TURKU UNIVERSITY OF APPLIED SCIENCES

ELECTRONICS REPORT

LAB 5 - Operational Amplifier

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Introduction

This lab is focused on Operational Amplifier and exploring its behaviour. An operational amplifier, often referred to as an op-amp, is a versatile and widely used electronic component in analog circuits. The device was used in the beginning to perform mathematical operations, however, nowadays they are linear integrated circuits that use relatively low DC supply voltages and are both reliable and inexpensive.

The standard symbol for an op-amp is a triangle pointing to the right with one inverted and one non-inverted input, and an output indicated by an arrow pointing out. This is because the device is designed to amplify the difference in voltage between the two inputs. Typically, the inverting input is denoted with a negative sign and the non-inverting input with a positive sign.

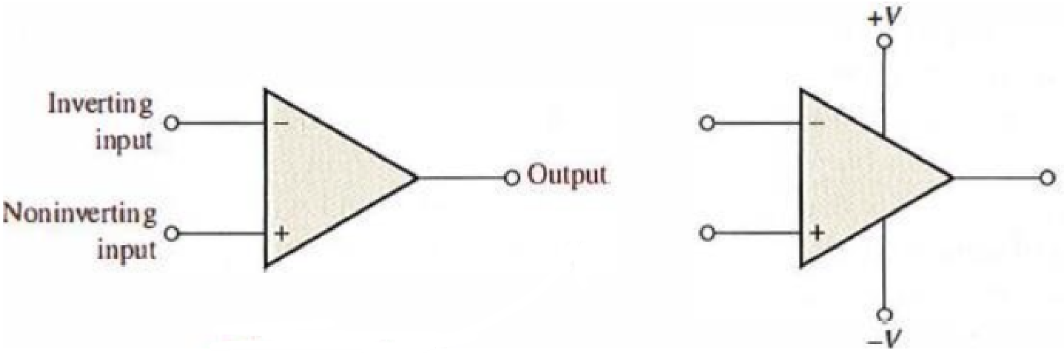

Figure 1: Op-amp symbol

The lab report is divided in six parts in which we are going to explore different aspects of the operational amplifier device. Along this report there will be studies about the slew rate of the LM741 operational amplifier, working with a non-inverting operational amplifier, an inverting operational amplifier, summing operational amplifier, and how to use an op-amp LM741 to adjust a signal described in a figure so the Arduino is able to read it.

During each part of the lab there will be conducted simulations which are made in LTSpice and real life experiments which were conducted in our lab at Turku University of Applied Sciences.

1 Slew rate of operational amplifier LM741

For the first part of this lab we had to use an operational amplifier LM741 (operating as a voltage follower) and measure the slew rate. The slew rate is the maximum rate of change of the output voltage in response to a step input voltage. Higher slew rate means the op-amp can handle rapid changes in input voltage more quickly. Lower slew rate means it takes more time for the op-amp to catch up to changes in the input. Furthermore, the operational amplifier LM741 operating as a voltage follower means that the configuration is a special case of the non-inverting amplifier where all of the output voltage is fed back to the inverting (-) input by a straight connection.

By doing some research, we observed that the operational amplifier LM741 has a low slew rate. According to the data sheet LM741 has a typical slew rate of 0,5V/µs.

1.1 Schematics

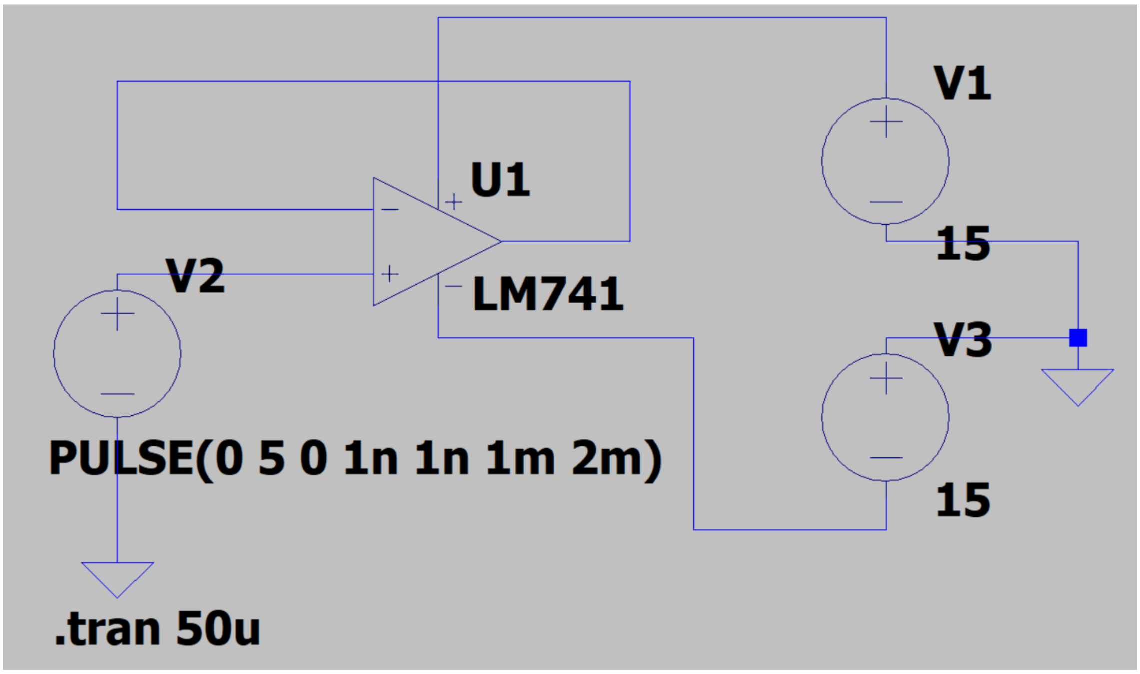

Figure 2: Schematic Operational Amplifier

1.2 Calculations

The slew rate can be calculated as the change of the input voltage divided by the corresponding change in time, and according to our simulation we got the following values:

$$slewrate = \frac{V2 - V1}{t2 - t1}$$
$$slewrate = \frac{4,50 - 2,90}{15,01 - 10,08}$$
$$slewrate = \frac{1,6}{4,93}$$
$$\text{slew rate} = 0,33\,\mathrm{V}/\mu\mathrm{s}$$

1.3 Simulation Values

While observing the result in LTspice we noticed that the slew rate was as shown in the picture:

Figure 3: Simulation Operational Amplifier

1.4 Real Values

By making the same schematics and measuring with picoscope we got the following results: (Output - Red and Input - Blue)

