Visual feedback to sonar clicks

Fredrik Mårtensson

2017

LUND UNIVERSITY

Masters Thesis in
Biomedical Engineering

Faculty of Engineering LTH
Department of Biomedical Engineering

Supervisor: Christian Antfolk

Contents

1 Abstract

The wildlife park Kolmården in Norrköping, Sweden, asked for a device that could visually feedback how dolphins use their ultrasound signals while echolocating objects. By recording the sound from the dolphin, process the sound and then create a visual feedback by having LED's flash in different frequencies, depending on the distance between dolphin and device. The purpose of the device is having an opportunity to inform the audience about the dolphins behavior in a way that is fun for both the audience and the dolphin. The signals which will be processed are in the area of 20-160 kHz and they will be divided into three spectra, depending on their frequencies. The prototype will be using an Arduino Nano micro-controller and most of the processing will be done by analog electronics. In this project the priority has been to try to make the electronics and code work, one step at a time. It did however not come past measuring in the water tank because of noise which were picked up by the device. The shell which to make the device water proof has just been drawn, not actually built. There are a lot of potentials for further development, e.g, making the shell or implementing some other features to the signal processing.

2 Preface

While visiting Kolmården wildlife park in Norrköping the initial contact with Mats Amundin was made. Mats who is head of research at Kolmården wildlife park has looked for someone to help him with this project for a while. I would like to thank my supervisor postdoc Christian Antfolk and assistant supervisor Mats Amundin for helping me during this project. In addition I would also like to thank professor Hans Persson for suggestions during problems and Axel Tojo for helping with printing the PCB's. The project started in spring 2016 and finished the winter 2016/2017.

3 Introduction

In the course "Ultrasound physics and technology" there was a field trip to Kolmården wildlife park in Norrköping. While there, the lead scientist Mats Amundin spoke of a project he would like to be done. A "mechanical fish" that would be used to visualize the dolphins hunting behaviors. Until now most dolphin shows are just for fun. Mats wants it to include, in a fun way, some educational possibilities. Creating an opportunity for the audience to learn some more about the animals. The device will sample the ultrasonic sound that the dolphins emit and then with some simple signal processing visualize this with flashing lights. The frequency in which the lights will flash depends on the distance between animal and device. The final product will be fully submerged in the water, however, this project focused on trying to get the electronics to work.

3.1 Kolmården

Kolmården is a wildlife park in Norrköping. It opened in 1965 and is today the largest wildlife park in Scandinavia. In 1969 they were also the first park in Scandinavia with a dolphinarium. The park is mainly a tourist attraction, with wild animals for display and an amusement park. Apart from the tourist attractions they are a part of some breeding programs to protect the endangered species they have in the park. They are also taking part in different research projects about dolphins and porpoises.

3.2 Structure of the report

The report will start of with a theory section were some useful basic knowledge will be presented. Thereafter comes a method section were all the different methods used will be described. After the method section, the results will be presented. Everything will be summed up in a discussion in which the focus will lie on why the project did not end up as a functional prototype. Lastly there will be an appendix section with the program codes to the Arduino and LabView, some additional pictures of setups and a popular scientific article about the project.

4 Theory

4.1 Ultrasound

Ultrasound is the name of all sounds with higher frequency then that audible for the human ear, all sound above 20 kilohertz.

4.1.1 The pulse-echo principle

The pulse-echo principle is what all echolocation is based on. A sound wave is dispatched and the time is measured until the echo returns. This time is called the "two-way travel time" and it is used to calculate the distance to the reflected object.

$$D = \frac{V \cdot T}{2} \tag{1}$$

Were D is the distance one way, V is the velocity of sound in water [$1480 m/s$] and T is the two-way travel time.

4.2 Hydrophones

To record sound in water a microphone called hydrophone is used. The hydrophone used in this project, like most hydrophones, uses a piezoelectric crystal. The crystal works as a transducer, generating an electric potential when exposed to a pressure. By choosing the right dimensions for the crystal, the hydrophone can be made to only react to sound waves within a specific frequency range. When the sound wave then hits the crystal, it will get deformed and an electric potential will be generated, which then will be measured.

The hydrophones used in this project will have a peak to peak voltage, when hit from a dolphin echolocation click of 180 dB re 1 μPa at 1 m distance, of approximately 10 mV. They will have their resonance frequency at about 170 kHz, in the upper part of the area of interest. This will be compensated in the amplification stages and wont matter in the final result.

4.3 Toothed whales

The dolphins is part of the teethed whales family. Other than having teeth the teethed whales got one major thing in common. They all use ultrasonic sound to scan the environment and orientate themselves. How they do it is believed to be similar between the different species but not exactly the same. They also do not use sound with the same frequency. Since the product will be used with dolphins, they are what will be taken a close look at.

4.3.1 Dolphins

The ultrasonic sound made by dolphins is referred to as clicks. These clicks had scientists baffled for decades. "How were they produced within the dolphins?" and "How do the dolphins interpret the response?" were some of the questions they asked themselves. Still today there are no definitive answers to these questions.

The most commonly acknowledged theory however, is that the sound is created in the blowhole. They got a structure called phonic lips inside the blowhole passage which are used to create the clicks. This is done by creating a high pressure within the cranial nasal passage and then letting it out through the closed phonic lips. The phonic lips starts to vibrate and these vibrations translates through a organ called the melon. The melon works like a lens, focusing the beam of sound. It also got about the same acoustic impedance as water, which lowers the loss when the beam changes medium, from dolphin to water. The dolphins got two sets of phonic lips, one to the right and one to the left. This enables them to click more frequently, alternatively making two clicks at the same time. Studies have however shown that the right side setup is more commonly used than the left side setup. [1]

The dispatched signal is a bit different between two dolphins. They got their own "signature" on their signals. However, the signal contains frequencies between a few kHz up to around 150 kHz. With peaks around 40-50 and/or 110-120 kHz. The upper limit of the frequency band is about the edge of what most dolphins are able to hear. The transient (a short sound with high amplitude in the beginning of a waveform) of the signal usually is between 50 and 80 μs and is called an "echolocation click". After that a signal has been dispatched and returned it takes the dolphin about 20-40 ms to process the signal before a new signal is dispatched, unless the dolphin is very close to its target. At close range (2-4m) the dolphin will dispatch signals as often as a couple of milliseconds, to irradiate the target as much as possible.[4] The usual amplitude difference within a signal is about 160-200 dB re 1 μPa.

4.4 Acoustic Impedance

Acoustic impedance can be seen as the resistance for a particle traveling through a medium. It is highly useful to know about the acoustic impedance when working with acoustic signals in water. Not only because it is possible to calculate how far the signal will travel before it is completely attenuated but also because it is needed to have the material of the sensor and/or the material of the protective case with a similar acoustic impedance as water. This to avoid having the signal reflected and thereby missing out of sampling it. [13]

The acoustic impedance Z may be determined by:

$$Z = \frac{p}{\dot{s}} \tag{2}$$

Were as p is the acoustic pressure and $\dot{s}$ is the speed of the particle.

Using the formulas:

$$s = s_0 e^{i(\omega t + kx)} \tag{3}$$

$$p = \frac{ik}{\kappa} s \tag{4}$$

The acoustic impedance can instead be calculated with:

$$Z = \frac{k}{\kappa\omega} = \rho c \tag{5}$$

Where κ is the coefficient of compressibility and ρ is the density of the medium, c is the wave velocity, $k = \frac{2\pi}{\lambda}$ where λ is the wavelength and $\omega = 2\pi f$ where f is the frequency. By rewriting this equation:

$$Z = \sqrt{\frac{\rho}{\kappa}} \tag{6}$$

On this form it is easy to see that the acoustic impedance is highly dependent on the density and compressibility of the medium.

4.5 Band Pass Filter

The band pass filter is used to let the signals with a frequency within a desired interval through while cutting the rest of. That way the resulting signal consists only of the desired frequencies.

