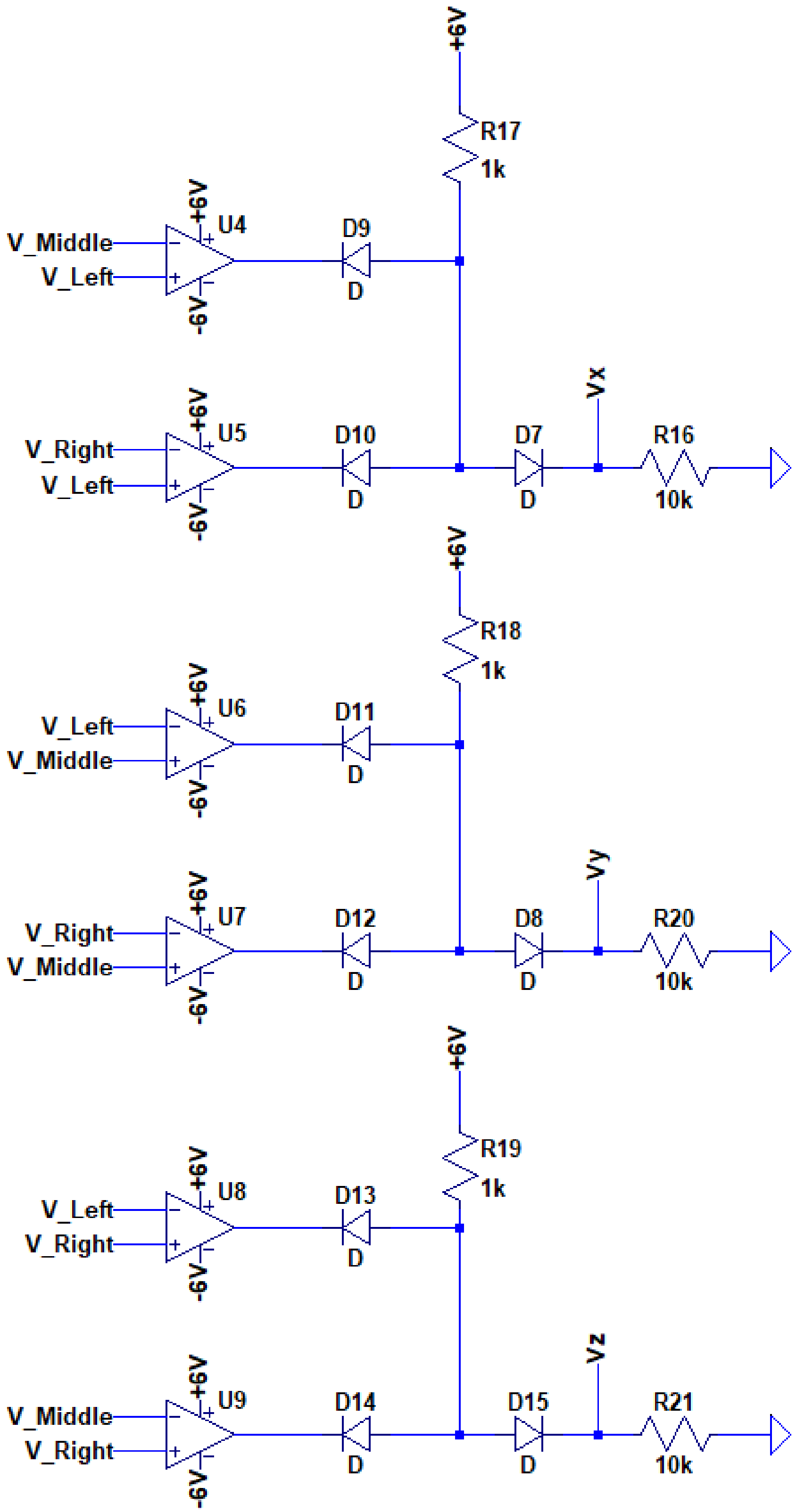


Figure 4: The circuit schematic of the control unit

In the control unit, three voltages obtained from the sensing unit are compared with each other, and the highest one is determined. As can be seen from the schematic (Figure 4), six operational amplifiers are used in this part of the circuit to compare all these three voltages with each other with different combinations. If we look at the first operational amplifier, it gives positive voltage when V_Left is higher than V_Middle. If we look at the second operational amplifier, it gives positive voltage when V_Left is higher than V_Right. When both voltages are +6V, all the current passes from +6V DC source to the ground and approximately +5V occurs Vx node. When even one of the operational amplifiers gives -6V, all the current pass from +6V DC source to -6V output of the operational amplifier, so no current passes through the 10k resistor and no voltage occurs in the Vx node. The other four operational amplifiers are for the other two voltages for the same purpose.

