Bilkent University

EE-202 Circuit Theory

Lab 1

Time Domain and Frequency Domain Analysis in LTSpice

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Section 02

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Purpose:

Purpose of this lab is to get familiar with the LTSpice software and circuit elements that will be used in the future labs.

Methodology and Software Lab Part:

The lab consists of three parts:

- Transient Analysis
- AC Analysis
- OPAMP Circuits

1.Transient Analysis

1.1 Voltage Divider

First aim of this part is to create a simple voltage divider and do time domain analysis in the circuit.

The expected circuit is:

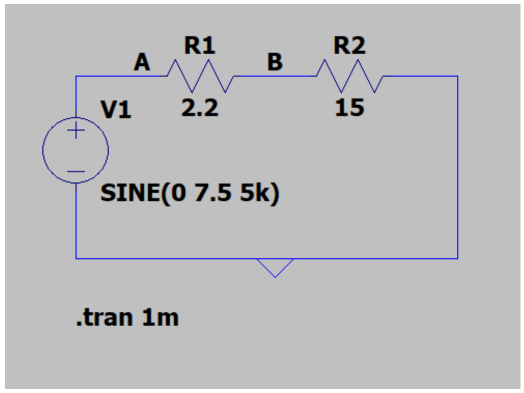


Figure 1: Voltage Divider

- R1 is asked to be 1-5 Ohms, picked value is 2.2 ohm
- Expected R2 is 10 – 20 Ohms, value chosen is 15 Ohm
- Voltage and frequency of the sinusoidal signal is 7.5 volts and 5khz, fitting to specification of 5-10 V and 5-10 kHZ

In this case the expected peak voltage is around 6.54 Volts from the voltage divider calculation.

1.1 Result:

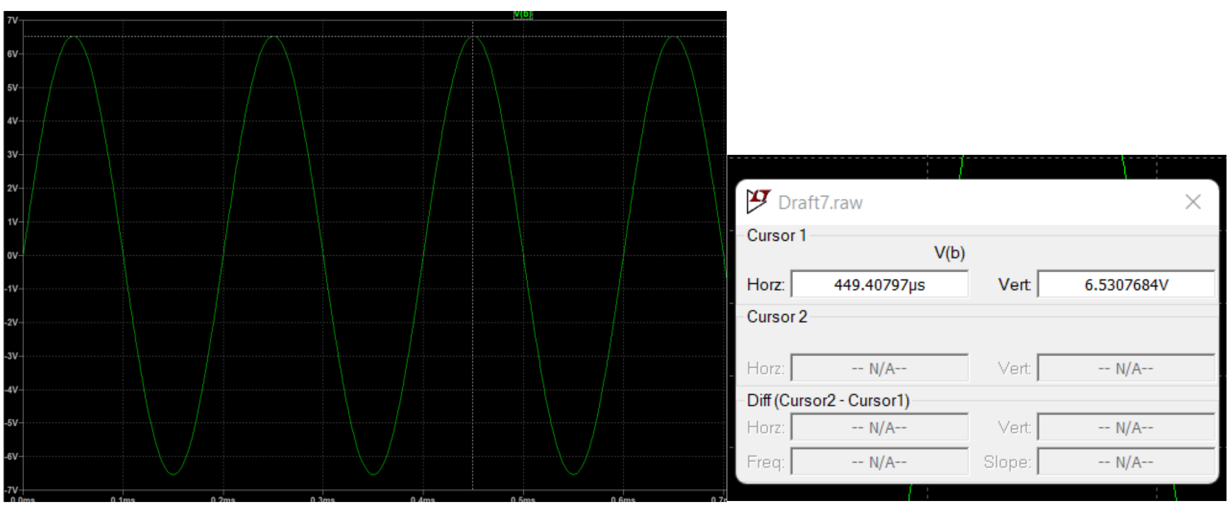


Figure 2&3: Time Analysis and Peak Voltage Value on Voltage Divider

As it can be seen from the graph the voltage measured at peak is 6.5307 Volts which is close to expected result and only has %0.15 error.

1.2 RL Circuit

After this part we are expected to replace the circuit with a simple RL circuit.

The expected circuit is,

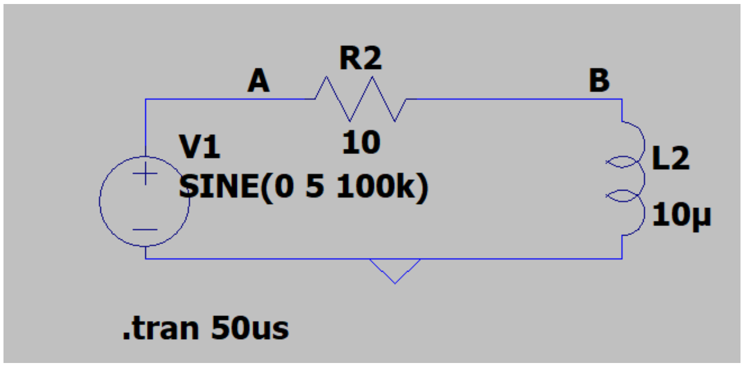


Figure 4: RL Circuit

The specifications of this circuit are,

- R2 to be 10-50 Ohms (10 Ohms is picked)
- L2 to be one of the following: 8.2 µH, 10 µH, 47 µH, 100 µH (10µH is picked)
- Sinusoidal Voltage Amplitude of 5V
- Frequency of sinusoidal input being 100kHz, 10kHz and 500kHz in order

The transfer function in this would be,

$$H(w) = \frac{Vout}{Vin} = \frac{jwL}{R2+jwL}$$

$$|H(w)| = \frac{wl/R2}{\sqrt{1+(\frac{wl}{R2})^2}}$$

As w goes to infinity this value goes to 1 indicating a high pass filter.

From this we can find Vout for 10kHz, 100kHz and 500kHz as

Where, Vin= 5(-j) in phasor form

$$Vout = \frac{j2\pi fL}{R2+j2\pi fL} * 5(-j)$$

Using this equation, we get:

- 312mV
- 2.66V
- 4.63 Volts as a result.

1.2 Result:

Here are the voltage levels of node D on 10kHz, 100kHz and 500kHz signal in order:

To be able to do analysis accurately, transient analysis stop time was 1ms, 100µs and 20 µs to fit into increasing frequency. The blue line (Voltage source) in figure 7 is shown to have a better understanding of the filter analyzed.

