Bilkent University
EE202-002 Lab 1 Report:
Time-Domain and Frequency-Domain Analyses in LTSpice

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Purpose:

The purpose of this lab is to perform time-domain and frequency-domain analyses on different circuits using LTSpice software and to familiarize with this software and the elements that will be used for later labs. In addition, some of the created circuits will be implemented on the breadboard and the values obtained from the oscilloscope will be compared with the LTSpice values. Thus, circuits will be examined in both software and hardware.

Software Lab

Part 1: Transient (time-domain) Analysis

1.1- Voltage Divider

In this part, we are expected to create the voltage divider circuit in Figure 1 and do a time domain analysis.

- Picked value for R1 is 2.2 Ohm between 1-5 Ohms

- Picked value for R1 is 15 Ohm between 10-20 Ohms

- Picked values for voltage and frequency are 7.5 volts and 5kHz between 5-10 V and 5-10 kHz

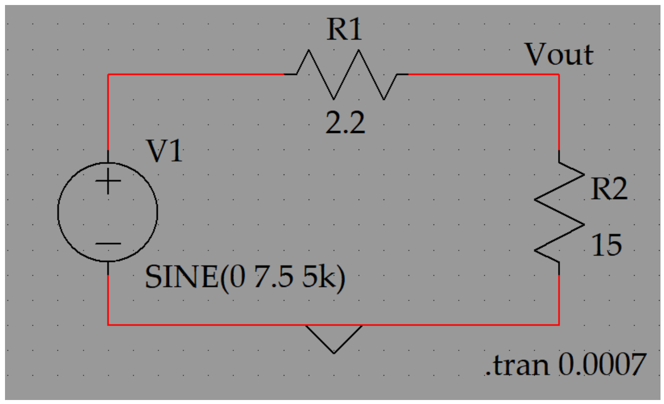

Figure 1: Voltage Divider Circuit

In LTSpice the peak voltage value of Vout should be 6.54 V from the voltage divider formula.

$$V_{out} = V_{in} * \frac{R_2}{R_1 + R_2}$$

1.1- Results

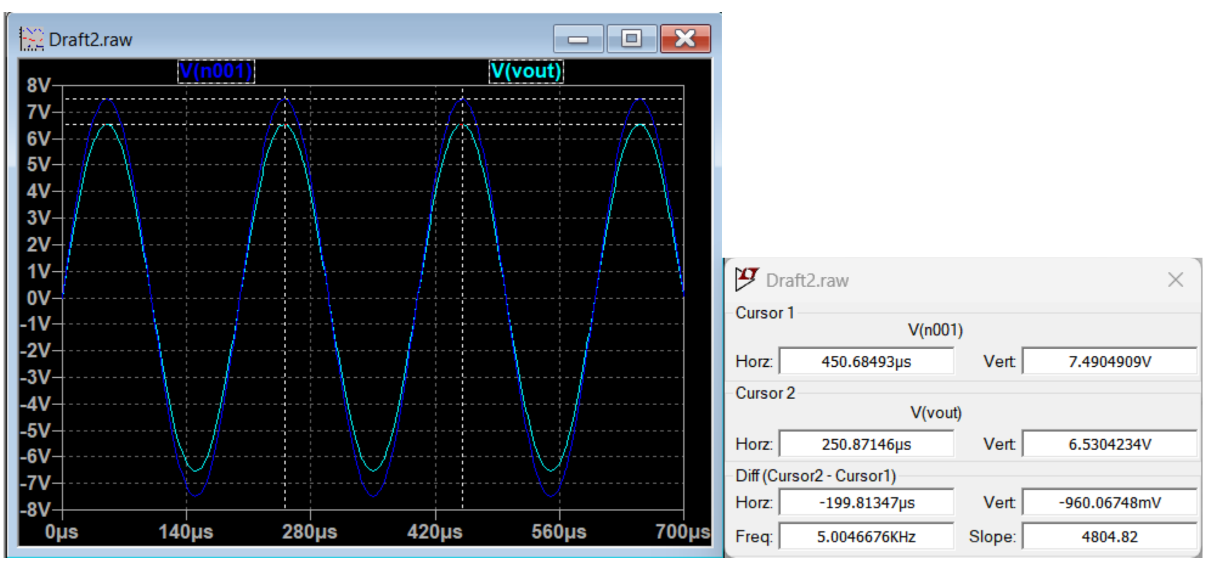

Figure 2: Time Analysis and Peak Voltage Value of Vin and Vout on Voltage Divider Circuit

The peak voltage value of Vout was measured as 6.53V. The expected value is 6.54V and the error is %0.15.

1.2- RL Circuit

After that, we are expected to replace the R2 with an inductor on the voltage divider circuit and create the RL circuit in Figure 3 and do a time domain analysis.

- Picked value for R1 is 27 Ohm between 10-50 Ohms
- Picked value for L1 is 47 µH between 8.2 µH, 10 µH, 47 µH, 100 µH
- Picked value for the amplitude of the sinusoidal voltage is 5V
- Picked values for frequencies of sinusoidal voltage are 100kHz, 10kHz and 500kHz

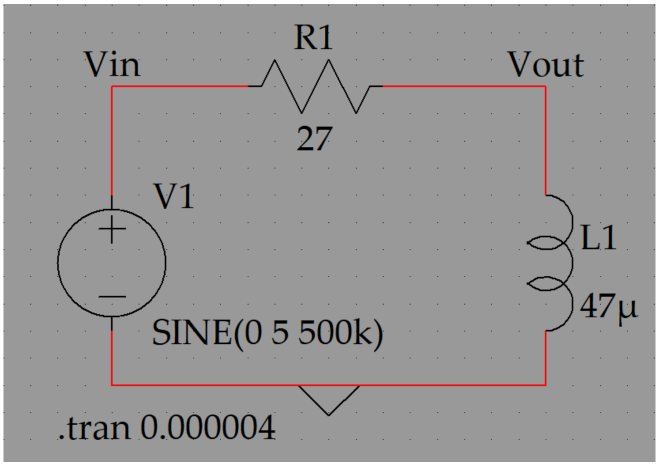

Figure 3: RL Circuit

From the Transfer Function formula, the equation for Vout is:

$$V_{out} = 5(-j) * \frac{j2\pi fL}{27 + j2\pi fL}$$

Where, Vin= 5(-j) in phasor form. So in LTSpice, the peak voltage values of Vout should be:

- 3.71 V for 100kHz
- 545.6 mV for 10kHz
- 4.73 V for 500 kHz

1.2- Results

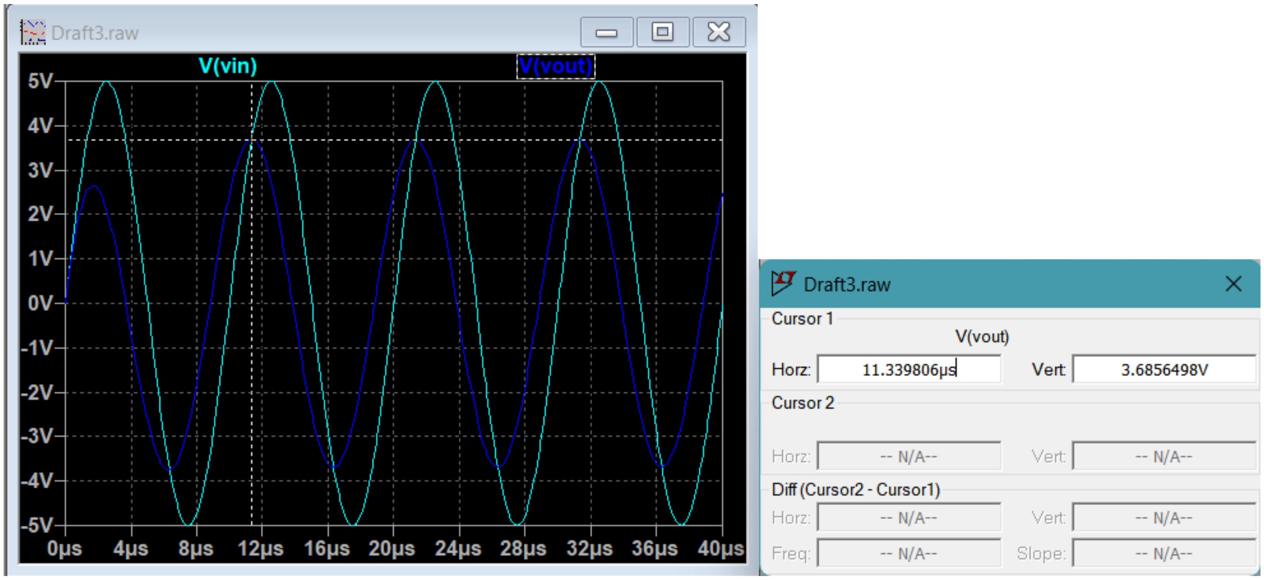

Figure 4: Time Analysis and Peak Voltage Value of Vin and Vout on RL Circuit for 100kHz

For 100kHz the peak voltage value of Vout was measured as 3.67V. The expected value is 3.71V and the error is %1.01.

