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

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Introduction

High frequency side-scan sonars, 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 in the limited space available in the vehicle, being the size of two soda cans stuck end-to-end together, enabling it to go down through the narrow glacial boreholes to explore the otherwise so unreachable subglacial lakes, which can be found at the bottom of the up to kilometers thick glacial ice sheets. These water bodies, mostly found in Antarctica, are of high interest to scientist since they are thought to habit 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, and 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. The longer the sonar is, and the higher the frequency is, the narrower is the beam width. A trade-off had thus to be made of the size, restricted by the vehicle size, and frequency of operation, set by the electronics controlling the sonar.

The purpose of this study is to establish how well COMSOL Multiphysics can characterize the performance of the sonars, especially the beam shape width which sets the resolution of the system.

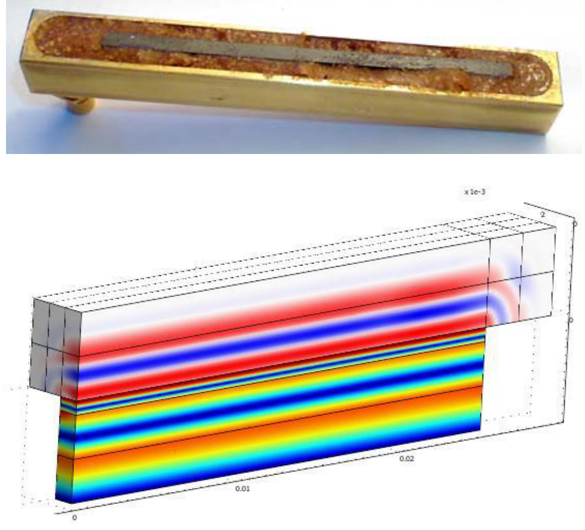

Figure 1: A manufactured sonar element fixed in a brass box (top) and a COMSOL 3-D model of the element (bottom).

Use of COMSOL Multiphysics

COMSOL Multiphysics 3.5 was used, with the Acoustics Module, in order to predict the behaviors and performances of different sonar designs. Several models were created, from using simple 2-D geometries to more complex 3-D models. 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 element, having a preset pressure amplitude. For the most complex model, Model D, full 3-D geometries, with the specific material data for the piezo-ceramics and drive voltage, were used. The other two models were in between these two in complexity, where Model B was a 2-D geometry with a 2-D sonar element and Model C a 3-D geometry with a 2-D sonar element.

The models were built with PMLs surrounding the model geometries, and the boundary conditions were set to radiation, except for the symmetry lines, which were set to sound hard (wall) boundary. For meshing the model geometries the density was set to twelve degrees of freedom per wavelength, with the frequencies used by the sonars being between 495-666 kHz. By using symmetries where possible the computational load of the models could be lowered, having one symmetry line for the 2-D models and two symmetry planes for the 3-D models. The beam shapes were plotted for a distance equaling that of the measurements performed on the self-manufactured sonars and the half-width half-maximum (HWHM) angles where then compared between the simulations and measurements.

Expected Results

Each of the four sonars, labeled Sonar 1 through 4, were simulated using the four different simulation models. The results, such as in Figure 2, were then compared with the measurements of the beam pattern performed on each of the sonars, such as Figure 3. The HWHM angles were then compared between the simulations and the measurements to see which of the models agreed best with the measurements.

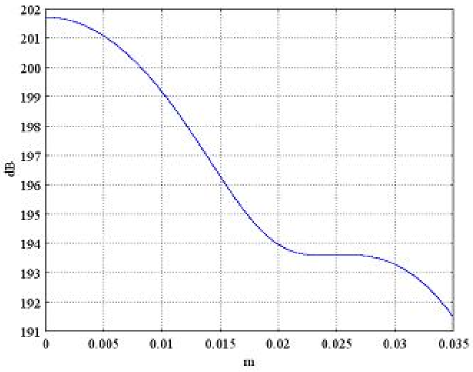

Figure 2. Simulation of the half-width beam shape at 500 kHz and at a distance of 357.2 mm using Model B.

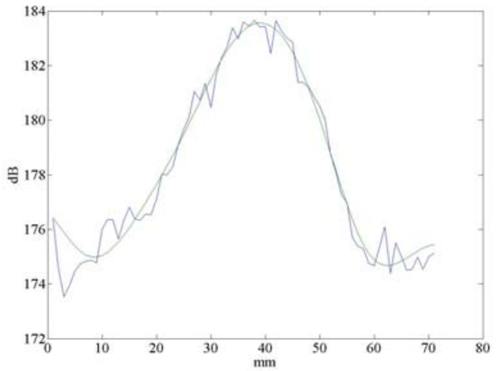

Figure 3. Measurement of the beam shape at 500 kHz and at a distance of 357.2 mm.

Conclusion

Working sonars, small enough to fit the miniaturized submersible explorer, has been modeled, manufactured and tested. The different COMSOL models agree with the experimental results to varying degrees, depending on the sonar geometries and the models, but mostly within 10 %. It was found that the more complex Model D agreed very well, as expected, with the measurements, but so did also the simplest model, Model A. Taking the computational time and load into consideration the simpler model could then be a better choice for predicting the beam shape characteristics of the sonars than the more complex. It was also found that Model B had a much larger deviation from the experimental data than the other models, making this model setup less suitable to use.