Middle East Technical University

EE213
ELECTRICAL CIRCUITS LABORATORY

Term Project

Final Report

Solar Tracking System

Authors:

- Yunus ÇAY
- Rafet KAVAK

Assistant:
Göktuğ Cihan Özmen

SUBMISSION DATE
12 January 2018

1 Introduction

Before invented first machines by fuel, The Earth has never polluted due to any kind of energy source except fuel powered ones. Also, because of increase in need of energy, fossil fuel energy costs more. Thus, transforming and capturing solar energy into electricity has been standing as hot topic since 1960's.

Solar energy is clean and renewable energy source. In addition, energy can be easily gained by solar panels with low cost. Because of the advantages of solar energy compared to other sources, researches are developing day by day. One of the most important topic, researches condensed, is efficieny of solar panels.

Sun's position is changing continuously during the day and also seasonal changes affect the sun position. Efficieny of fixed solar panels is low, solar energy cannot be gained effectively by these solar panels. This effectivity problem is solved by adjusting solar panels to sun. Systems achieve to solve this problem are called sun-tracking systems and they have two kinds: single-axis tracking system and dual-axis tracking system. While single-axis sun tracking system can respond to only daily sun position changes or east to west, dual-axis sun tracking system can also respond the seasonal changes.

Both single-axis and dual-axis sun tracking system provide solar panel with incident light at right angles. "A solar collector or photo-voltaic module receives the maximum solar-radiation when the Sun's rays strike it at right angles. Thus efficieny is increased considerably by sun tracking systems.

1.1 Brief Task Identification

Project task is to design and realize single-axis sun tracking system. These sun-tracking system according to light intensity adjust solar panel to suitable one of the three direction. These directions are specifically determined: 30°, 90° and 150° , they are corresponding to evening, noon and morning. Also the direction must be indicated by RGB led.

2 Block Diagram

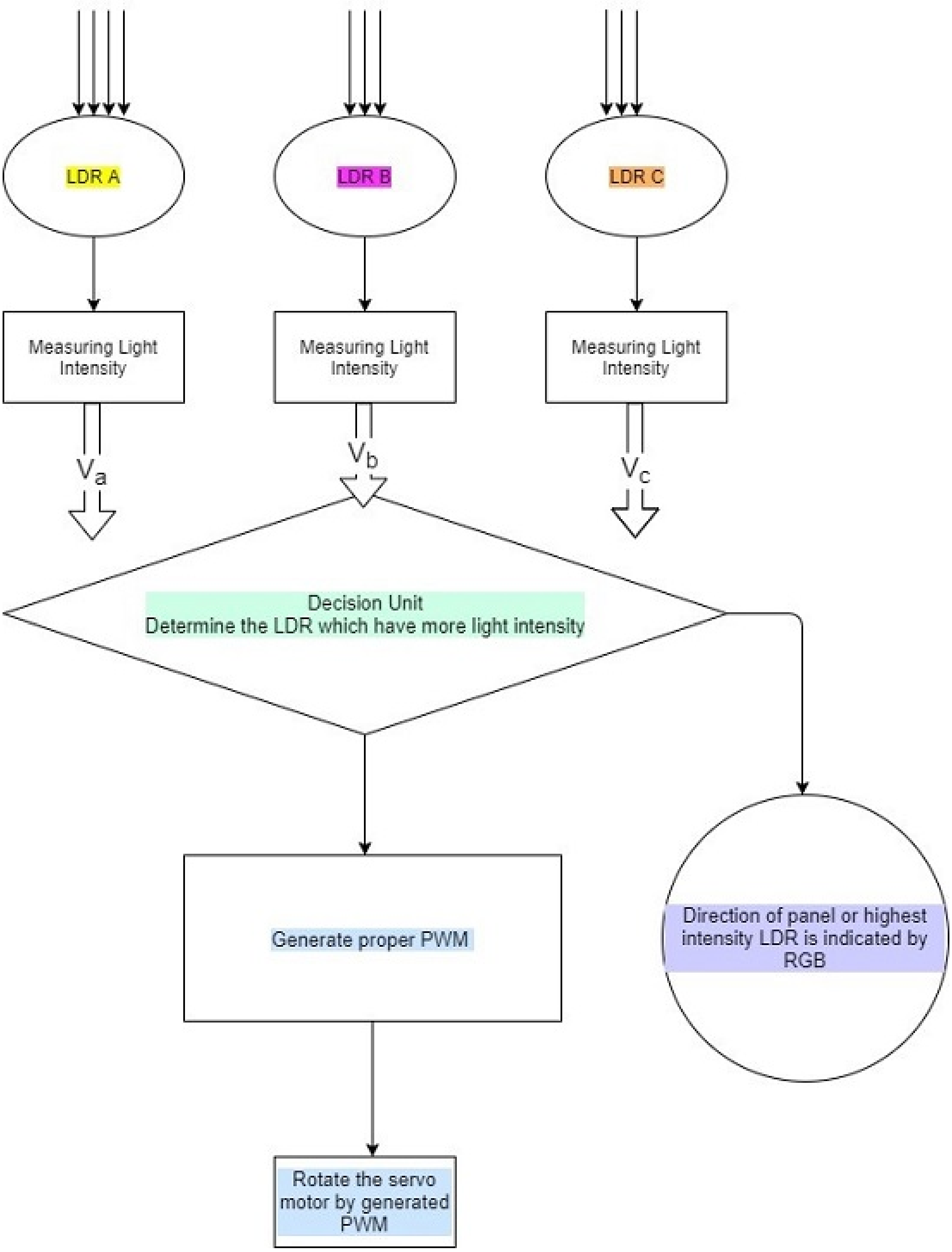


Figure 1: Working principle of realized single-axis sun tracking system is showned by flowchart

3 Selection of Equipment

3.1 LDRs

We have used LDRs to measure intensity of the light from three perspectives and we constructed the beginning of our circuit with LDRs to divide voltage relatively. Moreover, we are planning to construct LDRs fixed positions to measure light intensity.

3.2 Operational Amplifiers

We used

- Differential Amplifiers
- Non-inverting Operational Amplifiers
- Buffers
- Comparators
- Inverting Operational Amplifiers
- Summing Amplifiers

First, op-amps are the most important building block of our circuit. From beginning to end, while comparing, summing and inverting etc., we preferred use op-amps instead of transistors, switches and other components which are unfamiliar to us. Furthermore, we used op-amps to produce square waves with certain duty cycles.

3.3 Resistors

We used resistor to control our circuit. In generally, we used 1kohm resistor because it makes it easy calculating the outputs of op-amps.

3.4 Capacitors

We used capacitors for making square wave generator and we choose suitable resistor according to our capacitor to get proper period and duty cycle.

3.5 Diodes

We used diodes for controlling current in some cases. We had three different ways to RGB led and we had to control these ways to get yellow, purple, orange light respectively.

3.6 Ground Connections

We connected some of our circuit elements to ground because if we did not connect these components to ground our circuit does not work. Ground connection arranges the voltage differences of our circuit.

3.7 DC Power Supply

Dc power supply is the power source of our circuit and we distribute this source all-around of the circuit.

3.8 RGB Led

RGB led is the indicator of our circuit. With respect to intensity of light, our led is emits suitable light to correspond the determined light color.

4 Description of Circuit

System is observed and analysed part by part with actual values. These parts are sensing unit, control unit and angle adjustment unit.

Single-axis sun tracking sytem is designed and realized with some improvements for the design prepared for pre-report. Improvements are done on decision sub-unit and function sub-unit.

4.1 Sensing Unit

Every system must take input to give output. In this solar tracking system, incident light intensity can be input of the system and output can be turning direction of solar panel and colour of RGB led.

Sensing unit is responsible from input of system and taking input to system is provided by LDRs, stands for light dependent resistor.

As seen on the Figure 2 and based on our experiments, increase in the light intensity diminish the resistance of LDR. Behaviour of LDR is the original input of the system.

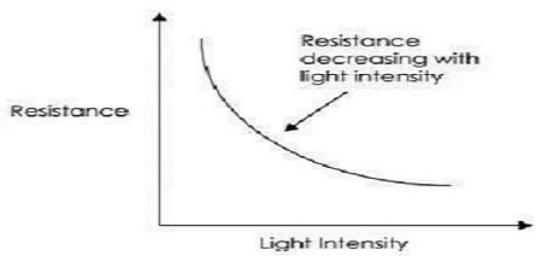


Figure 2: Change in resistance of LDR with varying light intensity

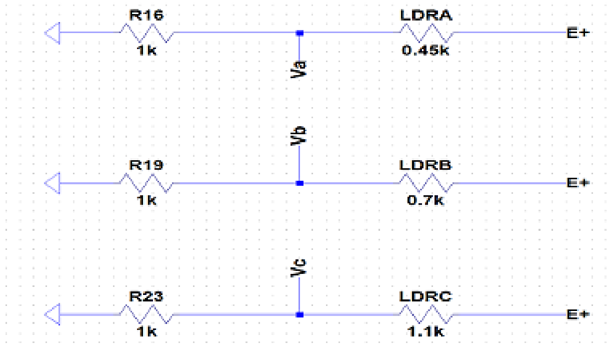


Figure 3: Voltage divider

$$V = IR \tag{1}$$

In the Figure 3, input transforming the voltage by voltage divider. If LDR have less resistance or highest light intensity, based on Ohm's Law (1) V_{out} (V_a, V_b, V_c) is the greatest.

$$V_{out} = (\frac{V_{in}}{R + LDR})R \tag{2}$$

Equation (2) is used to calculate $V_{out}(V_a, V_b, V_c)$ and LDR values are determined approximately. LDRA is flashed very closely, LDR B is not flashed as same as LDRA but flashed not so closely. Finally, LDR C is not flashed. In this case, V_{out} can be maximum 9 V approximately and minumum 5 V nearly.

4.2 Control Unit

The control unit consists of two sub-unit. These are a decision and a function sub-units.

Decision unit compares the inputs or voltage values of each LDR and determine the highest value as output. Some enhancements is done on the decision unit and these enhancements make the system more stable.

Function unit indicate direction by RGB and generates square wave according to output of the decision unit.

4.2.1 Decision Sub-unit

Decision unit resembles logic system. These system make a comparison between the inputs of sensing unit by arithmetic operations with the help of *operational amplifiers*.

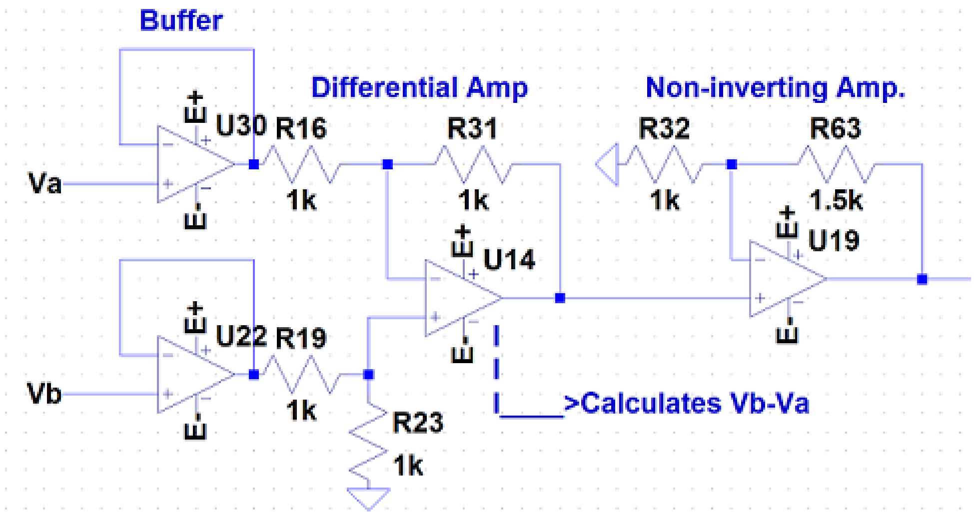


Figure 4: Comparison for the V_a and V_b

In the Figure 4, firstly buffer is used to apply operations on the input (V_a, V_b) without effect on them.

$$V_{out} = -V_a(\frac{R_{31}}{R_{16}}) + V_b(\frac{R_{19}}{R_{19} + R_{23}})(\frac{R_{16} + R_{31}}{R_{16}}) \qquad (3)$$

According to equation (3) V_{out} of differential amplifier equals V_b–V_a can be maximum approximately 3V theoritically. Also, it is possible that V_a is greater one. Then V_{out} becomes negative.

$$V_{out} = (1 + \frac{R_{63}}{R_{32}})(V_b - V_a) \qquad (4)$$

As stated in equation (4) $R_{63} = 1.5\text{k}\ \Omega$, $R_{32} = 1\text{k}\ \Omega$, V_out equals 2.5 times of V_b–V_a. Thus maximus output value of non-inverting amplifer is about 7.5 V. Differential amplifier is reason for why non-inverting amplifier is used. Which the signal is low due to differential amplifier is increased by non-inverting amplifier.

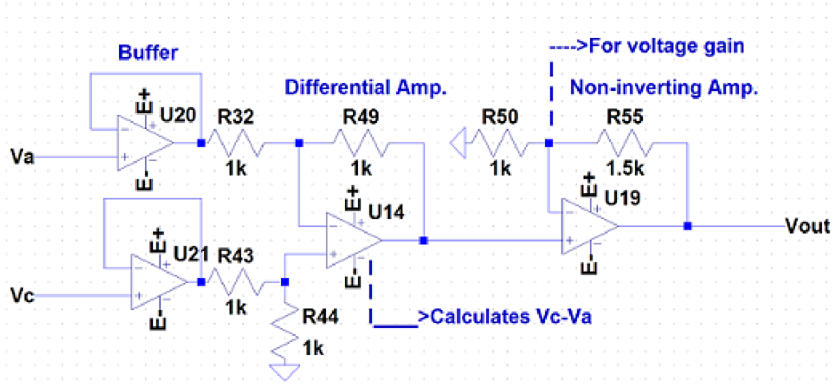


Figure 5: Comparison for the V_a and V_c

Figure 5 and Figure 4 are different from each other by inputs. Thus, exactly same formulas and arithmetic operations are used for V_a and V_c as used for V_a and V_b. Then V_{out} equals V_c–V_a. Also, there is a possibility of negative V_{out}.