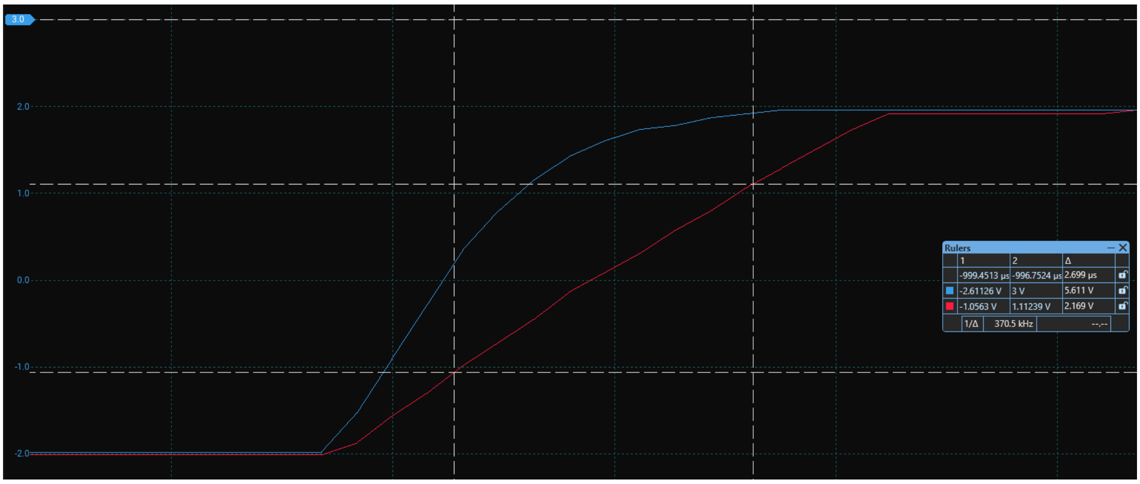

Figure 4: Real Simulation Operational Amplifier

2 Non inverting operational amplifier

For the second part of this lab we had to make a non-inverting operational amplifier. The connection for the non-inverting operational amplifier is with a closed-loop, which means that there is a feedback loop from output to input. The output is applied back to the inverting (-) input through the feedback circuit and the input signal is applied to the non inverting (+) input.

2.1 Schematics

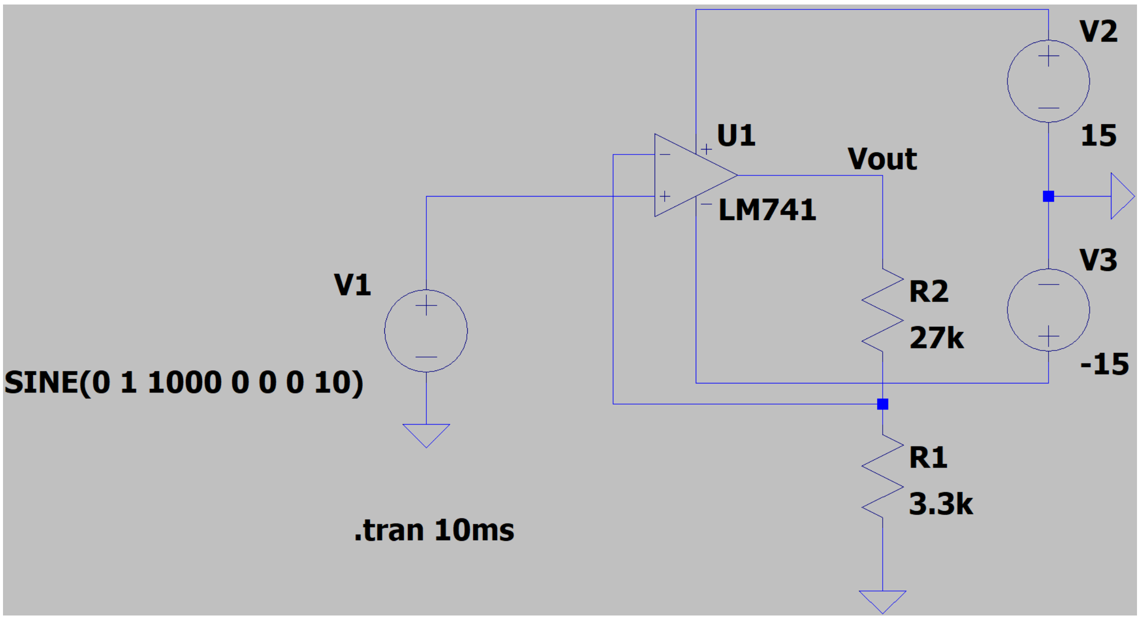

Figure 5: Schematic Non-inverting Operational Amplifier

2.2 Calculations

The non inverting operational amplifier should have a voltage gain of 10V. And use as input voltage $1V sin(\omega t)$ and output voltage of $10V sin(\omega t)$. Considering the formula for voltage gain (A) we can get candidates values for the resistors:

$$A = 1 + \frac{Rf}{Ri}$$
$$10 = 1 + \frac{Rf}{Ri}$$
$$9 = \frac{Rf}{Ri}$$

For the assignment we will use the resistor with the following values $Rf = 27K\Omega$ and $Ri = 3,3K\Omega$.

2.3 Simulation Values

While observing the result in LTspice we noticed that by adjusting the input voltage to be $1V sin(\omega t)$, we can verify that the output voltage is approximately $10V sin(\omega t)$.

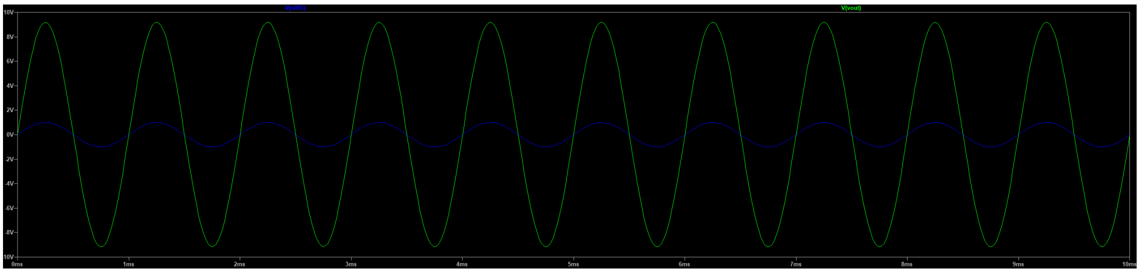

Figure 6: Simulation Non-inverting Operational Amplifier

2.4 Real Values

By making the same schematics and measuring with picoscope we got the following results:

