Technical documentation

Mitthic project

Integrated Microfluidics for Intracellular Therapeutic Treatment in Flow.

Project Group :

Audrey Arcel NEMBOT WENDZE

Engineering student of 4A GPSE

Project referent :

M. Rodolph WEBER

M. Arnaud STOLZ

M. Emmanuel Attal

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I. Introduction

The MITTHIC project (Integrated Microfluidics for Intracellular Therapeutic Treatment in Flow) is a project conducted as part of the Engineering Project Unit during the 7th and 8th semesters of the Physical Engineering and Embedded Systems program. As we will see, this project encompasses various aspects such as electronics, signal processing, fluid mechanics, instrumentation, and multiphysical simulation.

There is a significant interest in the identification of infected cells for their separation from blood, which can enable more targeted and effective medical treatments. One of the technologies for this purpose is the measurement of the electrical impedance of cells as they flow between two microelectrodes fabricated in a microfluidic channel. This is the aim of this project and we are going to present its management.

During this semester, the aim of our project is to design a data acquisition chain to enable the counting of cells as they pass through the microfluidic channel. Additionally, we plan to conduct a COMSOL simulation to compare the measurement results and to improve the modelling of the microfluidic chip.

The investment in such a project is driven by the desire to apply the knowledge learned in class to a project that demands scientific rigor akin to an engineering approach. This project also offers an opportunity to become acquainted with instrumentation and interfacing, amplification, signal processing, microfabrication, and COMSOL simulation.

This project is undertaken by two students:

Arcel NEMBOT: who is responsible for the measurement chain, signal processing.

Pierre-Philippe Horville: who is tasked with COMSOL simulation and manufacturing of the microfluidic chip.

1 General presentation

The MITTHIC project is a project aimed at eventually making an impact in the medical field. Indeed, this project is a small part of a larger-scale initiative. Our goal is to count the number of cells present in a microfluidic channel. The purpose of this device is to eventually identify infected cells, then treat them precisely and effectively, and finally return the treated blood to the body:

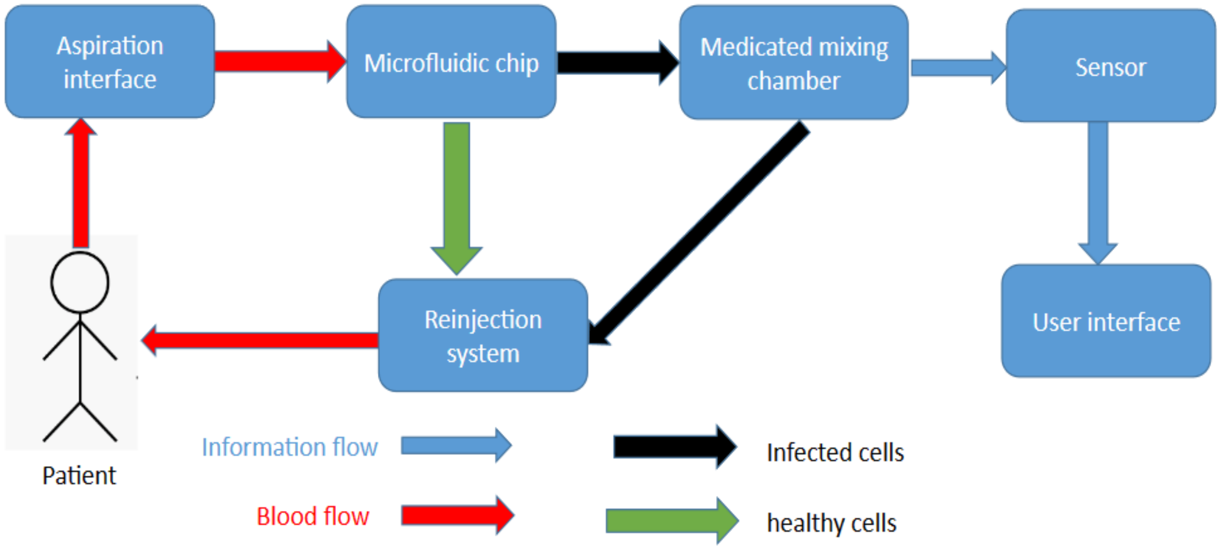


Figure 1: Global use case

This use-case outlines the integration of our project in the context of a patient's medical treatment. As mentioned previously, the principle of the project is to pass blood through a channel and count the number of cells present to identify the infected ones. To achieve this, we will utilize the dielectric properties of the cells.

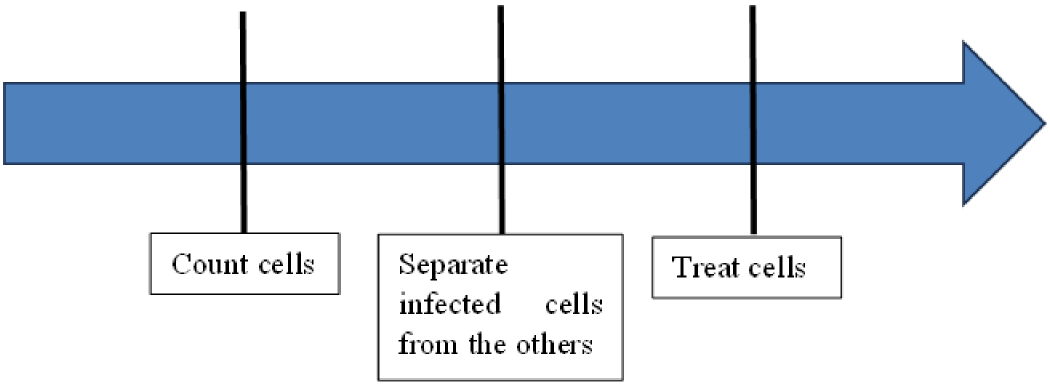


Figure 2: Key step of the MITTHIC project

I.1. Contextualisation of project

5W method

What? Cell counting through a microfluidic channel.

Who? This project involves the CBM and GREMI searchers

Where? The microfluidic chip will be manufactured at the GREMI laboratory, and the data acquisition system will be set up at Polytech Orleans.

When? The project will last approximately one month.

Why? Our goal is to make a functional system for the progress of treatment method.

I.1.1. Team support

Phase of life	Use case	Stakeholders
Conception and test	▪ Design and Manufacture of the current microfluidic chip. ▪ Place the order and receive the components ▪ Receive help, advices on the project	▪ Flore Rembert, PhD Student GREMI ▪ KADROUZ Kamel, Project member ▪ Rodolph WEBER, Arnaud STOLZ, Emmanuel ATTAL Participants, Project members

I.1.2. Task Chart

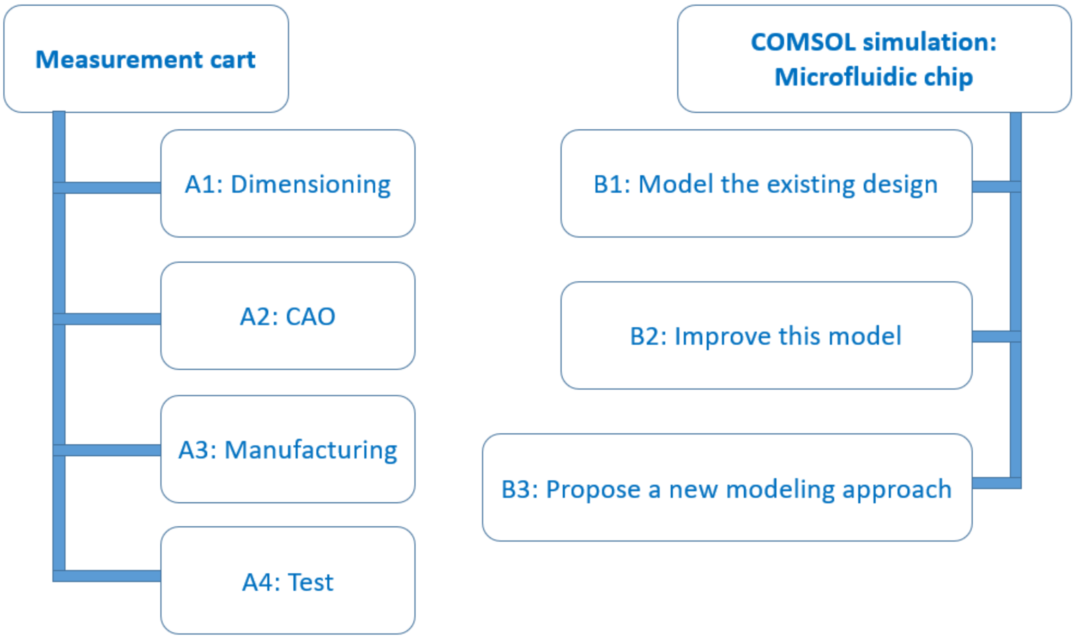


Figure 3 : Task Chart

I.1.3. Project overview, applications and Global Use cases: Medical diagnosis and treatments of infected cells.

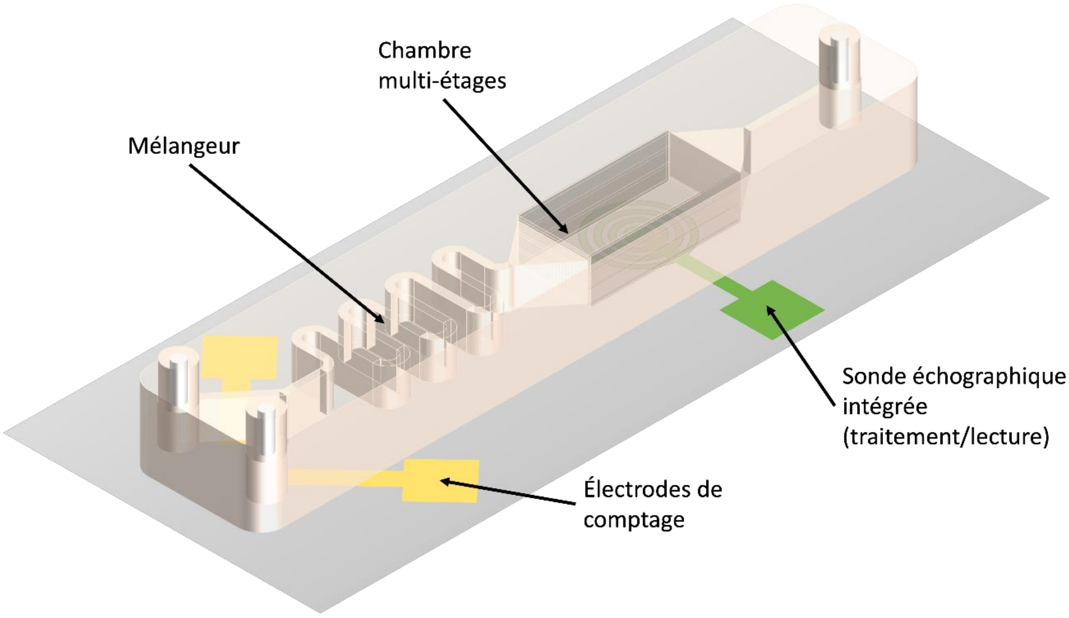


Figure 4: Microfluidic chip for medical diagnosis

1) Fluid is introduced into the channel using a pump.

2) Detect and quantify cells in the fluid using counting electrodes.

3) The fluid and the reagent are homogeneously combined within the chip thanks to the mixer.

4) A multi-stage chamber with an integrated ultrasonic probe in a microfluidic chip allows for real-time imaging and analysis for cell studies.

a) Focus on an application/ Counting cells

The diagram in Figure 2 was used for counting cells passing through the microfluidic chip.

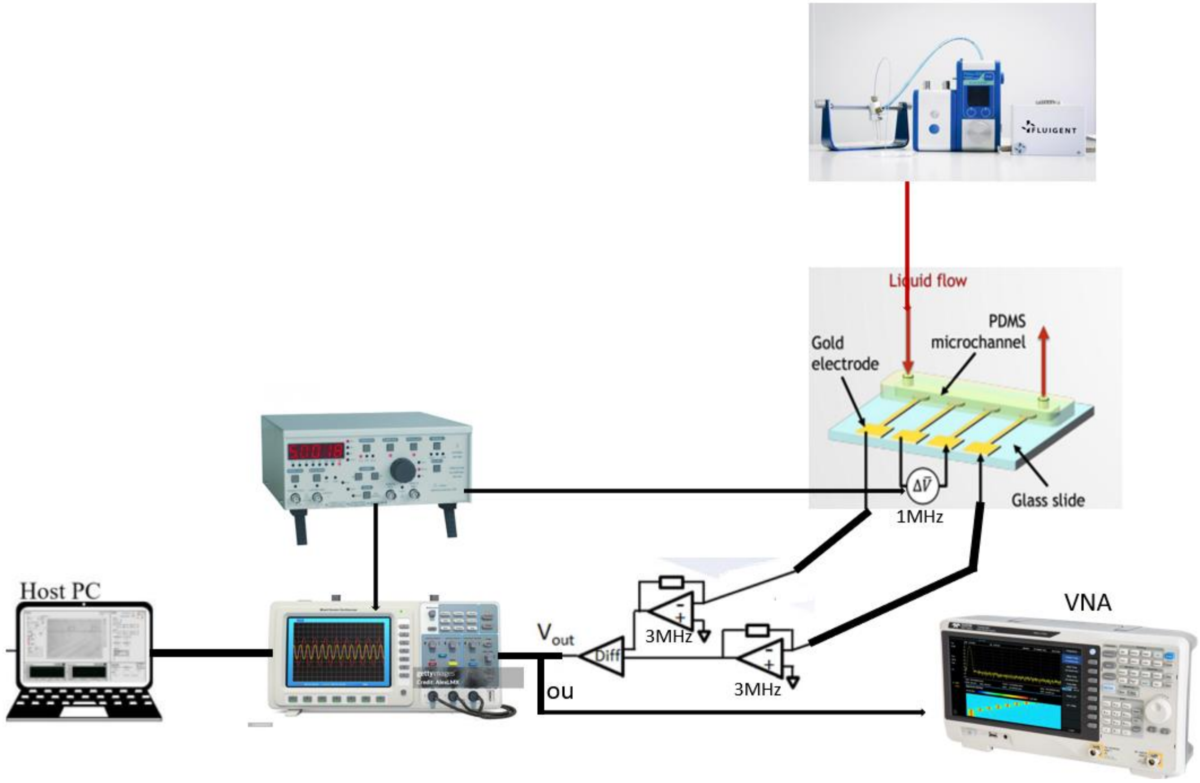


Figure 5: Microfluidic chip and the associated impedance measuring system

1) Fluid is introduced into the channel using a pump.