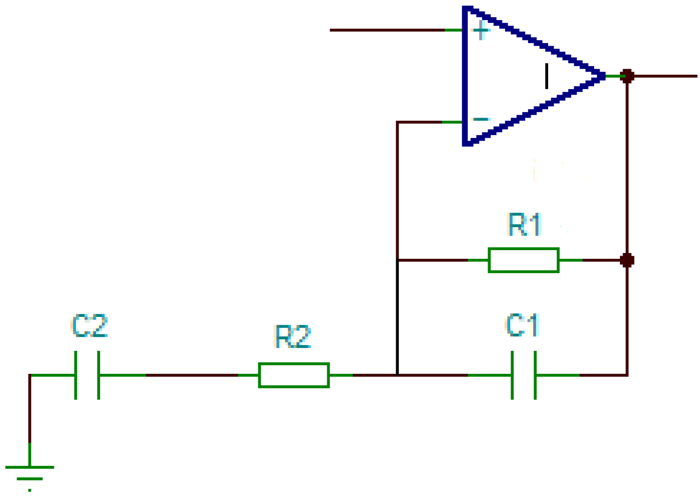

Figure 1: The Schematic of a band pass filter.

The maximum frequency is determined by:

$$F_{top} = R1 \cdot C1 \tag{7}$$

and the minimum frequency is determined by:

$$F_{min} = R2 \cdot C2 \tag{8}$$

At the same time as the band pass filter discards frequencies outside of the spectra it amplifies the wanted signals. The amplification A is determined by:

$$A = 1 + \frac{R1}{R2} \tag{9}$$

4.6 Peak Detector

A peak detector is used to maintain the highest value, the peak, of a signal. It will start with tracking the signals structure until the signal decreases. At that time the peak detector will maintain the peak value until it reaches another increase in amplitude. The most simple peak detector consists of a diod and a conductor in series. The downside with this setup is that it will not go back down to 0V between the different signals.

An improved version is to put a resistor in parallel with the conductor. By doing so the peak detectors output value will drop to 0 V over time. The discharge coefficient will be denoted by T.

How fast the peak detector discharges is determined by:

$$T = 5 \cdot R \cdot C \tag{10}$$

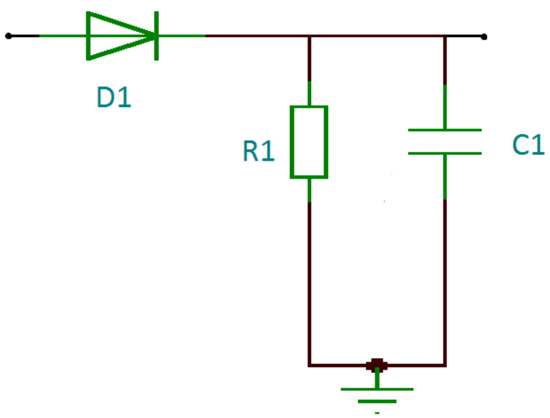

Figure 2: The schematic of a peak detector created with a diod, a resistor and a conductor.

There are more advanced versions of a peak detector using transistors and/or op-amplifiers, however, this will be sufficient for the problem at hand.

The peak detector used will have an output approximately 0.7 V higher then the actual value. This due to some loss in the diode. This because the diodes threshold voltage is approximately 0.7 V. There are methods to avoid this and make a " Precision Peak Detector" but it will not be necessary for this project.

4.7 By-pass Capacitor

A decoupling capacitor is a normal capacitor used to decrease the noise level within a circuit. If one component in a circuit generates noise, it will be shunt through the capacitor, minimizing the effect it has on the rest of the circuit. Often used to by pass the power supply and/or other high impedance components, thereby the name by-pass capacitor.[5] [14]

4.8 Color loss in water

As basic physics suggests, a signal traveling through a medium will get absorbed over time. The absorption rate depends on the medium and the wavelenght of the signal. When it comes to light in water, the lower the wavelength is, the longer distance it may travel without getting fully attenuated. The light with highest wavelenght (lowest energy) will thereby be attenuated fastest. For exampel, red light will be attenuated in approximately 4,5 m while green light will be attenuated at approximately 22 m.

Because of this the lights used for the visual response will be those colors with lower wavelength (higher energy), such as blue and green.

4.9 Computer programs

Most of the work done in the project has been done on the computer with several different computer programs. There are more program that has been tested during the project but these are the ones that were used while developing the device.

4.9.1 Filter Wizard

Filter Wizard [10] is a program created by Analog Devices. It is used to find the needed component size for a desired filter. In the first stage the user needs to chose the specifications of the desired filter. The specifications are: Passband, stopband, center frequency and filter response.

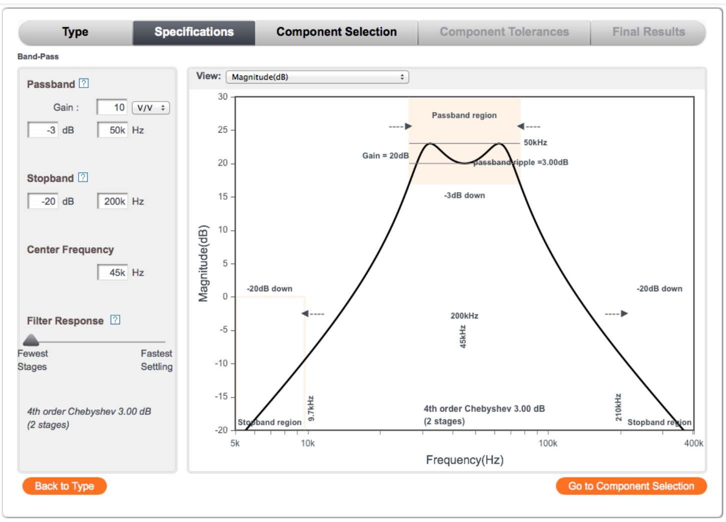

Figure 3: First it is needed to choose the desired specifications for the filter.

When that is done the program will give the user a schematic of the circuit which will correspond to the desired specifications. The user gets a list of op-amplifiers which would be suited for the setup and also the size of all the components needed. In addition it is possible to chose the tolerance of every type of component and from which series the user prefer to have the components.

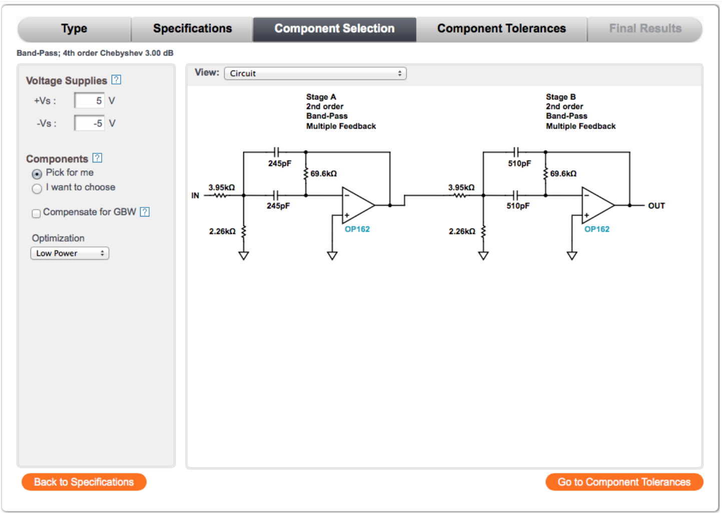

Figure 4: The result given from the program is a circuit of the desired filter with the size of every component.

4.9.2 National Instrument

The first National Instrument program used was Multisim [8] which is a program to simulate a circuit. It allows the user create a simulation of a circuit instead of having to set up the actual circuit. This way the user will not have to make a new circuit for every test.

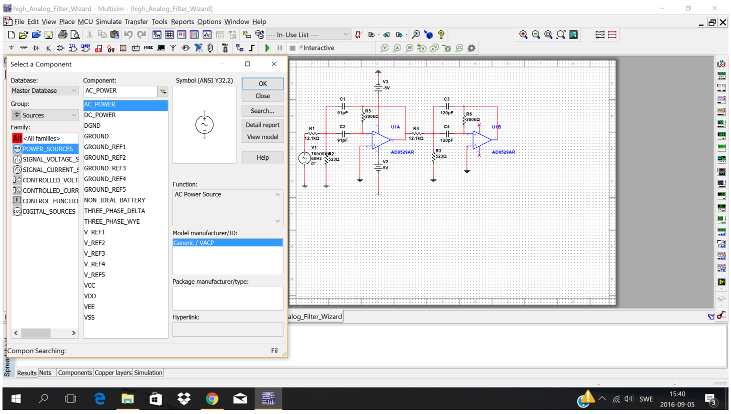

Figure 5: The user may choose between a wide variation of components and get an accurate circuit.