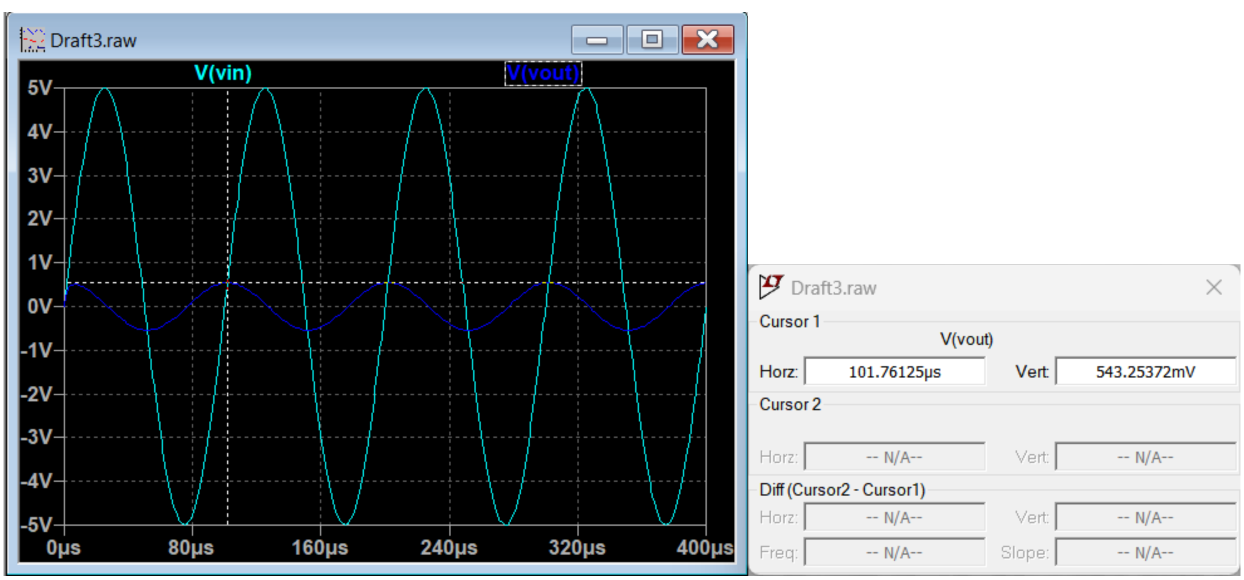

Figure 5: Time Analysis and Peak Voltage Value of Vin and Vout on RL Circuit for 10kHz

For 10kHz the peak voltage value of Vout was measured as 543.3 mV. The expected value is 545.6 mV and the error is %0.42.

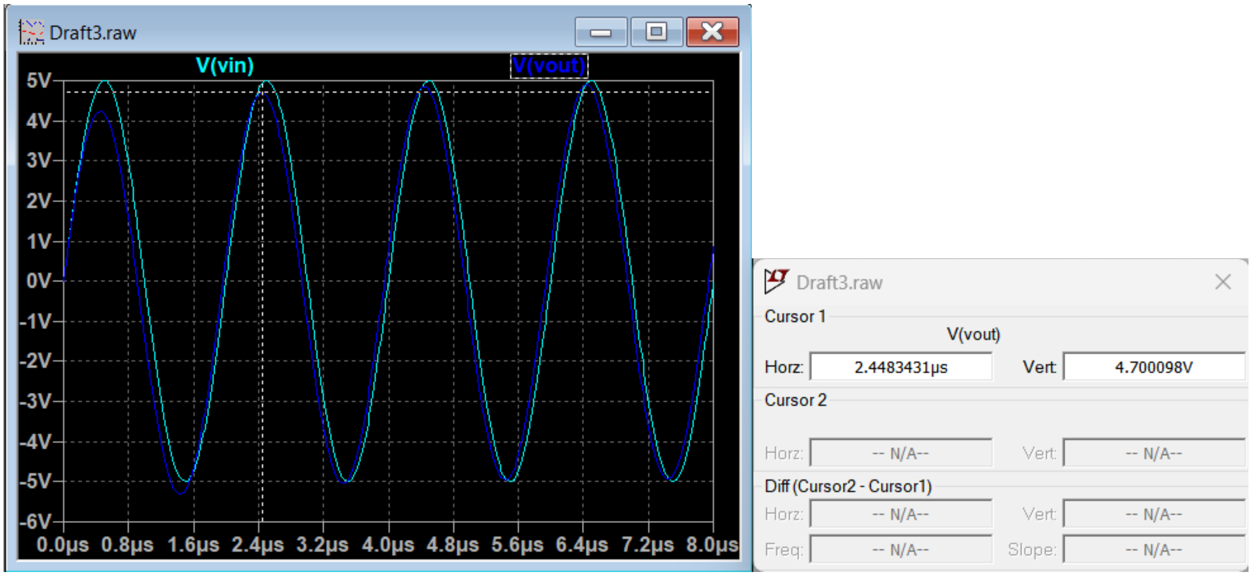

Figure 6: Time Analysis and Peak Voltage Value of Vin and Vout on RL Circuit for 500kHz

For 500kHz the peak voltage value of Vout was measured as 4.70 V. The expected value is 4.73 V and the error is %0.64.

As can be understood from these three different frequency values tried, this circuit gives higher Vout voltage values at high-frequency values. Therefore, it can be deduced that this circuit is a high-pass filter.

Part 2: AC (frequency-domain) Analysis

2.1- AC Analysis without Source Resistance

For part 2.1, for the circuit in which Transient Analysis was made in part 1.2, AC Analysis will be done this time. For this, the type of sweep was set to decade and the start and stop frequencies were determined to analyze 100 Hz to 10 MHz. Also, the voltage source is set for small signal AC analysis with an AC amplitude of 5. As a result, it is expected to see the change in the magnitude and phase of the output with respect to frequency, plotted on a logarithmic axis

2.1- Results

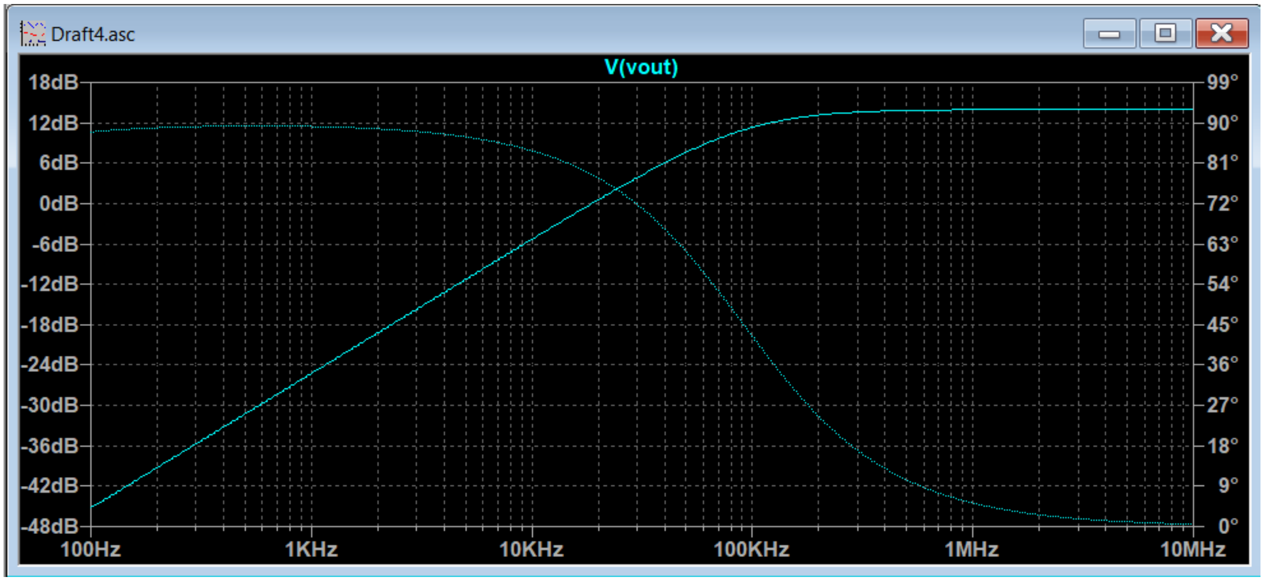

Figure 7: AC Analysis and logarithmic plot on Vout

As stated in part 1.2, this circuit is a high-pass filter as it passes better at higher frequencies.