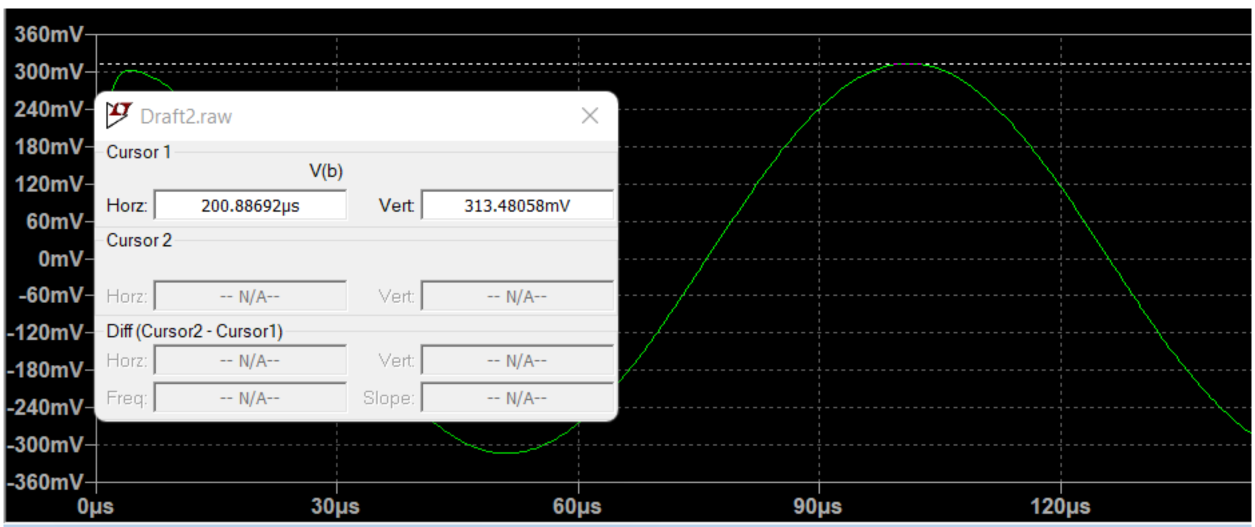


Figure 5: Peak Value of 313mV on 10kHz Signal

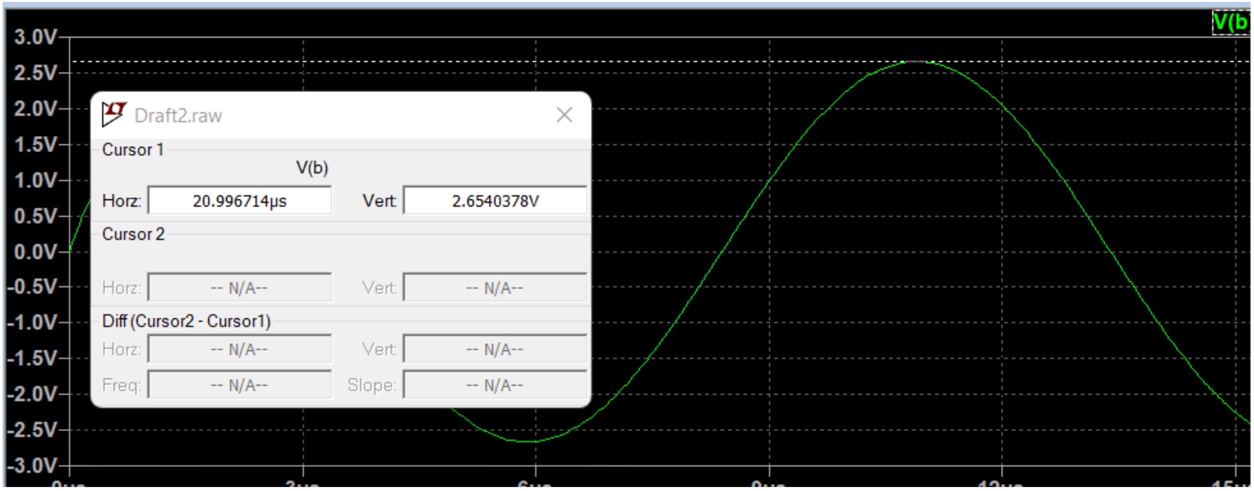


Figure 6: Peak Value of 2.65V on 100kHz Signal

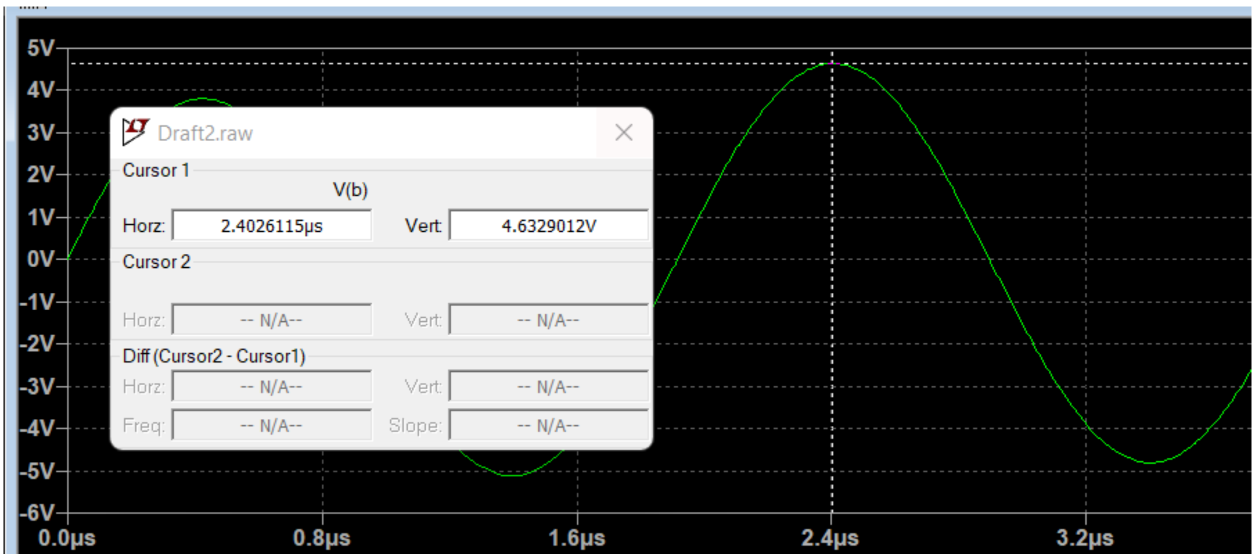


Figure 7: Peak Value of 4.63 Volts on 500kHz Frequency

From the results it can be understood that the voltage has risen parallel to frequency increase, in such case this is **a high-pass filter.** The error rate is significantly lower **(%0.31)** than %10 percent as well

2. AC (Frequency Domain) Analysis

2.1 AC Analysis without Source Resistance

On the first step of this part, we are asked to change from time domain analysis to frequency domain analysis on the RL circuit we did before. The circuit in that case is:

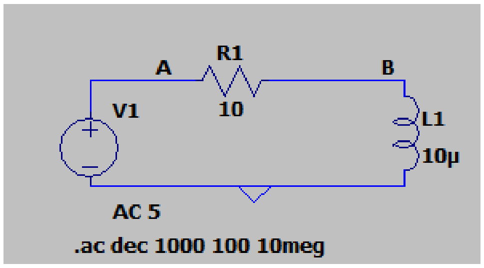


Figure 8: AC analysis on the RL circuit

Different parts of the specification of this circuit include:

- Small Signal (AC 5) requirement
- AC analysis from 100Hz to 10Mhz in sweep decade (1000)

After implementing the changes, there will be a logarithmic plot simulated on LTSpice.

2.1 Results:

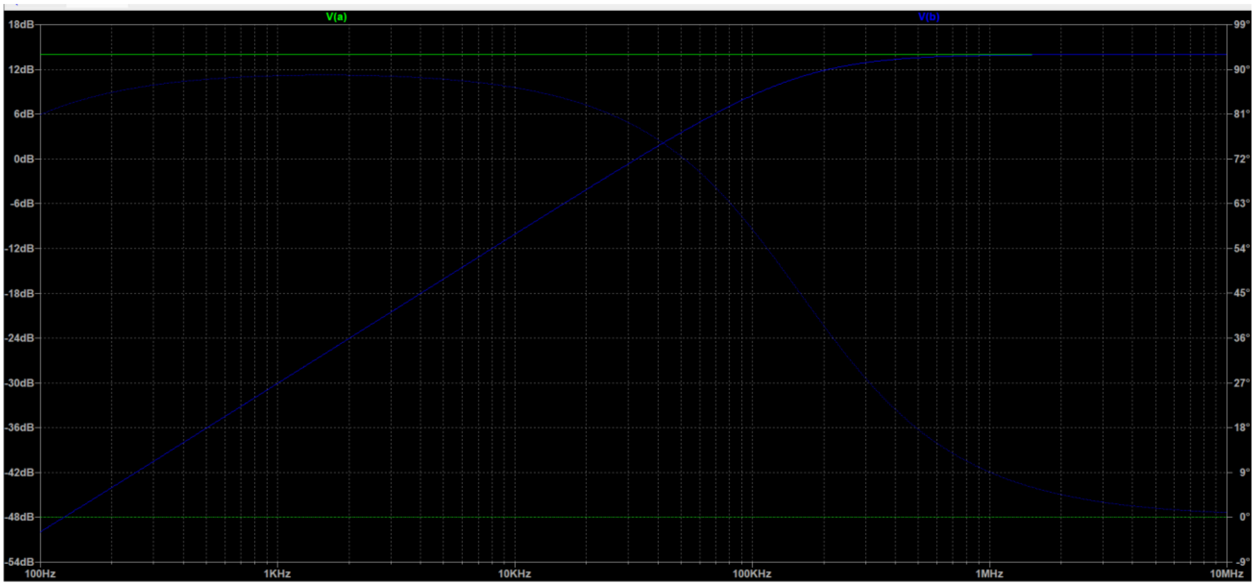


Figure 9: Logarithmic Plot on Output Nodes

As it can be seen from the plot the filter passes mostly high frequencies making it a high pass filter.