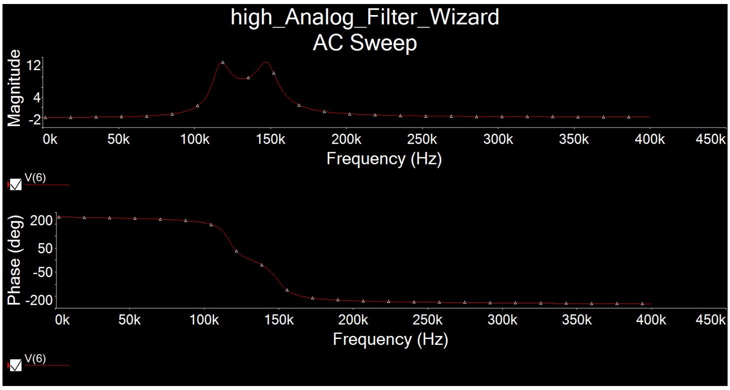

Figure 6: The result from the simulation is given by a graph, showing both the magnitude and phase depending on the frequency.

The second National Instrument program used was Ultiboard [9]. Ultiboard has several great features but it is mainly for making a Printed circuit board (PCB)[15]. If the user has selected a package manufacturer in Multisim the setup may be imported to Ultiboard. In Ultiboard the user places the components strategically on a board to minimize the number of connection crossings. No crossings means it is possible to make the PCB into a single layer PCB, however, some more complex circuits may need multiple layers. When the components are placed as space efficiently as possible the program can be exported as a GERBER file and later on be printed into a PCB.

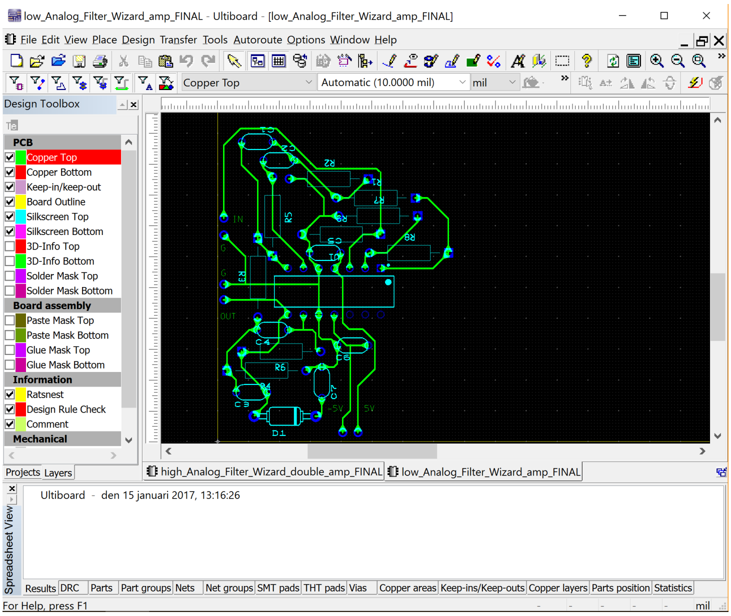

Figure 7: The sheet from which the GERBER file is exported. As seen, all connections are green, which implies that they are all on the same level, making this a single sided PCB model.

Another application in Ultiboard that was used in this project was to make a 3D model of the PCB. This is the same setup that was used when exporting the GERBER file for the PCB.

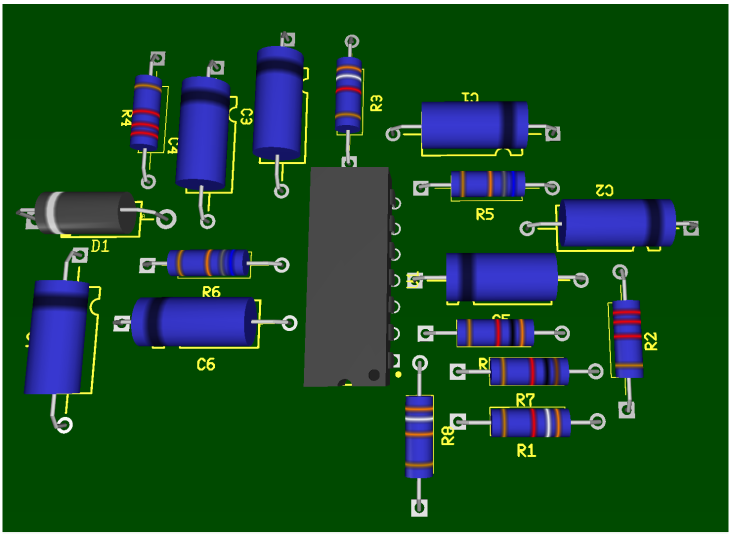

Figure 8: A 3d model of the lower frequency PCB circuit.

The third National Instrument program used was LabView. It is a programming language which offers a method of reading the information of measurement instruments directly into the computer. It has a graphical programming syntax which makes it easy to visualize.

4.9.3 Analog discovery 2

Analog Discovery 2 is not a computer program in itself, but an all-in-one USB oscilliscope and instrumentation system created by Digilent Inc. The user does not need both an oscilloscope and a signal generator. Just connect to the circuit and the computer and start running some tests. Through the computer the user may create the desired signal as the input and at the same time see the output from the circuit, without having to work with two devices at once. The Analog Discovery work together with a custom made program called WaveForms[11].

4.9.4 Matlab

In the project several different programs were used to get information and graphs. Matlab[12] was used to replace these graphs with the final graphs which are shown in this report. This made it easier to compare results from the different measurement methods and between the different programs.

5 Method

There are two ways to approach the creation of the prototype. In one method the majority of the signal processing would be done digitally and one in which it would be done with an analog approach. Perhaps the easiest way would be to do it digitally, making the number of components as low as possible and thereby lowering the chances of a component breaking. In the aspect of further development it would also be easier to have most of the work done digitally, since it is easier to write some more code than it is to rearrange the whole structure. A digital approach would also have higher accuracy and less components that might be destroyed and thereby cause problems. The downside is that it would require a more expensive DAQ-card than the analog method and in the case of accidents it would be a lot more expensive to replace.

To make the project analog would instead lower the costs since the Data acquisition card (DAQ-card) could instead be replaced with a micro controller such as Arduino, this would also make the project more demanding. That is the reason why this method was chosen for the project.

5.1 Block Diagram

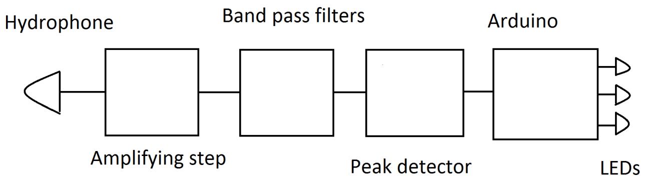

Figure 9: A simplified block diagram of the setup.

1. Hydrophone: The fist step of the setup is the hydrophone. This is the underwater microphone that will pick up the ultrasound emitted from the dolphin.
2. In the second step the signal will go through one or two amplifying steps. From here on, the signal will go in three parallel traces.
3. When the signal is amplified there will be a band pass filter. These will divide the signal into three different spectra, each corresponding to a colored LED.
4. Next the peak detector will identify the highest amplitude coming from the filters and pass it on to Arduino.
5. The Arduino will be loaded with the code to control the LEDs.
6. The last part of the line is the three LEDs.

5.2 Circuit development

Two different approaches for choosing components were used. At first, the components were chosen by using the formulas 6-9, to calculate the values needed to make a suitable band pass filter. Secondly the program "Filter Wizard" from Analogue Devices was used. Filter Wizard was used by choosing the desired specifications of the filter. The specification put into the program is bandwidth of the filter, the filters gain, center frequency and filter response. The program then returns a schematic of a circuit that will give the desired output.

To test the setups, "Multisim" from National Instruments was used to make a simulation of the setup. When a setup with a successful simulation was created it was mounted on a breadboard and measured using "Analog Discovery 2" to make sure it was close enough to the wanted output. Analog discovery is an "All-in-one" oscilloscope and signal generator which is used through the computer. By using WaveForms on the computer, the desired signal was chosen and the measurement was saved directly to the computer.

