Modeling and Testing of Carbon-Fiber Doubly-Resonant Underwater Acoustic Transducer

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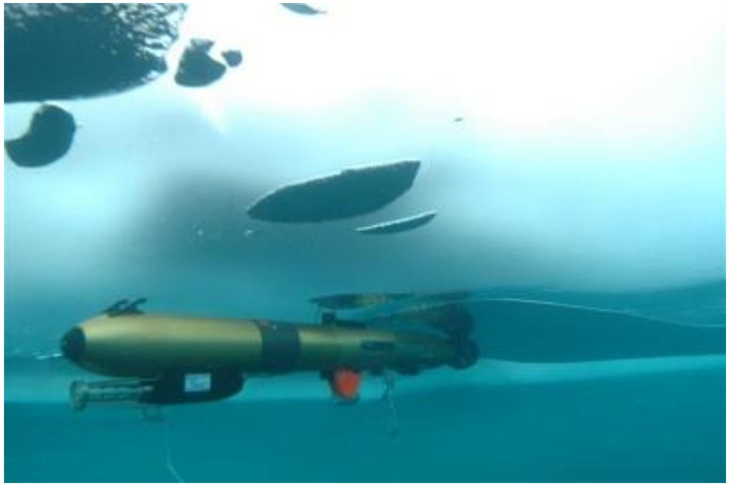
Presentation plan

- *Background. Low-frequency deep-water sound sources for long-range acoustic communications, navigation and ocean acoustic tomography. WHOI patent for doubly-resonant organ pipe.*
- *Design of innovative sound source with carbon-fiber composite materials and a depth independent, oil-filled acoustic driver. Demand for precise adjustment of its parameters using finite-element analysis.*
- *COMSOL simulation and sea test of a sound source prototype.*
- *Comparison of COMSOL simulations and experimental data.*

Long-Range Underwater Navigation and Communications

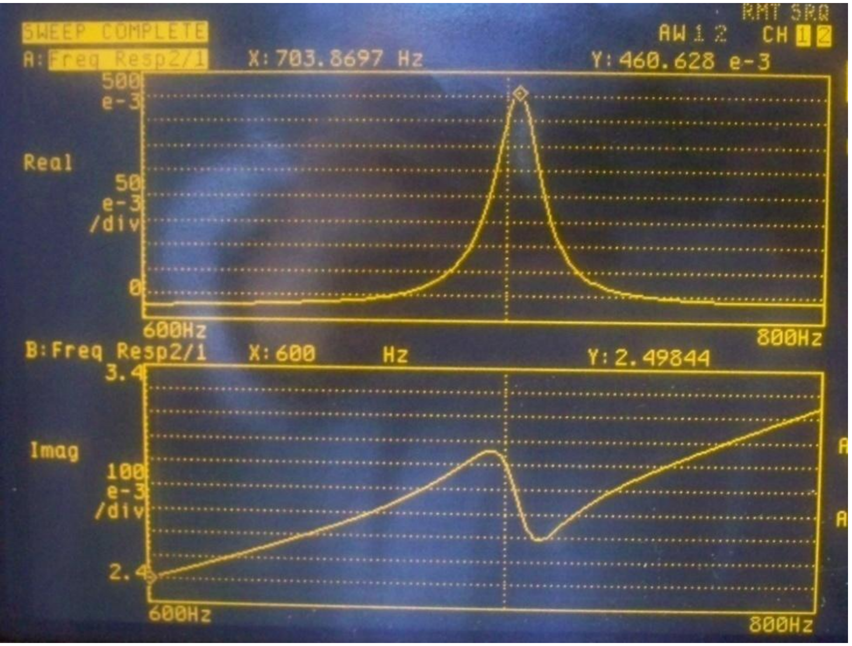


Navigation and telemetry for AUVs operating in the Arctic currently rely on GPS and satellite communications that are poorly suited for polar areas where partial or complete ice cover restricts or makes hazardous access to the sea surface. Underwater acoustic systems can provide geo-location and telemetry in ice-covered regions. The broadband sound sources with precision clocks can provide underwater navigation in the Arctic, with frequency and signals selected for the ranges of interest, which span tens to thousands of kilometres.

Approaches considered here for broadband sources include mechanically swept tube resonators, single-tube organ pipes and multi-tube organ pipe resonators. The mechanically swept device is excellent for frequency-modulated sweeps supporting tomography, while the non-swept tubes allow transmission of arbitrary waveforms within their bandwidth. Initial experiments in the Fram Strait in 2010 have shown the utility of the single-tube source for transmitting long-range communications and navigation signals.