## D) FIRST LIGHT EMITTER UNIT

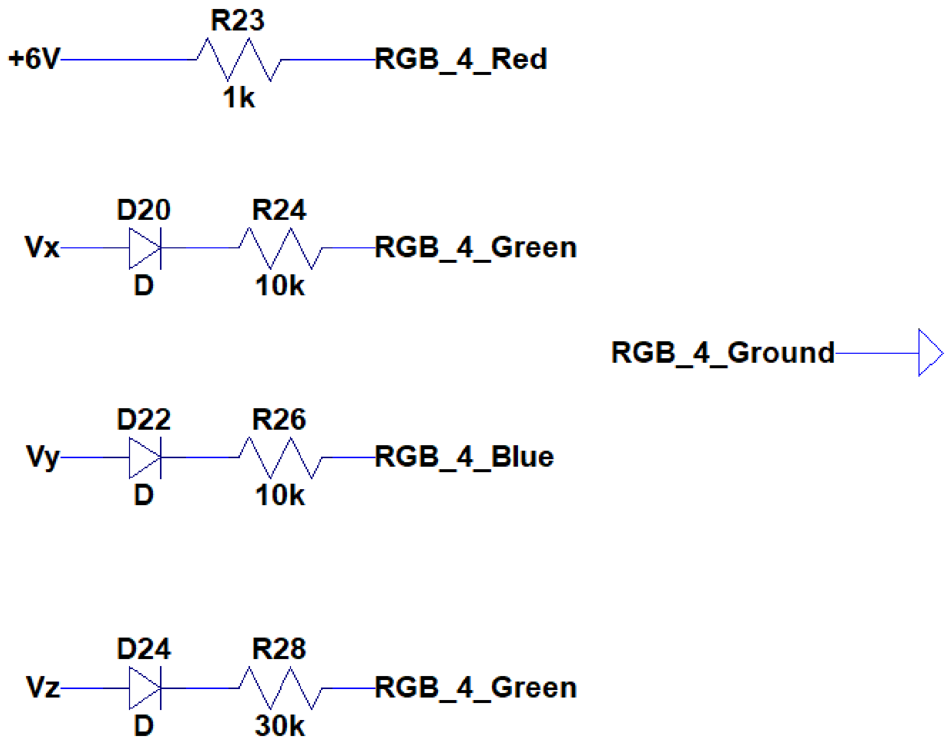


Figure 5: The circuit schematic of the first light emitter unit

In the first light emitter unit, the objective is to emit a yellow color, that is red color plus green color when V_Left is the highest, emit a purple color, that is red color plus blue color when V_Middle is the highest, and emit an orange color, that is red color plus green color when V_Right is the highest. The RGB is common cathode. As can be seen from the schematic (Figure 5), the red node is directly connected to +6V DC source as it will always produce red color in all three cases. When V_Left is the highest, a voltage occurs in Vx, and RGB produces a green light. When V_Middle is the highest, a voltage occurs in Vy, and RGB produces a blue light. When V_Right is the highest, a voltage occurs in Vz, and RGB produces a green light, but it is less intense then the first case because the resistance value is higher than the first case. In this part, in order not to affect the control unit by withdrawing some current from it, buffers are used so that the current will be withdrawn from the buffers.

## E) SECOND LIGHT EMITTER UNIT

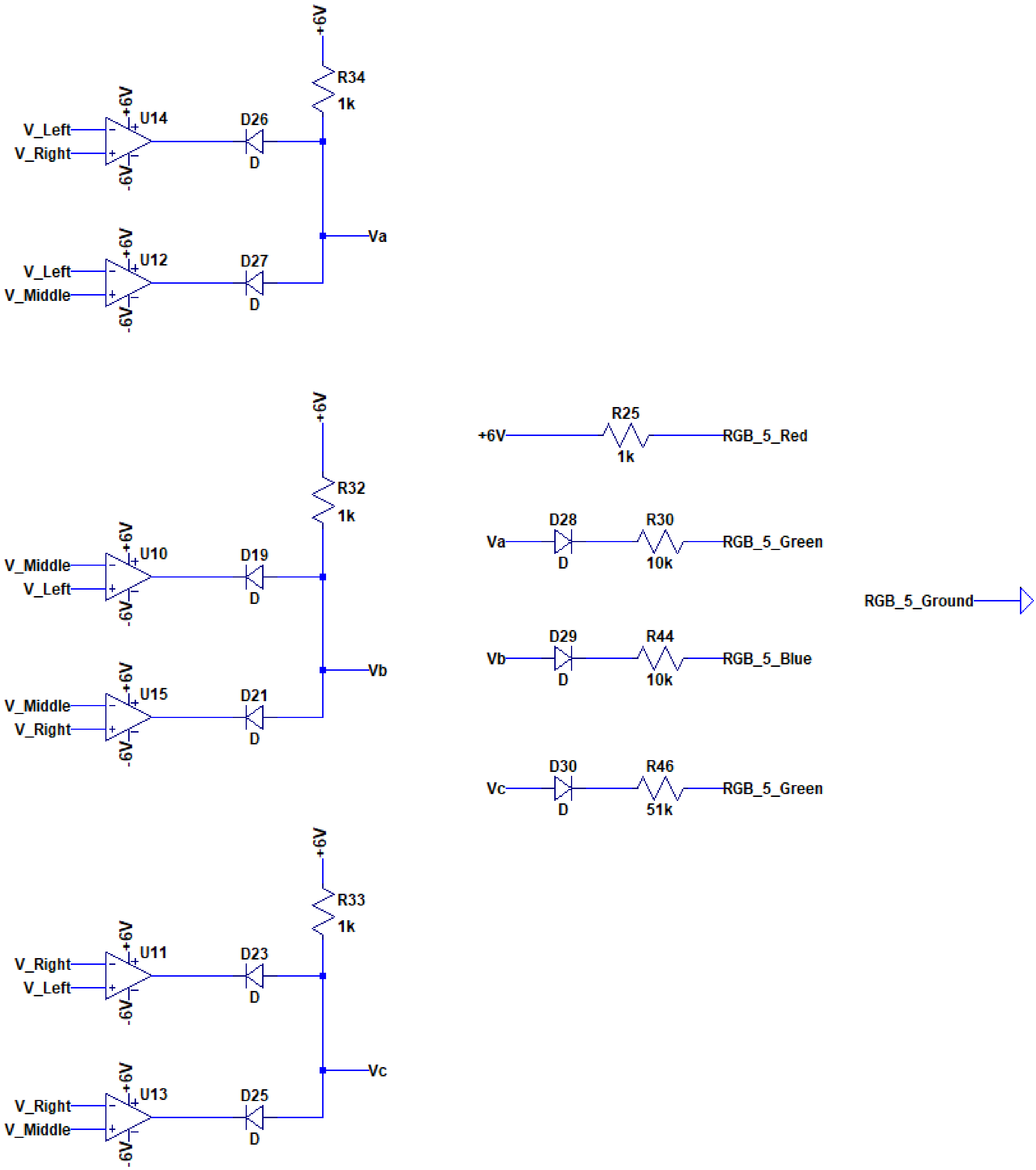


Figure 6: The circuit schematic of the second light emitter unit

In the second light emitter unit, to show the lowest intensity direction, another RGB is used. The objective is to emit a yellow color, that is red color plus green color when V_Left is the lowest, emit a purple color, that is red color plus blue color when V_Middle is the lowest, and emit an orange color, that is red color plus green color when V_Right is the lowest. Because a common cathode RGB is used in this part, the red node of the RGB is directly connected to the +6V as can be seen from the schematic (Figure 6) because it lights in all three cases. The first operational amplifier gives +6V if V_Left is less than V_Middle, and the second operational amplifier gives +6V if V_Left is less than V_Right. If both are +6V, Va will be +6V. However, if even one of them is -6V, the current will pass from +6V to -6V, and Va will be -6V. Therefore, among Va, Vb and Vc, only one of them will be +6V, and the others will be -6V. If Va is +6V, a green color will be produced, mixed with red, and produce a yellow color. If Vb is +6V, a blue color will be produced, mixed with red, and produce a purple color. If Va is +6V, a green color will be produced, mixed with red, but produce an orange color because the resistance value is higher. The operational amplifiers used in this part are the same ones as used in the control unit, so no extra op-amps were used for this part of the project. Before implementation, theoretical values of the resistors were calculated from the color tables [2], and then, the exact values were found during implementation by optimization. The other four operational amplifiers do the same thing for the other two voltages. Also, buffers are used to connect Va, Vb and Vc nodes to the RGB nodes to prevent influencing the main part.

