Bilkent University

EE202-002 Lab 4 Report:

Waveform Generator

Mehmet Emre Uncu - 22003884

Purpose:

This lab aims to design a circuit that generates the voltage waveform shown in Figure 1. The design should be based on OPAMPs and RC circuits.

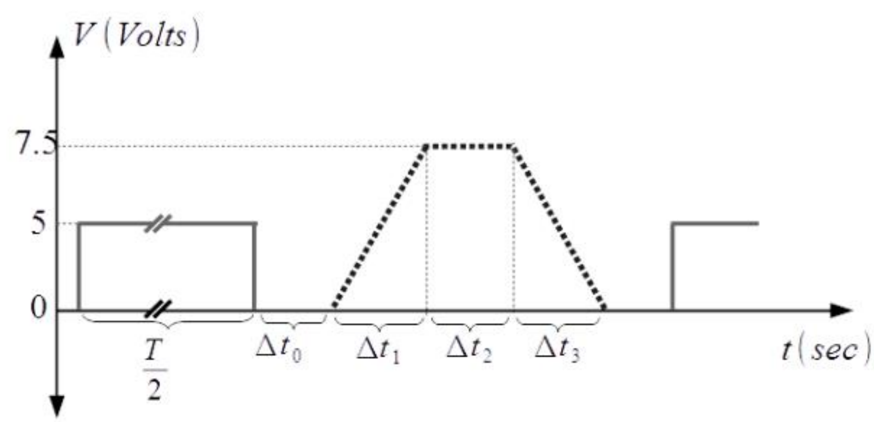

Figure 1: Desired Output and Input

- Δt_0 = 3ms, Δt_1= 2ms, Δt_2= 3ms, Δt_3= 2ms
- Input peak voltage: 5V
- Output peak voltage: 7.5V
- Input frequency: f < 50 Hz

Methodology:

Three stages are required to make the waveform seen in Figure 1. First, shift the square wave for 3ms and (3+2+3+2)10ms by implementing delays. Next, integrate the two waveforms to obtain the skew line shape. Finally, subtract waveforms to achieve the required shape.

Three different sources are used for the design. The V_{cc+} = 9V, V_{cc-} = 0V, the input for the comparator OPAMPs V_c = 2.5V, and lastly, the main input V_{in} is 5 Volt Pulse with 20Hz frequency.

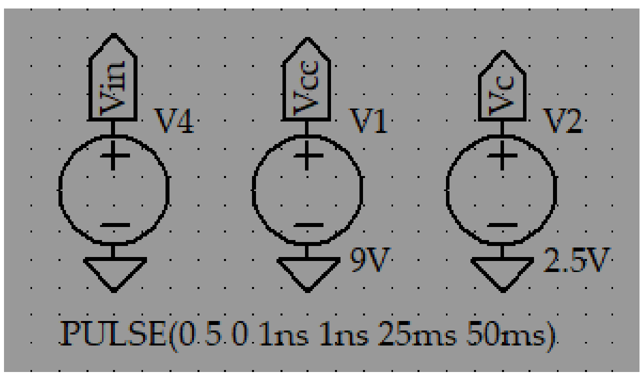

Figure 2: The Source Values

First, to generate delay, a comparator OPAMP circuit can be used. To produce two different delays, 3ms and 10ms, two different comparator OPAMP circuits should be designed after dividing the input into two. For both comparators, V_- has the threshold voltage that is V_c, and V_+ has the RC circuit. The OPAMP is positively saturated when the input (V_+) is greater than the reference voltage and negatively saturated when the input is less than the reference voltage. The calculations for comparator OPAMPs are as follows:

$$C * \frac{dV_C}{dt} = \frac{V_{in} - V_C}{R}$$

The characteristic equation is:

$$C * \lambda + \frac{1}{R} = 0 \text{ so, } \lambda = \frac{-1}{RC}$$

$$V_{C\,natural} = c_1 * e^{\frac{-t}{RC}}$$

Using the initial conditions t = 0 and V_C = 0, and $c_1 = -5$

$$V_C(t) = -5 * e^{\frac{-t}{RC}} + 5$$

For the 3ms delay, t = 3ms, and V_C = 2.5V

$$2.5 = -5 * e^{\frac{-3m}{R_1 * C_1}} + 5 \text{ so, } R_1 * C_1 = 0.0043$$

For the 3ms delay, t = 3ms, and V_C = 2.5V

$$2.5 = -5 * e^{\frac{-11m}{R_2 * C_2}} + 5 \text{ so, } R_2 * C_2 = 0.0144$$

Using these equations, the values are $R_1 = 10k\Omega, C_1 = 430nF$, for 3ms delay, and for 10ms delay, $R_2 = 100k\Omega$, $C_2 = 140nF$.

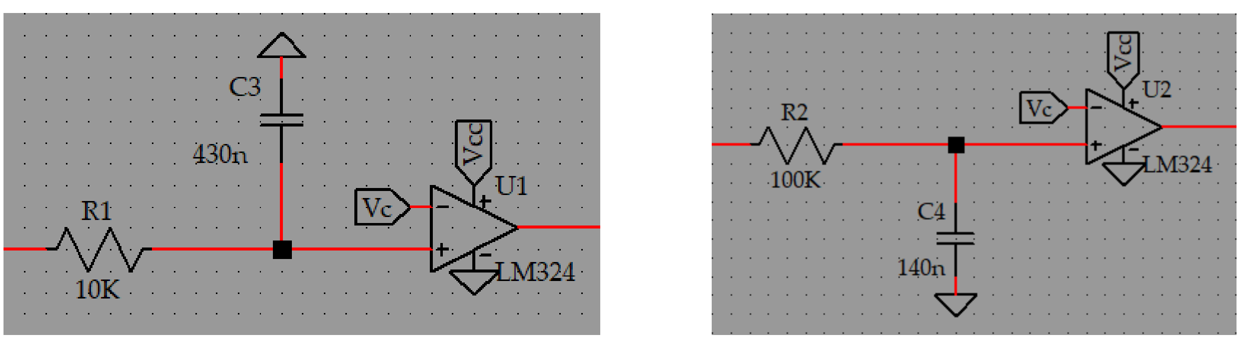

Figure 3: The 3ms and 10ms Delay Circuit

The next step is to produce the circuit's proper rise and fall times by converting these square voltage outputs to trapezoids. As the integrator OPAMP is known to triangulate a square waveform, it can be used to generate the required rise and fall times. The required rise and fall times are Δt_1 = 2ms and Δt_3 = 2ms. The calculations for integrator OPAMPs are as follows:

$$C * \frac{dV_C}{dt} = \frac{V_{in} - V_-}{R}$$

Using $V_+ = V_-$

$$dV_C = \frac{V_{in} - V_+}{RC} dt$$

Using the initial conditions t = 0 and V_C = 0, and integrating both sides

$$V_C = \frac{2.5}{RC} * t$$

For the 2ms rise and fall times, t = 2ms, and V_C = 7.5V

$$R * C = 6.66 * 10^{-4}$$

Using this equation, the values are $R = 1k\Omega,\ C = 660nF$ for both integrator OPAMPs as the rise and fall times are the same.

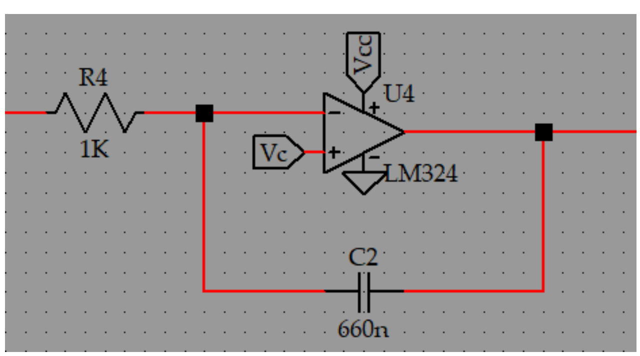

Figure 4: The Integrator OPAMP Circuit

Lastly, a subtractor OPAMP circuit is used. It is necessary to subtract these waveforms from each other to get the final desired output voltage waveform. The calculations for subtractor OPAMP are as follows:

Node equations in V_+ and V_-, respectively

$$\frac{V_+}{R_8} = \frac{V_{in1} - V_+}{R_5}$$

$$\frac{V_{in2} - V_-}{R_6} = \frac{V_- - V_{out}}{R_7}$$

Using $V_- = V_+$ and if all the resistors are chosen the same as $100K\Omega$

$$V_{in1} - V_{in2} = V_{out}$$

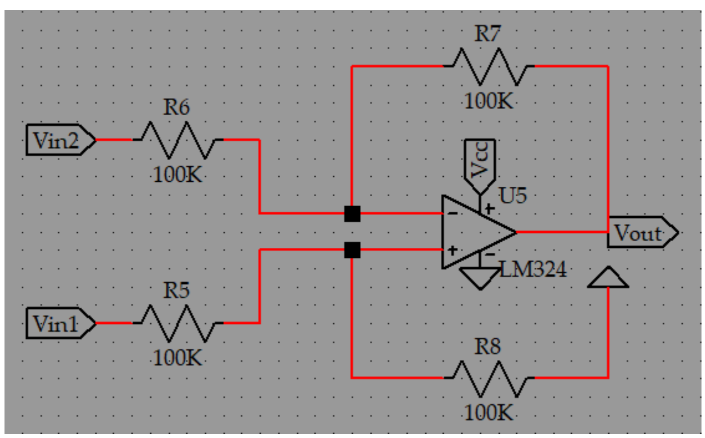

Figure 5: The Subtractor OPAMP Circuit

As a result of all the steps, the desired waveform is obtained.

Software Lab

The general view of the designed circuit is as follows.

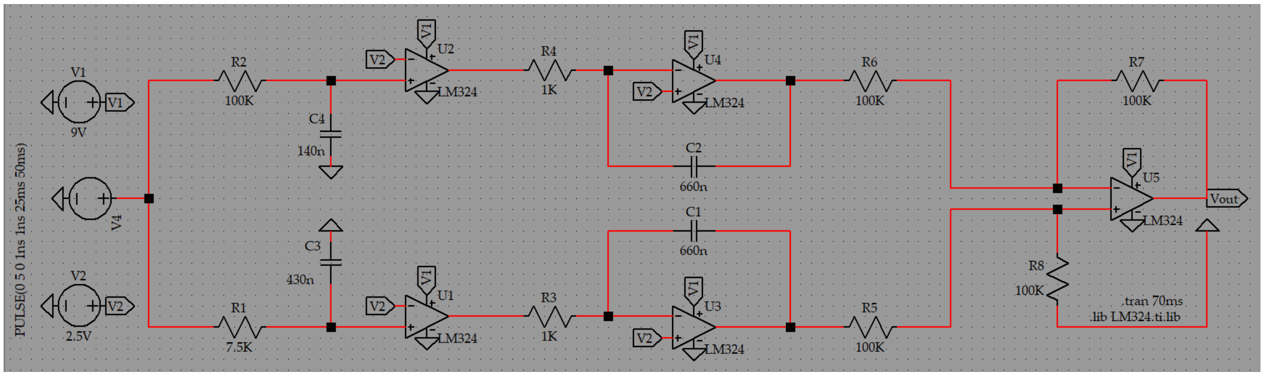

Figure 6: The Waveform Generator Circuit

The 3ms comparator circuit's 10k ohm resistor was changed with a 7.5k ohm resistor to reduce error.