Single Resonance Organ Pipes for RAFOS navigation and Long-Range Communications

RAFOS
Frequency range: Standard RAFOS sweep, 261Hz, SPL: 181 dB re 1 micropascal at 1 m
Controller: Programmable via external connector. Temperature compensated time base. df/f = 5 x 10-8
Batteries: Alkaline "D" cell assembly, endurance: >4000 transmissions
Weight: 360 kg (140 kg submerged)



Single-Tube Source Characteristics	
Resonant Frequency	694 Hz
Bandwidth	20 Hz
Weight in Water	6.75 kg
Carbon Fiber Tube Dimensions	20.4 cm diameter 47 cm length 4 mm wall thickness
SPL	186 re 1 micro-Pascal at 1 m
Efficiency	> 50%
Directivity Gain	3 dB

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BOSTON 2013

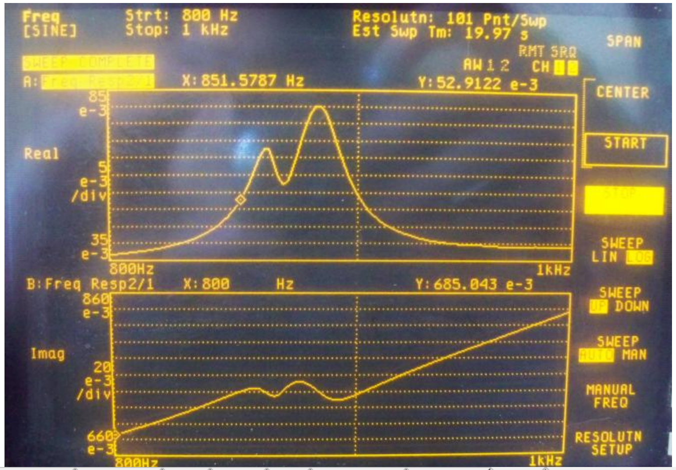
Broad-Band Sound Source for Long Distance Underwater Sound Propagation. Doubly Resonant Organ Pipe.

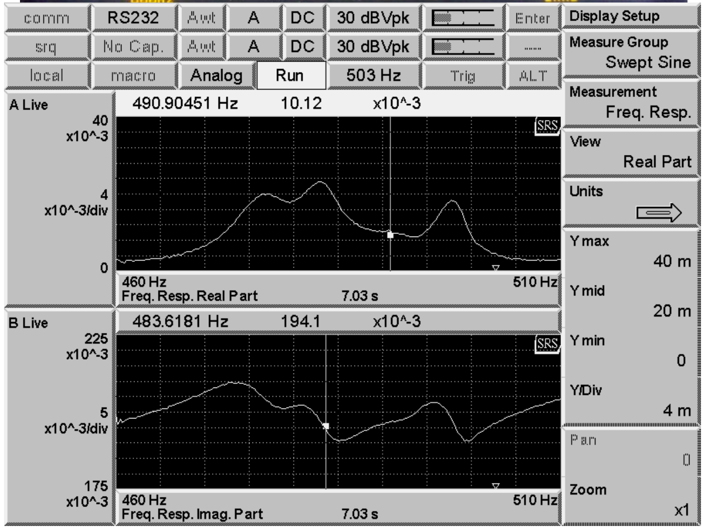
WHOI A. Morozov, Patent application number: 20120269037


12/17/2010


02/25/2011


03/24/2011



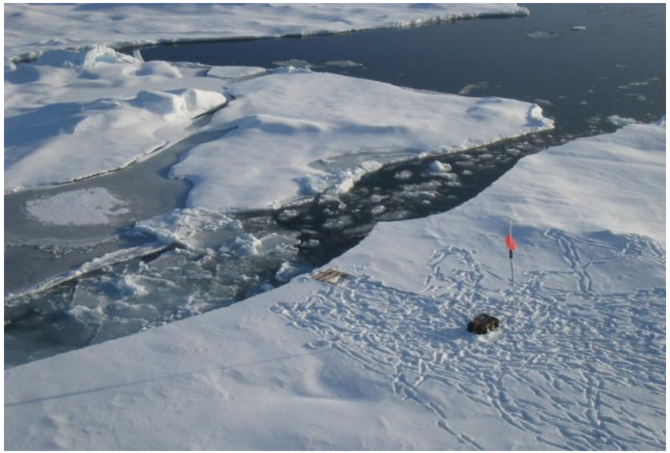


A Live 490.90451 Hz 10.12 x10^-3
460 Hz 510 Hz
Freq. Resp. Real Part 7.03 s

B Live 483.6181 Hz 194.1 x10^-3
460 Hz 510 Hz
Freq. Resp. Imag. Part 7.03 s

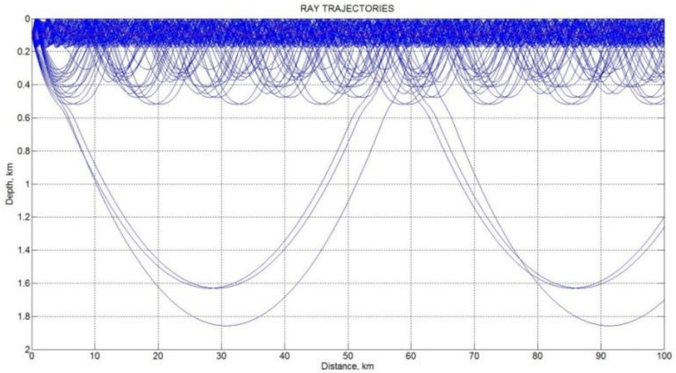
Display Setup
Measure Group: Swept Sine
Measurement: Freq. Resp.
View: Real Part
Units
Y max: 40 m
Y mid: 20 m
Y min: 0
Y/Div: 4 m
Pan: 0
Zoom: x1