2.2 AC Analysis with Source Resistance

In an actual voltage source, the source will have a resistance so that it doesn't breakdown in several cases. The resistance that is generally used in the labs are 50 Ohm and this step of the lab requires the addition of this resistance to past circuit. The implemented circuit will be analyzed in the same way as the circuit in step 2.1 so that one can compare the differences between them.

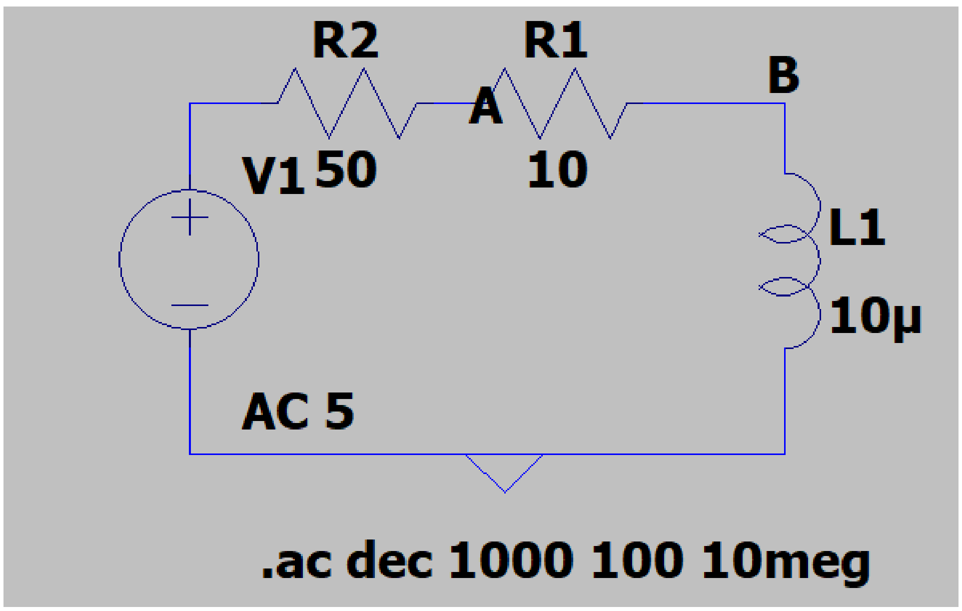


Figure 10: RL circuit with 50 Ohm source resistance

As there is now the source resistance as well this circuit is expected to reach maximum transfer function much later compared to the one before.

$$H(w) = \frac{Vout}{Vin} = \frac{jwL}{R2+R1+jwL}$$

$$Vout = \frac{j2\pi fL}{R2+R1+j2\pi fL} * 5(-j)$$

The values calculated for this part (10kHz, 100kHz, 500kHz) are 52 mV, 520mV and 2.32 V.

10kHz	100kHz	500kHz	968kHz(cutoff)
52mV	520mV	2.32V	3.55V

Table 1: Expected results

2.2 Results:

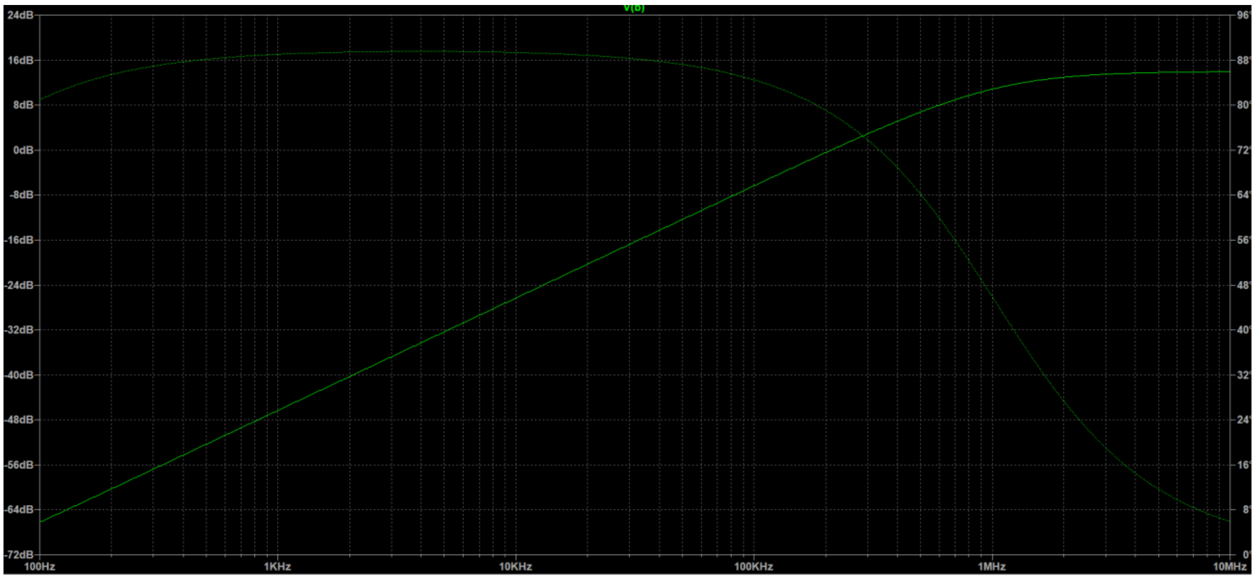


Figure 11: Logarithmic Plot of Output of RL circuit with source resistor

Comparing this plot, to the one before we can see that this plot reaches maximum transfer function much later compared to the former one. While the former one reaches maximum rate around 1MHz, the latter one reaches around 5MHz.

Moreover, there are also noticeable difference in the phases and the starting decibel on the plots.

