Acoustics'08 Paris
June 29-July 4, 2008
www.acoustics08-paris.org

Finite Element Modeling of 2-D Transducer Arrays

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There are a number of factors limiting the performance of transducer arrays for active sonar systems including, the crosstalk, and structure interactions, which affects the directivity patterns and the Transmitting Voltage Responses (TVR). In this paper, a 2D finite element model of active Sonar is constructed to analyze the crosstalk and structure interactions, using ATILA code and GiD graphical interface. In this work, we built several arrays, such as array with and without matching layers, with different filling material, and without housing. The results show how crosstalk and structure interactions affect the sonar performances. A comparison among the results for all the arrays, for the above mentioned cases, is presented.

1 Introduction

The active sonar is a system that allows transmitted and received acoustic signals; it is consisting of both a projector and hydrophone. There are a number of factors limiting the performance of active sonar systems including, the crosstalk, and structure interactions, which affects the directivity patterns and the TVR [1, 2]. Much study of this problem can be found in literature [3]. Several approaches based on numerical methods and experimental methods have been proposed [2, 3].

In this work, the geometry of transducer arrays considered is shown in Fig. 1 [1], composed of six piezoelectric elements, mounted in a housing whose main function is to provide mechanical support for array, and separated by an acoustically and electrically inactive material (Filler) which prevents acoustic wave propagation between elements. A waterproof material is used to protect the piezoelectric transducer elements; this material is usually selected to possess approximately the same acoustic properties than water to reduce energy loss at the water interface. The matching layers at the front face are used to adapt the different acoustic impedances of piezoelectric and water respectively, there are one or more (usually two) matching layer to increase the bandwidth [3].

In this paper we investigate the effect of the crosstalk due to matching layers, filling material and housing on the directivity patterns and the TVR. A 2D finite element model of active Sonar is constructed to analyze the crosstalk, using ATILA code and GiD graphical interface.

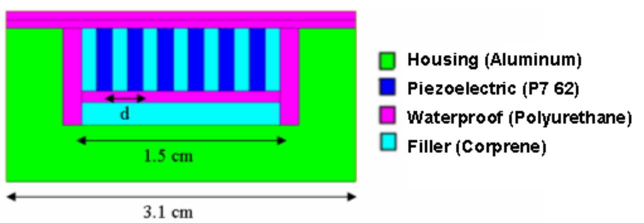

Fig. 1: Geometry of the transducer arrays

2 Modeling tools

2.1 Finite Element Method

FEM is used to simulate behaviors of complex systems. It simulates this behavior by solving differential equations. The method requires the transformation of continuum system to its equivalent discretized system in which the system is divided into elements [4]. FEM is widely used for the modeling of piezoelectric transducers [5, 6].

2.2 ATILA Code

ATILA (Analysis of Transducers by Integrating LAplace equations) is a user interactive finite element code originally developed by many French scientists and engineers during 1980s, and is specifically developed for modeling of two or three dimensional elastic, piezoelectric, magnetostrictive and fluid structures [7]. With ATILA, you can perform static, modal, harmonic and transient analyses of your active structures. Because the formulation is organized around a strong electrical/mechanical coupling and a strong fluid/structure coupling, ATILA is a very efficient design tool for all types of active materials applications: actuators, transducers, sensors, and so on. The program modules are independent, which means that we can customize the software configurations to meet your specific needs. Different types of materials can be used for the design of heterogeneous 2D and 3D structures, and multiple excitation sources (electrical potentials, currents into inductors, displacements, forces and pressures) can be used at the same time. Applications include sonar and acoustic transducers (piezoelectric and magnetostrictive), piezoelectric transformers, piezoelectric and magnetostrictive motors and most piezoelectric and magnetostrictive actuators and sensors (piezoelectric valves, magnetostrictive pumps, piezoelectric accelerometers, magnetostrictive torque sensor).

2.3 GiD

GiD is a graphic program, used to define and prepare data destined to make a numeric simulation, as well as to visualize results. Creating data implies the definition of the geometry we want to study, the materials it is composed, boundary conditions, strength…etc, and other parameters, as resolution strategy. This program generates a mesh (for finite elements, finite differences or other methods) and transfers geometric data. We also do the analysis of the results with GiD, because it is a unified package. Post processing consists of analysis of the results in such a way that it is very easy to interpret them. It is possible to visualize data and results by colors, level curves, labels, vectors, graphics, animations, etc. An essential characteristic of GiD is that it is not specialized in any particular problem. A priori, GiD doesn't take into account any material, or condition, until we load a "problem type". Any user can make its own particular "problem type", in such a way that GiD recognizes the syntax of its own particular simulation program [8].

