DEVELOPMENT OF A LOW-COST ACOUSTIC UNDERWATER COMMUNICATION SYSTEM

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Abstract

As part of my second year of engineering school, I completed an approximately 18-week internship at the Tokyo University of Sciences on the Katsushika-ku campus in the HashimotoLab robotics laboratory. During this internship I worked on the development of a low cost underwater acoustic communication system to be able to equip eventually small underwater robot.

The difficulty of communicating with robots in an underwater environment where most other conventional means of communication (Wi-Fi, GPS, radio,.) do not work is a well known problem. Today, one of the preferred solutions in this field is acoustic communication by ultrasound, however, if there are already systems for this, they are for the most part very expensive and very often rely on patented technologies making their operation and adaptation often complicated. This project aims to respond precisely to this problem.

Résumé

Dans le cadre de ma seconde année de mes études en école d'ingénieur, j'ai réalisé un stage d'approximativement 18 semaines à l'Université des Sciences de Tokyo au campus de Katsushika-ku dans le laboratoire de robotique HashimotoLab. Au cours de ce stage j'ai travaillé sur le développement d'un système de communication acoustique sous-marin et low cost devant pouvoir équiper à terme de petits robots sous-marins.

La difficulté que soulève la communication avec des robots dans un environnement sous-marin où la plupart des autres moyens de communication conventionels (Wi-Fi, GPS, Radio,..) ne fonctionnent pas est un problème bien connu. Aujourd'hui, une des solutions privilégiées dans ce domaine est la communication acoustique par ultrason, cependant, s'il existe bien déjà des systèmes pour cela, ils sont aujourd'hui pour la plupart très onéreux et repose très souvent sur des technologies brevetées rendant leur exploitation et adaptation souvent compliquées. Ce projet vise précisement à répondre à cette problématique.

Introduction

Underwater robotics plays a vital role in exploring and monitoring ocean environments, where human presence is limited due to extreme conditions. A key challenge in this domain is establishing reliable communication systems, as traditional radio waves and GPS signals are ineffective underwater. Acoustic communication, utilizing sound waves, has emerged as the most feasible solution for transmitting data over long distances in such environments. However, the high cost of existing acoustic communication systems limits their accessibility for many applications, particularly in small-scale or cost-sensitive projects.

This report presents the development of a low-cost underwater acoustic communication system designed to provide a viable alternative for researchers and engineers working with autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs), and other marine technologies. By focusing on affordability and ease of implementation, the system aims to enable broader adoption of underwater communication technologies in various scientific and industrial fields.

1 Work environement

1.1 University and Laboratory

The Tokyo University of Science, established in 1881, was the first institution in Japan dedicated to teaching the sciences. Today, it serves as a key hub for education and research nationwide. Recognized as a "Research University" of international standing, it emphasizes a balanced approach to both fundamental and applied research. With over 19,000 students from more than 20 countries, the university is divided across five campuses, offering both undergraduate and graduate programs. The Katsushika campus houses a research facility with 11 departments, conducting research in various fields, including mechanical engineering, where I completed my internship.

Figure 1.1: Tokyo University of Science

I completed my internship at the Hashimoto Lab, a mechanical robotics laboratory founded by Professor Takuya HASHIMOTO, who was also my supervisor during the internship. The lab's main research focus is the application of robotics in sports, medical and welfare, and human-robot interaction, although it is not limited to these areas. It also features projects like a welding robot and robotic fish for example, which fall outside of these core themes. My project was part of this latter category, being related to the robotic fish. The laboratory brought together around twenty students, mostly undergraduates with a few master's students, each working on their own projects, which were often complementary to one another. The laboratory was well-equipped, especially with 3D printers, featuring three state-of-the-art models of different sizes, allowing for a level of flexibility and creativity in project development that was far different from what I had experienced previously. The laboratory was also equipped with an indoor pool to test the waterproofing as well as the robotic fish behaviour.

Figure 1.2: Laboratory equipment

1.2 Work supervision

The work organization in the lab allowed students a great deal of freedom and autonomy in how they approached their tasks, in selecting the materials they deemed necessary for their projects, and in setting their own lab hours. There were no strict rules regarding the specific hours students had to be present in the lab, except that they needed to complete a certain number of hours by the end of the week. As a result, most students would arrive late in the morning or early afternoon and stay until late in the evening to work in the lab, with some also working remotely on the lab's computers. Each student had their own workstation with a desk and computer, which allowed those with complementary projects to be grouped together, fostering collaboration.

As for supervision, we were required to give a weekly progress report to the lab director, Professor Takuya HASHIMOTO, on the work we had accomplished. These reports were given individually or as a group if we were working in teams. The weekly meetings served to showcase project progress and discuss any issues encountered, along with possible solutions. Every two weeks, we also had to give an individual PowerPoint presentation in front of the entire class about our projects. During these presentations, we discussed the project's challenges, objectives, and significance, as well as how we planned to tackle the issues and where we stood in this process. We also presented any problems we were facing. Following the presentation, which was more detailed than the weekly meetings, there was a discussion with the entire lab. It was often during these sessions that new goals were assigned if complications arose, or if an interesting new direction for the project was identified.

Figure 1.3: Presentation in front of the laboratory

1.3 Tasks ans objectives

During this internship, I was assigned only one main objective: to create a low-cost underwater acoustic communication system. I worked on this project alone, setting my own goals, except when new tasks were assigned to me during project progress meetings. Since this was a completely new project, I had a great deal of freedom in choosing the approach, though my supervisor did provide some scientific papers on the subject to guide my work and help me start. This project required me to focus equally on both theory and practice thus making it a very interesting and complete experience especially regarding what might be required of me as a future engineer. My primary goals were to develop the desired signal with the transmitter system, create a receiver system capable of receiving and demodulating the signal, establish clear communication using two ultrasonic transmitters, and finally, conduct underwater testing.

2 Acoustic underwater communication technology

2.1 Context

Underwater robotics can be divided into two subcategories. The first includes underwater robots that require a constant connection to the operator via a cable, and the second consists of those that do not. This second category can itself be split into two subcategories: robots guided by acoustic waves and autonomous underwater vehicles (AUVs). Given the difficulty of communicating underwater with signals other than acoustic ones, and the emergence of new concepts such as swarm robotics, which aligns with the AUV category, acoustic communication systems are poised to become central to underwater robotics. While a few acoustic communication systems already exist today, they are mostly designed for large-scale projects, making them expensive and difficult to access due to their reliance on numerous patented technologies. This often hinders research or the industrialization of certain systems, highlighting the need for simpler and more affordable underwater communication systems.