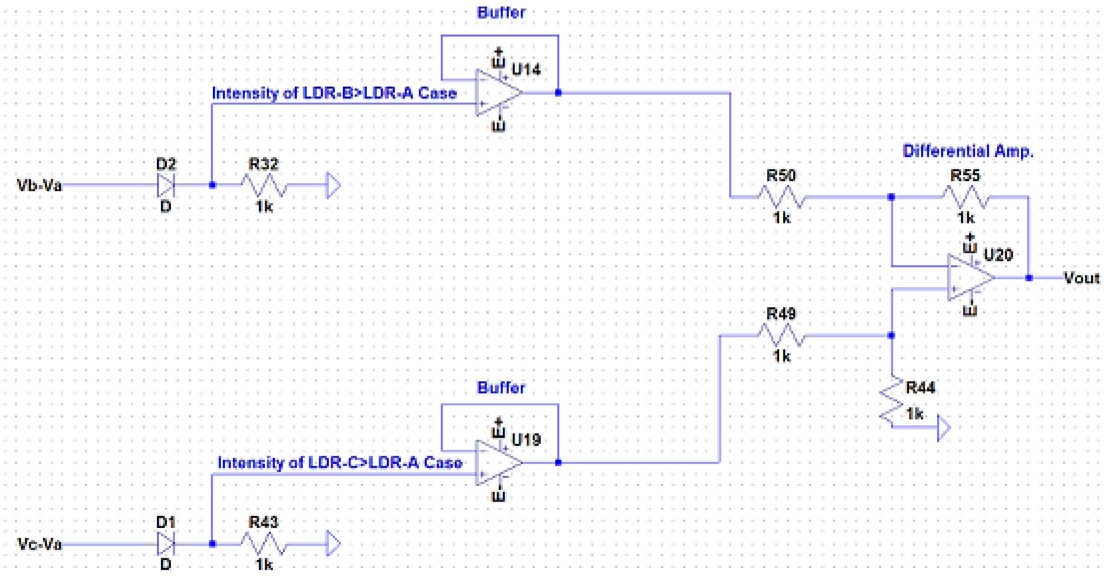


Figure 6: Taking only informations of case: $V_b, V_c > V_a$ and Comparison of V_b and V_c

Although V_{out} of differential amplifers are negative when V_a is greater than V_b and V_c, the possibility of V_a is the highest and medium value is ignored. That is, the cases V_a is the lowest are analyzed for now.

In the Figure 6, since V_b–V_a and V_c–V_a are positive, the diodes "D2" and "D1" allow current to pass. Then, the information are sended to inputs of differential amplifier through the buffers and V_{out} becomes $(V_c–V_a) - (V_b–V_a)$ based on the Eq. (3).

$(V_c–V_a) - (V_b–V_a)$ is equivalent to V_c–V_b. As expected, the comparison between V_c and V_b is completed with the help of diodes.

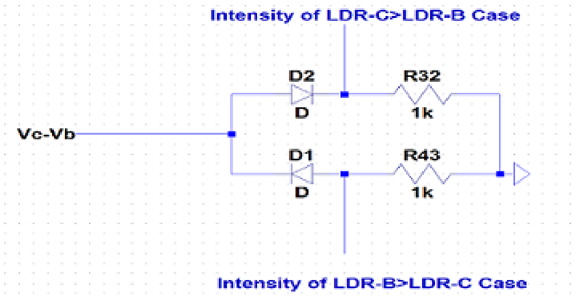


Figure 7: Comparison for the V_b and V_c

In the Figure 7, because of the differential amplifier, V_c–V_b could be either positive or negative. When V_c–V_b is positive, while any current flow occurs through "D1", diode "D2" allows current to pass. If V_c–V_b is negative , diode "D1" provide the current flow through below part.

Actually we construct a logic gate by diodes and $V_c > V_b > V_a$ and $V_b > V_c > V_a$ are satisfied.

The two cases $V_c > V_b > V_a$ and $V_b > V_c > V_a$ are analyzed and now, the cases that V_a is the medium value will be analyzed.

As stated before, in the Figure 4 and 5, V_{out} of differential amplifiers equals V_b–V_a and V_c–V_a. If V_a is the medium value, one of the outputs becomes negative and one of the diodes does not allow current to pass in the Figure 6. Therefore, one of the inputs of differential amplifer becomes 0V.

Assuming may facilitate to understand at the point of the analysing. Assume $V_c > V_a > V_b$;
Since $V_a > V_b$, inverting input of differential amplifier becomes 0V due to diode "D2" in the Figure 6. While inverting input of differential amplifier 0V, non-inverting input has positive voltage which result in that differential amplifier gives positive V_{out}. Thus, logic gate provides above part with current flow in the Figure 7. The case $V_c > V_a > V_b$ is satisfied.

Assume $V_b > V_a > V_c$;
Now, non-inverting input of the differential amplifer becomes 0V while inverting input has positive voltage. Then, differential amplifier gives negative V_{out}. Only diode "D1" allows current to pass. Therefore, information or positive voltage is sended to part which are activated when Vb is highest. The case $V_b > V_a > V_c$ is satisfied.

Only two cases out of the six case are not analyzed. These cases are that V_a is the highest. There will be no need to separation between two cases.

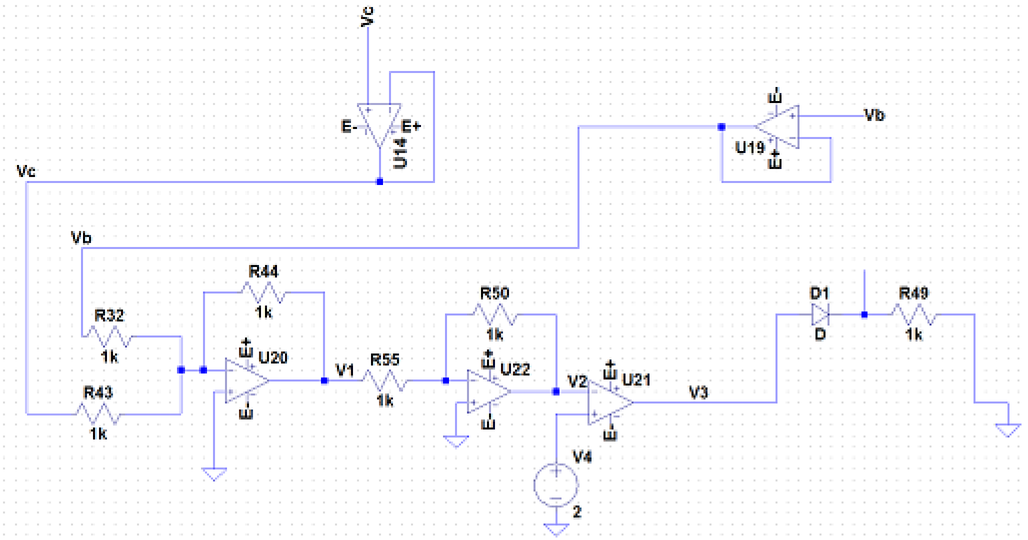


Figure 8: The circuit diagram determine whether V_a is highest or not.

In the Figure 8, the voltage information are taking from nodes which V_b and V_c are highest and these voltage values are summed by summing amplifier based on Eq. (5)

$$V_1 = -(V_b + V_c)\frac{R_{44}}{1kW} \tag{5}$$

Then V_1 is inverted with inverting amplifier because summing amplifier make an input anti-phase with an output. V_2 is the inverted form of V_1.

After inverting amplifier, comparator is used. This comparator "U21" compares the 2V and output of the summing amplifier. The comparator works in positive saturation mode when 2V is greater than V2 and "D1" allows current to pass only when the comparator "U21" works in positive saturation mode.

As proved above, if V_b or V_c have positive voltage, the comparator works in negative saturation mode in the Figure 8. Then "D1" pass any current to parts which are activated when V_a is the highest value.

Also, there is a very important point in usage of difference amplifier in Figure 6. Theoratically comparator can be used instead of difference amplifier. However, application may not give proper results as expected. The reason why the comparator is not used instead of difference amplifier is that the comparator works in linear mode when V_a is highest. The comparator works in linear mode since both of the inputs become nearly 0V. Thus, V_{out} varies between -12V and 12V, which cause sending information to V_b and V_c nodes while V_a is the greatest. Output of difference amplifier is approximately zero when both of the input is 0V, 0V cannot break V_{on} values of diodes. Therefore, no information is sended to Vb and Vc nodes while Va is the highest input.

4.2.2 Function Sub-unit

Function sub-unit indicates the direction by using RGB led and generates square wave for each case. We can say that the input of the function sub-unit is output of the decision sub-unit and output of the function sub-unit is RGB color and square wave with proper duty cyle.

Table 1: Colour of RGB according to information of decision unit

Highest Voltage	Red	Green	Blue	Net Colour
V_a		*	*	Yellow
V_b	*		*	Purple
V_c	**	*		Orange

According to result of comparison in decision sub-unit, RGB led colors changes and these colors are showned in the Table 1.

After current pass through the suitable branches of RGB, current goes through the square wave generators.

There are 3 square wave generators and each of them generates square wave with proper duty cycle. According to information coming from decision sub-unit, just suitable square wave generator is activated and generated square wave is sended to angle adjustment unit.

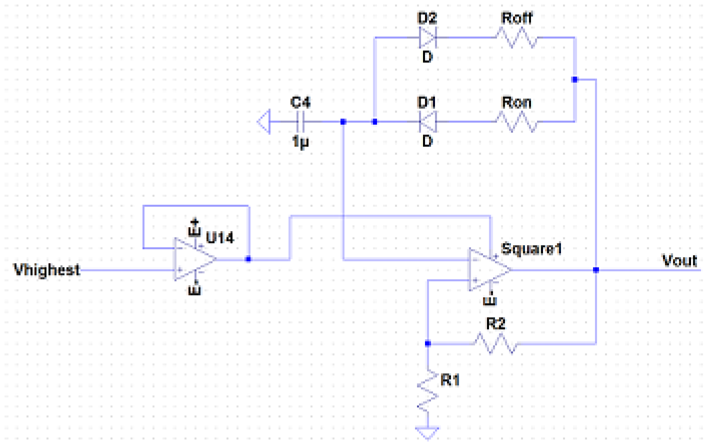


Figure 9: Square wave generator of Function unit.

In the Figure 9, activation of square wave generator and producing square wave generator with different duty cycles are expressed. Then, each square wave generator is analyzed with theoric and real values.

As shown in the Figure 9, V_{cc+} of op-amp is connected to nodes which V_a, V_b, V_c are the highest.

The op-amp in the Figure 9 behaves like comparator. R1 and R2 construct voltage divider and non-inverting input is calculated by the Eq. (6)

$$V_{noninverting} = (\frac{V_{out}}{R1 + R2})R1 \tag{6}$$

Inverting input voltage equals to voltage of capacitor and comparator works positive saturation mode or negative saturation mode depending on input values. Because V_{out} can take only 2 constant voltage values,square wave is generated with different duty cycles by R_{on} and R_{off}. That is, in the Figure 9 , square wave generator determines the period of wave based on Formula 6. Diodes with R_{on} and R_{off} resistors are used for adjusting V_{on} and V_{off} times of square wave.

$$T = RC\ln(\frac{1+\lambda}{1-\lambda}) \tag{7}$$

Where;

$$\lambda = \frac{R1}{R1 + R2} \tag{8}$$

In eq. (8) , since R1 and R2 are chosen equal, becomes $\frac{1}{2}$. Moreover, capacitor is chosen as 1 µF. Eq. (7) is transforming to Eq. (9).

$$T = R * \ln(3) * 10^{-6} \tag{9}$$

Table 2: Datasheet of the Sg90 servomotor.

1ms	0°
1.166667ms	30°
1.5ms	90°
1.8333ms	150°
2ms	180°

In the Table 2, we checked the duty cycles from SG90 servo motor datasheet and we calculated some certain time intervals to manage SG90 servomotor. These T_{on} durations time calculated from given angles in term project documents.

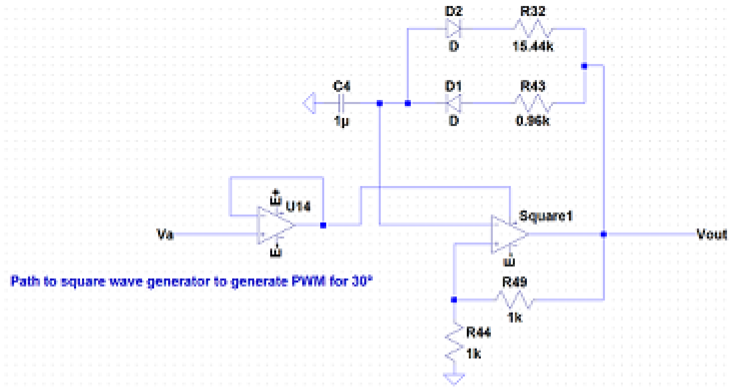


Figure 10: Square wave generator for LDRA.

According to the Table 2, T_{on} value is 1.166667ms for LDR A. To get 1.16667ms duration time, R_{on} for square wave generator "A" should be 1.061 kΩ and R_{off} should be 17.14 kΩ according to Eq. (9). Summing of T_{on} and T_{off} should be 20 ms according to datasheet of the SG90 servomotor. According to these resistor values, duration of square waves exceeds 20 ms by 2.25 ms. To get 20 ms duration, resistor values are calculated again in Eq. (10).

$$\begin{aligned} 1.061 * \frac{100 - 10.1123}{100} &= 0.96kohm \\ 17.17 * \frac{100 - 10.1123}{100} &= 15.4067kohm \end{aligned} \tag{10}$$

$$\frac{2.25}{22.25} * 100 = 10.1123 \tag{11}$$

Eq. (11) is used to calculate percentage of excessed time duration, then according to calculated percentage of excessed time, resistance of resistors are revisited again to get 20 ms in simulation.