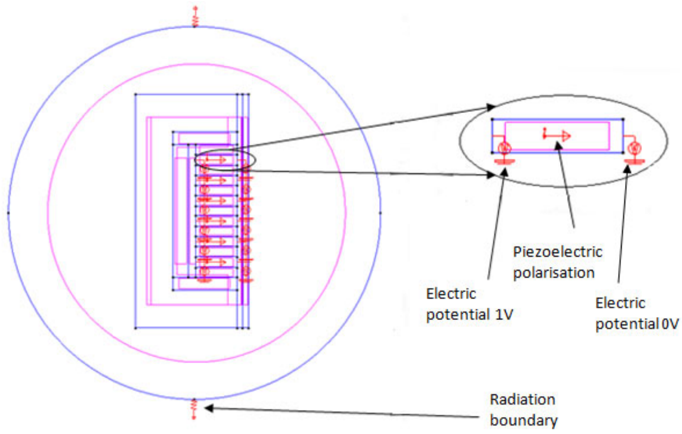

Fig. 2: Boundary condition and piezoceramic polarization

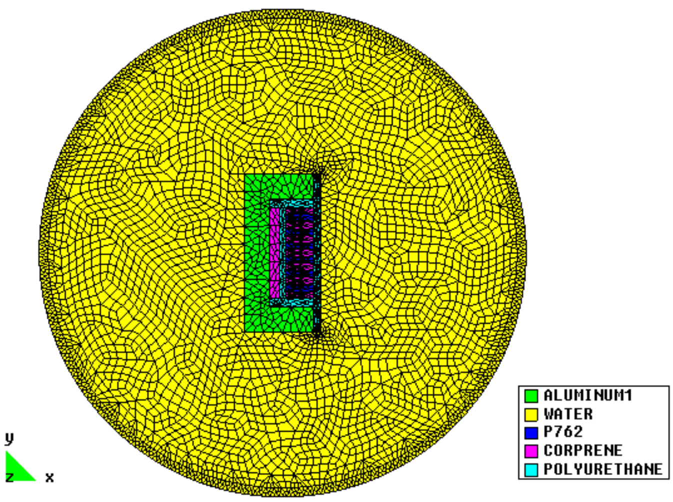

Fig.3: Automatic meshing of transducer arrays

3 Simulation results

A 2D finite element model is proposed and developed here to simulate transducer arrays. The procedure to construct this model is to use GiD for creating data file; we choose the geometry (Fig. 1), and physical properties of the materials. The piezoelectric material used in this work is the P762 ceramic type NAVY I. 2D plane strain condition is considered, that imply the absence of strain in the third geometrical dimension, which physically means a structure with either a very thin (plane stress) or an infinitely long (plane strain) third dimension.

For this simulation we use harmonic analysis with loss. A non reflecting boundary condition to the fluid domain (water) is applied; it creates a limit (not infinite) on the finite element mesh of the fluid. This condition and piezoelectric polarisation are shown in Figure 2. After choosing quadrilateral finite element type to describe the region under study, and size of mesh spacing that is related to the smallest acoustic wavelength used, GiD allows the use of an automatic mesh generator which creates node coordinates and element topologies Figure 3. Finally, when the data file is created, ATILA can run, provides a results file and some file containing arrays for post processing. A graphic display of the directivity patterns and TVR can be easily obtained graphically. Animated views of the vibrating structure or of the pressure in the fluid are also available on graphic terminals.

The typical center-to-center spacing between transducer elements is d=λ/2. Usually, these transducers operate at their resonant frequency. If the resonant frequency is f_r=300 kHz, then the wavelength, is λ=0.5 cm.