2) Inject a 1MHz sinusoidal signal into an electrode.

3) Electrode current detection circuit, conversion of this current into voltage, and signal amplification.

4) Measurement of the Vout signal and the excitation signal on the oscilloscope.

5) Program for signal processing to obtain phase and amplitude.

6) Or impedance measurement with the VNA.

I.2. SMART objectives/goals

Main objectives:

1- Design the data acquisition system (components, configuration, testing)

2- Perform signal processing.

3- Conduct modelling and simulation using COMSOL.

4- Manufacturing of the new microfluidic chip.

By using the SMART method (Specific, Measurable, Achievable, Relevant and Timed), we specify each objective and characterize them.

I.2.1. Design the data acquisition system (components, configuration, testing)

Specific: The objective defines what needs to be designed, namely the complete design of the data acquisition chain, including all aspects necessary for its operation.

Measurable: The success of this project can be measured by the realization and delivery of a functional acquisition chain.

Achievable: The objective is feasible thanks to the available expertise and resources.

Relevant: The acquisition chain will be designed by students specializing in physical engineering and embedded systems, making the objective realistic and suited to their skills.

Timed: The project will last over a one month period.

II. Acquisition chain

II.1. FAST diagram

The following FAST diagram presents the various steps for counting cells.

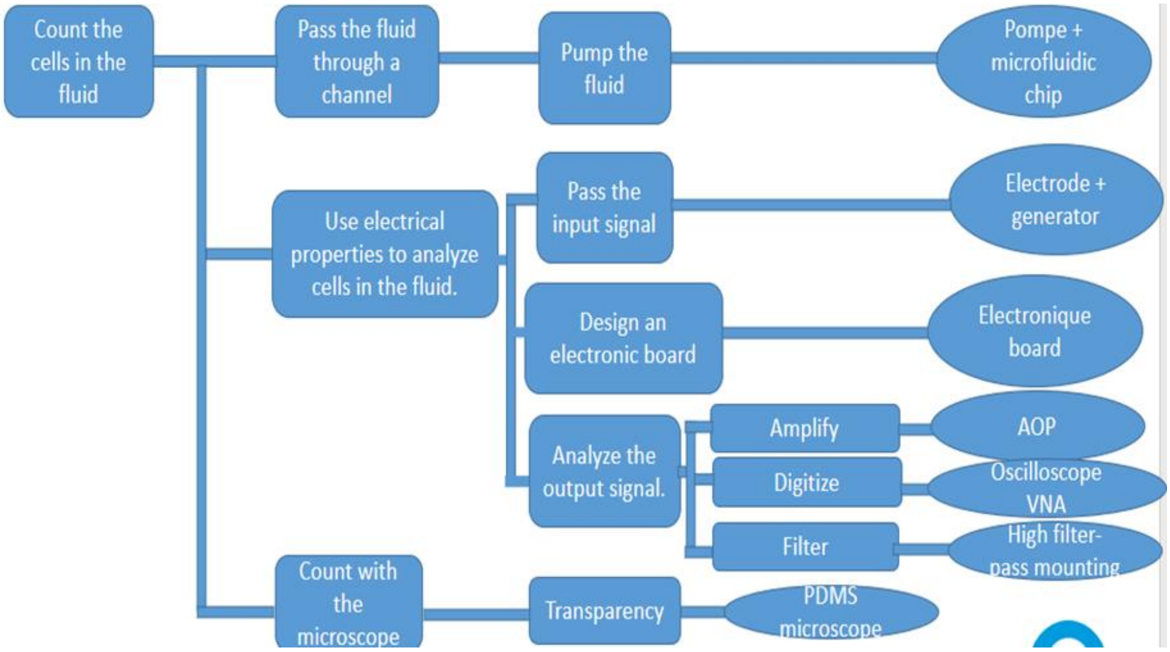


Figure 6: FAST diagram

The primary function of counting cells present in a fluid is divided into several sub-functions: pumping the fluid through the microfluidic channel using a pump, employing a sinusoidal signal to create an electric field in the channel, and measuring current with a signal generator and an electronic board. This is followed by an analysis of the output signal. Octopus diagram

II.2. Functional analysis

To visualize the relationship between the system and its users or other systems, the Octopus diagram is presented.

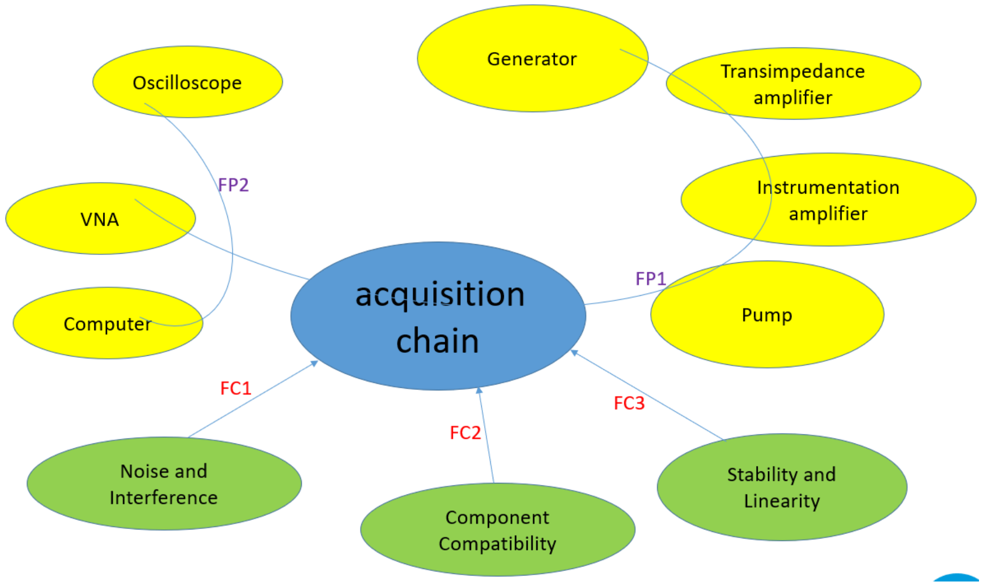


Figure 7: Octopus diagram

FP1: Measure the impedance and count the number of cells passing through the microfluidic channel.

FP2: Measure the dielectric properties of the cells.

FC1: Minimizing electrical noise and electromagnetic interference

FC2: Ensuring compatibility between different components in terms of impedance, voltage levels, and frequencies.

FC3: Maintaining signal stability and linearity across a range of operating conditions.

Characterisation of main functions					
Main functions	**Criteria**	**Level**	**Flexibility**	**Possible technical solutions**	**Surrounding environments**
FP1 → Count cells	The number of cells in the fluid	Not determined	Not specified	Microfluidic Chip Technology	Temperature and Humidity

FP2 → Measure the impedance of the system	The value must be compared to that of the literature. Connection with an oscilloscope	Measurement at 1MHz. 2BNC ports		Choice of AOP oscilloscope measurement	

Characterisation of service functions					
Service functions	**Criteria**	**Level**	**Flexibility**	**Possible technical solutions**	**Surrounding environments**
FC1 → Minimizing electrical noise	Choice of components with low noise.	Bruit < 50dB			
FC2→Ensuring compatibility between different components.	choice of operational amplifier	Bandwidth around 1 MHz			
FC3→ Works whatever the temperature	Temperature	10<T<50(°C)			
FC4 →Have possibility to count cells with a microscope	Transparent channel	n>1,2(n relative index)			

II.3. Technical choices

The data acquisition chain enables the measurement of cell impedance (the number of cells) from the current measurement at two electrodes of the microfluidic chip. It consists of a part for converting current to voltage and for amplifying the voltage difference.

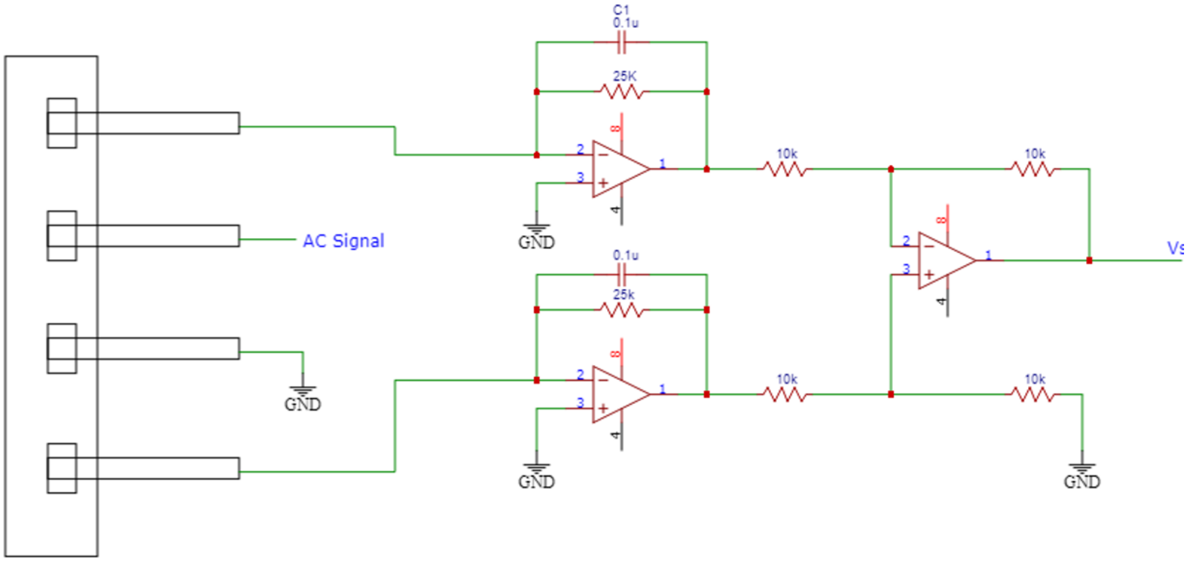


Figure 8: Acquisition chain with differential amplifier

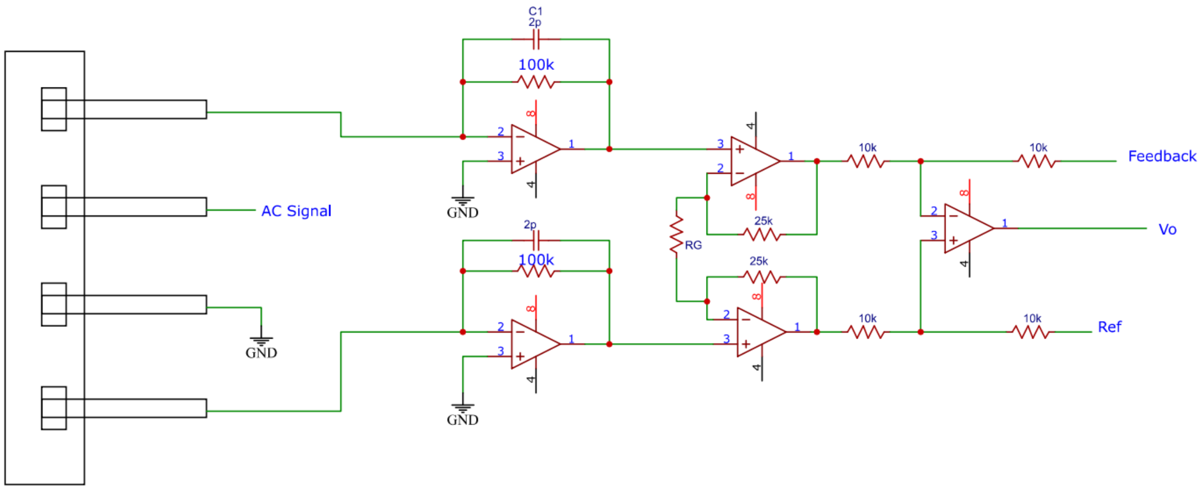


Figure 9: Acquisition chain with instrumentation amplifier

The instrumentation amplifier (IA) offers several advantages over differential amplifiers:

- High CMRR (Common-Mode Rejection Ratio): The IA has a superior CMRR, enabling it to better ignore signals common to both inputs, such as electrical noise or interferences, which is essential for accurate measurements in noisy environments.
- Precision and Stability of Gain: Thanks to its internal design, which often includes precision resistors and compensation circuits, the AI offers more stable and precise gain.
- Reduced Noise: The IA is specifically designed to minimize electronic noise, a critical aspect for amplifying low-amplitude signals.

- High Input Impedance: It has a very high input impedance, minimizing the loading of the source signal, ideal for interfacing with high-impedance sensors or electrodes.
- Adjustable Gain: Its gain can be easily modified by adjusting the external resistor, thus offering great flexibility.
- Ease of Integration: It is designed to be simpler to integrate than differential amplifiers, requiring fewer external components for gain adjustment and compensation.

II.3.1. Components

a) Amplifiers chosen: Op-Amp: current-to-voltage conversion

The MAX44267 is a dual, precision, low-noise, and low-drift operational amplifier. Its input common-mode range extends from +13.5V to -12V. It operates with a single supply from +4.5V to +15V, as efficiently as a normal dual-rail amplifier from ±4.5V to ±15V. This architecture eliminates the need for a negative power rail, reducing system cost and size. The MAX44267 is stable with a unity gain and features a gain-bandwidth product of 5MHz. It exhibits low offset voltage of 50µV (max), drift of 0.4µV/°C (max), and noise of 200nVP-P from 0.1Hz to 10Hz. Its low offset and noise specifications, along with its wide input common-mode range, make it ideal for various applications, including precision sensors and medical measurement systems.

