TECHNICAL DOCUMENTATION

Proof of concept for acoustic underwater communication

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ABSTRACT

This report presents a study on the development of a wireless underwater communication solution for a marine connected devices solution startup. The core of the startup end-product relies on transmitting a signal from a cargo anchor to the cargo itself to prevent anchors slippage. The report focuses on the signal transmission, emission, and reception using acoustic immersible transducers at very high frequencies associated to STMicroelectronics STM32 microcontrollers. The report also discusses signal amplification methods as well as frequency modulation for signal encoding. Once encoded the signal must be decoded at reception using filters and a stabilizer. Two types of filters have been implemented: analog and digital filter. The analog filter uses a second-order Bandpass Rauch structure filter, and the digital filter simulates a sixteen-order Butterworth bandpass filter. However, working with very high frequencies can be particularly challenging due to incongruous behaviors. Consequently, such technology requires distinct acoustic expertise and high financial resources. The report concludes with an assessment of the project, discussing task scheduling, difficulties encountered, and potential improvements such as real in situ experiments.

Key words: Underwater Communication, Transducers, High-Frequency Signal Amplification, Frequency Modulation, Filters.

Ce rapport présente une étude sur le développement d'une solution de communication sous-marine sans fil pour une startup spécialisée dans les dispositifs marins connectés. Le cœur du produit final de la startup repose sur la transmission d'un signal d'une ancre de cargaison marine à la cargaison elle-même afin de prévenir en cas de dérapage de l’ancre. Le rapport se concentre sur la transmission, l'émission et la réception de signaux à l'aide de transducteurs acoustiques immergeables à très haute fréquence, associés à des microcontrôleurs STMicroelectronics STM32. Le rapport traite également des méthodes d'amplification du signal ainsi que de la modulation de fréquence pour le codage du signal. Une fois encodé, le signal doit être décodé à la réception à l'aide de filtres et d'un stabilisateur. Deux types de filtres ont été mis en œuvre : un filtre analogique et un filtre numérique. Le filtre analogique utilise un filtre passe-bande de structure Rauch d’ordre 2, et le filtre numérique simule un filtre passe-bande de Butterworth d’ordre 16. Cependant, travailler avec des fréquences très élevées peut s'avérer particulièrement difficile en raison de comportements parfois incongrus.

Par conséquent, une telle technologie nécessite une expertise acoustique distincte et des ressources financières importantes. Le rapport se termine par une évaluation du projet, discutant de la planification des tâches au sein de l'équipe, des difficultés rencontrées et des améliorations potentielles telles que des expériences réelles en conditions réelles.

Mots clés : Communication sous-marine, transducteurs, amplification des signaux à haute fréquence, modulation de fréquence, filtres.

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1. INTRODUCTION

As part of our study work, the purpose of this report is to present a proof of concept that enables elementary submarine communication between an emitter and a receiver. Therefore, the first part will present the required specifications and the state of art of existing technologies for signal transmission. The following part will show the development of the project, before finishing with the project assessment.

2. PROJECT SPECIFICATIONS

2.1. SPECIFICATIONS AND OBJECTIVES OF THE PROJECT

As mentioned above, the proof of concept intended to present two separate electronics cards that are communicating under water without wires. More precisely, only the sensors had to remain submerged, while the electronic cards could remain above water. Thus, waterproofness was only required for the sensors. Moreover, at least one card had to calculate the distance between the two cards.

Therefore, the several required technical constraints were the following:

- Minimal distance between the cards: 3 m
- Maximum length for each card: 200 mm
- Carrier signal frequency: no obligation
- Data transmission frequency: 1 Hz
- Volume of data to send: 1 byte
- Microcontroller: no obligation
- Output data: inter-card distance
- Programming language: C, C++ or MicroPython
- Power supply: on batteries

2.2. STATE OF THE ART OF EXISTING COMMUNICATION SOLUTIONS

The first part of the project was to take stock of all existing signal transmission techniques and products that could be used for the proof of concept. The main concern was to find an efficient wireless means of communication for signal transmission. Therefore, during research, different categories of waves were first compared with each other to select the most efficient and suitable one for underwater communication. First, high frequency electromagnetic waves induce a significant and quick attenuation due to skin effect. However, low frequencies (radio frequencies) are more suited. Then, for acoustic, radio frequency and optical waves, the main key parameters were the following:

Parameters	Acoustic	Radio Frequency	Optical
Attenuation	0.1 - 4 dB/km	3.5 - 5 dB/m	0.39 dB/m
Speed (m/s)	1500 m/s	≈ 2.255 x 10^8 m/s	≈ 2.255 x 10^8 m/s
Data rate	~ kbps	~ Mbps	~ Gbps
Latency	High	Moderate	Low
Distance	kilometers	≈ 10 meters	100 meters
Frequency band	10 – 15 kHz	30 – 300 Hz (ELF)	10^12 – 10^15 Hz
Antenna size	0.1 meters	0.5 meters	0.1 meters

Chart 1. Comparison between acoustic, radio frequency and optical waves for different parameters (Kaushal, 2016)

According to the previous chart, the use of radio frequency waves required both high power and a significant antenna size, which did not match with our specifications above. On the other hand, both acoustic and optical waves were suitable for our work. Indeed, for an operating distance of 3 meters, the attenuation is not significant, and the antenna size is appropriate. However, acoustic waves remain more efficient.

Only two different options were possible for optical waves. The first one was the use of optical cables, but it did not match the specifications. The other alternative was to use a laser in blue/green light wavelengths, as they are less attenuated in water than other colors. However, these two options were too complicated and expensive to apply. That is why the acoustic waves transmission was eventually selected. Sensors called acoustic transducers are already used in some scientific fields for underwater communication. These sensors act as both transmitter and receiver, which are devices that convert electrical waves to acoustic waves and the other way around. (Jaruwatanadilok, 2008)

The following diagram describes this principle:

Figure 1. Diagram illustrating acoustic transducers use.

Given that the technology had been chosen, the solution could be implemented. The following part describes how the project was led step by step the emission to the reception of a signal.

3. PROJECT DEVELOPMENT

3.1. SIGNAL TRANSMISSION

3.1.1. Acoustic immersible transducer

The technology chosen for the proof of concept was acoustic transmission. Mr. Jean-Pierre Nikolovski kindly lent us two underwater transducers with a maximum emission of 2 MHz and a bandwidth of 1 MHz.

Without amplification and with a sinusoidal signal emitted with a magnitude of 20 V at 2 MHz, the received signal had a magnitude between 150 and 350 mV at a distance of around twenty centimeters.

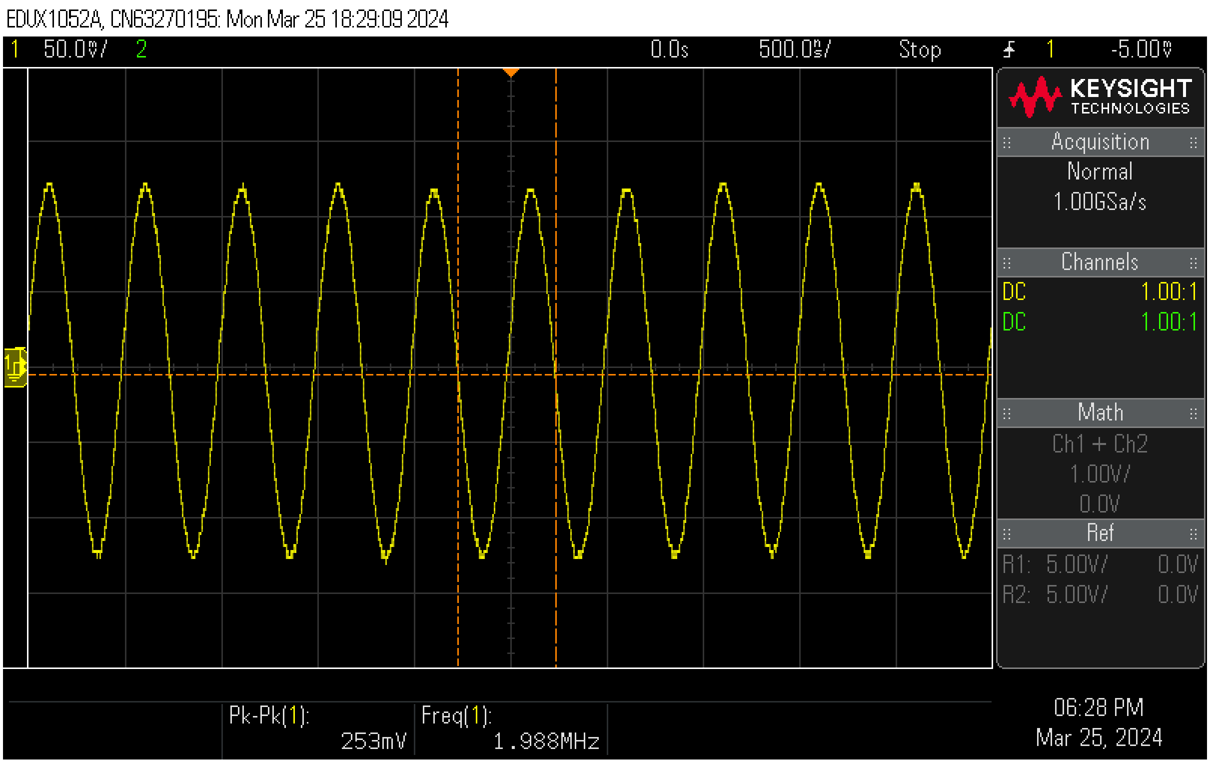


Figure 2. Receiving signal for an emitting signal with an amplitude of 20V at 2MHz