- for 90°, from the same calculations, new resistors values are 1.3 kohm and 16.0371 kohm
- for 150°, from the same calculations, new resistors values are 1.5753 kohm and 15.617 kohm

While these resistor values give correct result in theory, different resistor values are required in application. These values are slightly changed but changed. These differences probably result from op-amps and capacitor.

Table 3: Actual Values and target ones

Square Wave	In Theory	In application
For A(30°)	$R_{on} = 0.96$ kΩ $R_{off} = 15.41$ kΩ	$R_{on} = 0.40$ kΩ $R_{off} = 17.15$ kΩ
For B(90°)	$R_{on} = 1.3$ kΩ $R_{off} = 16.04$ kΩ	$R_{on} = 0.86$ kΩ $R_{off} = 16.77$ kΩ
For C(150°)	$R_{on} = 1.58$ kΩ $R_{off} = 15.62$ kΩ	$R_{on} = 18.10$ kΩ $R_{off} = 1.19$ kΩ

Table 3 shows the R_{on} and R_{off} values in theory and application.

4.2.3 Angle Adjustment Unit

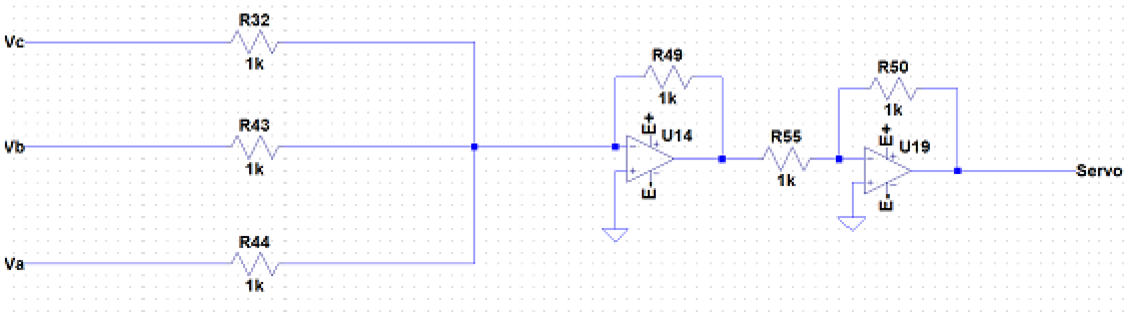


Figure 11: Path of signal to Servomotor from Squarewave generators.

In the Figure 11, the information coming from function sub-unit forward to angle adjustment unit or servomotor by summing amplifier. Because the system is constructed with only one servomotor, these signals are summed. Then, servomotor adjust the solar panel to proper angle according to square wave.

5 Simulation Results

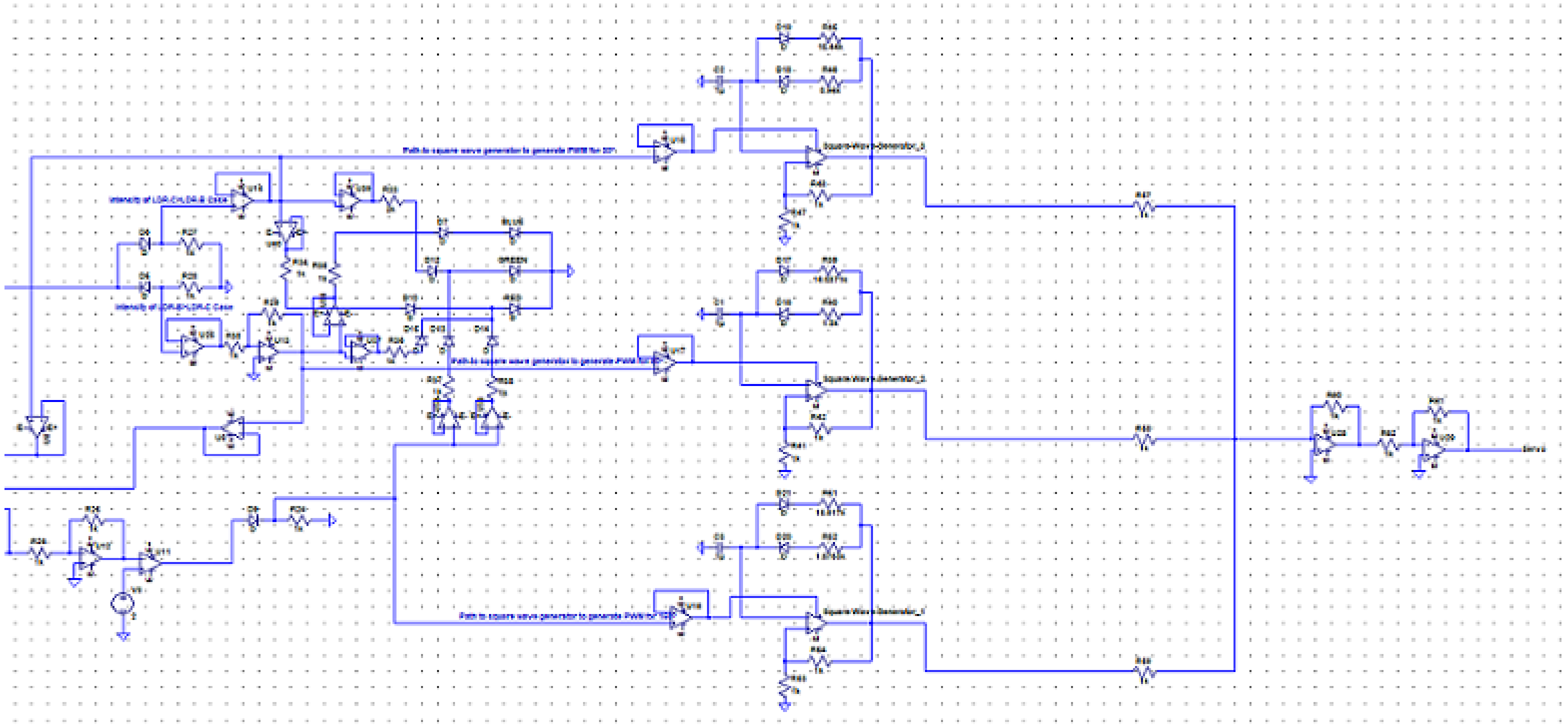


Figure 12:

When $V_a > V_b > V_c$

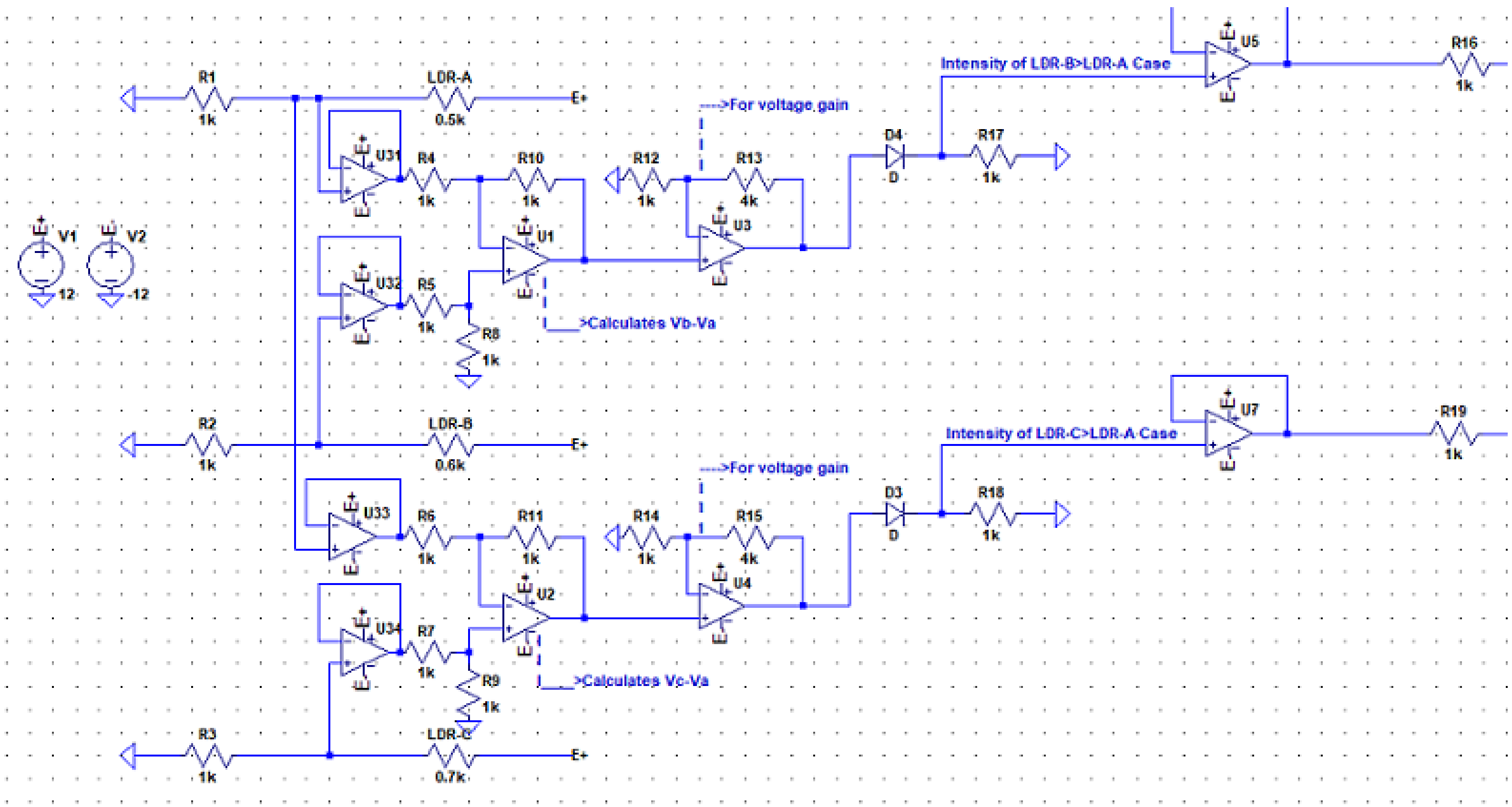


Figure 13: When LDR A takes more intense light than others, while LDR B is following it and LDR C is taking lower intensity light.

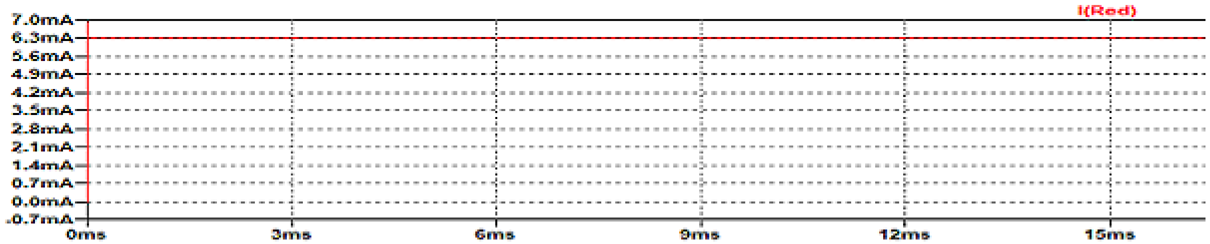


Figure 14: The current which is passing through from red part of RGB.

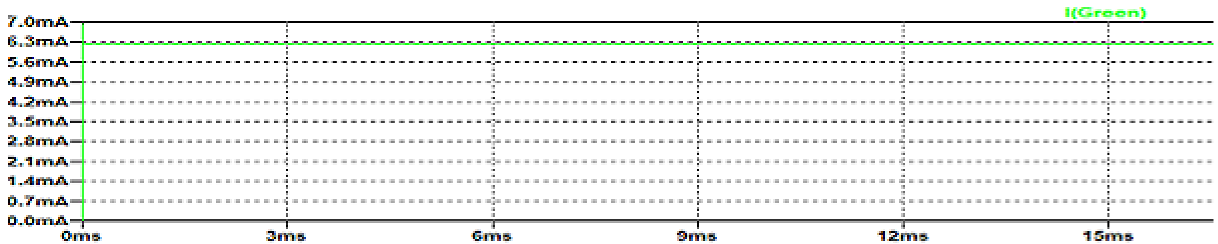


Figure 15: The current which is passing through from green part of RGB.

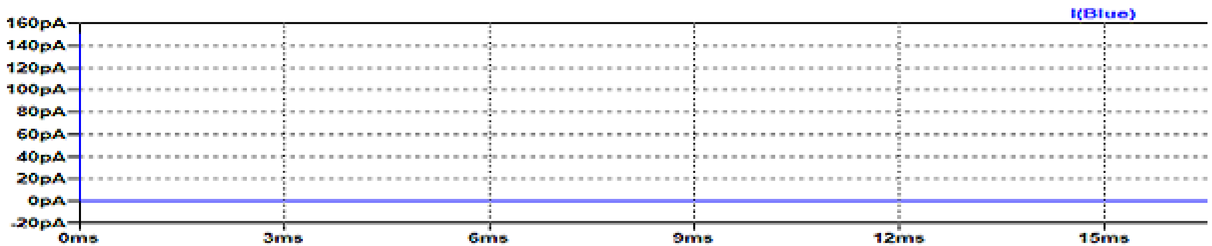


Figure 16: The current which is passing through from blue part of RGB.

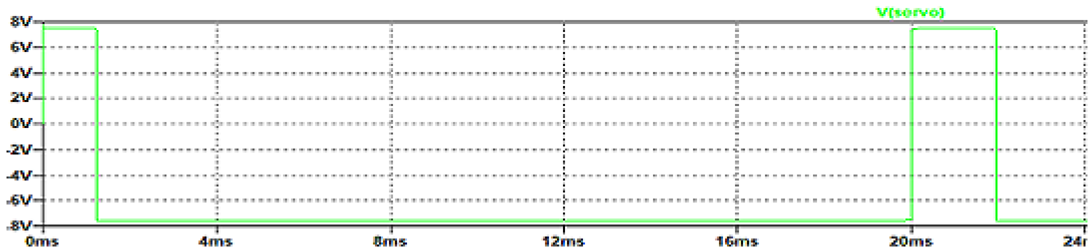


Figure 17: Period and Duty Cycle of wave coming to the servo motor.

