An ultrasound measurement system is built for the “Section For Electrical And Mechanical Engineering” of the Oslo University College. The system will be used for research purposes. Ultrasound is used both in industrial applications and in medicine.

The objective is to design, build and test a measurement system with water tank in order to compare the quality of different ultrasound transducers.
Declaration

We confirm that we have done the report by ourselves and we used just the denoted resources.

_____________________________
(Date, Place)

___________________________
(Sara Sánchez-Palencia)

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(Stef Schraven)

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(Sergio Pérez)

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(Daniel Böhner)
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1. Introduction & Background Information

1.1. Introduction
An ultrasound measurement system is built for the “Section For Electrical And Mechanical Engineering” of the Oslo University College. The system will be used for research purposes. Ultrasound is used both in industrial applications and in medicine. In the current project, the aim is focused on medical imaging. The objective is to design, build and test a measurement system in order to compare the quality of different transducers. As water is quite similar to the human body regarding ultrasound wave propagation, the medium in which the measurements are performed will be water. Therefore water will be stored in a water tank which will have an acoustic window with a soft surface in it in order to avoid the reflections and allow good ultrasound wave propagation. The system will need a small device that measures the pressure of the pulsed waves sent into the water tank. This device is the hydrophone. It will be attached to a positioning system made up of 3 axes in order to take automated measurements in 2 dimensions and store the data to the computer. This positioning system will be moved by step motors and controlled automatically by a computer program (LabVIEW).

1.2. Medical Imaging
Medical diagnostic ultrasound systems use high-frequency sound waves to produce images of soft tissues and internal body organs. Frequently, they are the first diagnostic imaging devices that physicians buy for their private practice. This is due to a number of advantages: these systems are easy to operate, are known for their relatively high safety, are affordable and capable of displaying soft tissues. The current system is different of ultrasound systems because is meant to test transducers. For testing transducers a human body can’t be used, so water is used instead because of its similar resistance.

1.3 Ultrasound
Ultrasound is an acoustic sound wave having a frequency above the human hearing range. The highest frequency that the human ear can detect is approximately 20 thousand cycles per second (20,000 Hz). This is where the sonic range ends, and where the ultrasonic range begins. Ultrasound is used in electronic, navigational, industrial, and security applications. It is also used in medicine to view internal organs of the body.

1.4 Transducer
A transducer is an electronic device that converts energy from one form to another. Common examples include microphones, loudspeakers, thermometers... In our project the transducer converts an electric pulse into an ultrasound beam, we use it like a loudspeakers to send the ultrasound waves.

1.5 Hydrophone
A Hydrophone is a device which receives underwater sound waves and converts them to essentially equivalent electric waves. A hydrophone is the underwater analogue of a microphone.
2. Approach
The approach exists of all components needed to make a fully operating measurement system. The order of the approach is as next: the mechanical parts to start with, which are followed by the electrical parts and the program to run the measurements automatically.

2.1 Water Tank
The water tank has been made of plastic due to a number of advantages: it is cheaper, far easier to handle and causing less reflections then a glass aquarium. For this reason the idea to buy a glass aquarium is skipped. The idea was to build an aquarium made of plastic but this would have been even more expensive. The solution is a plastic box from IKEA.

Figure 2.1 – Water Tank (For details see appendix 5.1)
2.2 Acoustic Window

In the water tank an acoustic window had to be made in order to make it possible for the ultrasound waves to go through. This acoustic window has a hole with a soft surface, where the ultrasound waves can go through. This will be made waterproof with 2 aluminium rings that will be held together with 8 bolts and nuts (see drawings below, all dimensions in mm).

Figure 2.2 - Acoustic Window (For details see appendix 5.2)
2.3 Positioning System

The positioning system will exist of 3 axes, and 2 of them will be automatically moved with step motors.

On the drawings below only the 2 axes that will be moved automatically are shown. These axes are moved by screws (specified as M10*1.5) which are run by the step motors. The green part is a plastic part that will slide in an aluminium part.

