Lab 3

Date: 30.03.2022

Name: Busenaz Kerimgil

ID Number: 21901927

Section: 2

Purpose:

The aim of this lab is to design a circuit generating the voltage waveform shown in the Figure 1 which based on OPAMPs and RC circuits. The design expects a step function transitioning from 5V to 0V or a square wave between the same values as input. Furthermore, the desired result is a trapezoidal form, as seen in the Figure 1.

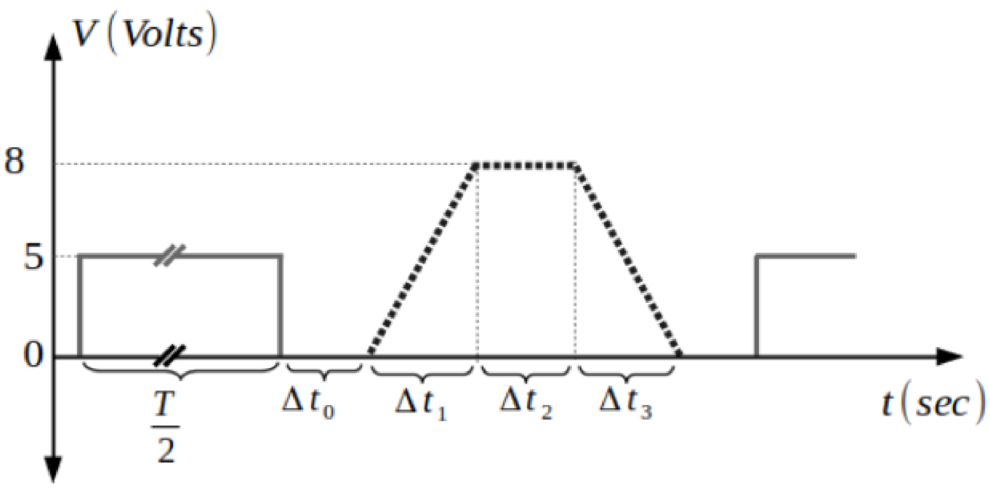


Figure 1- Desired output and input

The input frequency must be less than 50Hz and $\Delta t0$ = 3ms, $\Delta t1$ = 3ms, $\Delta t2$ = 3ms, $\Delta t3$ = 2ms

Methodology:

Many mathematical operations, such as inverting, subtracting, differentiating, and integrating, may be performed using the OPAMPs Operational Amplifiers. Moreover, it is possible to arrange saturation with V_{cc} pins.

Simulation Part:

In order to create the waveform which shown in figure below, there need to be 3 steps. First by creating delays, shift the square wave for 3ms and 11ms. Second to get the skew line shape integrate the both waveforms. Lastly subtract waveforms from each other's and reach desired shape.

In the first part, it will be RC circuits and comparator OPAMPs (LM324) will be using in order to create desired delays. There need to be separate configuration for 3ms and 11ms. For both configurations, a square wave with a frequency of 20 MHz and an amplitude of 5 Vpp was sent. Since OPAMPs are in non-linear region, their output voltage is saturated. The positive V_{cc} is connected to 9.5 V and the negative V_{cc} is connected to ground since we want the waveform on the positive region. (Figure2)

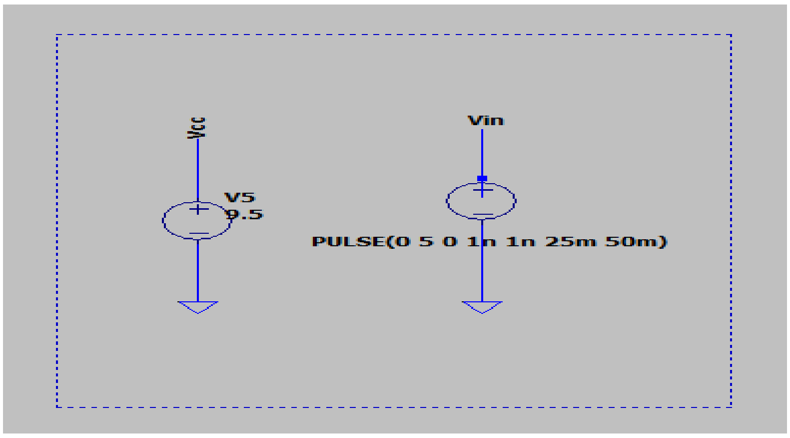


Figure 2 – Input and the Vcc voltage values

For 3ms delay, 430nF capacitor and 10k ohm resistor is used. For 11ms(3ms + 3ms + 2ms +3ms) delay, 3.3µF capacitor and 4.7k ohm resistor is used (Figure 3). Following calculations made in order to reach these results.