Table 1; Electrical characteristics of the MAX44267 amplifier.

MAX44267	Valeur
Power-supply Voltage Input Range	4.5 - 15.5 V
Gain – bandwidth product	5 MHz
Input voltage-noise density e_N	9 $nV/\sqrt{Hz}$
Input current-noise density i_n	200 $fA/\sqrt{Hz}$
Common-mode rejection ratio CMRR	150 dB
Input impedance	50 kΩ

The pins of MAX44267 amplifier :

The pins of the MAX44267 have been soldered to a 14-pin TSSOP package and are specified for an operating temperature range of -40°C to +125°C.

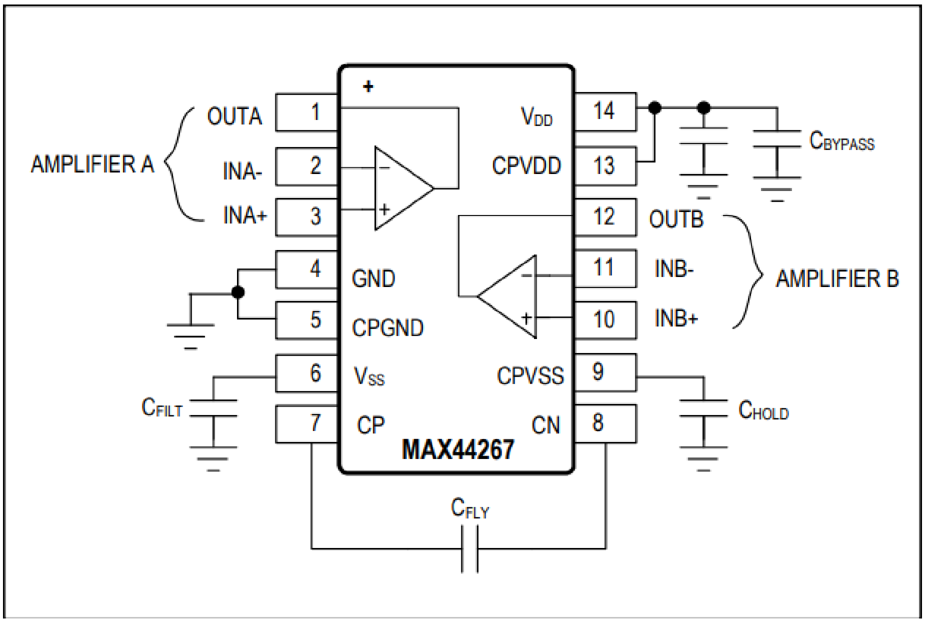


Figure 10: Block Diagram and External Capacitor Connections

The MAX44267 requires three external capacitors (C_{BYPASS}, C_{HOLD}, and C_{FILT}) to generate the V_{SS} negative supply rail. Place a 0.047µF Flying Capacitor (C_{FLY}) to reduce the output resistance. Increasing the value of the output capacitor (C_{HOLD}) reduces the output ripple voltage. The C_{PVSS} decoupling capacitor is essential for reducing the AC impedance of the power supply, attenuating switching noise, and stabilizing the power supply voltage of the IC. It must be placed as close as possible to the integrated circuit. Connect a minimum of a 0.1µF low-ESR capacitor from CPVSS to CPGND in close proximity to the IC.

b) Amplifiers chosen: Op-Amp: instrumentation amplifier

The INA111 is a high-speed instrumentation amplifier with FET input, characterized by excellent performance. It uses a current-feedback topology for extended bandwidth (2MHz at G=10) and fast settling time (4µs to 0.01% at G=100). The gain is adjustable from 1 to over 1000 with a single external resistor. This amplifier exhibits low offset voltage (max 500µV). With FET inputs, the input bias current is reduced to less than 20pA, simplifying the design of filtering and limiting circuits. Its features include high common-mode rejection (min 106dB) and it is suitable for applications such as medical instrumentation and data acquisition.

Ideal for various applications, including precision sensors and medical measurement systems.

Table 2 : Electrical characteristics of the INA111BP amplifier.

INA111BP	**Valeur**
Power-supply Voltage Input Range	- 13 V to 15,5V
Gain – bandwidth product	2MHz
Input voltage-noise density e_N	10 $nV/\sqrt{Hz}$
Input current-noise density i_n	0,8 $fA/\sqrt{Hz}$
Common-mode rejection ratio CMRR	106 dB
Input impedance	50 kΩ

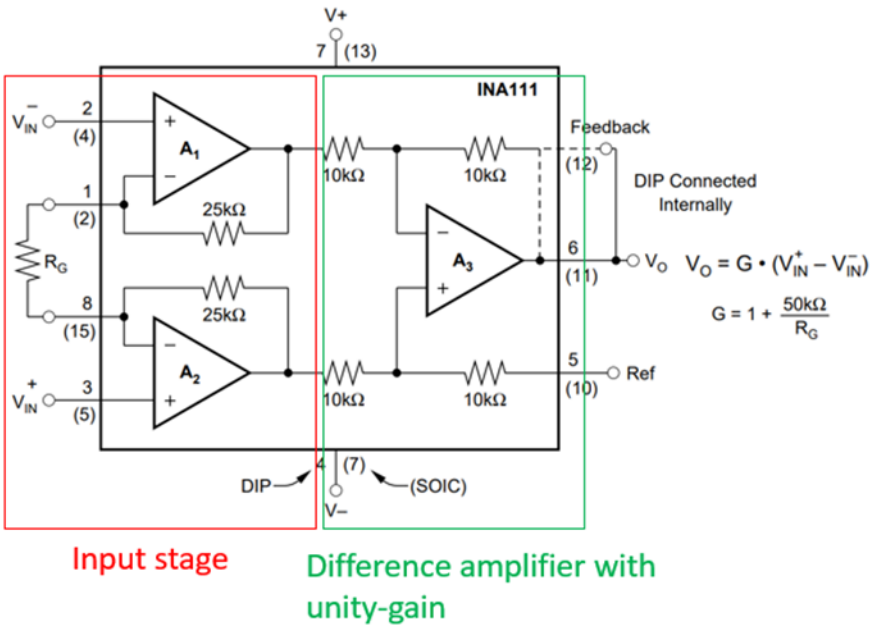


Figure 11: Internal Structure of Instrumentation Amplifier INA111BP

DESIRED GAIN	R_G (Ω)	NEAREST 1% R_G (Ω)
1	No Connection	No Connection
2	50.00k	49.9k
5	12.50k	12.4k
10	5.556k	5.62k
20	2.632k	2.61k
50	1.02k	1.02k
100	505.1	511
200	251.3	249
500	100.2	100
1000	50.05	49.9
2000	25.01	24.9
5000	10.00	10
10000	5.001	4.99

II.4. Study of theoretical noise

The study of theoretical noise in the measurement chain, which includes a current-to-voltage converter and an instrumentation amplifier, involves several steps and considerations. Noise can originate from various sources and can affect the performance of the measurement system. Here is an approach to study the theoretical noise:

Noise Sources:

- Thermal Noise (or Johnson-Nyquist Noise): Generated by resistance in circuits.
- 1/f Noise (Pink Noise or Flicker Noise): Primarily appears at low frequencies.
- Intermodulation Noise: Caused by the non-linearity of components.

II.4.1. Analyse individual components

a) Current-to-voltage converter

The Study of the noise contribution of the converter, which may include the thermal noise from the feedback resistor and the intrinsic noise of the operational amplifier used

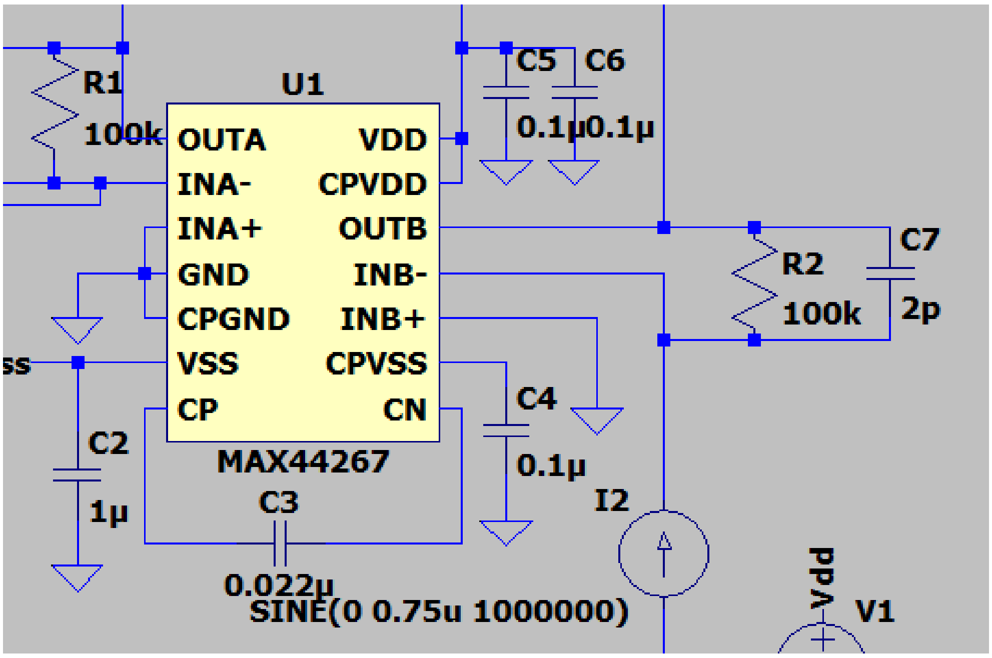


Figure 12: schematic current-to-voltage converter

In the datasheet, current noise and voltage noise, respectively, of the op-amp.

$$i_n = 9\ fA/\sqrt{Hz}$$

$$e_n = 200\ nV/\sqrt{Hz}$$

Calculate voltage noise density (V/√Hz) :

$$V_{n,CT} = \sqrt{V_{n,res}^2 + V_{n,op-amp}^2} \quad (1)$$

Thermal noise of a resistor:

$$V_{n,res} = \sqrt{4KTRB} \quad (2)$$

$V_{n,res}$ is the voltage noise density, K is the Boltzmann constant, T is the temperature, R is the value of the resistor in Ohms, and B is the bandwidth in Hertz.

For B = 100 KHz and T = 25°C

$$V_{n,res} = 12{,}82\ \mu V/\sqrt{Hz}$$

Total Noise of the Op-Amp

The total noise introduced by the op-amp is calculated by combining the voltage noise and the current noise. The current noise is converted into an equivalent voltage noise by multiplying it by the feedback resistance:

The total noise of the circuit is the root sum square of the thermal noise of the resistor and the op-amp noise, as these noise sources are statistically independent.

$$V_{n,op-amp} = \sqrt{e_N^2 + (\mathrm{in.R1})^2 + (\mathrm{in.R2})^2} \quad (3)$$

$$V_{n,op-amp} = 200\ nV/\sqrt{Hz}$$

voltage noise density of current-to-voltage converter is :

$$V_{n,CT} = 4{,}05\ mV/\sqrt{Hz} \quad (4)$$

b) Amplifier instrumentation

The study of the noise contribution of the IA (Instrumentation Amplifier) includes the amplifier's input noise, encompassing both voltage and current noise, as well as the effect of the noise from its resistors.

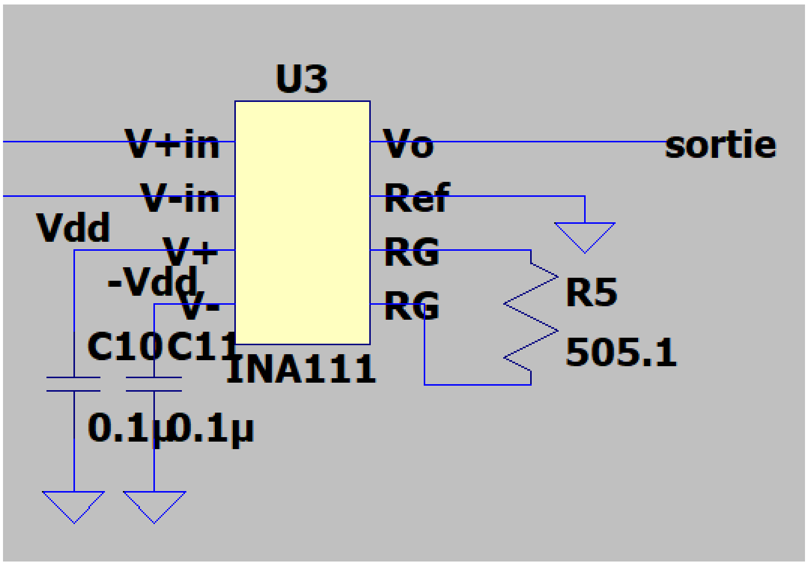


Figure 13: Schematic amplifier instrumentation

In the datasheet, current noise and voltage noise, respectively

$$i_n = 0{,}8\ fA/\sqrt{Hz} \quad (5)$$

$$e_n = 10\ nV/\sqrt{Hz}$$

Voltage noise density (V/√Hz)

$$V_{n,IA} = \sqrt{V_{n,res}^2 + (\text{in.R5})^2 + e_n^2} \qquad (6)$$

- Thermal noise of a resistor:

$$V_{n,res} = \sqrt{4KTRB} \quad 7 \qquad (7)$$

➢ For B = 100 KHz and T = 25°C

$$V_{n,res} = 911{,}75\ nV/\sqrt{Hz}$$

- Total Noise of the IA

$$V_{n,IA} = 0{,}288\ mV/\sqrt{Hz}$$

c) Total noise calculation

Use the noise model of each component to calculate the total noise. This typically involves the root sum square method (square root of the sum of squares) for different types of noise, as the noise sources are usually independent.