The 3 axes have to be adjusted manually before the automated measurement begins in order to place the hydrophone in the centre of the beam. Then all measurements will be done in 2 axes. Because the beam propagates the waves almost identically in the 2 axes (X&Y-axes) across to each other the measurement will only be done in one of these.

Accuracy of the positioning system

The positioning system can reach a high accuracy. The maximum accuracy that the positioning system can reach will be determined by 2 facts:

- The pitch of the screws which is 3 mm for every rotation.
- The amount of steps the motor has to do for 1 full revolution (which is 200 steps).

For these reasons the maximum reachable accuracy will be \( \frac{3}{200} = 0.015 \text{ mm or } 15 \mu \text{m} \)
Definition Of The Axes (Positive / Negative)

The directions will be set from the point of view of the transducer (top view).

Figure 2.4 – Axes Directions Definition
2.4. Digital Oscilloscope
The frequency of the samples to be measured is between 2.5 MHz and 3.5 MHz. As this exceeds the frequency range of the I/O-card and the signal strength is also too low to be read, a digital oscilloscope is used and the data is transmitted into LabVIEW via USB. In this case, we used a Tektronix TDS 2012B. The general settings are used for all measurements and the signals are always to be connected in this way. The detailed settings may vary (See 2.11 “Finding the acoustic signal”).

<table>
<thead>
<tr>
<th>General settings for the digital oscilloscope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel 1: Connected to DC coupler (hydrophone) via BNC</td>
</tr>
<tr>
<td>Channel 2: Connected to pulse generator via BNC</td>
</tr>
<tr>
<td>Coupling: DC</td>
</tr>
<tr>
<td>Auto range: Off</td>
</tr>
<tr>
<td>Probe: 1 x Voltage</td>
</tr>
<tr>
<td>Acquire: Sample</td>
</tr>
<tr>
<td>Trigger source: Channel 2</td>
</tr>
<tr>
<td>Type: Edge</td>
</tr>
<tr>
<td>Slope: Rising</td>
</tr>
<tr>
<td>Coupling trigger: DC</td>
</tr>
</tbody>
</table>

Table 2.1 General Settings Oscilloscope

2.5. Transducer: Specifications & Mount
The transducer is custom made, so there are no written specifications about this part. The transducer will be powered by a pulse generator with the following settings. The pulse generator will send short electrical pulses which the transducer will convert into ultrasound pulses.

<table>
<thead>
<tr>
<th>Settings pulse generator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repetition time: 1 ms</td>
</tr>
<tr>
<td>Delay: 10 ns</td>
</tr>
<tr>
<td>Duration: 10 ns</td>
</tr>
<tr>
<td>Single signal: ON</td>
</tr>
<tr>
<td>Amplitude: 10 V</td>
</tr>
<tr>
<td>200 mA into 50 Ω</td>
</tr>
<tr>
<td>Connected to: Pulse out</td>
</tr>
</tbody>
</table>

Table 2.2 Settings Pulse Generator
Transducer Mount:

In order to hold a variety of transducers a holder has been designed, which can hold a variety of transducers with a maximum diameter of 40 mm. This holder has been attached in a vertical device in order to fix the height of the transducer.

Basically the transducer holder consists of a metallic ring with four holes of M5. Three holes are separated $120^\circ$ between them in order to hold the transducer, the other one is just to fix the height. (all dimensions in mm)

Figure 2.5 – Transducer Mount (For details see appendix 5.4)
2.6. Hydrophone: Specifications & Mount

<table>
<thead>
<tr>
<th>Hydrophone’s specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name:</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Sensor Type:</strong></td>
</tr>
<tr>
<td><strong>Sensor diameter:</strong></td>
</tr>
<tr>
<td><strong>Frequency:</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Output Impedance:</strong></td>
</tr>
<tr>
<td><strong>Typical Probe Sensitivity:</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Sensitivity Tolerance:</strong></td>
</tr>
</tbody>
</table>

Table 2.3 – Hydrophone’s specifications

![Hydrophone Probe](image)

Figure 2.6 – Hydrophone Probe
Preamplifier:

<table>
<thead>
<tr>
<th>Preamplifier’s specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name:</strong></td>
</tr>
<tr>
<td><strong>Voltage Gain:</strong></td>
</tr>
<tr>
<td><strong>Bandwidth:</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Max Output Level:</strong></td>
</tr>
<tr>
<td><strong>Input Impedance:</strong></td>
</tr>
<tr>
<td><strong>Output Impedance:</strong></td>
</tr>
<tr>
<td><strong>Output Noise Level:</strong></td>
</tr>
<tr>
<td><strong>Power Requirements:</strong></td>
</tr>
<tr>
<td><strong>Operating Range:</strong></td>
</tr>
</tbody>
</table>

Table 2.4 – Specifications Preamplifier

![Figure 2.7 – Dimensions Preamplifier](image)

Power supply:

<table>
<thead>
<tr>
<th>DC coupler &amp; power supply’s specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name:</strong></td>
</tr>
<tr>
<td><strong>RF input impedance:</strong></td>
</tr>
<tr>
<td><strong>RF output impedance:</strong></td>
</tr>
<tr>
<td><strong>Input power supply requirements:</strong></td>
</tr>
</tbody>
</table>

Table 2.5 – DC coupler specifications
Hydrophone Mount:
The hydrophone mount consists of an L shape which has two holes, one of them is to hold the hydrophone underwater and the other one is to attach it to the positioning system. The piece which will hold the L-shaped mount is just a solid tube with a screw on the top, which makes allows attaching it to the positioning system. The parts have been made of plastic, to prevent it reflecting the ultrasound waves.

Figure 1.8 – Connection diagram DC coupler

Figure 2.9 – Hydrophone Mount (For details see appendix 5.5)
2.7. Step Motors: Specifications & Mount

Two axes are to be moved automatically by two motors attached to these axes with the motor mounts (see drawings next on the page). Each step motor rotates a screw on one of the axes of the positioning system very accurately which makes it possible to move the hydrophone in any position.

The motors are connected to the drivers that convert the signals that are sent by the computer program into signals according to the motors can interpret.

The step motors and drivers have been bought on the Internet of the company “Interinar Electronic”: www.interinar.com

<table>
<thead>
<tr>
<th>Motor specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name: 23KM-K2255U</td>
</tr>
<tr>
<td>Connection: Bipolar</td>
</tr>
<tr>
<td>Voltage: 4.9 V DC</td>
</tr>
<tr>
<td>Current: 1.1 A</td>
</tr>
</tbody>
</table>

Table 2.6 – Motor specifications

Motor Mount:
The motor mount has been designed in order to attach the motor to the positioning system. This piece was made in aluminium (All dimensions in mm).

Figure 2.10 – Motor Mount (For details see appendix 5.6)
2.8. Driver: Specifications & Mount

<table>
<thead>
<tr>
<th>Driver specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name:</strong> BSD-02LH</td>
</tr>
<tr>
<td><strong>Jumper configuration:</strong> Full step mode</td>
</tr>
<tr>
<td><strong>Voltage:</strong> 24 V DC</td>
</tr>
<tr>
<td><strong>Current:</strong> 2.2 A</td>
</tr>
<tr>
<td><strong>V_{ref}:</strong> 1.8 V (Max current limit: 1.1 A/phase)</td>
</tr>
<tr>
<td><strong>Logic level:</strong> 5 V TTL level active low</td>
</tr>
</tbody>
</table>

Table 2.7 – Driver specifications

Connection For The Motor With The Driver:

![Connection diagram](image)

Higher torque at low speed
Lower current
Less heat

Figure 2.11 – Connection diagram Motor & Driver

Setting the maximum current limit:

To guarantee proper operation of the motor it is important to adjust maximum current limit by adjusting V_{REF} to an appropriate level. For the motor used the maximum current is 1.1 A.

\[
V_{REF} \ [V] = 1.6 \times I_{\text{max}} \ [A] = 1.8 \ [V]
\]

