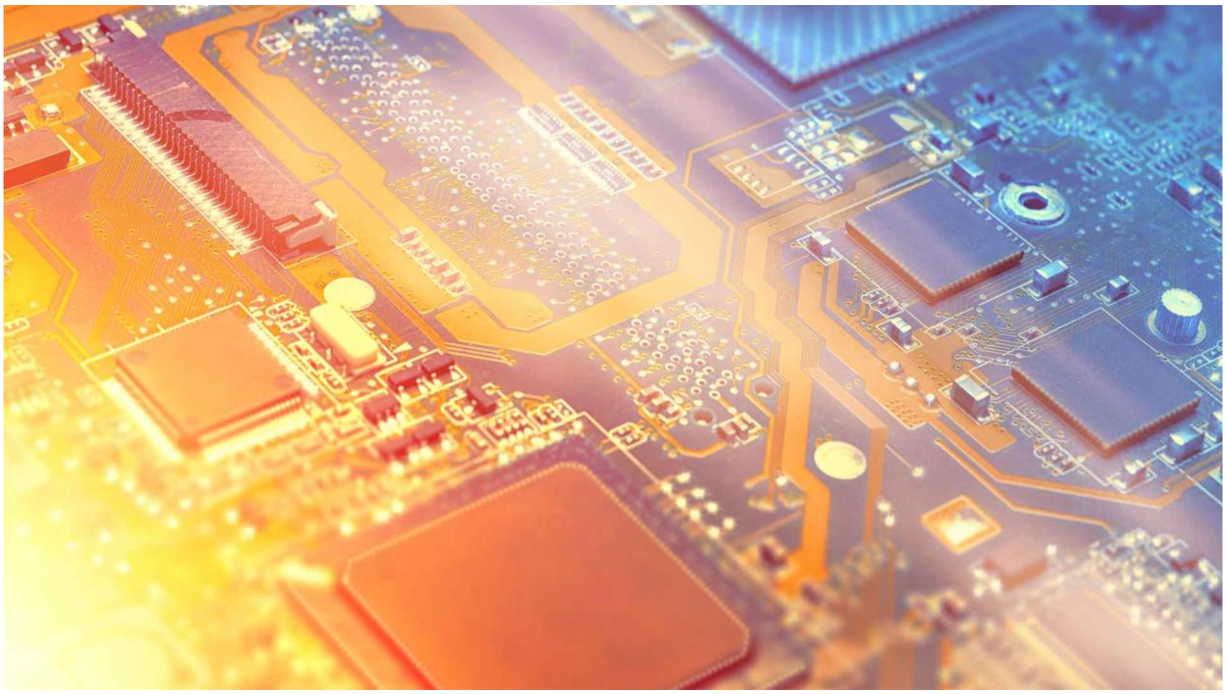
Lab Report - Electronics

Teacher: Jarno Tuominen



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Double Degree in Embedded Electronics and IoT

Turku, December 1st, 2022

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1. Constitution of the Group

The group elements are: Ana Rita dos Santos Videira, Sérgio Apolinário da Costa and Viktoriya Chekun. The editor-in-chief of this lab report was Ana Videira.

2. Date and Version of the report

This report lab corresponds to the class of December 1st, 2022.
The version of this document is number *1*.

3. Description of device under test (DUT)

The device in test is the operational amplifier (op-amp) .

The standard **operational amplifier** symbol is shown in Figure 12-1 (a). It has two input terminals, the inverting (-) input and the noninverting (+) input, and one output terminal. Most op-amps operate with two DC supply voltages, one positive and the other negative, as shown in Figure 12-1 (b), although some have a single DC supply. Usually, these DC voltage terminals are left off the schematic symbol for simplicity but are understood to be there. Some typical op-amp IC packages are shown in Figure 12-l(c).

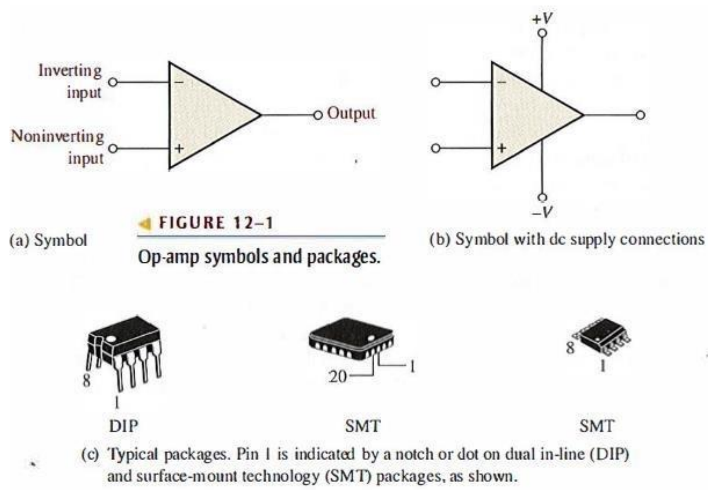

FIGURE 12–1
Op-amp symbols and packages.

4. List of instruments used

- Oscilloscope Tektronix TDS 1012B
- Proto-Board PB-503
- TG120 Function Generator
- Multimeter Fluke 112
- Resistors with different values: 1kΩ, 2.2kΩ, 3kΩ, 3.3kΩ, 3.9kΩ, 4.9kΩ, 5.6kΩ, 10kΩ, 18kΩ, 39kΩ
- N-POP inverter ML741CN
- Conducting cables

5. Procedures

This lab work was done flowing the lab instructions provided.
This report is following the same structure.