## F) PULSE WIDTH MODULATOR UNIT

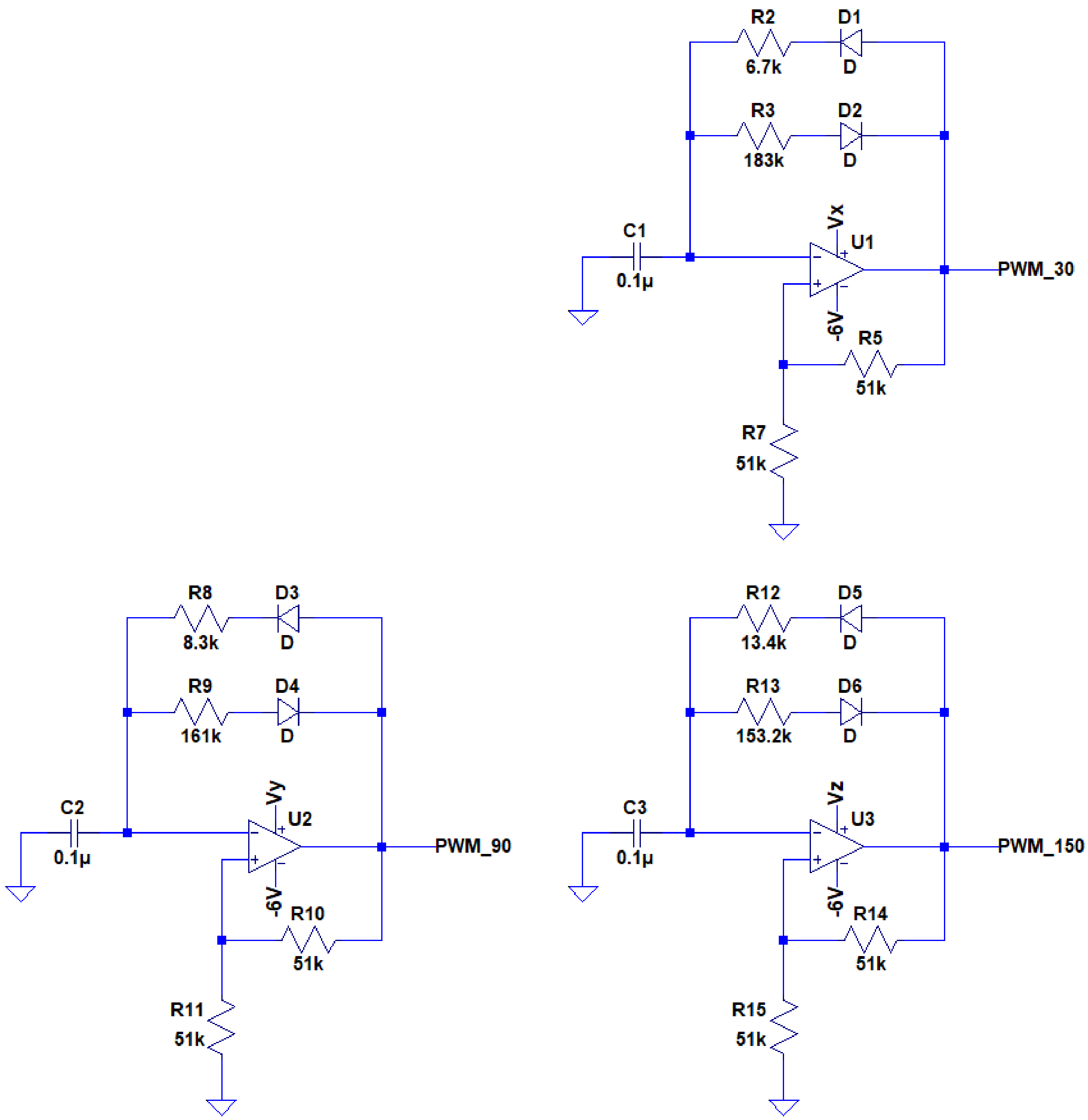


Figure 7: The circuit schematic of the pulse width modulator unit

As can be seen from the schematic (Figure 7), there are 3 square wave generators in this part. Their negative voltage supplies are -6V, and their positive supplies come from the control unit. This way, only one them will produce a square wave between +5V and -6V. The resistance values were calculated theoretically before implementation. However, by rotating the servo motor to the desired angles with the help of the resistors, and afterwards, by equating the total period to 20ms, the experimental values were finalized. The difference between the theoretical and experimental values is because of the voltage differences across the diodes. Vx, Vy and Vz are connected to the positive voltage suppliers of the op-amps with the help of buffers to prevent withdrawing current from the other unit and affecting it. Also, 51k resistors are used instead of 1k resistors to decrease the current withdrawn from the DC sources and to keep low the power dissipated. The simulation results obtained using the resistance values obtained experimentally are as below (Figures 8, 9, 10).