2.2 QPSK modulation

Quadrature Phase Shift Keying (QPSK) or 4-PSK modulation, as the name suggests, is a phase shift keying modulation method. This relatively simple modulation technique conveys information through phase shifts in the carrier signal. The simplest form of phase modulation is called Binary Phase Shift Keying (BPSK). Here, "Binary" refers to the number of available phases, which are two: one phase at 0° and the other at 180°, ensuring the phases are as distinct as possible. Each phase is assigned a value of information, and in this case, with two phases, one represents 1 and the other 0. This arrangement is visualized using a constellation diagram which will be used by the demodulator after determining the phase of the signal to maps it back to its corresponding symbol, thus recovering the data transmitted.

QPSK modulation is based on the same principle as BPSK, with the difference that QPSK uses four phases, allowing two bits to be assigned to each symbol or phase instead of just one, effectively doubling the data rate compared to BPSK, while maintaining the same signal bandwidth. In practice, QPSK can be viewed as the sum of two BPSK signals shifted by $\pi/2$, and this is the approach that will be taken during this project. Despite its higher data rate, QPSK remains relatively simple and is widely used in various communication systems, including satellite transmissions and wireless networks.

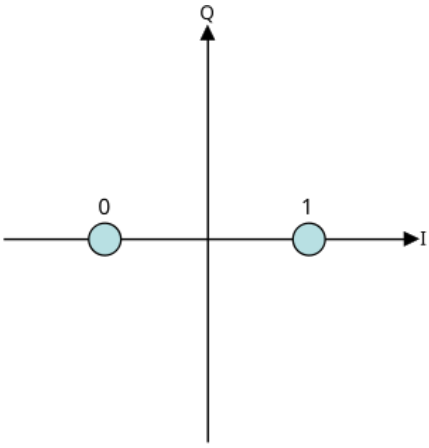


Figure 2.1: Constellation diagram for BPSK modulation

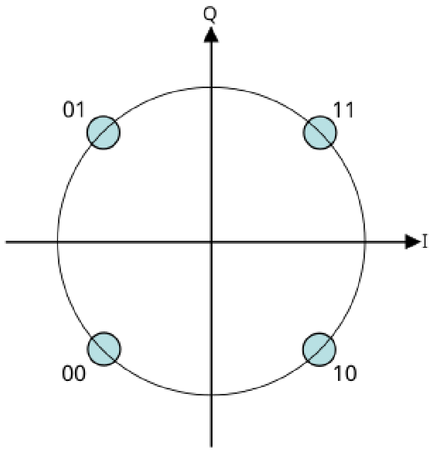


Figure 2.2: Constellation diagram for QPSK modulation

2.3 Design choices

As previously mentioned in this report, this project was guided by a specific scientific paper[1]. The hypotheses, methods and design choices chosen for the system design are therefore similar, if not identical. The decision was made not to implement a communication protocol but to create two fixed systems: one for transmitting and the other for receiving, thereby avoiding issues related to access conflicts. Similarly, as stated earlier, the chosen modulation method will be the QPSK modulation as it is a simple and efficient method to implement not requiring a high computing power.

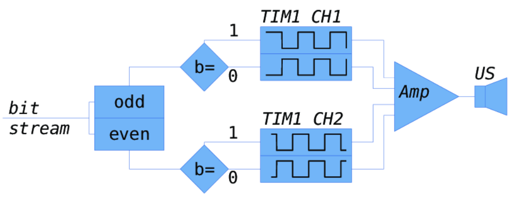


Figure 2.3: Emitter node

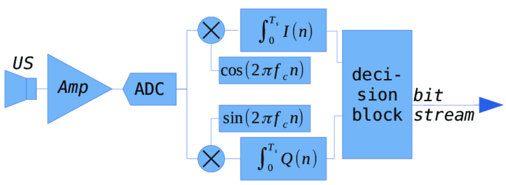


Figure 2.4: Receiver node

In line with this decision and the aim to create low-cost systems, the microprocessor selected for both systems is the M4 Cortex Microcontroller, which in our project takes the form of the Nucleo F411RE.

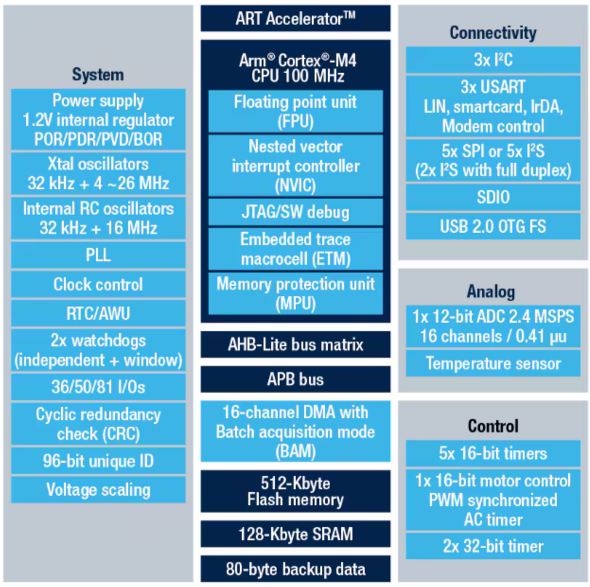


Figure 2.5: STM32F411RE circuit diagram

The transducers chosen for the project are not the same as those used in the paper[1] due to the difficulty of sourcing them, their IP67 rating, and the lack of more precise information about the product. Instead, the decision was made to use the IP68-rated CUSA-TR65-065-2200-WC68 ultrasonic transducer, which, like the other transducer, is also designed for use at a frequency of 40kHz.