5.1 Exercise 1

5.1.1 Description of Procedure

Measurement of the slew rate of LM741 operational amplifier when it is operating as a voltage follower. Input signal of +15Volts and -15Volts. Non-inverting input of 5 Volts.

5.1.2 The equations

The slew rate is a standard parameter in the op-amp LM741CN so, after analysing the datasheet the slew rate of the component is between 0.3 to 0.7 V/µs .

For the next calculations, the slew rate is: $SR = \frac{\Delta V}{\Delta t}$

5.1.3 Simulation results

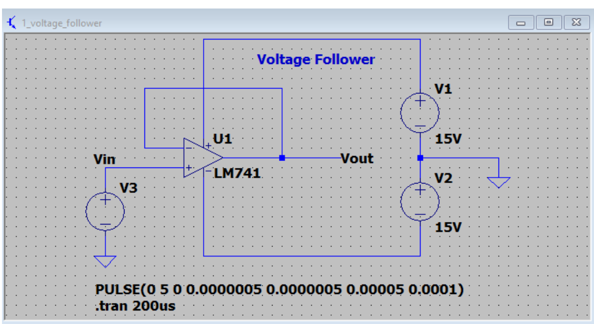

Figure 1 – Schematics voltage follower circuit – exercise 1

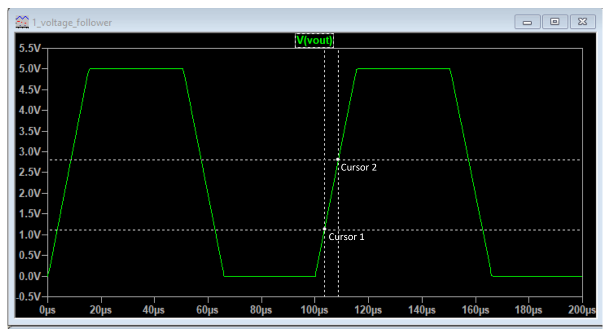

Figure 2 – Simulation – exercise 1

The figure 2 reveals the V_{out} of the voltage follower circuit. The slew rate was measured and with the Slope tool from LTSpice and the two cursors as showed in the figure 2.

Slew Rate in the simulation = 0.32 V/µs

5.1.4 Measurement results

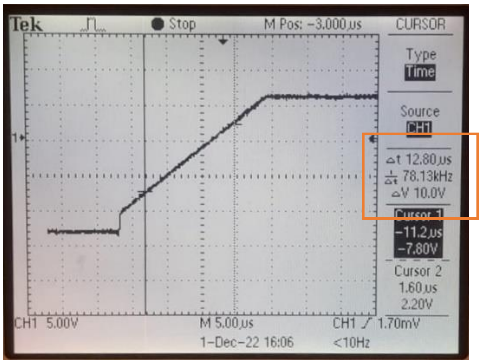

Figure 3 – Exercise 1
Oscilloscope measurements of the output voltage follower circuit

With the osciloscope and using the formula described before:

$$SR = \frac{\Delta V}{\Delta t} = \frac{10.0V}{12.8\mu s} = 0.78V/\mu s$$

And the result was what was inside of the range that was expected.

5.2 Exercise 2

5.2.1 Description of Procedure

(Exercise 2.a)
Design of a noninverting amplifier circuit which voltage gain is 10.
Adjust the input voltage to 1sin(ωt) checked if the output voltage is 10sin(ωt).
After increasing the amplitude of the input voltage and check when the voltage is cut (saturated).
(Exercise 2.b)
Increase the input frequency and check with oscilloscope when the output voltage starts to decrease.
(Exercise 2.c)
Measure the bandwidth of the amplifier.

5.2.2 The equations and calculations

As described in the lab instructions, more precisely in the *example 12-3* of a on inverting amplifier circuit, the closed-loop voltage gain of the amplifier is $\boldsymbol{A_{cl(NI)} = 1 + \frac{R_f}{R_i}}$

Knowing that $\boldsymbol{A_v = 10}$ so for convenience, if $\boldsymbol{R_i = 2k\Omega}$ then $\boldsymbol{R_f = 18k\Omega}$

Note: The resistor $R_i = 2k\Omega$ was not available on the lab so it was used $R_i = 2.2k\Omega$ instead.

5.2.3 Simulation results

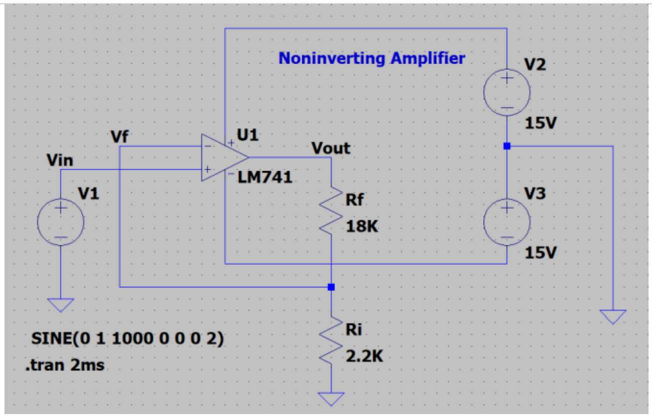

Figure 4 - Schematics of the noninverting amplifier circuit simulated and implemented for exercise 2