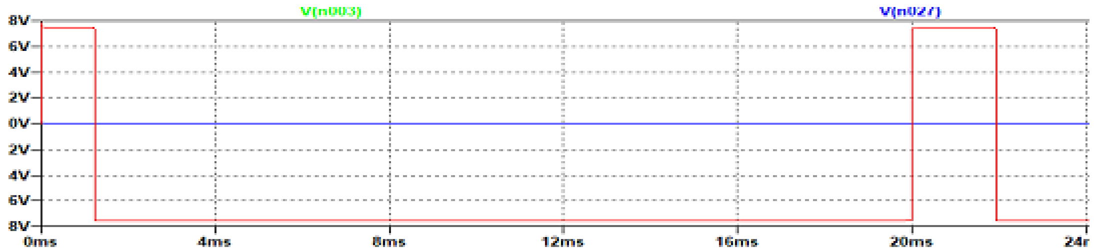


Figure 18: Waveforms of square wave generators.

When $V_a > V_c > V_b$

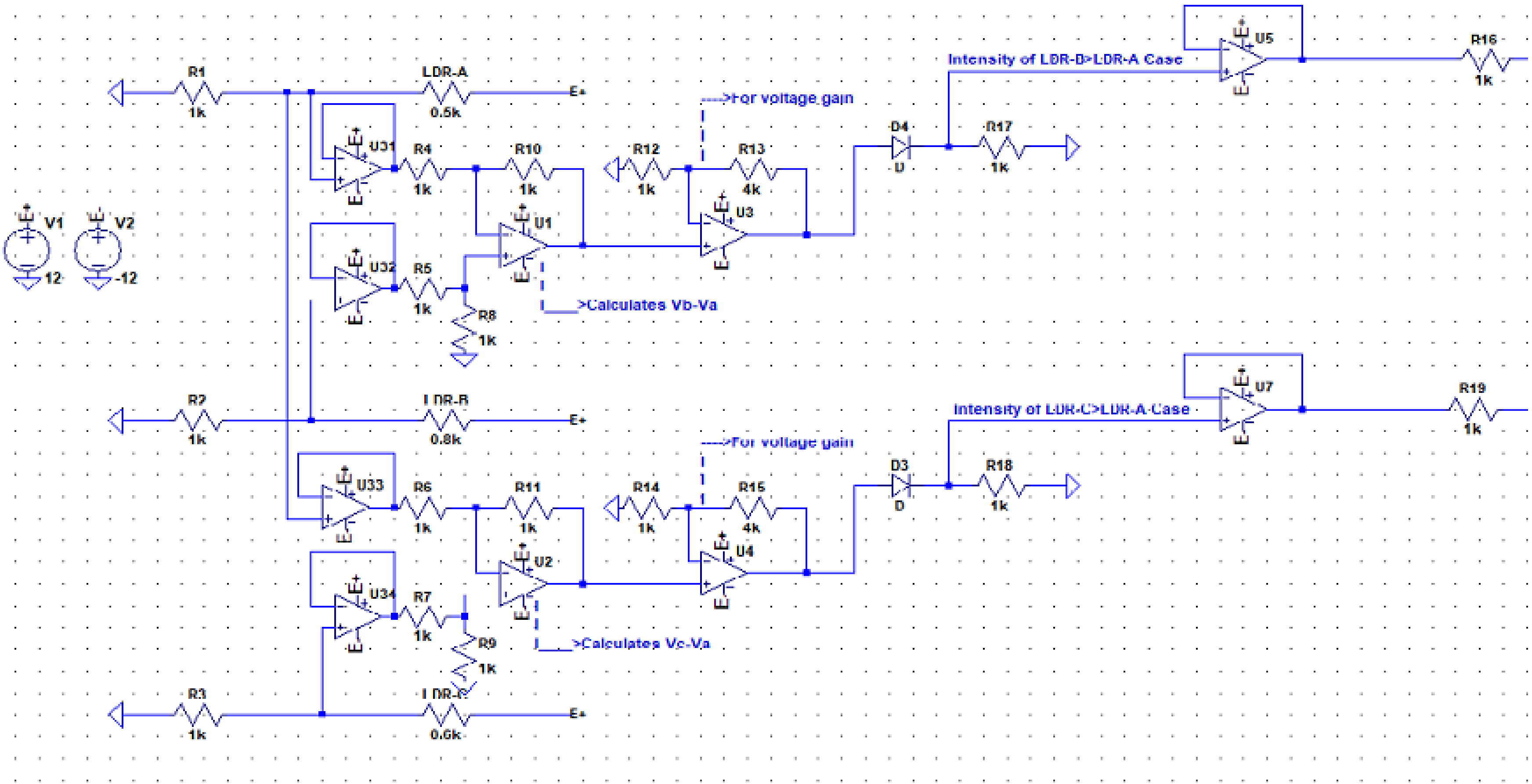


Figure 19: When LDR A takes more intense light than others, while LDR C is following it and LDR B is taking lower intensity light

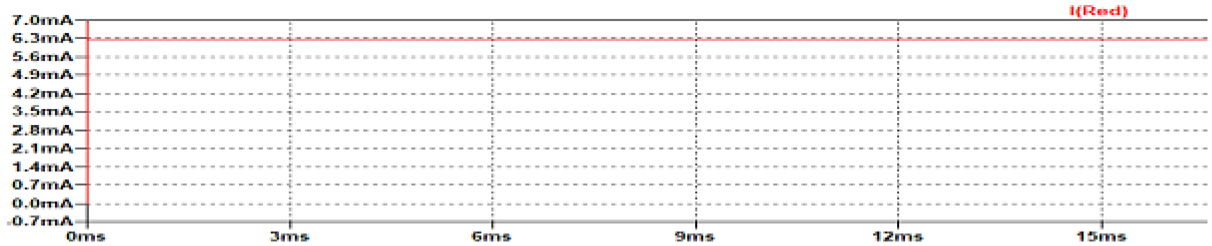


Figure 20: The current which is passing through from red part of RGB.

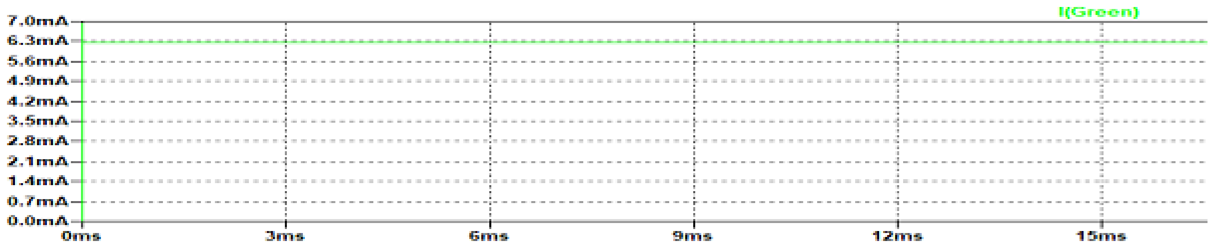


Figure 21: The current which is passing through from green part of RGB.

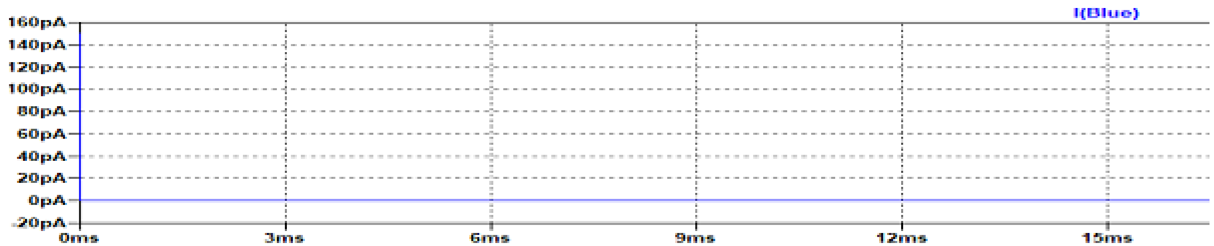


Figure 22: The current which is passing through from blue part of RGB.

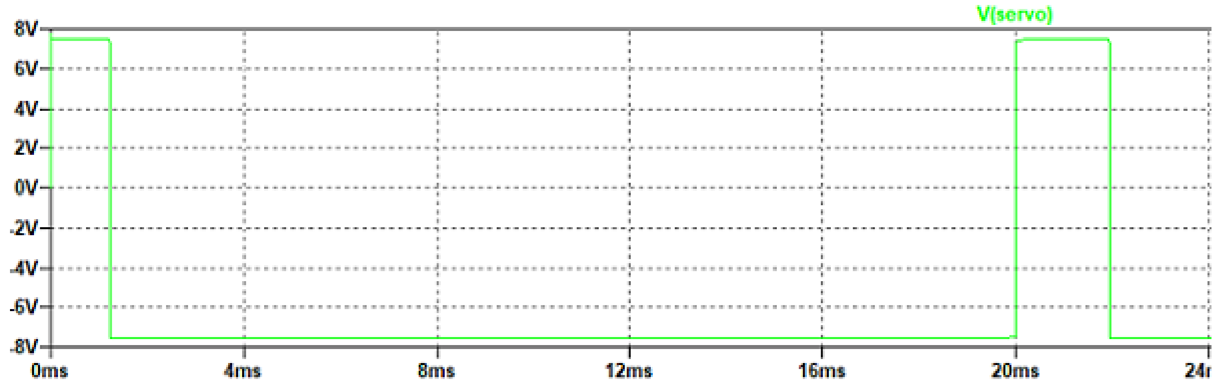


Figure 23: Period and Duty Cycle of wave coming to the servo motor.

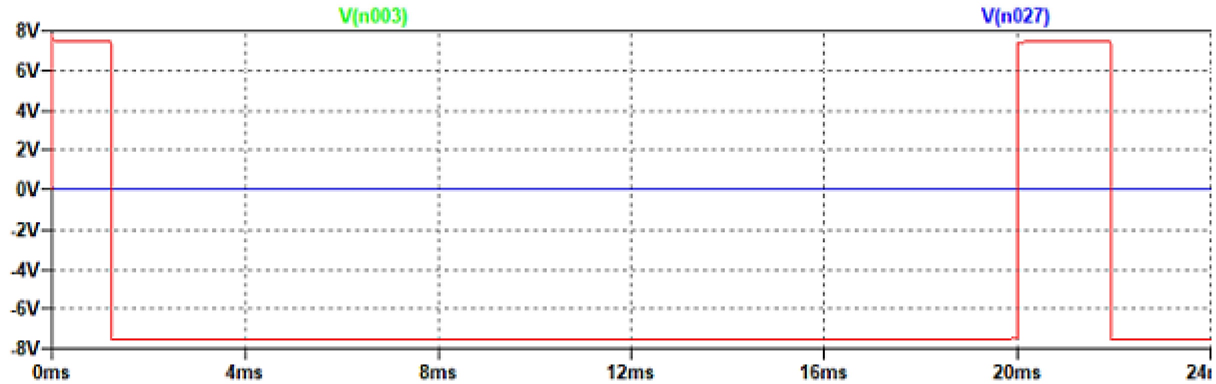


Figure 24: Waveforms of square wave generators.

When $V_b > V_c > V_a$

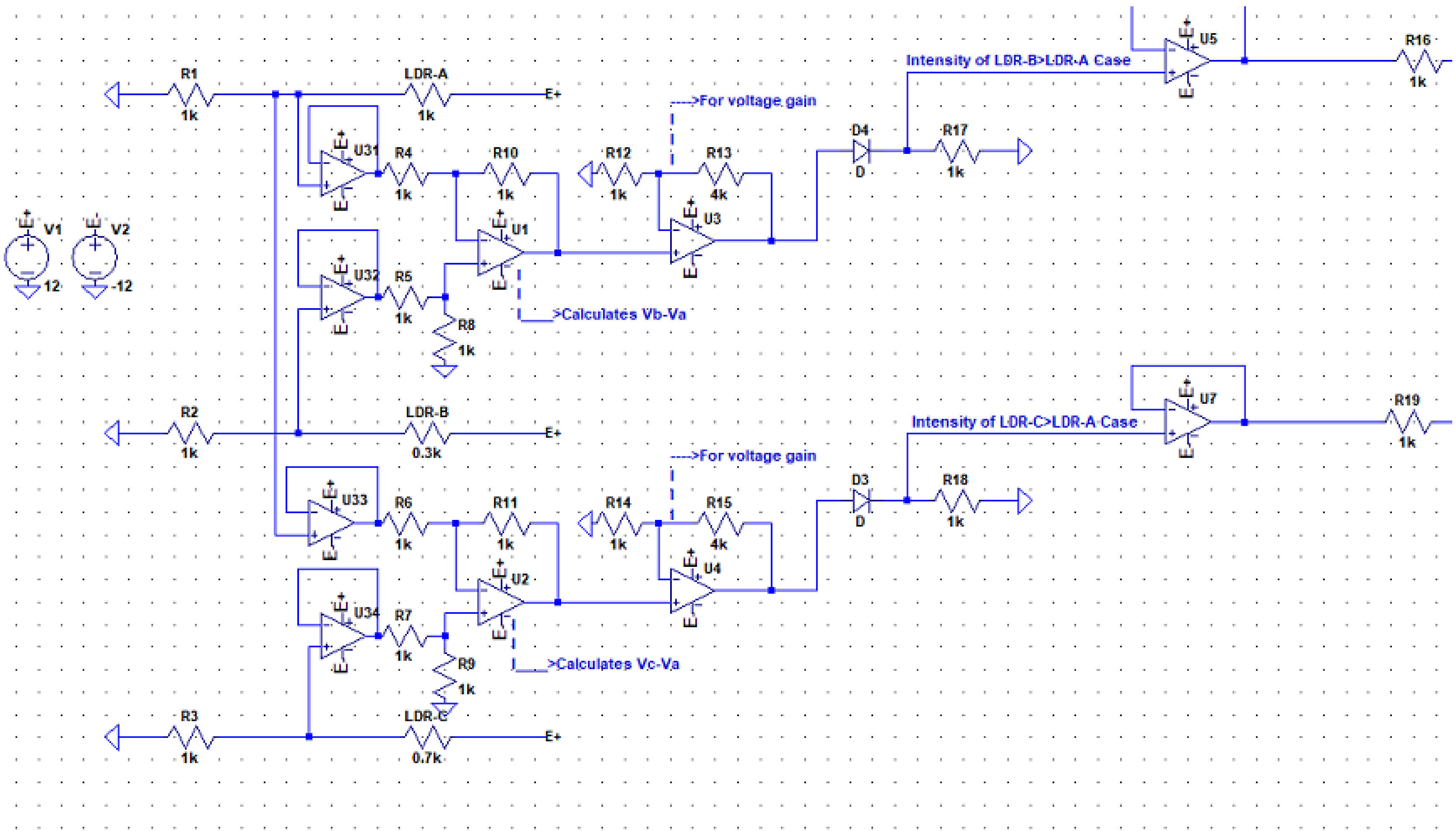


Figure 25: When LDR B takes more intense light than others, while LDR C is following it and LDR A is taking lower intensity light