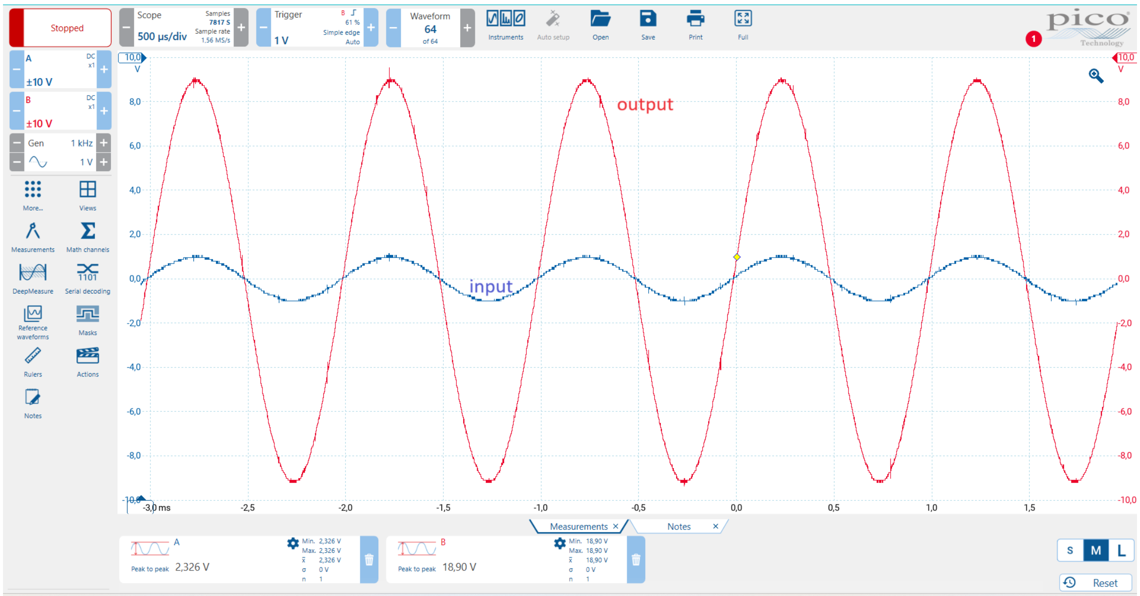

Figure 7: Real Simulation Non-inverting Operational Amplifier

As we increase the amplitude of the input voltage to 1,5V, the output voltage got saturated from "top" and "bottom".

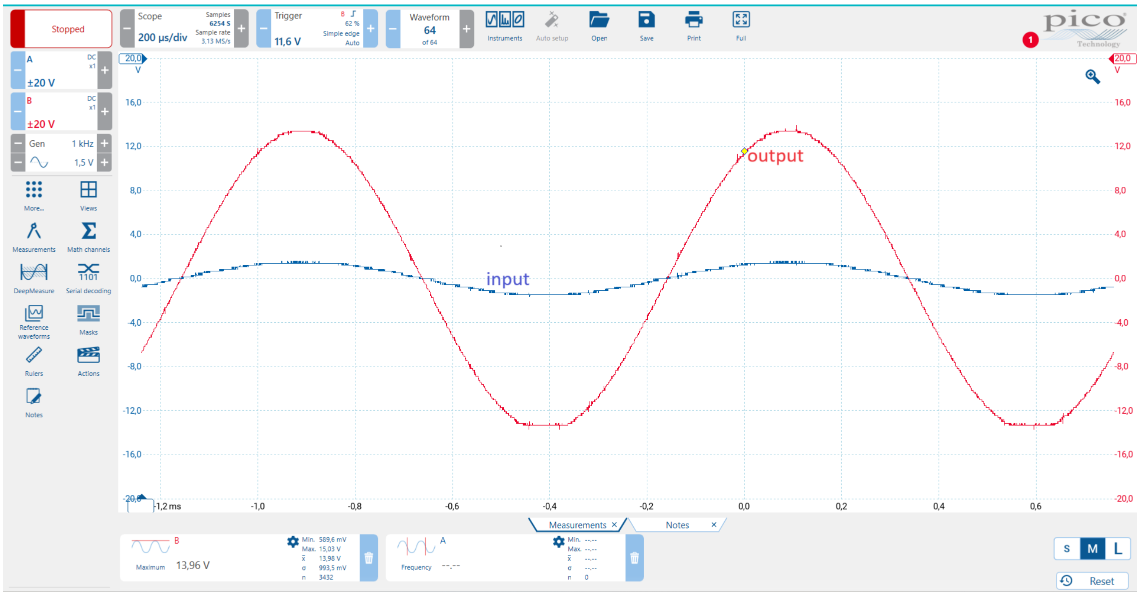

Figure 8: Real Simulation Saturated Non-inverting Operational Amplifier

When we increased the frequency of the input voltage to 20kHz we could notice that the output voltage starts to decrease.

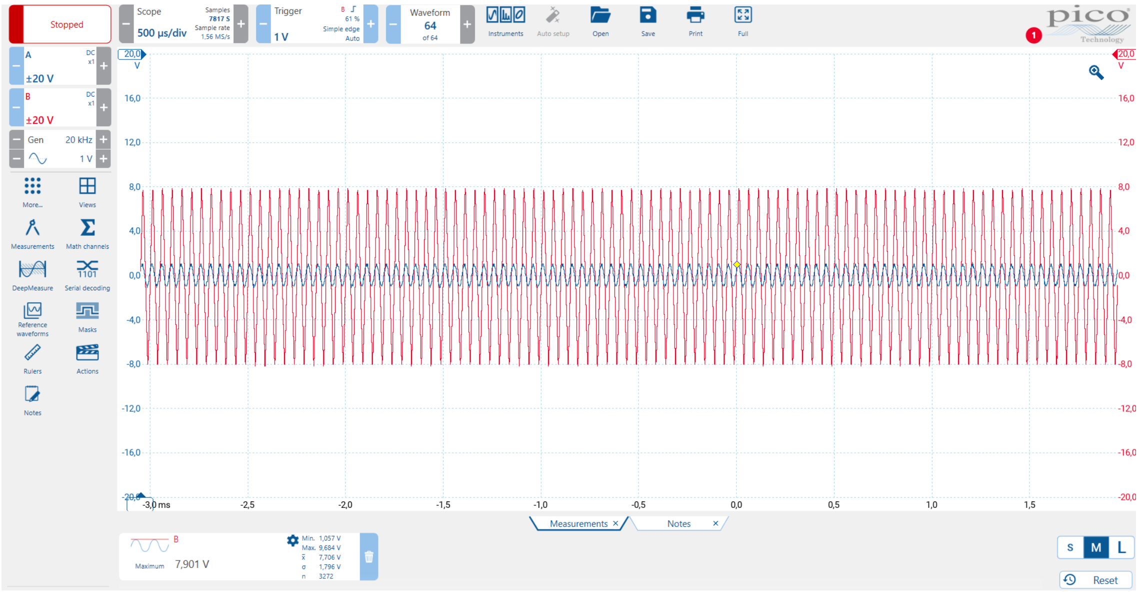

Figure 9: Real Simulation Non-inverting Operational Amplifier with decreasing Vout