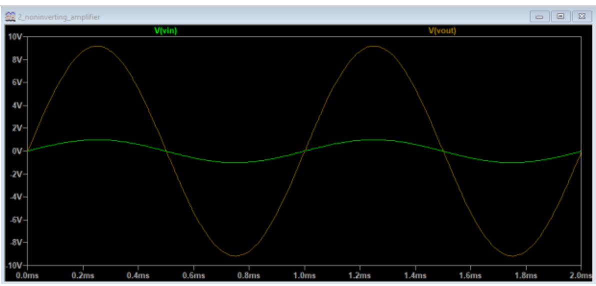

Figure 5 – Simulation exercise 2.a
V_{in} = 1sin(1000t) V and V_{out} ≅ 10sin(1000t) V

V_{out} will not show exactly 10V as in the calculations because of the change in the register R_i *of* $2k\Omega$ *to* $2.2k\Omega$.

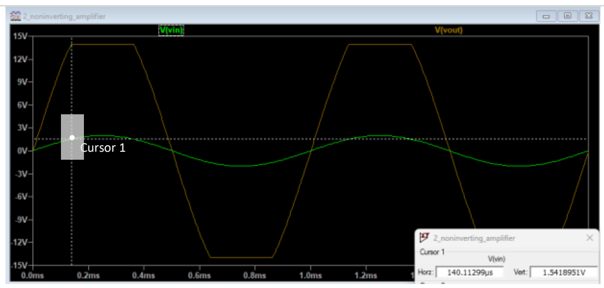

Figure 6 - Simulation exercise 2.a
V_{in} = 1sin(1000t) V and increased amplitude to 2V

Saturation happens with $V_{in} = 1.54V$

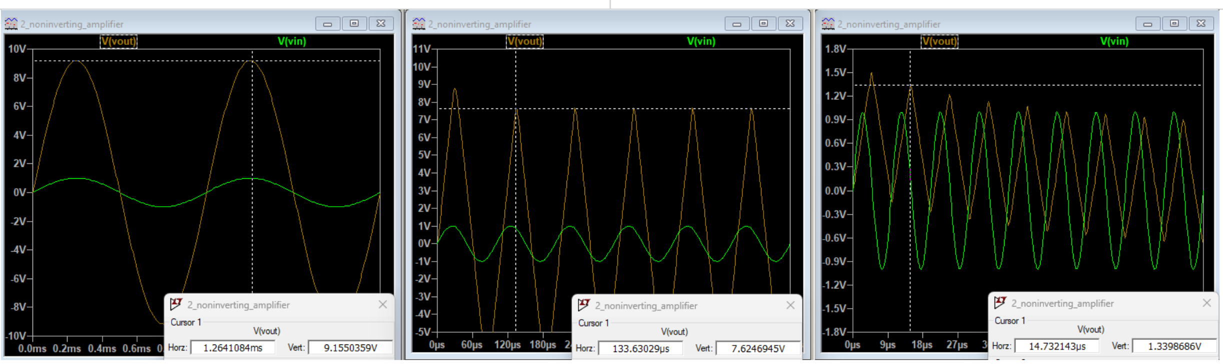

Figure 7 - Simulation exercise 2.b
increased frequency so V_{in} = 1sin(1kt) V (left) , V_{in} = 1sin(10kt) V (centre) , V_{in} = 1sin(100kt) V (right)

V_{out} is decreasing as expected.

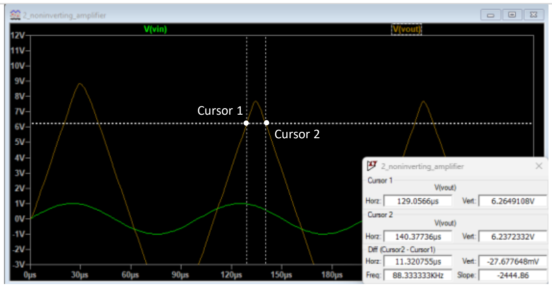

Figure 8 – Simulation exercise 2.c , V_{in} = 1sin(1000t) V

$0.71 \cdot V_{outMax} = 0.71 \cdot 8.81 = 6.2V \rightarrow$ So, this means that the cut off frequency is the frequency where the V_{out} $declines$ to $6.2V$.

So, the bandwidth will be 90 kHz.

5.2.4 Measurement results

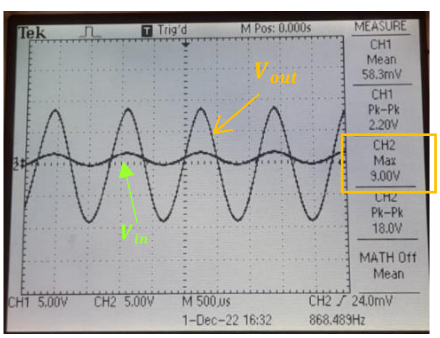

Figure 9 – Exercise 2.a
Before increasing the amplitude on the input

As expected, with V_{in}= 1sin(ωt)V the V_{outMax} $= 9V$ which is close to V_{out} = 10sin(ωt) V

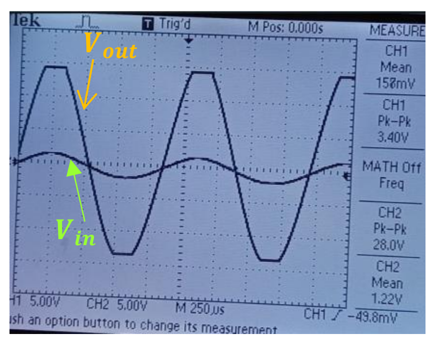

Figure 10 – Exercise 2.a
After increasing the amplitude on the input (saturated)

As expected, increasing the amplitude (the peak-to-peak on the oscilloscope) the V_{out} saturates.