Therefore, the reference voltage is set to 1.8 V.
Connecting The Motors And Drivers Should Be Done By Following Steps:

- Connect the motor to the driver
- Connect power supply
- Disable the driver by disconnecting any signal from ENABLE pin
- Connect Voltmeter between GND and TP1
- Calculate $V_{\text{ref}}$ based on the phase current of the motor (see above)
- Adjust R15 to achieve desired $V_{\text{ref}}$
- Connect ENABLE, STEP and DIRECTION signals

Driver Mount:
Because it has to be possible for the drivers to get fresh air flowing (to emit heat), a driver mount has been designed. This part has been made of plastic because it’s easy to handle and it is insulating. This makes it safer because there is risk of short-circuiting. The small holes are made to attach the plastic mount to the driver with some spacers in between, and the bigger holes are made to attach the driver mount to the positioning system close to the step motors. (All dimensions in mm)

Figure 2.12 – Driver mount (For details see appendix 5.7)
2.9. Step motors controlled by LabView

I/O-Card:
For the project a standard I/O-card from National Instruments was used. It is the same type of I/O-card that is in use in most of the electronic labs on Oslo University College, a so called NI USB-6008. This card was chosen for the following reasons:

- The specifications (i.e. frequency range, amount of digital in- and outputs, logic level) fit the demands
- A card was available from the electronic lab from the 6th floor, so testing could start immediately and no money had to be spent.
- For programming in LabVIEW it is much more comfortable to use I/O-cards from National Instruments than from other companies

Connecting Control Signals:
All signal inputs of the drivers are 5 Volt TTL-level and have internal pull-up resistors of 4.7kΩ connected to +5 V. All inputs are sourcing type and ACTIVE LOW in reference to GROUND. This allows direct connection to our I/O-card. To test them, simply shorting any input to GROUND will change its status.

The drivers are controlled by 3 signals:

- ENABLE - INPUT, ACTIVE-LOW. When logic-low all outputs are enabled. When logic-high all outputs are disabled but STEP and DIRECTION signals are still processed in translator. The board has a built in pull-up resistor so if this input is left disconnected the driver will be disabled.
- STEP - INPUT. A low-to-high transition advances the motor one increment. The size of the increment is determined by the jumpers MS1 and MS2 (see figure 2.13). The minimum step pulse width is 1.0 µs and the minimum step low time is 1.0 µs.
- DIRECTION - input. Determines the direction of the rotation of the motor and depends on how motor was connected. If low was counter clockwise then high will be clockwise and vice-versa.
Port Configuration Of The I/O-Card:

<table>
<thead>
<tr>
<th>Port Nº</th>
<th>Connected to</th>
<th>Wire Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>P 0.0</td>
<td>Enable</td>
<td>White</td>
</tr>
<tr>
<td>P 0.1</td>
<td>Step</td>
<td>Green</td>
</tr>
<tr>
<td>P 0.2</td>
<td>Direction</td>
<td>Brown</td>
</tr>
<tr>
<td>GND</td>
<td>GND</td>
<td>Yellow</td>
</tr>
<tr>
<td>P 0.4</td>
<td>Enable</td>
<td>Red</td>
</tr>
<tr>
<td>P 0.5</td>
<td>Step</td>
<td>Pink</td>
</tr>
<tr>
<td>P 0.6</td>
<td>Direction</td>
<td>Grey</td>
</tr>
<tr>
<td>GND</td>
<td>GND</td>
<td>Yellow</td>
</tr>
</tbody>
</table>

Table 2.8 – Port Configuration I/O-Card

Figure 2.13 – Connection ports on the driver
2.10 LabVIEW

What Is LabVIEW:
LabView (short for Laboratory Virtual Instrumentation Engineering Workbench) is a platform and development environment for a visual programming language from National Instruments. It is commonly used for data acquisition, instrument control, and industrial automation on a variety of platforms including Microsoft Windows, various flavours of UNIX, Linux, and Mac OS X. For the project the latest version of the software was used, LabView 2009. It is the same as the Oslo University College is using, so no license was needed.