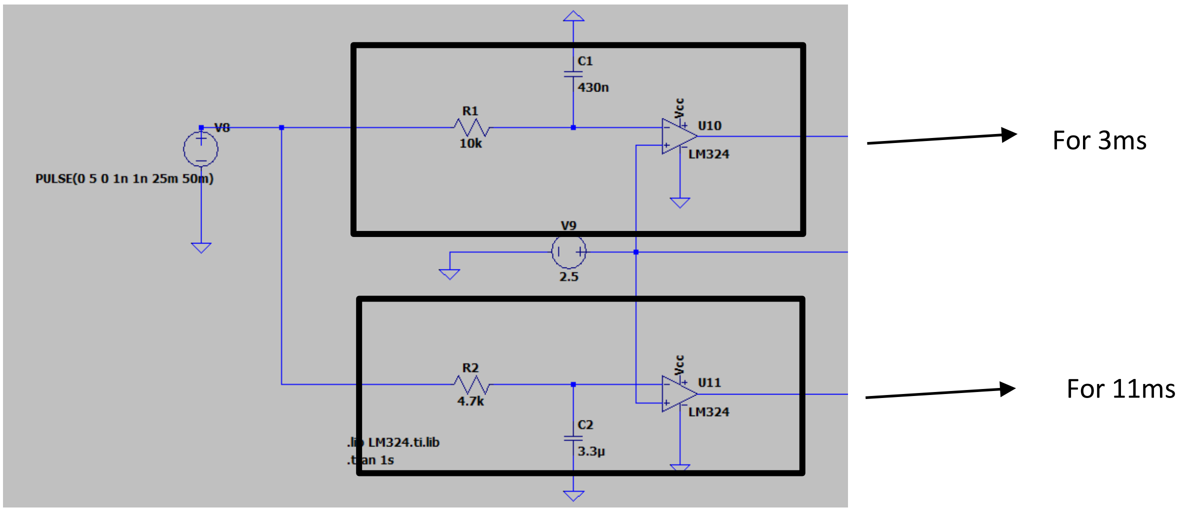


Figure 3 – Comparator Part

The equation for a comparator OPAMP is given below:

$$\frac{dV_c}{dt} * C = \frac{V_{in} - V_c}{R} \qquad (1)$$

$$\frac{dV_c}{dt} * C + \frac{V_c}{R} = \frac{V_{in}}{R} \qquad (2)$$

The Characteristic Equation:

$$\lambda * C + \frac{1}{R} = 0 \qquad (3)$$

$$\lambda = -\frac{1}{R * C} \qquad (4)$$

The Natural Response Equation:

$$C_1 \; * e^{-\frac{1}{R*C}} = V_{cnatural} \quad (5)$$

Basis for Forced Response:

$$Basis = \{1\}$$

$$V_{cforced} = 1 * A \qquad (6)$$

Solution for Forced Response:

$$\frac{A}{R} = \frac{V_{in}}{R} \qquad (7)$$

$$V_{cforced} = V_{in} \quad (8)$$

In order to find C_1 give t = 0, Vc(t) =0

$$C_1 \; = \; -5$$

The General Solution of Vc(t):

$$-5 \; * \; e^{-\frac{t}{R*C}} + 5 = \; Vc \quad (9)$$

When t = 3ms and t = 11ms Vc has to be 2.5 V so that the delays can be created. By inserting the 3ms and 11ms to the general solution, it can be found the capacitance and resistance values separately.

For 3ms:

$$-5 \, * \, e^{-\frac{3m}{R1*C1}} + 5 = 2.5 \qquad (10)$$

$$e^{-\frac{3m}{R1*C1}} = 0.5 \qquad (11)$$

$$R_1 \, * C_1 \, = 0.043$$

For 11ms:

$$-5 \, * \, e^{-\frac{11m}{R2*C2}} + 5 = 2.5 \qquad (12)$$

$$e^{-\frac{11m}{R2*C2}} = 0.5 \qquad (13)$$

$$R_2 \, * C_2 \, = 0.0159$$

The suitable RC values are as follows:

$$R_1 = 10k\ Ohm \quad C_1 = 430nF \quad R_2 = 4.7k\ Ohm \quad C_2 = 3.3\mu F$$

In the second part, skew lines are generated from 3ms and 11ms delayed waveforms. Integrator OPAMP is used to obtain skew line by taking the integral of a step function. The integrating OPAMP configuration can be seen in Figure 4. Following calculations made at the below.

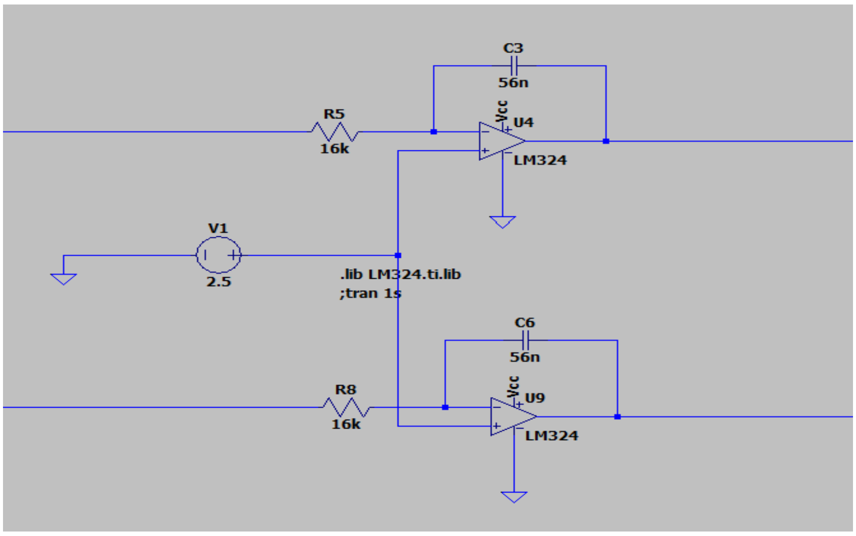


Figure 4 – Integrating OPAMPs

KCL at V^- :

$$\frac{V_{in} - V^-}{R} = C\frac{dV_c}{dt} \quad (14)$$

$$\frac{V_{in} - V^+}{R * C} dt = dV_c \quad (15)$$

When take the integral of both sides:

$$\int \frac{V_{in} - V^+}{R * C} dt = V_c \quad (16)$$

$$\frac{V_{in} - V^+}{R * C} * t + Constant = V_c \quad (17)$$

In order to find Constant give t = 0 and Vc(t) =0 Hence, Constant= 0:

$$\frac{V_{in} - V^{+}}{R * C} * t = V_c \quad (18)$$

$$\frac{2.5}{R * C} * t = V_c \quad (19)$$

When t = 3ms, it is wanted that Vc = 8V:

$$\frac{1}{R * C} * 3m = 3.2 \quad (20)$$

$$R * C = \frac{3m}{3.2} \quad (21)$$

RC values were found by trial-and-error method:

$$R = 17k\ Ohm \qquad C = 56nF$$

Finally, after integrating the both waveforms, subtract them from each other to obtain final result. In order to subtract, the subtractor OPAPM is used as can be seen on Figure 5.

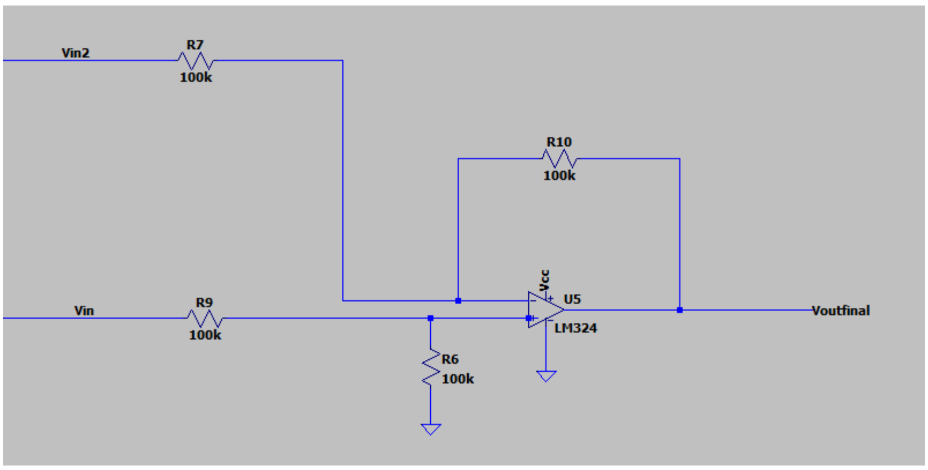


Figure 5 – Subtractor OPAMP

$$\frac{V_{in2} - V^{-}}{R7} = \frac{V^{-} - V_{out}}{R10} \quad (22)$$

$$\frac{V_{in2}}{R7} - \frac{V^{-}}{R7} = \frac{V^{-}}{R10} - \frac{V_{out}}{R10} \quad (23)$$

$$V^{-} = \left(\frac{V_{in2}}{R7} + \frac{V_{out}}{R10}\right) * \frac{1}{\frac{1}{R10} + \frac{1}{R7}} \quad (24)$$

$$\frac{V_{in} - V^{+}}{R9} = \frac{V^{+}}{R6} \quad (25)$$

$$\frac{V^{+}}{R6} - \frac{V^{+}}{R9} = \frac{V_{in}}{R9} \quad (26)$$

$$V^{+} = \frac{V_{in}}{R9 * (\frac{1}{R6} + \frac{1}{R9})} \quad (27)$$

Since $V^{+} = V^{-}$:

$$\frac{V_{in}}{R9 * (\frac{1}{R6} + \frac{1}{R9})} = \left(\frac{V_{in2}}{R7} + \frac{V_{out}}{R10}\right) * \frac{1}{\left(\frac{1}{R10} + \frac{1}{R7}\right)} \quad (28)$$

If all the resistors make the same value it can be reach:

$$V_{in} - V_{in2} = V_{out} \quad (29)$$

Hardware Part:

In the hardware part, the simulation design is implemented on a breadboard as can be seen on Figure 6. For the OPAMPs 2 LM324 Quad OPAMP IC is used. The schematic of the IC can be seen on Figure 7. The reference resistance 2.5 V is connected to V^+ of both integrator and comparator OPAMPs which from their 3rd, 5th, 10th, 12th pins. Moreover, OPAMPs are fed with 9.5 V from their 11th pin. Since 4.9k ohm and 17k ohm is not available at the lab they are exchanged with 4.7k ohm and 18k ohm. Also, to get more accurate values 10k ohm is replaced with 8.2k ohm.