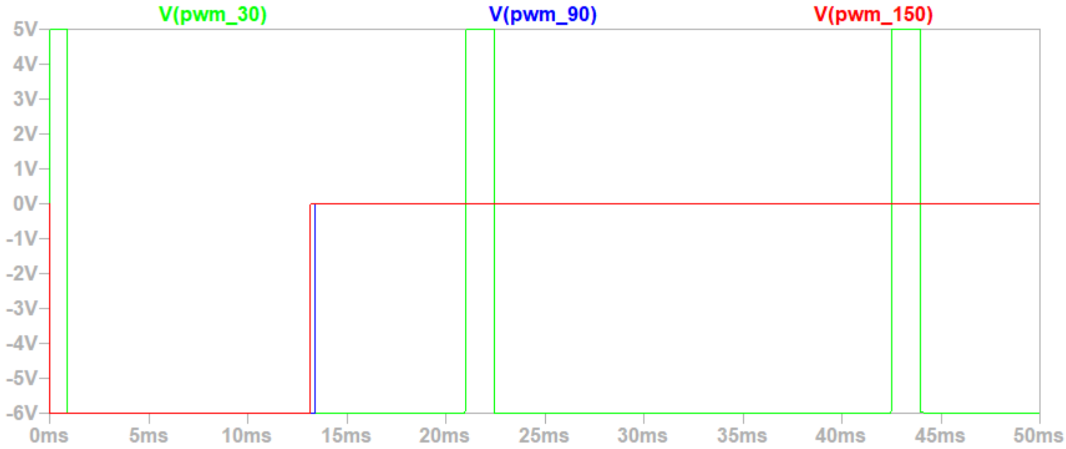


Figure 8: Waveforms of PWM's when Vx=5V, Vy=0V, Vz=0V

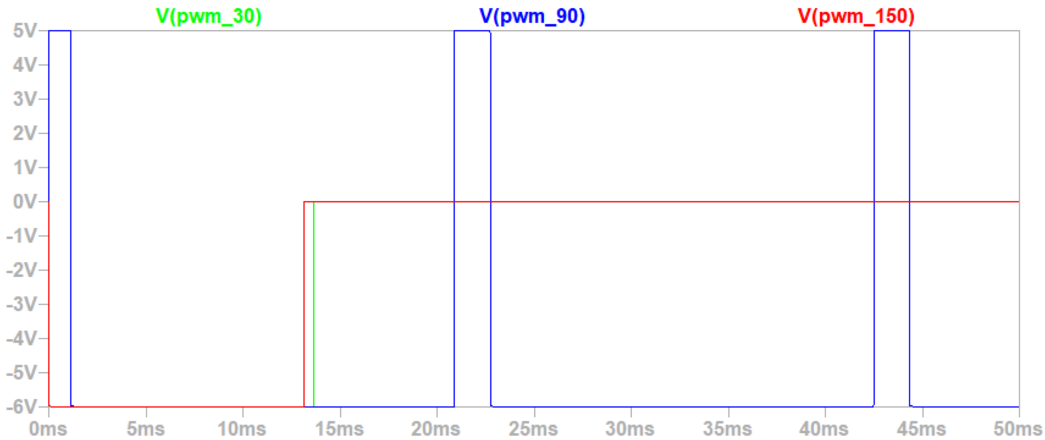


Figure 9: Waveforms of PWM's when Vx=0V, Vy=5V, Vz=0V

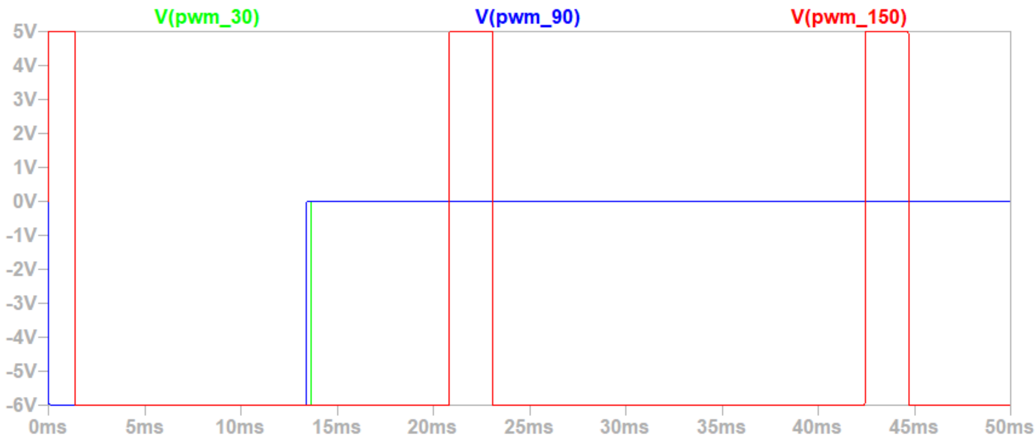


Figure 10: Waveforms of PWM's when Vx=0V, Vy=0V, Vz=5V

### G) ANGLE ADJUSTMENT UNIT

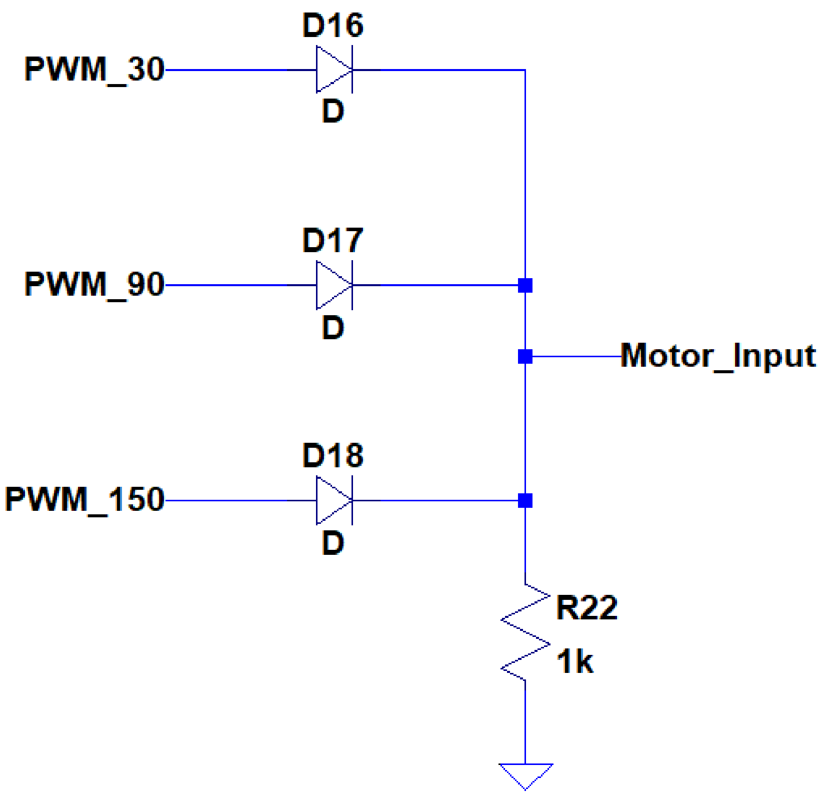


Figure 11: The circuit schematic of the angle adjustment unit

As can be seen from the schematic (Figure 11), this angle adjustment unit connects the outputs of square wave generators to a node with diodes. Because of the diodes, if there is a positive voltage, a current will pass, and Motor_Input voltage will be equal to that positive voltage. If there is a negative voltage, no current will pass, and Motor_Input voltage will be equal to the ground voltage, 0V. As only one the square waves will be between +5V and -6V, only that one will influence the Motor_Input. However, while it is -6V, it will not affect it again, so the obtained voltage will be between +5V and 0V. Finally, the Motor_Input node is connected to the PWM input of the servo motor with the help of a buffer.

