Hydrophone measurements of ultrasound pressure field

Aims:

The purpose of this exercise is to learn more about how the ultrasound pulse looks, how beamforming works, about thermal noise and the concept of the signal to noise ratio (SNR). Attached to this exercise are measurement results from a setup in the laboratory where the pressure field is measured using a hydrophone. The protocol for the measurements is included below. The exercise is done individually using Matlab.

Laboratory setup

Equipment

- GE Vingmed Vivid 7 Ultrasound scanner, equipped with a 2.5MHz phased array probe
- Digital oscilloscope
- Positioning robot
- Computer equipped with Matlab to control the robot position and to save the collected data
- Water tank. The tank is filled with room tempered and de-gassed water.
- Needle hydrophone

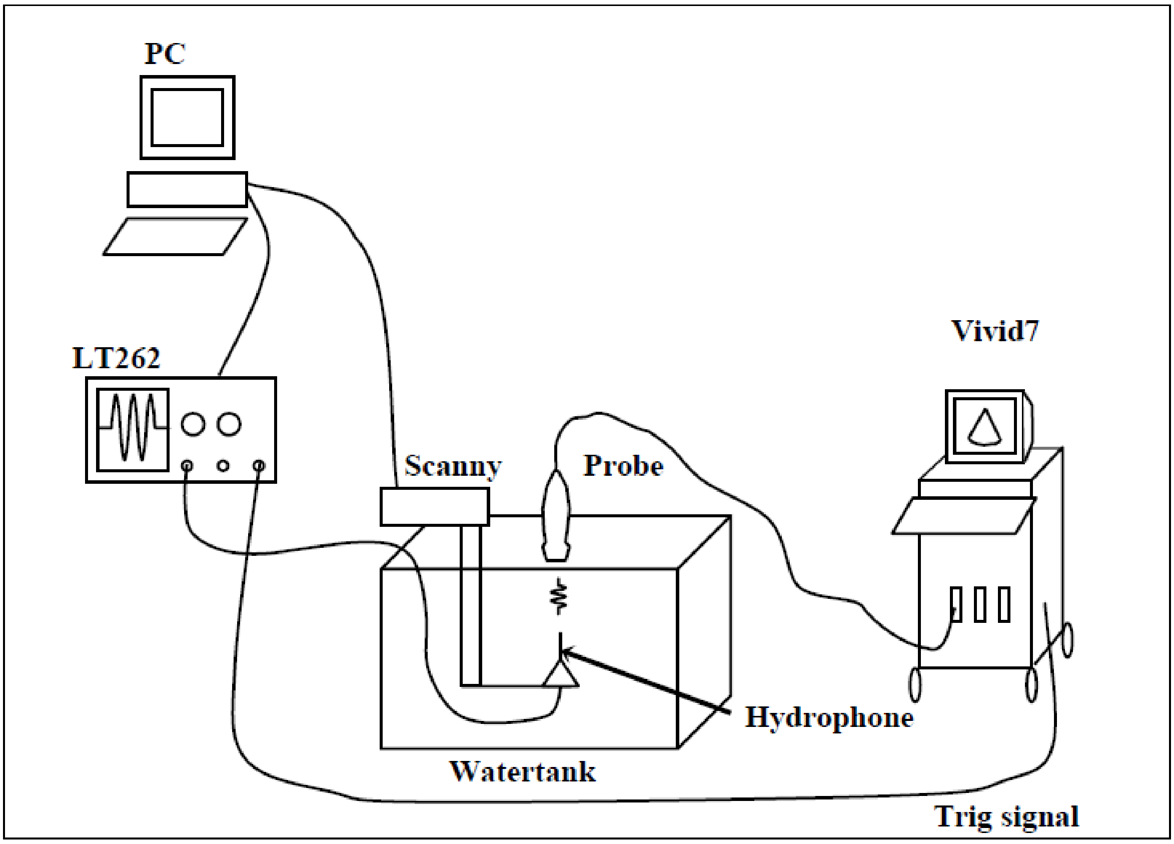

Figure 1 Laboratory setup

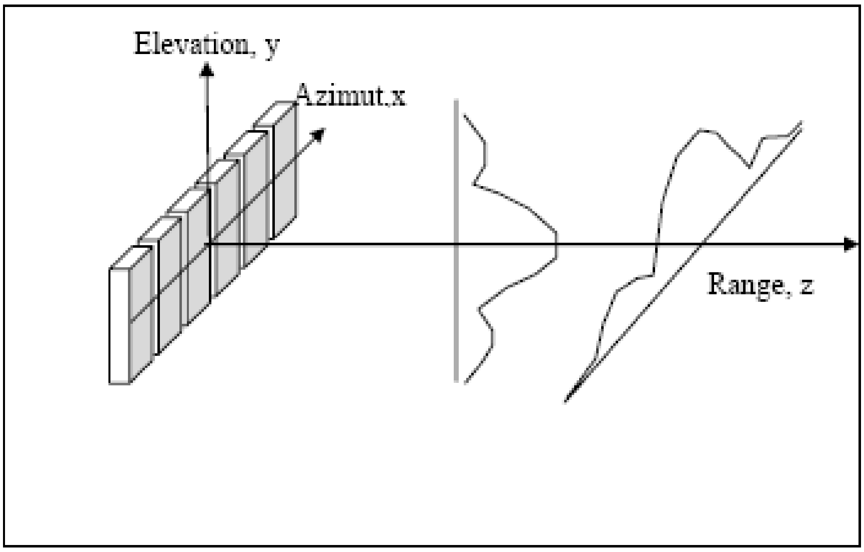

Figure 2 Axis definition

Measurement 1 – Pulse in focus

First, we measure the pulse in focus for different power levels.

- The hydrophone is placed at more than 6cm depth
- The probe is carefully placed just at the water surface. It is *very* important not to submerge the probe. It costs more than NOK100.000. Make sure that there are no bubbles at the probe surface or the hydrophone, as they can cause total reflection, and thus, useless images. Bubbles on the probe can be removed with the finger. Bubbles on the hydrophone can be removed using a syringe filled with water and gently blowing away the bubbles on the hydrophone.
- The scanner is set to operate in M-mode, and the M-mode cursor is pointed directly downwards.
- The transmit pulse is set to 1.67MHz. We start off using a power of -14dB
- The oscilloscope receives a trig signal from the front end controller card (FEC), to aid in capturing the pulse. Enable external trig on the oscilloscope.
- The robot is used to position the hydrophone at 7cm distance from the probe surface.
- Adjust the oscilloscope to capture the pulse. That means you have to adjust the time/div and V/div to get a nice image of the pulse.
- Use the robot to find the point where the pulse has its maximum strength. This is the profile center. Record the pulse and save to file.
- Enable averaging using 10 pulses and record the pulse again.
- Repeat for 0dB and -8dB settings.

Mesurement 2 – Azimuth scan (X)