- voltage noise density

$$V_{n,total} = \sqrt{V_{n,CT}^2 + V_{n,IA}^2} \qquad (8)$$

$$V_{n,total} = 4{,}06\ mV/\sqrt{Hz}$$

- Signal-to-Noise Ratio Calculation

$$SNR_{dB} = 20log_{10}\left(\frac{Signal\ max}{V_{n,total}}\right) \qquad (9)$$

Or output voltage IA ±12.7 V

$$SNR_{dB} = 39{,}2\ dB$$

II.5. Study of noise simulation

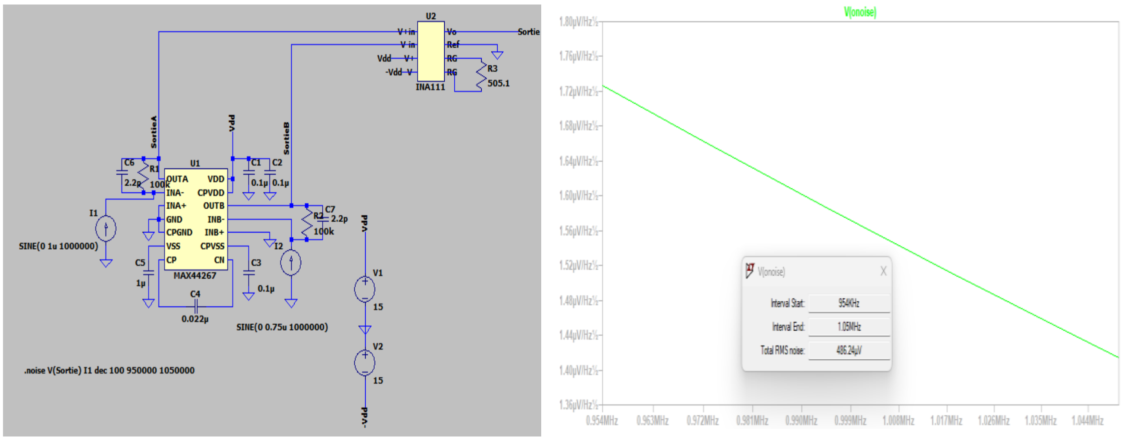


Figure 14: noise simulation

Total RMS noise = 486,24µV

- voltage noise density $$V_n = \frac{Total\ RMS\ noice}{\sqrt{Bandwidth}} \qquad (10)$$

Total RMS noice = 486,24µV and *BW* = 100KHz

$$V_n = 1{,}69\ \mu V/\sqrt{Hz}$$

- Signal-to-Noise Ratio Calculation

$$SNRdB = 20log10(\frac{Vout}{V_n}) \qquad (11)$$

Total RMS Vout = 405,67mV

$$SNRdB = 34{,}7\ dB$$

SNR simulation	**theoretical SNR**
34,7 *dB*	**39,2 *dB***

II.6. Theoretical test, simulation on LTSpice and experimentation

II.6.1 First test

Design of the first board for testing the current-to-current conversion circuit and the operational amplifier circuit.

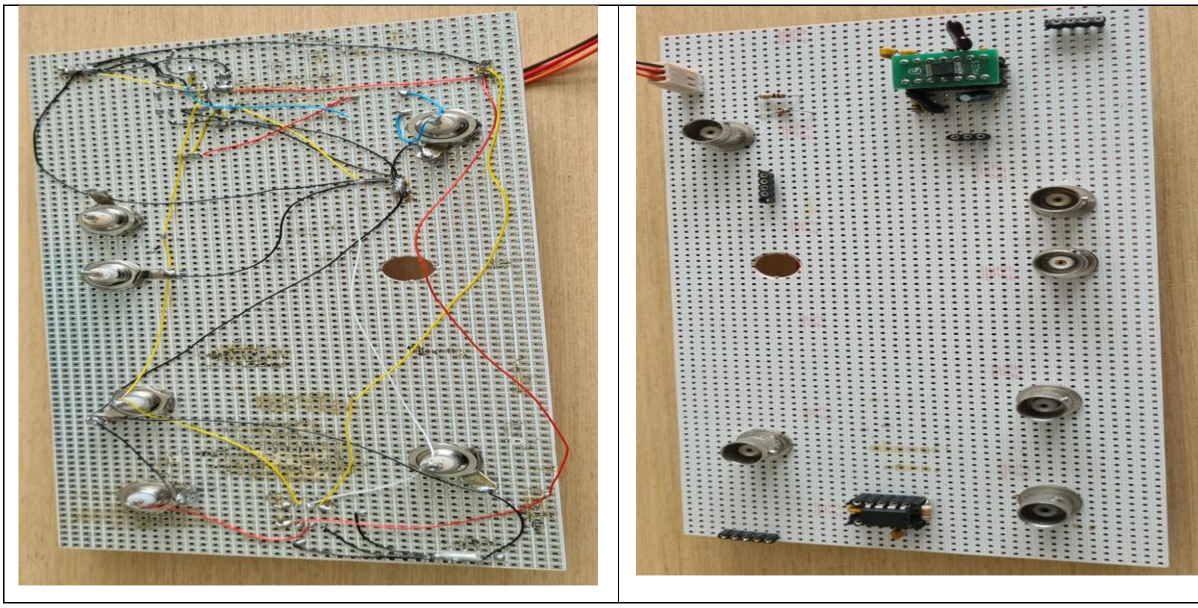


Fig : First card

PCB design, component soldering and testing.

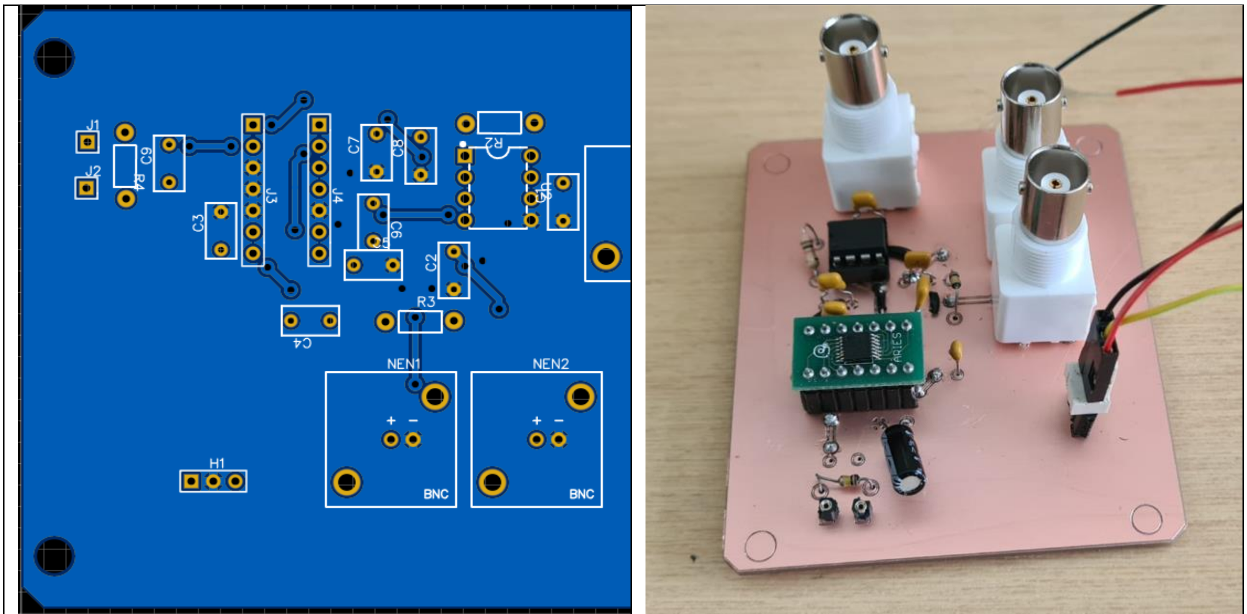
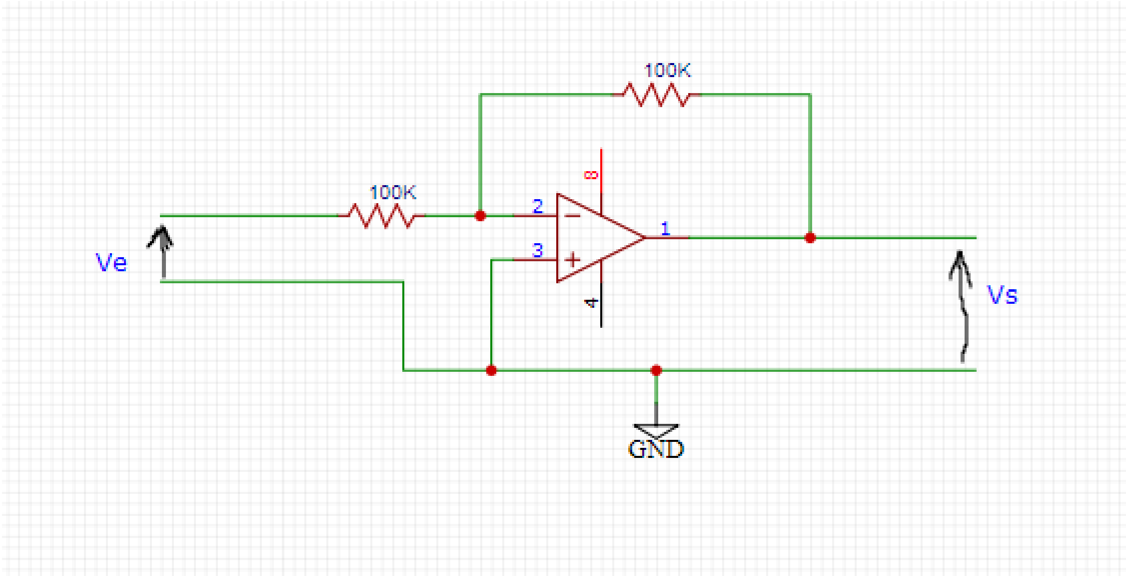


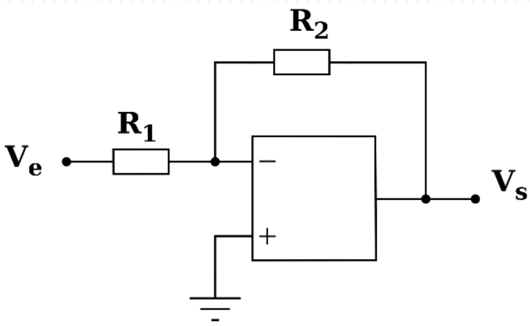
Fig : PCB

III.5.1 Current-to-voltage conversion circuit

The current-to-voltage converter employs an operational amplifier (MAX44267). This amplifier, when combined with a feedback resistor, determines the circuit's gain, enabling the conversion of input current into a corresponding output voltage.

- Associate equation of converter





The output voltage is giving by the equation:

$$V_s = -V_e\left(\frac{R_2}{R_1}\right)$$

$$= \quad - R_2 \times i$$

The equation associated with an instrumentation amplifier.

$$V_O = G \cdot (V_{IN}^{+} - V_{IN}^{-})$$

$$G = 1 + \frac{50k\Omega}{R_G}$$

Verify the relationship between the input current and output voltage and the gain characteristics.

$V^+_{IN} = - R_2 \times i$

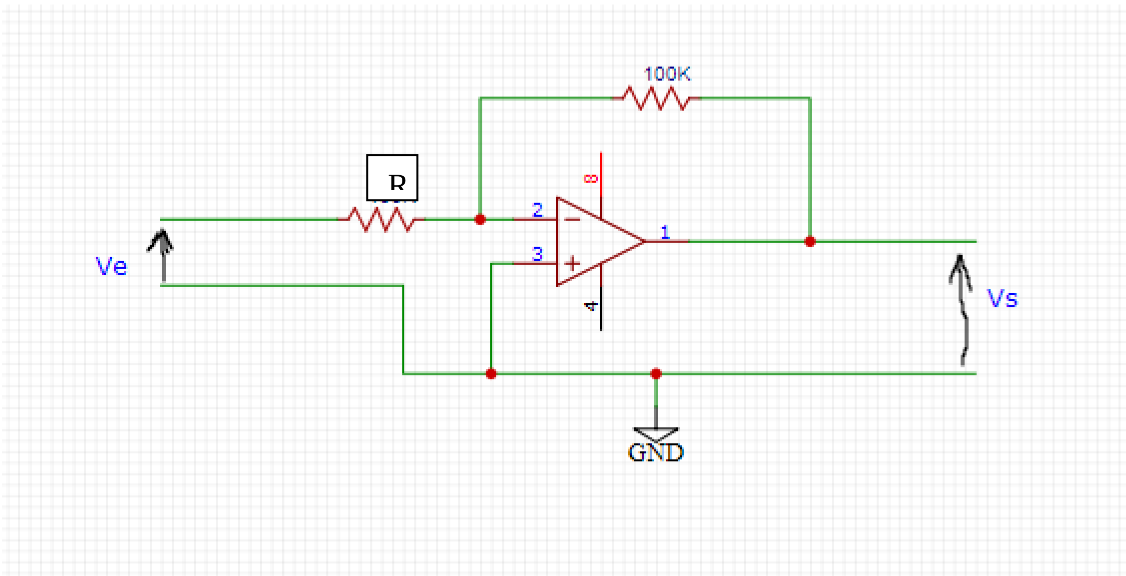
$V^-_{IN} = - R_{2'} \times i'$

$Vs = G(V^+_{IN} - V^-_{IN})$

$Vs = G(R_{2'} \times i' - R_2 \times i)$

- Linearity transimpedance

By varying the value of resistor R between 10k and 100k, a current on the order of microamperes is obtained, which will be converted into voltage by the converter.