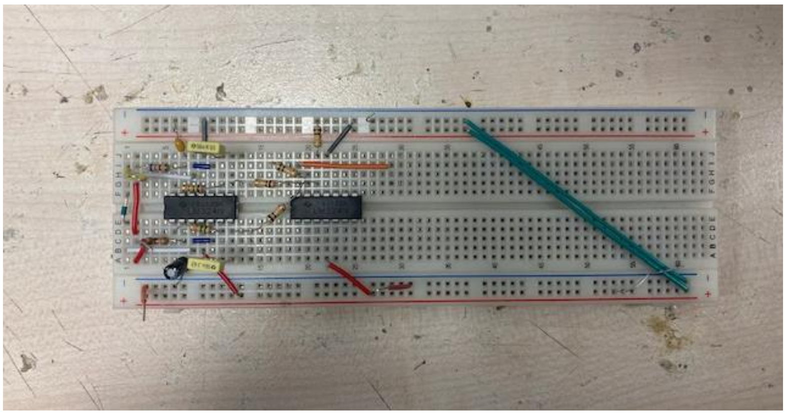


Figure 6 – Hardware Implementation

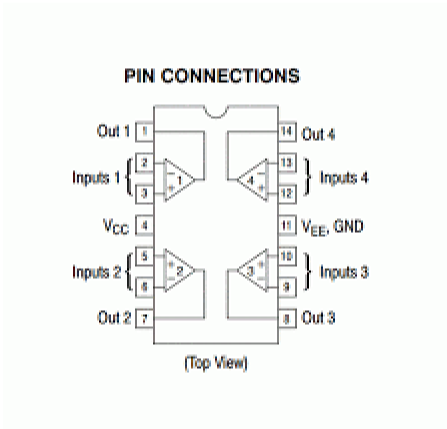


Figure 7 - LM324 Quad OPAMP IC Schematic

A signal generator and voltage source configuration can be seen on Figures 8 and 9. The signal generator, generates the square wave with 20Hz frequency, 2.5Vpp, and 1.25V offset voltage Since without the offset voltage the square wave varies between negative and positive values, in order to shift the voltage values to the positive side, an offset voltage is given.

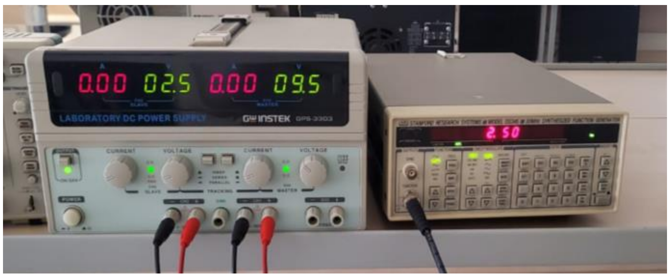


Figure 8 – Input Configuration

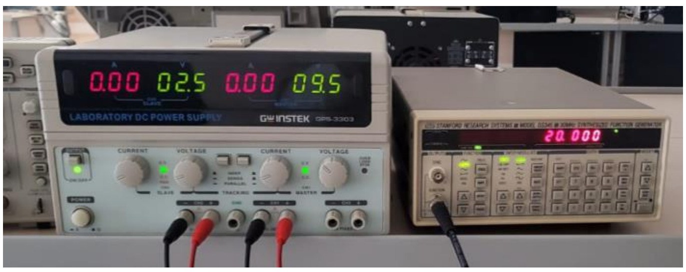


Figure 9 – Input Frequency

Results:

Simulation Results:

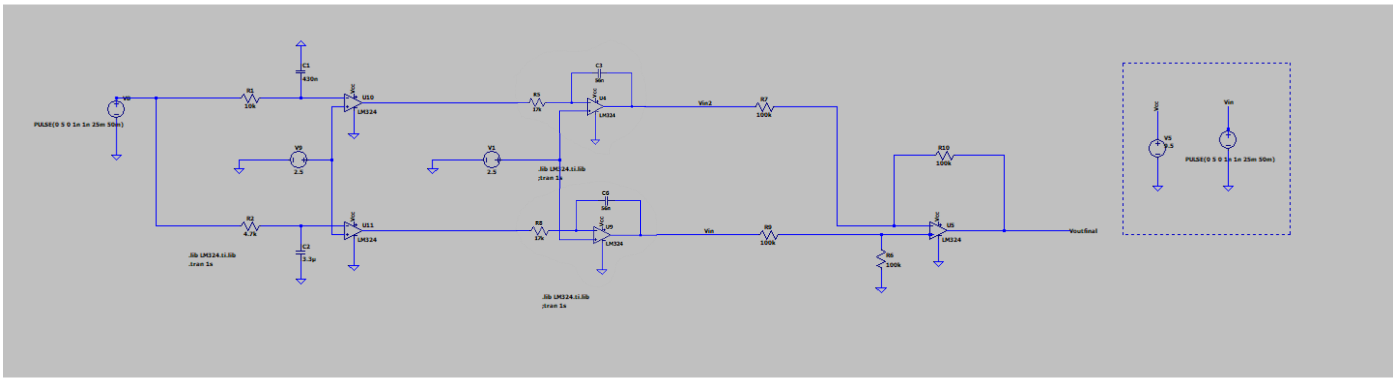


Figure 10 – Simulation Design

The simulation result of Comparator OPAMP:

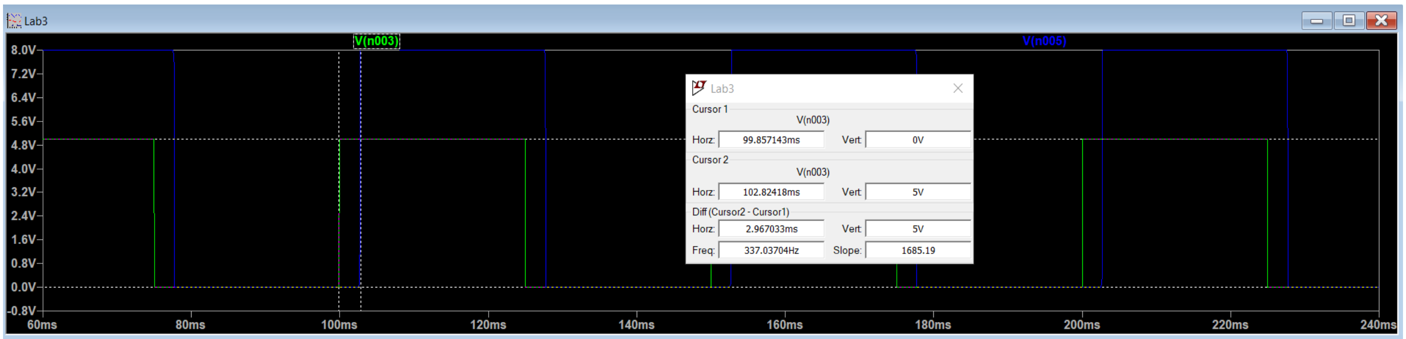


Figure 11 – Delay of 3ms Comparator

Delay: 2.96 ms

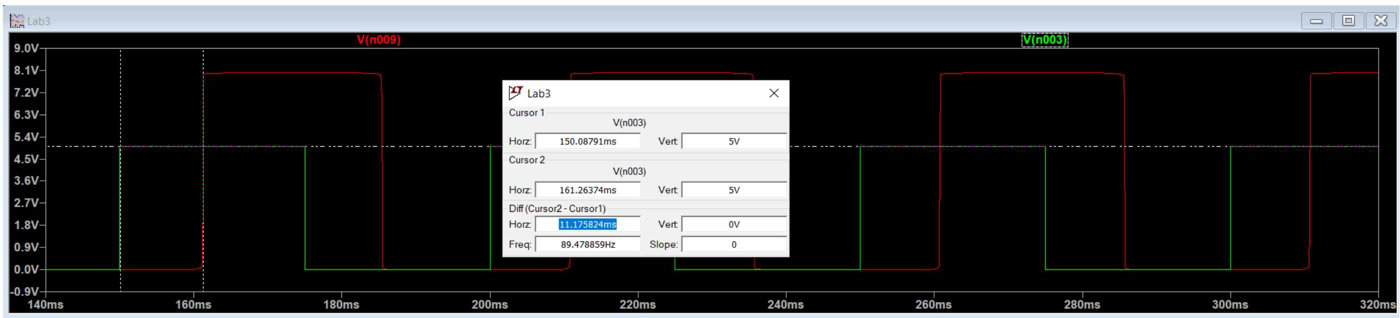


Figure 12 – Delay of 11ms Comparator

Delay: 11.17ms

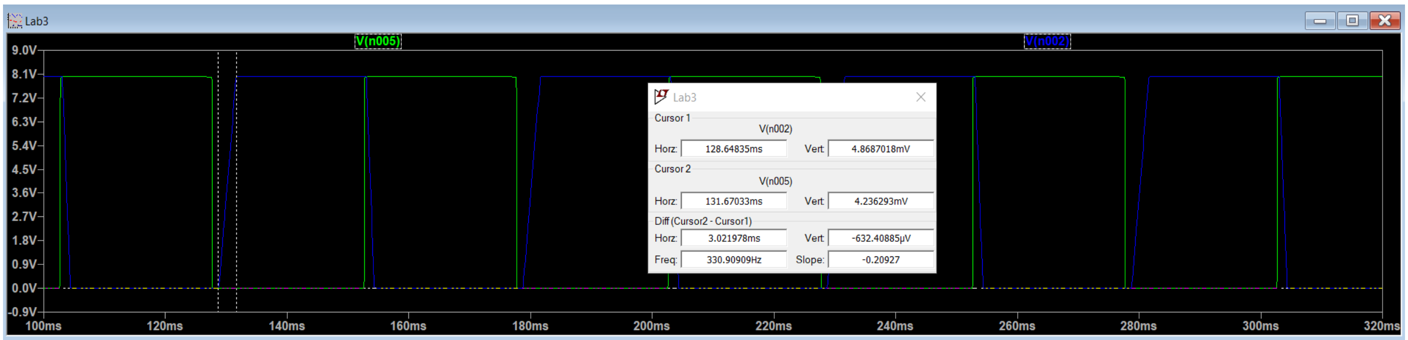


Figure 13 – The delay of Integrated wave

Delay: 3.02ms

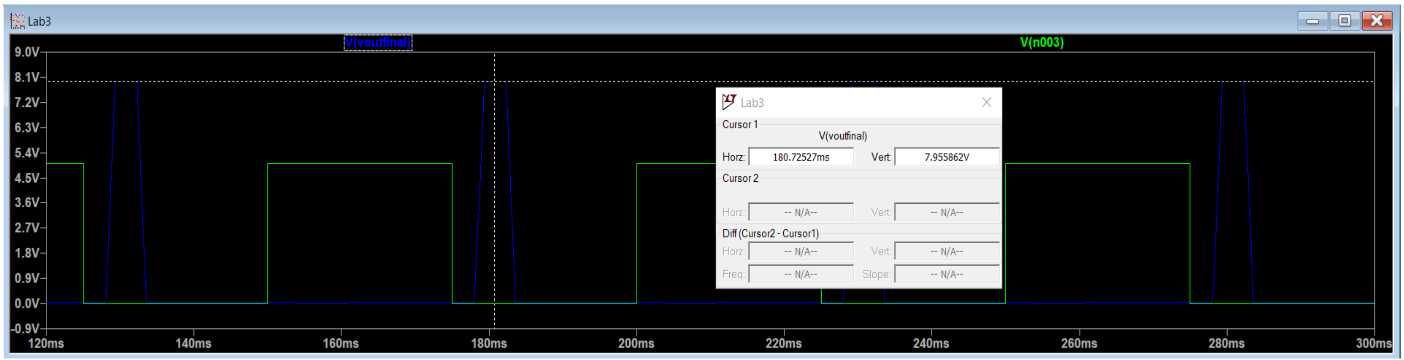
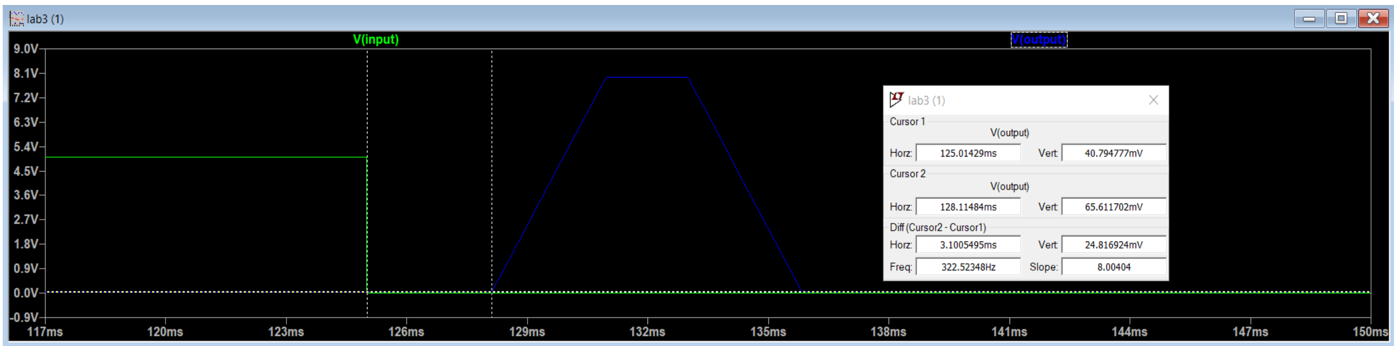