Definition Of The Signals:
Assigning a virtual port in LabVIEW to a real port on the I/O-card is done by creating a new DAQ-Assistant (Data Acquisition Assistant). These assignments can be changed at any time, but have to be done carefully as this may cause collision of hardware resources (e.g. 2 virtual ports using 1 real port simultaneously). As the driver signals are defined as ACTIVE LOW in reference to GROUND, the signals in LabVIEW have to be defined in the same way. This inversion of line has to be done for each input and output separately.

Figure 2.14 – Defining signals in LabVIEW
**ENABLE Signal:**
Generating the ENABLE-signal in LabVIEW is quite simple. A toggle switch (Behaviour: Switch when pressed) sets the signal to true or false. As the DAQ-Assistant cannot interpret Boolean values (true/false), the signal has to be converted into a 1 digit array of scalars (0/1). The LED indicates whether the motor is enabled or disabled. Generally the motors can stay enabled during the whole time, but this means they will require much higher current in order to build a torque and remain exactly in their position. Unfortunately this high current creates an electric field that causes a lot of noise on the signal. As this holding torque is not necessary for proper operation of the positioning system, the motors should be disabled when not needed in order to reduce this noise on the signal.

Figure 2.15 – ENABLE-Signal in LabVIEW

**DIRECTION Signal:**
The DIRECTION-signal is the same signal type as the ENABLED-signal, so it can be implemented in the same way. As the orientation of the axis (positive/negative) are defined before (See Figure 2.4) the DAQ-Assistant for the direction signal of the X-axis has not to be inverted!

**DEFINITION DAQ-Assistant:**  
X-Axis: NOT INVERTED  
Z-Axis: INVERTED

So for the signals in LabVIEW that means:

<table>
<thead>
<tr>
<th>Axis</th>
<th>True</th>
<th>False</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-Axis</td>
<td>positive</td>
<td>negative</td>
</tr>
<tr>
<td>Z-Axis</td>
<td>positive</td>
<td>negative</td>
</tr>
</tbody>
</table>

When different LabVIEW programs are used simultaneously it may cause a resource conflict and result in inverted DIRECTION-signals, so the positioning system will move in the opposite direction. Therefore a reset of the I/O-card should be done when changing from one program to another. This is done by selecting the device to reset in the “NI Measurement & Automation Explorer” and executing “Reset Device”.
**STEP Signal:**

A low-to-high transition in the step signal advances the motor one increment. So the step signal has to be alternating which is a bit more complex than generating constant signals. As the positioning system was designed for high-precision measurements, it is very important that the motors can be controlled step by step and work reliably without losing any steps. This is basically implemented by a flip-flop-logic inside a for-loop. First the number of steps and the frequency are set by the user. As one increment requires one low-to-high transition and the signal has to go back to low again, both these values have to be multiplied by 2. The “Steps To Do” value sets the number of loops the for-loop has to do. Controlling the frequency of the alternating signal is implemented by converting the “Frequency in Hz” value into milliseconds first and then forces the loop to wait the amount of milliseconds set. When the loop starts, the shift register is initialized as “false”. So the port will receive a “0” and be set as high (as the line is inverted). The flip-flop-logic will invert this “false” into “true” and store this value in the shift. The iteration terminal provides the current loop iteration count, which ranges from 0 to n-1. It is used to count the numbers of steps that have been done already. As it is implemented inside the loop, this information will be displayed in real-time. For the second loop, the shift register will be initialized as “true”, which makes the flip-flop logic working and the STEP-signal alternating while frequency and number of steps can be controlled.

![Generating step signal in LabVIEW](image)

*Figure 2.16 – Generating step signal in LabVIEW*
User Interface: Front Panel For Manual Adjustment Of The Position
This front panel is designed to control the positioning system manually. The X-axis and the Z-axis can both be moved separately. For each motor it is possible to:

- **Enable/Disable** the motor in order to prevent starting them accidentally and damage the hydrophone or positioning system. Also this will reduce noise on the acoustic signal (e.g. when finding the signal).
- **Set the Direction** to move the hydrophone to the wanted position.
- **Set the amount of steps to do** so the distance to move can be defined. To convert length units into amount of steps see conversion table in the middle of the front panel.
- **Control the speed** in which the positioning system will move. The speed limit is set to 50 steps/second.
- **Monitor** the step signal on the waveform chart.