Comparing the output voltage with respect to the voltage at the output of the realistic signal generator model and comparing this result to the circuit without a source resistance:

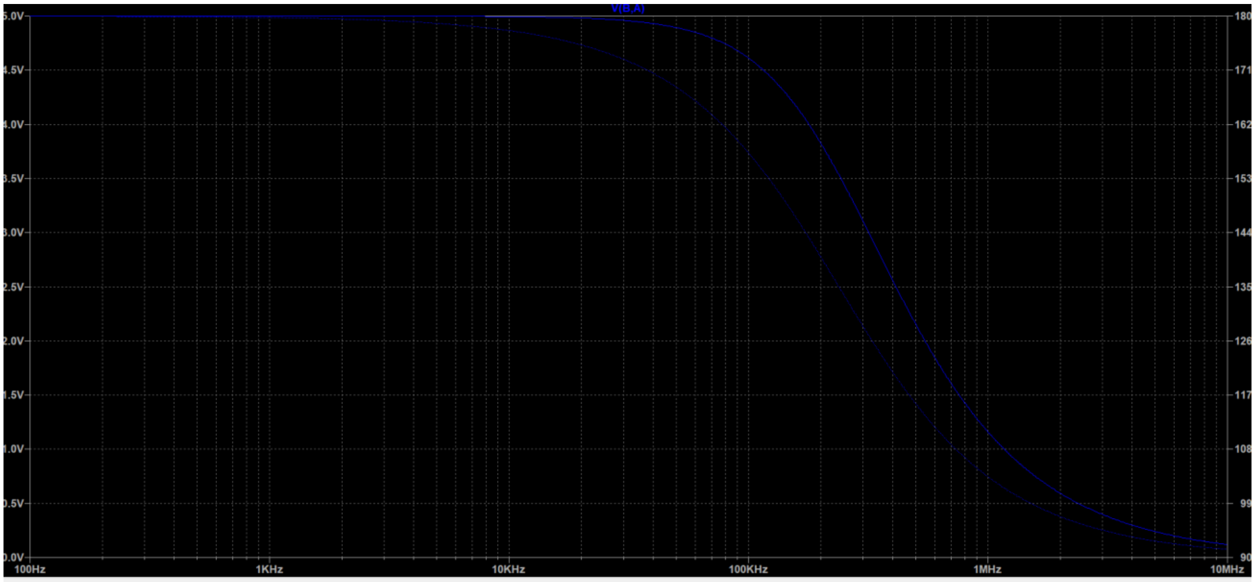


Figure 12: Circuit without the Source Resistance (Voltage Difference)

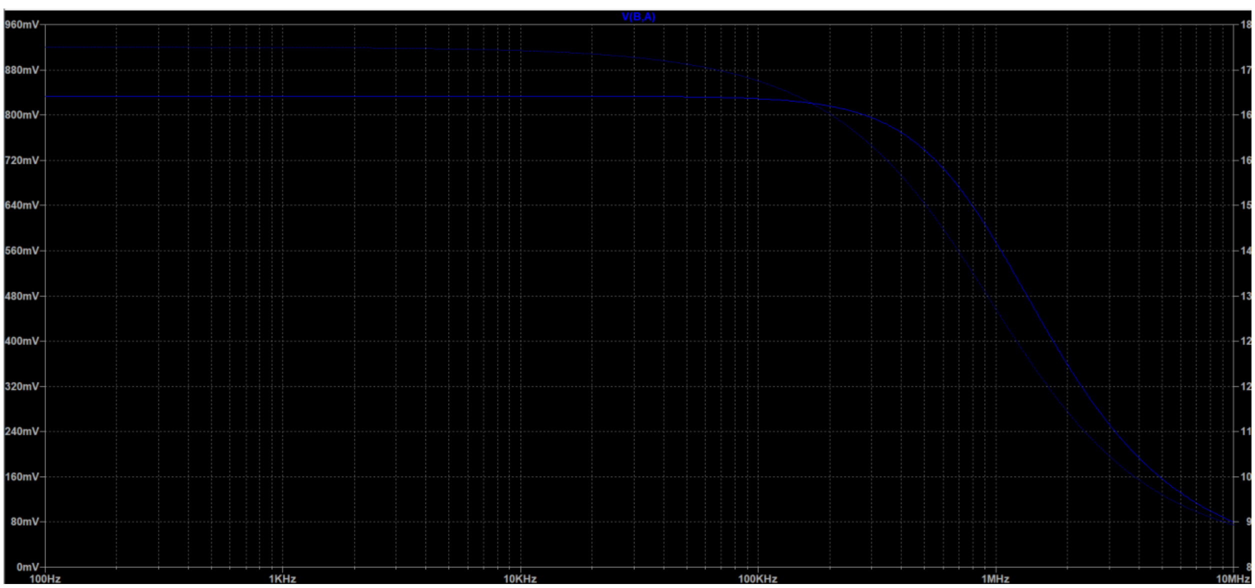


Figure 13: Circuit with the Source Resistance (Voltage Difference)

The voltage difference starts lower on the circuit with the source resistance as some of the voltage is lost due to 50 Ohm causing a voltage difference on node A. This can be seen as the latter circuit starts from a lower mV. The values are repeated in the hardware lab as well for comparison**.** The values for 10kHz, 100kHz and 500kHz, 968 kHz are 52mV, 520 mV and 2.32V, 3.55V indicating almost no error.

Frequency	Measured	SW Result	Error
10Khz	52mV	52mV	N/A
100kHz	520mV	520mV	N/A
500kHz	2.32V	2.32V	N/A
968kHz	3.55V	3.55V	N/A

Table 2: Software Results

3. OPAMP Circuit

3.1 OPAMP Circuit with Only Resistors

In the first step of this part, we are asked to design an OPAMP (using LM324) circuit whose R6/R1 ratio is 4. The voltage input is 1 Volts and frequency of the signal is 1kHz. Required resistance on the output is 1kOhm. The used DC supplies for the OPAMP are + - 8 Volts.

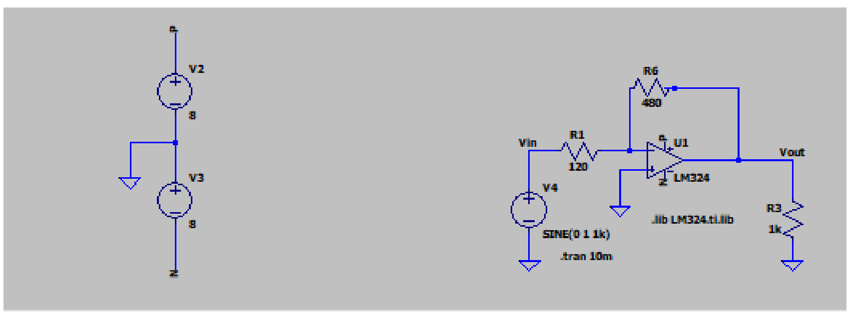


Figure 14: OPAMP circuit with only resistors

From the node equations,

$$\frac{0 - Vinput}{R1} + \frac{0 - Vout}{R6} = 0$$

$$Vout = -\frac{R6}{R1}Vin$$

$$\frac{R6}{R1} = 4$$

It can be said that this is an inverting amplifier OPAMP.

3.1 Result:

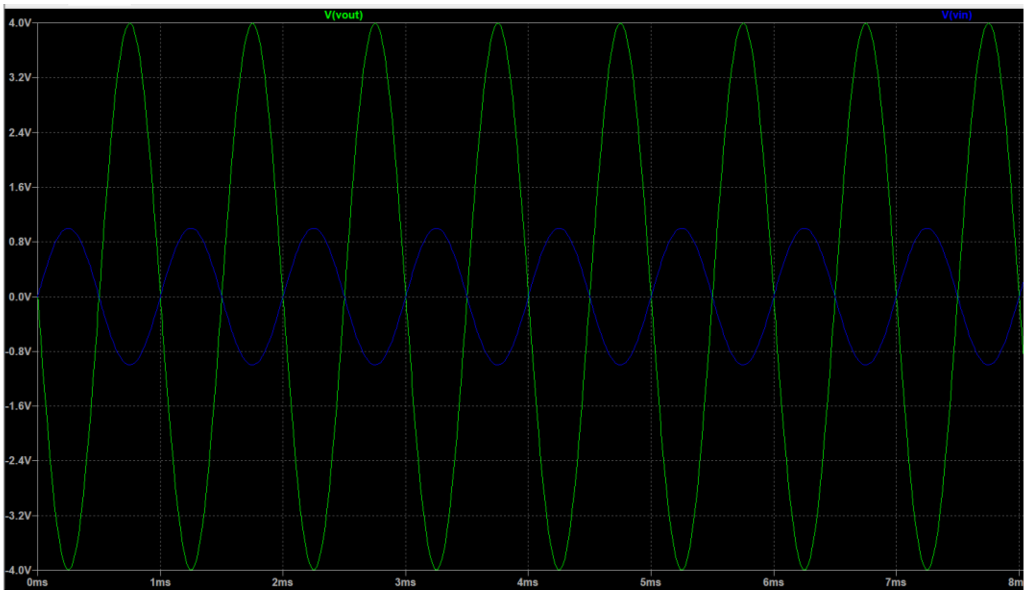


Figure 15: Plot of Negative Amplifier OPAMP

It can be seen from the graph that the circuit is a inverting amplifier meaning it reverses the direction of the voltage and amplifies it by R6/R1 ratio of 4. It can be seen that the input of +1V reaches -4 V on the output.