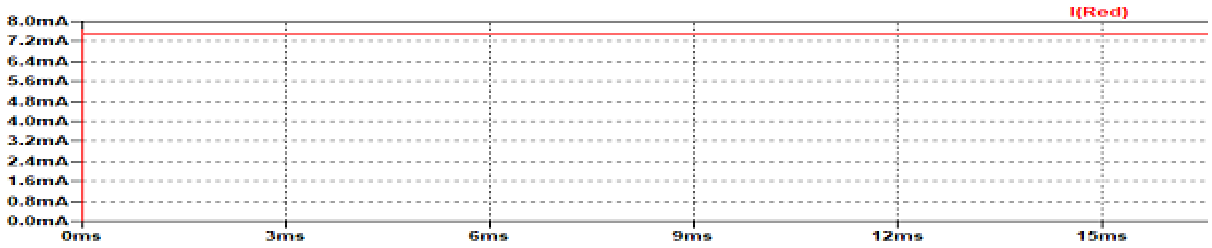


Figure 26: The current which is passing through from red part of RGB.

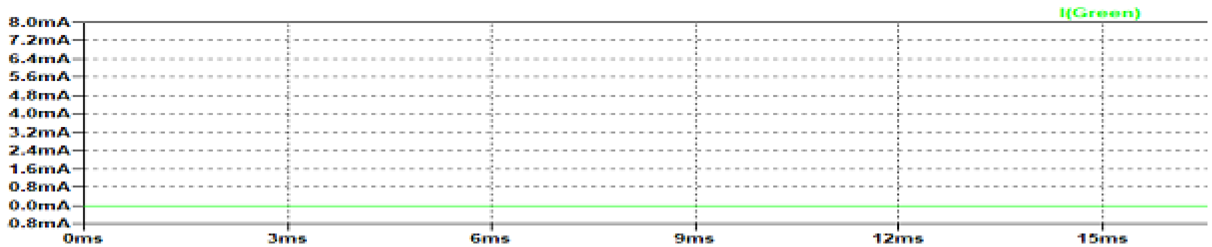


Figure 27: The current which is passing through from green part of RGB.

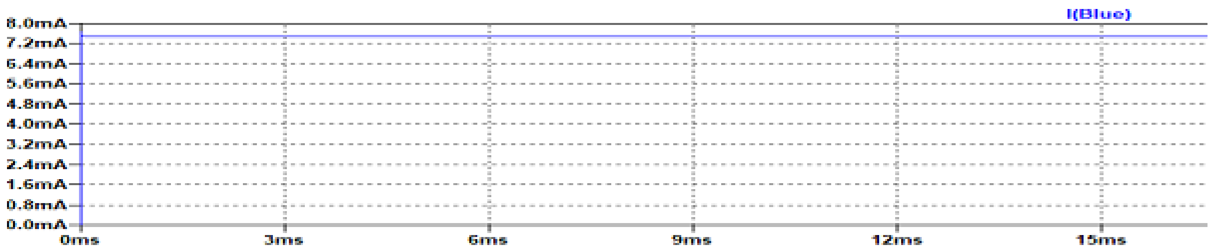


Figure 28: The current which is passing through from blue part of RGB.

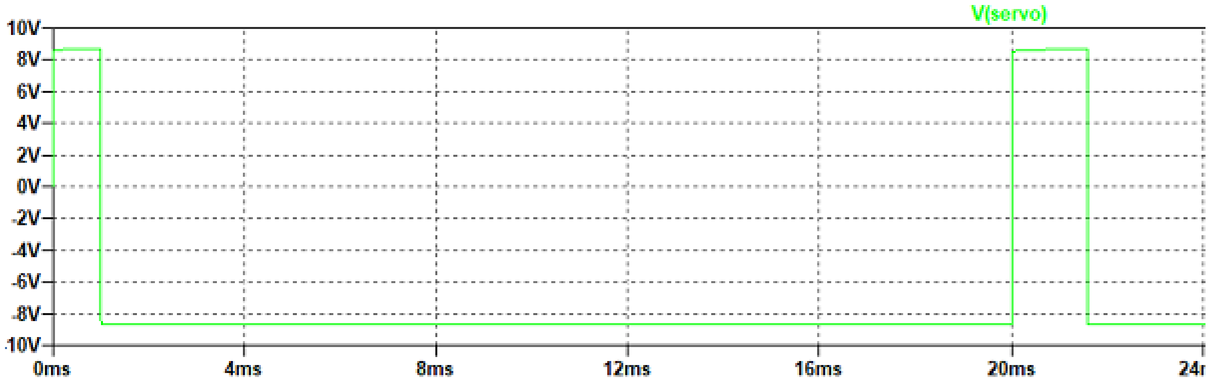


Figure 29: Period and Duty Cycle of wave coming to the servo motor.

Figure 30: Waveforms of square wave generators.

When $V_b > V_a > V_c$

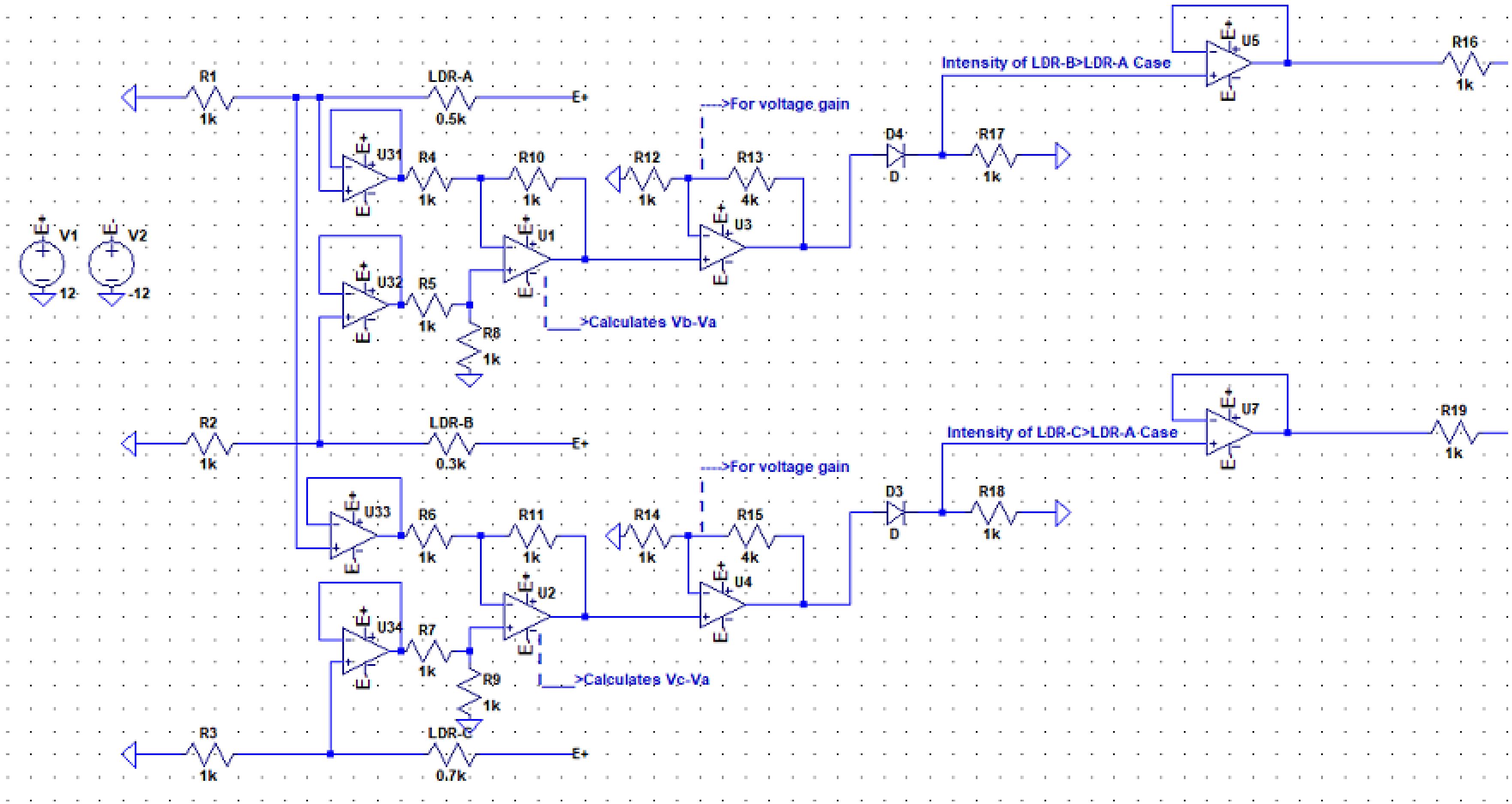


Figure 31: When LDR B takes more intense light than others, while LDR A is following it and LDR C is taking lower intensity light

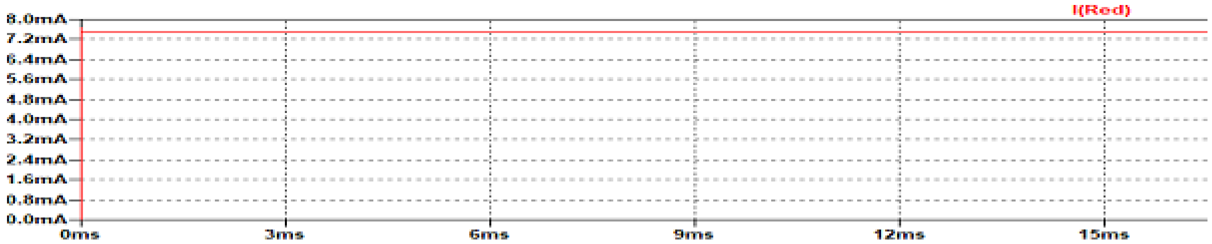


Figure 32: The current which is passing through from red part of RGB.

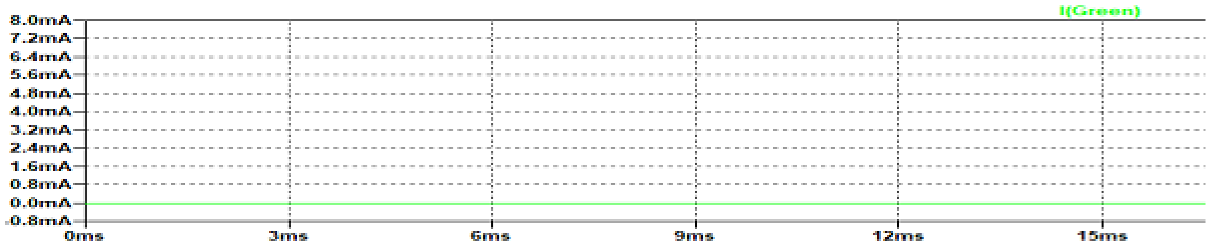


Figure 33: The current which is passing through from green part of RGB.

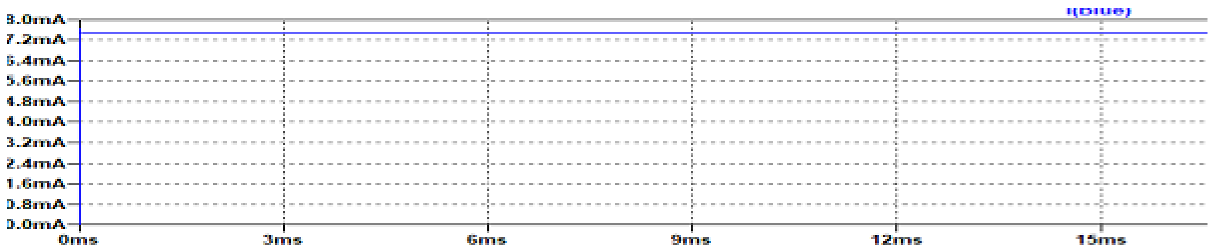


Figure 34: The current which is passing through from blue part of RGB.

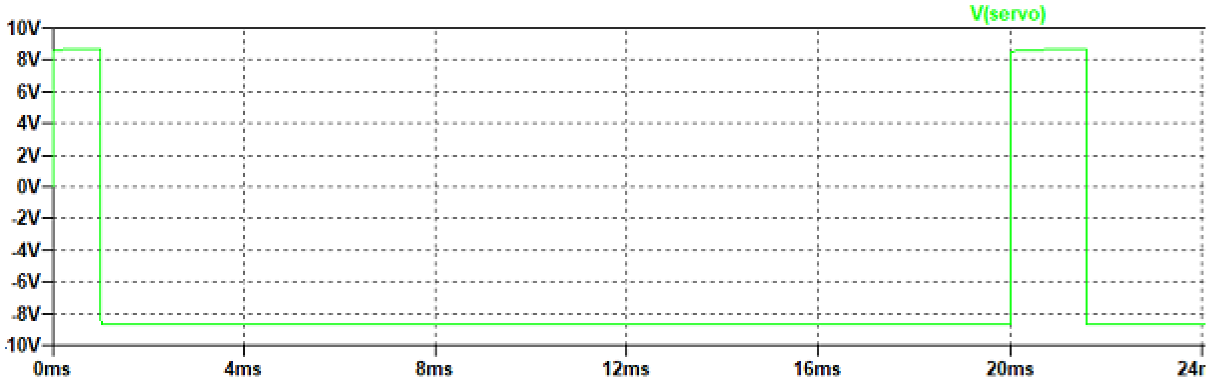


Figure 35: Period and Duty Cycle of wave coming to the servo motor.