After exchanging some components to make the measurement match the simulation, an amplification stage was implemented before the filter stages. Some more measurements were made to ensure that the output voltage from the circuit were between 3 and 5 volt.

There were two different methods of creating the circuit itself. The first method to create the circuit was initially copied from the setup on the breadboard. The second method was to make a PCB version of the circuits. Instead of, like in the first method creating all circuits on the same board the circuits were given each an individual board. The PCB's were made by exporting the Multisim-files to Ultiboard. There the components were arranged to minimize the size of the circuit, while having no crossing of the line wires. If there still would have been any crossings, the circuit had to be made a double sided PCB. After having the PCB's printed, the components were soldered onto the PCB's.

5.3 Measuring in water tank

When connecting the circuit to the hydrophones in the water tank, some new disturbances appeared. It appeared because the circuits op-amplifier started to self oscillate. This was fixed by implementing some by-pass capacitors between the voltage feed and earth, as well as a resistor between input and earth. Other than the self oscillation the circuit picked up noise from the connection cables as well. This was corrected by replacing them with a coaxial cable instead.

When measuring in the tank a signal generator is used to send out a pulse signal, consisting of all frequencies(up to 5 MHz), through the first hydrophone. The second hydrophone then picks up the signal and puts it through the circuit before it is measured in an oscilloscope. The oscilloscope was of an older model and the only internal save function was to a floppy disc. As no floppy discs were available during the project, LabView was used to read the waveform signal information on the oscilloscope and save it to the computers hard drive.

The first measurement in the tank would be as a reference signal to which the other measurements would be compared. It would be made with just the hydrophones connected to make sure how much impact the hydrophones had on the measurements.

With the reference measurements done there was meant to be some tests with just the circuits and hydrophones. This to see how much impact the hydrophones actually had on the output from the circuit and to see if it was necessary to compensate for this impact.

Some final measurements were meant to be made with the peak detector and Arduino connected, as well as the diodes in different color. Instead of sending out a pulse with all frequencies, a signal with a known frequency would be emitted. Also all channels were to be connected instead of just one at a time. Knowing what frequency that would be emitted, the test would have consisted of making sure the corresponding colored diode flashed. By changing the repetition rate of the pulses the frequency of the flashes should change and thereby it would be possible to make sure that the program worked as desired.

5.4 Programming

The code made for the project was written in Java. The program will first calculate the time between two signals. After which it will compare the three in-signals and choose the one with highest amplitude. It will then put on the corresponding LED and make it flash in the same frequency as the elapsed time between the last two signals, unless the elapsed time is lower than 20 ms, in which the LED will stay lit.

```
if(valOne =!0 || valTwo !=0 || valThree!= 0){
   elapsedTime = millis() - startTime; // Calculates the time between two
        signals.


   if( startTime != 0){
     startTime = millis(); // If start time exists it gets replaced with
          current time, as start time for next iteration.
     ...
     ...
     ...
     }
      else{
   startTime = millis(); // For the first iteration no lights will be
        turned on.
   }
```

The code for calculating the time between two signals.

6 Results

The following section consists of all the results during the simulations and measurements done in the project. Since the final steps were not conclusive, the result will contain the graphs of the final measurements on the functional steps. There will however be a section with the inconclusive tests but with no figures.

6.1 Circuit development

This was done in three steps for every band pass filter. The simulations of the three band pass filters with their frequency domains shown in a fast fourier transform (FFT). Two steps of measuring with Analog Discovery 2, one with just the band pass filters and one with amplification before the band pass filtering.

6.1.1 Lower band pass filter

This section is for the band pass filter in the interval of 20-75 kHz.

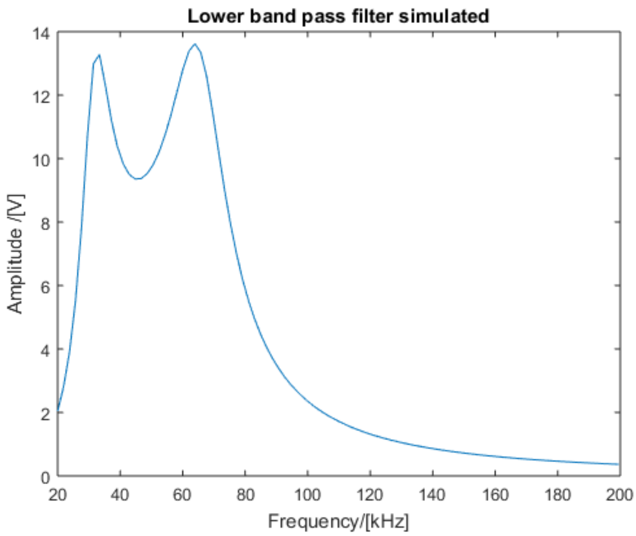

Figure 10: The simulated band pass filter in the interval 20-75 kHz.

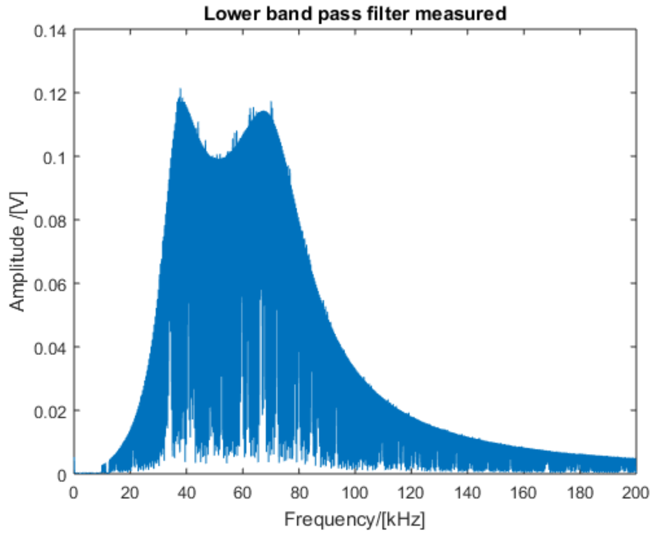

Figure 11: The measured band pass filter in the interval 20-80 kHz.

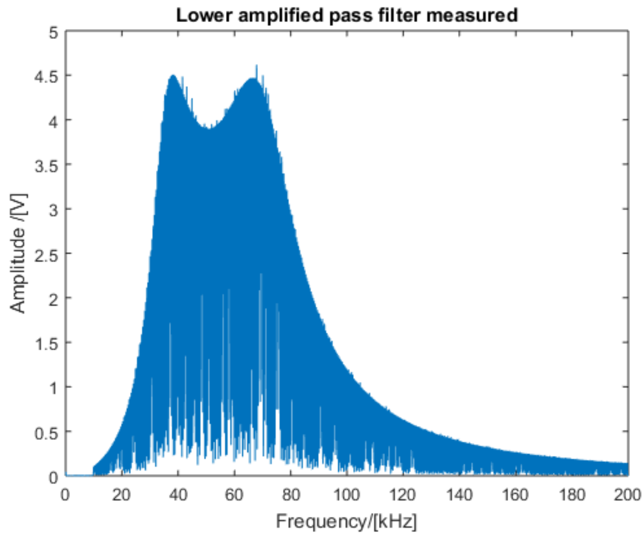

Figure 12: The measured amplified band pass filter in the interval 20-80 kHz.

6.1.2 Central band pass filter

This section is for the band pass filter in the interval of 75-115 kHz.

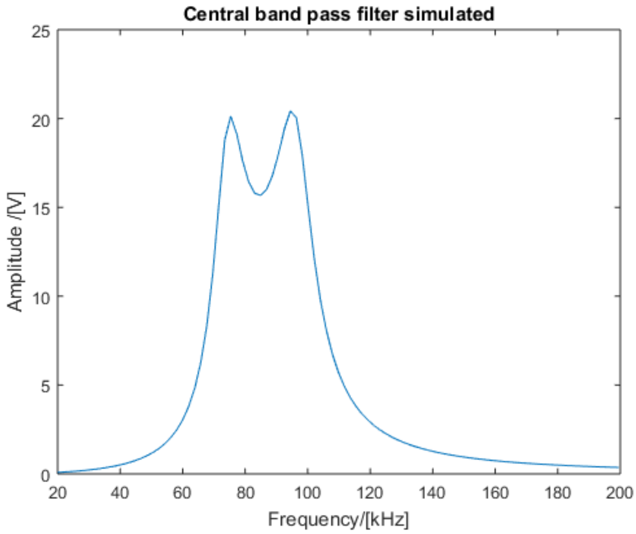

Figure 13: The simulated band pass filter in the interval 75-115 kHz.