2.2- AC Analysis with Source Resistance

Since there is a 50 Ohm internal series resistance in the voltage sources used in the lab, it would be more accurate to use a 50 Ohm resistor in series with the voltage source in the circuit created in LTSpice to obtain a more accurate result with the result obtained in the hardware part. The circuit formed after adding the resistor is as in Figure 8.

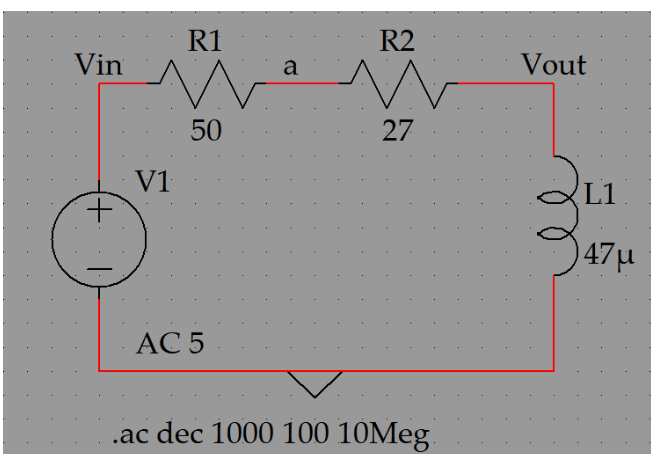

Figure 8: RL Circuit with Source Resistance

2.2- Results

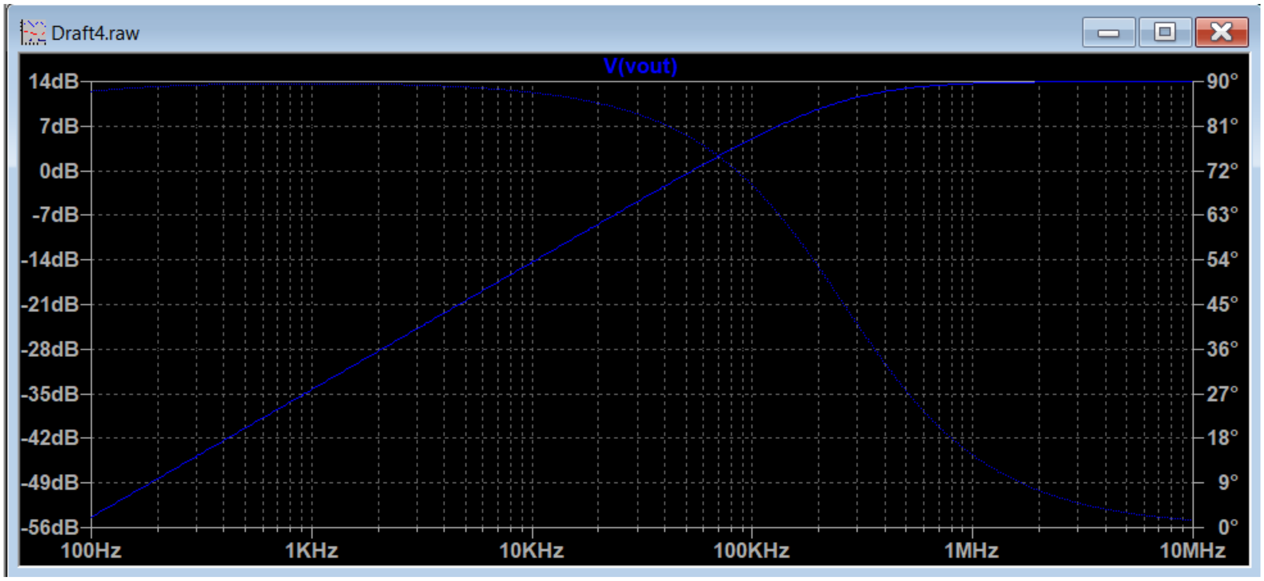

Figure 9: AC Analysis of RL Circuit with Source Resistance

When this plot is compared with Figure 7 in part 2.1, the total resistance increases due to the source resistance in the realistic model. Therefore, the RL circuit with the source resistor reaches the maximum voltage value later than the RL circuit without the source resistor. It can also be seen that the cut-off frequency goes from about 100k Hz to around 600k Hz.