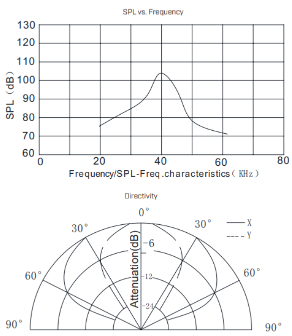


Figure 2.6: Beam pattern of the CUSA transducer

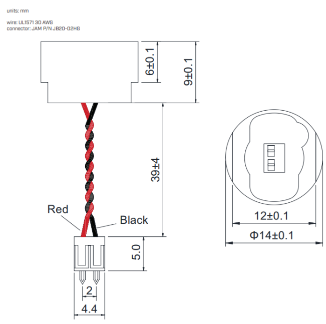


Figure 2.7: Mechanical drawing of the CUSA transducer

3 Development of the Emitter

If the overall design for both the emitter and the receiver was already established in the paper[1] with the architecture depicted in fig 2.4 and 2.5, the detail of the hardware design as well as the components used for it were not specified. As such, this is where this project might differ from the one presented in the paper[1] as the electronic design, aside from the M4 Cortex microcontroller had to be created from scratch.

3.1 Hardware Architecture

3.1.1 Electronic Schematics

As stated earlier, it is possible to view QPSK modulation as the sum of two BPSK signals, phase-shifted by $\pi/2$, and this is how the modulation will be approached in this project. A more detailed explanation of this process will be provided later; for now, it is important to note that the microcontroller processes the information to be transmitted, translates it into binary, and then outputs two BPSK signals phase-shifted by $\pi/2$. From there, as previously explained, we need to sum them to obtain our QPSK signal. To achieve this, we have chosen to use the OPA552 operational amplifier. Its role will be to sum the two BPSK signals and amplify them to produce a QPSK signal strong enough to be transmitted by the ultrasonic transducer. Since this op-amp requires a dual-supply of +/-15V for our purposes, the decision was made to use two MT3608 DC/DC converters, one connected to the +5V output of the board and the other to the +3V output, to obtain two +15V DC sources, which when connected together provide our dual-supply of +/-15V.

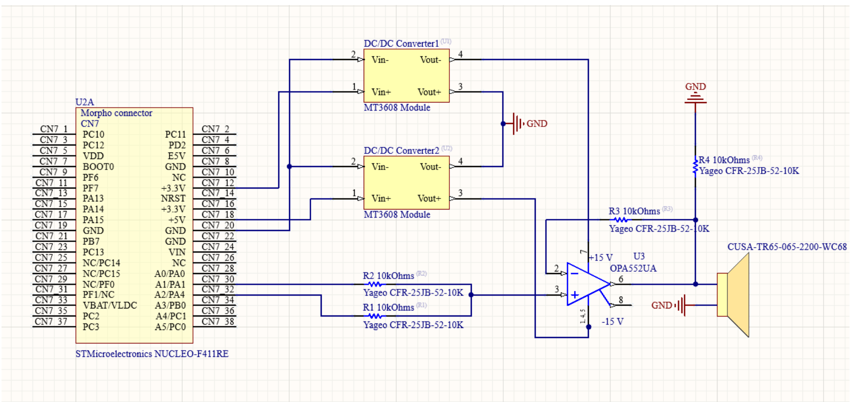


Figure 3.1: Emitter circuit schematics

3.1.2 Components

- **Microcontroller:**
  - **Nucleo F411RE (STM32F411RE)**
    Role: Processes the information and generates two BPSK signals phase-shifted by $\pi/2$.
    Output Signals Voltage: Two BPSK signal of +3.3V.

- **Operational Amplifier:**
  - **OPA552 (Operational Amplifier)**
    Role: Sums the two BPSK signals and amplifies them to create the QPSK signal for transmission.
    Supply Voltage: Dual-supply of $\pm$15V.
    Gain: G=2. *Gain-Bandwith Product (GBP)*: 12MHz.
    Slew-rate: 24V/μs.
    Output Signal Voltage: Staircase signal of +13V.

- **DC/DC Converters:**
  - **MT3608 (Boost Converter)**
    Role: Used to generate the $\pm$15V dual-supply.
    Quantity: 2 units (one connected to the +5V output, the other to the +3V output, to create the dual-supply).

- **Ultrasonic Transducer:**
  - **CUSA-TR65-065-2200-WC68**
    Role: Used for transmitting the QPSK-modulated signal.
    Operating Frequency: 40kHz.
    IP Rating: IP68. *Capacitance*: 2640 pF.

3.2 Code description

Since the initial objective of this code is simply to test the device, it is designed to continuously send the same message. The message sent is structured as follows: the first part of the message, which lasts for 100 microseconds, is a training sequence that will allow the receiving system to detect the beginning of each message. In this project, it is a continuous signal at 0V. The second part of the message also lasts 100 microseconds, which corresponds to 4 periods for our carrier frequency, allowing us to send an 8-bit message via QPSK modulation (00101101 in this case). Each period corresponds to a symbol, which is the sum of two square waves of the same frequency, phase-shifted by $\pi/2$. By modifying the phase of these two square waves (which are our two BPSK signals), we can create a total of four different symbols, each representing one of the 4 pairs of bits shown on the constellation diagram of QPSK modulation in Figure 2.2.

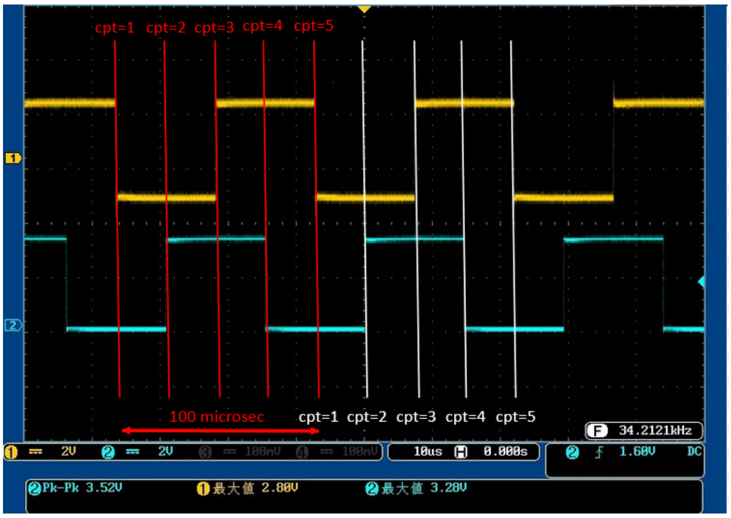


Figure 3.2: Interruption pattern explained

To achieve this, the method applied is inspired by the one described in the paper[1], namely using an integrated timer to generate these two square waves, instead of generating sinusoidal signals, which are more complex and require more computational resources. The code is based on a timer set to 6.25 microseconds, which is a quarter of the time corresponding to one symbol, allowing us to have 4 interrupts per period and thus generate our two square waves phase-shifted by $\pi/2$. From there, a counter is initialized at 1 and increments with each interrupt, and once it reaches 5, it triggers the symbol change and resets to 1. It is through this counter that the code knows where it is in the symbol generation process and therefore on which signal to act and what to do.