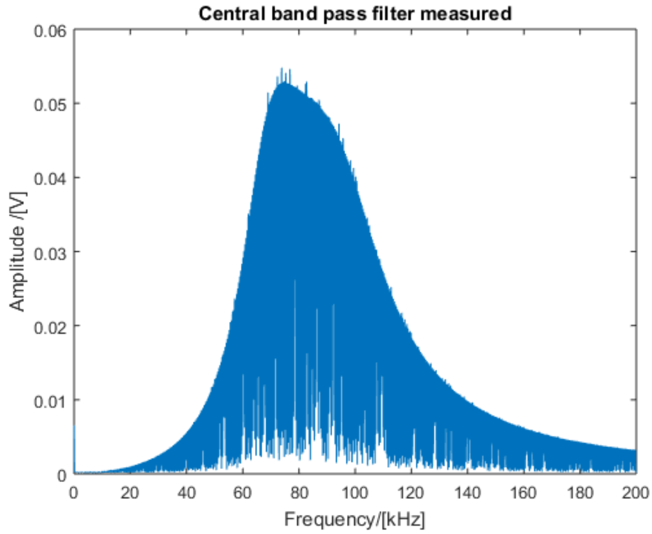

Figure 14: The measured band pass filter in the interval 75-115 kHz.

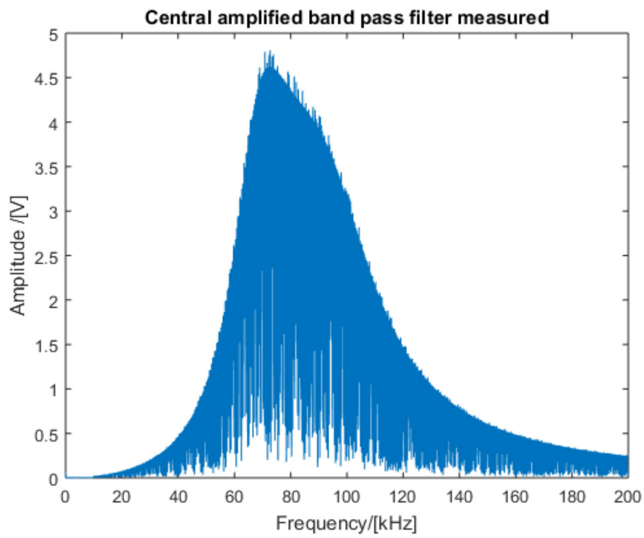

Figure 15: The measured amplified band pass filter in the interval 75-115 kHz.

6.1.3 Higher band pass filter

This section is for the band pass filter in the interval of 115-160 kHz.

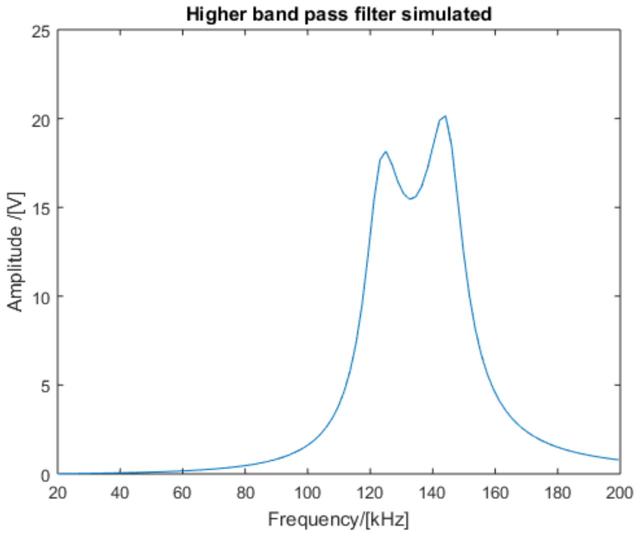

Figure 16: The simulated band pass filter in the interval 115-160 kHz.

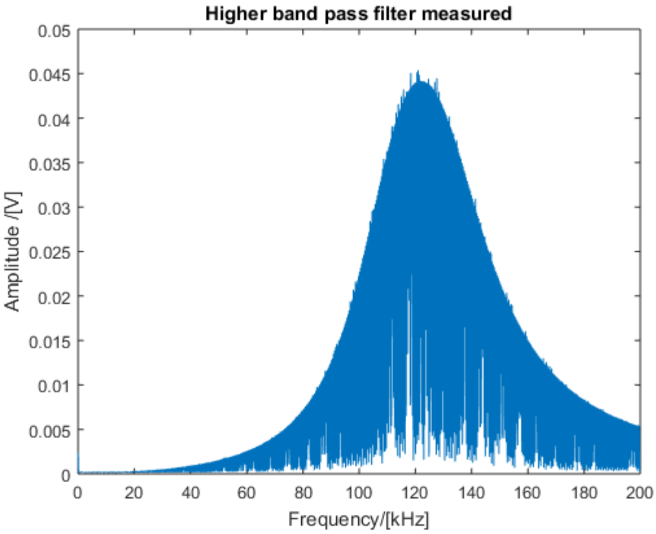

Figure 17: The measured band pass filter in the interval 115-160 kHz.

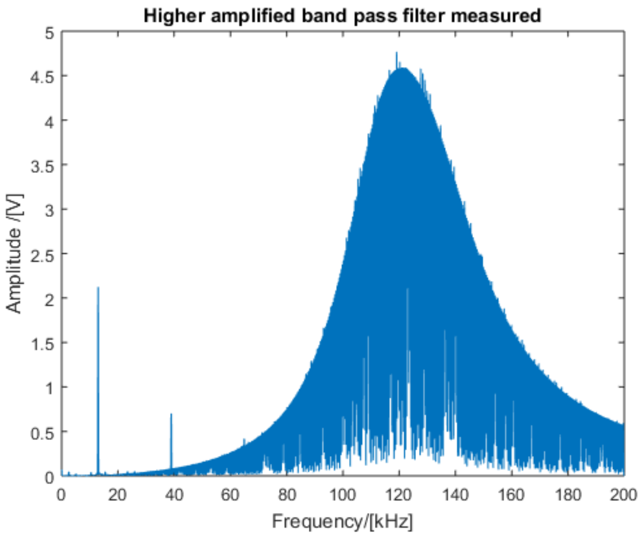

Figure 18: The measured amplified band pass filter in the interval 115-160 kHz.

6.2 Measurements in water tank

The first measurements in the tank looked promising with a lot of similarities to the measurements done with Analog discovery. The problems with noise were fixed and the resulting signal on the oscilloscope looked like the desired one. These measurements were more as a trial to find out if the measurements did fit what had been seen on the previous measurements as at the time there was no code written for saving the measurements to the computer.

After finishing the LabView code the measurements were made all over again, exactly the same as before with no changes made in the setup nor on the circuit. The results were disappointing. Instead of having the promising results from the previous measurements, all shown on the oscilloscope was noise and statics. Having a lot of small cables these were thought to cause the noise. Changing the input and output to coaxial-cables did however not lower the noise enough.

The measurements were made a third time. This time with the PCB-circuit, hoping that the lack of cables and smaller area of the circuit would lower the chance of picking up noise from the surrounding. The noise remained.

7 Discussion

The first approach of creating the circuit using some formulas for filters were inconclusive. When using the filter wizard program the results were much more pleasing. This might be because the formulas used in the first approach were not advanced enough to get the precision wanted for the project, while the algorithms used in filter wizard probably are much more complex.

The final simulations of the circuits were good enough to use in the project (Figure 7-9). They got two tops because the setup for a perfect filter would be to complex and would have to use more op amplifiers than were available.

During the first measurements of the circuits (Figure 10-12) it shows that the band pass filter for the lower frequencies had more than twice the amplitude than the other two filters. This is compensated in the amplifying steps that later on were implemented before the filters. It is also shown here that the two tops in the central and higher band pass filters are gone and instead resulted in a more suited singular top.