3.2 Pulse Source OPAMP and Saturation

Changing the sinusoidal input with a pulse source of 1V amplitude with 1ms period and %50 duty cycle, the same amplitude in part 3.1 but on a square waveform is expected.

As long as the ratio of R6/R1 does not surpass 8 there will not be any saturation to be expected. The saturation will occur as the OPAMP circuit designed is at most capable of delivering positive and negative 8 voltages. For this part, R6 value of 480, 960, 970, 1050 will be used to demonstrate the saturation of the OPAMP.

The 960 Ohm is picked due to it being a boundary value on the ratio of R6/R1. When this value is implemented 8 voltage peak value is expected.

The 1050 and 970Ohm value is to show that OPAMP needs to exceed 8 volts but expected to stay at 8 volts indicating saturation. Here is the circuit used:

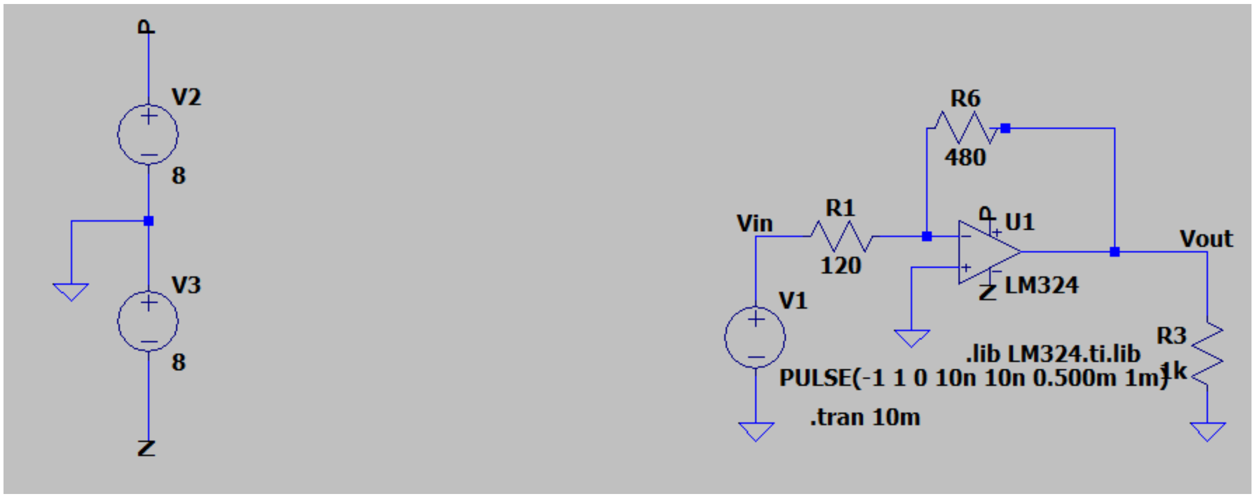


Figure 16: OPAMP with Pulse Source

As the other two values will cause repetitiveness they are not put in this report as figures.

3.2 Results:

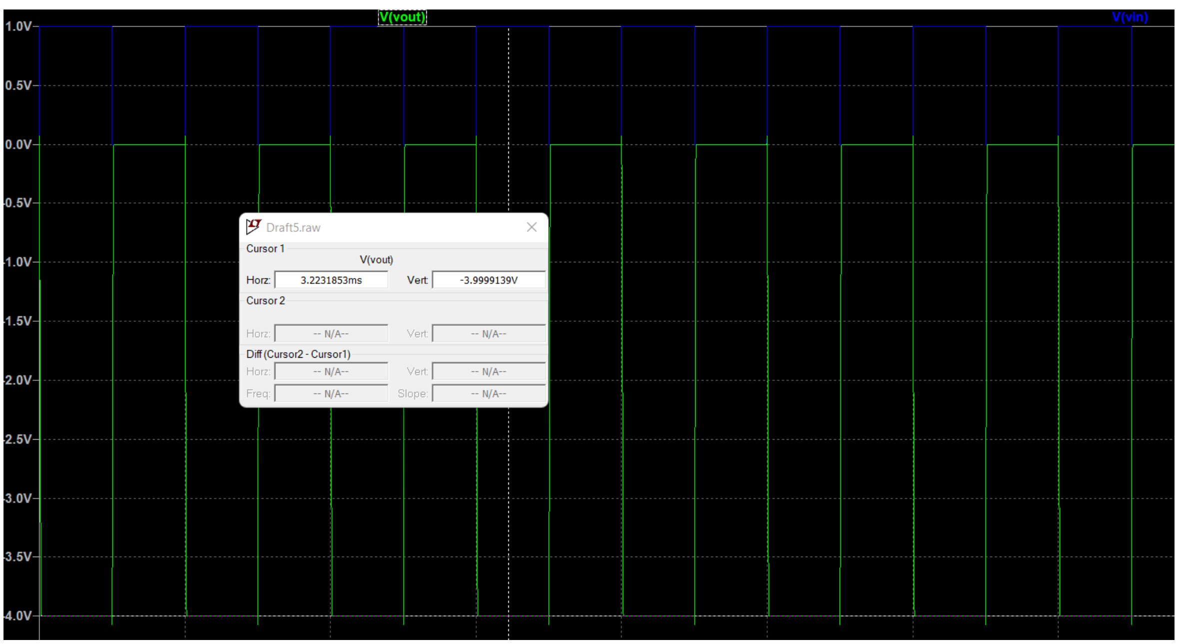


Figure 17: Plot of R6= 480 Ohms

As expected, the voltage is reversed in square wave form and amplified by 4 times. The result in this case is Vout = 3.99 Volts.

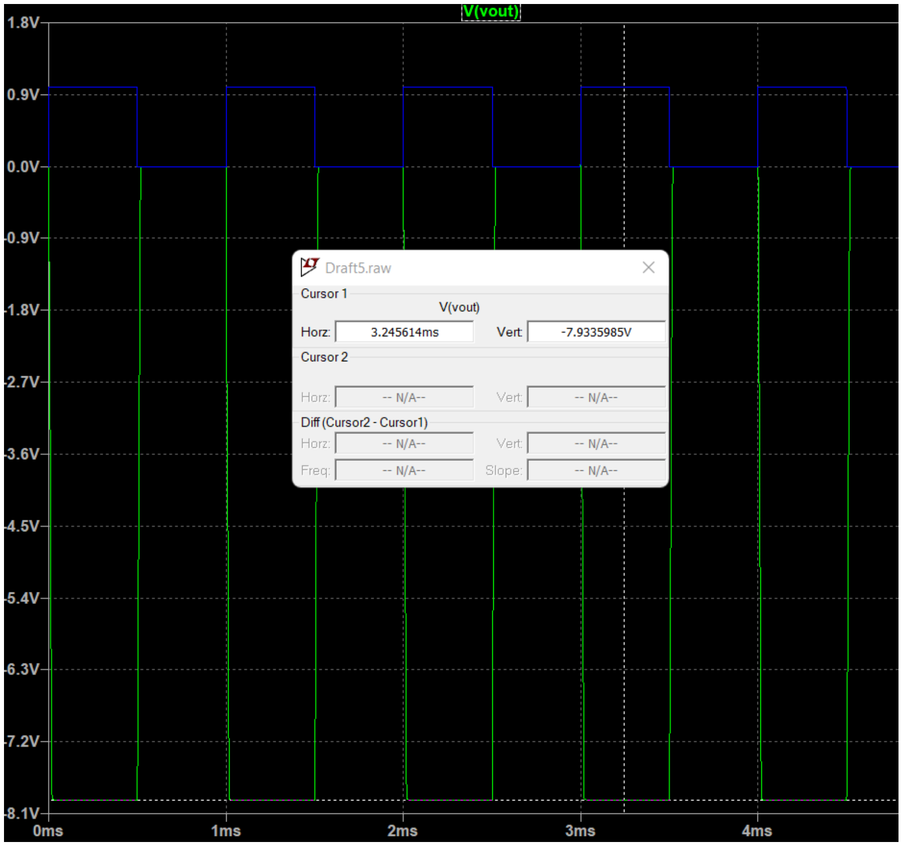


Figure 18: Plot of R6= 960 Ohm

With the **error rate of 0.8% Vout** = 7.93 Volts as peak value when R6 is 960 Ohm which is 0.07 volts lower than the expected voltage.