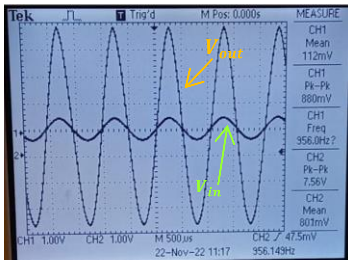

Figure 11 – Exercise 2.b
Input 1 kHz , $V_{out} = 801\ mV$

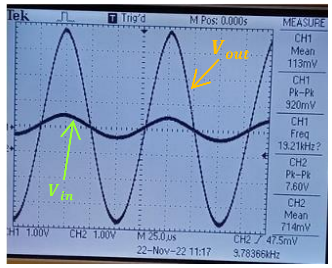

Figure 12 – Exercise 2.b
Input 10 kHz, $V_{out} = 714\ mV$

Figure 13 – Exercise 2.b
Input 100 kHz $V_{out} = 621\ mV$

As expected, with the increasing of the Input frequency, the output is decreasing.

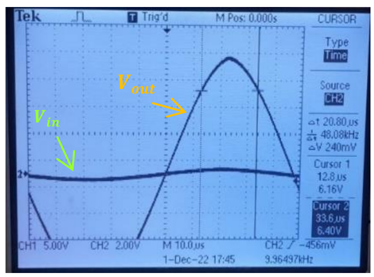

Figure 14 – Exercise 2.c

$$0.71 \cdot V_{outMax} = 0.71 \cdot 9 = 6.39V$$

So, the bandwidth will be 50 kHz.

5.3 Exercise 3

5.3.1 Description of Procedure

(Exercise 3.a)
Design of an inverting amplifier circuit which voltage gain is -10.
Adjust the input voltage to 1sin(ωt) checked if the output voltage is -10sin(ωt).
(Exercise 3.b) Increase the input frequency and check with oscilloscope when the output voltage starts to decrease.
(Exercise 3.c) Measure the bandwidth of your amplifier.

5.3.2 The equations

As described in the lab instructions,

the voltage gain of an inverting amplifier circuit can be expressed as: $\boldsymbol{A_{cl(I)} = -\frac{R_f}{R_i}}$

Knowing that $\boldsymbol{A_v = -10}$ so for convenience, if $\boldsymbol{R_f = 39k\Omega}$ then $\boldsymbol{R_i = 3.9k\Omega}$

5.3.3 Simulation results

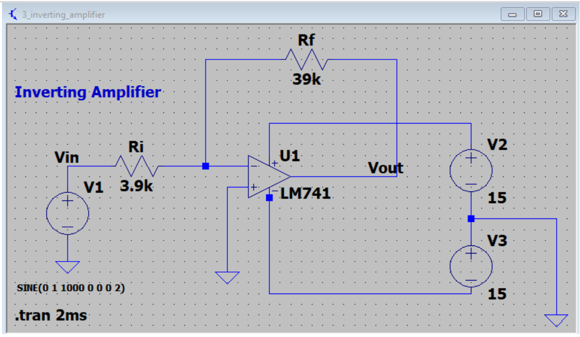

Figure 15 – Schematics of the inverting amplifier circuit simulated and implemented for exercise 3

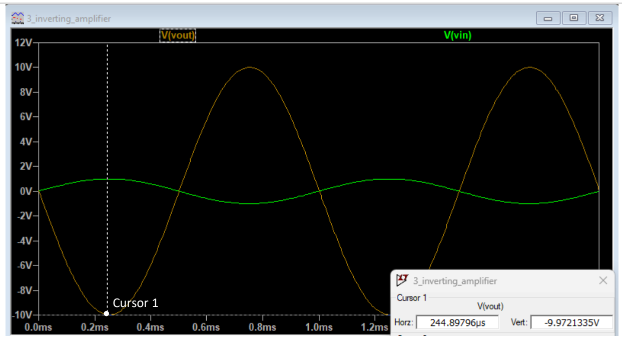

Figure 16 – Simulation exercise 3.a
V_{in} = 1sin(1000t) and $V_{out} \cong$ 10sin(1000t)