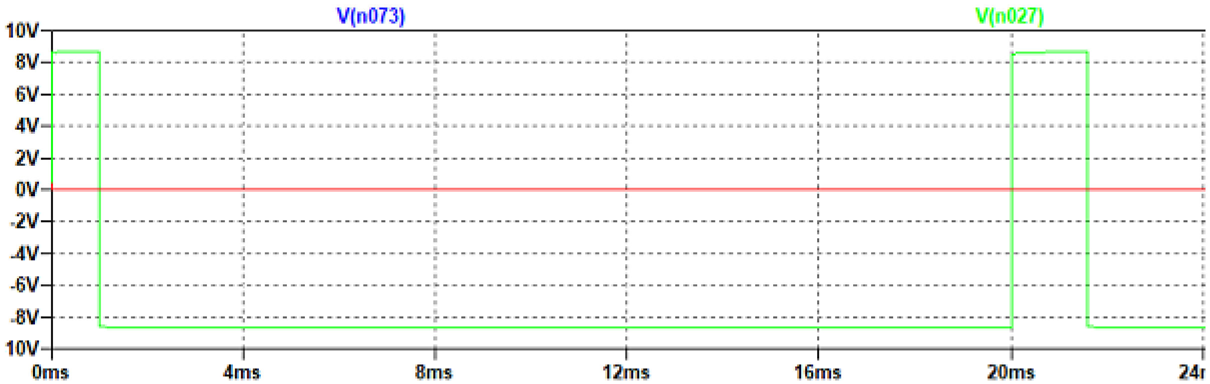


Figure 36: Waveforms of square wave generators.

When $V_c > V_b > V_a$

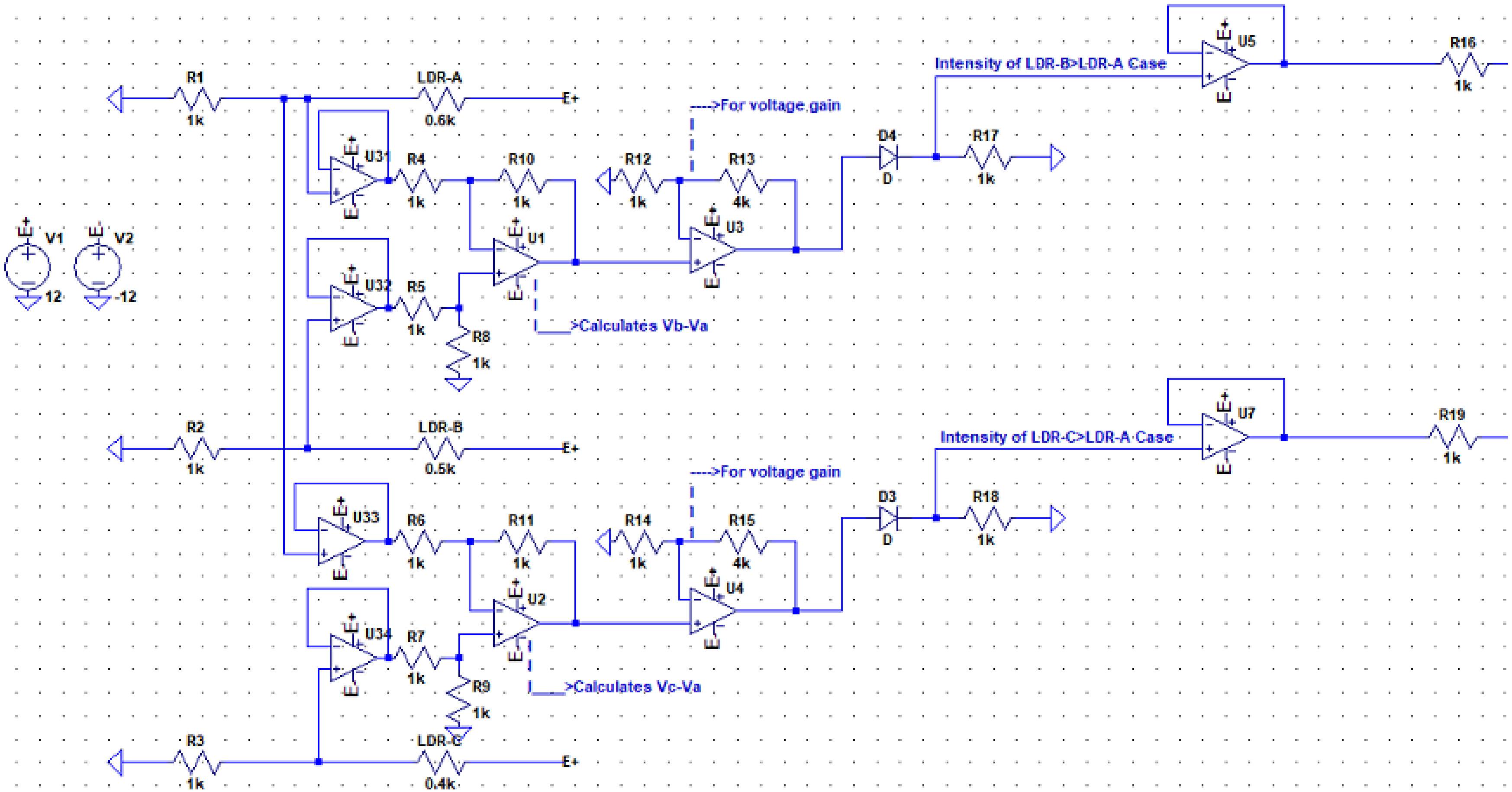


Figure 37: When LDR C takes more intense light than others, while LDR B is following it and LDR A is taking lower intensity light

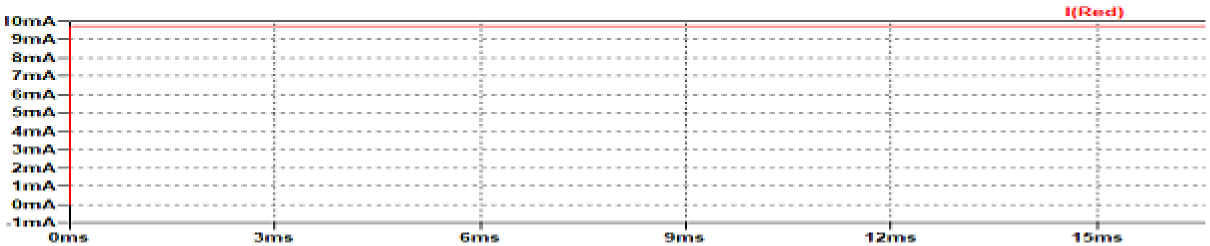


Figure 38: The current which is passing through from red part of RGB.

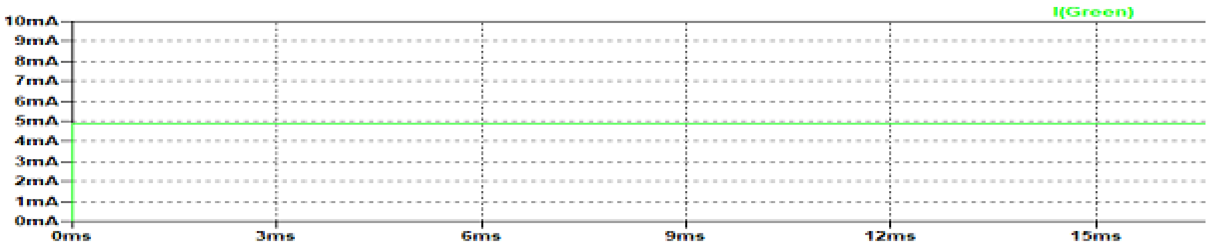


Figure 39: The current which is passing through from green part of RGB.

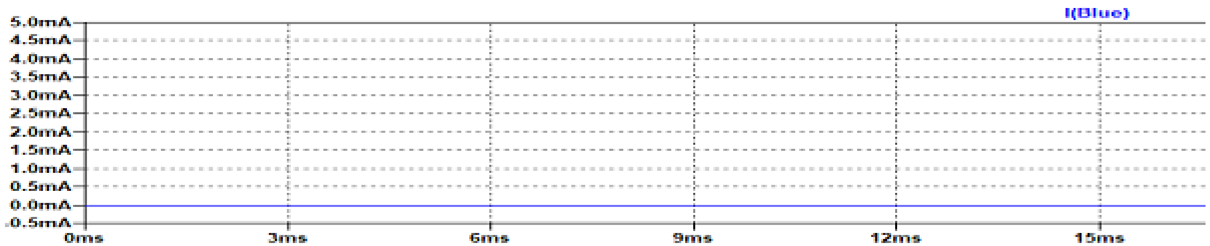


Figure 40: The current which is passing through from blue part of RGB.

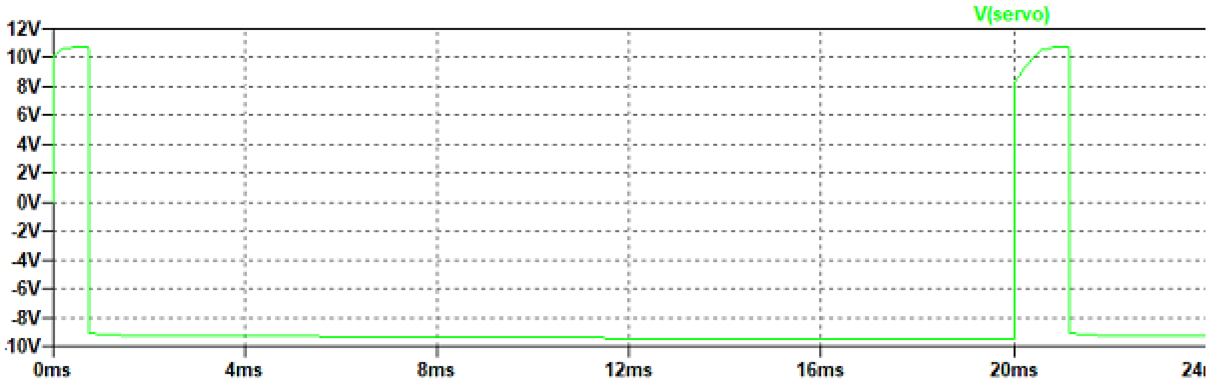


Figure 41: Period and Duty Cycle of wave coming to the servo motor.

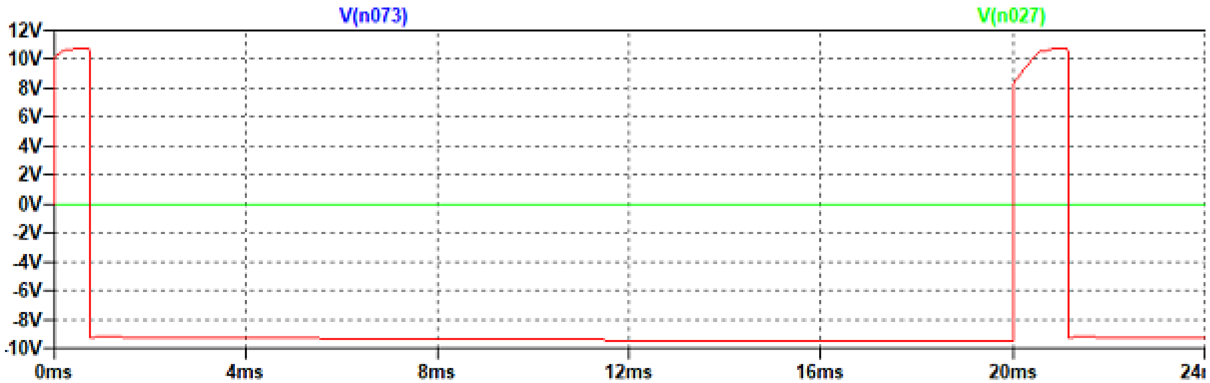


Figure 42: Waveforms of square wave generators.