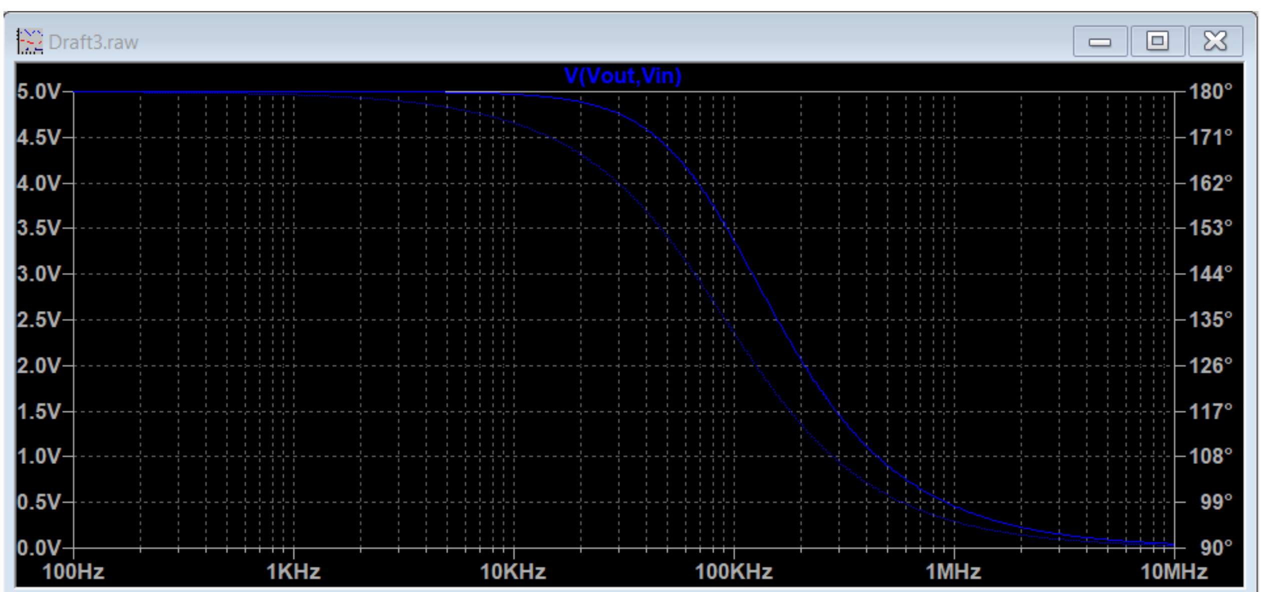

Figure 10: Voltage Difference of RL Circuit without Source Resistance

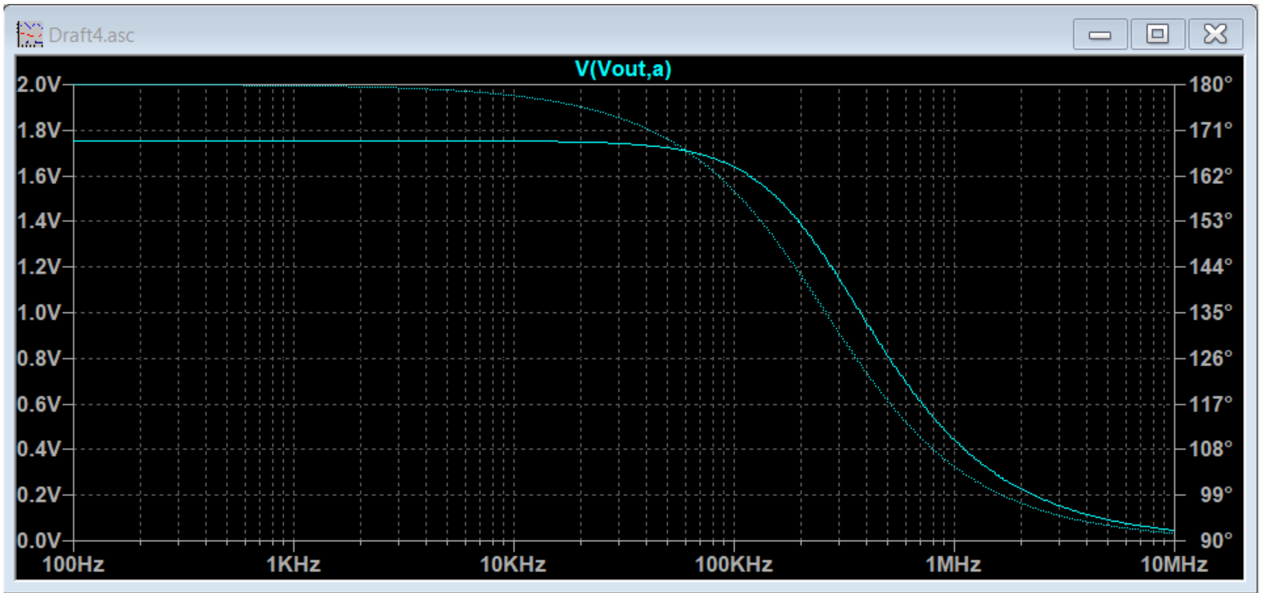

Figure 11: Voltage Difference of RL Circuit with Source Resistance

When we look at the difference between the output voltage and the voltage after the source resistance, it is seen that the starting voltage of the realistic model is lower. This is the voltage loss due to the 50 Ohm resistance added as the source resistance.

Part 3: OPAMP Circuits

3.1- OPAMP Circuit with Resistors

In this part, the basic OPAMP circuit will be simulated. The circuit below was constructed and LM324 was added from the library.

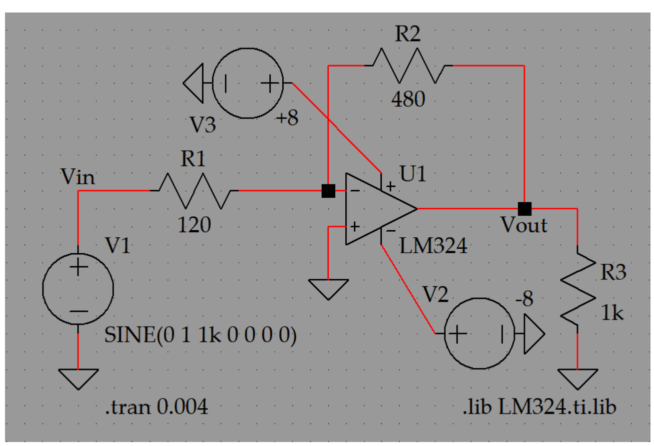

Figure 12: OPAMP Circuit with resistors

- Picked value for the DC voltage of OPAMP is 8 V, between 6-10 V

- Picked value for R1 is 120 Ohm, between 100-500 Ohm

- Picked value for R2 is 480 Ohm such that R2/R1 = 4

- The input voltage is set to a sinusoidal wave with an amplitude of 1V, and 1 kHz frequency

3.1- Results

If KCL is done at the inputs of the OPAMP, the following result is obtained.

$$\frac{V_{out}}{R_2} = \frac{0 - V_{in}}{R_1}$$

$$V_{out} = -\frac{R_2}{R_1} * V_{in}$$

As can be said this is an inverting amplifier because it increases and reverses the input voltage at a certain rate.

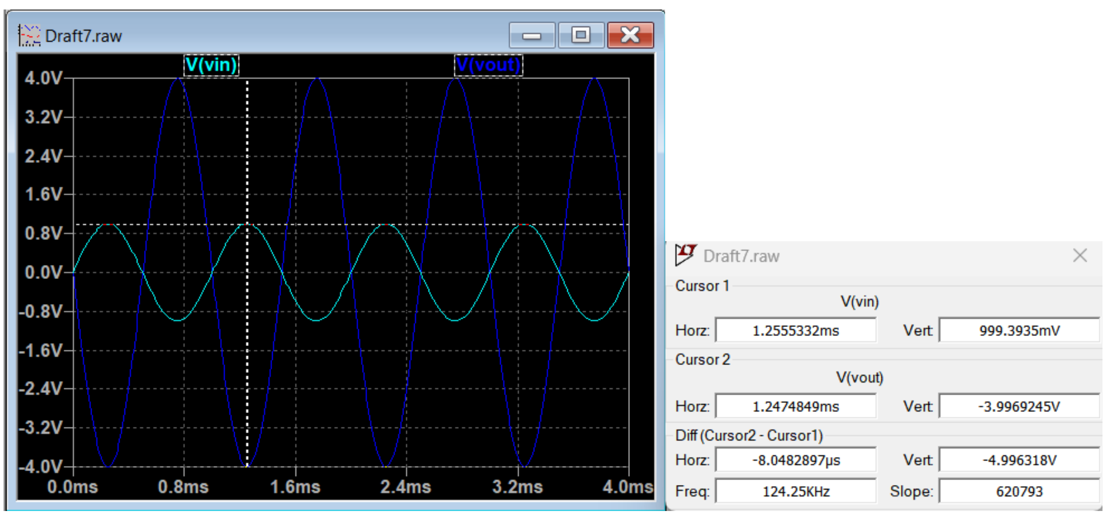

Figure 13: Peak Voltage Value of Vin and Vout on OPAMP Circuit with Resistors

Since the R2/R1 ratio is 4 in the circuit created, the inverting amplifier transmits the 1 V input voltage to the output as -4 V.

3.2- Saturation on OPAMP Circuit

For this part firstly, we are expected to change the input source to a square wave (pulse) with the 1V amplitude with a 1ms period and 50% duty cycle and set it to rise and fall times to

10ns. Afterward, it will be observed that OPAMP is saturated by increasing the R2/R1 ratio. For this, the values of 480 Ohm, 840 Ohm, and 1200 Ohm will be given to R2. In case the R2/R1 ratio exceeds 8, Vout is expected to remain constant at 8 V.

3.2- Results

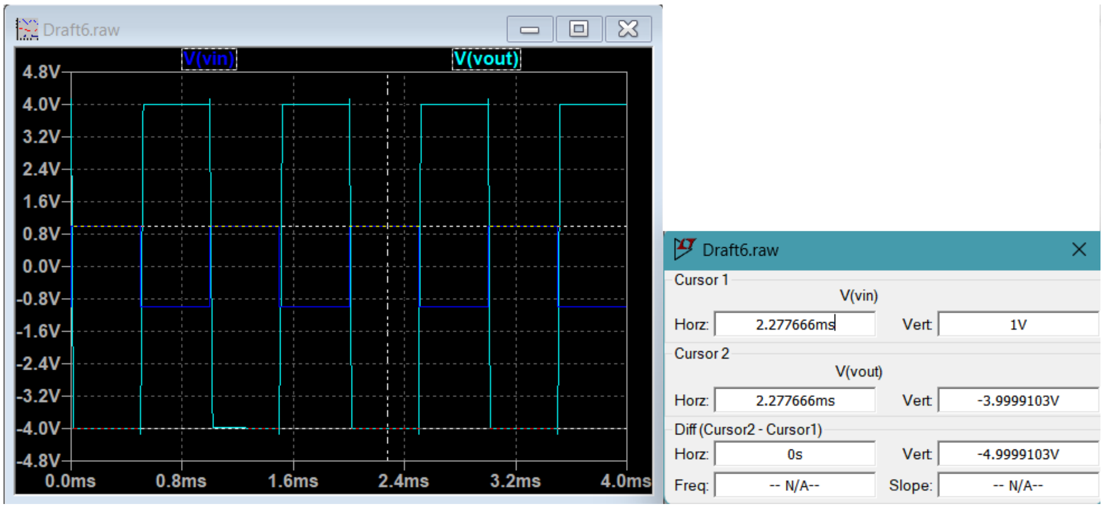

Figure 14: Peak Voltage Value of Vin and Vout on OPAMP Circuit when R2 is 480 Ohm

Since the R2/R1 ratio is 4 in the circuit created, the inverting amplifier transmits the 1 V input voltage to the output as -4 V as a square wave.