During the measurements of the amplified circuits (Figure 13-15) it can be read from the graphs that the resulting circuits got the same output amplitude and thereby is suited for comparison.

While measuring in the water tank, the real problems appeared. Noise and disturbance not seen prior to this stage appeared. The worst was fixed with by pass capacitors and changing to coaxial cables but the high frequency disturbance remained. Changing to a PCB circuit dampened it some but not enough for the input to take over.

Why the circuits worked as they were meant at first and suddenly started to pick up disturbance has not yet been figured out. All components were replaced and several methods of lowering disturbance were implemented without pleasing results.

7.1 Future work

There are some potential to continue the development of the prototype. With some more advanced shielding methods it might be possible to get rid of the disturbance.

Another approach would be to make the signal processing digital. Buying a good DAQ-card and make digital filters instead would decrease the chances of disturbance. Making the solution digital would enable easier ways to add additional functions to the device. For example making a FFT of the signal instead of dividing the spectra into three parts.

Aside from needing to further develop the technical part of the prototype, it requires some design and material improvement. A see through material that protects the device without harming the dolphin. The material would also need to have an acoustic impedance close to water's to enable the sound waves to travel through to the transducers.

7.1.1 Drawings of shell

While waiting for components to arrive the author decided to outline an example of the shell to the device. It has an electronics "cradle" which is built up by springs enabling the device to sit steady within the shell independent of the size of the shell. That way it is possible to have the same cradle to different shells. The drawing also has a service hatch to enable changing batteries without having to dismantle the whole shell. Surrounding the whole shell is a rubber list to both increase the water resistance and decrease the risk of injuries to the dolphins.

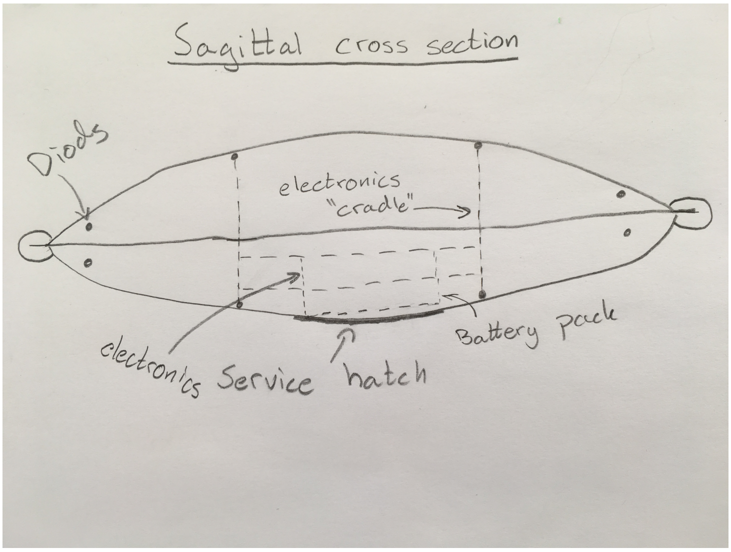

Figure 19: The drawings of a sagittal cross section of the shell.

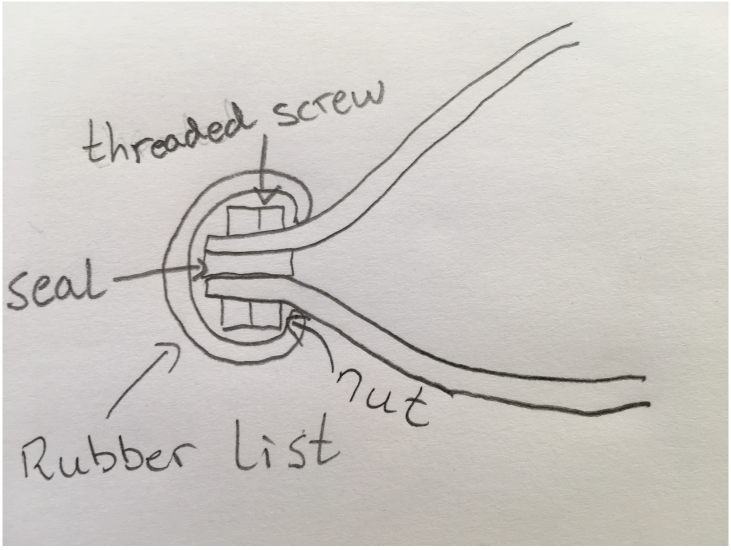

Figure 20: A sagittal cross section of the rubber list around the shell.

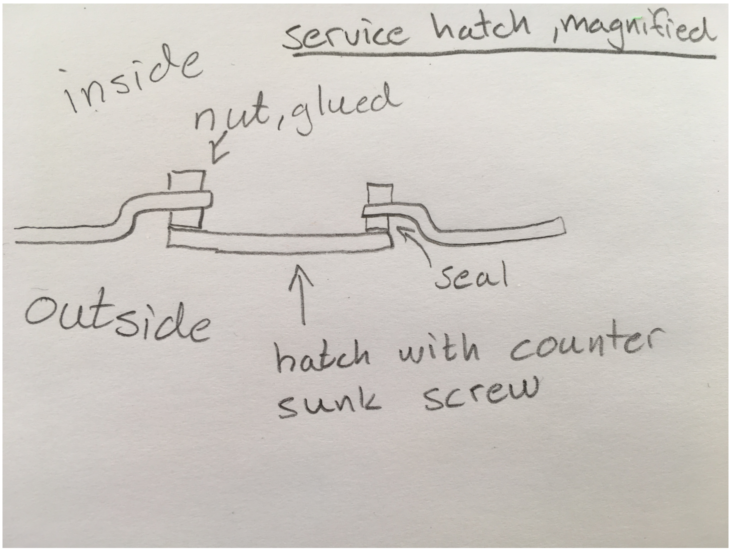

Figure 21: A sagittal cross section of the service hatch.

8 Appendix

8.1 Arduino Code

```
int ledPin1 = 10;
int ledPin2 = 11;
int ledPin3 = 12;
int valOne, valTwo, valThree, maximum = 0;
long startTime, elapsedTime = 0;

void setup(){
  Serial.begin(9600);
  pinMode(A1, INPUT); // Declares analog pins A1-A3 to inputs.
  pinMode(A2, INPUT);
  pinMode(A3, INPUT);
  pinMode(ledPin1, OUTPUT); // Declares digital pins 10-12 to outputs.
  pinMode(ledPin2, OUTPUT);
  pinMode(ledPin3, OUTPUT);
  }

void loop(){

  valOne = analogRead(A1); // Reads in the values from the three different
      channels.
  valTwo = analogRead(A2);
  valThree = analogRead(A3);


  if(valOne =!0 || valTwo !=0 || valThree!= 0){
    elapsedTime = millis() - startTime; // Calculates the time between two
        signals.


    if( startTime != 0){
      startTime = millis();

      if(valOne > valTwo && valOne > valThree){
      if(elapsedTime < 20){
         digitalWrite(ledPin3,LOW); //Sets the yellow LED to off.
         digitalWrite(ledPin2,LOW); //Sets the green LED to off.
      }
            valOne == valTwo == valThree == 0;
            digitalWrite(ledPin1,HIGH); //Sets the blue LED to on.
      if(elapsedTime > 20){
            delay(elapsedTime); //Waits as long as the elapsed time.
```

```
            digitalWrite(ledPin1,LOW); //Sets the blue LED to off.
            delay(elapsedTime); //Waits as long as the elapsed time.
      }
      }
      if(valTwo > valOne && valTwo > valThree){
      if(elapsedTime < 20){
        digitalWrite(ledPin1,LOW); //Sets the blue LED to off.
        digitalWrite(ledPin3,LOW); //Sets the yellow LED to off.
      }
          valOne == valTwo == valThree == 0;
          digitalWrite(ledPin2,HIGH); //Sets the green LED to on.
      if(elapsedTime > 20){
            delay(elapsedTime); //Waits as long as the elapsed time.
            digitalWrite(ledPin2,LOW); //Sets the green LED to off.
            delay(elapsedTime); //Waits as long as the elapsed time.
      }
      }
      if(valThree > valOne && valThree > valTwo){
      if(elapsedTime < 20){
        digitalWrite(ledPin1,LOW); //Sets the blue LED to off.
        digitalWrite(ledPin2,LOW); //Sets the green LED to off.
      }
      valOne == valTwo == valThree == 0;
        digitalWrite(ledPin3,HIGH); //Sets the yellow LED to on.
      if(elapsedTime > 20){
          delay(elapsedTime); //Waits as long as the elapsed time.
            digitalWrite(ledPin3,LOW); //Sets the yellow LED to off.
            delay(elapsedTime); //Waits as long as the elapsed time.
      }
      }
    }
    else{
    startTime = millis(); // For the first iteration no lights will be
        turned on.
    }
  }
}
```