In order to investigate crosstalk due to transducer arrays structure, we have built several arrays from the main transducer arrays. The first test is the simulation of transducer arrays (Fig. 1) and Fig. 4a,b present respectively

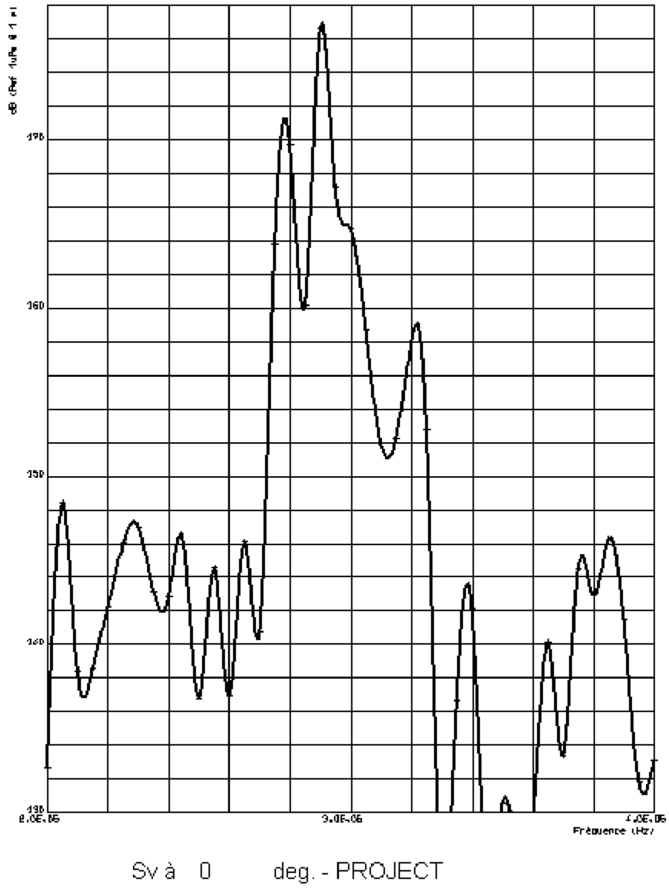

Fig. 4a: TVR of transducer arrays

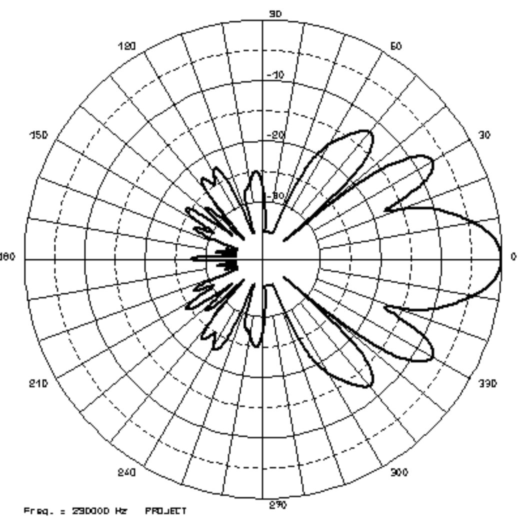

Fig. 4b: Directivity pattern of transducer arrays

TVR and directivity pattern results around the resonance frequency.

The second one is to build the array without mechanical support (Housing) and Fig. 5a,b display simulation results. A comparison between obtained results shows more deformation away from the central frequency for TVR, a reduction of the width of the main lobe of directivity pattern and we note radiation at the rear of the sonar.

We conclude that most of its role as mechanical support for array, it allows the limitation of radiation acoustics on the other side of transducer arrays.

For the third simulation, we build the sonar without matching layers and the gotten results is given in Fig. 6a,b. A TVR graph of sonar without matching layers it is not perturbed, and a narrow main lobe of directivity pattern is obtained. These results imply that matching layers are source of crosstalk, and confirm that matching layers increase the bandwidth.