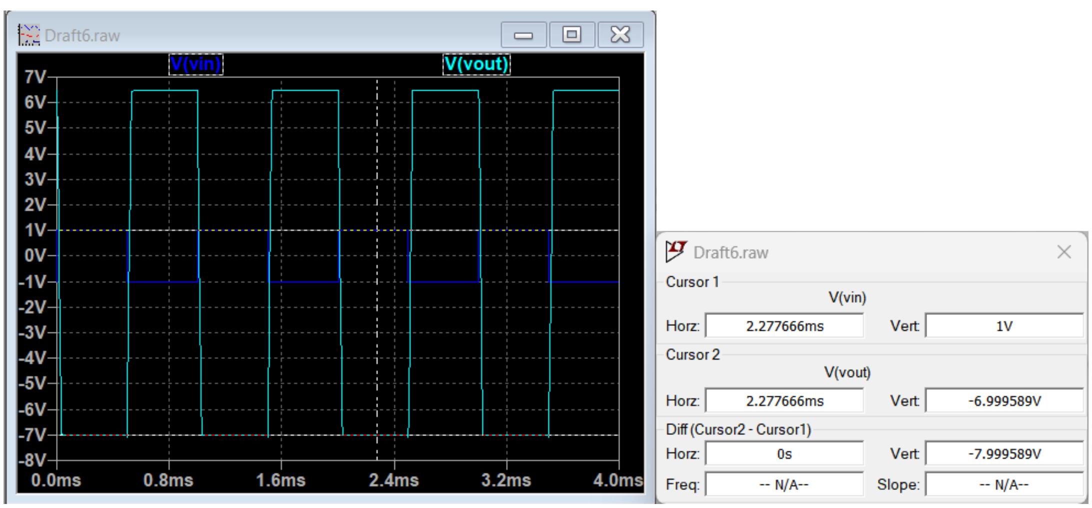

Figure 15: Peak Voltage Value of Vin and Vout on OPAMP Circuit when R2 is 840 Ohm

Since the R2/R1 ratio is 7 in the circuit created, the inverting amplifier transmits the 1 V input voltage to the output as -7 V as a square wave.

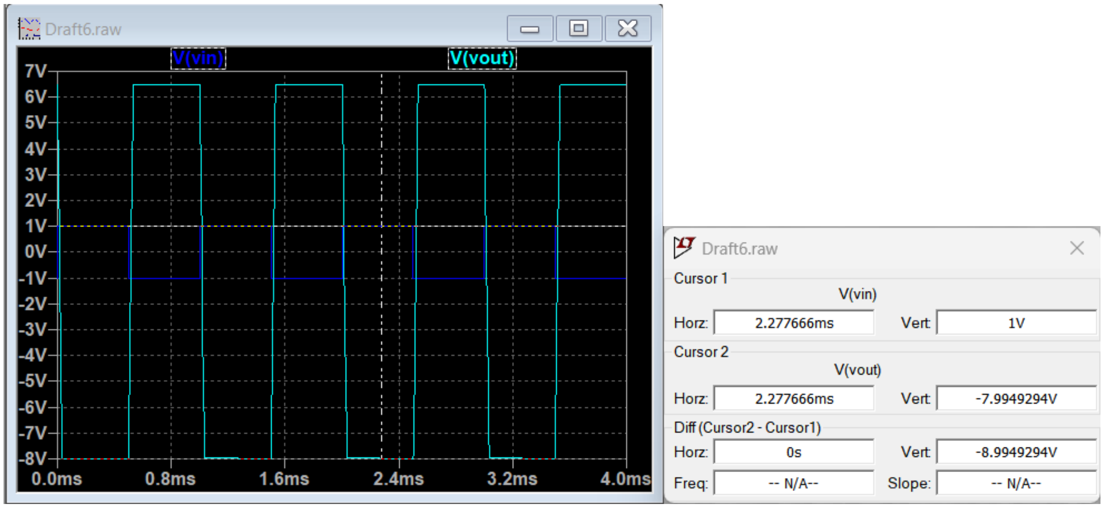

Figure 16: Peak Voltage Value of Vin and Vout on OPAMP Circuit when R2 is 1200 Ohm

Since the R2/R1 ratio in the created circuit is 10, the inverting amplifier should transmit the 1 V input voltage as -10 V to the output as a square wave, but since the DC voltage value given to the OPAMP is 8 V, the OPAMP is saturated in this circuit and 8 V is transmitted to the Vout no matter how much R2 increases.

3.3- OPAMP Circuit with Capacitor

For this part, we are asked to replace R1 with 8k Ohm and R2 with a 3 nF capacitor and observe the output with the same square wave input. The circuit formed as a result of these changes is as follows:

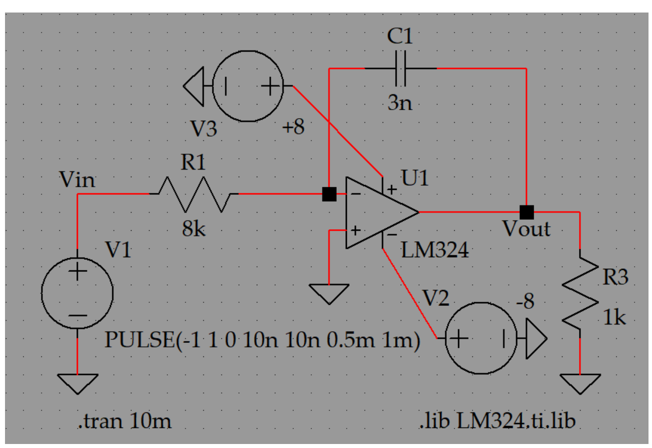

Figure 17: OPAMP Circuit with Capacitor

3.3- Results

If KCL is done at the inputs of the OPAMP, the following result is obtained.

$$C_1 * \frac{d\,V_c}{dt} = \frac{0 - V_{in}}{R_1}$$

$$V_c = V_{out} = -\frac{1}{R_1 * C_1} \int_0^t V_{in}\,\mathrm{dt}$$

As can be said this is an integrator amplifier because it integrates the input voltage.

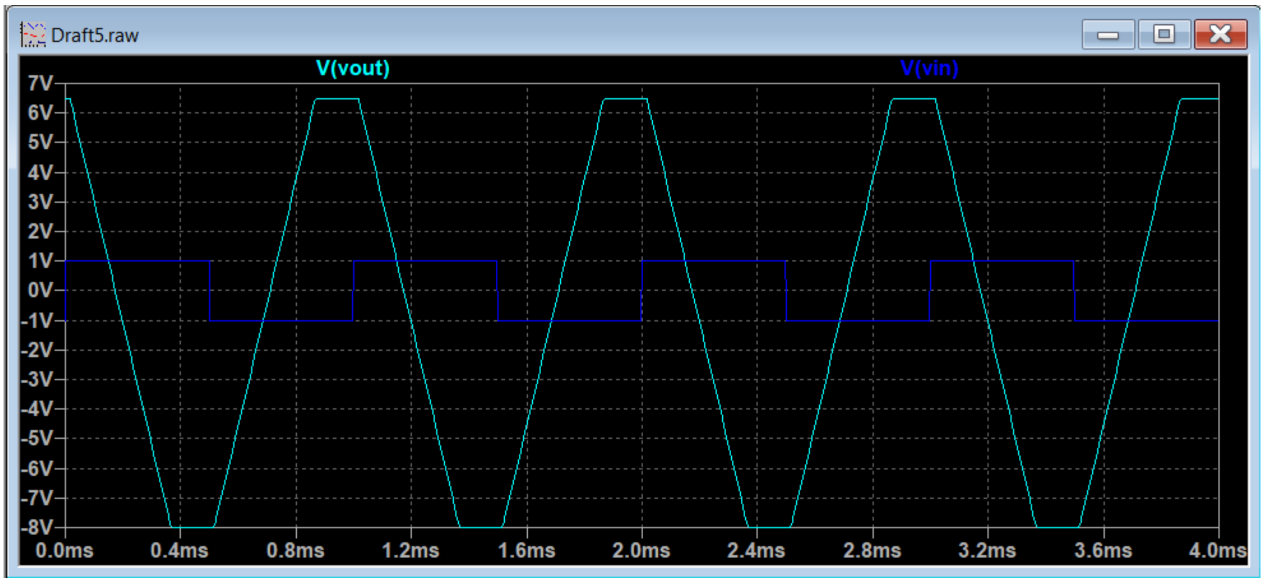

Figure 18: Waveforms of Vin and Vout on OPAMP Circuit with Capacitor

Since it transmits the square wave input as a triangular wave output, it is verified that it is an integrator OPAMP.