- The laboratory software is used to move the robot in the X-direction (Y and Z coordinates are constant). After the scan is finished, save to file. The resulting file contains pulses for each of the azimuth positions.

Measurement 3 – Elevation scan (Y)

- As for measurement 2, but the hydrophone is moved in the Y-direction.

Measurement 4 – Azimuth and elevation scans using reduced aperture

- The aperture is electronically reduced using the software setup of Vivid 7.
- Redo measurements 2 and 3 for the new reduced aperture.
- Later you are going to calculate how large the actual aperture was, based on these experiments.

Measurement 5 – Pulse shape in the near field

- The aperture is reduced to approximately 6 elements. The power is set to -8dB and the hydrophone is set to 2cm distance from the transducer.
- Measure the pulse using averaging. Due to the short propagation distance and the small aperture, the pulse will be little distorted and without significant edge wave effects.

Measurement 6 – Scan along transducer axis

- In this scan, the X and Y coordinates are kept constant, while Z is allowed to vary. The power setting is -12dB. The origin of the hydrophone's reference system is straight below the probe at a distance of 3 cm.

Measurement 7 – Grating lobes

- Grating lobes may be visible when you try to steer the beam far out to the side, using a transducer with large elements (large compared to the wavelength). This happens because you get constructive interference in other directions than the main or side lobes. We will try to demonstrate this by increasing the frequency and steer the beam to the edge of the sector.

Matlab exercises

Use Matlab to analyze the data sets. Make a script to generate plots. The plots should be included in your solution report.

The data files contain the variables *Position*, *RF* and *Ts*.

- RF: Array containing the pulse measurements. The signals are given in Volts. Every column is a measurement. RF(m,n) is sample number m in measurement number n.
- Position: Array with four rows and the same number of columns as RF. The 3 first rows contain the x, y and z positions for each measurement. The last row contains the time delay from the trig signal (i.e time since last pulse transmit) to the start of the recording, measured in seconds.
- Ts: Sampling interval in seconds.

Task 1: Pulse shapes in focus

Plot pulse shapes in focus vs. time. Use vertical axis in mV and horizontal axis in μs. Set axis labeling and title on all plots. Use windows with 4 subplots.