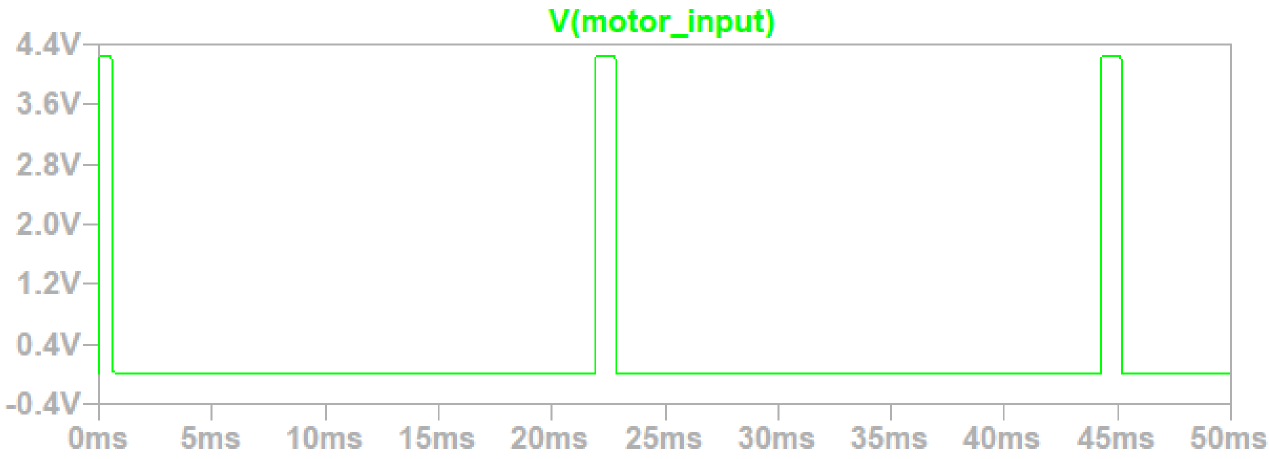


Figure 12: PWM obtained by simulation when light comes from the left

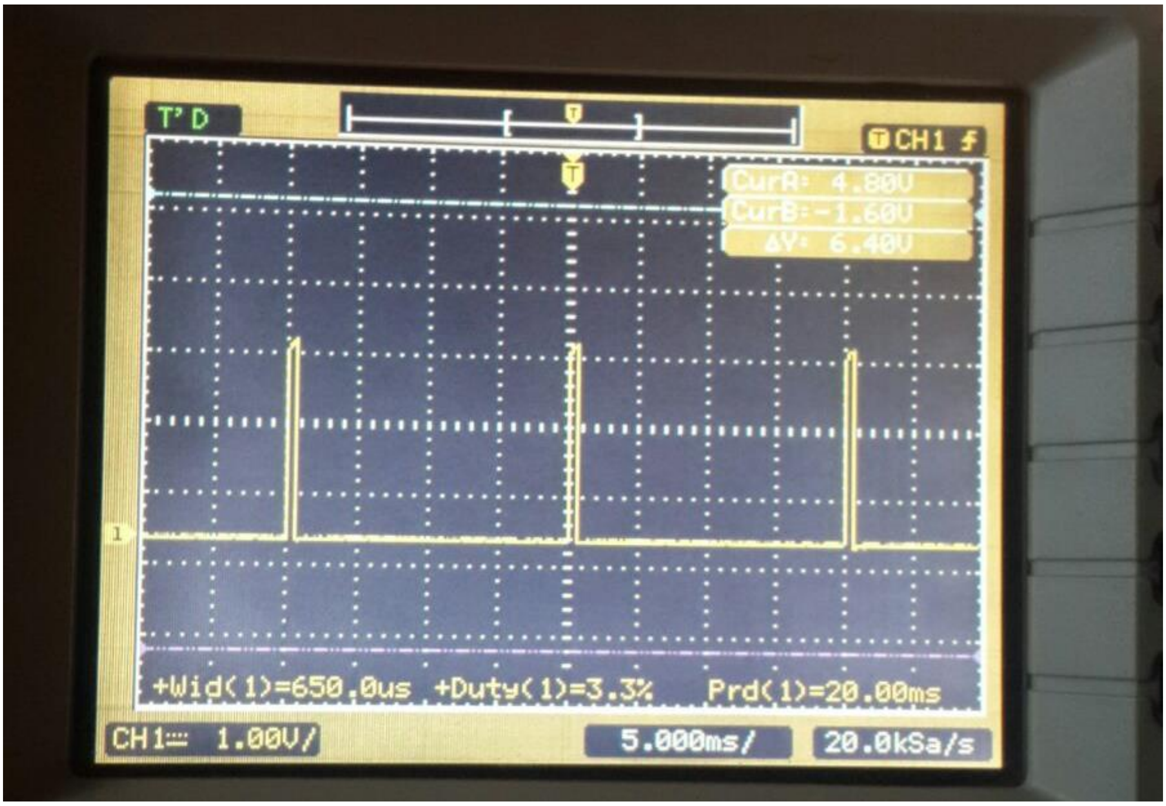


Figure 13: PWM input of the servo motor when light comes from the left

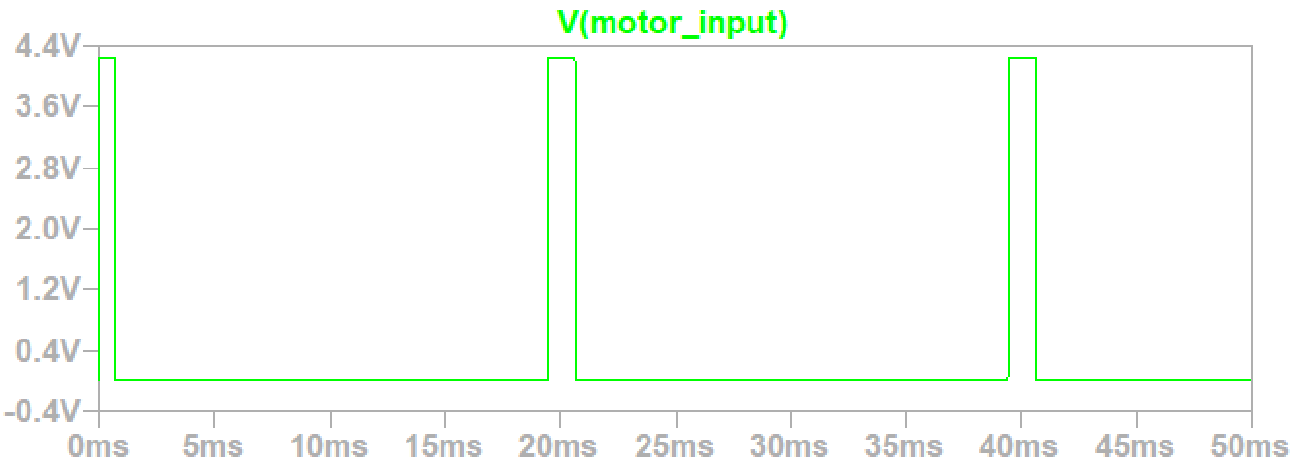

Figure 14: PWM obtained by simulation when light comes from the middle

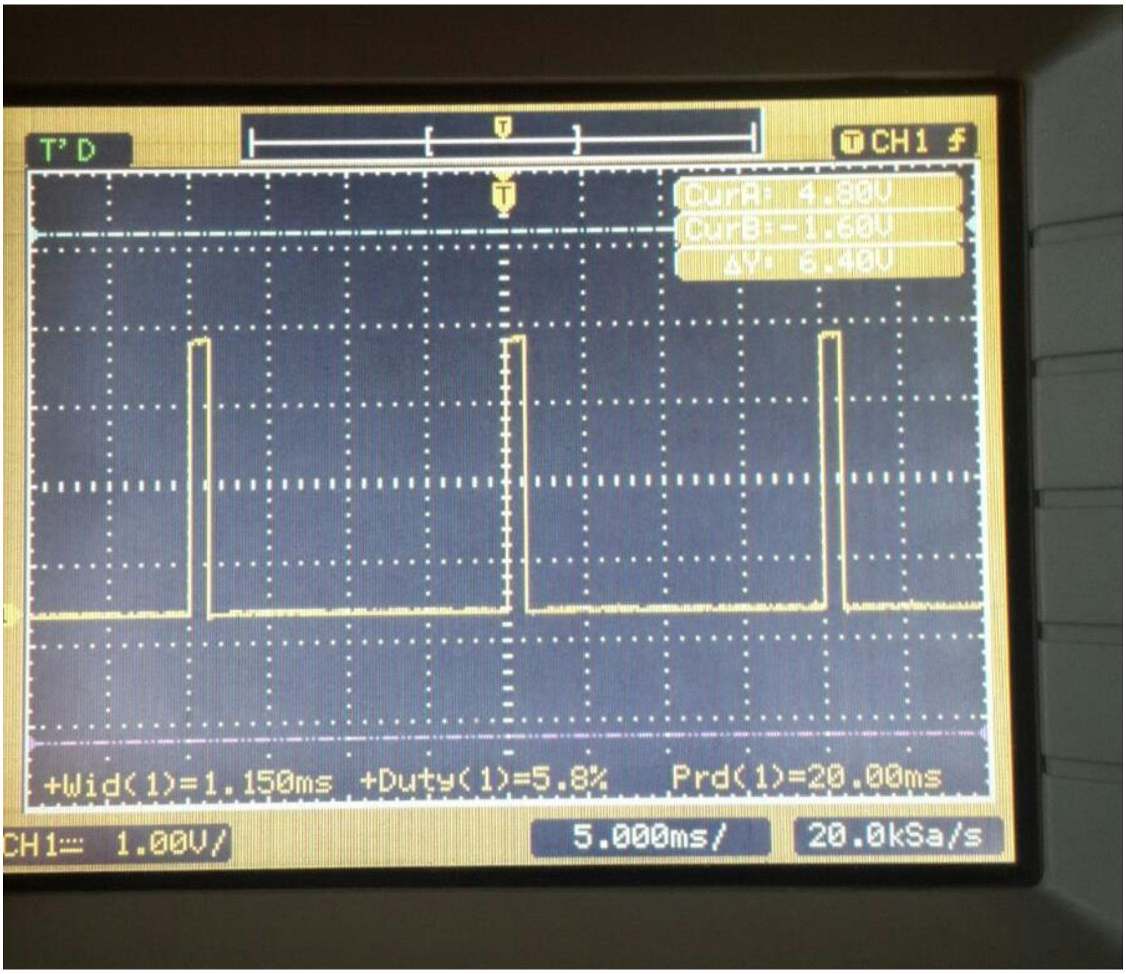

Figure 15: PWM input of the servo motor when light comes from the middle

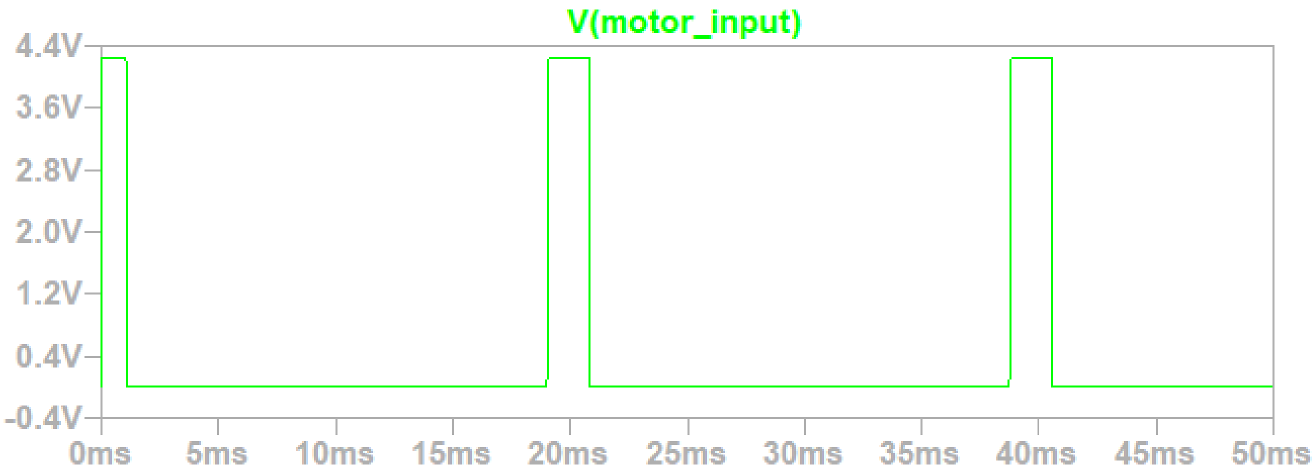