The bandwidth is defined as the frequency range over which the voltage gain is greater than (approximately 70%) of its maximum value. By measuring the bandwidth of our amplifier we got the theoretical value of:

$$Voutmax = 9,5V$$
$$bandwidth = 0,71 * Voutmax$$
$$bandwidth = 0,71 * 9,5$$
$$bandwidth = 6,745$$

To get this voltage we have to use frequency $25KHz$

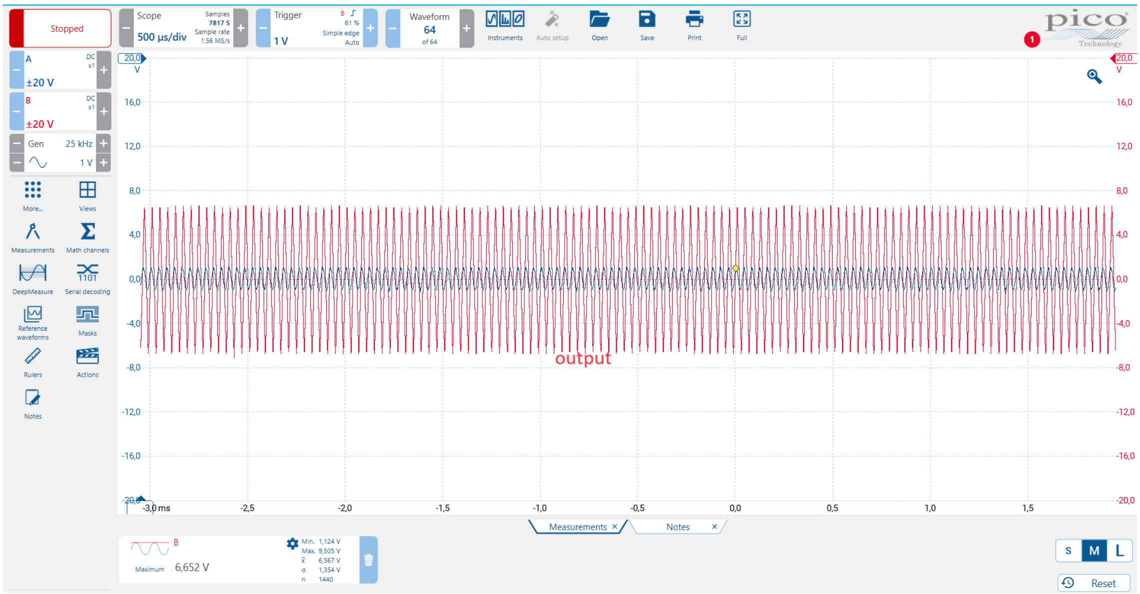

Figure 10: Real Simulation Bandwidth Non-inverting Operational Amplifier

3 Inverting operational amplifier

For the third part of this lab we had to make an inverting operational amplifier. For this configuration the input signal is applied through a series input resistor Ri to the inverting(-) input. Also, the output is fed back through R1 to the same input. And the non-inverting (+) input should be grounded.

3.1 Schematics

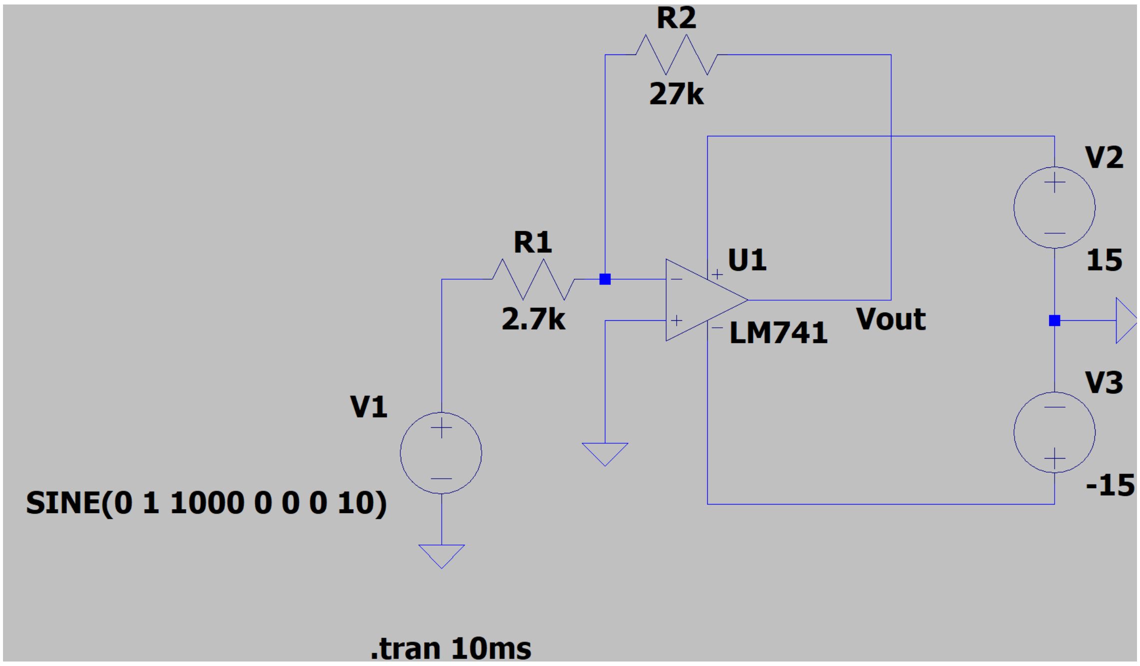

Figure 11: Schematic Inverting Operational Amplifier

3.2 Calculations

The inverting operational amplifier should have a voltage gain of -10V. And use as input voltage $1 * Vsin(\omega t)$ and output voltage of $-10 * Vsin(\omega t)$. Considering the formula for voltage gain (A) we can get candidates values for the resistors:

$$A = -\frac{Rf}{Ri}$$
$$|-10| = \frac{Rf}{Ri}$$

For the assignment we will use the resistor with the following values $Rf = 27k\Omega$ and $Ri = 2,7k\Omega$.