The graph below shows the attenuation of the received signal as a function of the distance between emitter and receiver:

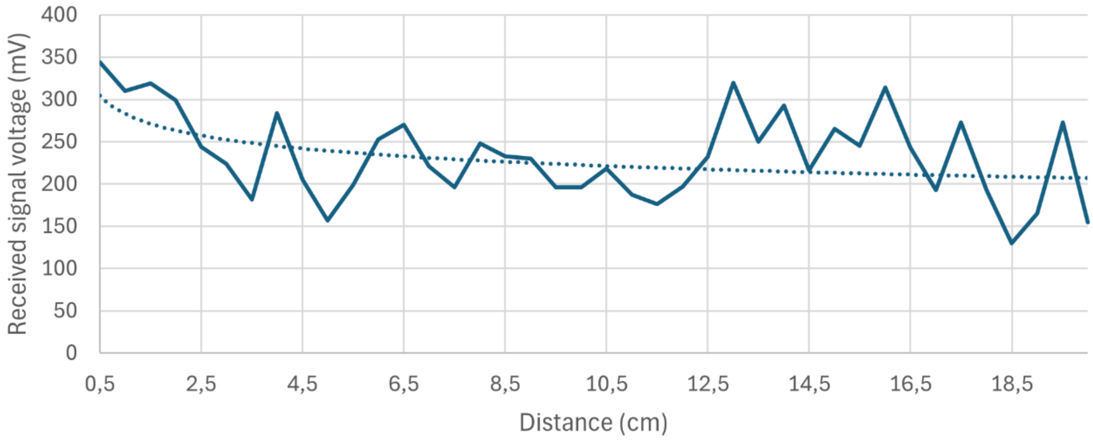


Figure 3. Receiving signal voltage as a function of distance between emitter and receiver.

3.1.2. High frequency signal amplification

Since the signal was greatly attenuated even at close range, it needed to be amplified after reception to obtain a usable signal. As the working frequency was in the megahertz range, it was not possible to use a standard operational amplifier, as its cut-off frequency was too low (in the range of a few tens of Hertz) and would have filtered out the entire signal. The chosen method was to use an instrumentation amplifier whose cut-off frequency depends on the selected gain: the chosen reference (INA111 (Texas Instruments, created in 1998, revised in

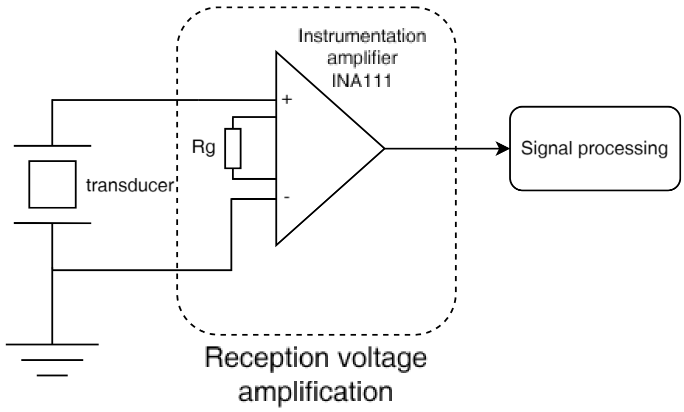


Figure 4. Signal reception amplification circuit

2024)) has a cut-off frequency of 2 MHz for a gain of 10.

3.2. SIGNAL EMISSION

3.2.1. Signal encoding: frequency modulation

To send a message from one microcontroller to another with transducers, the signal must be encoded. To achieve this, specific signal patterns were selected to represent binary 0s and 1s, this method is called frequency modulation. The straightforward approach involved choosing two distinct frequencies and alternating the signal between them. The graph below illustrates this concept:

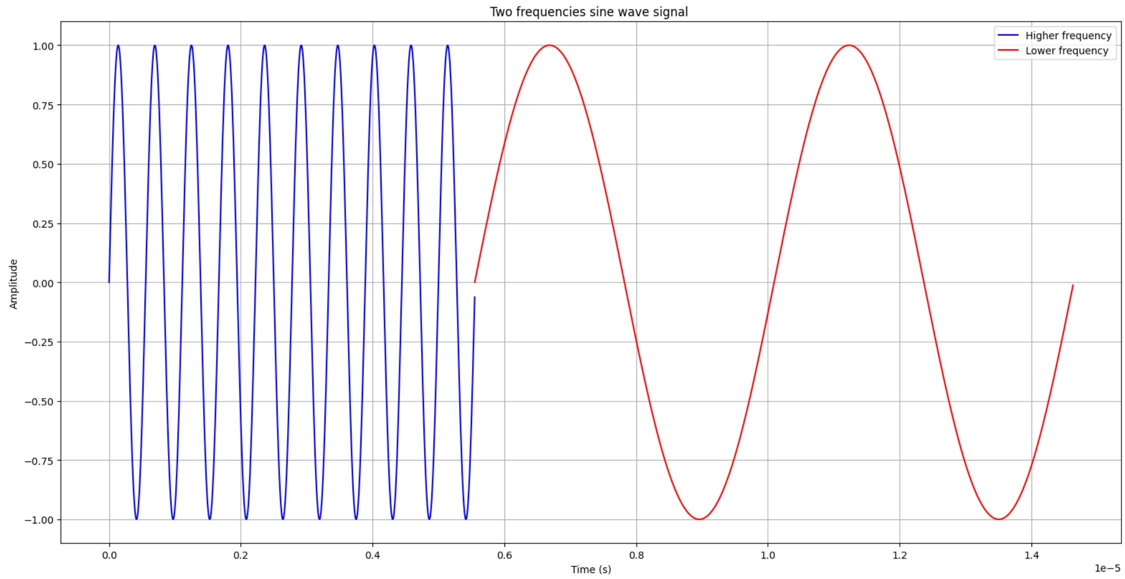


Figure 5. Concatenation of two sine wave signal of two different frequencies.

On Figure 5, the blue part of the signal had a higher frequency than the red part which allowed the creation of a pattern by choosing the number of periods the waves are sent. Once the patterns were chosen, the order of the two frequencies must be differentiated to determine the pattern encoding for a 1 bit or a 0 bit. One method was to provide different magnitude for both frequencies. For instance, the following graph illustrates how to code for a bit:

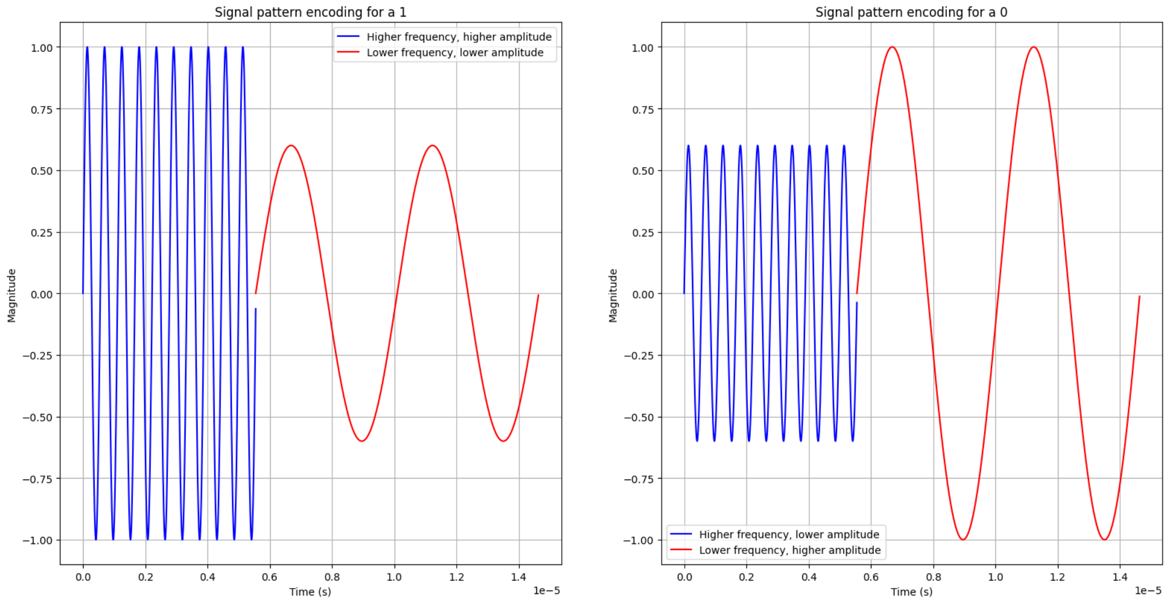


Figure 6. Patterns encoding for 1 or 0 logical values.