a) Theoretical result

R	100k	47k	22k	10k			
Ie(uA)	3.54	7.53	16	35.4			
Us(V)	0.354	0.753	1.6	3 .54			

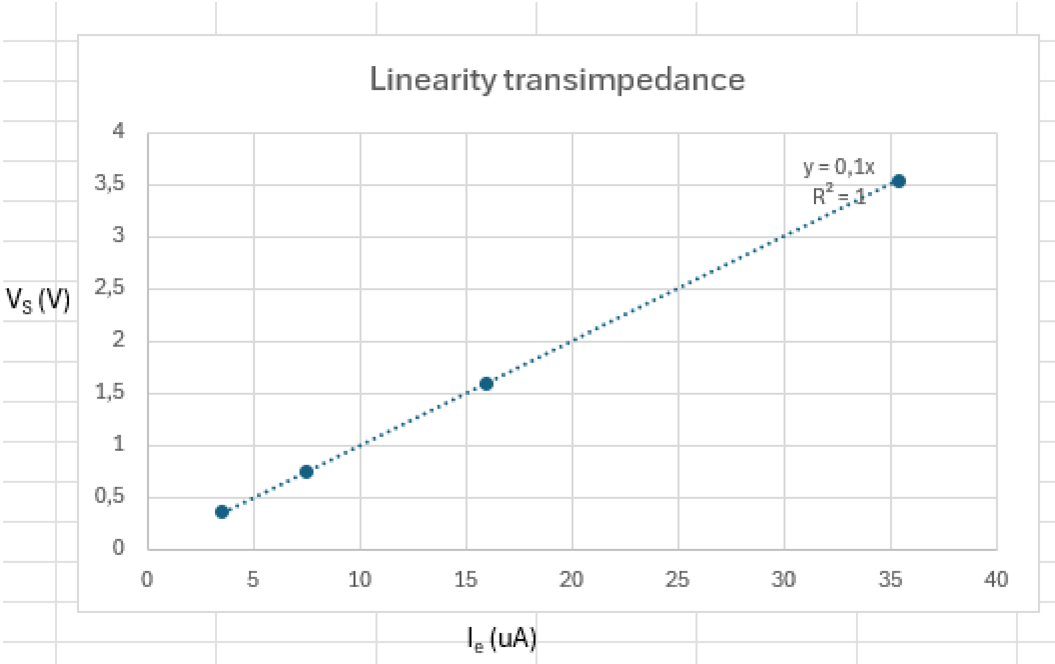


Figure 1 : Theoretical study of the linearity of the transimpedance.

b) Simulation result

R	100k	47k	22k	10k			
Ie(uA)	3.54	7.53	16	35.4			
Us(V)	0.302	0.691	1.2	3.23			

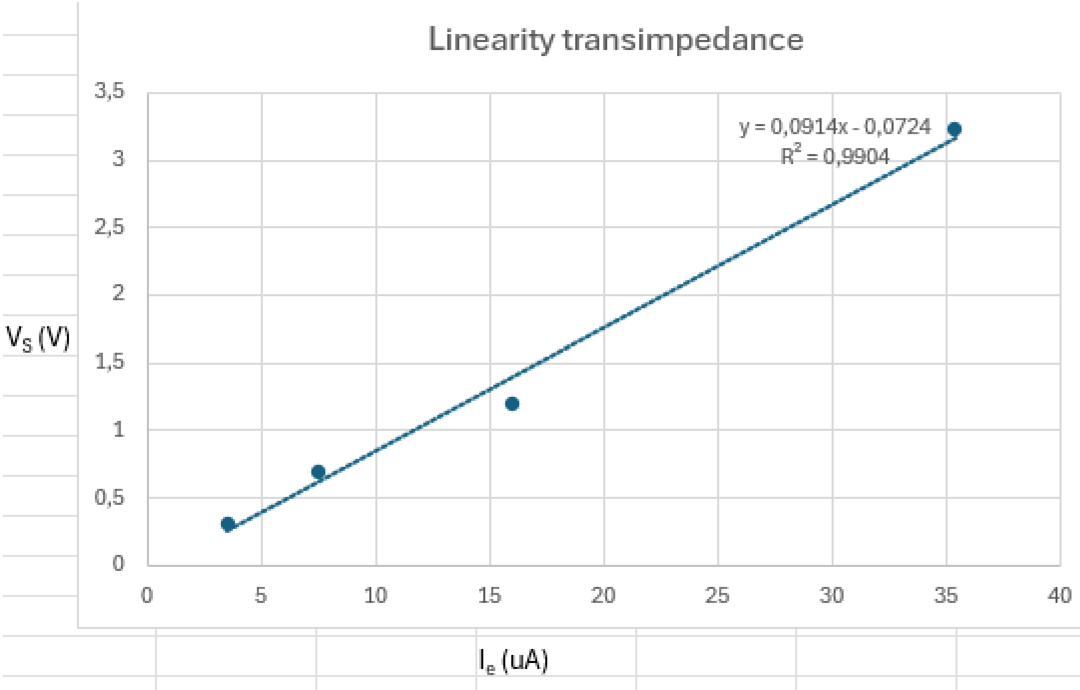


Figure 1 : Simulation of the linearity of the transimpedance.

C) Experimental result

R	100k	47k	22k	10k			
Ie(uA)	3.35	6.07	14.58	30.13			
Us(V)	0.318	0.666	0.99	2.438			

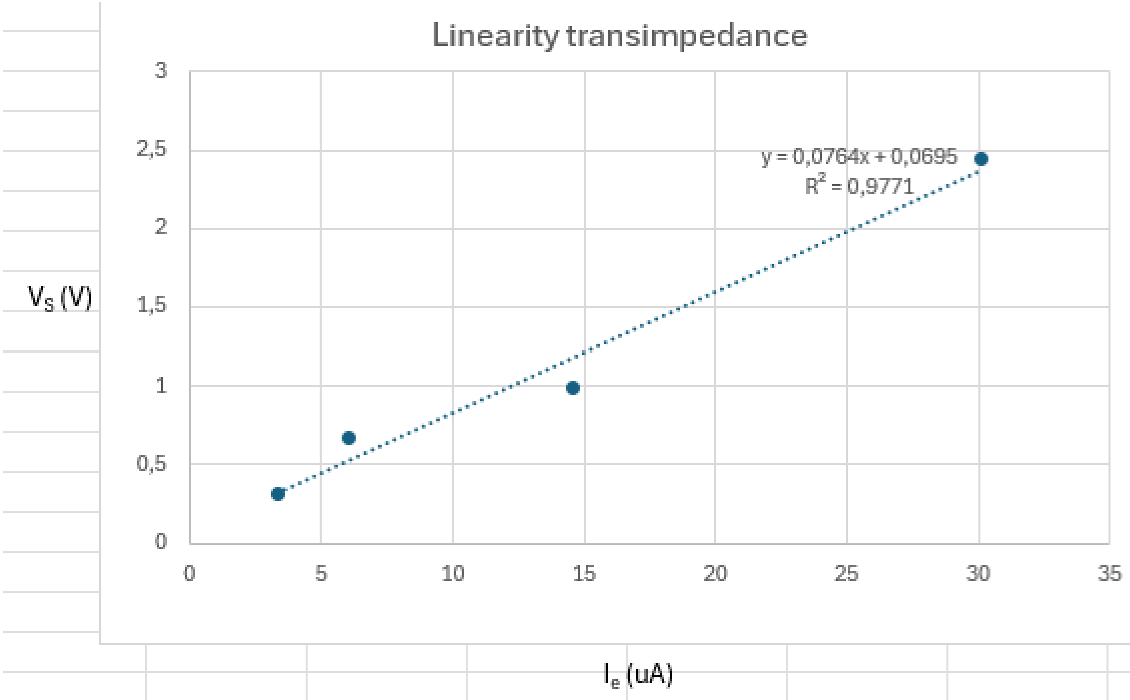


Figure 1 : Experimental study of the linearity of the transimpedance.

In the figures above, we observe that the relationship between current and voltage is linear. For the theoretical relation, we have R = 100 KOhm, simulation 91,4 KOhm and experimental R = 76,4 KOhm.

- Simulation and experimental

  The transient analysis of the current-to-voltage conversion circuit is presented below. At the input, there is a sinusoidal current, and at the output, there is sinusoidal current, and at the output, a sinusoidal voltage is observed. The 6.5 uA sinusoidal current at the input is generated by a sinusoidal voltage generator at 1 MHz, 0.5V and a 100 KHz resistance. The simulation and experimental results are in agreement. At the converter's output, a sinusoidal voltage at 1MHz with an amplitude of 500 mV is obtained.

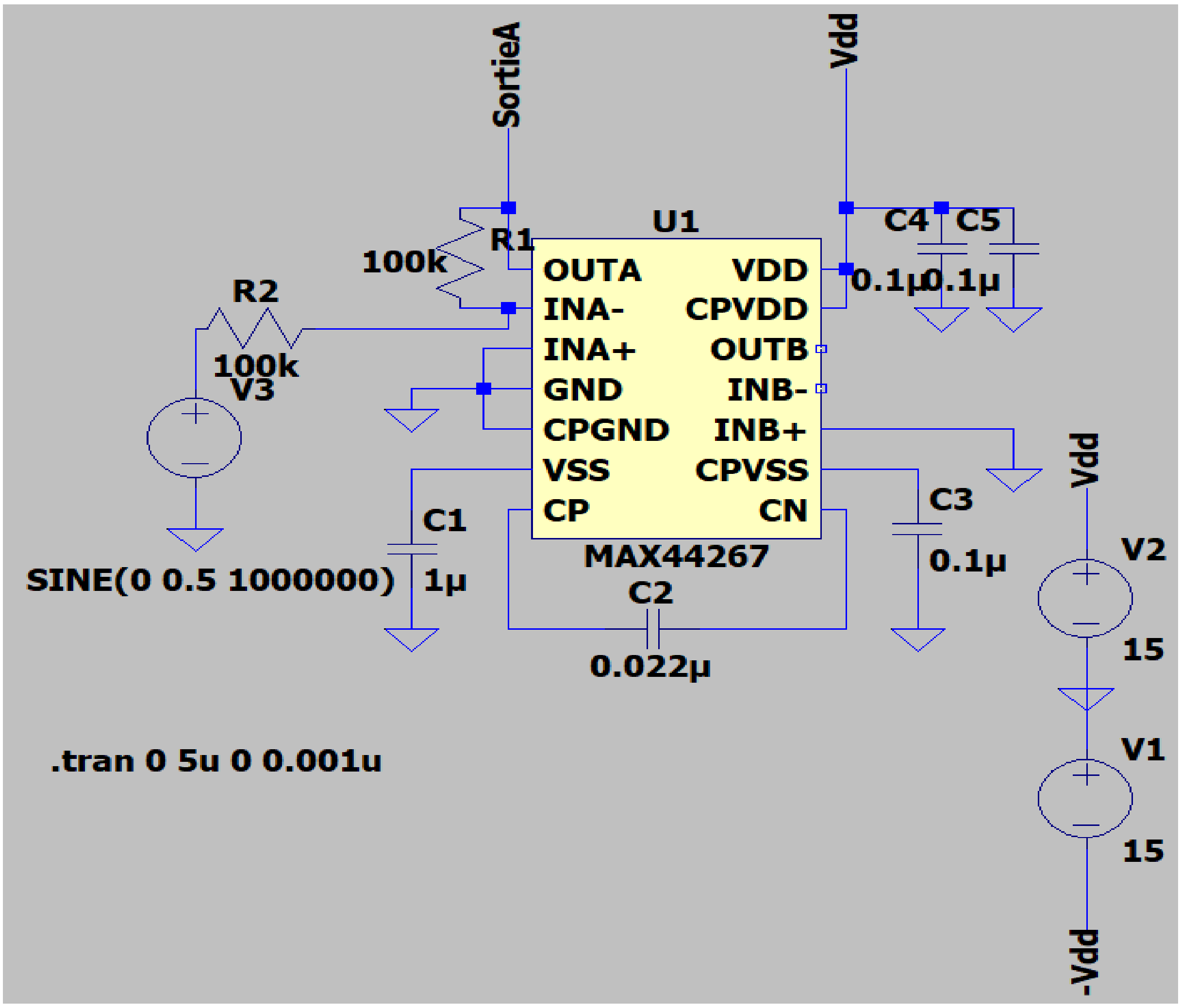


Figure: Current-to-voltage conversion circuit

The current-to-voltage converter utilizes an operational amplifier (MAX44267). This amplifier, in conjunction with a feedback resistor, establishes the circuit's gain, enabling the conversion of input current into a proportional output voltage.

Figure depicts the measurement chain comprising the current-to-voltage converter and the INA111BP instrumentation amplifier. The circuit in Figure ... is designed to convert two sinusoidal currents at 1MHz with amplitudes of 1u and 0.75u, respectively. As observed in Figure , the output voltages are sinusoidal in shape, matching the frequency of the input currents. The RMS values of the output voltages at outputs A and B are respectively 46.969 mV and 36.384 mV.

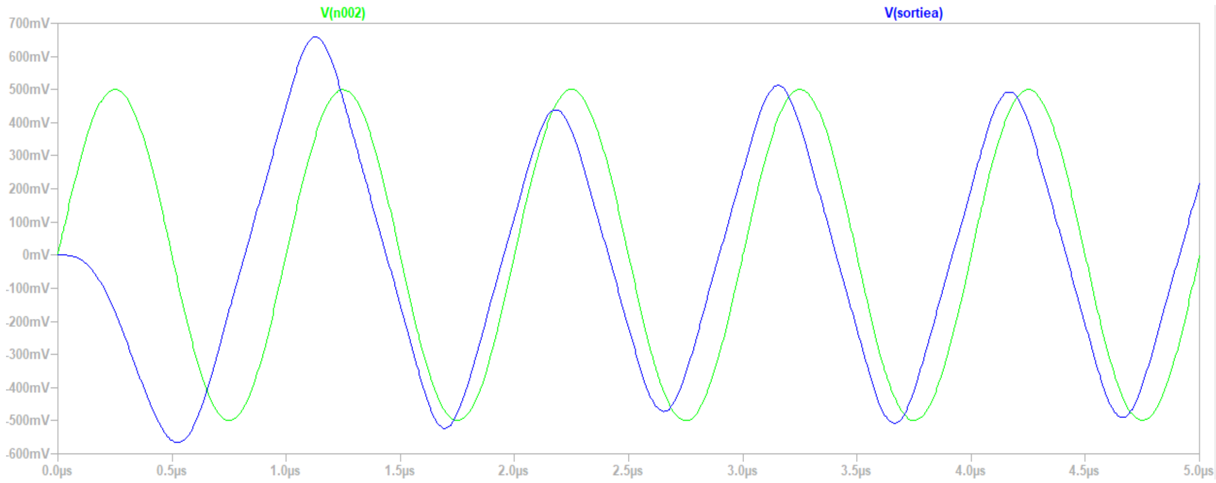


Figure : Simulation results for input current and output voltage.