When $V_c > V_a > V_b$

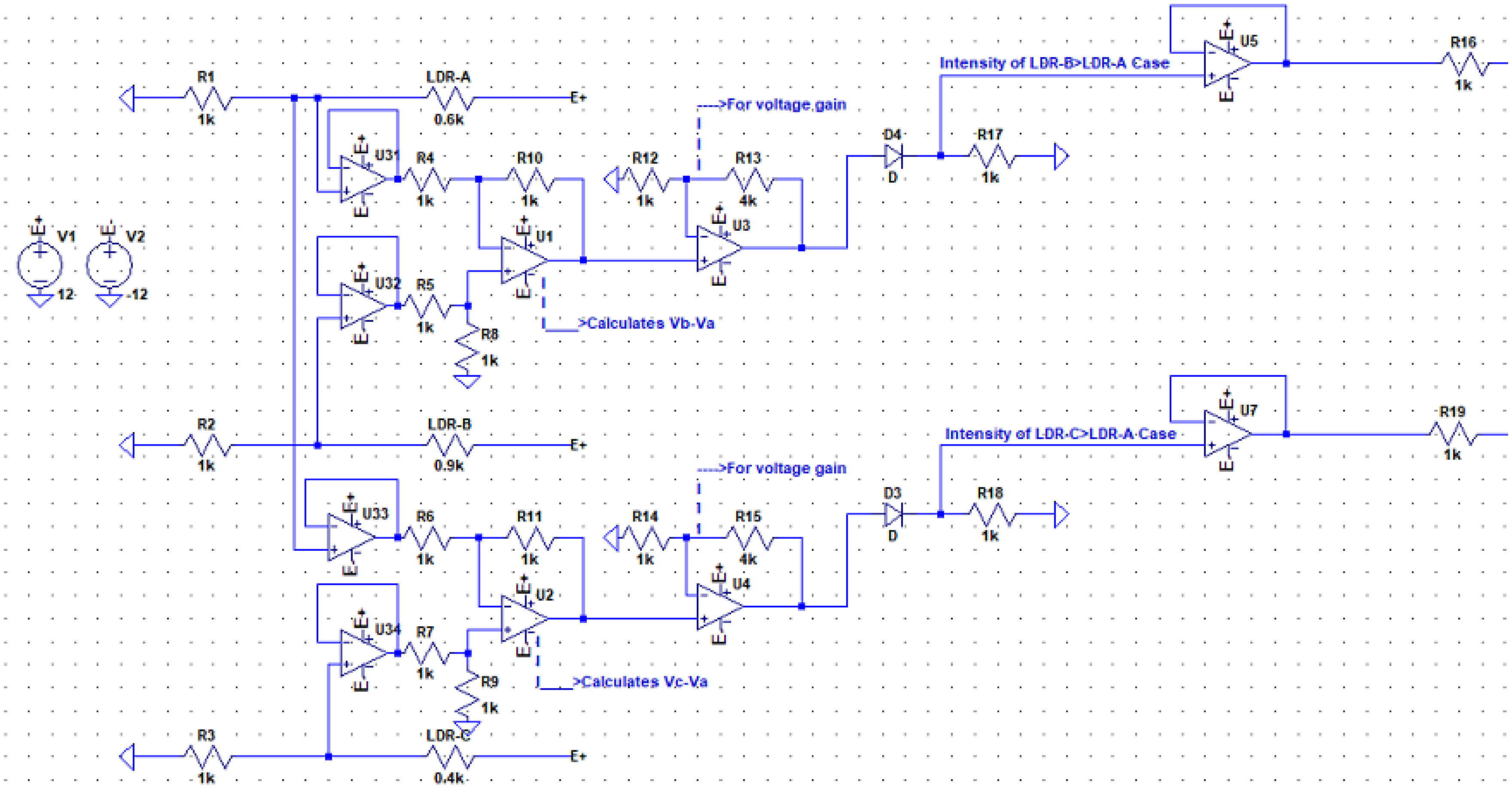


Figure 43: When LDR C takes more intense light than others, while LDR A is following it and LDR B is taking lower intensity light

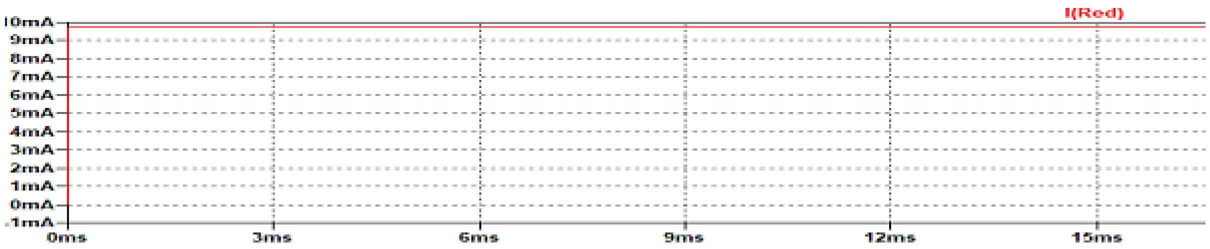


Figure 44: The current which is passing through from red part of RGB.

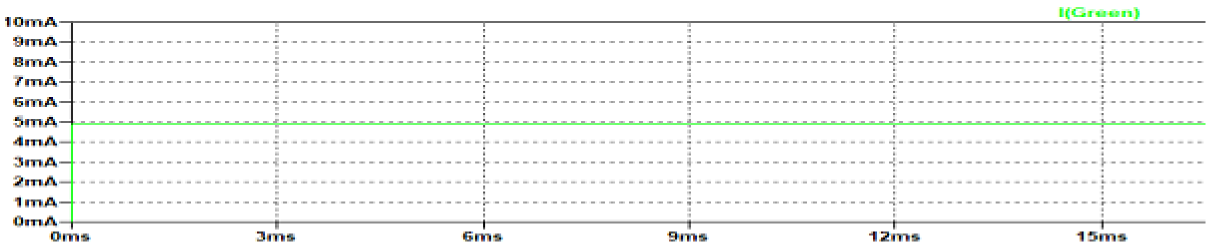


Figure 45: The current which is passing through from green part of RGB.

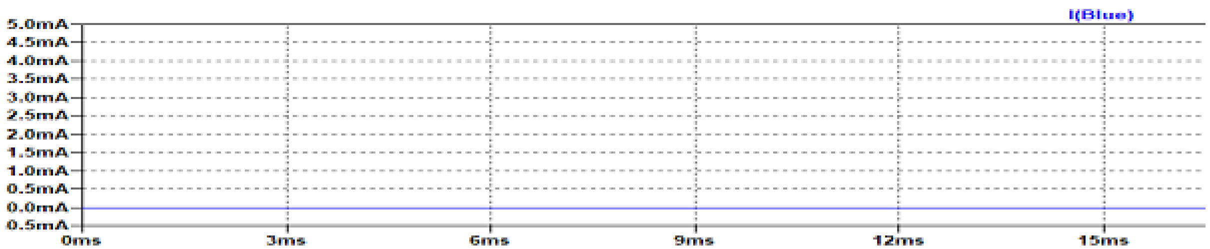


Figure 46: The current which is passing through from blue part of RGB.

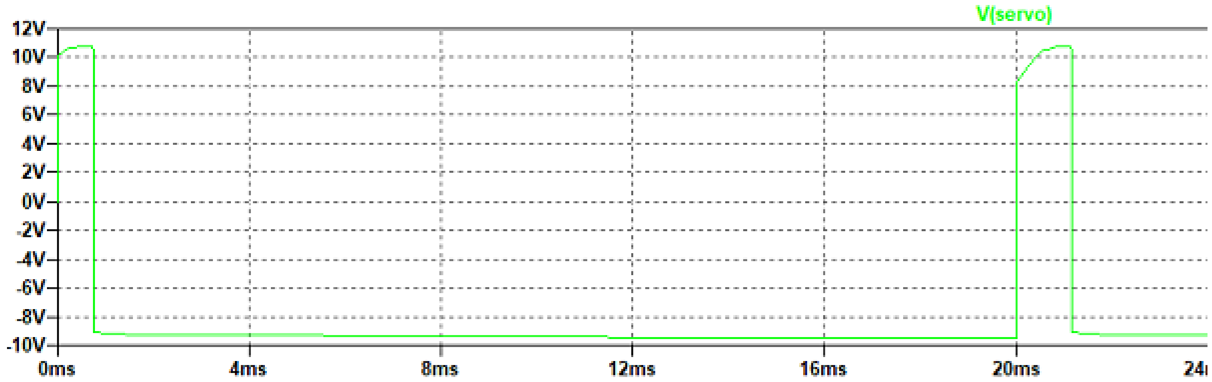


Figure 47: Period and Duty Cycle of wave coming to the servo motor.

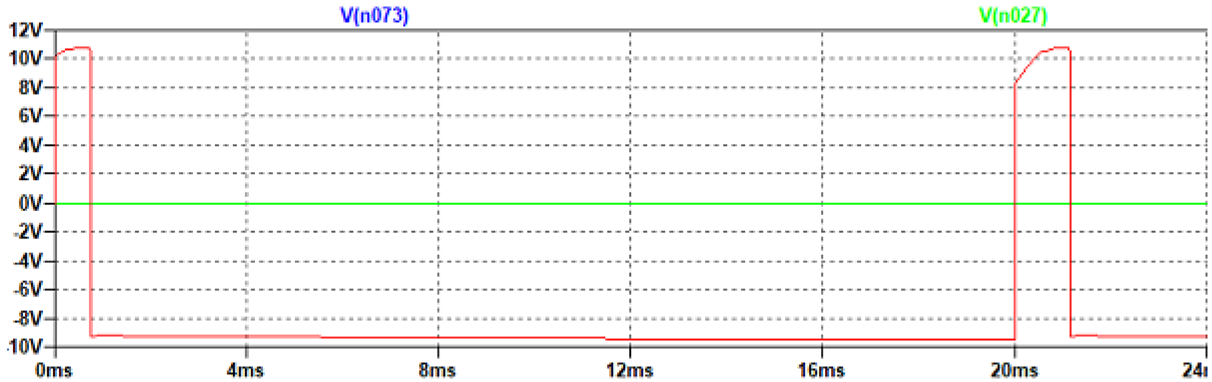


Figure 48: Waveforms of square wave generators.

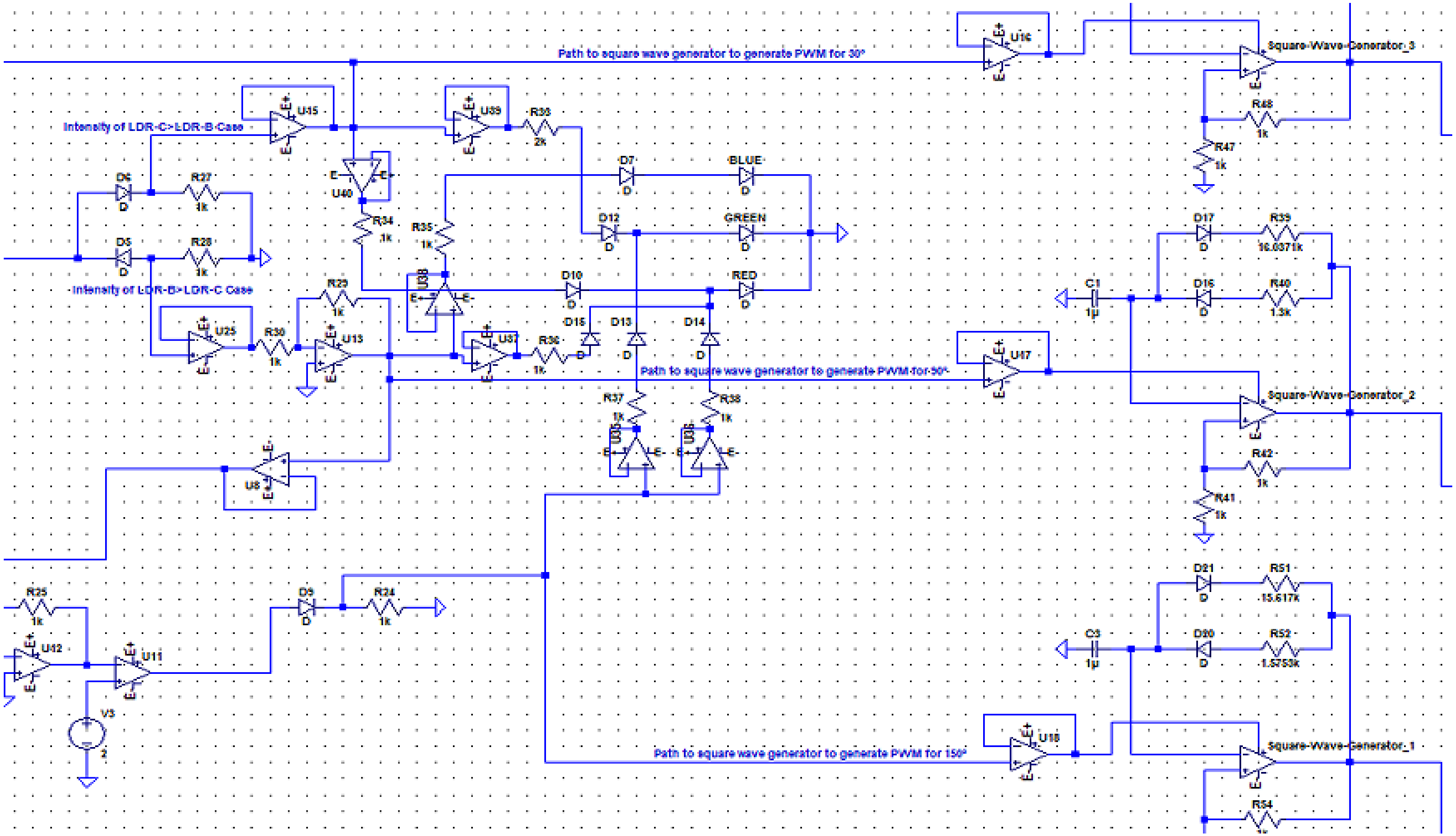


Figure 49: For following graphs

When V_a greater than all voltages:

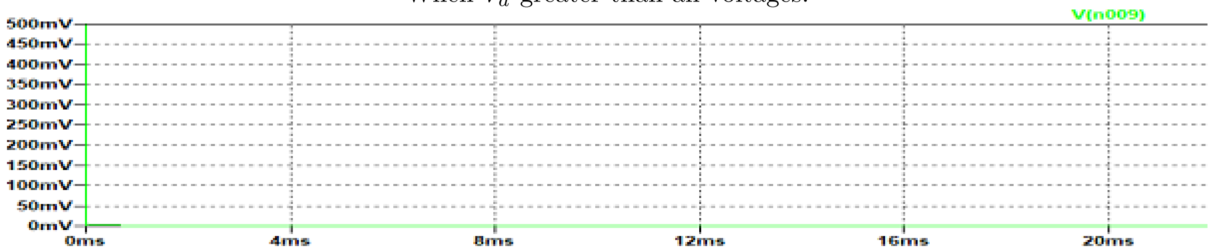


Figure 50: Input voltage of square wave generator 3 which comes from decision unit.