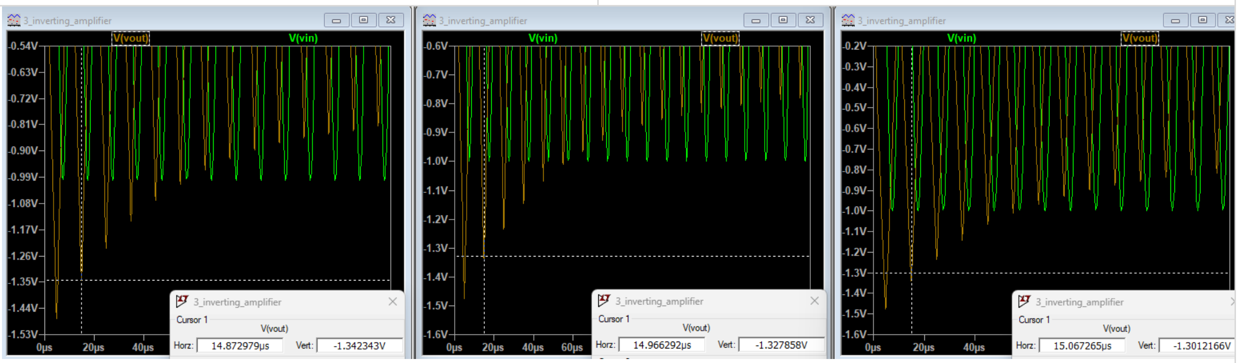

Figure 17 - Simulation exercise 3.b
increased frequency so V_{in} = 1sin(1kt) V (left) , V_{in} = 1sin(10kt) V (centre) , V_{in} = 1sin(100kt) V (right)

V_{out} is decreasing as expected.

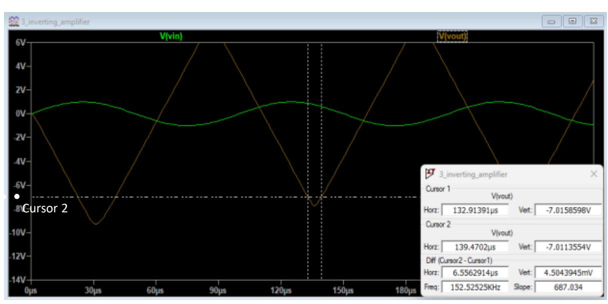

Figure 18 – Simulation exercise 2.c
V_{in} = 1sin(10000t) V

$0.71 \cdot V_{outMax} = 0.71 \cdot 9.9 = 7.02V$ -> So, this means that the cut off frequency is the frequency where the $V_{out}\ declines\ to\ 7.02V$.
So, the bandwidth will be 152 kHz.

5.3.4 Measurement results

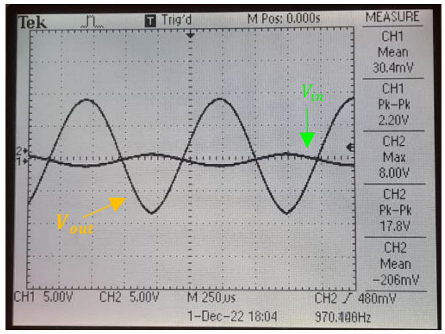

Figure 19 – Exercise 3.a

As expected, with V_{in}= 1sin(ωt)V the $V_{outMax} = 8V$ which is close to V_{out} = 10sin(ωt) V

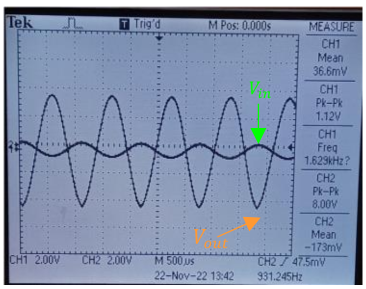

Figure 20 – Exercise 3.b

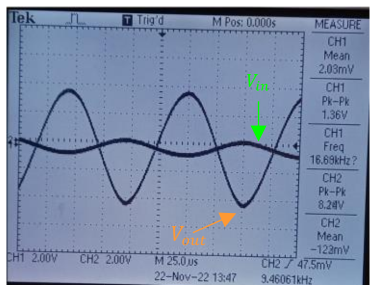

Figure 21 - Exercise 3.b

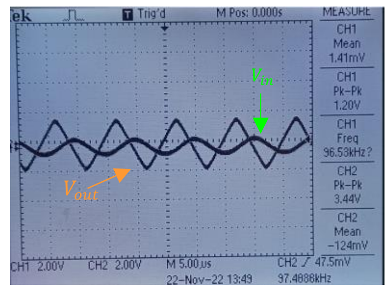

Figure 22 - Exercise 3.b

As expected, with the increasing of the Input frequency, the output is decreasing.

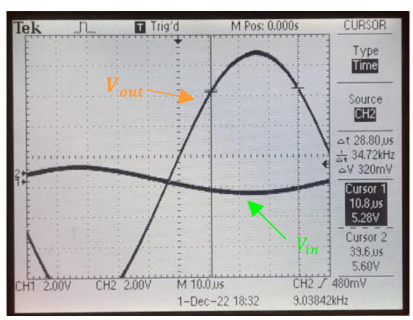

Figure 23 – Exercise 3.c

$$0.71 \cdot V_{outMax} = 0.71 \cdot 8 = 5.68V$$

So, the bandwidth will be 35 kHz.

There's a difference in the V_{outMax} in the simulation and in the measurements obtain with the oscilloscope. This can be the motive for the discrepancy in between bandwidth values.

5.4 Exercise 4

5.4.1 Description of Procedure

Design of a summing amplifier circuit which output voltage is $V_0 = -1.8\,V_{in1} - 2.5V_{in2}$
Calculate the component values, simulate with LTSpice and Implement the circuit.