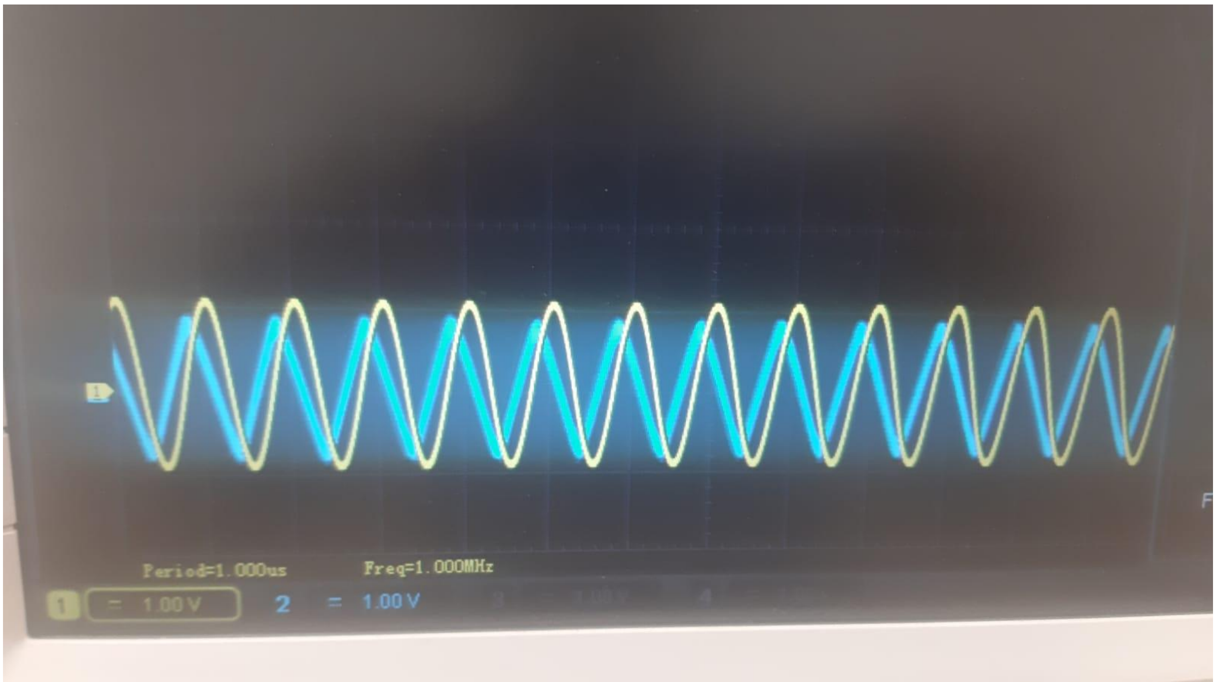


Figure: Experimental results of input current and output voltage.

- Frequency analysis

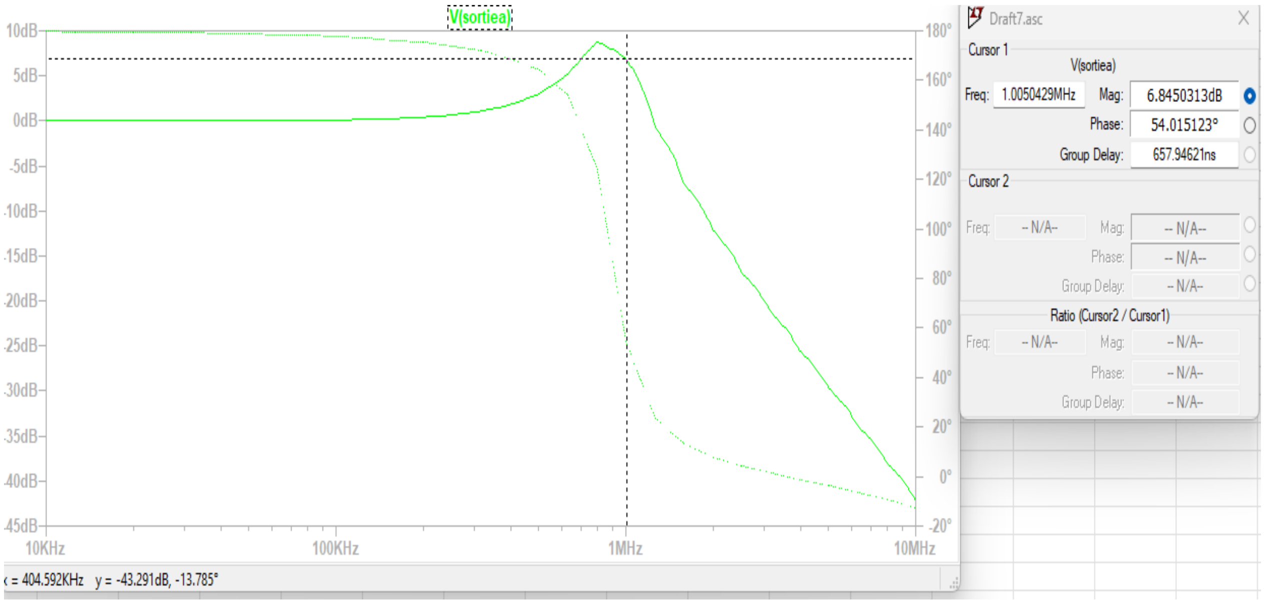


Figure : Bode diagram

Above is the frequency analysis of the current-to-voltage conversion circuit with the Bode diagram plotted. On this graph at 1 MHz, we have a bandwidth of 667.95 kHz.

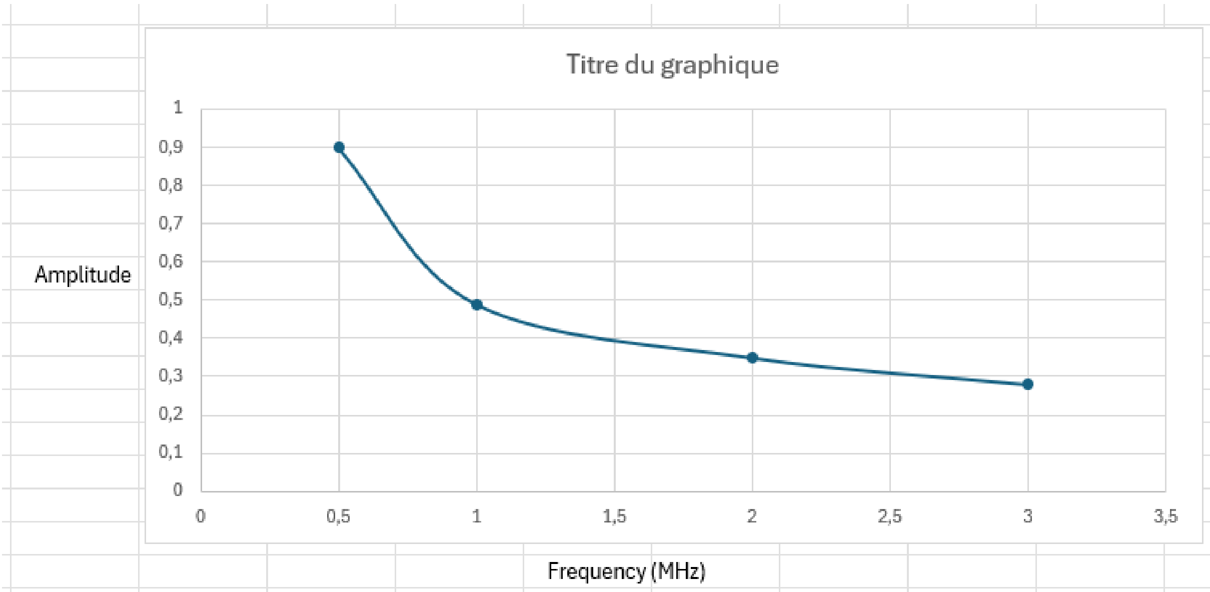


Figure: Experimental frequency analysis

- Instrumentation amplifier

To conduct the test, a sinusoidal voltage with a frequency of 1 MHz and an amplitude of 1V is applied to the non-inverting input, while no voltage is applied to the inverting input. After taking the difference between the two signals, the same signal is obtained at the output of the instrumentation amplifier.

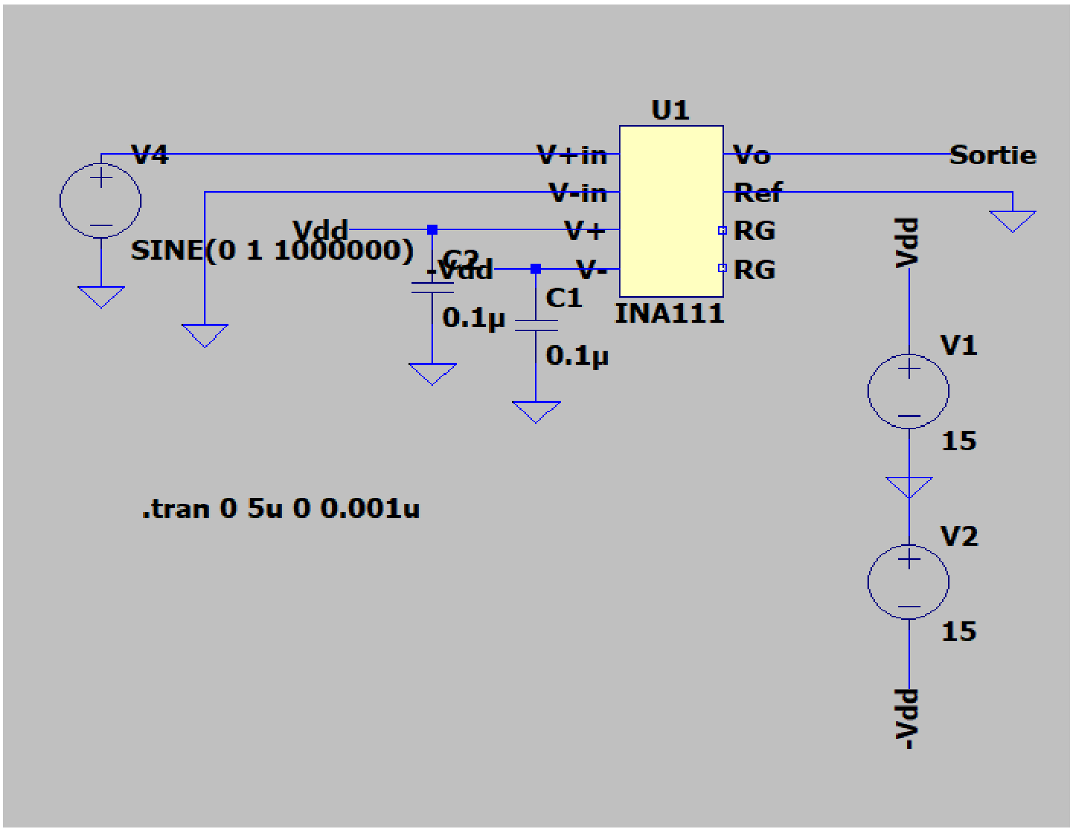


Figure: Instrumentation amplifier INA111

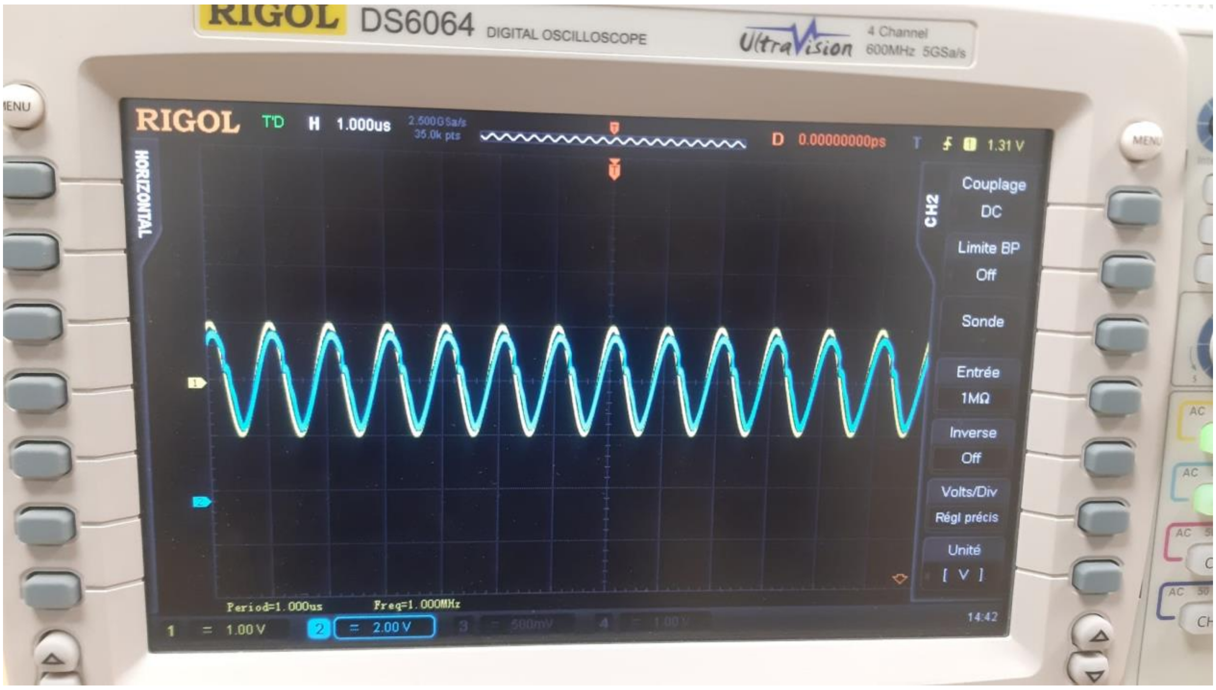


Figure : Experimental test of the instrumentation amplifier.