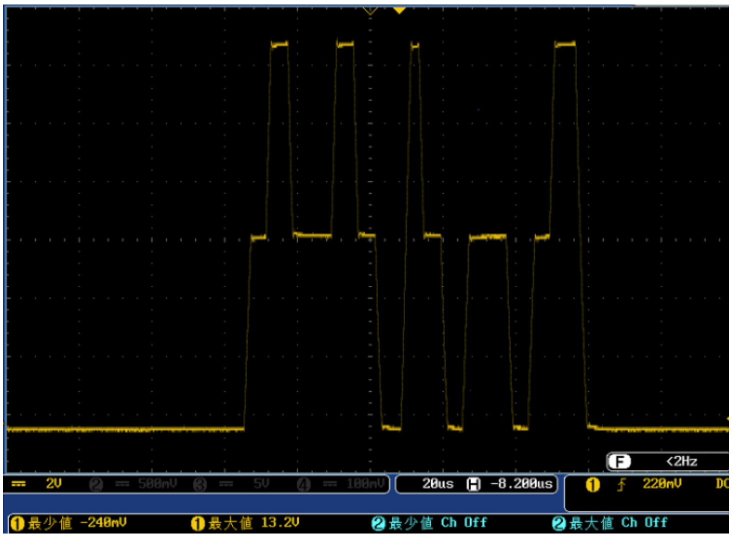


Figure 3.3: Resulting QPSK signal for the message "00101101"

4 Development of the Receiver

4.1 Hardware Architecture

4.1.1 Electronic Architecture

After receiving our signal through the CUSA ultrasonic receiver, it is very weak and thus needs significant amplification. For this, we use the low-noise operational amplifier TLV2316, set to a gain of $G = 100$. Given that it has a gain-bandwidth product (GBW) of 10MHz, the amplification is distributed across two stages of the operational amplifier to maintain optimal bandwidth and minimize signal distortion. Since the signal is a staircase waveform, it contains numerous high-frequency components. This amplifier is also low-voltage, and its power supply can be provided directly from the +5V output of the Nucleo F411RE. From there, the amplified signal is sent directly to one of the pins corresponding to the Analog-to-Digital converter (ADC) of the microcontroller.

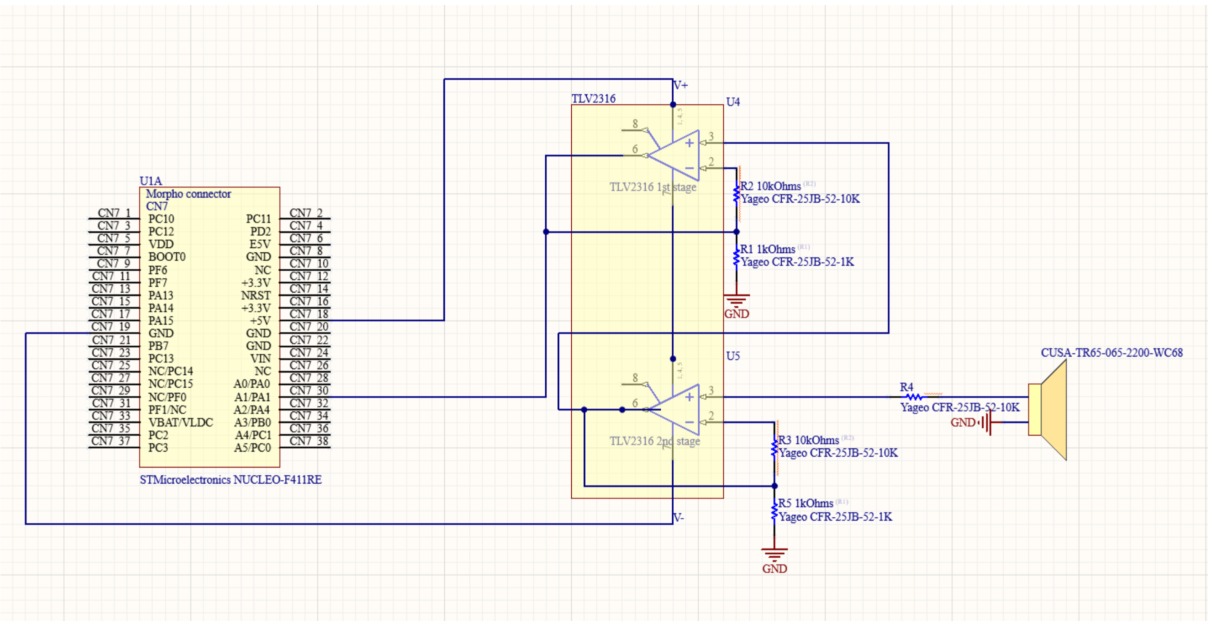


Figure 4.1: Receiver circuit schematics

One thing to note about both systems, the receiver and the transmitter, is the absence of a band-pass filter. Although the paper does indeed mention the use of a "band-pass filter created with passive components"[1], we will assume here that this role is already fulfilled by our two CUSA ultrasonic transducers. Tests were conducted with band-pass filters created with passive components, but the signal was always too distorted to be usable

4.1.2 Components

- **Ultrasonic Transducers:**
  - **CUSA-TR65-065-2200-WC68** (Transmitter and Receiver)
    Role: Ultrasonic transducers for sending and receiving signals.
    Frequency: 40kHz.
    IP Rating: IP68. *Capacitance*: 2640 pF.
- **Operational Amplifier:**
  - **TLV2316 (Low-noise Operational Amplifier)**
    Role: Amplifies the weak signal from the ultrasonic receiver.
    Gain: G = 100.
    Gain-Bandwidth Product (GBP): 10MHz.
    Slew-rate: 6V/μs.
    Supply Voltage: Powered from the +5V output of the Nucleo F411RE.
- **Microcontroller:**
  - **Nucleo F411RE (STM32F411RE)**
    Role: Processes signals, translate the recepetion.