![Figure 2.17 – Front panel for manual adjustment](image)

2. Approach
User Interface: Front Panel For Automated Measurement
As LabVIEW will read the measurements from a “Virtual instrument”, all the controls on the oscilloscope will be disabled. Therefore everything needs to be adjusted on this virtual instrument. Using the front panel for performing automated measurements the user can set the:

- **Width of field** (X-Direction) in mm.
- **Length of field** (Z-Direction) in mm.
- **Δx** (resolution of measurements in X-Direction) in mm.
- **Δz** (distance between different rows in Z-Direction) in mm.
- **Channel** to capture the measurement.
- **Trigger channel** to define the trigger.
- **Device** on which the measurement will be performed.
- **Vertical coupling** (AC/DC/Ground).
- **Probe attenuation** in V.
- **Appending data to existing file** (Enable/Disable).
- **Saving path for data file**.

![Figure 2.18 – Front panel for automated measurement](image-url)
2.11 Finding The Acoustic Signal

Finding the acoustic signal is quite difficult. First of all, the beam is quite narrow and the transducer will not point in exactly 90° from the water tank, so that makes it hard to know exactly where it is. Also there is a lot of noise on the signal from the hydrophone, which makes triggering on the acoustic signal impossible. Another problem is that the transducer will also send an electromagnetic radiation with every pulse. This electric pulse will be measured by the hydrophone as well. Unlike an acoustic signal (propagation speed in water = 1435m/s), an electromagnetic waves travel with the speed of light, so the hydrophone will detect the electromagnetic signal much earlier before the acoustic signal, which makes it even more difficult to trigger on.

So the acoustic signal has to be found manually at first. That means using the program for manual control of the positioning system in order to move the hydrophone to a point where the ultrasound beam is suspected. Then the hydrophone has to be moved slightly around in this area until the acoustic signal is detected by the oscilloscope. Following oscilloscope settings have been approved as helpful for this task:

<table>
<thead>
<tr>
<th>Oscilloscope settings to find the acoustic signal manually</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Channel 1:</strong> 2 mV/Div</td>
</tr>
<tr>
<td><strong>Channel 2:</strong> 5 V/Div</td>
</tr>
<tr>
<td><strong>Trigger level:</strong> + 1 V</td>
</tr>
<tr>
<td><strong>Time base:</strong> 50 µs/Div</td>
</tr>
</tbody>
</table>

Table 2.9 – Oscilloscope settings finding the acoustic signal manually

The time delay between the trigger event (=pulse from generator) and the actual ultrasound signal varies with different distance between transducer and hydrophone. Therefore the time base is set quite high. This may not allow a detailed image of the pulse, but adjusting the position of the hydrophone manually in order to find the actual beam gets more comfortable in this way.

Suggested procedure to find the ultrasound beam manually:

- Move hydrophone close (≈1cm) to acoustic window
- Adjust hydrophone to point right to the middle of the acoustic window (easier when looking through the acoustic window)
- Move only Z-axis in positive direction away from hydrophone as far as possible
- Place transducer in mount
- Carefully adjust position of transducer until acoustic signal is detected by the oscilloscope

Following these steps helps to adjust the acoustic axis straight line and prevents bad measurement results caused by skew acoustic axis, which means the hydrophone would measure in wrong positions and not capture any signal of the beam.
2.12 Capturing The Measurements

As described above, it is not possible to trigger on the actual ultrasound signal (See chapter 2.11 “Finding the acoustic signal”). Therefore the Oscilloscope will trigger on the signal from the pulse generator. As the delay time between the electric signal and the acoustic signal increases with the distance between transducer and hydrophone, the timebase for the measurement will be set wide enough to capture even signals with the largest possible distance. The maximum time delay is defined as the quotient of the maximum distance (0.3m) and the propagation velocity in water (1435m/s):

\[ t_{\text{max}} = \frac{s_{\text{max}}}{v_{\text{water}}} = \frac{0.3 \text{ m}}{1435 \text{ m/s}} = 209\mu\text{s} \]

While capturing the signal, LabVIEW will set the trigger position in a way to center the electric signal. So the divisions between the electrical and acoustic signal can be 5. Setting the timebase for the measurement to 50µs will cover even the highest time delay possible.