On Figure 6, the left plot shows a blue wave with both high magnitude and high frequency followed by a red wave with both low magnitude and low frequency. This pattern can encode for a logical value, 1 for example as mentioned above. However, the right plot shows a blue wave with a low magnitude but high frequency followed by a red wave with a high magnitude but low frequency. This new pattern can encode for another logical value, 0 for instance.

Now that the theoretical principle had been established, the two frequencies that could be used for the project needed to be chosen. As mentioned before, the lent transducers could emit a maximum magnitude signal at 2MHz. However, the bandwidth of the transducers falls within a range from 1.5MHz to 2.5MHz. In other words, sending a signal with a frequency close to 2MHz mitigates the strength of the wave but remains usable. The selected frequencies for communication with those specific transducers are 1.78MHz and 2.22MHz. Once the frequencies were selected, the signal had to be generated with a microcontroller to provide it to the transducers.

3.2.2. Signal generation

At first, the microcontrollers chosen for the project were Arduino UNOs due to its simple programming process and its large user community making it more accessible for prototype makers. Various components or existing modules can be easily connected to the Arduino and rapidly programmed in order to allow fast prototyping for example by adding an Arduino accelerometer. However, signal generation for very high and specific frequencies can sometimes be troublesome without purchasing any other component such as high frequency clock generator.

Afterwards, it seemed to be more relevant to use higher performance microcontrollers better suited for signal generation and signal processing. The chosen microcontrollers are STM32 devices from STMicroelectronics[1].

In STM32, or more generally in electronics, a technique called Pulse Width Modulation (PWM) is used to generate a signal. It involves cycling a digital signal ON and OFF at a fast rate, then by adjusting the width of the pulse, the microcontroller can generate an analog signal. STM32 microcontrollers provide timers that allow to generate PWM signals by configuring various parameters.

Thus, the microcontroller attached to the emitter transducer has been programmed to generate 10 periods of a PWM signal at 2.22MHz then 5 periods at 1.78 MHz as the following figure represents it.

[1] STM32 devices are STM32-NUCLEOF401RE and STM32-NUCLEOL478RG

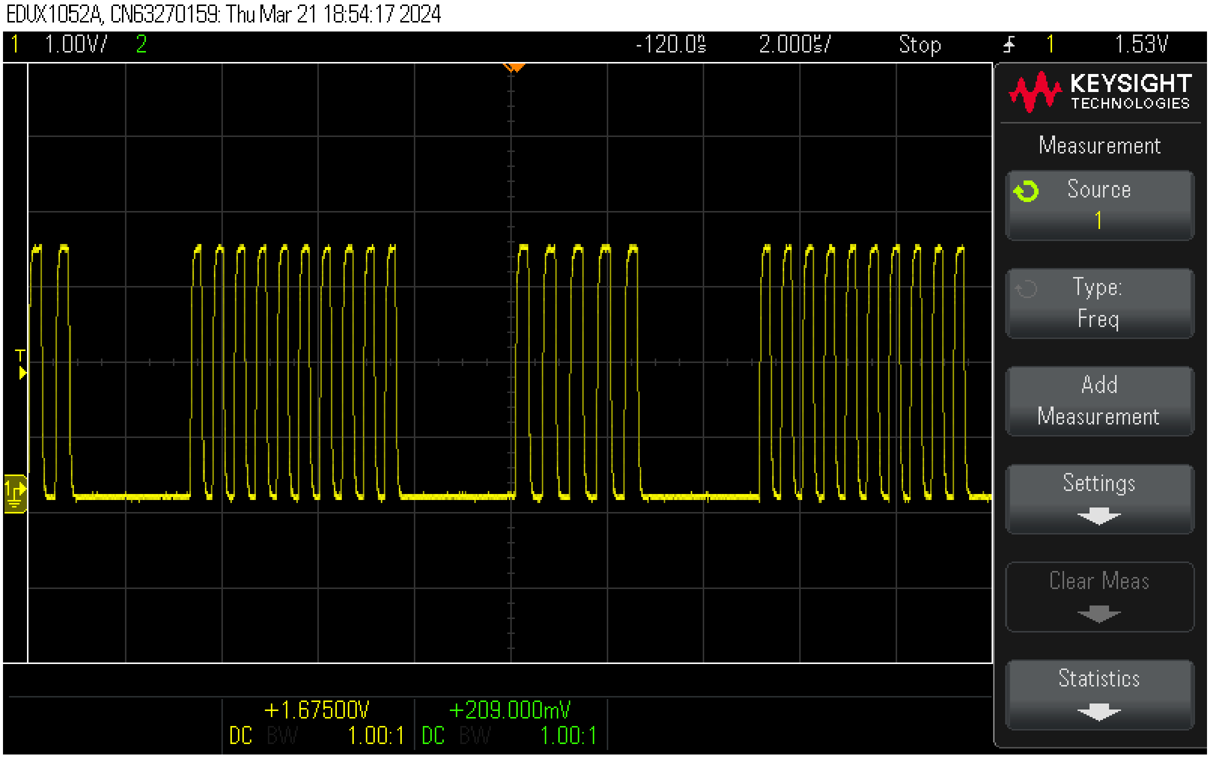


Figure 7. PWM visualization on an oscilloscope probing the output of the microcontroller.

The Figure 7 shows the PWM signal sent by the programmed microcontroller connected to the emitter transducer. Afterwards, the magnitude of the waves could be manipulated by adding a voltage-divider bridge on the circuit before the transducer.

3.2.3. Board configuration

The first thing to configure is the microcontroller clock. Timer clocks and internal clock has been set to the maximum, 84MHz, in order to allow the emission of the best waveform possible by the STM32 board. The higher the internal clock the best estimate of the waveform it will deliver. The following figure shows the clock configuration of the STM32F401RE board :

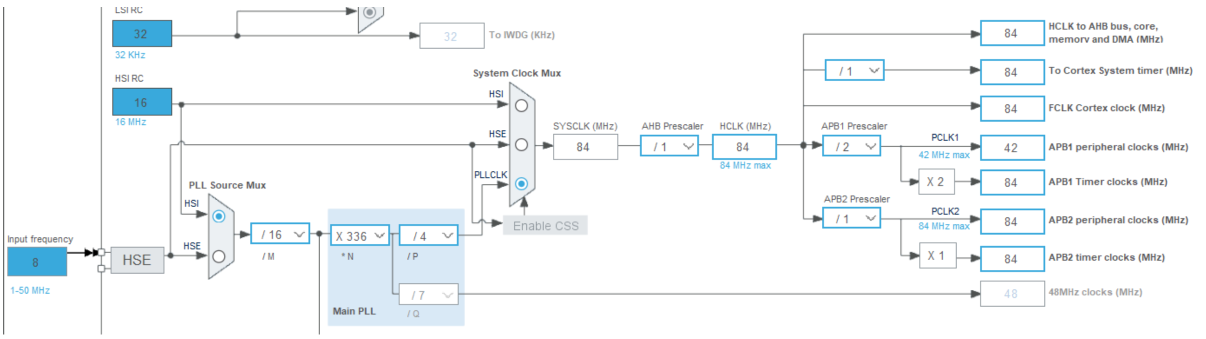


Figure 8. Clock configuration

Then, the TIMER1 CHANNEL 1 is used to generate the PWM with the following pinout and parameters using a 84MHz APB2 timer clock frequency :