After this trying any value higher than 960(970, 1050) indicated the same results and the voltage never surpassed 8 Volts.

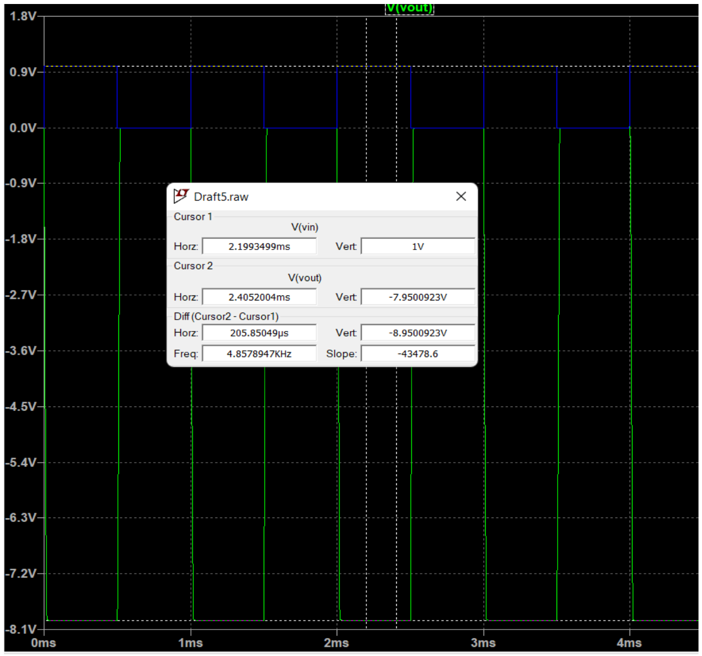


Figure 19: Plot when R6> 960

In each case the magnitude of the voltage output was increasing and getting closer to 8volts however as from the calculations the voltage is expectd to be much higher meaning the opamp starts to saturate starting from 960 Ohms.

For an example, the expected voltage for R6= 1050 is 8.75 volts however the OPAMP delivered 7.95 volts indicating saturation.

The same process was repeated also with voltage while R6= 480 ohms and saturation began the moment voltage passed 2 Volts.

3.3 OPAMP Circuit with Capacitor

In the last part of this lab we are asked to replace the resistor R6 with a 3nF capacitor and the other resistance with 8k Ohms. The OPAMP circuit will look like:

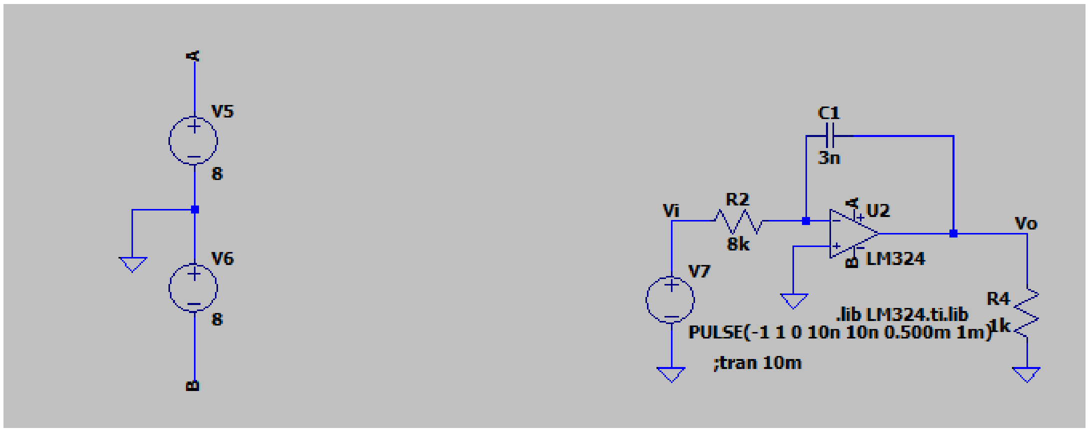


Figure 20: OPAMP Circuit with the capacitor

Using KCL on + node we get:

$$\frac{0 - Vinput}{R2} + C1\frac{dVc}{dt} = 0$$
$$Vc = Vout$$
$$Vout = \int \frac{Vinput}{R2 * C1}$$

In such case this OPAMP is an Integrator OPAMP

3.3 Results:

The simulation results of this circuit is:

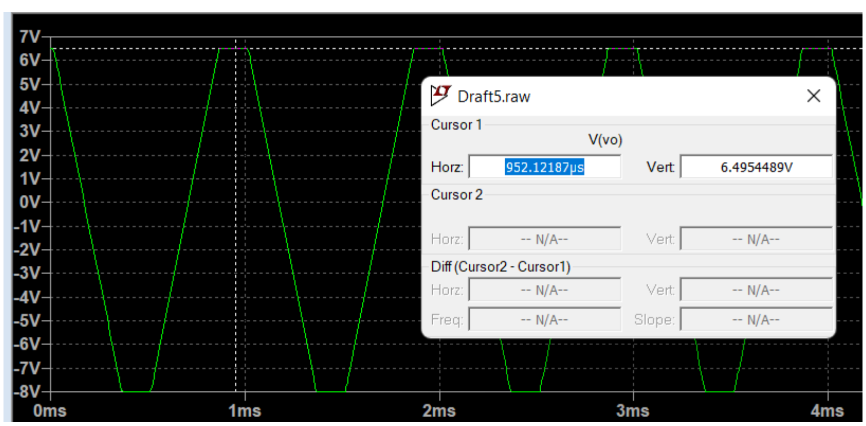


Figure 21: Waveform caused by the capacitor

It can be said that an integrarator OPAMP is used as it triangulizes the square waveform with max voltage of 6.5 volts.

- **Table and some graphs of the software part will be shown after hardware result for comparision**

Hardware Lab

1.1 RL Circuit with source resistance

In the first part of hardware we are asked to implement the RL circuit we did in part 2.2 of Software Lab. As I had picked all the values that was in the lab I had no problems implementing the circuit. Here's the circuit:

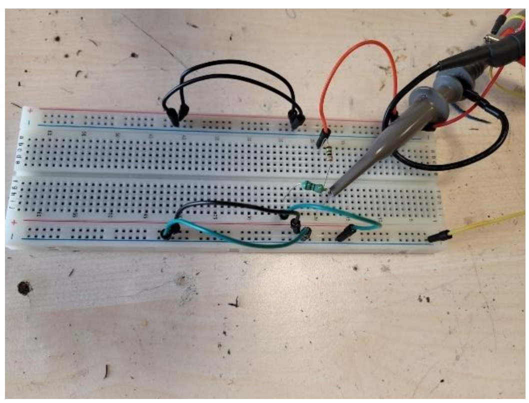


Figure 22: RL circuit

After implementing the circuit we were asked to look measure values at 10kHz, 100kHz and 500kHz.