4.2 Code description

The reception system sends the signal data to the pin corresponding to the ADC of the NucleoF411RE. From there, the code uses Direct Memory Access (DMA) channels to transfer the data from the ADC to the buffer, which will contain the signal's amplitude values over time using the ping-pong buffering (or double buffering) method. This method divides the buffer into two parts. While the code processes the data in one half, the ADC writes its received data to the other half. When it finishes writing to its assigned half, it triggers an interruption that switches to the other half, while the code also switch to the other half and processes the newly filled half.

The demodulation algorithm must first detect the beginning of each message. To achieve this, it detects the training sequence implemented in the transmitter, which is also known to the receiver. As a reminder, this consists of a 0V signal lasting 100μs. Then, as shown in Figure 2.4, once the signal is isolated, it is multiplied on one side by $\cos(2\pi f_c t)$ and on the other by $\sin(2\pi f_c t)$ (with f_c being the carrier frequency, in this case, 40kHz), resulting in two complex signals named I (for the signal multiplied by the cosine) and Q (for the signal multiplied by the sine). To reduce computing time, the sine and cosine function are pre-calculated.

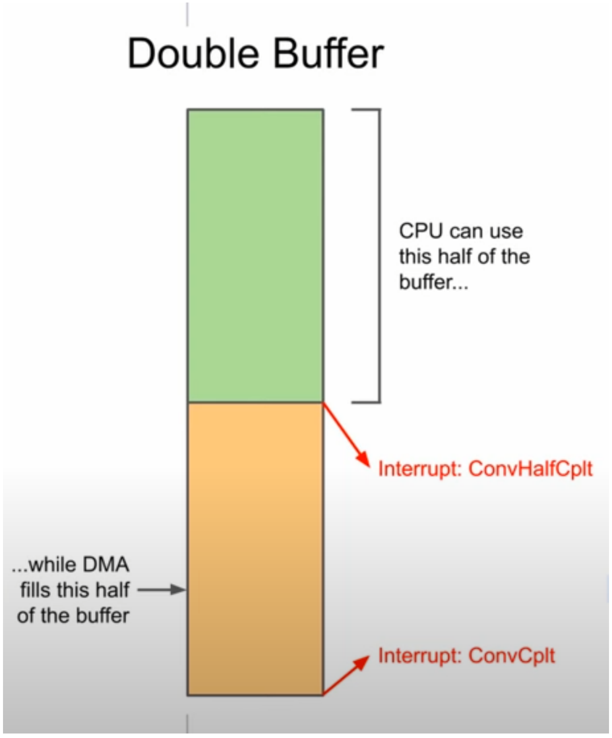


Figure 4.2: Pin-pong buffering method

The algorithm then divides these signals into four parts since the signal contains 4 symbols, and integrates each part over the duration of one symbol, which corresponds to one period of the carrier frequency, or 25μs. This yields two coordinates, I and Q, which, once placed in a complex plane, allow us to decode the final message using the QPSK modulation constellation diagram shown in Figure 2.2.

5 Experiments

This project, with the main objective of developing a physical communication system, involved a great deal of practical and theoretical experimentation, leading to numerous adjustments and component changes. Since it is not possible to present all of them, we will focus on the three most significant ones that align with the main goals outlined at the beginning of this report: first, the establishment of the QPSK signal, second, the development of the receiver system and particularly its demodulation algorithm, and finally, the communication using CUSA transducers. In every experiments, the nucleo boards were powered by PCs.

5.1 Establishing a QPSK Signal

This first experiment focused on establishing the desired QPSK signal without the goal of communication via transducers. During this process, a problem with powering the operational amplifier was identified. The amplifier required a dual supply provided by two DC/DC converters connected to the +5V and +3.3V outputs of the board, which, when used, drew too much power from the board, causing it to shut down. As a temporary solution, it was decided to use an external power supply, which, together with the DC/DC converter connected to the 5V output, provided the necessary dual supply. After these adjustments, the desired QPSK signal was successfully established.

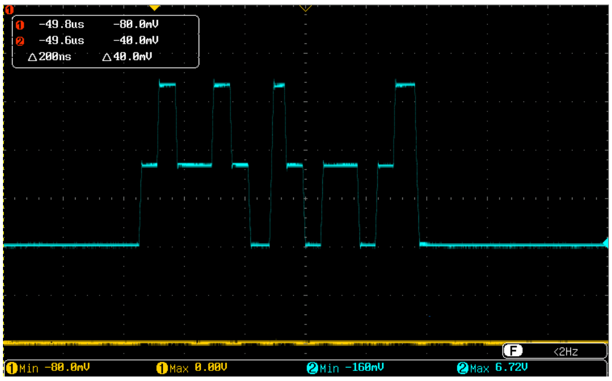


Figure 5.1: QPSK signal generated

5.2 Demodulating a Signal

The goal of this experiment was to develop the demodulation algorithm for the signal in the receiver system. For simplification, the decision was made to transmit the QPSK signal via wired connections, providing the system with an ideal signal to work on. While the demodulation algorithm proved functional and was able to successfully demodulate the transmitted signal, another issue arose concerning the choice of the training sequence. While effective during signal reception, it became problematic during phases where the system was on, but no signal was being transmitted. The sequence, consisting of a 0V signal for 100 microseconds, led the system, when receiving a near-zero signal when no signal was transmitted, to continuously triggered the demodulation algorithm.