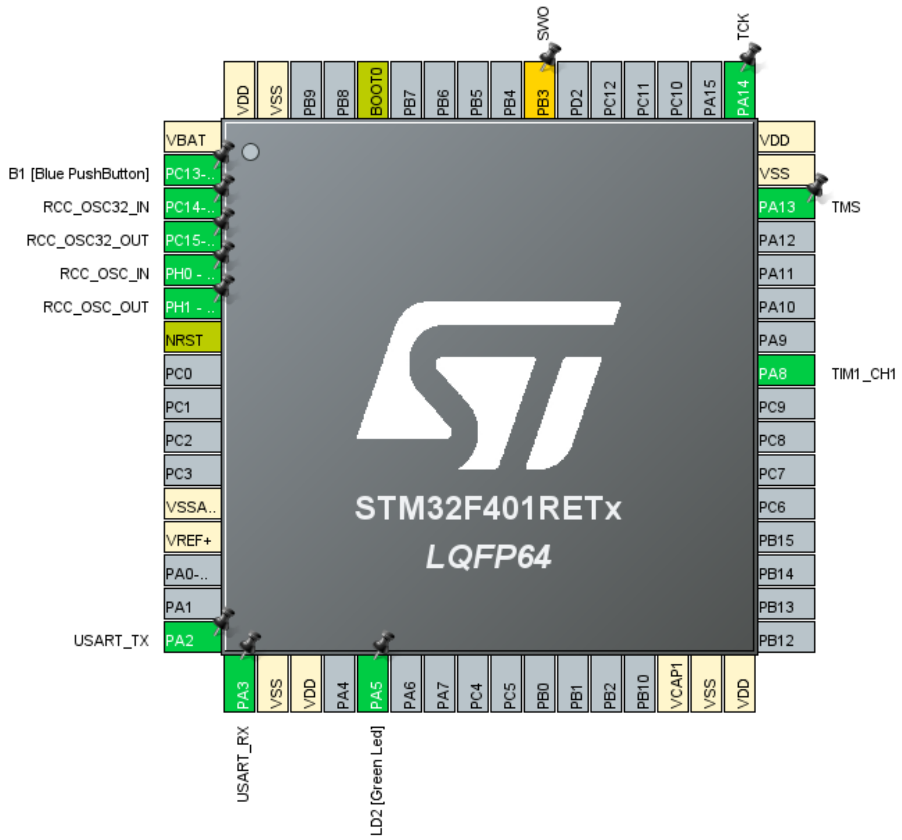
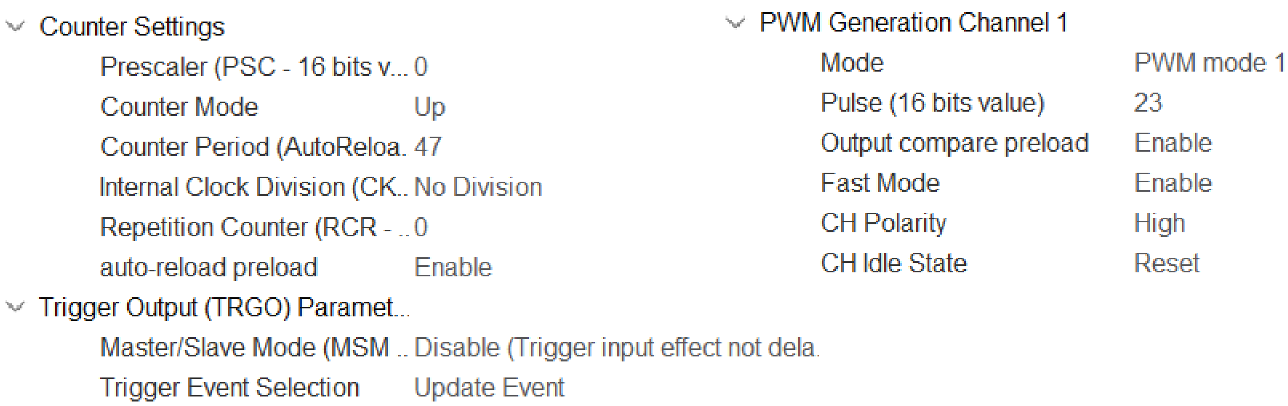


Figure 9. STM32F401RE PINOUT for PWM frequency modulation



Counter Settings	
Prescaler (PSC - 16 bits v...	0
Counter Mode	Up
Counter Period (AutoReloa.	47
Internal Clock Division (CK..	No Division
Repetition Counter (RCR - ..	0
auto-reload preload	Enable
Trigger Output (TRGO) Paramet...	
Master/Slave Mode (MSM ..	Disable (Trigger input effect not dela.
Trigger Event Selection	Update Event

PWM Generation Channel 1	
Mode	PWM mode 1
Pulse (16 bits value)	23
Output compare preload	Enable
Fast Mode	Enable
CH Polarity	High
CH Idle State	Reset

Figure 10. TIMER 1 CHANNEL 1 parameters

In order to get the wanted frequency, the following equation has been used to set the Counter Period (ARR) : $PWM_{frequency} = \frac{Clock_{frequency}}{(Prescaler+1)(ARR+1)}$

The prescaler value has been arbitrarily set to 0.

3.2.4. Emission amplification

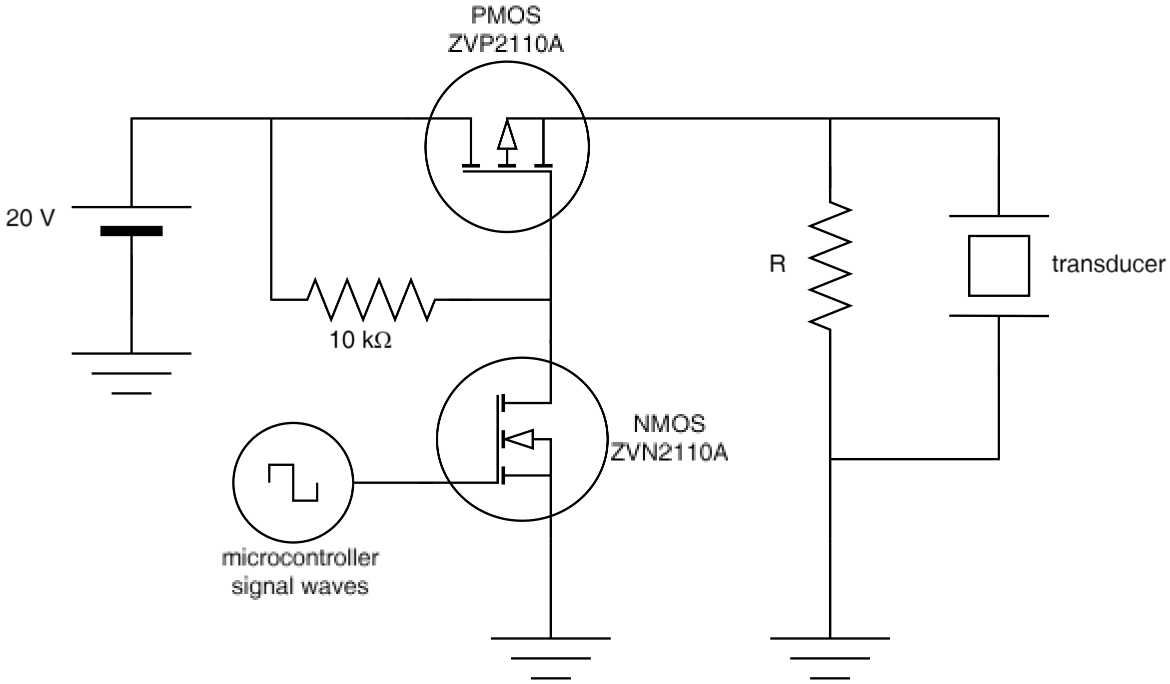


Figure 11. Microcontroller signal amplification circuit

However, the microcontroller does not provide 20V output or enough current to properly power the transducer. Therefore, we had to create an auxiliary circuit to supply the transducers directly from the battery.

The two transducers lent by Jean-Pierre Nikolovski can be compared to 0.6nF and 1.9nF capacitors. In order for the transducers to properly discharge when they were no longer powered by the battery (when the PWM is OFF), a resistor was placed in parallel with the transducers.

The resistor (R) value would have been chosen according to the expected circuit discharge duration. This value determines the time constant of the circuit (τ), that is to say: $\boldsymbol{\tau} = \boldsymbol{R} \times \boldsymbol{C}$ (with C ≈ 1nF). This constant controls the speed of discharge in response to voltage variations. Discharging times are five times the time constant. The duration of the PWM OFF state is $t_{OFF} = 225\ ns$. In order for the discharge to be sufficiently fast for the emitted signal by the transducer to be faithful to the signal generated by the microcontroller, the following conditions must be met: $\boldsymbol{5\tau} \leq \boldsymbol{t_{OFF}}$, resulting in $R \leq 45\Omega$.

Given that a message could be encoded, the message needed to be sent and received by the receiver transducer and microcontroller. However, the receiver block had to know when the message starts the decode the message and also which magnitude it was supposed to expect to receive.

3.2.5. Starting sequence and magnitude referencing

To induce the start of the communication and the incoming message, the communication process begins with the transmission of a sequence of high-magnitude waves followed by low-magnitude waves. These waves serve a dual purpose. They establish magnitude references and signal the start of the communication. The receiver microcontroller will be programmed to interpret the starting sequence activating the decoding process. For example, if the receiver detects a wave signal during 1 second, which is quite a lot of time according to the microcontroller internal clock, then another wave signal with lower magnitude for 1 second also, then the starting sequence is detected, and the microcontroller will be ready to read the following signal to decode the message. The two magnitudes serve as reference and are use as described in 3.3.1. The receiver microcontroller will know the end of a message if no signal is received for a certain period of time.

Given that the message could be emitted, the receiving block had to filter and decode the receiving signal by the receiver transducer.