Hardware Lab

1- RL Circuit

In the first part of the hardware lab, the RL circuit in the first part of the software lab is expected to be created. Afterward, measurements were made at three different frequency values, 10 kHz, 100 kHz, and 500 kHz, to observe the change in output voltage. The image and schematic of the circuit created with the same values in the software lab are as follows:

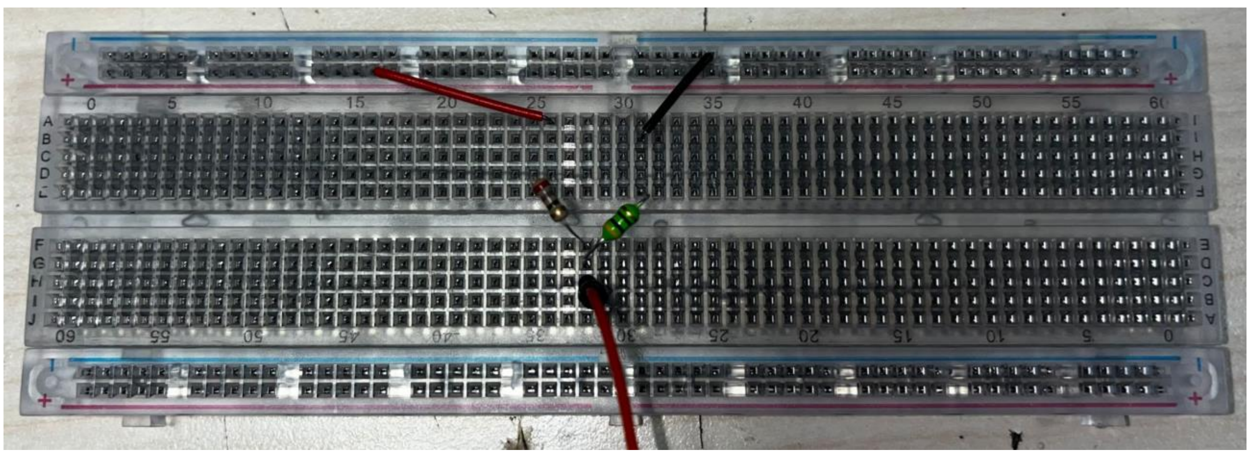

Figure 19: The RL Circuit

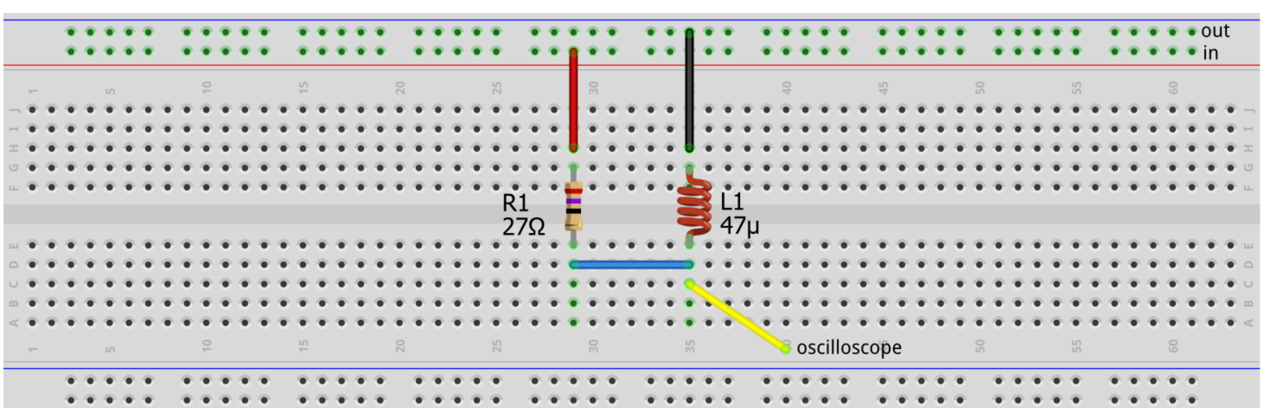

Figure 20: Schematic of RL Circuit

1- Results

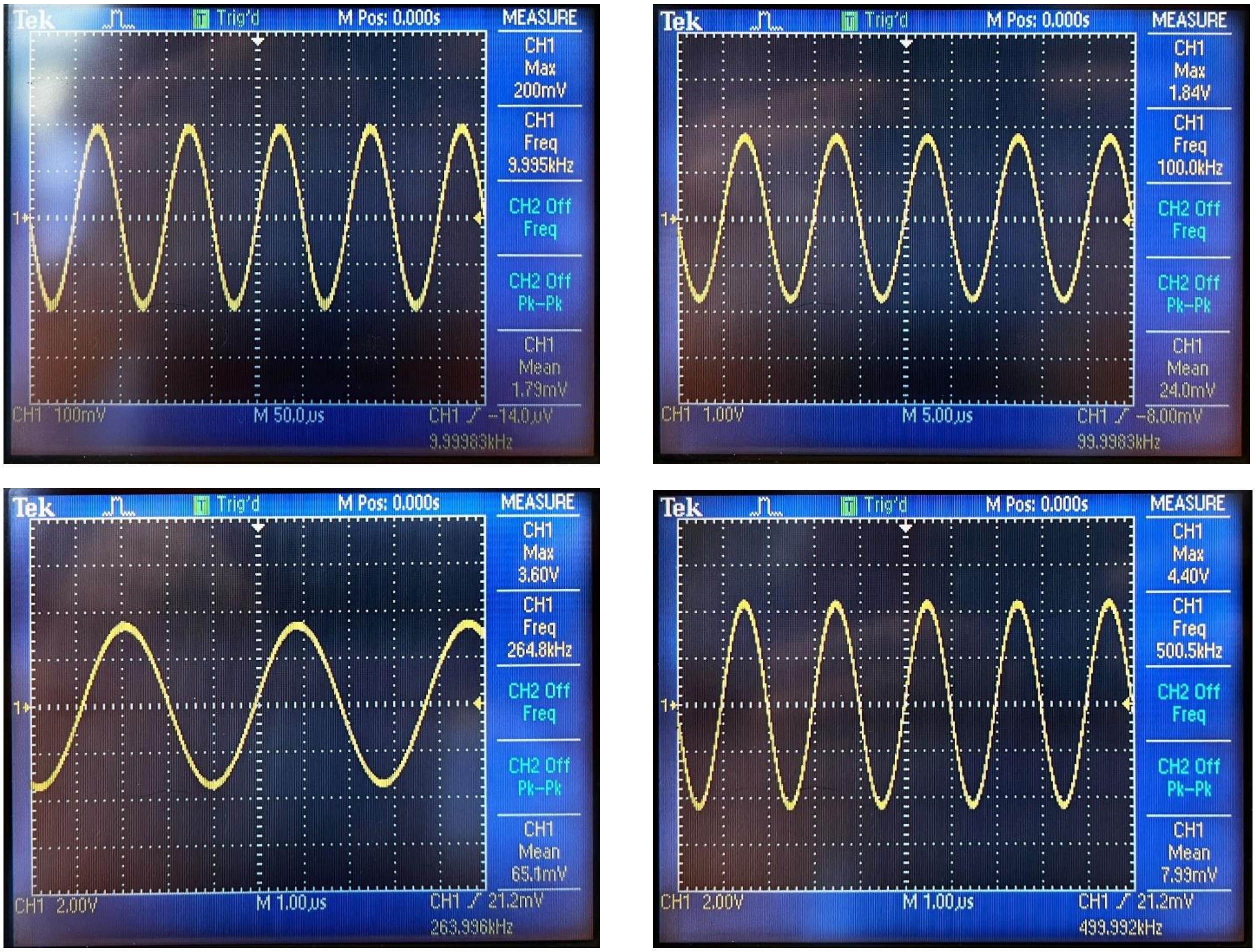

Figure 21: RL Circuit at 10k Hz, 100k Hz, 264k Hz and 500k Hz

Frequency	Software Result	Hardware Result	Error
10k Hz	193.3 mV	200.0 mV	%3.47
100k Hz	1.80 V	1.84 V	%2.22
264k Hz	3.56 V	3.60 V	%1.12
500k Hz	4.43 V	4.40 V	%0.68

Table 1: Software and Hardware Results of RL Circuit

After the measurements made at 10 kHz, 100 kHz, and 500 kHz and corner frequencies, it is seen that the output voltage of this circuit increases as the frequency increases. So it is verified that it is a high-pass filter. The values measured in hardware are close to the values measured in software, and the error rate is between %0.68 and %3.47.