To capture the measurement, a VI (Virtual Instrument) from Tektronix is used. This VI comes with the Oscilloscope (See Tektronix Drivers & Applications CD) and is called “Tektronix TDS 200 1000 2000 Series Edge Triggered Acquisition”. Following changes were made to the original VI to customize it to the demands of the project:

- Changing the timebase from 500µs to 50µs
- Changing the vertical range from 10V to 5mV
- Implementing a second channel to allow triggering on channel 2
- Implementing a bandpass filter
- Implementing a file path control to simplify the setting of the file location
- Implementing a routine to write the measurement data to the selected spreadsheet
- Modifying this routine to enable appending data to an existing file

Filtering The Signal:

Unfortunately there is still a lot of noise on the signal. To compensate that, a band pass filter is implemented in LabVIEW. The cutoff frequencies are set to 2.5 MHz and 3.5 MHz. So all noise below or above these frequencies will be cleaned from the signal. As the step motors cause a lot of noise, they will be disabled before each measurement. The following images show the result of the filter and disabling the motors.

![Unfiltered and filtered signal](image-url)
Storing The Measurements:
The measurement results will be saved in the selected location. It can be chosen whether all the measurement results should be saved in separate files or appended to one single file. The file format will be a LabVIEW specific spreadsheet. These files can be viewed with any editor or easily imported to various spreadsheet processing programs (e.g. Microsoft EXCEL). As it was not defined whether the peak-to-peak voltage or the voltage over time will be used for further data analysis, all the captured voltage values over time will be written to this spreadsheet and separated by lines. For each measurement, LabVIEW will capture and save 2500 voltages over 50µs. This allows a very detailed analysis in further data processing but creates quite sustained spreadsheets as well. If only the peak-to-peak voltage will be used, these spreadsheets can be sorted with routines or macros.

Stepping Procedure For Moving Positioning Device:

Before starting the automated measurement, the hydrophone needs to be moved to the closest position centred in the ultrasound beam manually (See 2.11 “Finding the signal”). Then it will move to the outer left point (negative direction). The amount of steps to do is defined as:

\[
\text{Field width \times \frac{X [mm]}{2} \times \frac{67 \ [steps]}{1 \ [mm]} \times 2}
\]
There it will capture, filter and store the first measurement in the location selected by the user (if “Appending data to existing file” is disabled, a location and filename for each measurement position needs to be set manually). Then the hydrophone will be moved to the next position in this row. The distance in between the measurement points is defined by the resolution of the X-axis (Δx) and the amount of steps to do are calculated according to:

$$Δx \times 67 \text{ [steps]} \times 2$$

The program will continue capturing measurements and increasing the X-position in positive direction until it comes to the last point of this row. The amount of measurements per row is set by the field width (X) and the resolution of the X-axis (Δx). The resulting number of measurements is:

$$\frac{\text{Field width } X \text{ [mm]}}{Δx \text{ [mm]}} + 1$$

When a row is completed, the positioning system will be moved along the Z-axis in positive direction to the next row. The distance in between rows is the resolution of the Z-axis (ΔZ) and therefore the amount of steps to do is:

$$ΔZ \times 67 \text{ [steps]} \times 2$$

To avoid confusion in the spreadsheet, the sequence of measurements for each row will be from the most negative to the most positive position. So the hydrophone needs to be moved back to the most negative position of the new row. As this is the whole field width, the amount of steps to do results from:

$$\frac{\text{Field width } X \text{ [mm]}}{1} \times \frac{67 \text{ [steps]}}{1 \text{ [mm]}} \times 2$$

Now the current row will be measured position after position again. This whole procedure will be executed until the last row has been measured completely. The amount of rows is set by the field length (Z) and the resolution of the Z-axis (Δz). The resulting number of rows is:

$$\frac{\text{Field length } Z \text{ [mm]}}{Δz \text{ [mm]}} + 1$$
2.13 Analyzing The Ultrasound Pulse

The picture shows a characteristic ultrasound pulse.