3.3. SIGNAL RECEPTION

3.3.1. Analog filtering[2] and numerical comparison

At the receiver transducer output, here should be one example of the electrical signal composed of two patterns:

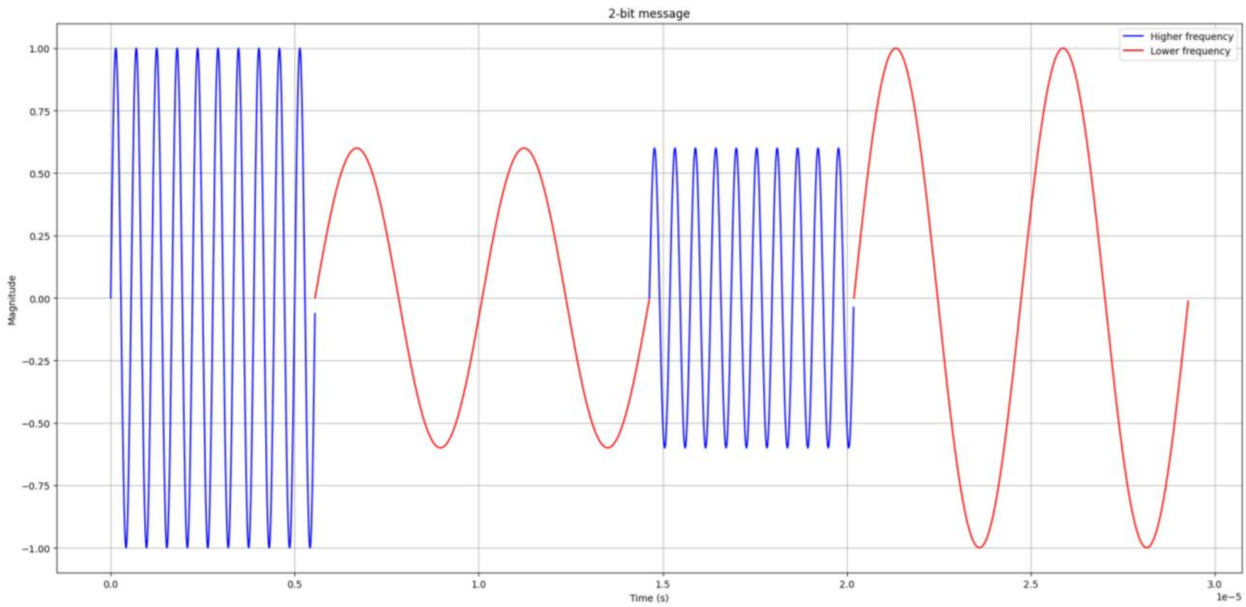


Figure 12. Example of a received electrical signal composed of two patterns.

To receive the emitted acoustic signal and decode the different patterns, the initial idea was to use two separate analog filters on the received electrical signal coming from the reception transducer. Each filter was a bandpass, with two different cut-off frequencies (Fc) of 1.8MHz and 2.2MHz. Indeed, the received signal had to undergo simultaneous analog processing along two distinct paths. The first filter had to isolate only the red signal (**Erreur ! Source du renvoi introuvable.**), while the other one had to isolate only the blue signal (**Erreur ! Source du renvoi introuvable.**). Then, the goal was to compare the amplitude of these two new signals with each other. Both processes consist of the same steps, but the components were adapted to each filter.

[2] Analog filtering: method or circuit used to modify or extract certain frequencies of an electrical signal, while blocking other frequencies. It can be used to remove or reduce noise or undesired frequencies to a certain point.

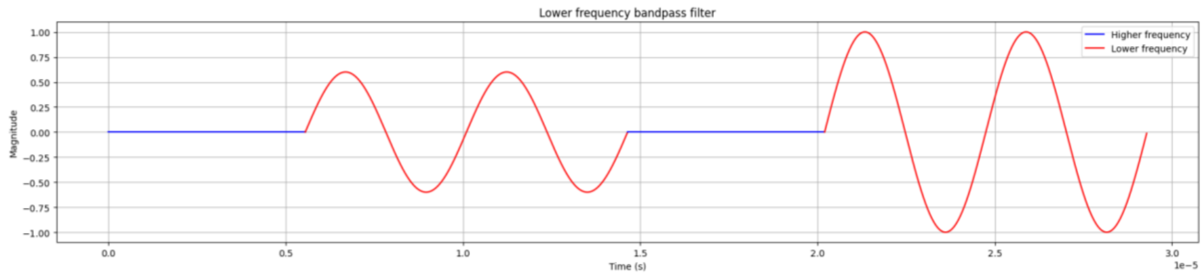


Figure 13. Isolation of the red signal after filtering

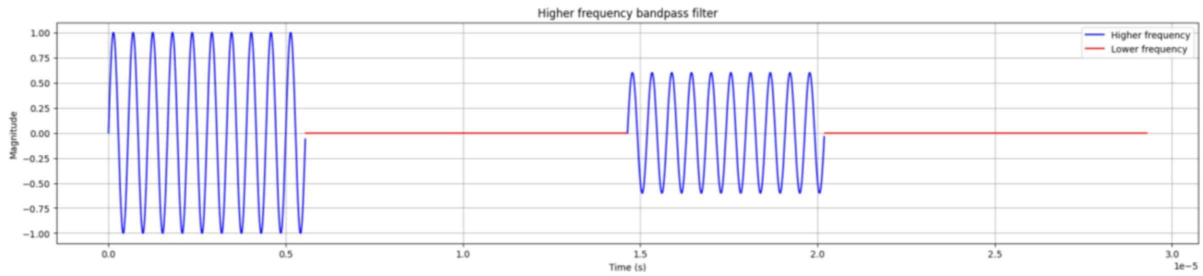
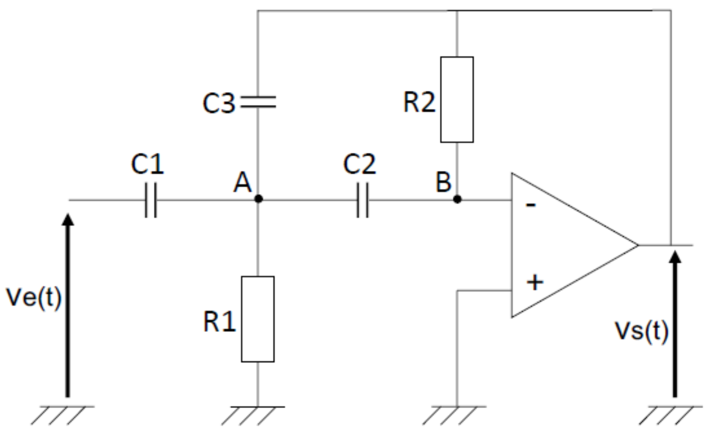


Figure 14. Isolation of the blue signal after filtering

The Rauch structure filters was chosen as the circuit design (Figure 12).



$$G(j\omega) = \frac{\frac{jC_2\omega}{R_1}}{\frac{R_1 + R_2}{R_1R_2R_3} + j\omega\left(\frac{C_1 + C_2}{R_3}\right) - C_1C_2\omega^2}$$

Figure 15. Rauch Structure for bandpass and the associated transfer function (Dutertre, 2021)

It is a type of second-order filter that enables accurate control over filtering process. This filter is composed of operational amplifiers et capacitors. The capacitors were all considered equal, leading to the following transfer function and parameters:

$$G(j\omega) = \frac{A\, 2jm\frac{\omega}{\omega_0}}{1 + 2jm\frac{\omega}{\omega_0} + \left(j\frac{\omega}{\omega_0}\right)^2} \qquad A = -\frac{R_3}{2R_1} \qquad \omega_0 = \frac{1}{C}\sqrt{\frac{R_1 + R_2}{R_1 R_2 R_3}} \qquad m = \sqrt{\frac{R_1 R_2}{R_3(R_1 + R_2)}}$$

In order to select the components that match with the expected cut-off frequencies, all the resistors are considered equal. Thus, the previous formula become:

$$\boldsymbol{F_c = \frac{\omega_o}{2\pi} = \frac{1}{2\pi C}\sqrt{\frac{2}{R^2}}}$$

By fixing the capacitor value at 1pF, the resistor value can be calculated that way ($\boldsymbol{F_c = 1,8\ MHz}$) :

$$\boldsymbol{R = \frac{1}{2\pi C}\sqrt{\frac{2}{(2\pi F_c C)^2}} \approx 1,250.10^5\Omega}$$

Eventually, according to the cut-off frequency, their selected values were the following:

- For 1.8MHz, R1 = R2 =1.25043 x 10^5 Ω and C1 = C2 = C3 = 1pF.
- For 2.2Mhz, R1 = R2 =1.02301 x 10^5 Ω and C1 = C2 = C3 = 1pF.

After filtering, the expected next step was to stabilize each signal to retain only the maximum amplitude of the two signals, for easy comparison between them. Therefore, a passive peak detector circuit would have been connected to the output of each filter.

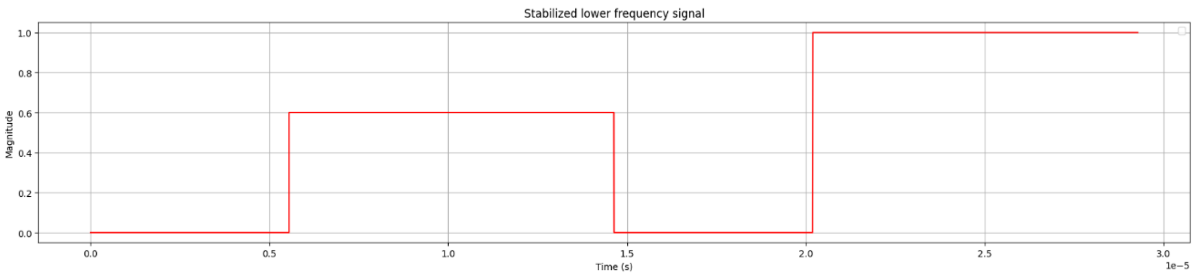


Figure 16. Stabilization of the red signal, at peak detector circuit output

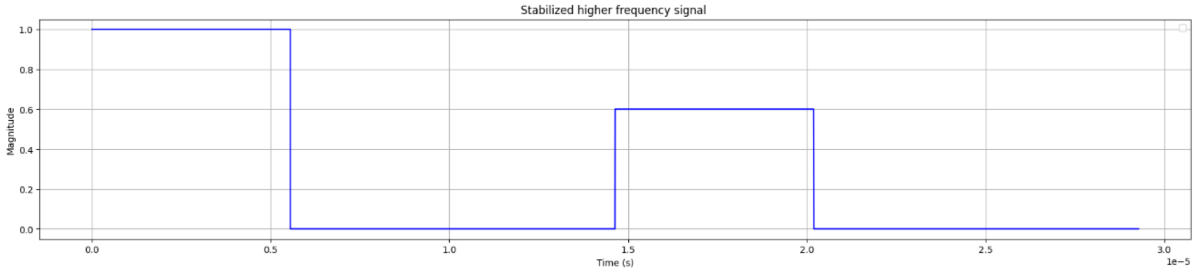


Figure 17. Stabilization of the blue signal, at peak detector circuit output

This circuit would have been simply composed of a diode, a resistor, and a condenser.