Results for Comparators

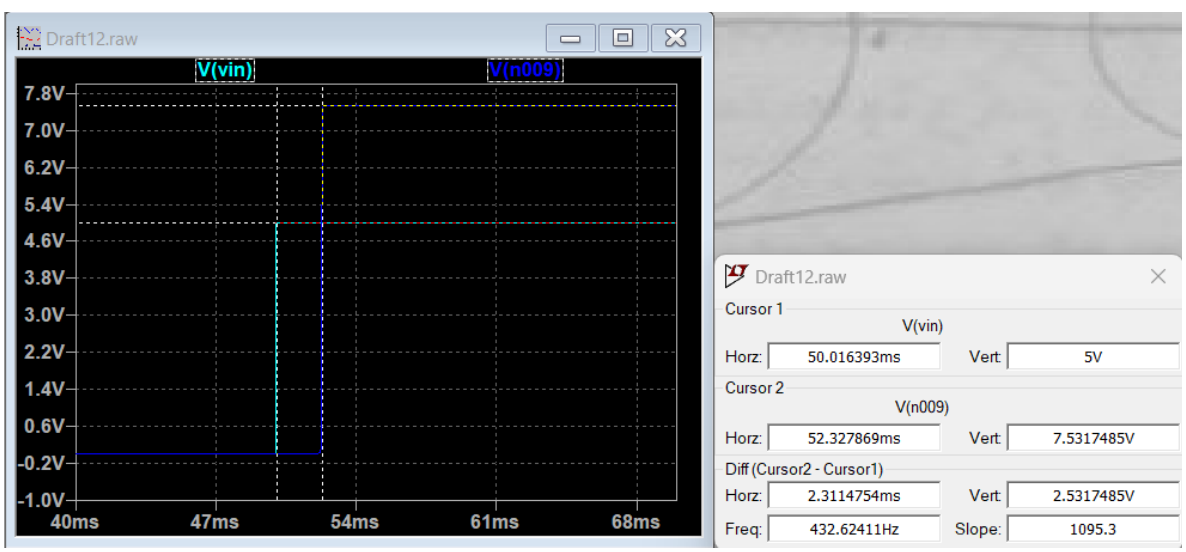

Figure 7: The 3ms Delay Circuit

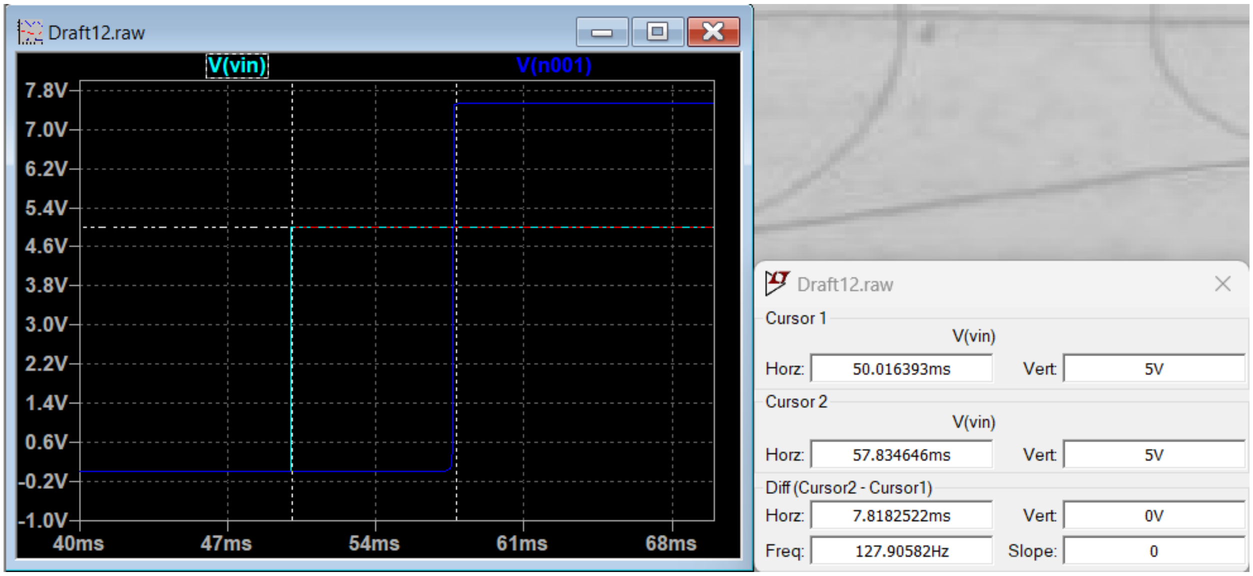

Figure 8: The 10ms Delay Circuit

When the delay created by the Integrator OPAMP circuits is considered, these values provide the 3ms and 10ms delay required for the desired waveform, even if these values are different than expected.