Figure 16: PWM obtained by simulation when light comes from the right

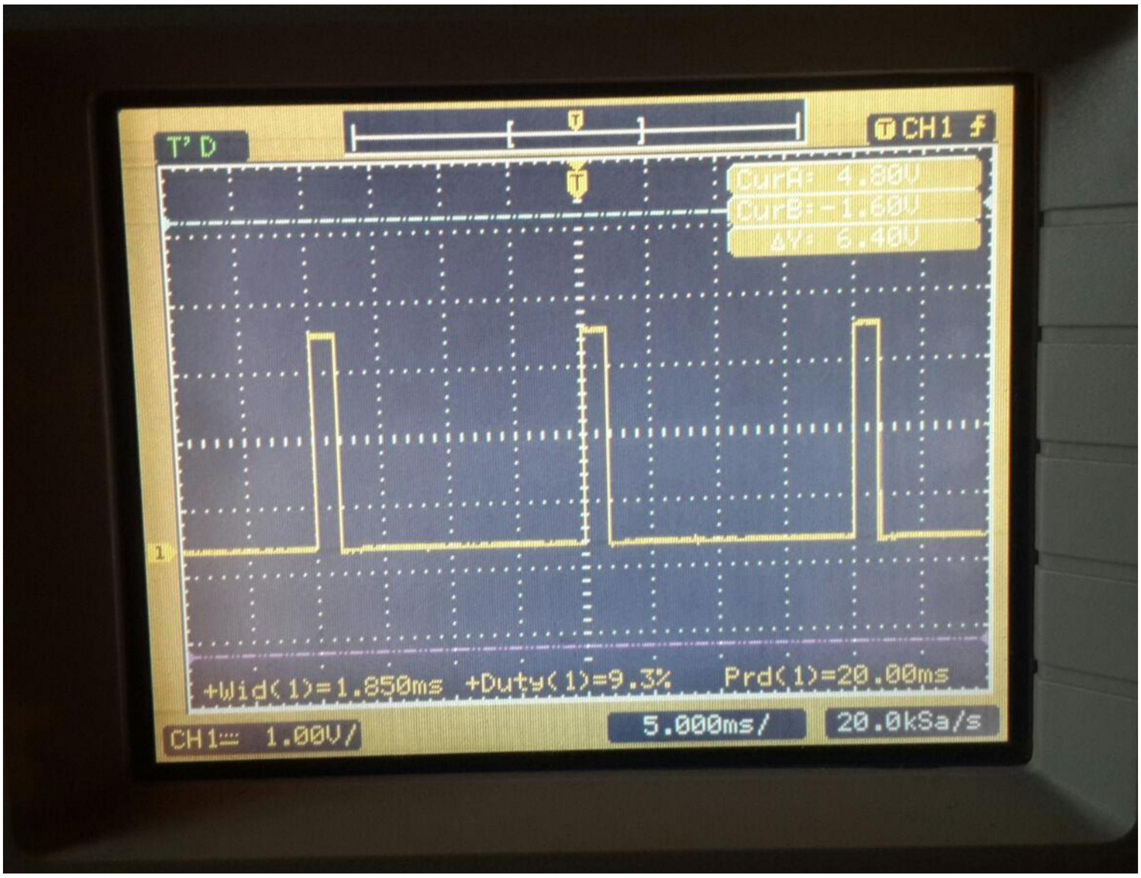

Figure 17: PWM input of the servo motor when light comes from the right

The pictures in Figures 12, 14 and 16 are obtained from the simulation program LTSpice, and the pictures in Figures 13, 15 and 17 are taken from the oscilloscope screen connected to the PWM input of the servo motor. As light comes from different directions, the project successfully generates the necessary square wave to rotate the servo motor to the desired angle. The experimental values were a bit different from the theoretical values given in the datasheet of the SG90 servo motor used in the project [3]. While it writes the period of the pulse width must be between 1ms and 2ms in the datasheet, we had to make it less than 1ms to direct it to the left. Also, as seen from the pictures, the amplitude of the PWM's are only 3V, but it seems it is enough since the servo motor is operating properly.