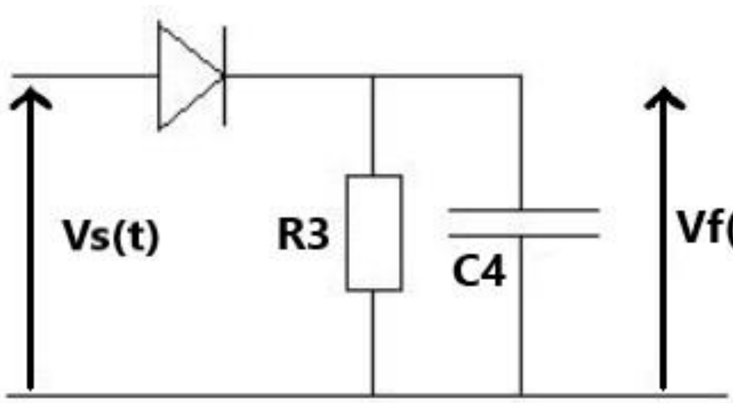


Figure 18. Peak detector circuit

The resistor (R3) and capacitor (C4) values would have been chosen according to the expected circuit charge and discharge times[3]. These values determine the time constant of the circuit (τ), that is to say: $\tau = \boldsymbol{R3} \times \boldsymbol{C4}$. This constant controls the speed of charge and discharge in response to voltage variations. Charging and discharging times are five times the time constant. In an ideal case, the circuit charge time should have been quick (about one quarter of the signal period), whereas the discharge time should have been much longer (about several periods of the signal). Thus, an accurate compromise should have been made by choosing one period as a time for example, resulting in a charge time of $t_{charge1}$ = 0.56µs (Fc = 1.8MHz; R3 = 555Ω; C4 = 1pF) and $t_{charge2}$ = 0.45µs (Fc = 2.2MHz; R3 = 456Ω; C4 = 1pF).

[3] For this RC circuit, these times are considered equal.

These circuits were first tested with a received 20kHz signal. The Rauch structure and the peak detector operated well. Unfortunately, due to the high frequency level, the chosen components for the filter could not operate at 2 MHz properly because of a bandwidth that was too low, leading to signal attenuation. This is the case for the initially used operational amplifier of the filter: LM6132 (Texas Instruments, APRIL 2000–REVISED SEPTEMBER 2014). It was then replaced by the instrumentation amplifier INA111 (Texas Instruments, 2024). This idea was then abandoned.

Afterwards, each signal would have been received separately by the second STM32 board[4]. A numerical comparison would have been made after the ADC acquisition. The subtraction between the two signals should have been made on STM32CubeIDE software, analyzing the patterns of the transmitted signal. First, the algorithm would have been used the starting sequence as maximum and minimum magnitude references: $\mathbf{A_{RefMax}}$ and $\mathbf{A_{RefMin}}$. Then, if the result of for the half pattern subtraction is negative, the maximum amplitude of the red signal is higher than the maximum amplitude of the blue signal and the other way around. Then, the algorithm checks the value of the result: if the value is between the limits: $\boldsymbol{A_{RefMin}} \pm \mathbf{0.1} \times \boldsymbol{A_{RefMin}}$, the signal amplitude for the half pattern is the minimum. On the contrary, if the value is between the limits: $\boldsymbol{A_{RefMax}} \pm \mathbf{0.1} \times \boldsymbol{A_{RefMax}}$, the signal amplitude for the half pattern is maximum. Following these half pattern comparisons, the algorithm determines if the final pattern corresponds to a logical 0 or 1. Eventually, the message can be interpreted.

The following pseudocode summarizes the decoding algorithm to be implemented into the receiving microcontroller.

[4] STM32 board : NUCLEO-L476RG

Algorithm 1 Half pattern decoding pseudocode

```
Get result after filtering&comparison // 1/2pattern comparison
if result < 0 then
        Red signal magnitude > Blue signal magnitude
else
        Blue signal magnitude > Red signal magnitude
end if
if A_RefMin −0.1×A_RefMin <= result <= A_RefMin +0.1×A_RefMin then
        1/2pattern magnitude = Min signal magnitude
else if A_RefMax − 0.1 ∗ A_RefMax <= result <= A_RefMax + 0.1 ∗ A_RefMax then
        1/2pattern magnitude = Max signal magnitude
end if
```

3.3.2. Digital filtering

As the analog filter might not work for very high frequencies, one solution is to use a digital filter. Digital filters are systems that perform mathematical operations on a sampled signal. It allows the signal to be modeled as required, or to perform mathematical functions such as differentiation and integration without using any of the physical component mentioned for an analog filter.

The design of a digital filter is based on the specifications of its frequency. The filter is then applied to the data. It's important to note that digital filters introduce delay into the signal, which can sometimes be compensated for by shifting the signal in time but can also alter the waveform of the signal.

The filter can easily be design with MATLAB and the tool *Filter Design.*

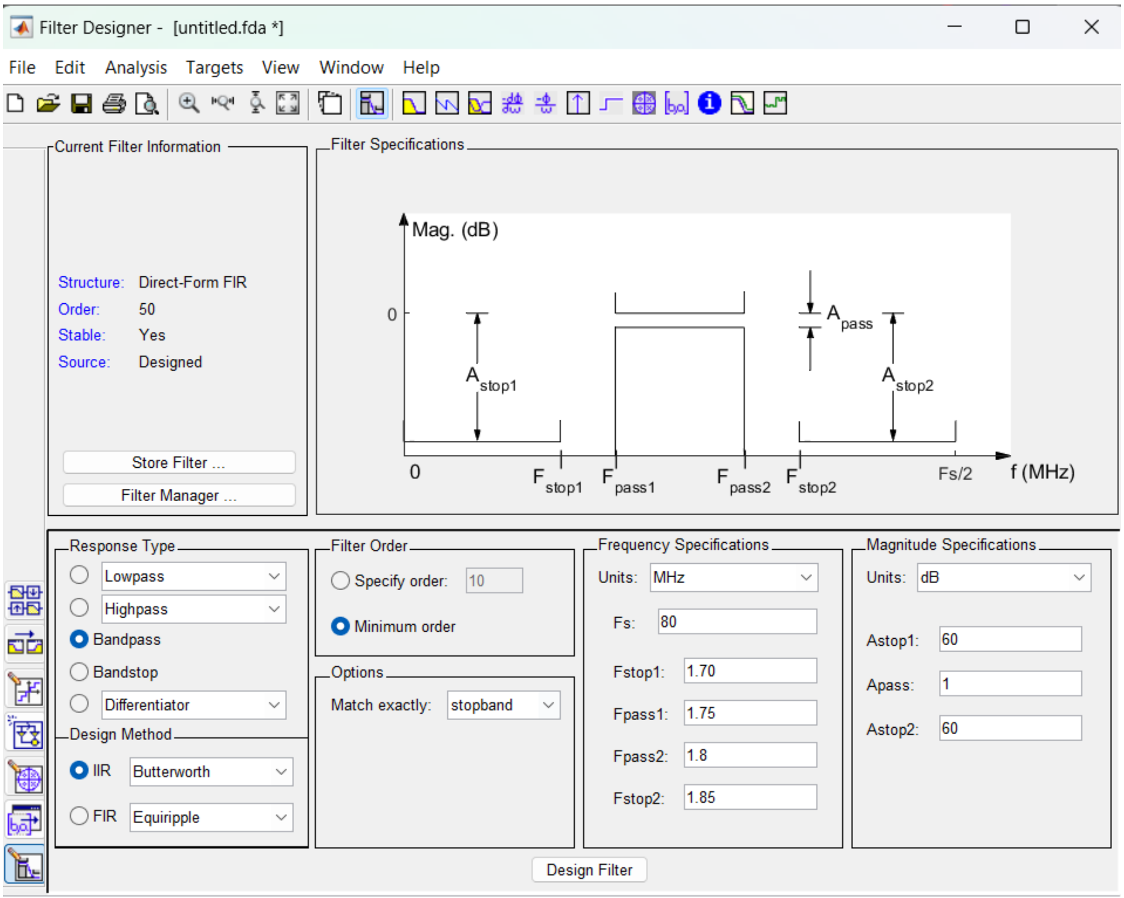


Figure 19. Screenshot of the Filter Design MATLAB tool page

On **Erreur ! Source du renvoi introuvable.**, each parameter that defines the behaviors of the filter can be tuned in order to suit at best the purpose of the filter. Here, the bandpass filter has its bandwidth between 1.75 and 1.8MHz which means that a signal with a frequency of 1.78MHz will pass and not be attenuated. Nevertheless, frequencies outside the bandwidth will be strongly attenuated. Once designed, a response analysis of the filter is plotted giving its theoretical Bode diagram[5] and the filter coefficients filter that define its behavior.