Figure 14 – Final result and 8V output voltage

$V_{out} = 7.95\ V$



$\Delta t_0 = 3.10$ms

Figure 15 - Δt_0

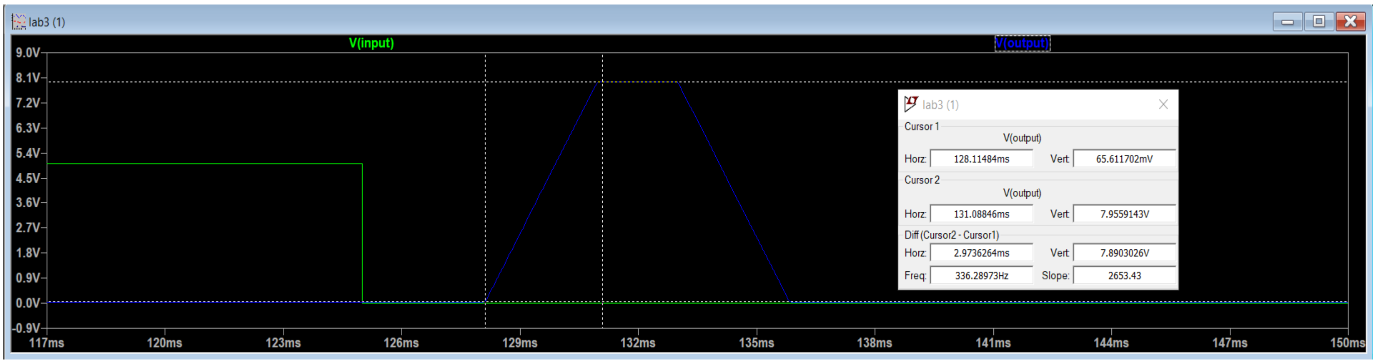


Figure 16 - Δt₁

$\Delta t_1 = 2.97$ms

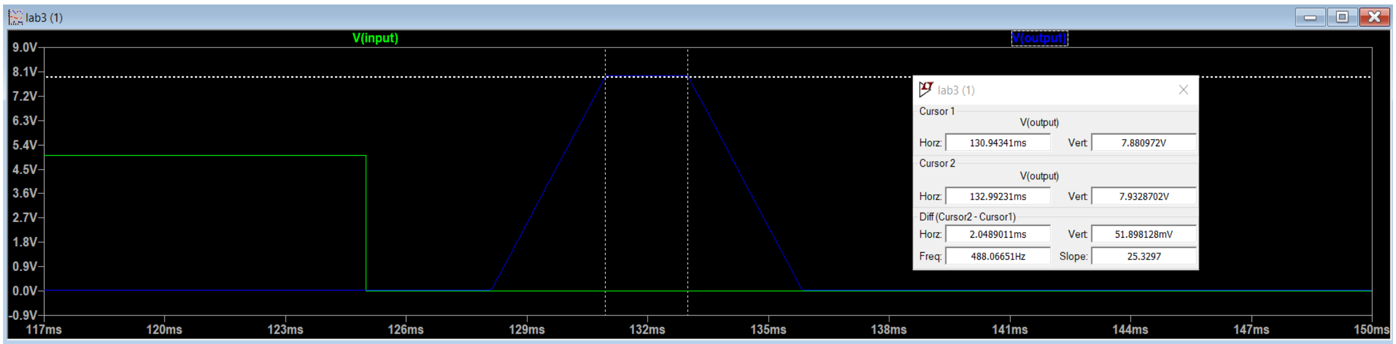


Figure 17 - Δt_2

$\Delta t_2 = 2.04$ms

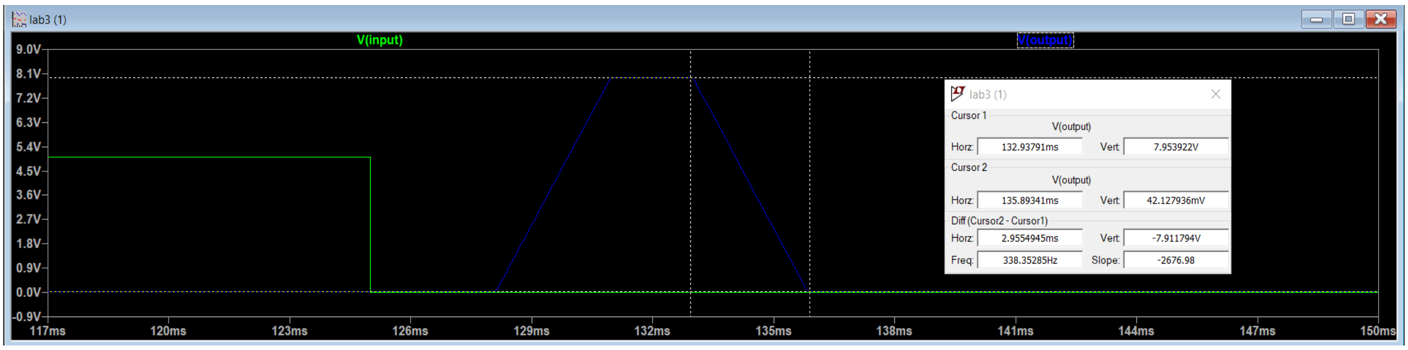


Figure 18 - Δt_3

$\Delta t_3 = 2.95$ms

Table 1- The Error table

	Δt_0	Δt_1	Δt_2	Δt_3
Expected Value	3ms	3ms	2ms	3ms
Simulation Value	3.10ms	2.97ms	2.04ms	3.95ms
Error	3.33%	1.0%	2%	2.7%

Hardware Results:

The results of Hardware Graph:

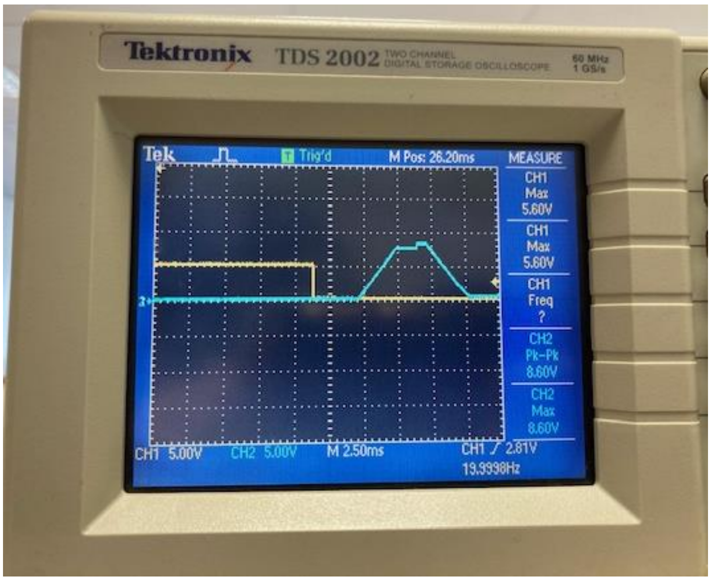


Figure 19 – Final output

V_{in} = 5.60 V

V_{out} = 8.60 V

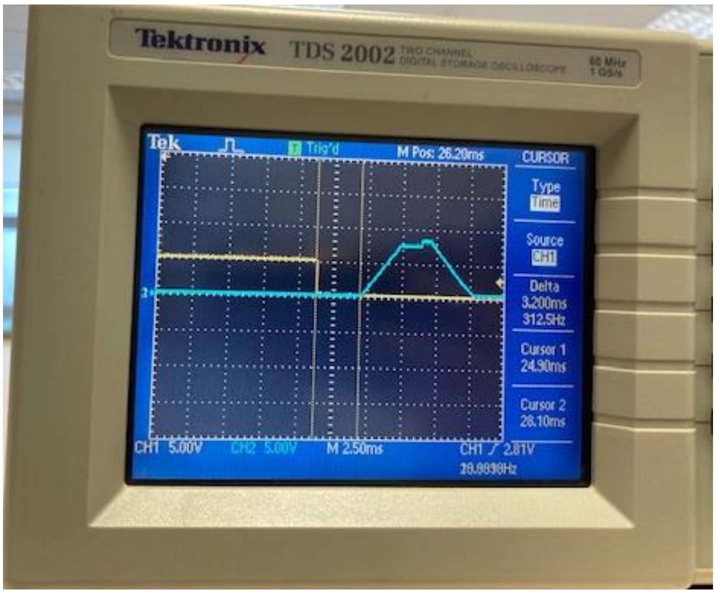


Figure 20 - Δt₀

$\Delta t_0 = 3.2$ms

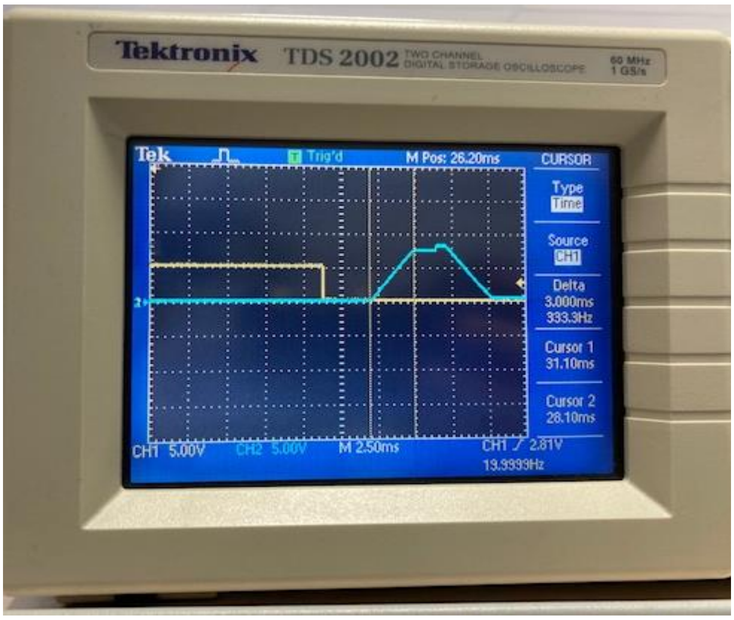


Figure 21 - Δt_1

$\Delta t_1 = 3.0$ms

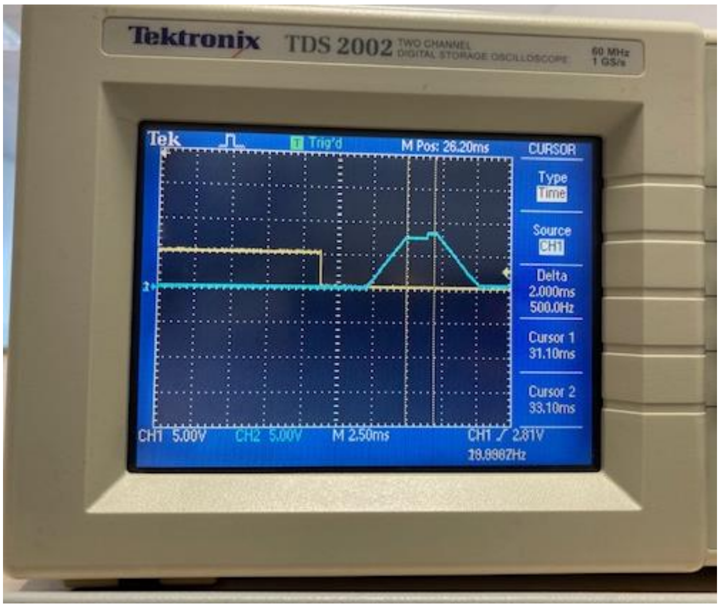


Figure 22 - Δt_2

$\Delta t_2 = 2.0$ms

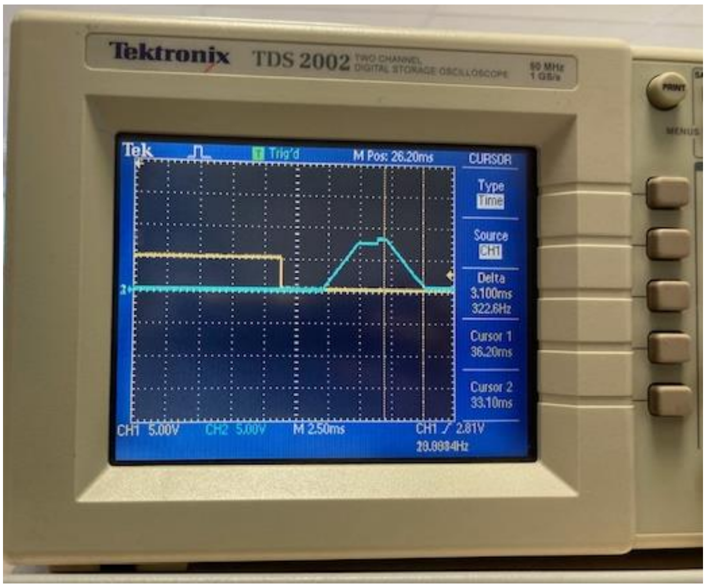


Figure 23 - Δt_3

$\Delta t_3 = 3.1$ms

Table 2- The Error table

	Δt_0	Δt_1	Δt_2	Δt_3
Expected Value	3ms	3ms	2ms	3ms
Hardware Value	3.2ms	3.0ms	2.0ms	3.1ms
Error	6.66 %	0%	0%	3.33%

Conclusion:

In this experiment, it is learnt how to create different forms of waves and create delays by using OPAMPs and RC circuits. The goal of this experiment to modify a given input waveform according to the desired specifications with delays which we successfully conduct. In order to do that it is used 3 methods which are shifting, integrating and subtracting. There are some errors occurred since we made scientific calculation by considering the OPAMP is real. However, in both simulation and the hardware, we used the LM324 library to obtain realistic results. The error percentage of simulation part is deviated from 1% - 3.33% and for the hardware part the error percentage deviate from 0% - 6.66%. If we did not make a change to the resistor values this percentage may be much higher. The reason behind of the errors are because of the OPAMPs are ideal. Since we made all of the calculation considering the OPAMP is ideal, when we implement on hardware and software, we could not reach the desired values precisely. Moreover, in the hardware part the wave we obtain on the oscilloscope was a little distorted at the top the waveform. This defection is occurred at the integrating part and when we inputted to the subtractor, there is a little spike is occurred. In order to solve this problem, resistor can be added to the negative feedback loop which is parallel to the capacitor in the integrator OPAMP.