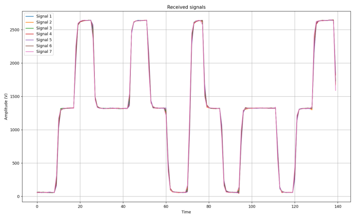


Figure 5.2: Signals received and isolated by the demodulation algorithm

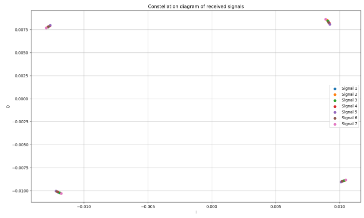


Figure 5.3: Resulting constellation diagram

```
Name : msg_halfbuffer
    Details:{"\0\0\0\0\0\0\0", "00101101", "00101101", "00101101", "00101101", "00101101", "00101101", "00101101"}
    Default:0x200055a4 <msg_halfbuffer>
    Decimal:536892836
    Hex:0x200055a4
    Binary:100000000000000101010110100100
    Octal:04000052644
```

Figure 5.4: Display of the messages received by the demodulation algorithm (the messages that were sent were "00101101")

5.3 Communicating a Signal Using Transducers

After setting up the signal transmission and reception systems, it was time to attempt communication using the ultrasonic transducers. For simplicity, this first experiment was conducted in air rather than water. During the experiment, it became clear that the receiver system was not receiving any signal from the transmitter system, despite successful signal reception from a signal generator at similar or even lower voltage levels. Communication was also successfully established when the transmitter system was connected to an external amplifier, which raised the signal to 120V before supplying it to the transducers. It was later discovered that the issue stemmed from the OPA552 amplifier used in the final amplification stage, which was not designed to handle the capacitance of the ultrasonic transmitter. A last-minute solution was attempted by connecting another amplifier, the LT1167, in series with the OPA552. While theoretically capable of handling the transmitter, the error rate for this component at this capacitance value was around 80

6 Going further

Since the project has not been fully completed and some issues remain unresolved, this section aims to highlight them and provide some potential solutions to address them and move forward. Firstly, as mentioned in the report of the last experiment, the OPA552 operational amplifier in the transmitter system must be replaced. Ideally, its replacement should be able to function without requiring a dual supply, which would also resolve many of the system's general power supply issues. Additionally, it should be able to handle very high capacitance values if we intend to keep using our current ultrasonic transmitters. Finally, it should have a good slew rate, ideally around 6V/microsecond minimum, as tests with amplifiers featuring lower values resulted in a signal too distorted for efficient demodulation.

The second important point that needs to be addressed in the future is the training sequence, which causes issues when no signal is being transmitted, as explained earlier. One idea would be to replace it with a recognizable pattern that cannot be confused with a message while still being simple enough to implement. Lastly, once communication between the two systems is established using ultrasonic transmitters, it would be interesting to tackle the communication protocol issue and merge the transmitter and receiver. Ultimately, having two nodes that can serve both as transmitters and receivers, and that could be part of a larger system with more nodes, would allow for practical and beneficial use of this technology in robotics in general, and specifically in the underwater field.

Conclusion

Although the creation of a low-cost underwater acoustic communication modem was not fully realized, the work completed during this internship has nonetheless laid the foundation for its development and identified potential paths to its completion. Most of the primary objectives were achieved, and when they were not, explanations and potential solutions were provided to overcome the challenges. This project proved to be very interesting in many respects. First, it highlighted and provided insight into the challenges of underwater communication, offering an initial approach to acoustic communication. As underwater swarm robotics is a field that interests me for the future, this project has been very relevant in that regard. Furthermore, since this project is not directly related to the core area of my studies at ENSTA Bretagne, it placed me in a situation where I was able to understand what is expected from an engineer, namely the ability to adapt and manage a project regardless of the subject, based on the knowledge and methods acquired during my studies.

This project also allowed me to strengthen my knowledge in electronics and microcontroller programming, two fields that are highly useful for robotics. As this internship took place in Japan, it provided me with my first experience working internationally, allowing me to understand the challenges this can sometimes represent. With a great deal of freedom in this project, I was able to deepen my understanding of project management from a technical perspective, particularly in terms of choosing the right electronic components and setting up proper intermediate objectives.

I am delighted to have had the opportunity to undertake this internship and nearly complete this project, given its ambitious scope and relevance to robotics, and I would like to once again thank Professor HASHIMOTO for this wonderful experience in Japan, both from a human and scientific perspective.

Bibliography

[1] Boguslaw Slzachetko, *Low-Cost Underwater Communication System: A Pilot Study*, applied sciences, 2022.

[2] Morvan Antoine, Low-cost-acoustic-underwater-communication-system, codes of the project, 2024.

Appendix

SPECIFICATIONS

parameter	conditions/description	min	typ	max	units
type	transmitter/receiver				
operating voltage	at 40 kHz			150	Vp-p
frequency		38.5	40	41.5	kHz
echo sensitivity	at 1 m	120			mV
sound pressure level	at 10 V, 30 cm, sine wave	90			dB
directivity	horizontal angle at -6 dB vertical angle at -6 dB	105 50	120 65	135 80	degree degree
capacitance	at 1 kHz	1,760	2,200	2,640	pF
detectable range		0.4		6.5	m
response time				1.8	ms
impedance				3,000	Ω
dimensions	Ø14 x 9.0				mm
material	aluminum				
terminal	wire leads with connector				
weight			2.96		g
operating temperature		-40		80	°C
storage temperature		-40		85	°C
RoHS	yes				
IP level	IP68				

Figure 1: **CUSA-TR65-065-2200-WC68 data specs**

At T_J = 25°C, V_S = ±30 V and R_L = 3 kΩ, unless otherwise noted.