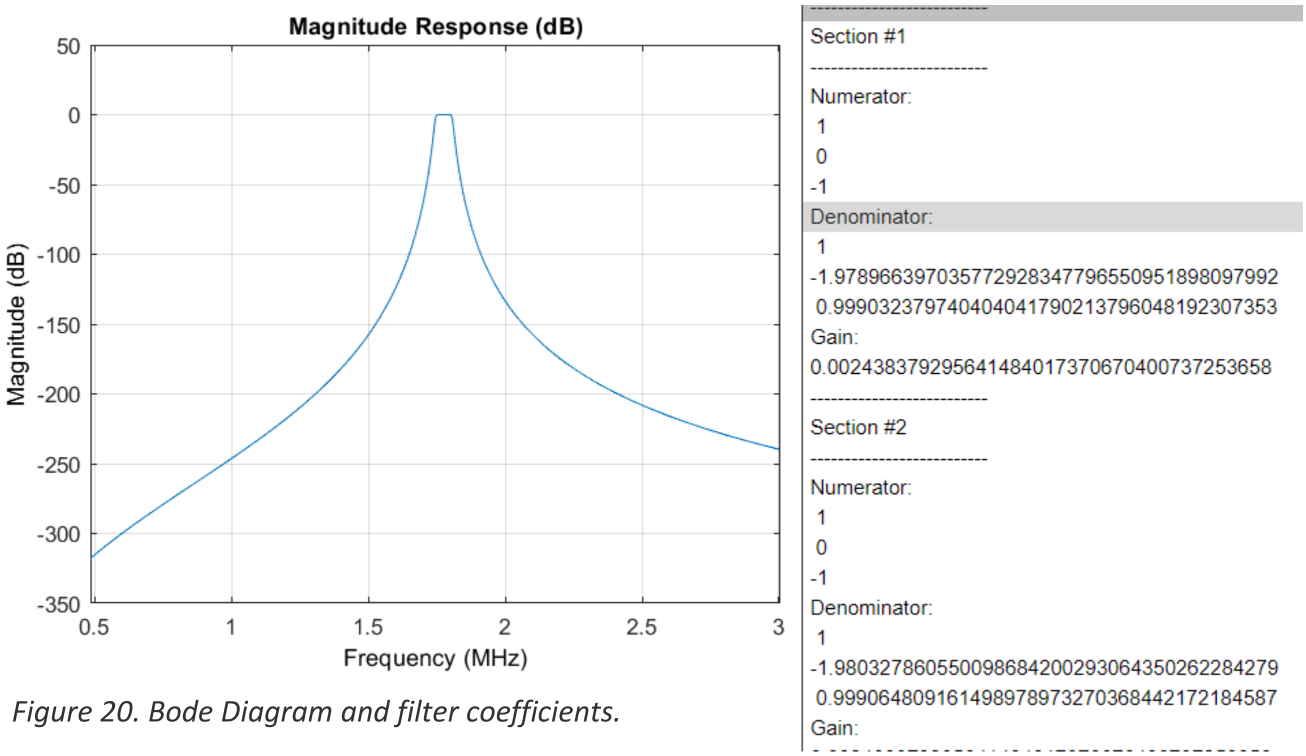


Figure 20. Bode Diagram and filter coefficients.

In addition, the Filter Design tool can import the filter to a Simulink[6] file. Moreover, Simulink can be used with an Add-On package called Embedded Coder which generate code for STM32 devices. The STM32 device parameters are set and the digital filtering algorithm is generated in C language understood by the microcontroller.

Once the signal is filtered, it is processed the same way described in 3.3.1.

[5] A Bode diagram is a graph that represents the frequency response of a system. It consists of the Bode magnitude plot which expresses the magnitude of the frequency response and the Bode phase plot which expresses the phase shift.

[6] Simulink is a graphical programming environment based on MATLAB for modeling, simulating, and analyzing dynamical systems.

3.4. FINAL TECHNICAL SOLUTION

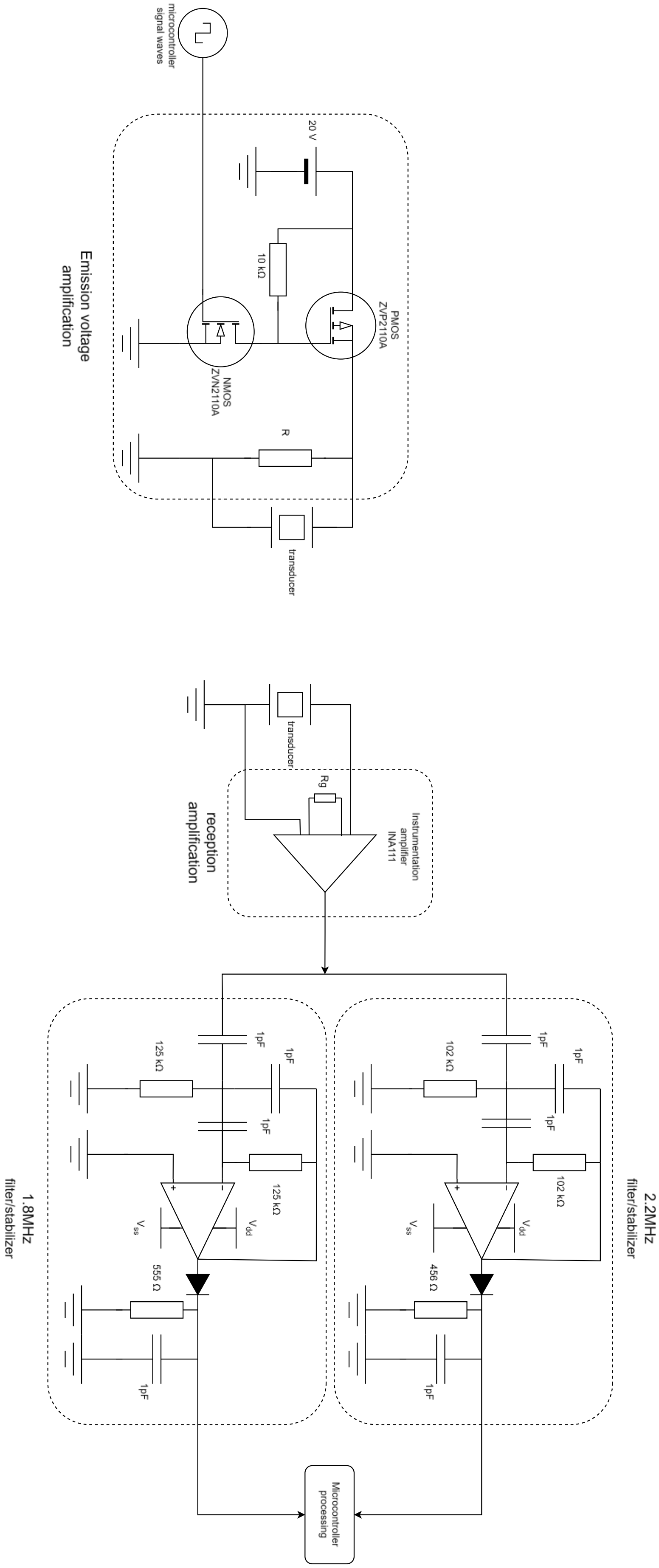


Figure 21. Overall technical solution with emission and reception blocks

4. PROJECT ASSESSMENT

4.1. ENCOUNTERED DIFFICULTIES

One of the first main encountered difficulties was the availability and financial constraints of underwater transducers. The usual non-submersible transducers were less expensive and much easier to obtain as they are more common. In the actual case, a submersible sensor increases its complexity, as the used technology is not similar, and makes production tedious. Thus, underwater transducers were overly expensive. That was why these sensors caused difficulties before obtaining M. Nikolovski's transducers. Moreover, working at high frequencies was significantly challenging too. Most of the ordered components were not conceived to work at high level frequencies. To finish, the project was delayed because of the lack of acoustic knowledge. The behavior of acoustic signals under water was totally unknown, as well as the operation of transducers.

4.2. POTENTIAL IMPROVEMENTS

4.2.1. Understanding analog filter behaviors over very high frequencies (MHz)

Thorough research into the behavior of analog filters at very high frequencies, particularly in the MHz range, is crucial for refining its structure. An analog bandpass Rauch structure is used for this project however other designs such as Butterworth or Chebyshev filters can be experimented and analyzed to try optimizing the performance of the filter. Simulation software such as STMicroelectronics eDesignSuite[7] can be used to model and fine-tune the filter components before implementation, ensuring optimal functionality at high frequencies.