Results for Integrators

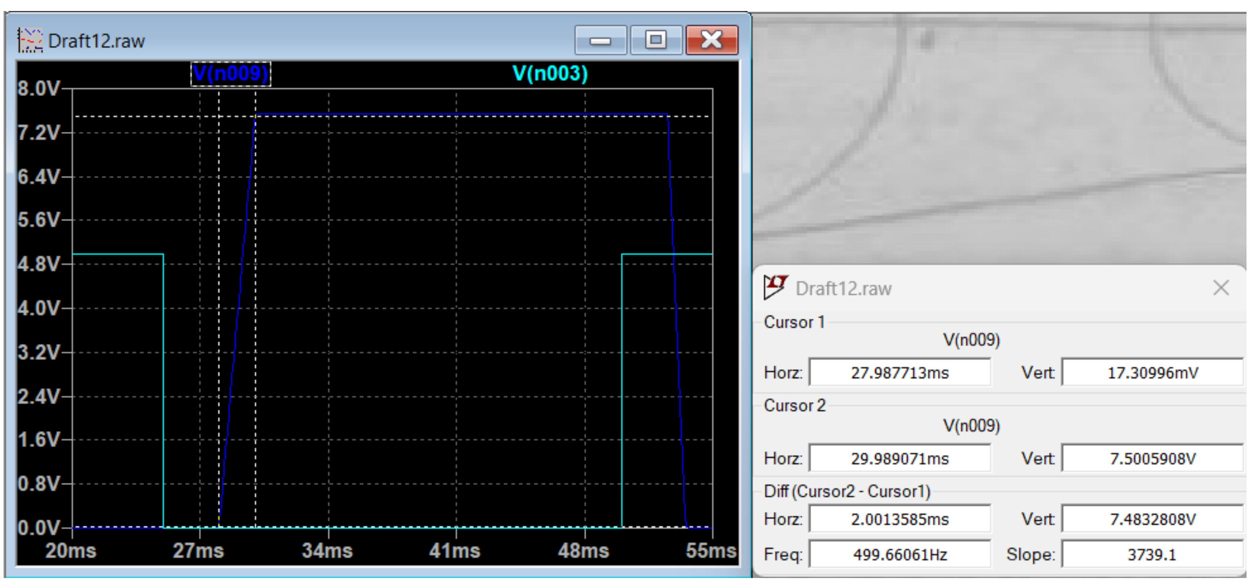

Figure 9: The First Integrator Circuit

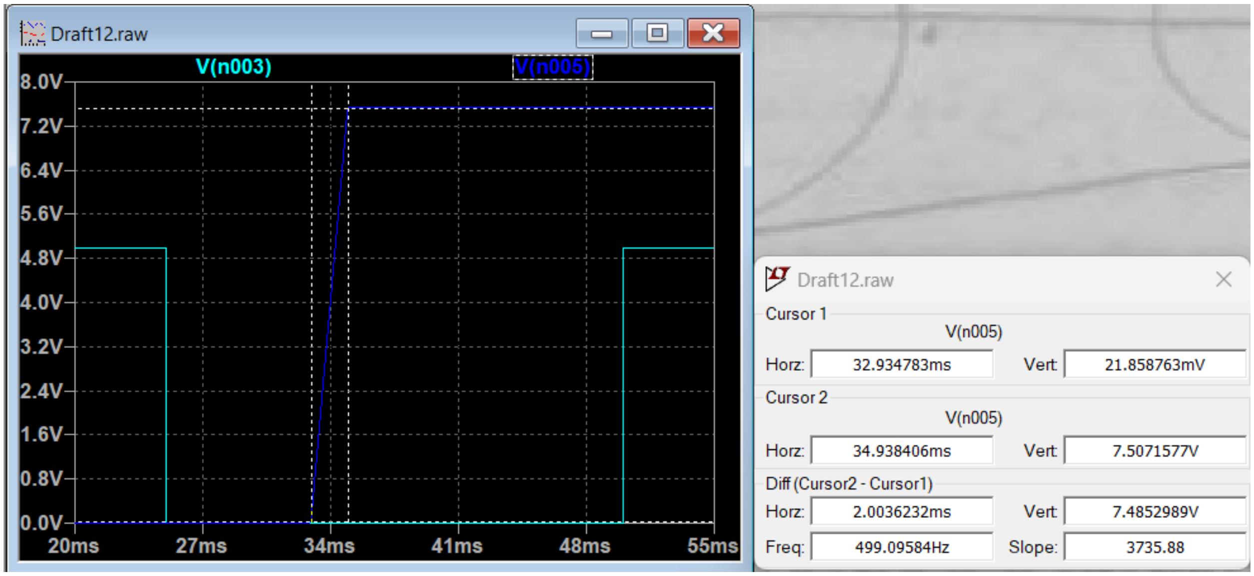

Figure 10: The Second Integrator Circuit

Results for Subtractor

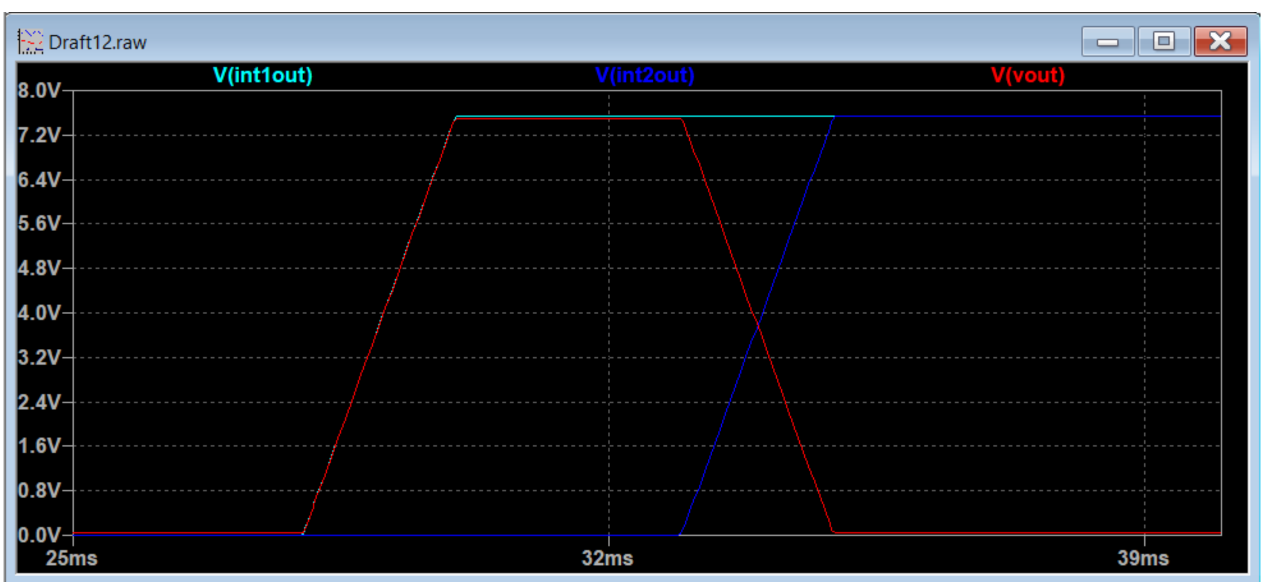

Figure 11: The Subtractor Circuit

Final Results

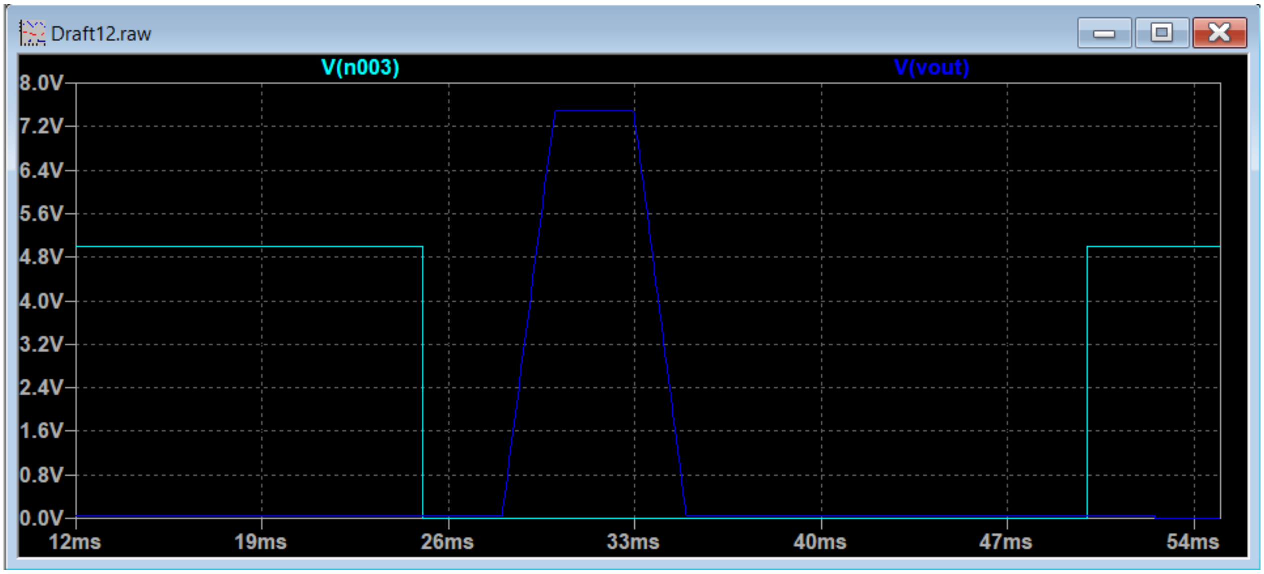