5.4.2 The equations

Because the voltage gain is negative it concludes that this will be a *summing inverting amplifier circuit.*

As the lab instruction refer, the equation for this type of circuit, with 2 inputs is:

$$V_{out} = -\left(\frac{R_f}{R_1}V_{in1} + \frac{R_f}{R_2}V_{in2}\right)$$

Recalling the voltage gain equation from the previous exercise (point 5.3.1) for the same type of circuit:

$$\boldsymbol{A_{cl(I)} = -\frac{R_f}{R_i}}$$

So, these two expressions will be used to determinate the registers values:

$$V_{out} = -\left(\frac{R_f}{R_1}V_{in1} + \frac{R_f}{R_2}V_{in2}\right) \leftrightarrow V_{out} = -\frac{R_f}{R_1}V_{in1} - \frac{R_f}{R_2}V_{in2}$$

$$\frac{V_{out}}{V_{in1}} = -\frac{R_f}{R_1}V_{in1} \leftrightarrow A_{cl(I)_1} = -\frac{R_f}{R_1} \leftrightarrow -1.8 = -\frac{R_f}{R_1}$$

$$\frac{V_{out}}{V_{in2}} = -\frac{R_f}{R_2}V_{in2} \leftrightarrow A_{cl(I)_2} = -\frac{R_f}{2} \leftrightarrow -2.5 = -\frac{R_f}{R_2}$$

if, for convenience, $\boldsymbol{R_f = 10k\Omega}$ then

$$-1.8 = -\frac{10}{R_1} \leftrightarrow \boldsymbol{R_1 = 5.5k\Omega}$$

$$-2.5 = -\frac{10}{R_2} \leftrightarrow \boldsymbol{R_2 = 4k\Omega}$$

5.4.3 Simulation results

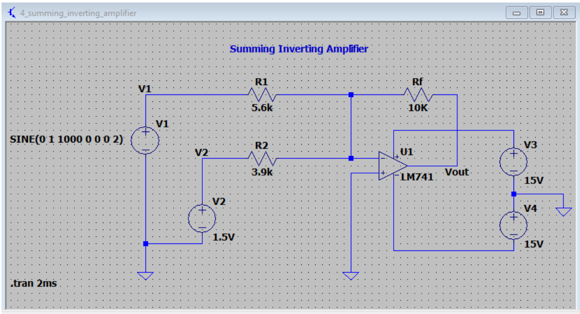

Figure 24 – Schematics of the summing inverting amplifier circuit simulated and implemented for exercise 4

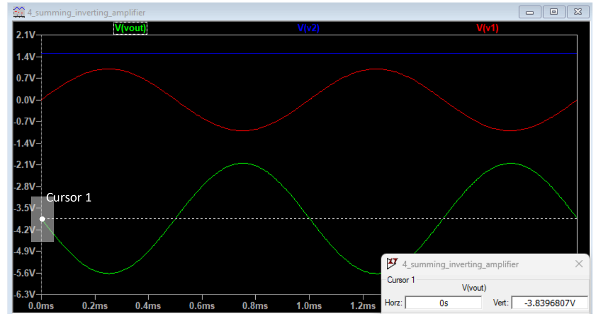

Figure 25 - Simulation exercise 4
V_1 = 1sin(ωt)=0V V_2 =1.5V V_{out} ≅ -2.55V

Note: Some resistors were not available on the lab, so they were switched to approximated values:
$R_1 = 5.5k\Omega \rightarrow \text{using } R_1 = 5.6k\Omega$
$R_2 = 4k\Omega \rightarrow \text{using } R_2 = 3.9k\Omega$

$V_0 = -1.8\, V_{in1} - 2.5 V_{in2}$
$\leftrightarrow V_0 = -1.8 * 0 - 2.5 * 1.5$
$\leftrightarrow V_0 = -3.73\ V \cong V_{0\ simulation} = -3.83\ V$

Values for V_0 calculated and simulated with LTSpice are not completely equal because of the change in the register's values.

5.4.4 Measurement results

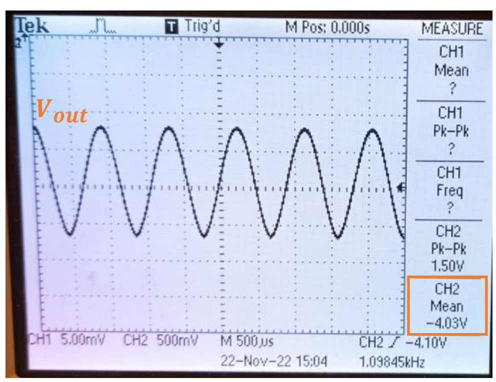

Figure 26 - Exercise 4 – Measuring the Mean on V_{out}
V_1 = 1sin(ωt)=0V , V_2 =1.5V , $V_{outMean}$ = -4,03V

So $V_{0\ simulation} = -3.83\ V$ and $V_{Mean} = -4.03\ V$

5.5 Exercise 5

5.5.1 Description of Procedure

Design of a summing amplifier circuit which output voltage is $V_0 = 3\,V_{in1} + 4V_{in2}$
Calculate the component values, simulate with LTSpice and Implement the circuit.