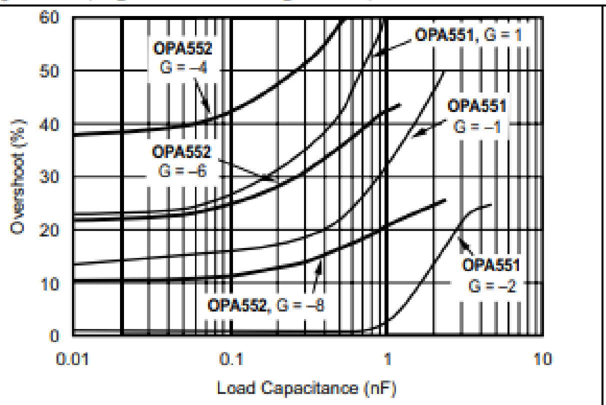


Figure 19. Small-Signal Overshoot vs Load Capacitance

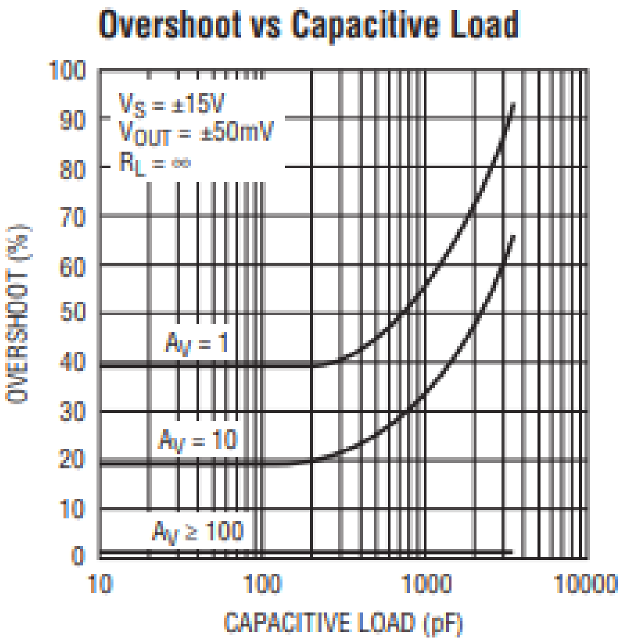
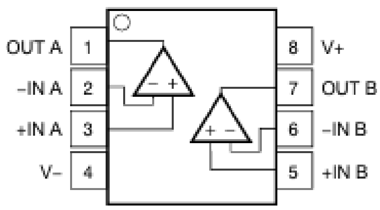


Figure 2: **Overshoot vs Capacitive load for LT1167**

D, DGK Packages
8-Pin SOIC, VSSOP
Top View



Pin Functions: TLV2316

PIN		I/O	DESCRIPTION
NO.	NAME		
2	–IN A	I	Inverting input, channel A
3	+IN A	I	Noninverting input, channel A
6	–IN B	I	Inverting input, channel B
5	+IN B	I	Noninverting input, channel B
1	OUT A	O	Output, channel A
7	OUT B	O	Output, channel B
4	V–	—	Negative (lowest) supply or ground (for single-supply operation)
8	V+	—	Positive (highest) supply

- Unity-Gain Bandwidth: 10 MHz
- Low I_Q: 400 μA/ch
  - Excellent Power-to-Bandwidth Ratio
  - Stable I_Q Over Temperature and Supply Range
- Wide Supply Range: 1.8 V to 5.5 V
- Low Noise: 12 nV/$\sqrt{\text{Hz}}$ at 1 kHz
- Low Input Bias Current: ±10 pA
- Offset Voltage: ±0.75 mV
- Unity-Gain Stable
- Internal RFI/EMI Filter
- Extended Temperature Range: –40°C to +125°C