8.2 LabView program

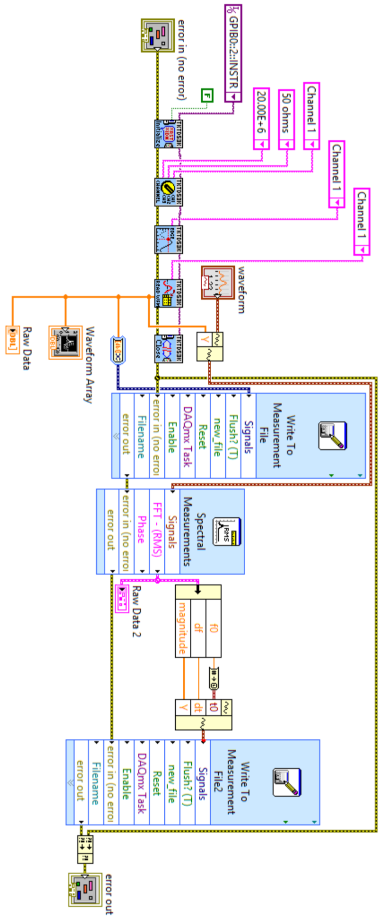

Figure 22: The program made in LabView to read the measurements from the oscilloscope and send it to the computer. It is automatically saved to the hard drive. The information saved on the hard drive must be configured in Matlab to get the wanted x/y-lables and to narrow it down to the interesting spectra instead of the full bandwidth of the oscilloscope.

8.3 Circuit diagrams

Following three circuit diagrams were drawn in Multisim.

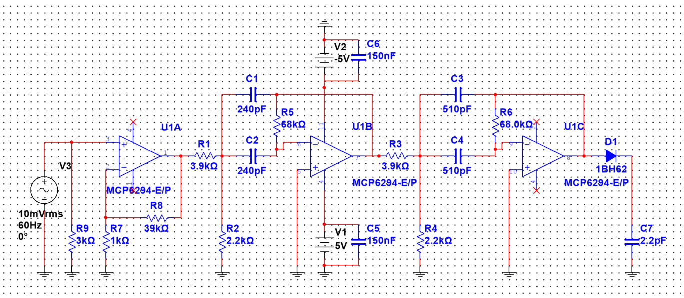

Figure 23: The circuit diagram of the low frequency channel.

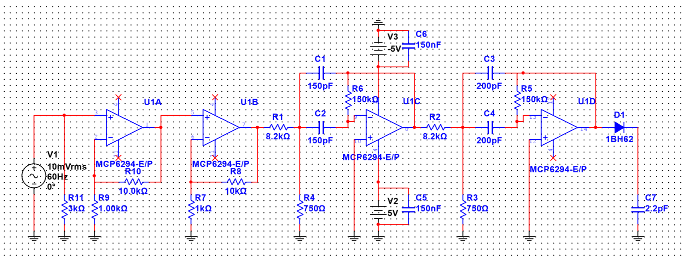

Figure 24: The circuit diagram of the central frequency channel.

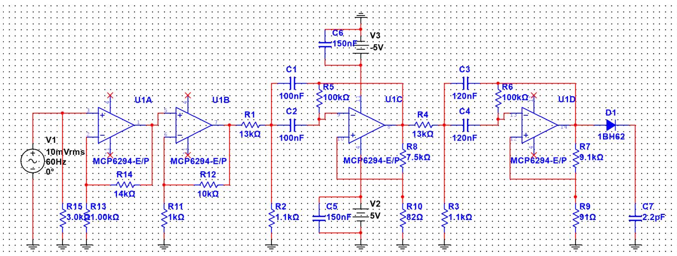

Figure 25: The circuit diagram of the high frequency channel.

8.4 Ultiboard drawings of the PCB circuits

The remaining sheets of the PCB circuits.

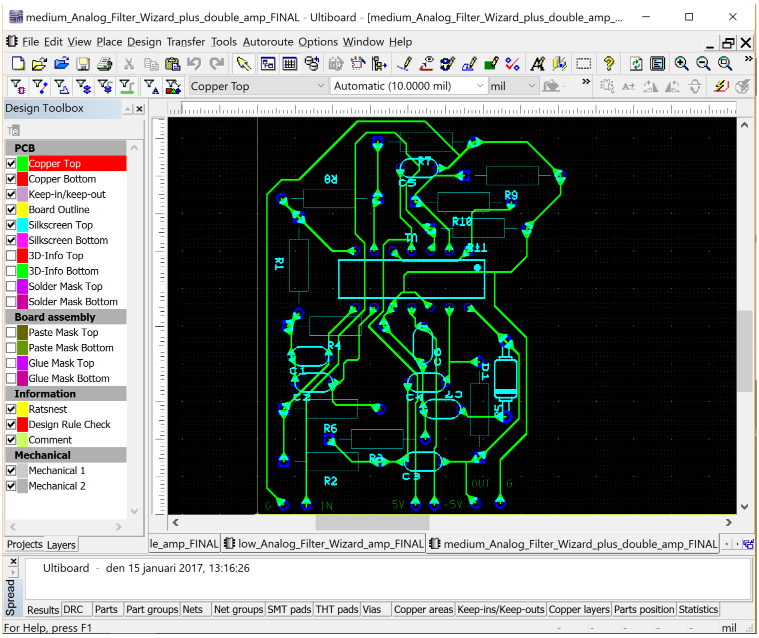

Figure 26: The drawing of the central frequency PCB circuit.

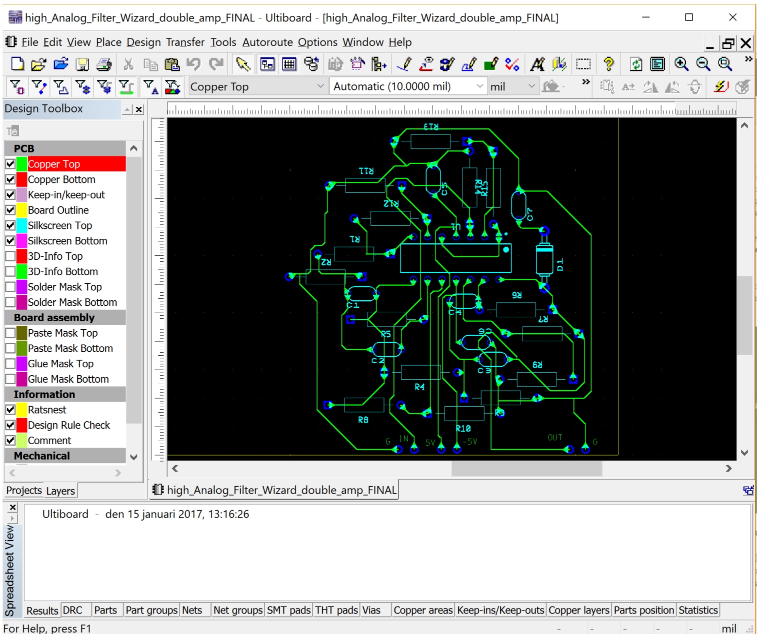

Figure 27: The drawing of the higher frequency PCB circuit.

8.5 3D models of the circuits

These are the remaining two PCB circuits. The lower one is in the text about Ultiboard.