5.5.2 The equations

Because the voltage gain is positive it concludes that this will be a *summing non-inverting amplifier circuit.*

As in the lab instructions, a summing inverting amplifier circuit has the following formulation for the voltage output

$$V_o = \frac{R_3 + R_4}{R_3}\left(\frac{R_2}{R_1 + R_2}V_{in1} + \frac{R_1}{R_1 + R_2}V_{in2}\right)$$

Also, by the lab instructions we know that the gain can be calculated by:

$$A_{v_{in1}} = \frac{R_3 + R_4}{R_3} \cdot \frac{R_2}{R_1 + R_2} \text{ and } A_{v_{in}} = \frac{R_3 + R_4}{R_3} \cdot \frac{R_1}{R_1 + R_2}$$

The values for the resistors can be discovered by doing

$$\begin{cases} A_{v_{in1}} = \dfrac{R_3 + R_4}{R_3} \cdot \dfrac{R_2}{R_1 + R_2} \\ A_{v_{in2}} = \dfrac{R_3 + R_4}{R_3} \cdot \dfrac{R_1}{R_1 + R_2} \end{cases} \leftrightarrow \begin{cases} 3 = \dfrac{R_3 + R_4}{R_3} \cdot \dfrac{R_2}{R_1 + R_2} \\ 4 = \dfrac{R_3 + R_4}{R_3} \cdot \dfrac{R_1}{R_1 + R_2} \end{cases}$$

Because we can relate, $R_1 \text{ and } R_2 \text{ as }$ $\boldsymbol{R_2 = \frac{3}{4}R_1}$

If for convenience, $\boldsymbol{R_1 = 4k\Omega}$ then $\boldsymbol{R_2 = 3k\Omega}$

$$\leftrightarrow \begin{cases} 3 = \dfrac{R_3 + R_4}{R_3} \cdot \dfrac{R_2}{R_1 + R_2} \\ 4 = \dfrac{R_3 + R_4}{R_3} \cdot \dfrac{R_1}{R_1 + R_2} \end{cases} \leftrightarrow \begin{cases} 3 = \dfrac{R_3 + R_4}{R_3} \cdot \dfrac{3}{7} \\ 4 = \dfrac{R_3 + R_4}{R_3} \cdot \dfrac{4}{7} \end{cases} \leftrightarrow \begin{cases} 7 = \dfrac{R_3 + R_4}{R_3} \\ 7 = \dfrac{R_3 + R_4}{R_3} \end{cases}$$

So, if $\boldsymbol{R_3 = 1k\Omega}$

$$\leftrightarrow \left\{ 7 = \frac{R_3 + R_4}{R_3} \right. \leftrightarrow \left\{ 7 = \frac{1 + R_4}{1} \right. \leftrightarrow \{\, \boldsymbol{R_4 = 6k\Omega}$$

5.5.3 Simulation results

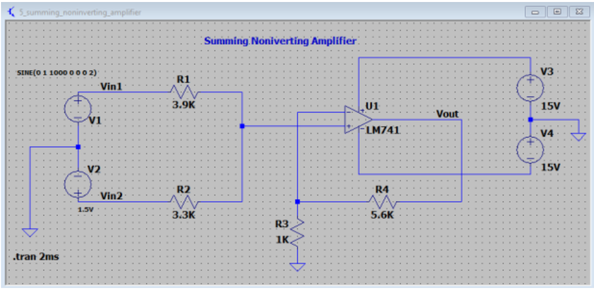

Figure 27 – Schematics of the summing non-inverting amplifier circuit simulated and implemented for exercise 5

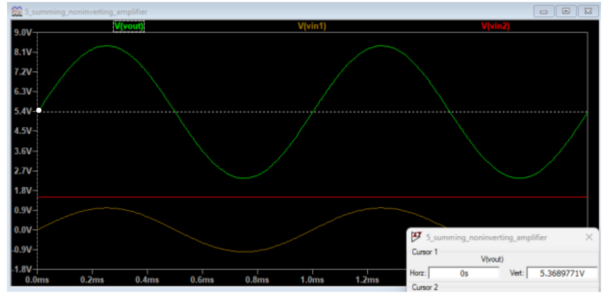

Figure 28 - Simulation exercise 5
V_1 = 1sin(ωt)=0V V_2 =1.5V V_{out} ≅ 5.36V

Note: Some resistors were not available on the lab, so they were switched to approximated values:

$R_1 = 4k\Omega \rightarrow$ using $R_1 = 3.9k\Omega$
$R_2 = 3k\Omega \rightarrow$ using $R_2 = 3.3k\Omega$
$R_4 = 3k\Omega \rightarrow$ using $R_4 = 5.6k\Omega$

$$V_0 = 3\,V_{in1} + 4V_{in2}$$
$$\leftrightarrow V_0 = 3 * 0 + 4 * 1.5$$
$$\leftrightarrow V_0 = 2.66\,V \cong V_{0\,simulation} = 5.36V$$

Values for V_0 calculated and simulated with LTSpice are not completely equal because of the change in the register's values.