- Acquisition Chain

- Simulation

i= 3.35 uA i'= 6.07 uA

Absence of a capacitor at the input of the current-to-voltage converter and instrumentation amplifier gain set to 1.

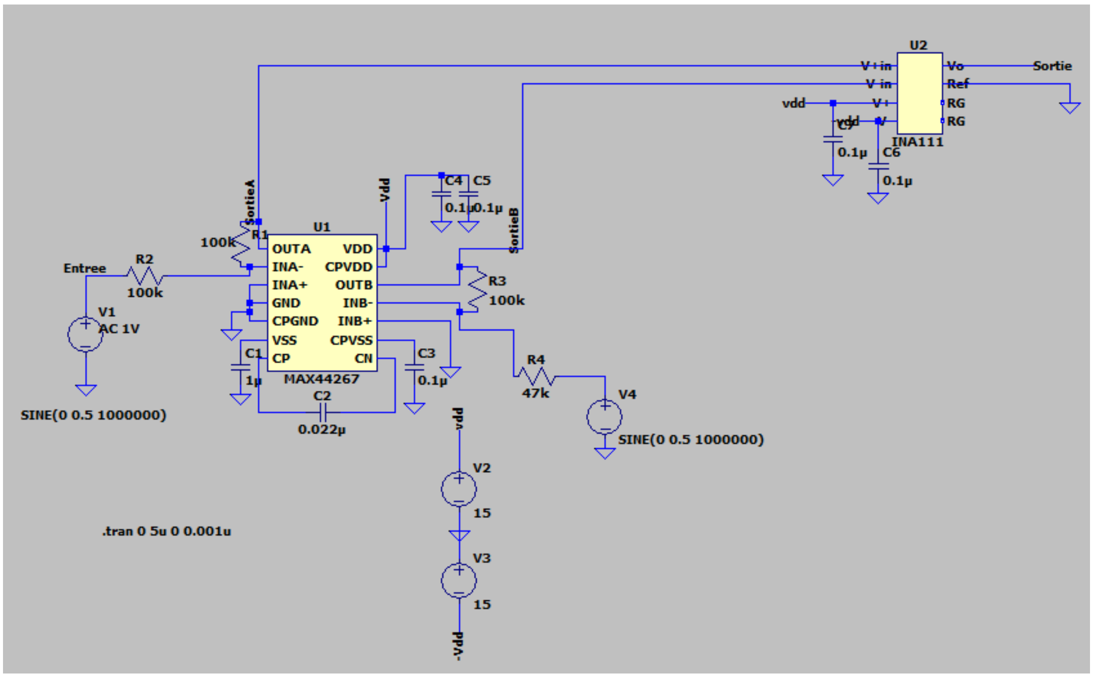


Figure : Acquisition chain

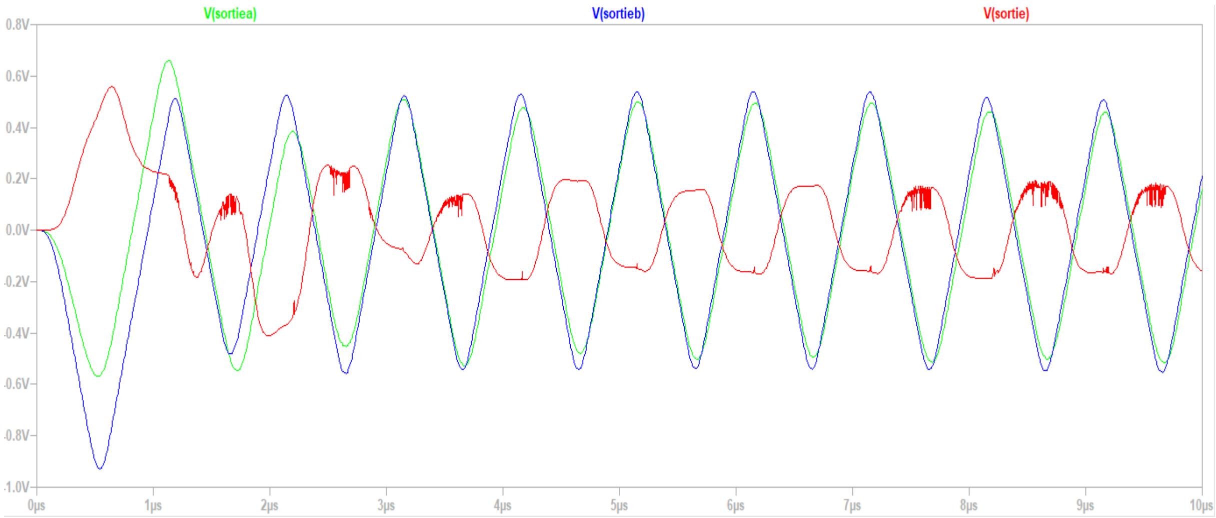


Figure : simulation signal

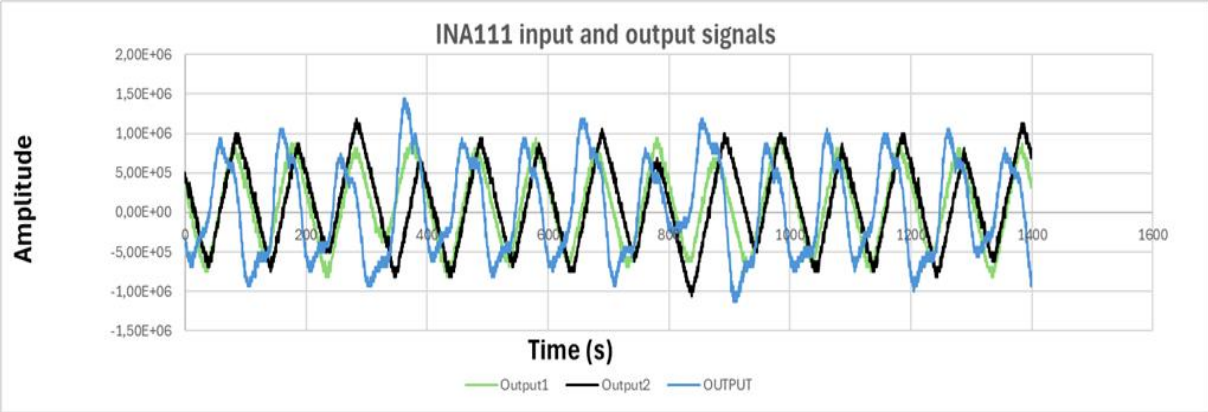
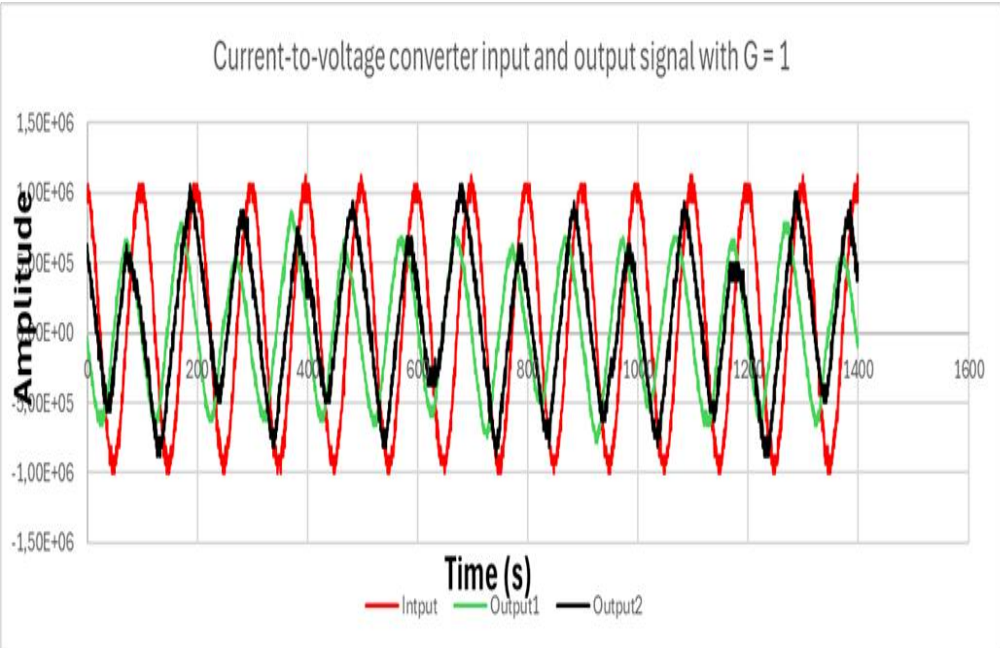


Figure : Experimental Results



On channel 1, we have the sinusoidal signal at the input, and on channel 2, the output signal. Channels 3 and 4 display the voltage signals at the output of the current-to-voltage converter. From these signals, circuit instability is observed.

Capacité de compensation c= 2.2p et le gain de l'amplificateur d'instrumentation est 1.

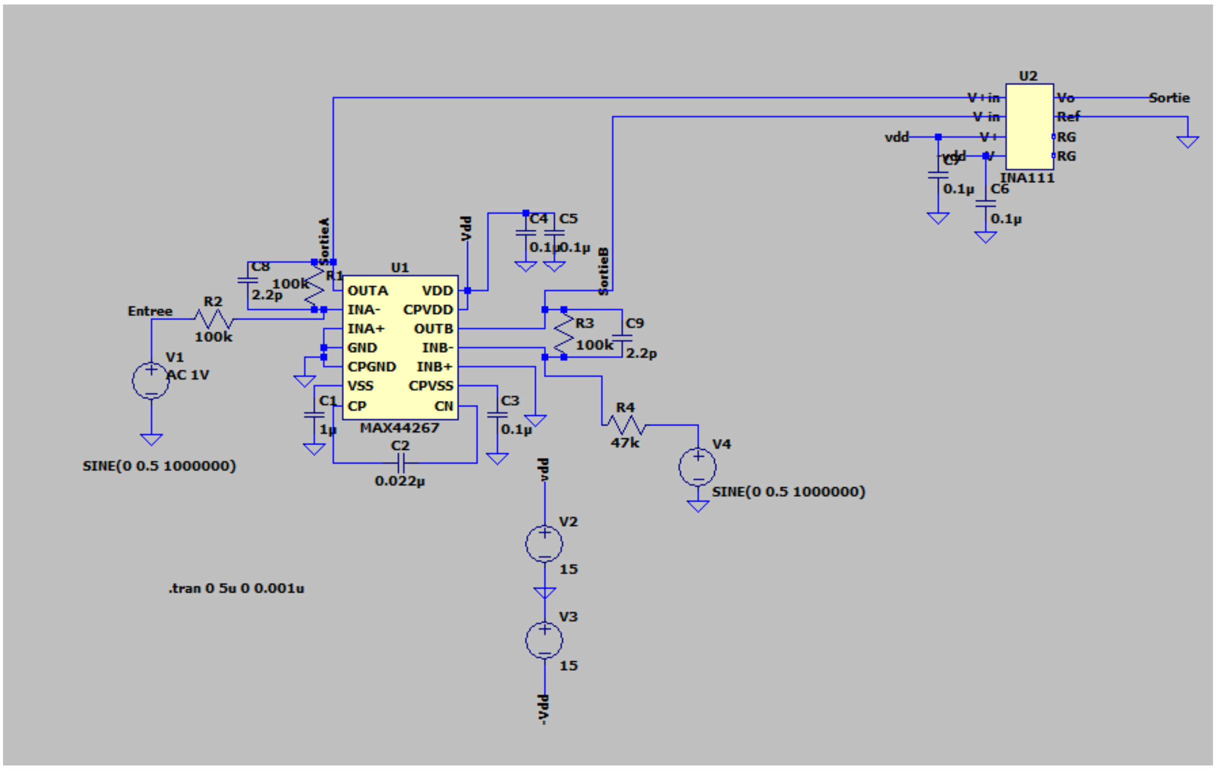


Figure : Acquisition chain with a gain of 1.

