Simulation and Evaluation of Small High-Frequency Side-Scan Sonars using COMSOL

Jonas Jonsson*[1], Erik Edqvist[1], Henrik Kratz[1], Monica Almqvist[2], and Greger Thornell[1]
[1]Ångström Space Technology Centre, Uppsala University, Uppsala, Sweden,
[2]Department of Measurement Technology and Industrial Electrical Engineering, Lund University, Lund, Sweden.
*Corresponding author: Box 534, 751 21 UPPSALA, Sweden, jonas.jonsson@angstrom.uu.se

Abstract:
High frequency side-scan sonar, to be fitted on a miniaturized submersible explorer, have been simulated and built. The purpose of this study is to see if COMSOL Multiphysics can be used to predict the performance of the sonar, especially the beam width, setting the resolution of the system. Four models were created, from simple 2-D geometries to more complex 3-D models. The simulated beam widths were compared with measurements to see which of the models agreed best. It was found that all models agree with the experimental results to varying degrees, and mostly with a difference of less than 6%. . It was found that the simplest model agreed best with the measurements, closely followed by the most complex model. Also taking the computational load into consideration the simpler model might then be a better choice to use.

Keywords: Sonar, beam width, acoustic imaging

1. Introduction

High frequency side-scan sonar, to be fitted on a miniaturized submersible explorer currently under development at the Ångström Space Technology Centre, Sweden, have been simulated, using COMSOL Multiphysics, and built. The sonar system had to be tailored to fit the limited space available in the vehicle, being the size of two soda cans stuck end-to-end together, enabling it to pass through the narrow glacial boreholes to explore the otherwise so unreachable subglacial lakes, which can be found beneath the up to kilometers thick glacial ice sheets [1]. These water bodies, mostly found in Antarctica, are of high interest to scientists since they are thought to accommodate a unique biota, having been sealed off from the surrounding environment for as much as millions of years, and have yet to be explored.

A side-scan sonar, usually mounted on a ship hull or on a towfish, is an acoustic imaging system. It works by sending out fan-shaped acoustic beams as the sonar is moving along a path. By switching between ensonifying and listening for echoes at a rate matching the speed of the sonar's movement, a stack of acoustic fans, progressively adds line after line, assembling an acoustic image of the bottom.

The shape of the acoustic beam sent out by the sonar should be narrow in the direction of travel, for higher resolution, and broad in the perpendicular direction, for a large coverage out to the side of the submersible. The beam width is dependent on the dimension of the sonar and the frequency used [2]. The longer the sonar is, and the higher the frequency is, the narrower is the beam. A trade-off thus has to be made of the dimensions, restricted by the vehicle size, and frequency of operation, set by the electronics controlling the sonar.

The purpose of this study is to see if COMSOL Multiphysics can be used to predict the performance of the sonar, focusing on the beam shape width which sets the resolution of the system.

2. Theory

As a measure of the beam width, the half-width half-maximum, HWHM, angle can be used. This is the half angle of the main lobe at zenith, seen from the transducer surface, where the sound pressure level has dropped to half of the maximum, that is -3 dB.

The equation describing this angle, θ_{3dB}, for a simple line element is

$$\theta_{3dB} = 25.4 * \lambda / L \,, \qquad (1)$$

where λ is the wavelength and L is the length of the transducer [3].

This equation shows, thus, that the larger the transducer element is, the smaller is the beam angle. However, the size of the sonar for DADU is restricted by the size and weight limitations of the submersible itself. For the wavelength, a limiting factor is the attenuation of the acoustic wave in water, which increases with the frequency. Taking these factors into consideration, the sonar elements where designed to be 50 mm long, referred to as the long side, and 1 to 2 mm wide, referred to as the short side, and to have an operating frequency just under the MHz domain, between 500 to 700 kHz, as determined by thickness, essentially.