4.2.2. In situ trials and transducers adjustment

Since the transducers have been lent for the project, they will not be the one to be used for the end-product. Consequently, experiments with the proper final transducers ought to be conducted to evaluate the performance in saline environments, particularly in ocean water

[7] STMicroelectronics eDesignSuite is a set of user-friendly tools to design the system block components with a wide range of STMicroelectronics products

at distances exceeding 3 meters. Also, each parameter has been designed to work with 2MHz transducers, new values must be computed if other transducers are used.

Besides, an analysis of the signal-to-noise ratio must be conducted to better understand the amplification and filtering system over longer distances in saltwater environments.

4.2.3. Encoded message robustness

Rigorous testing and validation must be conducted to verify the reliability and resilience of the encoded message such as Error-checking mechanisms, for instance checksums[8] and cyclic redundancy checks[9], must be integrated to ensure the integrity of transmitted data under various operational scenarios.

4.2.4. Transducers box encapsulation

Waterproof and corrosion-resistant enclosures will be designed to protect transducers from environmental factors such as saltwater corrosion.

[8] A checksum is an error detection constant in data transmission. It is computed by adding up the binary values of the data. If the data changes, the checksum also changes, indicating an error.

[9] Cyclic Redundancy Check (CRC) is a more advanced error-detection method. It involves treating the data as a large polynomial and dividing it by another polynomial. The remainder of this division is the CRC, which is appended to the data. If the data is altered, the calculated CRC changes, indicating an error.

5. Conclusion

This project was found atypical. The topic was genuinely different from what engineers usually work on. This enables engineers to open their critical minds to uncommon fields, in particular environmental and safety issues. Moreover, it was the opportunity to put into practice acquired theorical skills, to complete an entire project.

As a research project, the work involved a lot of uncertainty. Additionally, for such a project, the allocated time was not enough to explore, experiment and test our conception and the different components. To be feasible, the project needs more time, financial and human resources, given all the encountered problems.

Thus, concerning the specifications of the project, several constraints could not be met, especially the 3 meters minimal distance and the distance calculation.

6. BIBLIOGRAPHY

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7. APPENDICES

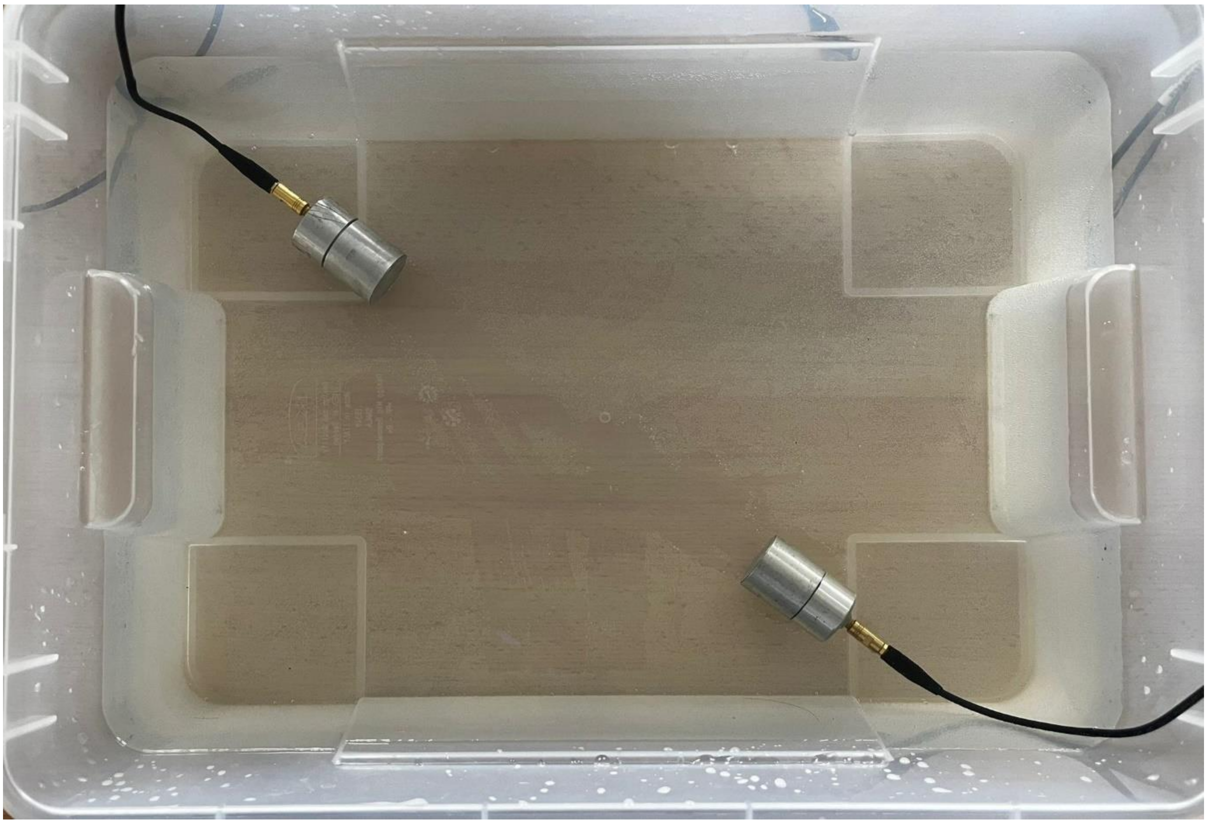

Figure 22. Immerged transducers transmitting signals inside a 30cm-large container.

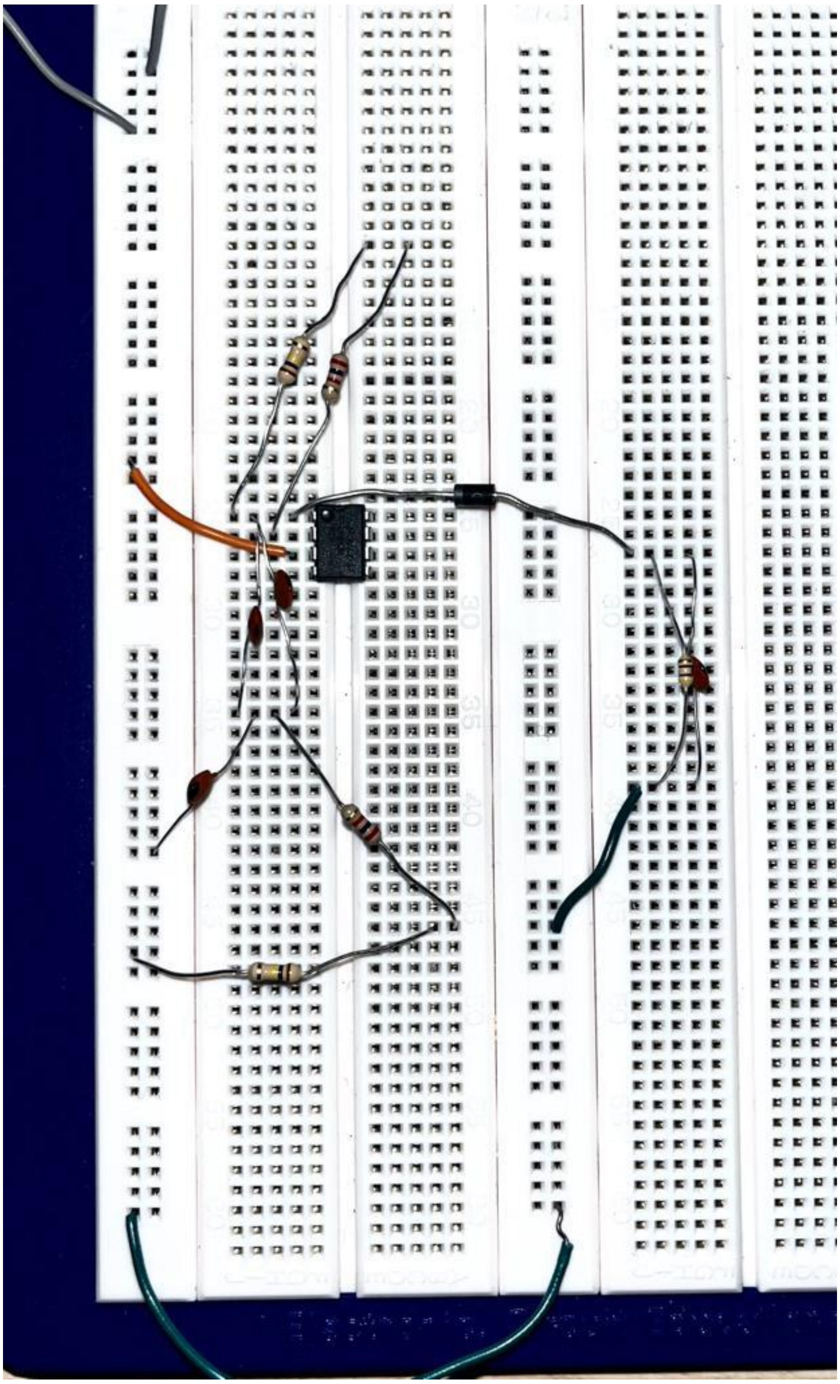

Figure 23. Rauch filter and peak detector on a prototyping board without power supply.

8. TABLE OF ILLUSTRATIONS