![Ultrasound Pulse Image]

Figure 2.21 – Characteristic ultrasound pulse

To get a detailed image of the signal, following oscilloscope settings should be applied:

<table>
<thead>
<tr>
<th>Oscilloscope settings for detailed image</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Channel 1</strong></td>
</tr>
<tr>
<td><strong>Channel 2</strong></td>
</tr>
<tr>
<td><strong>Trigger level</strong></td>
</tr>
<tr>
<td><strong>Time base</strong></td>
</tr>
</tbody>
</table>

Table 2.10 – Settings for detailed image
3. Results

When the system had been completed, some measurements had been done. One of these measurements is shown below here. The graph to the left below shows the measurement that has been done, and on the right side the theoretical beam profile is shown. The following measurement was done in distances from 20mm, 40mm, 80mm, 160mm away from the transducer. In the axis across the transducer (X-axis) the measurement has been taken in 11 positions, with a distance of 1mm between each position. On the horizontal axis the distance from the transducer is shown in the X-axis. So 0 means that the hydrophone is right in front of transducer and 10 for example means that is has moved 10 positions to the right. The Y-axis indicates the measured peak-to-peak-voltage for each position.

The first row is on a distance of 20mm. If the graphs are compared the first obvious thing is that they are not the same. In fact they differ a lot from each other. But there are some similar things as well. There are two peaks in figure, and then further to the middle the graph goes down. The major difference is that the theoretical graph has another peak in the very middle and the measurements graph doesn’t. This can be because the distance between the measurements was chosen to big.

![Graph](image1)

**Distance between transducer and hydrophone: 20mm**

The second row has been made on a distance of 40mm. Again the left graph is the measurement that has been done and the right side the theoretical beam profile for this distance. If these graphs are compared, again there are some similar things but in a general view they don’t look like each other. With a little bit of imagination 2 peaks can be seen in the left graph just like as in the right one.

![Graph](image2)

**Distance between transducer and hydrophone: 40mm**
If the 3\textsuperscript{rd} and the 4\textsuperscript{th} row are compared to the theoretical beam profiles, the conclusion can be made that they are very similar. The 3\textsuperscript{rd} row is on a distance of 80mm and the 4\textsuperscript{th} row is on a distance of 160mm. The theoretical beam profiles show that the 3\textsuperscript{rd} row has a sharper peak than the 4\textsuperscript{th} row, what also is shown in the graphs of the actual measurements.

4. Conclusion

The result shows that the measurement system in general works well. As the tested transducer is not a high precision device, this may explain why the theoretical and the measured beam profile differ from each other, especially in the close distance. Quite a few changes to the automated measurement program were implemented (e.g. disabling motors during measurements, filtering the signal) but for some reason there is still a lot of noise on the signal. Until the end of the project the source of this noise could not be identified. So that undefined noise might affect the measurement results.
5. Appendix

5.1 Water Tank
5.2. Acoustic Window
5.3. Stepping Procedure
5.4. Transducer Mount
5.5. Hydrophone Mount

All dimensions in mm

SCALE
1:1

HYDROPHONE_MOUNT

H.I.O

DATE:  2-12-09

DRAW N°:  5
<table>
<thead>
<tr>
<th>SCALE</th>
<th>HYDROPHONE_MOUNT</th>
<th>H.I.O</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:1</td>
<td></td>
<td>DATE: 2-12-09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DRAW #: 6</td>
</tr>
</tbody>
</table>
5.6. Motor Mount
5.7. Driver Mount
5.8. Detailed Program Structure
5.9. Electrical Circuit