3. Modelling

COMSOL Multiphysics 3.5, with the Acoustics Module, was used to predict the behaviors and performances of different sonar designs. Four models, labeled A through D, were selected and used in the study. The simplest model, Model A, used only 2-D geometries with a 1-D sonar transducer element, having a preset pressure amplitude, Figure 1. Increasing in geometric complexity Model B was a 2-D geometry with a 2-D sonar element, Figure 2, and Model C a 3-D geometry with a 2-D sonar element, Figure 3. For the most complex model, Model D, full 3-D geometries were used, Figure 4.

The models were built with PMLs surrounding the geometries. For models A and C the transducer was represented by a line element and a rectangular element, respectively, both with a preset pressure amplitude. For model B and D, the transducer elements were modeled with the material properties for the specific PZT materials used for the transducer, as a 2-D rectangle and a 3-D element, respectively.

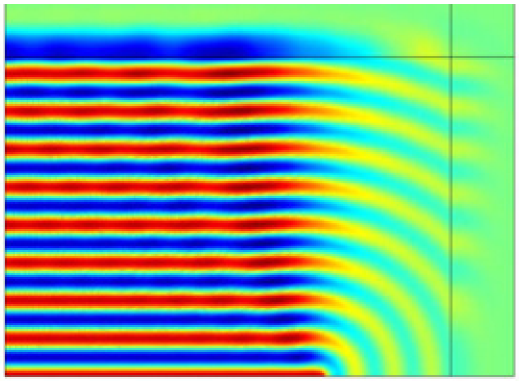

Figure 1. Solution of the acoustic pressure for the 2-D model with a 1-D element, Model A.

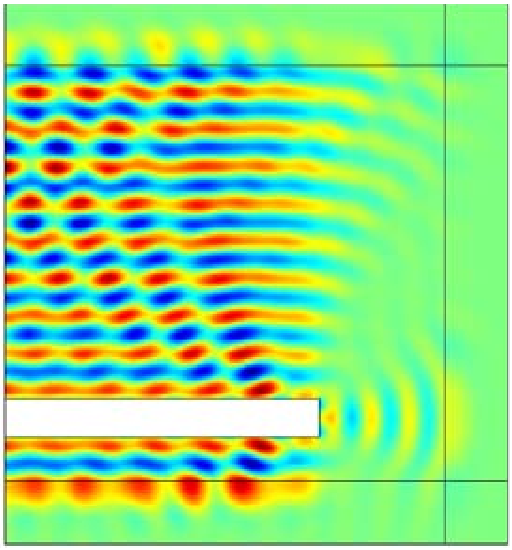

Figure 2. Solution of the acoustic pressure for the 2-D model, with a 2-D element, Model B.

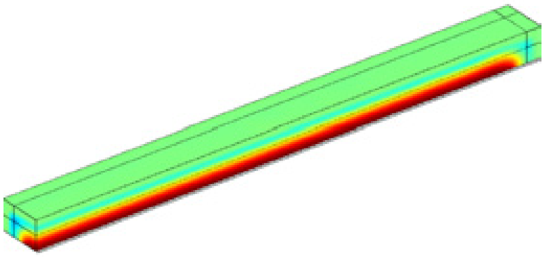

Figure 3. Solution of the acoustic pressure for the 3-D model, with a 2-D element, Model C.

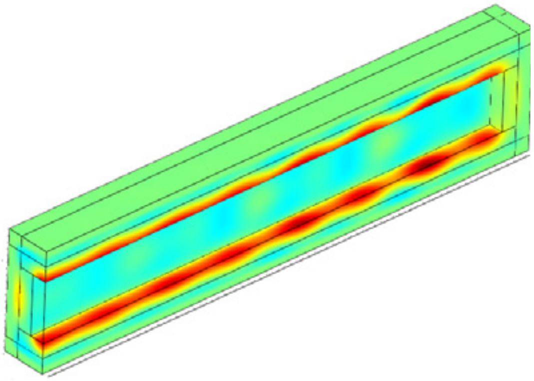

Figure 4. Solution of the acoustic pressure for the full 3-D model, Model D.