Figure 12: The Input and Desired Output Waveform

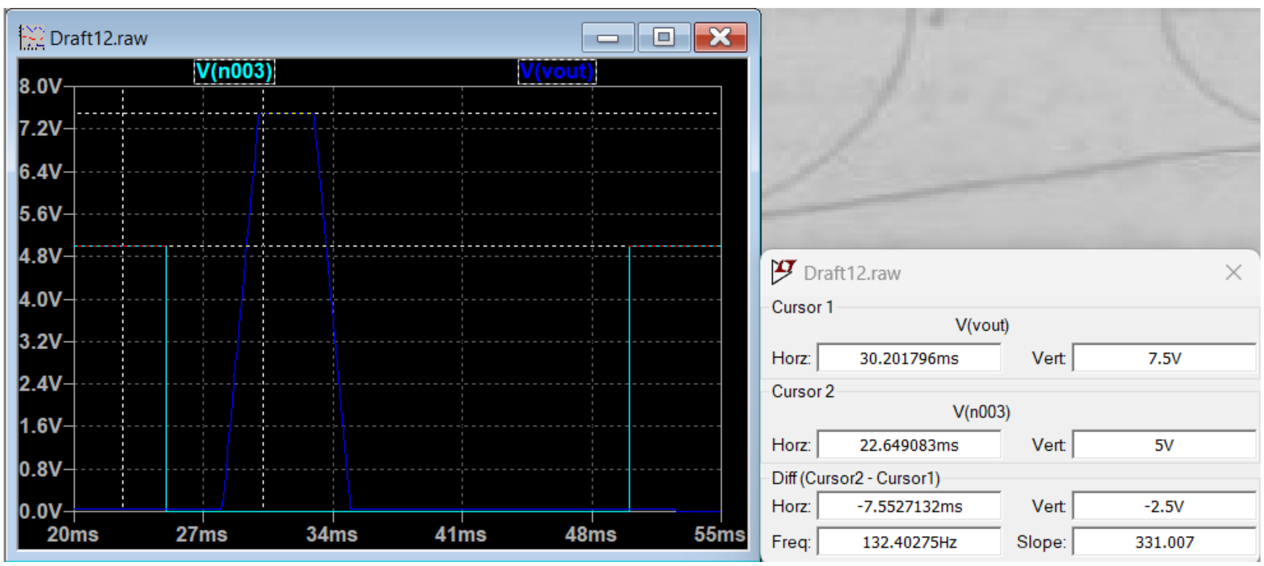

Figure 13: The Peak Voltage Values of Input and Output

Peak Voltage	Expected Result	Software Result	Error
20 Hz	7.50 V	7.50 V	0.00 %

Table 1: Software and Expected Results

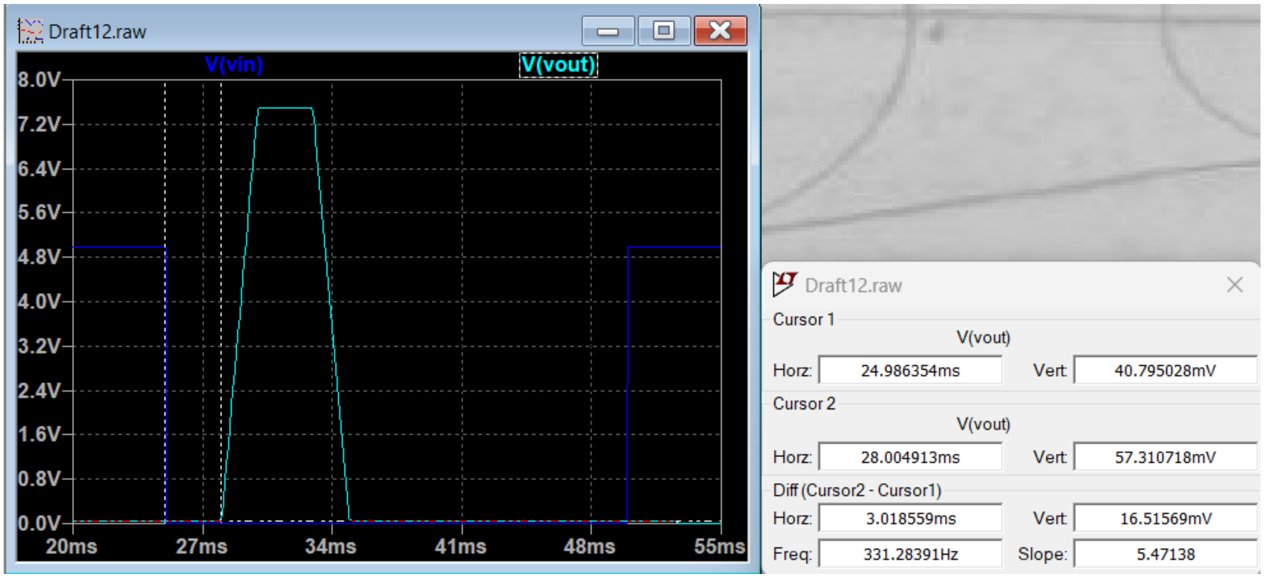

Figure 14: $\Delta\, t_0$

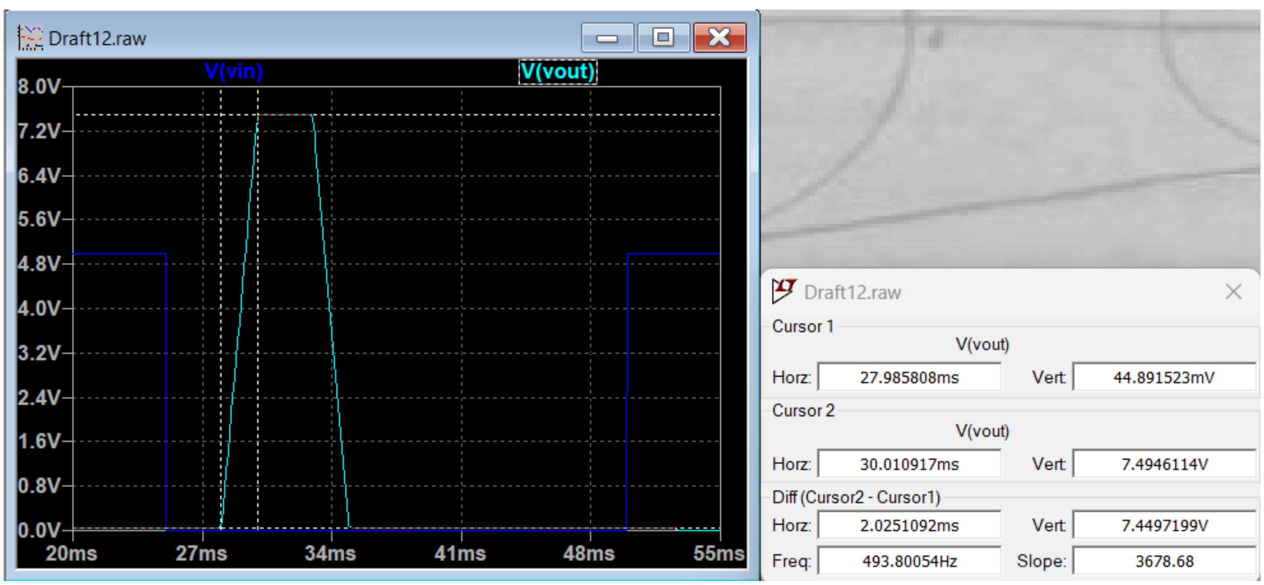