5.5.4 Measurement results

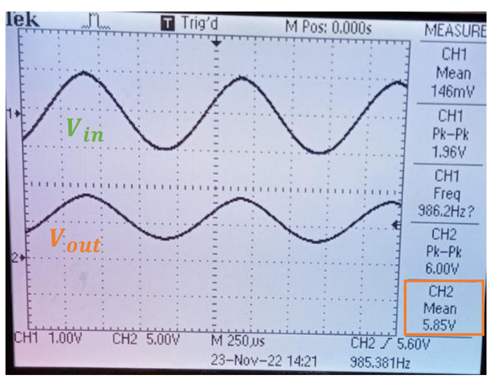

Figure 29 - Exercise 5 – Measuring the Mean CH2 is V_{out}

So $V_{0\,simulation} = 5.36\,V$ and $V_{Mean} = 5.85\,V$

5.6 Exercise 6

5.6.1 Description of Procedure

Using an operational amplifier LM741 adjust the signal described in the *figure 30* so that Arduino would be able to read it. Design the circuit, simulate in LTSpice, implement the circuit.

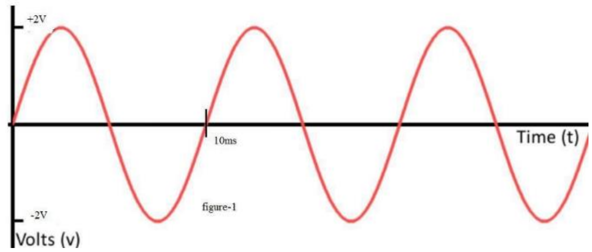

Figure 30

5.6.2 The equations

As indicated in the lab instructions, the circuit to used is a summing inverting amplifier and an Arduino must be able to read the signals produced by this circuit. Because of the Arduino input range the circuit's output voltage must be between 0 to 5 Volts.

Being a summing inverter amplifier, by the lab instructions the circuit has the following equation:

$$V_{out} = -\left(\frac{R_f}{R_1}V_{in1} + \frac{R_f}{R_2}V_{in2}\right)$$

Because $V_{out_{max}} = 5V$, V_{in1} needs at least 2v for amplitude on AC and $V_{in2} = 1.5V$ was the voltage available at the lab:

$$V_{out} = -\left(\frac{R_f}{R_1}2 + \frac{R_f}{R_2}1.5\right) = -5$$

If for conveniance , $\boldsymbol{R_f = 5k\Omega}$

$$V_{out} = -\left(\frac{5}{R_1} * 2 + \frac{5}{R_2} * 1.5\right) = -5$$

Then the other values for the reisitors can be:

$$\boldsymbol{R_1 = 4k\Omega} \text{ and } \boldsymbol{R_2 = 3k\Omega}$$

5.6.3 Simulation results

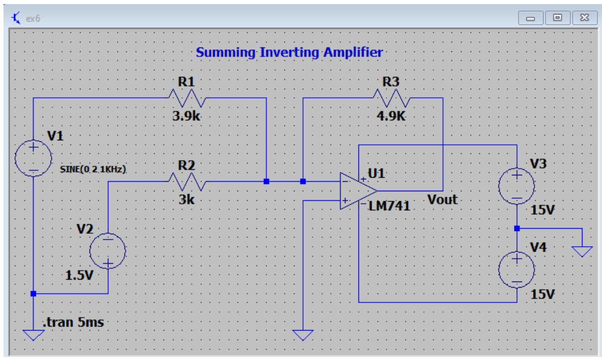

Figure 31 – Schematics of the summing inverting amplifier circuit simulated and implemented for exercise 4

Note: Some resistors were not available on the lab, so they were switched to approximated values:

$R_1 = 4k\Omega \rightarrow \text{using } R_1 = 3.9k\Omega$

$R_2 = 3k\Omega \rightarrow \text{using } R_2 = 3k\Omega$

$R_f = 5\ k\Omega \rightarrow \text{using } R_f = 4.9k\Omega$

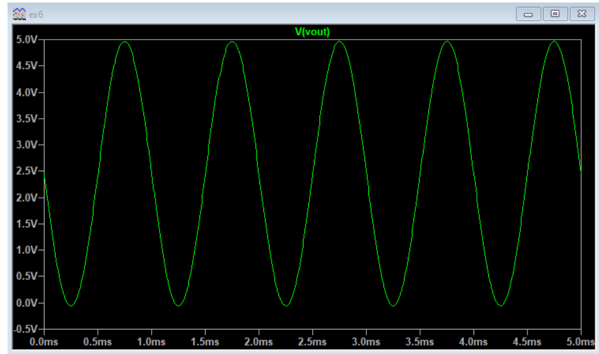

Figure 32 - Simulation exercise 6

As we can see in the simulation, the V_{out} range is 0 Volts to 5 Volts

5.6.4 Measurement results

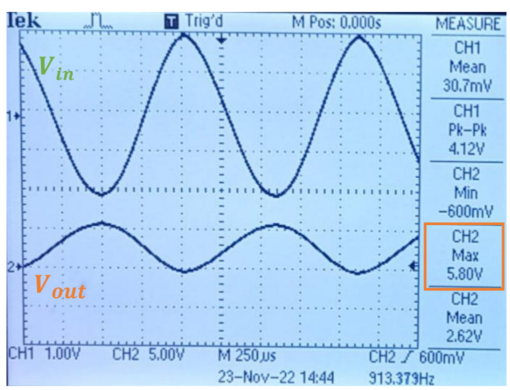

Figure 33 - Exercise 6 – Measuring the Mean CH2 is V_{out}

and $V_{outMax} = 5.80V$ and $V_{outMin} = -600mV$

The range observed with the oscilloscope [-0.6V , 5.80V] is essentially the same as the range obtain by the simulation, [0V , 5V].