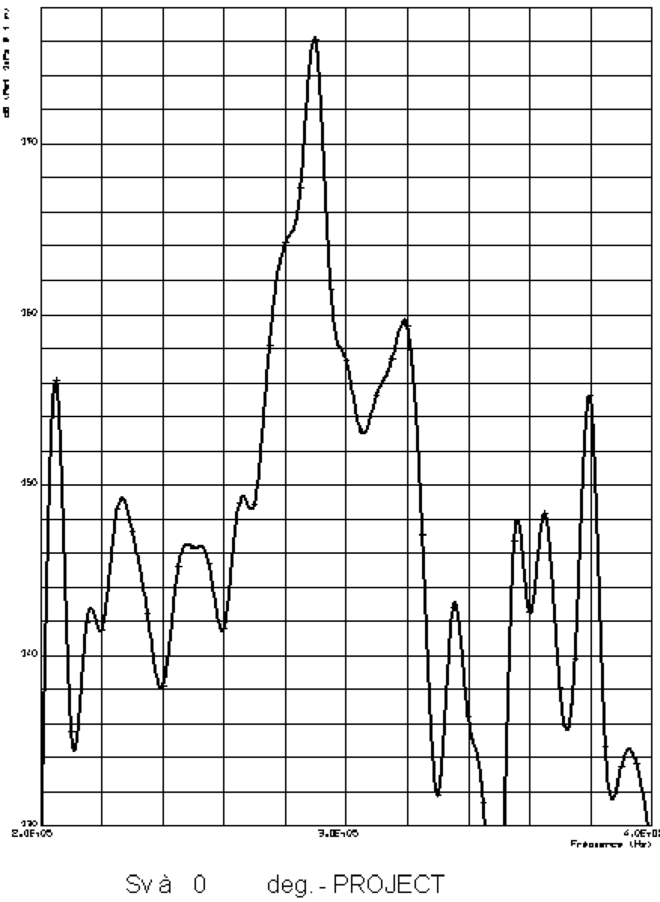

Fig. 5a: TVR of transducer arrays without Housing

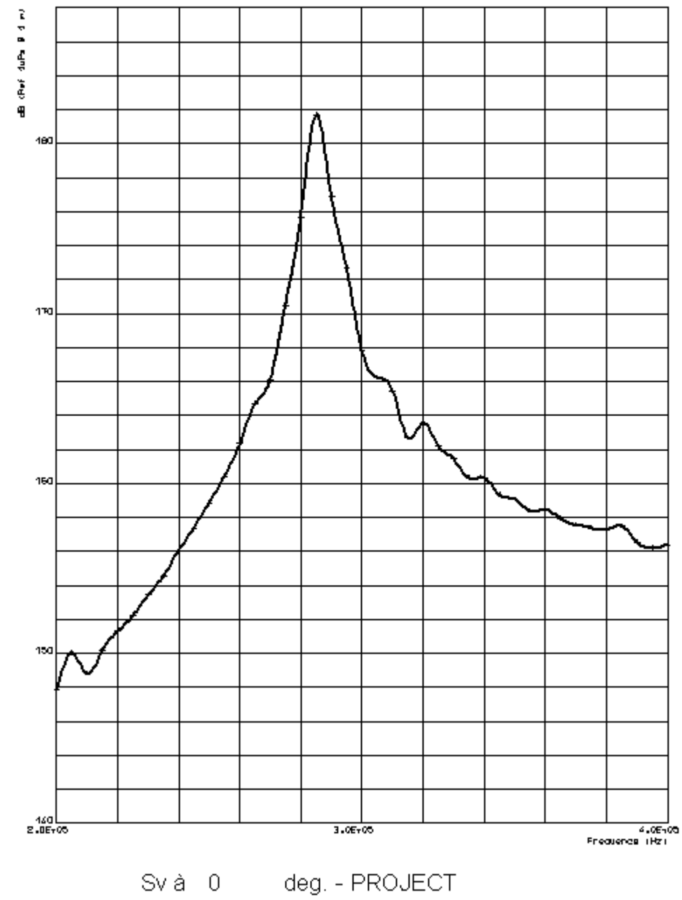

Fig.6a: TVR of transducer arrays without matching layers

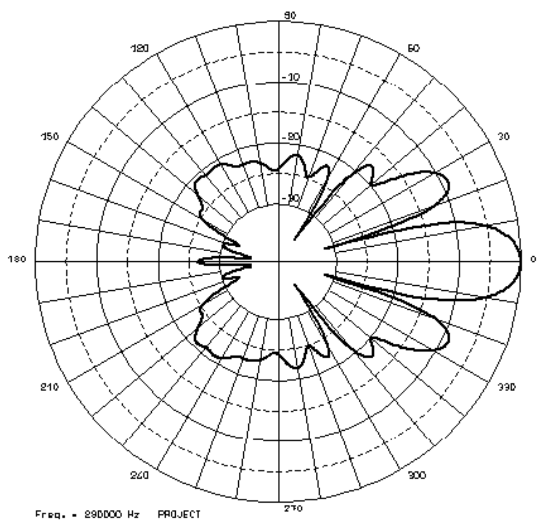

Fig. 5a: Directivity pattern of transducer arrays without Housing

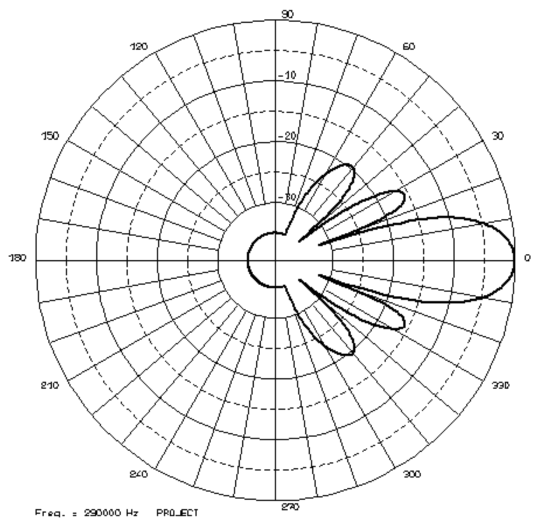

Fig. 6b: Directivity pattern of transducer arrays without matching layers

The fourth case, who the results shown in Fig. 7a,b. We simulate the transducer arrays with matching layers but without filling material. For this raison, we replaced the filling material (Corprene) by castor oil, which has almost the same characteristics as water. The absence of the filler has caused strong perturbation of TVR about ten dB away from the central frequency, a large main lobe of directivity pattern and important side lobes. These results show that filling material reduces the crosstalk between the transducer elements, but it decreases the width of main lobe of directivity pattern.

The last simulation, we have built transducer arrays without matching layers and without filling material. A comparison between Fig. 6a, Fig. 7a and Fig.8a indicate that matching layers are a main source of crosstalk. But directivity patterns results confirm that filler decreases the width of main lobe.