Adjusting the input voltage to be $1 * Vsin(\omega t)$ we have the value X and we can verify that the output voltage is $-10 * Vsin(\omega t)$, or X.

$$Vsin(\omega t) =$$
$$10 = 1 + \frac{Rf}{Ri}$$
$$9 = 1 + \frac{Rf}{Ri}$$

3.3 Simulation Values

While observing the result in LTspice we noticed that by adjusting the input voltage to be $1V sin(\omega t)$, we can verify that the output voltage is approximately $-10V sin(\omega t)$.

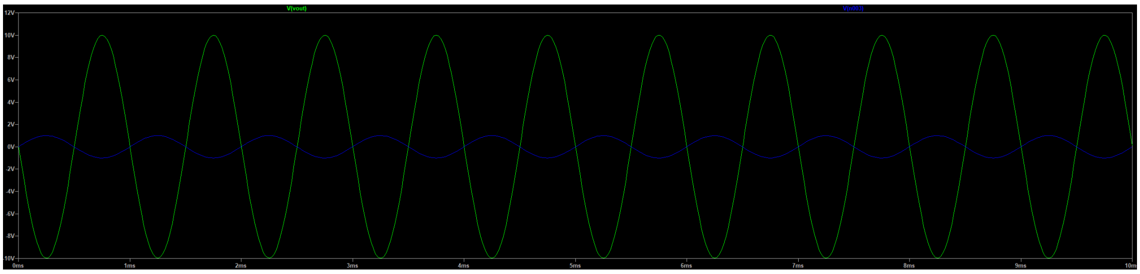

Figure 12: Simulation Inverting Operational Amplifier

3.4 Real Values

By making the same schematics and measuring with picoscope we got the following results:

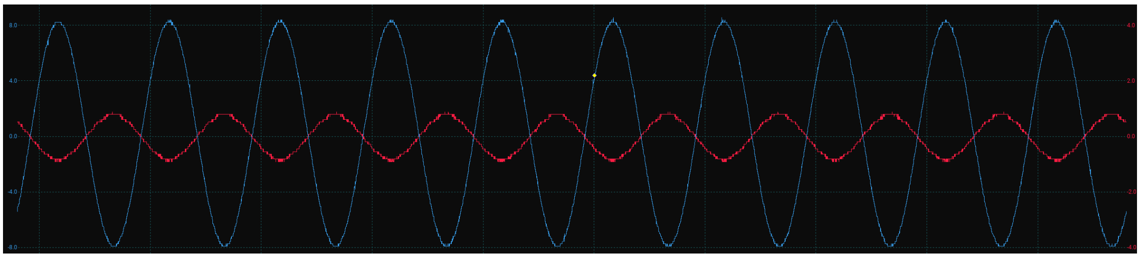

Figure 13: Real Simulation Inverting Operational Amplifier

As we increase the amplitude of the input voltage to 1,5V, the output voltage got saturated on "top" and "bottom".

When we increased the frequency of the input voltage to 20kHz we could notice that the output voltage starts to decrease.

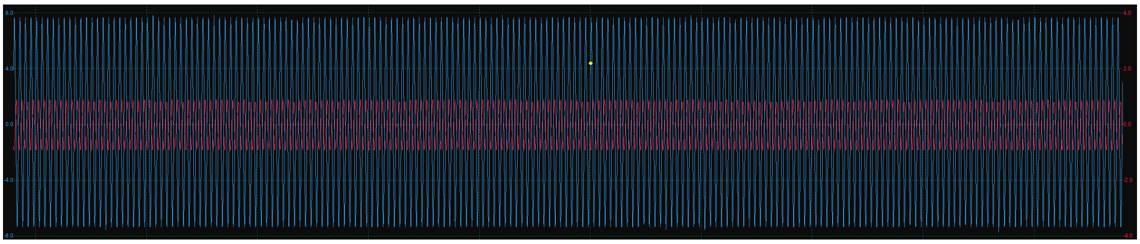

Figure 14: Real Simulation Saturated Inverting Operational Amplifier

The bandwidth is defined as the frequency range over which the voltage gain is greater than (approximately 70%) of its maximum value. By measuring the bandwidth of our amplifier we got the theoretical value of:

$$Voutmax = 8.3$$
$$bandwidth = 0,71 * Voutmax$$
$$bandwidth = 0,71 * 8.3$$
$$bandwidth = 5.9$$

To get this voltage we have to use frequency $30KHz$

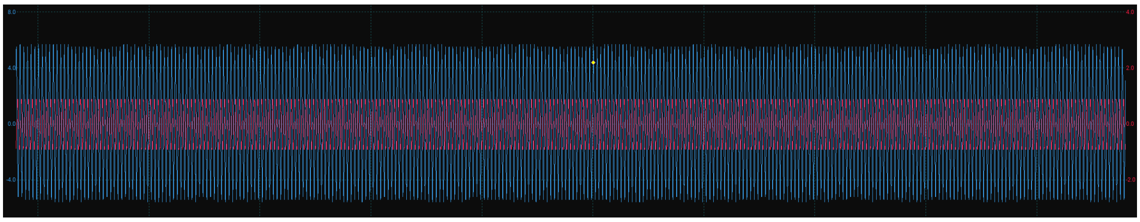

Figure 15: Real Simulation Inverting Operational Amplifier with decreasing Vout

4 Summing inverting amplifier

For the fourth part of this lab we had to build a summing amplifier. As we know the early operational amplifiers were used primarily to perform mathematical operations such as addition, subtraction, integration, and differentiation. The circuit has both inverting and non-inverting inputs and can be configured to provide weighted or unweighted sums of the input signals.

The goal for the circuit is to amplify Vin1 by 1.8 and Vin2 by 2.5 - and both of those are inverted.