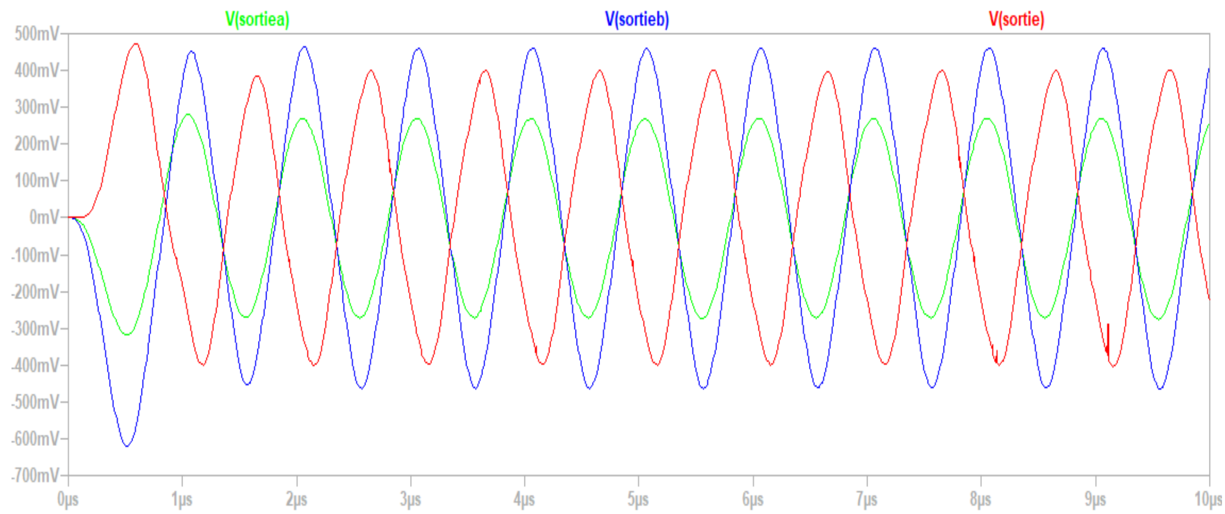


Figure : simulation signal

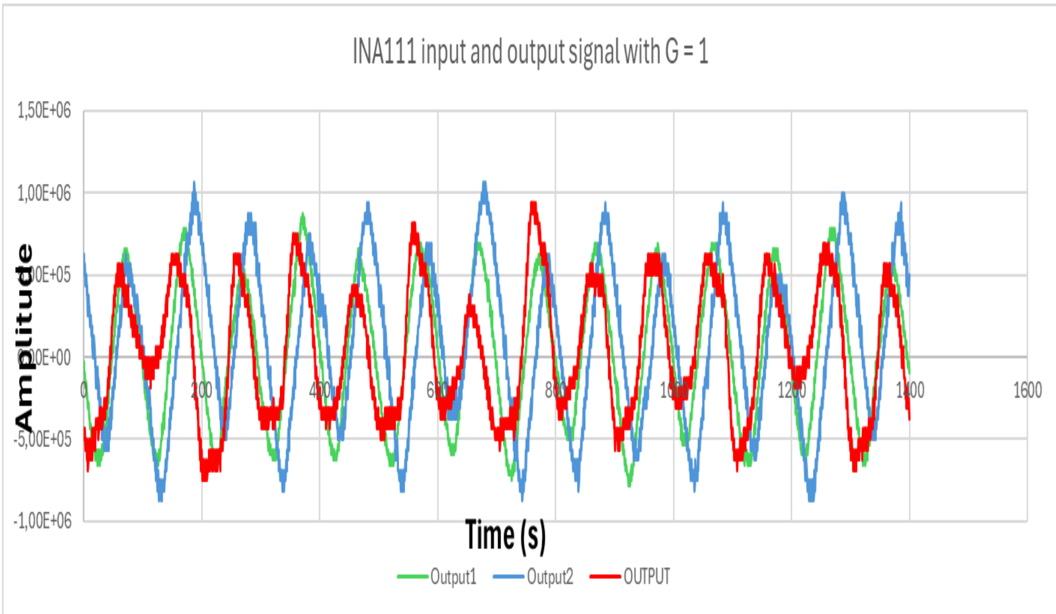


Figure : Experimental result

The four sinusoidal signals observed on the oscilloscope have a sinusoidal shape.

The simulation results correspond to the experimental results.

Compensation capacitance c=2.2p and the gain of the instrumentation amplifier is 5.

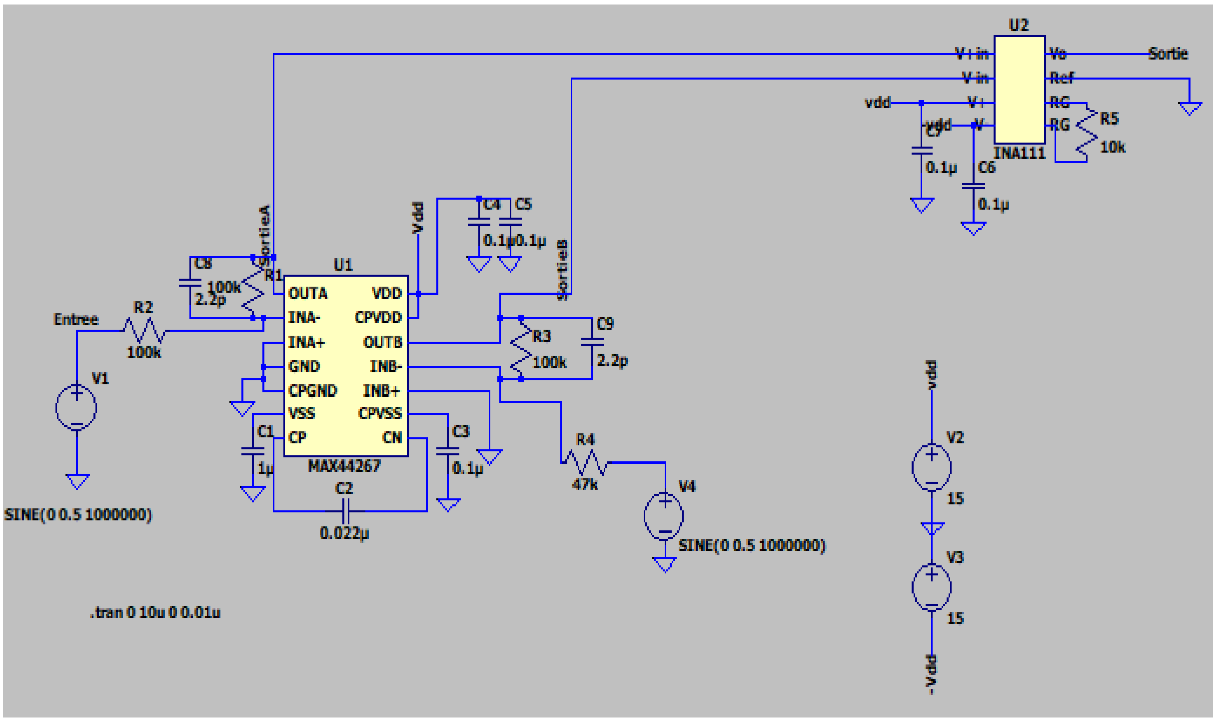


Figure : Acquisition chain with a gain of 5.

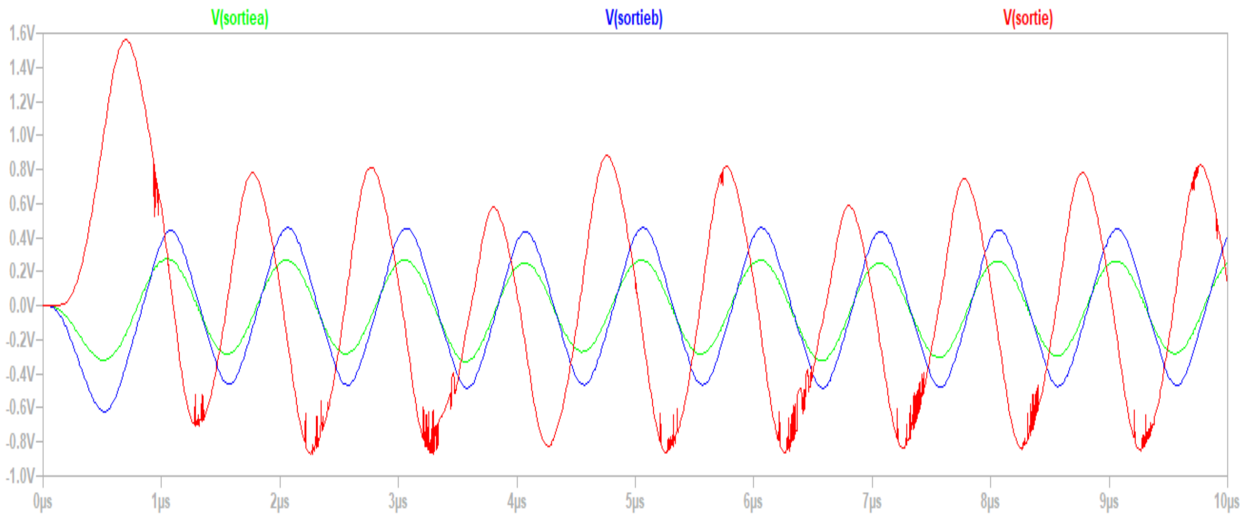


Figure : simulation signal

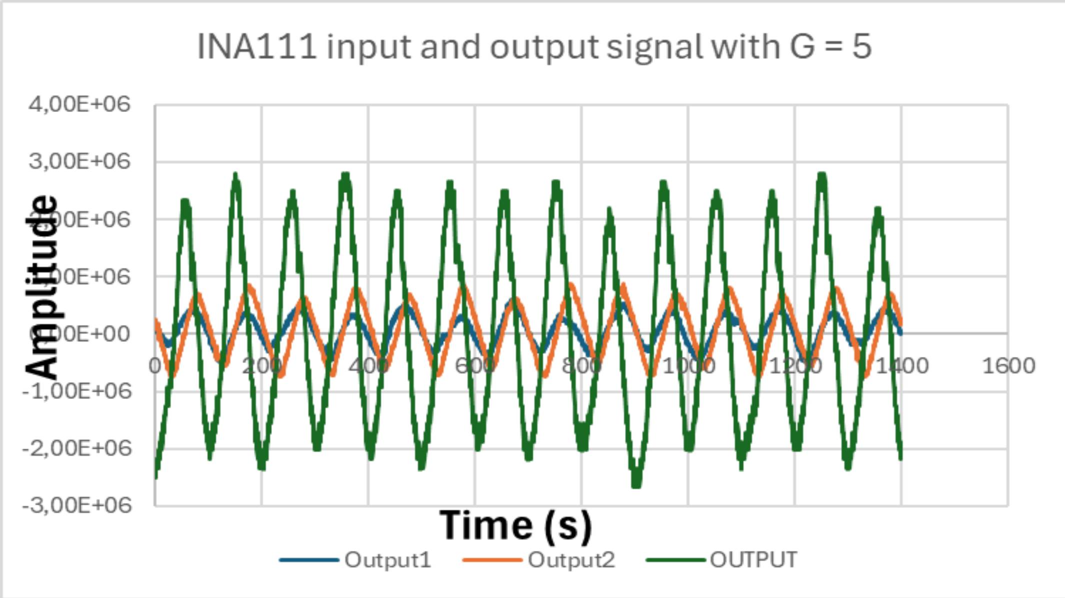


Figure : Experimental result

II.7. Progress update

- Component Selection, including the operational amplifier and instrumentation amplifier.
- Theoretical calculation of the Signal-to-Noise Ratio (SNR).
- LTSpice simulation of the data acquisition chain and SNR estimation.
- Designing the data acquisition board and carrying out tests.

II.8. Continuation and perspectives

Carrying out tests on the new micro-fluidic chip and signal processing: amplitude and phase analysis.

III. Conclusion

The MITTHIC project, undertaken during this academic year, was a remarkable opportunity to apply the theoretical knowledge acquired in class to a complex, interdisciplinary problem. The specific aim of the project was to develop a data acquisition chain for counting cells in a microfluidic channel, exploiting the dielectric properties of the cells while integrating skills in electronics and simulation. The main objective was to design a functional card for data acquisition. The results obtained, in particular the successful design of the data acquisition chain and preliminary tests, demonstrated the significant potential of our approach, converting microampere current into voltage and amplifying the voltage to a level of 2 to 5. In addition, this project has proved to be a rewarding experience both personally and professionally, improving our skills in project management, electronic system design, use of the vector network analyser (VNA) and simulation.

IV. Bibliographies

[1] R.-J. Yang, L.-M. Fu, H.-H. Hou, Review and perspectives on microfluidic flow cytometers, Sensor. Actuator. B Chem. 266 (2018) 26–45

[2] J. Panwar, R. Roy, Integrated Field's metal microelectrodes based microfluidic impedance cytometry for cell-in-droplet quantification, Microelectron. Eng. 215 (2019) 111010

[2] Y.Feng , L.Huang , P. Zhao, A microfluidic device integrating impedance flow cytometry and electric impedance spectroscopy for high-efficiency single-cell electrical property measurement. analytical Chemistry 2019

[3] https://www.allaboutcircuits.com/video-tutorials/op-amp-applications-current-to-voltage-converter/

V. Table des annexes

VI. Annexe

Self-evaluating of acquired/reinforced skills and knowledge, Qualities/skills/motivation of each member in the project and how each member participated in the project and how he advanced it:

Arcel NEMBOT:

Self-Assessment of Acquired/Reinforced Skills and Knowledge:

In my self-assessment, I've noticed a significant improvement in my project management skills, especially in communication and task planning. I've learned to set deadlines and allocate resources effectively. The importance of effective communication with both the team and clients has become clearer to me, a crucial element for project success. Technically, I've enhanced my understanding and problem-solving abilities, particularly in designing data acquisition chains. This includes selecting operational amplifiers, understanding their functioning, performing simulations on LTSpice, and evaluating theoretical noise in a data acquisition chain. My critical thinking skills have also been sharpened, enabling me to identify and resolve challenges encountered during the project. Additionally, I have developed my skills in conducting bibliographic research.

Participation in the Project and Progress:

Throughout the project, my primary role focused on designing the data acquisition chain, as I was responsible for the design of the electronic board and conducting the tests.

Participation in the Project and Progress:

The various tasks assigned to me initially involved conducting literature reviews on the subject. Subsequently, I was able to focus on the signal processing aspect and ultimately conclude with the part related to the device, simulations, and the design of the new setup.

Table: A self-assessment of acquired/reinforced skills + the level

First and Last Name	Acquired/Reinforced Skills	Level
NEMBOT ARCEL	Technical Skills in Microfluidics	Deepening
	Skills in Circuit Design and Electronics	Deepening
	Use of LTSpice Software	Expertise
	Team Collaboration and Communication	Deepening
	Technical Research and Learning	Expertise

Table: Functions Performed and the People Who Worked on Them

First and Last Name	Function Performed
NEMBOT ARCEL	Literature Review
	Selection of Operational Amplifiers
	LTSpice Simulation
	Estimation of Theoretical Noise
	Design card and Testing