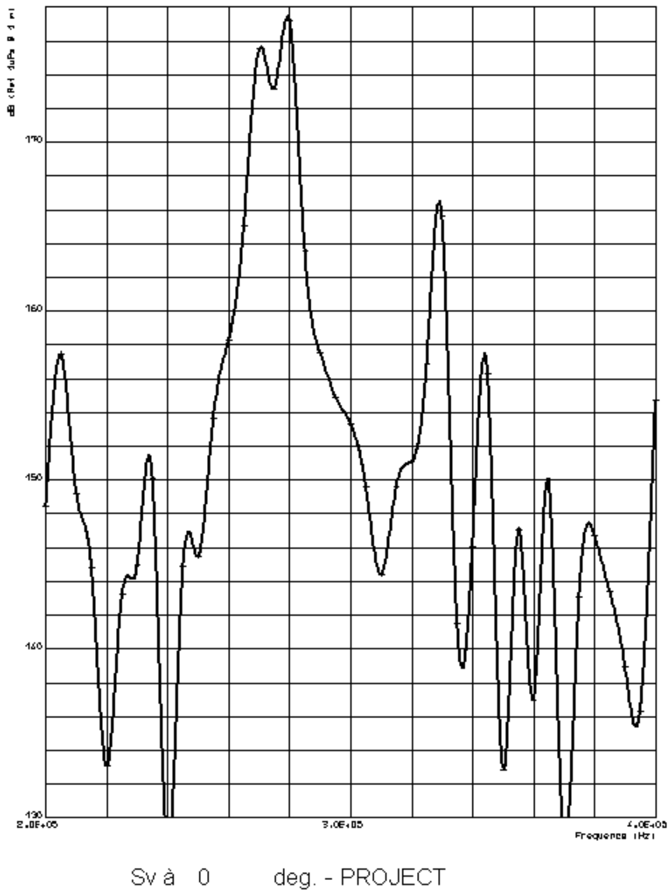

Fig. 7a: TVR of transducer arrays without Filler

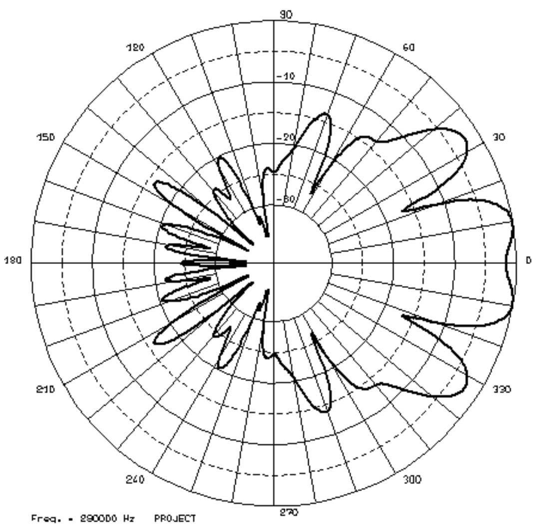

Fig. 7b: Directivity pattern of transducer arrays without Filler

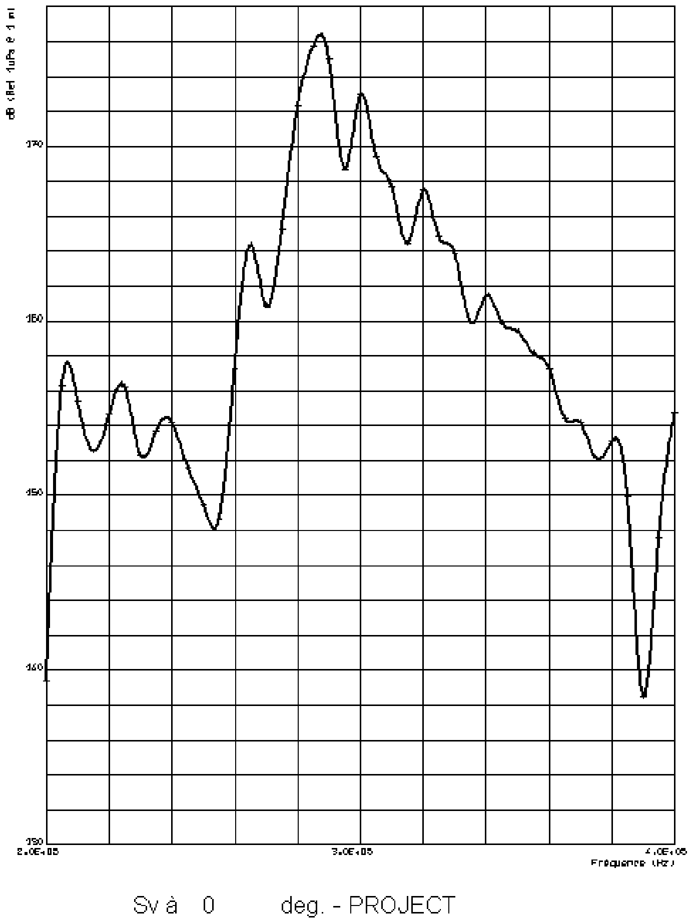

Fig. 8a: TVR of transducer arrays without Filler and Matching layers

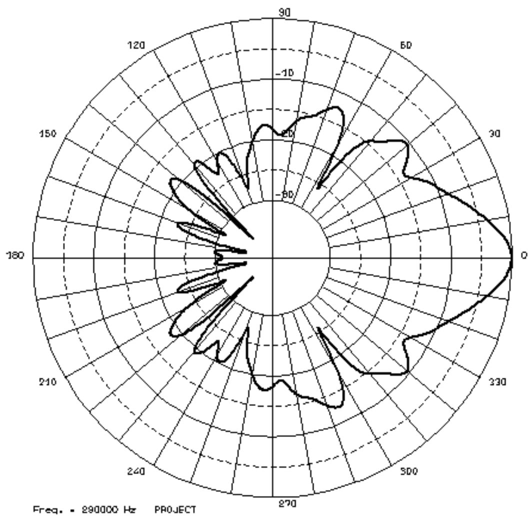

Fig. 8b: Directivity pattern of transducer arrays without Filler and Matching layers

5 Conclusion

We have presented a 2D finite element model of active sonar systems. Finite Element Method to analyze crosstalk and structure interactions, using ATILA code and GiD graphical interface has been shown. Several arrays had been built. The different results show the effect of each material in sonar performances and that matching layers was the main source of crosstalk. The numerical analysis FEM and ATILA code can be used for designing and analysing sonar transducers in many different aspects, material and structure influences. Thereby we can improve sonar performances and reduce crosstalk. Future applications will also handle complete transducer arrays including environmental noise and the role of sonar dome.

Acknowledgments

Thanks to BREST METROPOLE OCEANE and EUROPE (FSE) for funding.

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