4.1 Schematics

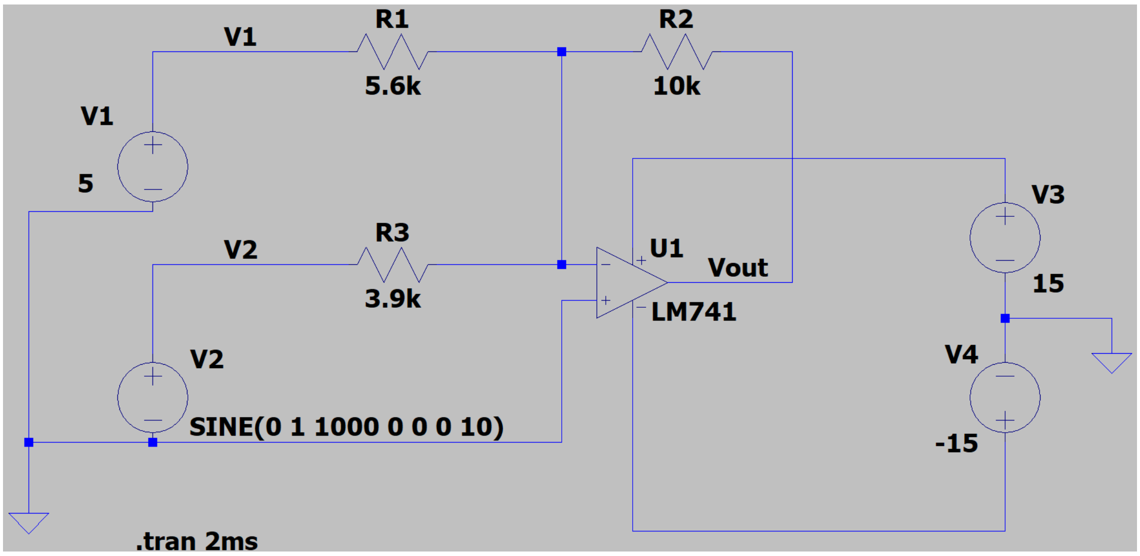

Figure 16: Schematic Summing Inverting Amplifier

4.2 Calculations

Considering the output voltage as $Vout = -1,8 * Vin1 - 2,5 * Vin2$, we can use the output voltage formula and the formula for voltage gain in a inverting operating amplifier to obtain the results. The reason why we should use the inverting operating amplifier formula for voltage gain is because the summing amplifier is built based on the inverting op-am.

$Vout = -(\frac{Rf}{R1} * Vin1 + \frac{Rf}{R2} * Vin2) <=> Vout = -\frac{Rf}{R1} * Vin1 - \frac{Rf}{R2} * Vin2$

$A = -\frac{Rf}{R1}$

Therefore we get:

$-1.8 = -\frac{Rf}{R1}$

$-2.5 = -\frac{Rf}{R2}$

Using $Rf = 10k\Omega$ just for the calculations to be easier, we then get: $R1 = 5.6k\Omega$ and $R2 = 4k\Omega$.

4.3 Simulation Values

While observing the result in LTspice when we added a sine wave for the V2, there was some times where V2 = 0. Which means that the Vout would only depend on V1, according to the formula $Vout = -1,8 * Vin1 - 2,5 * Vin2$. We can notice that Vout should be when V1 = 5 and V2 = 0: $Vout = -1,8 * V1 - 2,5 * V2$ $Vout = -1,8 * 5 - 2,5 * 0$ $Vout = -9V$

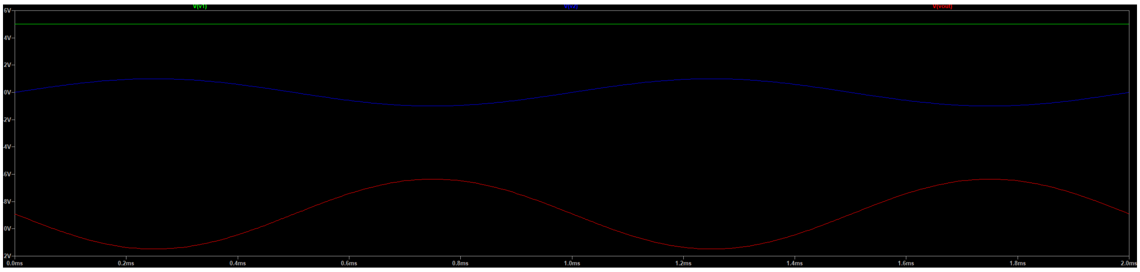

Figure 17: Schematic Summing Inverting Amplifier

4.4 Real Values

By making the same schematics and measuring with picoscope we got the following results:

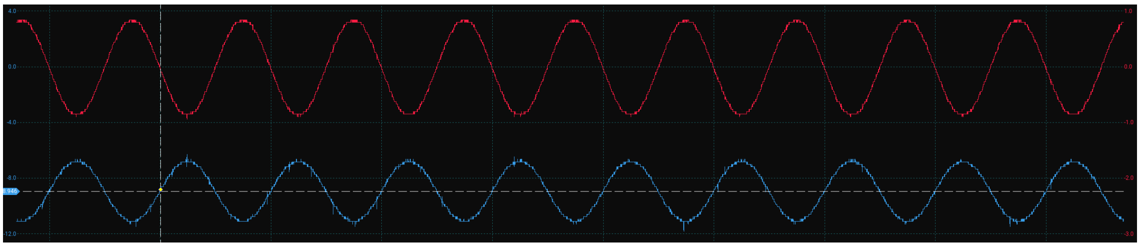

Figure 18: Schematic Summing Inverting Amplifier

5 Summing non-inverting amplifier

For the fifth part of this lab we had also to built a summing amplifier, referring to schematics of non-inverting summing amplifier. However, this time with an output voltage of $Vout = 3*V1 + 4*V2$.

5.1 Schematics

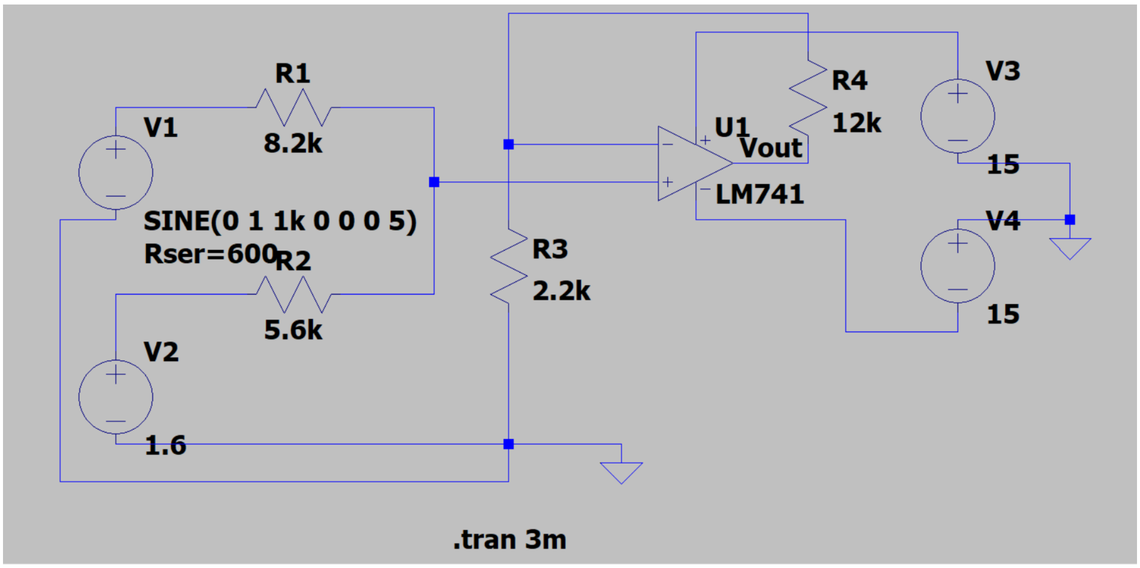

Figure 19: Schematic Summing Non-inverting Amplifier

5.2 Calculations

The Voltage Output can be calculated with the formula:

$$Vout = \frac{R3 + R4}{R3} * \frac{R2 * Vs1 + R1 * Vs2}{R1 + R2}$$

The Common Gain for both inputs can be calculated with the formula:

$$Vout = \frac{R3 + R4}{R3} \left[Vs1 * \frac{R2}{R1 + R2} + Vs2 * \frac{R1}{R1 + R2} \right]$$
$$Vout = \frac{R3 + R4}{R3} * Vs1 * \frac{R2}{R1 + R2} + \frac{R3 + R4}{R3} * Vs2 * \frac{R1}{R1 + R2}$$

For an output voltage of $Vout = 3*V1 + 4*V2$ we should consider:

$$Vout1 = \frac{R3 + R4}{R3} * Vs1 * \frac{R2}{R1 + R2}$$
$$3 = \frac{R3 + R4}{R3} * Vs1 * \frac{R2}{R1 + R2}$$

$$Vout2 = \frac{R3 + R4}{R3} * Vs2 * \frac{R1}{R1 + R2}$$
$$4 = \frac{R3 + R4}{R3} * Vs2 * \frac{R1}{R1 + R2}$$

By doing so we can notice that the relationship between R3 and R4 should be something like 1/4 and if we use $R3 = 2K\Omega$ and $R4 = 12K\Omega$ we can get:

$$\begin{aligned}
3 &= \frac{R3+R4}{R3} * \frac{R2}{R1+R2} \\
\frac{3*R3}{R3+R4} &= \frac{R2}{R1+R2} \\
\frac{3*2}{2+12} &= \frac{R2}{R1+R2} \\
\frac{6}{14} &= \frac{R2}{R1+R2} \\
\frac{3}{7} &= \frac{R2}{R1+R2}
\end{aligned}$$

$$\begin{aligned}
4 &= \frac{R3+R4}{R3} * \frac{R1}{R1+R2} \\
\frac{4*R3}{R3+R4} &= \frac{R1}{R1+R2} \\
\frac{4*2}{2+12} &= \frac{R1}{R1+R2} \\
\frac{8}{14} &= \frac{R1}{R1+R2}
\end{aligned}$$

Finally, we can just assume two different values for R1 and R2 that would make this proportion work, for example $R1 = 8k\Omega$ and $R2 = 6k\Omega$.

$$\begin{aligned}
\frac{3}{7} &= \frac{R2}{R1+R2} \\
\frac{3}{7} &= \frac{6}{8+6} \\
\frac{3}{7} &= \frac{6}{14} \\
\frac{3}{7} &= \frac{3}{7}
\end{aligned}$$

$$\begin{aligned}
\frac{8}{14} &= \frac{R1}{R1+R2} \\
\frac{8}{14} &= \frac{8}{8+6} \\
\frac{8}{14} &= \frac{8}{14}
\end{aligned}$$

Which proves that those values for the resistance, work accordingly to the formula. However, for real resistor we have to use the values for the resistor as $R1 = 8,2k\Omega$, $R2 = 5,6k\Omega$, $R3 = 2,2k\Omega$, and $R4 = 12k\Omega$

5.3 Simulation Values

While observing the result in LTspice we noticed that with this schematic and a sine wave on the V1, when the V1 = 0 the Vout would work only depending on V2. That means that to follow the goal of this exercise $Vout = 3 * Vs1 + 4 * Vs2$, when we have a V1 = 0 and a V2 = 1.6V, the Vout should be:

$$\begin{aligned}
Vout &= 3*0 + 4*1.6 \\
Vout &= 6,4V
\end{aligned}$$

Which we can see on these simulation:

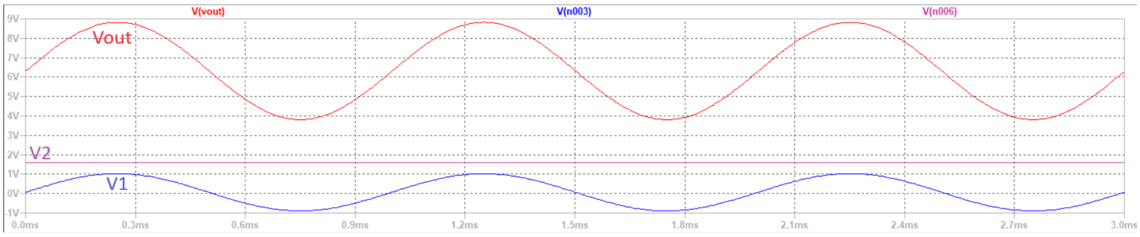

Figure 20: Simulation Summing Non-inverting Amplifier

5.4 Real Values

By making the same schematics and measuring with picoscope we got the following results:

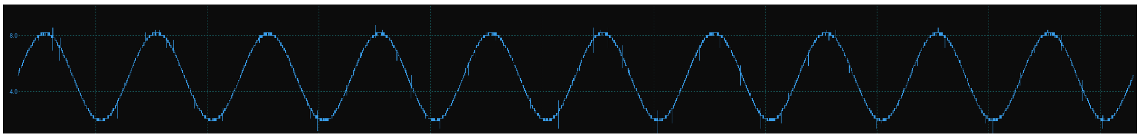

Figure 21: Real Simulation Summing Non-inverting Amplifier

6 Operational amplifier LM741 to adjust a signal

For the last part of this lab we had to use the operational amplifier LM741 to adjust a signal described in the figure bellow. The goal is for an Arduino to be able to read it, which means that the signal amplitude should be 0-5V.