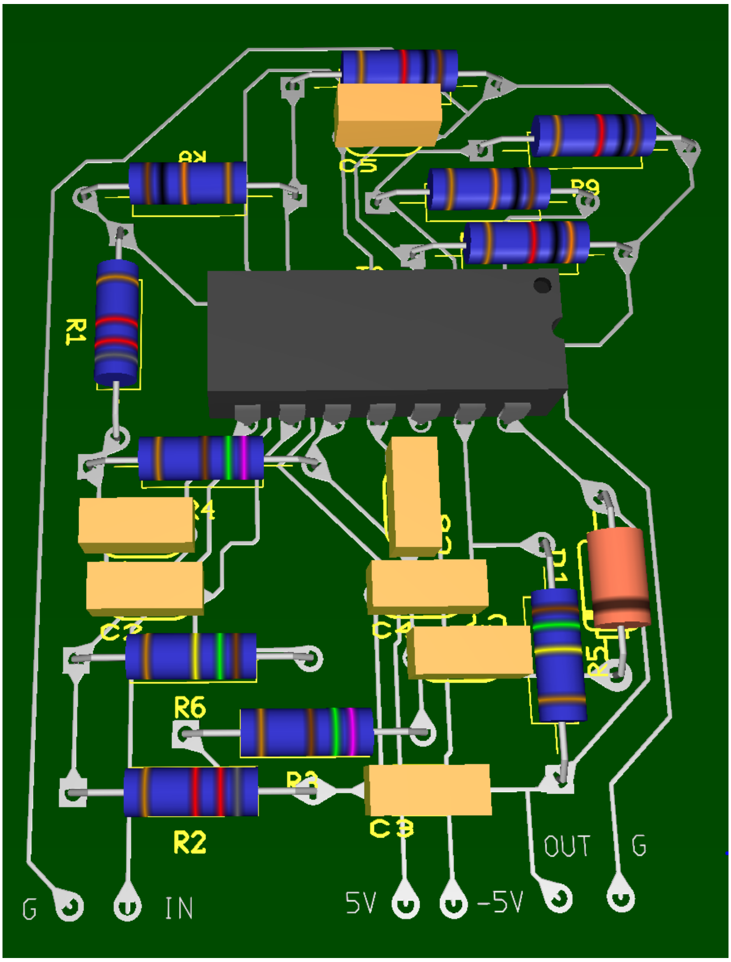

Figure 28: A 3d model of the central frequency PCB circuit.

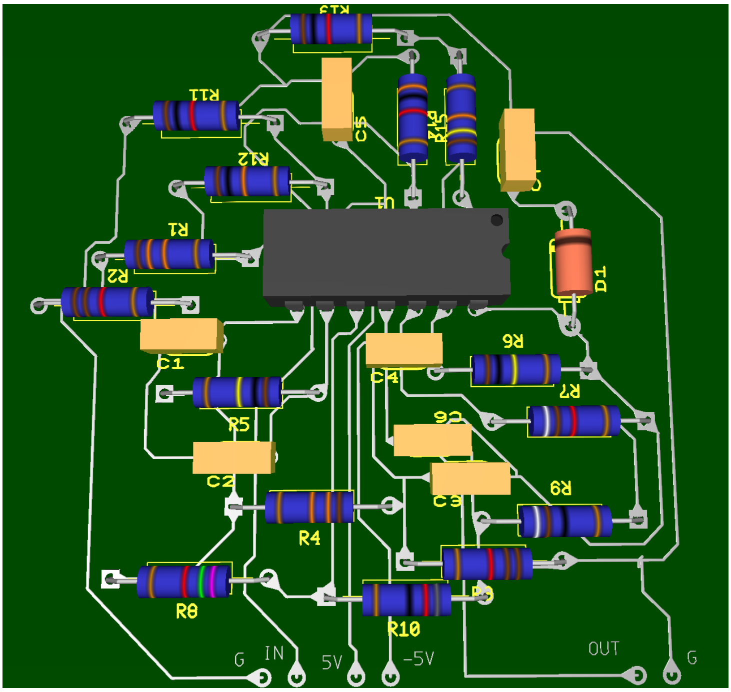

Figure 29: A 3d model of the higher frequency PCB circuit.

9 Popular scientific article

The last part of the project is to write a popular scientific article, which is included in the report.

9.1 Visual response to dolphin echolocation

It is well known that dolphins use echolocation but how about watching what actually happens? A device that shows the audience some of the information contained within the emitted ultrasonic waves.

It is a small fish look-alike device that is created to simulate how the dolphins behave while hunting. By picking up the echolocation signals sent out from the dolphins and process the signals to extract some information hidden within. The device was thought of to show the audience of dolphin shows, how the animals behave while hunting. The audience will be informed with flashing lights located on the top of the device. Different frequencies on the light depending on the distance between device and dolphin and different color on the light depending on which of the frequency domains that is prominent in the signal.

A major problem during the creation of the device was disturbance. Disturbances picked up by the device from the surrounding, from the plug in the wall and even self oscillating operational amplifiers. How to get rid of noise in the setup? Most of these disturbances were managed, such as: using a battery instead of the plug, using bypass capacitors and bypass resistors to avoid the self oscillating operational amplifiers. However, at the end there still remained some noise. This is suspected to be the noise picked up from the surrounding. By changing to shielded coaxial cables instead of regular copper the amplitude decreased some, but still remained. Recreating the circuit with a PCB (Printed circuit board) did decrease it even more, but still not enough for the ultrasonic wave to appear on the measuring equipment.

Although the end results were inconclusive it gives a head start for future development. Future work may focus more on dampening disturbance or even take this as a hint to make the solution all digital, thereby almost fully removing the chances of disturbance. This would also increase the accuracy of the signal processing. In addition it would enable the possibility to implement more features to the device.

10 References

1. **Multi-channer acquisition and visualization of the dolphin echolocation beam - Instrumentation design and bioacoustic results**
Starkhammar.J, Department of Measurement Technology and Industrial Electrical Engineering, Lund University, Lund.
ISBN: 978-91-7473-114-9

2. **A Digital Acoustic Recording Tag for Measuring the Response of Wild Marine Mammals to Sound**
Mark P.Johnson and Peter L.Tyack, IEEE Journal of Oceanic Engineering, VOL.28, NO.1, January 2003.
ISSN:1558-1691

3. **Sound Production and Sound Reception in Delphinoids**
Ted W. Cranford, Mats Amundin, and Petr Krysl,Dolphin communication and cognition: Past, present, and future, MIT Press, 2015.
ISBN: 978-0-262-02967-4

4. **Echolocation by two foraging harbour porpoises (Phocoena phocoena)**
Ursula K. Verfuß, Lee A. Miller, Peter K. D. Pilz and Hans-Ulrich Schnitzler, 2009, Denmark.
ISSN:0022-0949

5. **Does Your Op Amp Oscillate?**
Barry Harvey, Staff Design Engineer, Linear Technology® Corp, 2014, Application Note 148.
http://cds.linear.com/docs/en/application-note/an148fa.pdf

6. **Understanding Operational Amplifier Specifications**
Jim Karky, Texas Instrument, 1998.
SLOA011. http://www.ti.com/lit/an/sloa011/sloa011.pdf

7. **Handbook of operational amplifier applications**
Bruce Carter and Thomas R. Brown, Texas Instrument, 2001.
SBOA092A. http://www.ti.com/lit/an/sboa092b/sboa092b.pdf

8. **NI Multisim 14.0**
National instruments, software.
http://www.ni.com/multisim/

9. **NI Ultiboard 14.0**
National instruments, software.
http://www.ni.com/ultiboard/

10. **Analog Filter Wizard**
Analog Devices, software.
http://www.analog.com/designtools/en/filterwizard/

11. **WaveForms 2015**
Digilent Inc, software.
http://store.digilentinc.com/all-products/software/

12. **Matlab R2015A**
MathWorks, software.
https://se.mathworks.com/products/matlab.html

13. **Ultraljudsfysik och teknik VT-2015**
Biomedicinsk teknik, Lunds Tekniska Högskola.

14. **EMC for Product Designers (Fourth Edition)**
Tim Williams, 2007, Elsevier Ltd.
ISBN: 978-0-7506-8170-4

15. **PCB Design Tutorial**
David L. Jones, 2004.
http://www.alternatezone.com/electronics/files/PCBDesignTutorialRevA.pdf

16. **Basic Linear design**
Hank Zumbahlen © 2007 Analog Devices, Inc.
ISBN: 0-916550-28-1

17. **Op Amps for Everyone**
Ron Mancini, Texas Instruments Incorporated, 2002.
Advanced Analog Products, SLOD006B. **ISBN-10**: 0123914957

18. **The Sonar of Dolphins**
Whitlow W.L. AU, University of Hawaii, 1993.
ISBN: 3-540-97835-6