Here is a figure for one of the values while others are in the table:

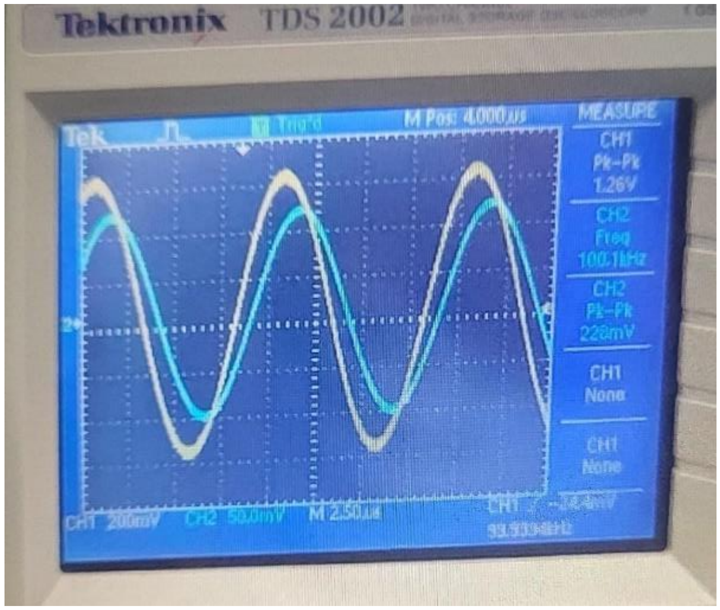
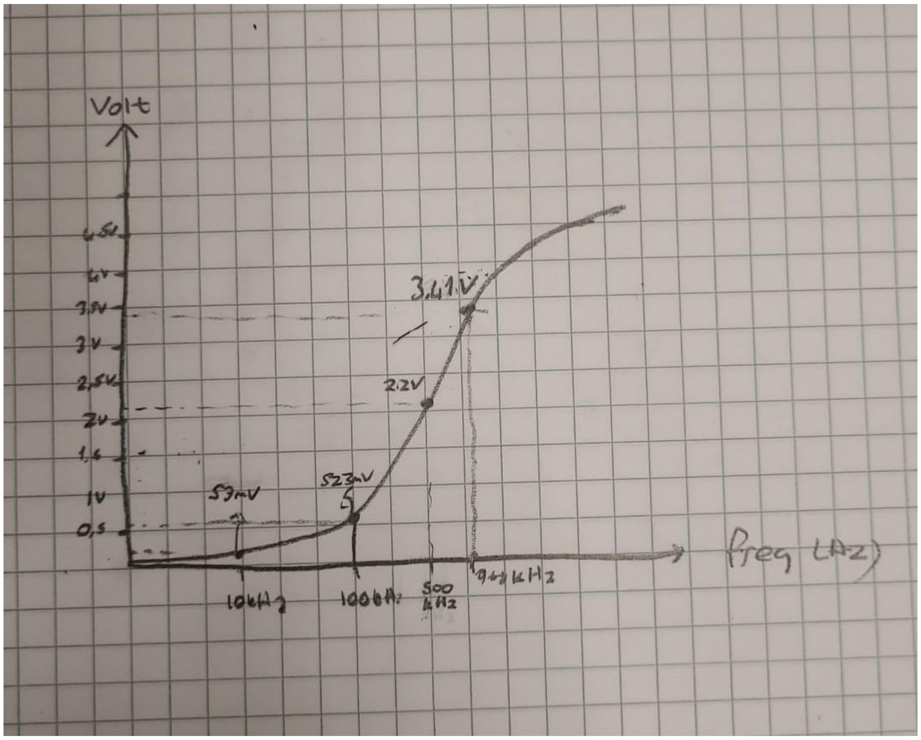


Figure 23: Value at output 100kHz

Freqıency	Software Results	Hardware Results	Error
10kHz	52 mV	57mV	9.61%
100kHz	520mV	523mV	0.57%
500kHz	2.32V	2.20V	2.25%
968kHz(cutoff)	3.55V	3.41V	3.94%

Table 3: RL Circuit Software vs Hardware Results

It can be inferred from the graph that RL circuit we made is a highpass filter. In all cases, error does not surpass %20 percent highest being %9.61 percent for 10kHz frequency. This might be due to oscilloscope's limits in showing small values precisely.



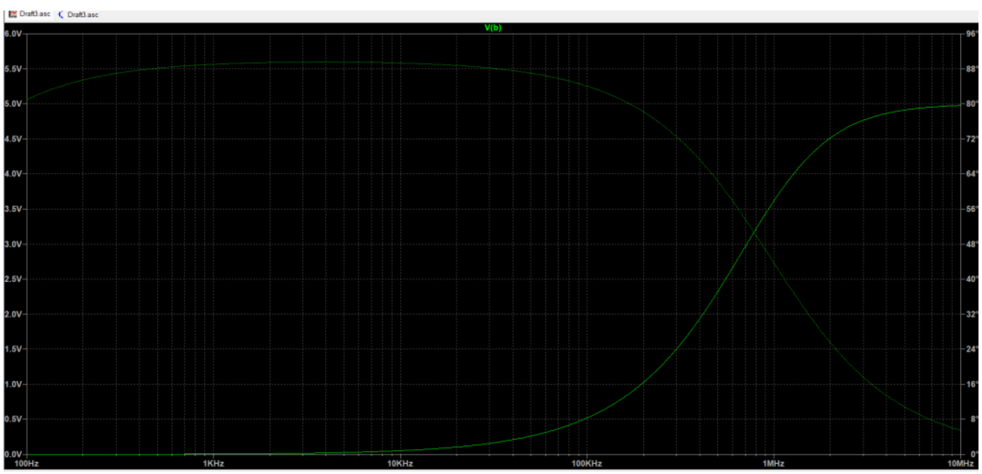


Figure 24&25: Plots in Hardware and Software

As you can see from the plots, behavior of a highpass filter is similar for both cases.

2.1 OPAMP with Resistors

In this part we were expected to implement a negative amplifier OPAMP. The circuit in question in this case is:

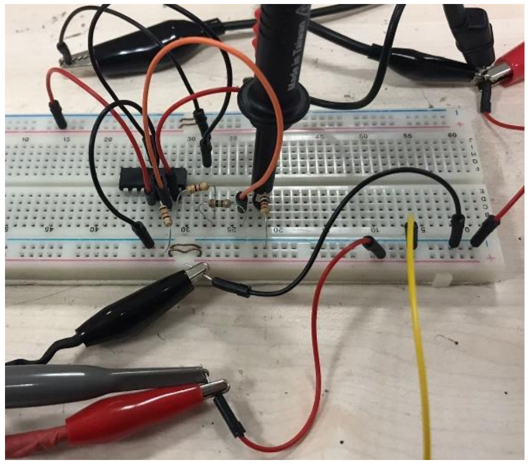


Figure 26: Resistor OPAMP Circuit

Rinput is 120 Ohms and the resistors in series are 480ohm(470+10)

Figure 27: Value output 4.04 volts on 1 Volt input

Output Voltage	Software output	Hardware output	Error

1V	3.99V	4.04Volts	1.25%
1.8V	7.2V (not saturated)	8.16 Volts(saturated)	13.3%
2.1V	7.95V(saturated)	8.28Volts	4.15%

Table 4: OPAMP Output at Different Voltage Levels

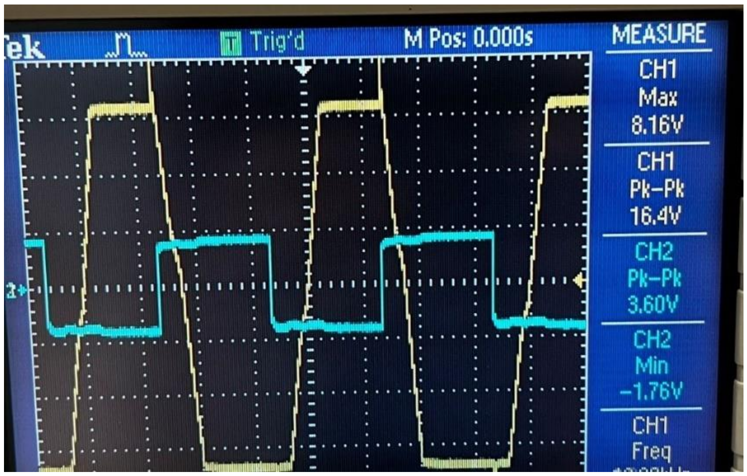


Figure 28: Saturation on the squarewave

In all three cases error was lower than %20 percent, highest being %13.3 percent for 1.8 volts. However, saturation started occuring at 1.8 volts which is different compared to the result in software.