- Low power (-14dB) without averaging
- Low power (-14dB) with averaging
- Medium power (-8dB) with averaging
- High power (0dB) with averaging

Bonus: The sensitivity of the hydrophone is given as 25.1 nV/Pa. Use the number for the sensitivity and plot again using kPa on the vertical axis.

Task 2: Frequency spectra, signal to noise ratio

Estimate the frequency power spectra (FFT) for all the pulses, measured in focus, and plot in a new figure window using 4 subplots. Limit the x-axis to 0.5-50 MHz, and use dB on the y-axis.

Plot the noise spectra in the same plot as the pulse spectra. Use different line types/colors for signal and noise. Avoid normalizing the frequency axis, so that it is possible to compare the power of the signal and the noise.

Hints:

- Quick Matlab code for generating spectra (define missing variables).

  ```
  freqtab = linspace(-0.5, 0.5, Nfft+1)*fs; freqtab(end) = [];
  pow_spect = 20*log10( abs( fftshift( fft( sig, Nfft) ) ) );
  ```

- When you are estimating the frequency spectra for the pulses, it can be wise to only select the part of the signal containing the pulse.
- The noise spectra are best estimated using the remainder of the signal after the tail of the pulse.

Questions:

- What frequency yields the strongest signal? What is the approximate signal to noise ratio (SNR) for the different pulses on this frequency?
- If the noise is white, it should have approximately equal power for all frequencies. Is the noise white? If not, can you explain why? How does this influence the SNR estimates above?
- How much SNR should you gain when averaging over 10 pulses? Do you see the same gain in the results?
- Measure the peak power at the fundamental frequency when increasing power from -14dB to -8db to 0dB? Is this as expected?
- Measure the peak power of the second harmonic frequency when increasing power from -14 dB to -8dB to 0dB. Compare to the corresponding results for the fundamental frequency. Can you explain? How does this affect the pulse shape?

Task 3: Beam profile

Load the files with the azimuth- and elevation scan of the beam profile with full azimuth aperture. Open a new figure window. Plot the intensity (power) of the pulses vs. X- and Y-position in separate subplots. Use dB-scale and normalize by dividing with maximum value. Use mm as unit on the horizontal axis.

Hints:
Intensity: Square all the elements and sum along the column
Normalization: PdB_norm=PdB-max(PdB);

Questions:
The definition of the beam width is where the intensity has fallen 6 dB from its maximum value.

- How large are the beam widths in mm for azimuth and elevation? Use two sided beam width in the calculations.

The dimension of the transducer is 1.853 cm in azimuth direction, and 1.2 cm in elevation. The acoustic lens on the probe has an elevations focus at about 7 cm. Azimuth focus is set to 7 cm. There is no apodization when transmitting, i.e. rectangular apodization.

- Calculate the wavelength λ and the F-number in azimuth and elevation.
- What function describes the beam profiles according to theory? Create a suitable position axis and plot the power of this function vs position in Matlab, using logarithmic scale. Estimate the beam width, distance to the sidelobes, and the sidelobe level. How should this function be rescaled (along the x-axis) to describe the beam profiles in azimuth and elevation.
- Are the measured beam profiles as expected? (Beam width, distance to sidelobes, sidelobe level).

Task 4: Beam profile with reduced aperture

Plot azimuth and elevations beam profiles measured with reduced azimuth aperture. Estimate the azimuth beam width and the distance to and level of the sidelobes, and use this to estimate the azimuth aperture. The probe has 3(elevation) x 64 (lateral) elements. How many were used?

Task 5: Beam profile along the beam axis

Load the files with the pulses scanned along the beam axis. Make a plot of the intensity (power) as a function of distance from the probe in mm. Note that the z-values in the. At what distance is the intensity at its maximum value? Comment.

Task 6: Two-dimensional grayscale image

Use the following code to make a grayscale image of the azimuth profile:

```
load('profile_Az_7cm_full.mat');
timescale=Position(4,1)+Ts(1)*[1:size(RF,1)]; %Ts= Sampling frequency
speedofsound=1500;%m/s
depthscale=timescale*speedofsound*1e3;%mm
azimutpositionscale=Position(1,:)*1e3; %mm
imagesc(azimutpositionscale,depthscale,RF); %Negative pressure> dark, positive > bright
colormap(gray);
```

Now use two subplots and make images with full and reduced azimuth aperture. Comment on lateral resolution, and what happens at the edges.