In all cases, the medium surrounding the transducers in the models were set to water at a temperature of 20ºC.

The models outer boundary conditions were set to radiation, except for where there were symmetry lines, which were set to sound hard (wall) boundary. Symmetries were used where possible, having one symmetry line in models A and B, and two symmetry planes in models C and D.

The meshing density was set to twelve degrees of freedom per wavelength.

The sonar was simulated using all four models. The beam shapes were plotted for a distance equal to that of the measurements, using a far-field variable (Full integral), Figure 5, representing one example. The obtained HWHM angles are collected in Table 1.

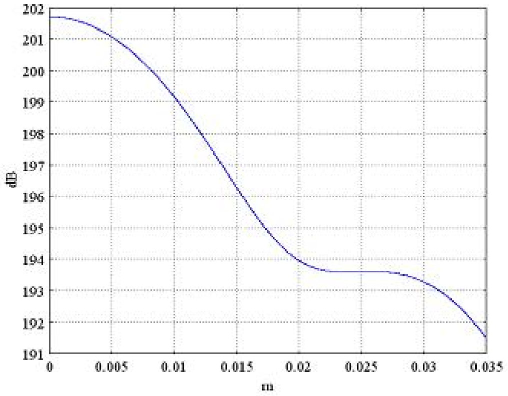

Figure 5. Simulated half-width beam shape.

Table 1. Comparison of the simulated and the measured HWHM angles for the sonar built.

Sonar HWHM angle comparison				
Sonar side	Model A	Model B	Model C	Model D
Long	1.66	1.77	1.66	1.66
Short	34.7	46.7	38.2	36.2

4. Physical Measurements

The sonar were built in a brass frame where the transducer element is encased in a backing layer, reducing the acoustic emission in unwanted directions, and a matching layer on top, increasing the transmittance into the water, Figure 6. Measurements were performed in a water tank, scanning a hydrophone at a certain distance in front of the sonar. This was done along both the short side and the long side of the sonar. From the resulting beam shape plot, the HWHM beam angle could be found for both the vertical and the horizontal lobes of the sonar, Figure 7, representing one example. The HWHM angles were found to be 1.68 degrees for the long side and 34.2 degrees for the short side.

Figure 6. A manufactured sonar element mounted in a brass box.

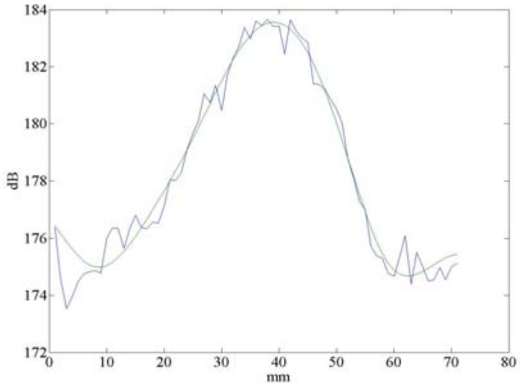

Figure 7. Beam shape of the long side of sonar, showing a jagged raw data curve with a smooth filtered curve on top.

5. Discussion

The results from the simulations and the measurements of the HWHM angles were compared to see which of the models agreed best with the measurements. It was found that models A and D agreed well with the measurements, differing with less than 1% on the long side and less than 2% an 6% on the short side, respectively. Model C also differed only within 1% on the long side, but with 12% on the short side. Model B differed with almost 6% on the long side and over 36% on the short side.

Further investigations regarding discrepancies between modeling and measurements are ongoing.

6. Conclusions

A working sonar, small enough to fit the miniaturized submersible explorer, has been modeled, manufactured and tested. The different COMSOL models studied agree with the experimental results to varying degrees, depending on the sonar geometries and the models. It was found that the simplest model, Model A, agreed best with the measurements, followed by the most complex Model D. Also, taking the computational time and load into consideration, the simpler model appears a better choice for predicting the beam shape characteristics of the sonars than the more complex ones. It was also found that Model B had a much larger deviation from the experimental data than the other models, making this model less suitable.

7. References

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