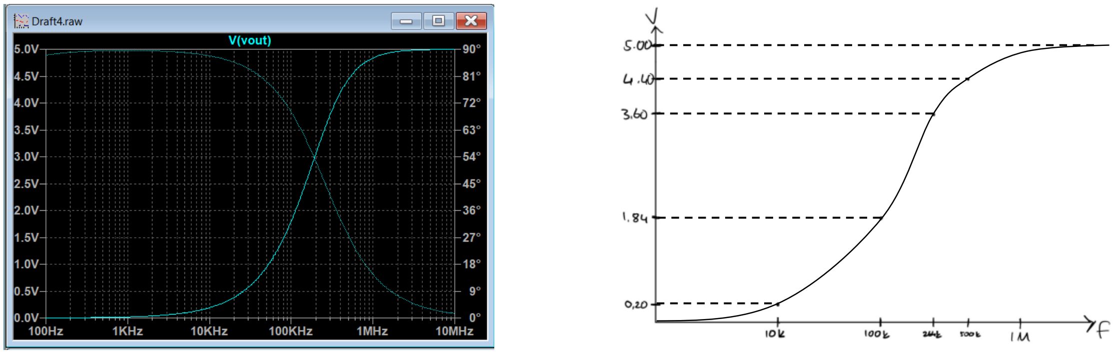

Figure 22: Software Result and Rough Frequency Response Plot of the Real-Life RL Circuit

2.1- OPAMP Circuit with Resistors

In this part, it is requested create the OPAMP circuit with resistors in the third part of the software lab. After the circuit was created, a saturation of the OPAMP was observed with different input voltages. The image and schematic of the circuit created with the same values in the software lab are as follows:

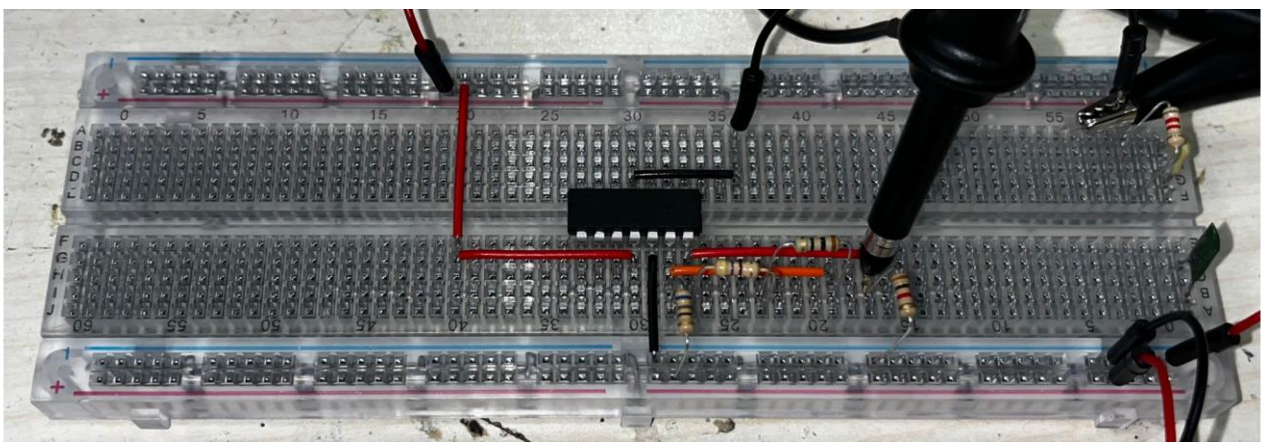

Figure 23: The OPAMP Circuit with Resistors

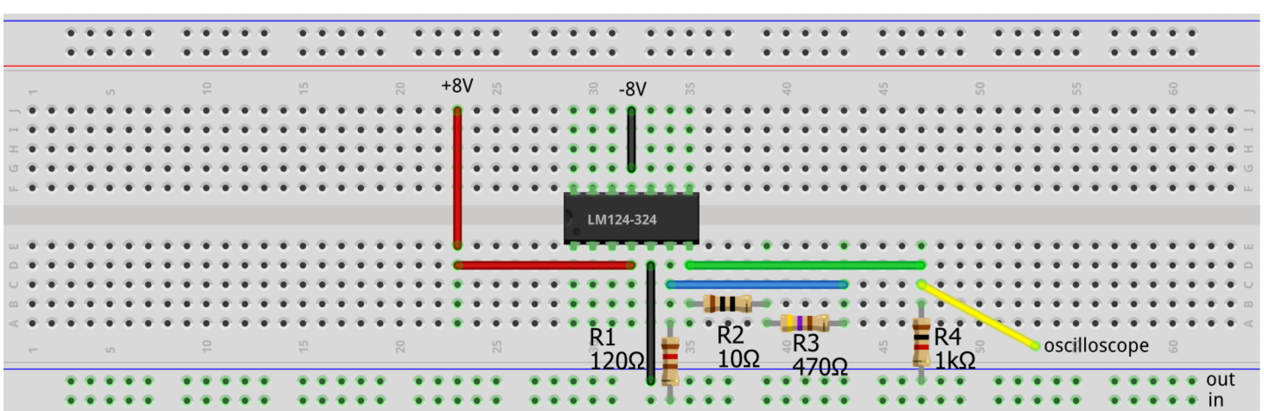

Figure 24: Schematic of OPAMP Circuit with Resistors

2.1- Results

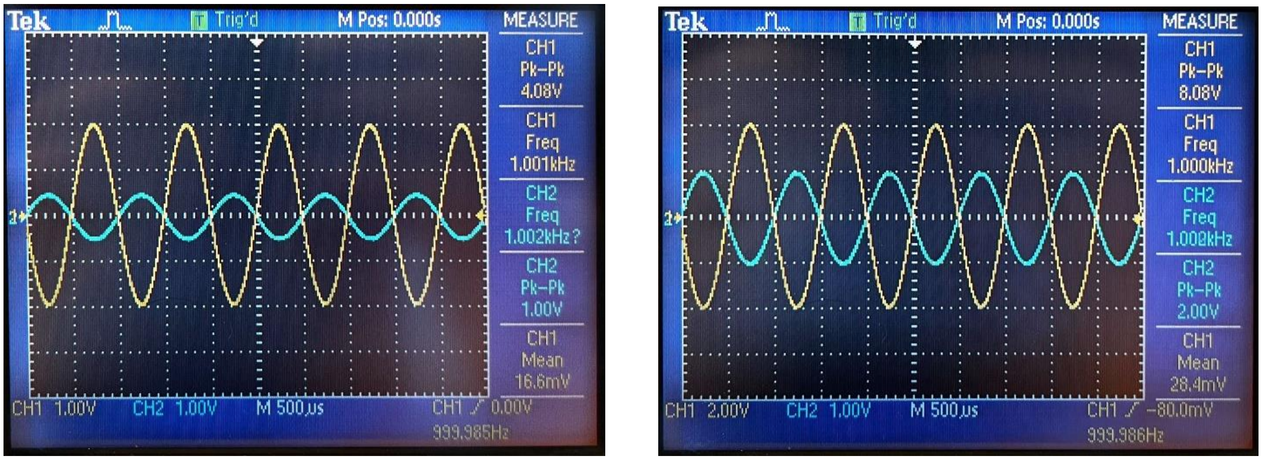

Figure 25: OPAMP Circuit with 1 V and 2 V input voltage

Input Voltage	Software Result	Hardware Result	Error
1.0 V	-4.0 V	-4.08 V	%2.00
1.5 V	-6.0 V	-5.96 V	%0.67
2.0 V	-8.0 V	-8.08 V	%1.00
2.5 V	-8.0 V	-8.16 V	%2.00

Table 2: Software and Hardware Results of OPAMP Circuit with Resistors

The values measured in hardware are close to the values measured in software, and the error rate is between %0.67 and %2.00. Since the R2/R1 ratio in the created circuit is 4, as said in the software part 3.1, the inverting amplifier multiplies the input value by -4 and transmits it to the output. Because the DC voltage value given to the OPAMP is 8 V, the OPAMP is saturated in this circuit and 8 V is transmitted to the Vout at values of input voltage greater than 8/4 = 2 V.