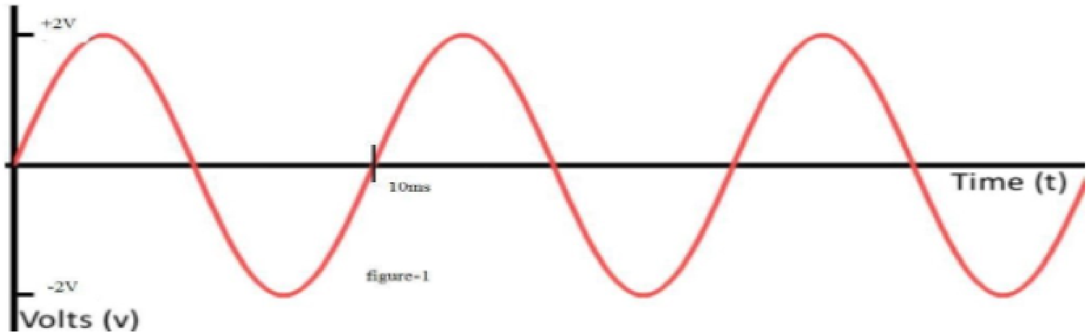

Figure 22: Original Signal

6.1 Schematics

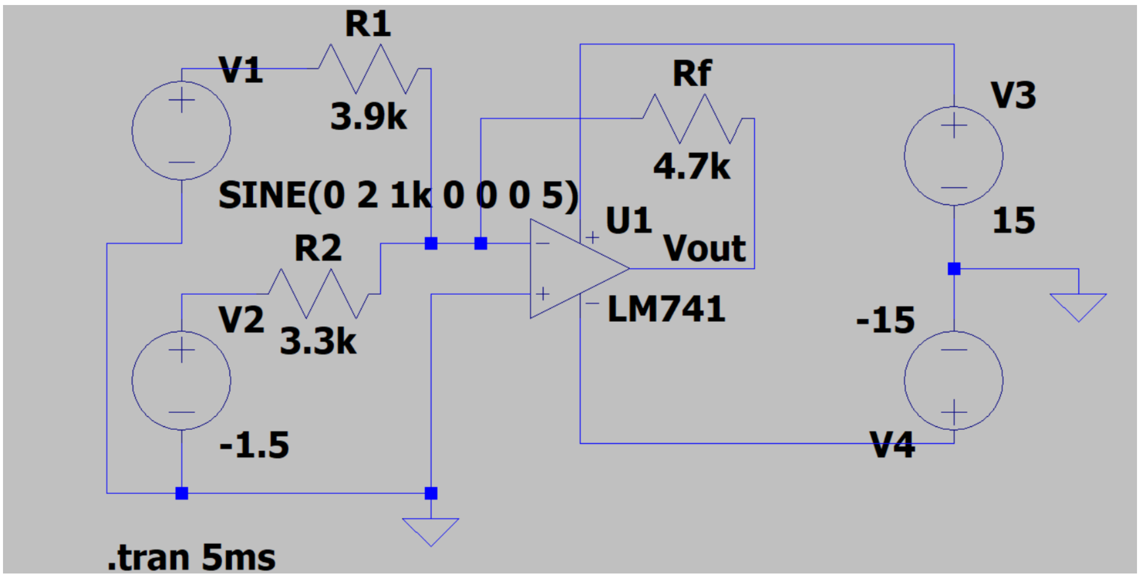

Figure 23: Schematics of the circuit

6.2 Calculations

First we discovered that to do that we would need the circuit to be a summing inverting amplifier. Which has the following formula:

$$Vout = -(\frac{Rf}{R1} * Vin1 + \frac{Rf}{R2} * Vin2)$$

With voltages of $Vin1 = 2V$, $Vin2 = 1,5V$, and $Vout = 5V$, and a resistance $Rf = 4,7K\Omega$ we can calculate the relationship between the resistances.

$$\begin{aligned}
Vout &= -(\frac{Rf}{R1} * Vin1 + \frac{Rf}{R2} * Vin2) \\
5 &= -(\frac{4,7}{R1} * 2 + \frac{4,7}{R2} * 1,5) \\
5 &= -\frac{9,4}{R1} - \frac{7,05}{R2} \\
5 &= -\frac{9,4}{R1} - \frac{7,05}{R2}
\end{aligned}$$

After consideration, if we use resistors $R1 = 3,9k\Omega$ and $R2 = 3,3K\Omega$ we can get pretty close results.

$$\begin{aligned}
5 &= -\frac{9,4}{R1} - \frac{7,05}{R2} \\
5 &= -\frac{9,4}{3,9} - \frac{7,05}{3,3} \\
5 &= -2,41 - 2,14 \\
5 &\approx |-4,55|
\end{aligned}$$

6.3 Simulation Values

While observing the result in LTspice we could see almost the ideal signal wave.

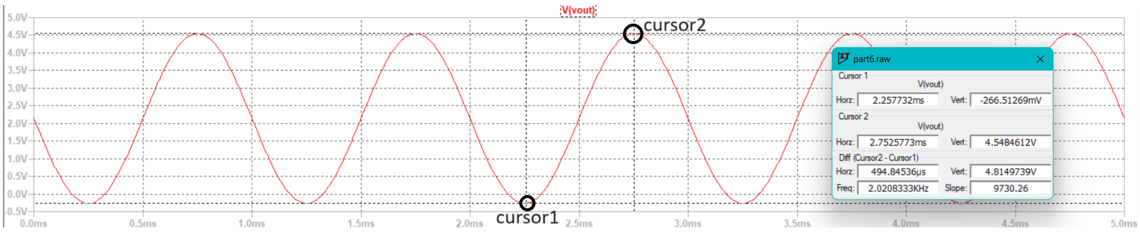

Figure 24: Simulation of the circuit

6.4 Real Values

By making the same schematics and measuring with picoscope we got the following results:

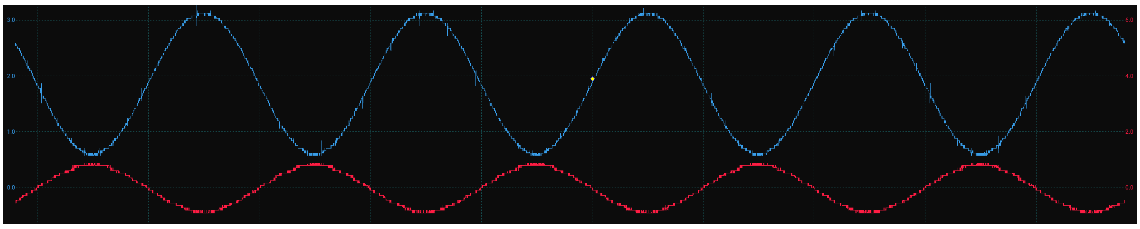

Figure 25: Simulation of the circuit