# 4. OVERALL SCHEMATIC OF THE PROJECT

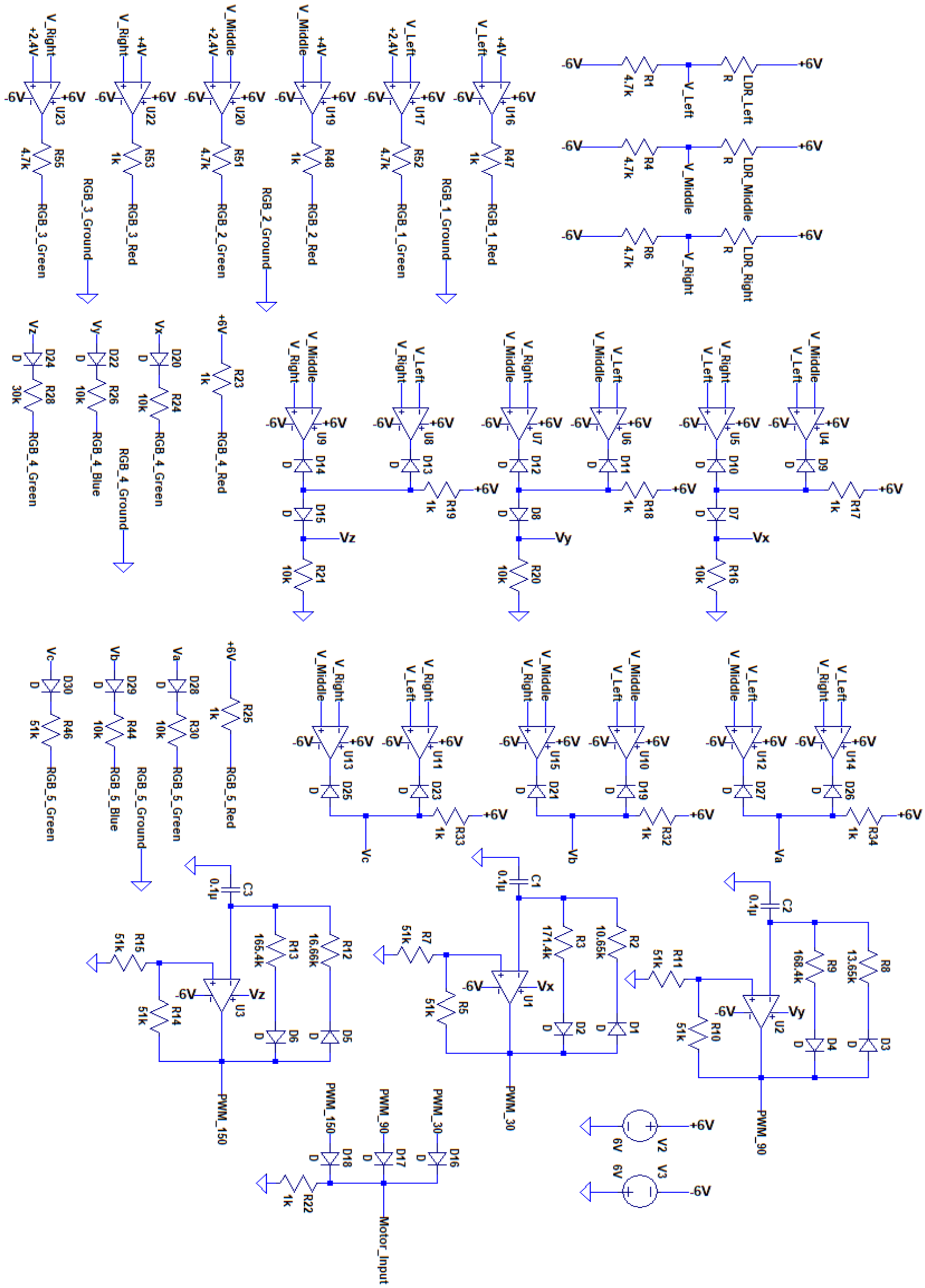


Figure 18: The overall schematic of the project

# 5. POWER ANALYSIS AND BUDGET

The following components are used in the project.

| | |
|---|---|
| - 22 x LM741 | 22 * 0.62 TL = 13.64 TL |
| - 2 x Common Cathode + 3 x Common Anode RGB LED | 5 * 0.70 TL = 3.50 TL |
| - 3 x LDR | 3 * 0.39 TL = 1.17 TL |
| - 27 x Diode | 27 * 0.11 TL = 2.97 TL |
| - 6 x 22K Potentiometer | 6 * 0.58 TL = 3.48 TL |
| - 1 x Servo Motor SG90 | 1 * 7.76 TL = 7.76 TL |
| - 5 x Breadboard | 5 * 6.21 TL = 31.05 TL |
| - 46 x Resistor | 46 * 0.01 TL = 0.46 TL |
| - 3 x 0.1uF Capacitor | 3 * 0.08 TL = 0.24 TL |
| Total | 64.27 TL |

In our project, +/- 6V DC source is used, and the currents withdrawn from the source are 55mA and 45mA while the motor is in static state. While the motor is rotating, while it is in dynamic state, the currents withdrawn are approximately 300mA and 45mA. The current withdrawn from the negative DC source does not change because the motor works only with the positive DC source. Therefore, the power dissipated in static state is calculated as follows:

$$P = V * I \tag{1}$$

$$P = 6V * (55mA + 45mA) = 6V * 0.1A = 0.6\ W \tag{2}$$

The power dissipated in dynamic state is calculated as follows:

$$P = 6V * (300mA + 45mA) = 6V * 0.345A = 2.07\ W \tag{3}$$

## 6. CONCLUSION

Most of the parts of the project worked as it did in the simulation, but there were just small voltage differences. However, it did not have an effect on the working of the project as our servo motor could tolerate these minor differences. Also, we learned that there can be some differences between theory and the application. For example, while preparing square waves, we used different values of resistances than we calculated in theory, so testing each part on its own and using it later is very important because it can cause a disorder otherwise. Another thing we learned is that there were deviations in application from the values in the datasheet of the servo motor. Also, knowing when to use some circuit elements also gives some advantage. For example, in our project, in some parts, we used common cathode RGB's in some parts, and used common anode RGB's in some parts. This gave us the advantage of using circuit design which is easier, and which wants less elements instead of arranging the voltage values according to the kind of the RGB.

While arranging the circuit on the breadboard, we learned that planning before putting the elements on the breadboard is very important because as some other parts are included, the overall circuit gets messy, and because of large number of jumpers, all things seem too complicated. To prevent this, at first, we planned where to put different parts of the project so that as we progressed, we could maintain our neatness, and everything could seem more organized.

To conclude, this project was a good way of putting our theoretical knowledge to practical application. We gained many experiences related to designing, updating when necessary, and testing the system we planned and implemented on our own. Therefore, this project was helpful in a sense that we will perform more effectively and wisely in our future practices.

## 7. REFERENCES


[1] TriColor RED GREEN BLUE LED [Online]. Available:
https://courses.cs.washington.edu/courses/csep567/10wi/labs/TriColorRGBLED.pdf

[2] RGB Color Codes Chart [Online]. Available:
https://www.rapidtables.com/web/color/RGB_Color.html

[3] SG90 9 g Micro Servo [Online]. Available:
http://www.micropik.com/PDF/SG90Servo.pdf