2.2- OPAMP Circuit with Capacitor

In this part, it is requested create the OPAMP circuit with a capacitor in the third part of the software lab. After the circuit was created, a saturation of the OPAMP was observed with different input voltages. The image and schematic of the circuit created with the same values in the software lab are as follows:

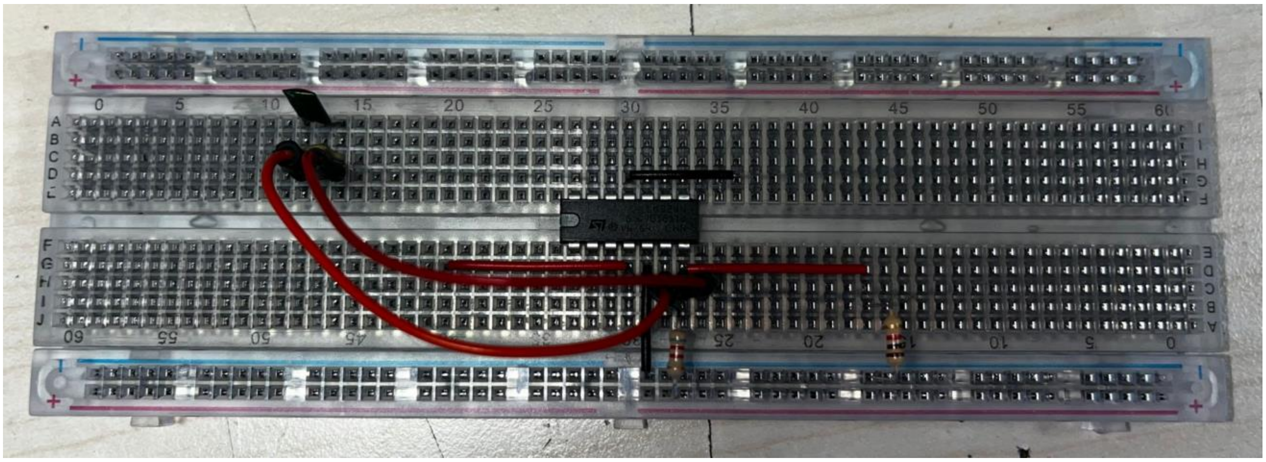

Figure 26: The OPAMP Circuit with Capacitor

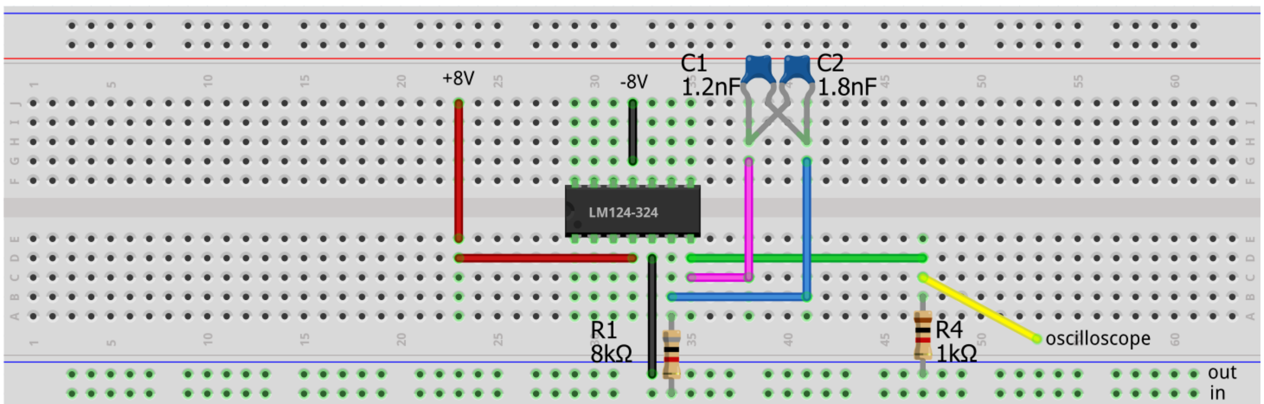

Figure 27: Schematic of OPAMP Circuit with Capacitor

2.2- Results

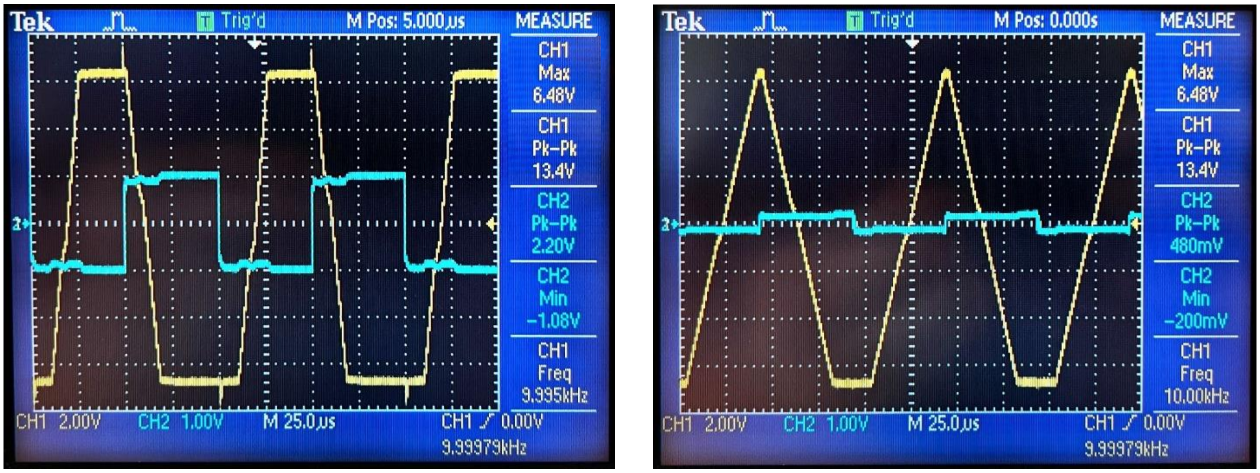

Figure 28: Integrator Amplifier with and without Saturation

Input Voltage	Software Result	Hardware Result	Error
240 mV	6.47 V	6.48 V	%0.16
1.10 V	6.50 V	6.48 V	%0.31
2.00 V	6.50 V	6.56 V	%0.94

Table 3: Software and Hardware Results of OPAMP Circuit with Capacitor

In software part 3.3, it was stated that this is an integrator amplifier. As expected, it is seen that the square wave input is transmitted as a triangular wave output via the oscilloscope. The values measured in hardware are close to the values measured in software, and the error rate is between %0.16 and %0.94.

Conclusion

The purpose of this lab was to perform Transient Analysis and AC Analysis on different circuits using LTSpice. First, a simple high-pass filter circuit was made using a resistor and an inductor. Then, a resistor was added to the circuit to make the software results closer to the hardware results, and a realistic signal generator model was obtained. In addition, inverting amplifier and integrator amplifier were made using LM324 OPAMP. It was observed that the output voltage obtained for both types of OPAMP circuits did not exceed the DC voltage values of the OPAMP, that is, it was saturated.

Errors in the hardware part were larger than the errors in the software part but did not exceed 5%. The highest error occurred when measuring with 10k Hz for the RL circuit in the first part of the hardware lab. This error was caused by the inability of the oscilloscope to measure mV precisely. Other hardware errors may be caused by non-linear components in OPAMP or imprecise component values. Internal resistances or material qualities of the breadboard and oscilloscope also contributed to the resulting error.

In summary, thanks to this lab, filter circuits, and OPAMP usage, as well as time-domain and frequency-domain analysis on circuits were learned. It has also been confirmed that the LTSpice program is a tool that gives very close values to real life and makes life easier.