Figure 15: $\Delta\, t_1$

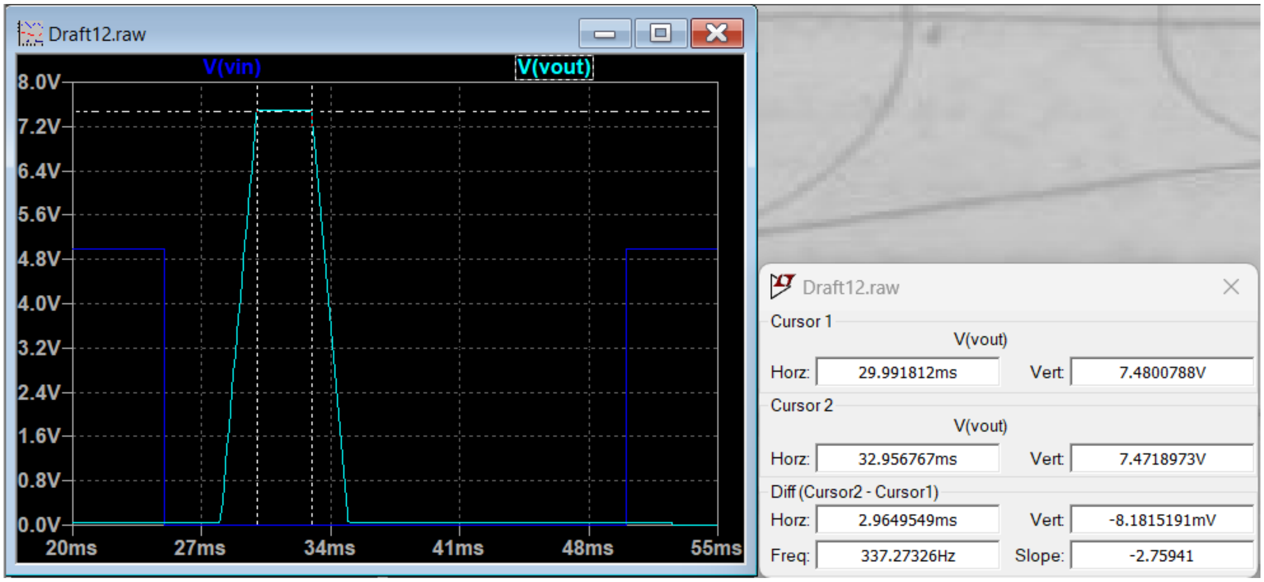

Figure 16: $\Delta\, t_2$

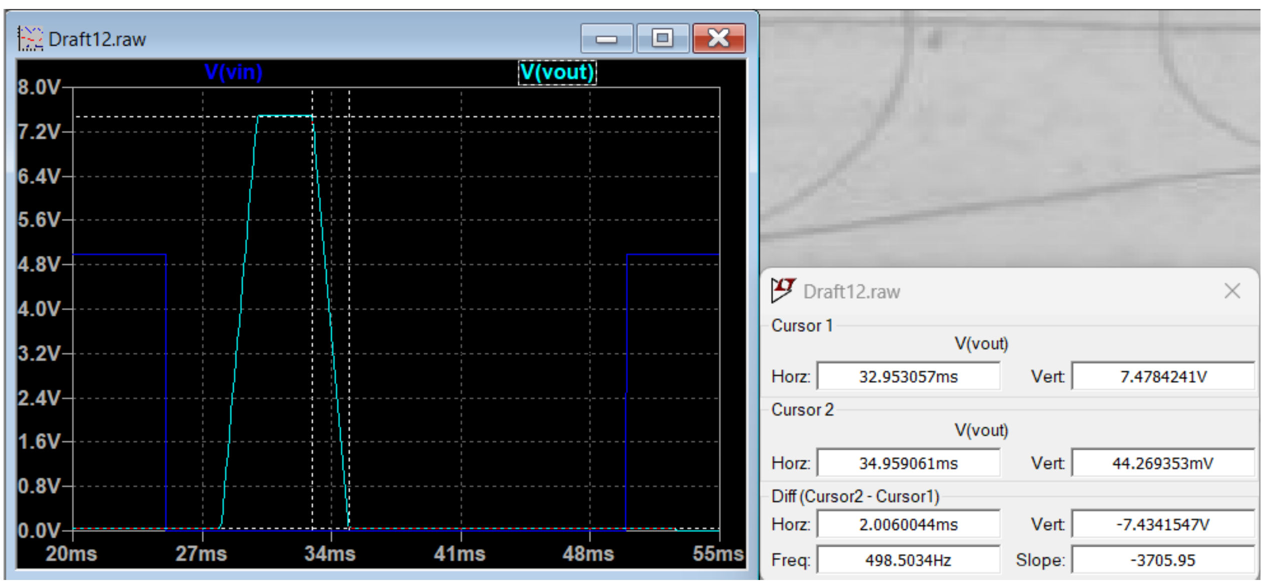

Figure 17: $\Delta\, t_3$

	Expected Result	**Software Result**	**Error**
$\Delta\, t_0$	3.00 ms	3.02 ms	0.67 %
$\Delta\, t_1$	2.00 ms	2.03 ms	1.50 %
$\Delta\, t_2$	3.00 ms	2.96 ms	1.33 %
$\Delta\, t_3$	2.00 ms	2.01 ms	0.50 %