2.2 Integrator OPAMP

In this part we are asked to utilize a İntegrator OPAMP and observe triangular wave. Here is the triangular wave and the circuit. The resistor of R1 is changed to 8k and the resistor R6 is switched with 3nF capacitor.

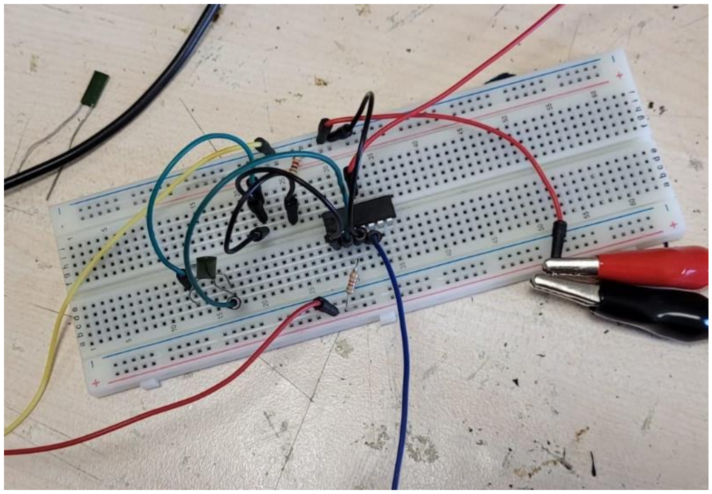


Figure 29: Integrator OPAMP

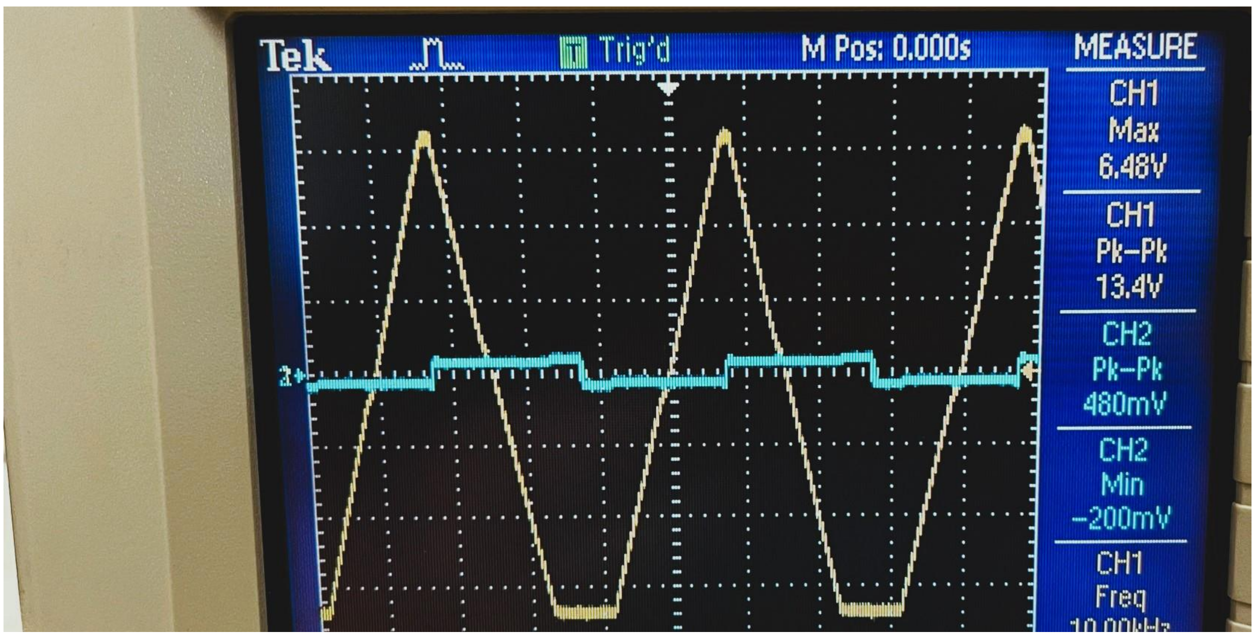


Figure 30: Integrator OPAMP

As it can be seen from the figure, it triangulized the squarewave. However, the voltage input was recommended to be lower for the sake of more accurate output through recommendation of the designated TAs in the lab. As a result the output values were similar in terms of to the ones found in the software lab.

- 6.48 Volt in Hardware vs 6.5V in software.

Conclusion

Throughout the lab we firstly learnt the relationship between inductor amd sinusodial signal wave. We also changed the frequency to see the highpass filter behavior of the RL circuit.

Afterwards I also observed the inverting amplifier OPAMP which interestingly caused a saturation earlier compared to the value found in the software lab. Other than this small problem, it was determnined that integrator OPAMP is an useful way of transforming a pulse wave into tringle wave.

To conclude, simulations we did throughout software lab were more or less proportional to the data found during hardware labs. However, due to challenges of breadboard, implementing the circuis was harder than designing it on LTSpice. Sometimes the connections on the breadboard was not working forcing me to try different spots on breadboard. Moreover, the error was especially higher in the hardware labs, due to several possible reasons varying from the breadboard itself to, accuracy of the components used. There could also be different errors from the oscilloscope and the probe as well. Finally, overall the lab was a good reminder in terms usi breadboards and oscilloscopes efficiently.

Index of comments

1.1 ":" at the end of titles are extraneous

2.1 but the voltage divider calculation is missing. -1

4.1 Time-constant computation for the RL circuit to justify the simulation length is missing. -1

The assignment asks "Set the stop time to see at least 3-4 periods of the chosen frequency or at least 10 time constants of the RL circuit based on which one is greater."; here we see less than 3 periods. It's especially important in a circuit like an RL-circuit due to the "steady state" concept. As you show here in the figure, (albeit the measurement subwindow blocks) the startings of the signal is not stable yet and therefore not informative enough. -2

9.1 Not the difference but the ratio was rather asked in the assignment (Part 2.4); that'd show the practical H(ω) directly. -2

12.1 The square wave here has an amplitude (and a DC offset) of 0.5V but 1V amplitude needed. It must have been fixed though not shown in Figure 21 otherwise a weird output signal against a 0-off voltage square wave have been obtained. -2

16.1 Figures of the other 2 frequencies are needed too; because these three figures together would justify the workings of the RL circuit as a high-pass filter. Table of results is necessary but not sufficient to that end. -2

21.1 Did they also say *why* this was needed for a more accurate output? Because you have ~0.5V peak-to-peak input signal against the desired 2V, i.e., 75% difference, which is very, very large of a discrepancy. Please ask them for concrete reasons if/when this happens, and indicate those reasons in the report because manipulating the input too much to get the desired output is not good.