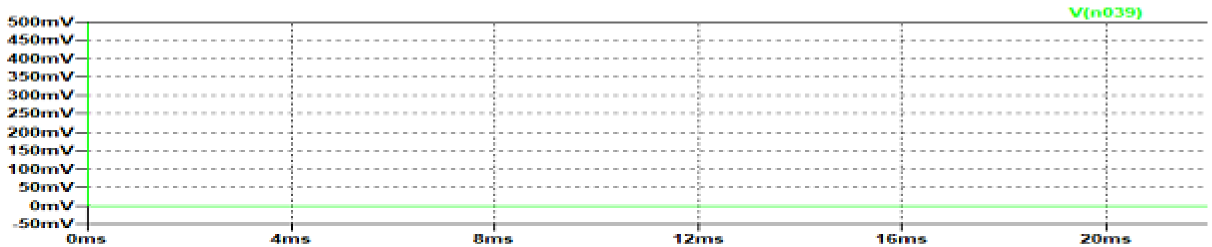


Figure 51: Input voltage of square wave generator 2 which comes from decision unit.

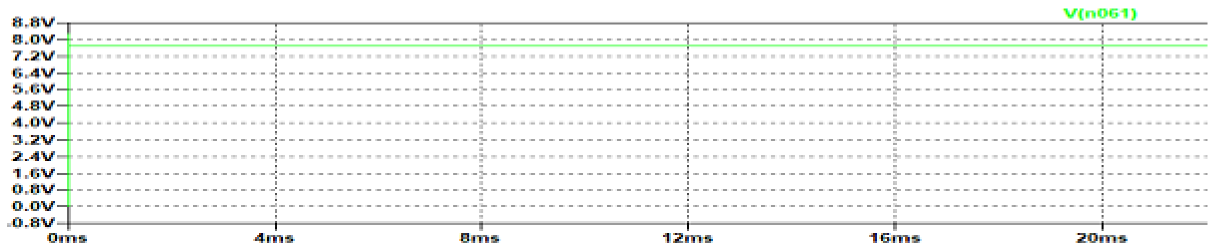


Figure 52: Input voltage of square wave generator 1 which comes from decision unit.

When V_b greater than all voltages:

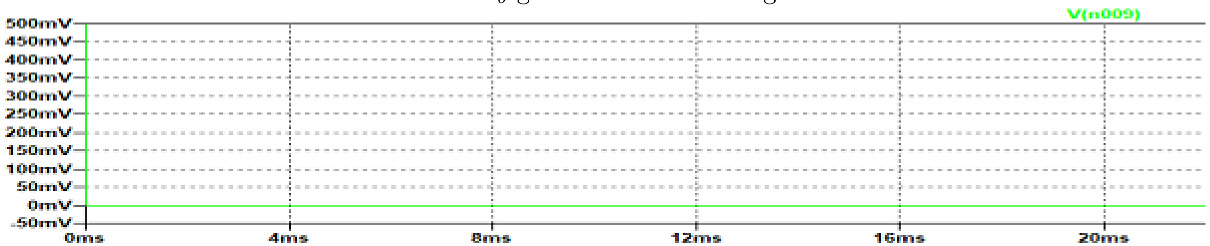


Figure 53: Input voltage of square wave generator 3 which comes from decision unit.

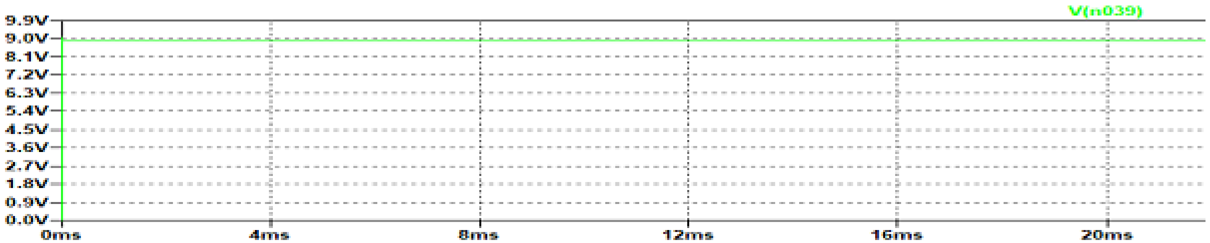


Figure 54: Input voltage of square wave generator 2 which comes from decision unit.

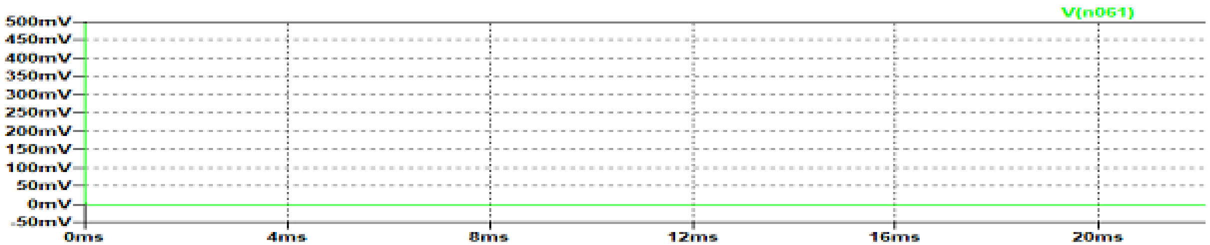


Figure 55: Input voltage of square wave generator 1 which comes from decision unit.

When V_c greater than all voltages:

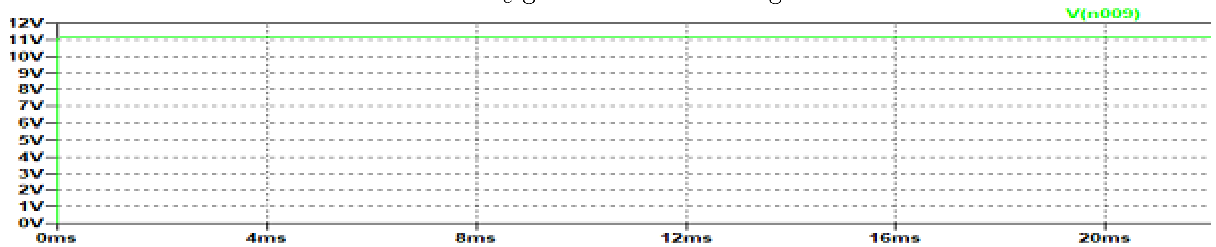


Figure 56: Input voltage of square wave generator 3 which comes from decision unit.

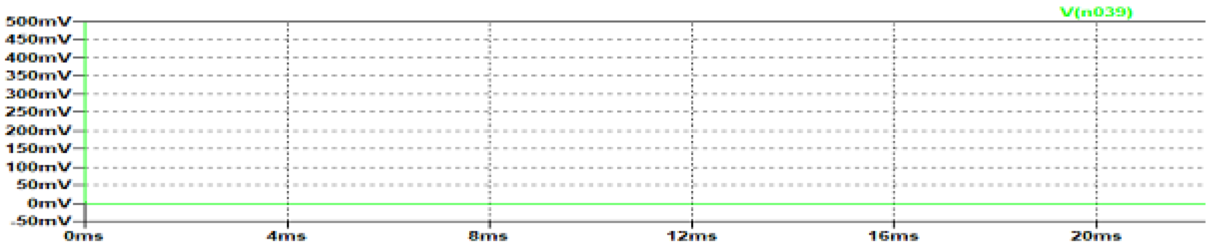


Figure 57: Input voltage of square wave generator 2 which comes from decision unit.

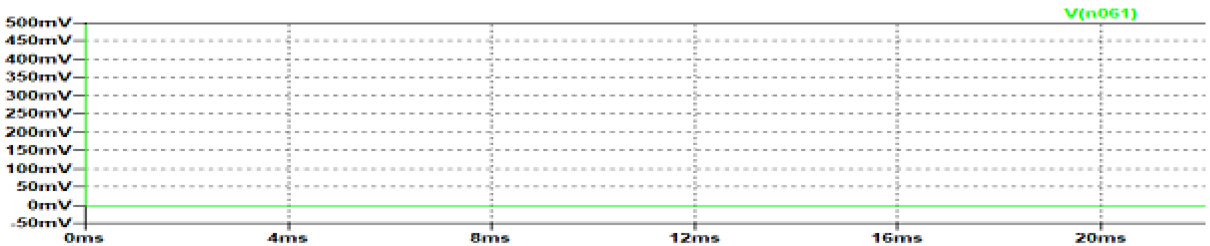


Figure 58: Input voltage of square wave generator 1 which comes from decision unit.

6 Results

6.1 Cost Analysis

Table 4: Price of each component used in the single-axis solar tracking system

Component	Unit Price	Total Amount of Comp	Total Cost
11 mm LDR	2.29 TL	3	6.87 TL
1N 4007 Diode	0.06 TL	17	1.02 TL
LM 741 Op-amp	0.73 TL	33	24.09 TL
1 µF Capacitor (250V)	0.14 TL	3	0.42 TL
1 kΩResistor	0.01 TL	55	0.55 TL
4.7 kΩPotentiometer	0.69 TL	3	2.07 TL
22 kΩPotentiometer	0.69 TL	3	2.07 TL
RGB Led	0.82 TL	1	0.82 TL
SG 90 Servomotor	9.16 TL	1	9.16 TL
Breadboard	7.33 TL	6	43.98 TL
Cable			5 TL

According to the Table 4, total cost is **96.05 TL**.

6.2 Power Analysis

The voltages connected to system are 12 V, 2 V and -12 V. These voltage differences provide the system with current flow.

$$Power = VxI \tag{12}$$

In Eq. (12), the power delivered to circuit is calculated. The current information, indicated by "I", is gotten from DC power supply.

For three cases; V_c, V_b, V_a are greatest, the power is delivered to circuit is calculated.

V_c is the greatest;

Table 5: Voltage sources, currents flow on them and the power

Voltage	Current	Power
12 V	0.105 A	1.26 W
-12 V	0.055 A	0.66 W
2 V	0.001 A	0.002 W

According to the Table 5, delivered total power is 1.922 W based on the Eq. (12) V_c is the greatest.

V_b is the greatest;

Table 6: Voltage sources, currents flow on them and the power

Voltage	Current	Power
12 V	0.108 A	1.296 W
-12 V	0.075 A	0.900 W
2 V	0.001 A	0.002 W

According to the Table 6, delivered total power is 2.198 W based on the Eq. (12) V_b is the greatest.

V_a is the greatest;

Table 7: Voltage sources, currents flow on them and the power

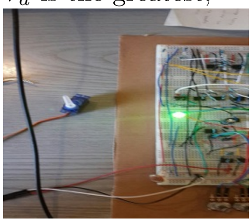
Voltage	Current	Power
12 V	0.091 A	1.092 W
-12 V	0.059 A	0.708 W
2 V	0.001 A	0.002 W

According to the Table 7, delivered total power is 1.802 W based on the Eq.(12) when V_a is the greatest .

7 Illustrations

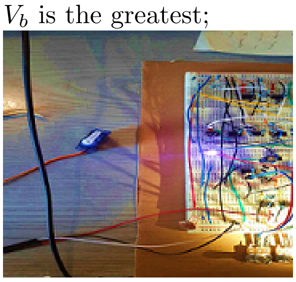
Firstly, the circuit is designed. After designing the system, the system is constructed. In this section, the illustrations of circuit is shown for the three cases; V_a, V_b, V_c are greatest.

V_a is the greatest;



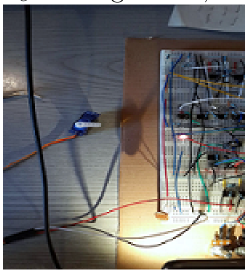
As shown in the illustration, Servomotor is in the position at 30° as stated in the Table 2 and RGB led give yellow light as stated in the Table 1 when V_a is the greatest.

V_b is the greatest;



As shown in the illustration, Servomotor is in the position at 90° as stated in the Table 2 and RGB led give yellow light as stated in the Table 1 when V_b is the greatest.

V_c is the greatest;



As shown in the illustration, Servomotor is in the position at 150° as stated in the Table 2 and RGB led give yellow light as stated in the Table 1 when V_c is the greatest.

8 Conclusion

Solar energy have taken significant role in energy industry, which result in increase in researches on efficiency of solar energy systems. These projects condense in sun tracking systems.Sun tracking systems provide solar panels with incident lights at almost right angles, which increase amount of energy generated from solar source. Under the influence of solar energy, single-axis sun tracking system was constructed in this Project.

Sun tracking system is divided into three parts: measurement unit, control unit and angle adjustment unit. Three LDR is fixed on not solar panel, but horizantal place to measure light intensity at morning, noon and evening. Fixed LDRs on panel could make the control unit more complex. Taking information of intensity, decision sub-unit, sub-unit of control unit, determine which LDR have more intensity. Then, information of comparison is sended to RGB led to indicate direction. Then, function sub-unit of control unit generate proper square wave to send angle adjustment unit. Finally, angle adjustment unit consisted by servo motor provide suitable angleaccording to square wave. Project design is based on some laws, which are Ohm's Law, KVL and KCL.While KVL and KCL is used mostly in control unit, especially in op-amps, Ohm's Law can be seen on overall circuit.

Finally, some problems arose from the application while the circuit worked properly in the simulation program. Difference of Ron and Roff values in application can be best example. The resistance values calculated theoretically did not provide the servomotor with suitable squarewave. This differences may result from that op-amps does nor work by infinitely gain. Also, in theory, when inputs of comparator does not have voltage, output of the comparator becomes 0V. On the other hand, in application, very small difference between the inputs result in high voltages at the output. Therefore, as stated before, difference amplifier replaced by the comparator.

9 References

[1] A. Al-Mohamad "Efficiency improvements of photo-voltaic panels using a Sun-tracking system." Applied Energy, vol. 79(3), pp. 345-354, Nov. 2004.

[2] https://www.kitronik.co.uk/blog/how-an-ldr-light-dependent-resistor-works/

[3] Lee, C. Y., Chou, P. C., Chiang, C. M., Lin, C. F. (2009). Sun tracking systems: a review. Sensors, 9(5), 3875-3890.

http://www.chd.hk/UploadFiles/Att/2012111511321031.pdf

https://ieee-dataport.org/sites/default/files/analysis/27/IEEE
https://randomnerdtutorials.com/electronics-basics-how-do-rgb-leds-work/

https://www.jameco.com/jameco/workshop/howitworks/how-servo-motors-work.html

http://hyperphysics.phy-astr.gsu.edu/hbase/Electronic/opampvar.htmlc1