Figure 3: **TLV2316 data specs**

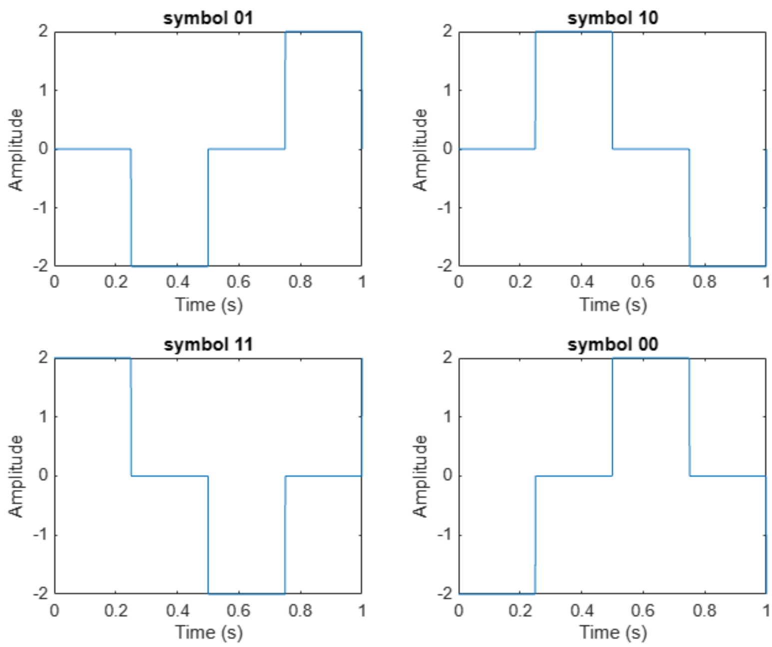


Figure 4: **The four QPSK symbols used in this project**

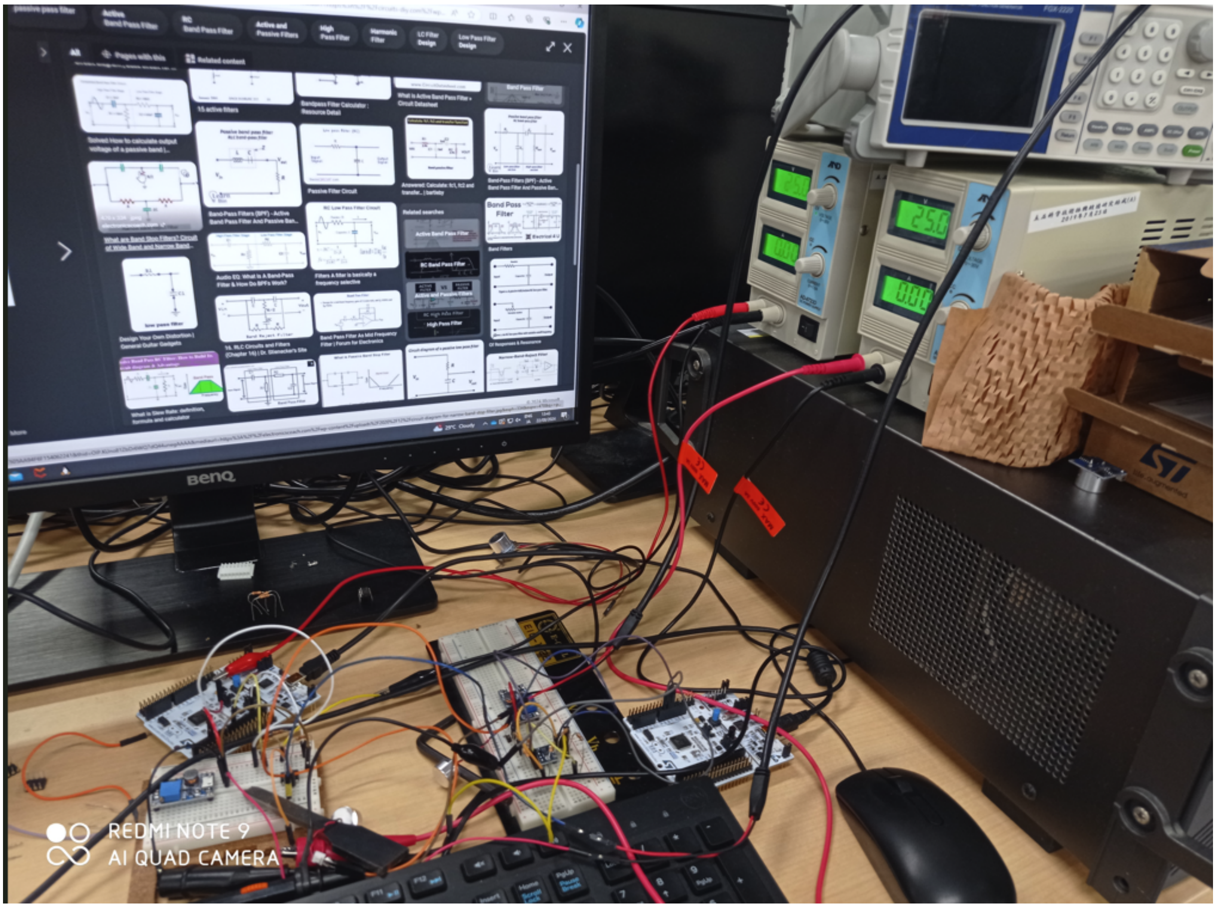


Figure 5: **System**

RAPPORT D'EVALUATION
ASSESSMENT REPORT

Merci de retourner ce rapport par courrier ou par voie électronique en fin du stage à :
At the end of the internship, please return this report via mail or email to:

ENSTA Bretagne – *Bureau des stages - 2 rue François Verny - 29806 BREST cedex 9 – FRANCE*
☎ 00.33 (0) 2.98.34.87.70 / stages@ensta-bretagne.fr

I - ORGANISME / *HOST ORGANISATION*

NOM / *Name* Tokyo University of Science

Adresse / *Address* 1-3, Kagurazaka, Shinjuku, Tokyo 162-8601, Japan

Tél / *Phone (including country and area code)* +81- 3-3260-4271

Nom du superviseur / *Name of internship supervisor*
Associate Prof. Takuya Hashimoto

Fonction / *Function* ____

Adresse e-mail / *E-mail address* tak@rs.tus.ac.jp

Nom du stagiaire accueilli / *Name of intern* Antoine Morvan

II - EVALUATION / *ASSESSMENT*

Veuillez attribuer une note, en encerclant la lettre appropriée, pour chacune des caractéristiques suivantes. Cette note devra se situer entre **A (très bien)** et **F (très faible)**
*Please attribute a mark from **A (excellent)** to **F (very weak).***

MISSION / *TASK*

- La mission de départ a-t-elle été remplie ? *Was the initial contract carried out to your satisfaction?* A B C D E F
- Manquait-il au stagiaire des connaissances ? *Was the intern lacking skills?* ☐ oui/*yes* ☑ non/*no*

  Si oui, lesquelles ? / *If so, which skills?* ____

ESPRIT D'EQUIPE / *TEAM SPIRIT*

- Le stagiaire s'est-il bien intégré dans l'organisme d'accueil (disponible, sérieux, s'est adapté au travail en groupe) / *Did the intern easily integrate the host organisation? (flexible, conscientious, adapted to team work)* A B C D E F

Souhaitez-vous nous faire part d'observations ou suggestions ? / *If you wish to comment or make a suggestion, please do so here* ____

COMPORTEMENT AU TRAVAIL / *BEHAVIOUR TOWARDS WORK*

Le comportement du stagiaire était-il conforme à vos attentes (Ponctuel, ordonné, respectueux, soucieux de participer et d'acquérir de nouvelles connaissances) ?

Did the intern live up to expectations? (Punctual, methodical, responsive to management instructions, attentive to quality, concerned with acquiring new skills)?

A B C D E F

Souhaitez-vous nous faire part d'observations ou suggestions ? / *If you wish to comment or make a suggestion, please do so here* ____________________

INITIATIVE – AUTONOMIE / *INITIATIVE – AUTONOMY*

Le stagiaire s'est –il rapidement adapté à de nouvelles situations ? A B C D E F
(Proposition de solutions aux problèmes rencontrés, autonomie dans le travail, etc.)

Did the intern adapt well to new situations? A B C D E F
(eg. suggested solutions to problems encountered, demonstrated autonomy in his/her job, etc.)

Souhaitez-vous nous faire part d'observations ou suggestions ? / *If you wish to comment or make a suggestion, please do so here* ____________________

CULTUREL – COMMUNICATION / *CULTURAL – COMMUNICATION*

Le stagiaire était-il ouvert, d'une manière générale, à la communication ? A B C D E F
Was the intern open to listening and expressing himself /herself?

Souhaitez-vous nous faire part d'observations ou suggestions ? / *If you wish to comment or make a suggestion, please do so here* ____________________

OPINION GLOBALE / *OVERALL ASSESSMENT*

- La valeur technique du stagiaire était : A B C D E F
  Please evaluate the technical skills of the intern:

III - PARTENARIAT FUTUR / *FUTURE PARTNERSHIP*

- Etes-vous prêt à accueillir un autre stagiaire l'an prochain ?
  Would you be willing to host another intern next year? ☐ oui/*yes* ☐ non/*no*

Fait à ____________________, le ____________________
In Tokyo ____________________, on ____________________

Thank you for introducing us such a great student like him. I was really glad to work with him.

Signature Entreprise 橋本卓弥 Signature stagiaire
Company stamp ____________________ *Intern's signature*

Merci pour votre coopération
We thank you very much for your cooperation