Table 2: Software and Expected Results

<u>Hardware Lab</u>

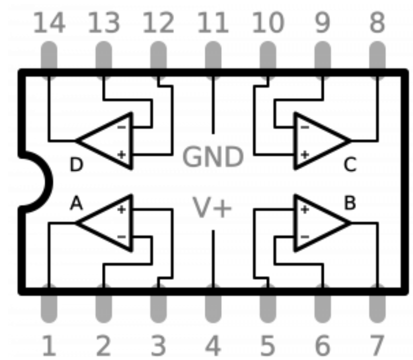

Figure 18: Pin Configuration of LM324 OPAMP

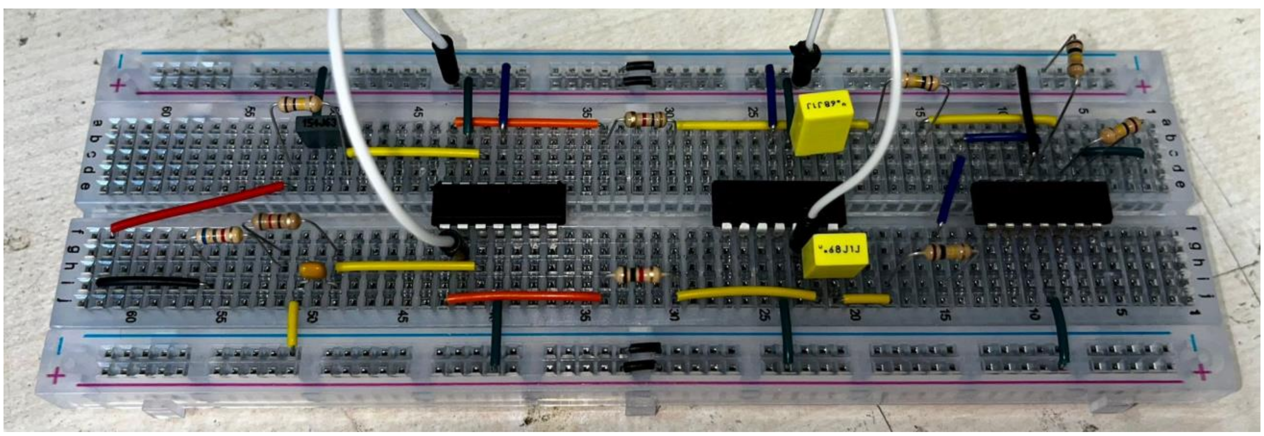

Figure 19: The Waveform Generator

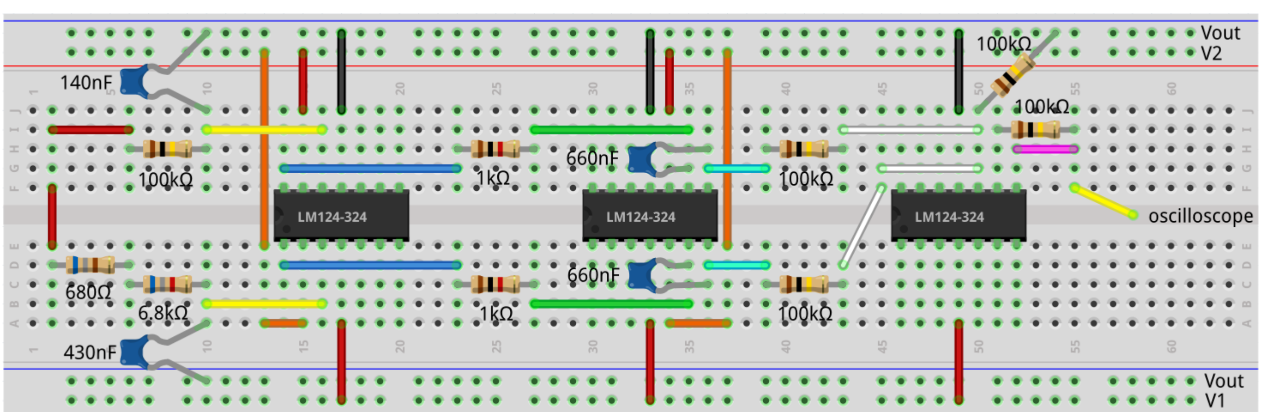

Figure 20: Schematics of Waveform Generator

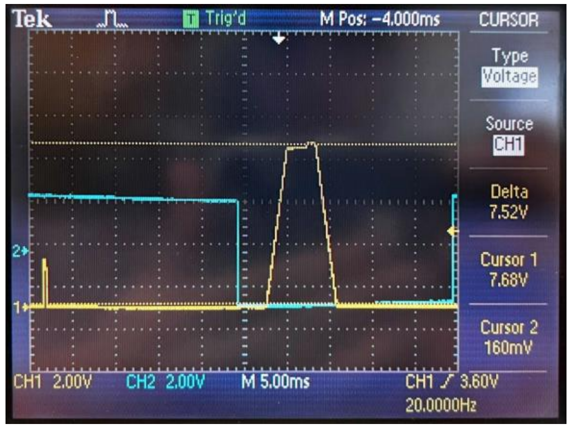

Figure 21: The Waveforms of Input and Output Voltage

20 Hz	Expected Result	Hardware Result	Error
Peak voltage	7.50 V	7.52 V	0.26 %

Figure 22: Hardware and Expected Results

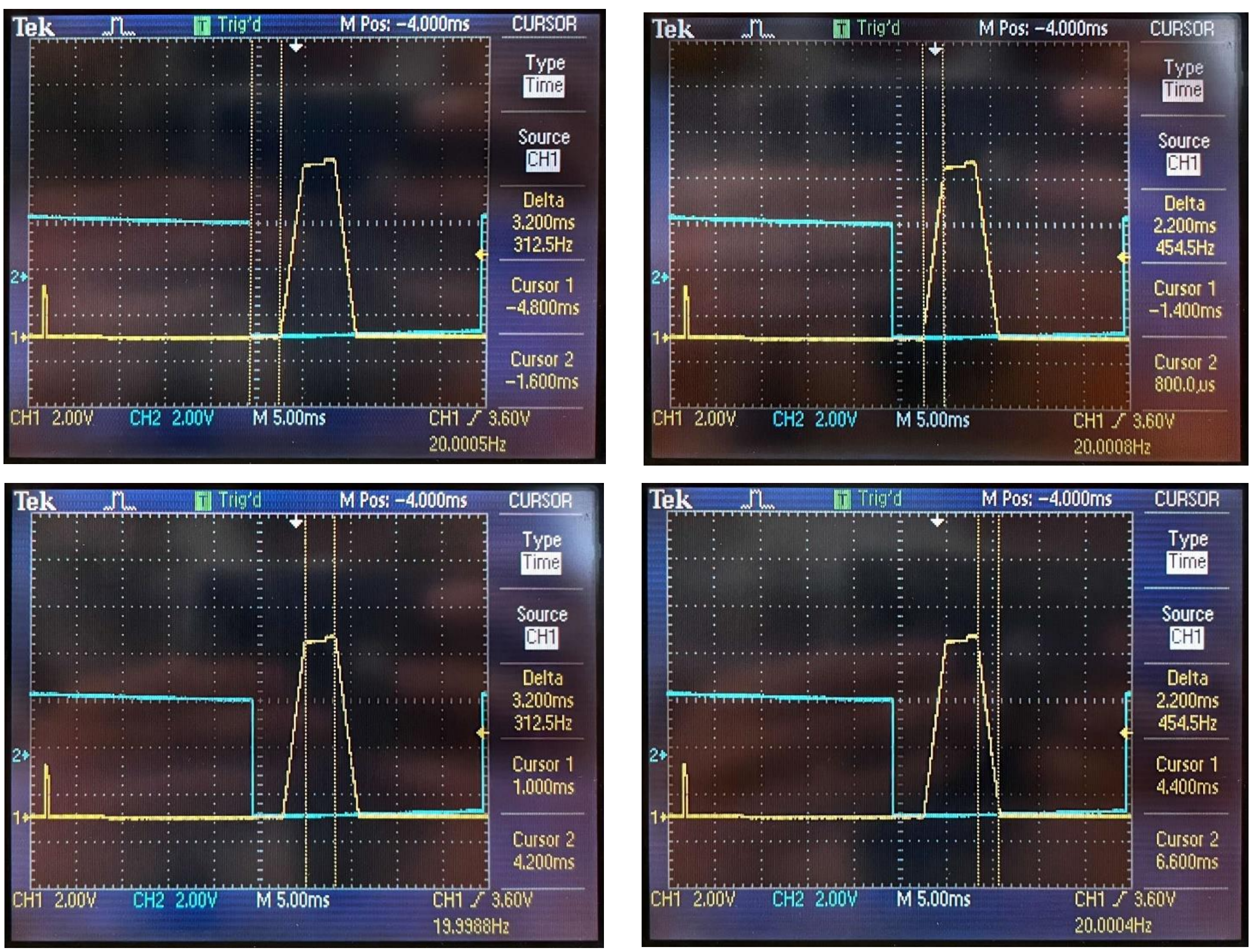

Figure 23: The Results of Δt_0, Δt_1, Δt_2 and, Δt_3

20 Hz	Expected Result	Hardware Result	Error
Δt_0	3.00 ms	3.20 ms	6.67 %
Δt_1	2.00 ms	2.20 ms	10.0 %
Δt_2	3.00 ms	3.20 ms	6.67 %
Δt_3	2.00 ms	2.20 ms	10.0 %

Figure 24: Hardware and Expected Results

Conclusion

This lab aimed to design a circuit that modifies the input waveform using OPAMPs and RC circuits to create the desired waveform. This waveform was made in three steps. First, the comparator OPAMP circuits were used for generating 3ms and 10ms delays. Then, the integrator OPAMP circuits were used to triangulate the pulse input and obtain proper rise and fall times. Lastly, the subtractor OPAMP circuit was used to subtract the waveforms from each other and get the desired output waveform. The values of the circuit simulated in the software part and the value of the circuit implemented on the breadboard in the hardware part were compared with the expected values , and tables were created. The errors between 0.26 % - 10.0 % occurred in the waveform values due to the non-linear components in OPAMP and imprecise component values, and the material quality or sensitivity of the oscilloscope, signal generator, and breadboard. In summary, thanks to this lab, it was learned how to convert a given waveform to another waveform and how different types of OPAMPs work together.