Underwater Long-Range Communications

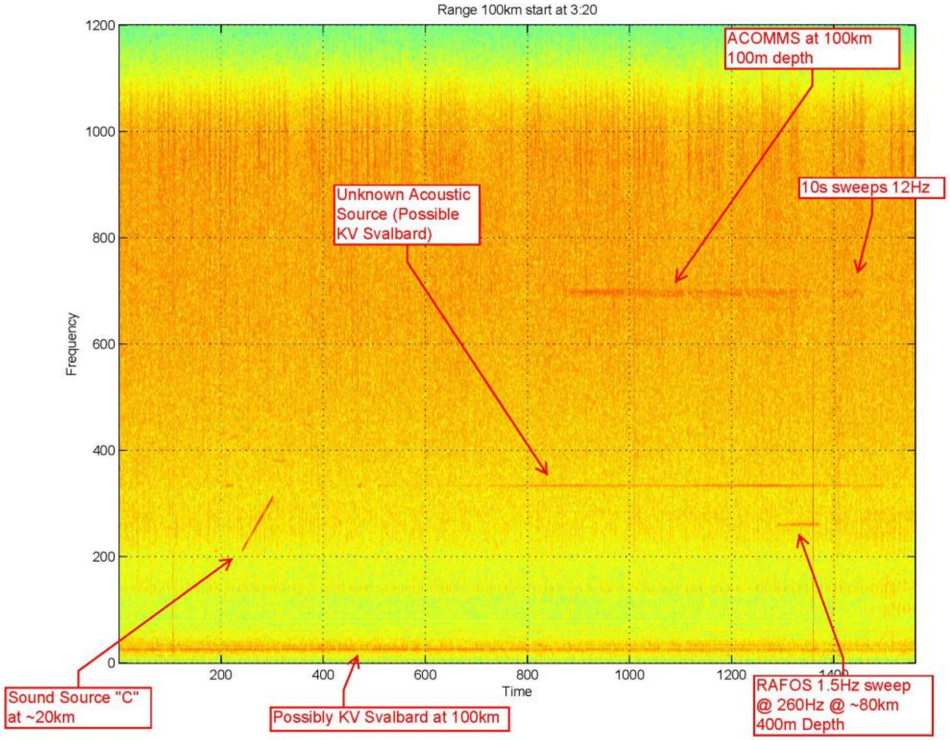


September 2010, a small four-channel receiving array and digital recorder deployed at 79N26, 000W20. The vessel transited away, stopping at 10 km intervals to lower the source and transmit test signals. Ranges from 10 to 100 km were tested. The receiver array was deployed at 75 m, and the source at 100 m depth The BPSK signals had an uncoded rate of 12 bps that was successful to 40 km using a single hydrophone, and to 80 km when 4 hydrophones were utilized with a multi-channel decision-feedback equalizer. At ranges past 80 km additional coding gain is necessary, and the estimated data rate using all 4 hydrophones at 90 km is 6 bps.

Under-Ice Communications 700 Hz



ACOMMS signal starts at 0822L (0622Z)



ACOMMS at 100km
100m depth

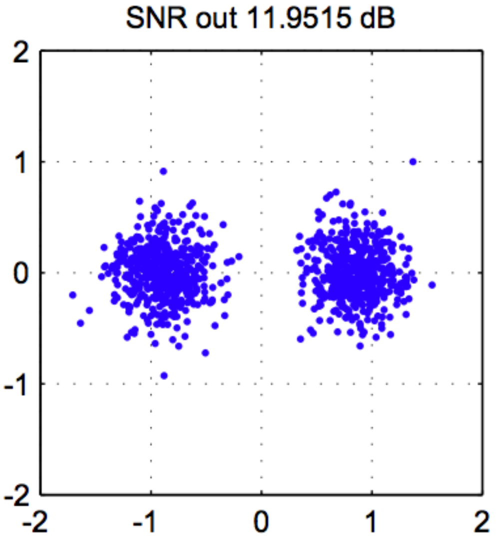
10s sweeps 12Hz

Unknown Acoustic
Source (Possible
KV Svalbard)

Sound Source "C"
at ~20km

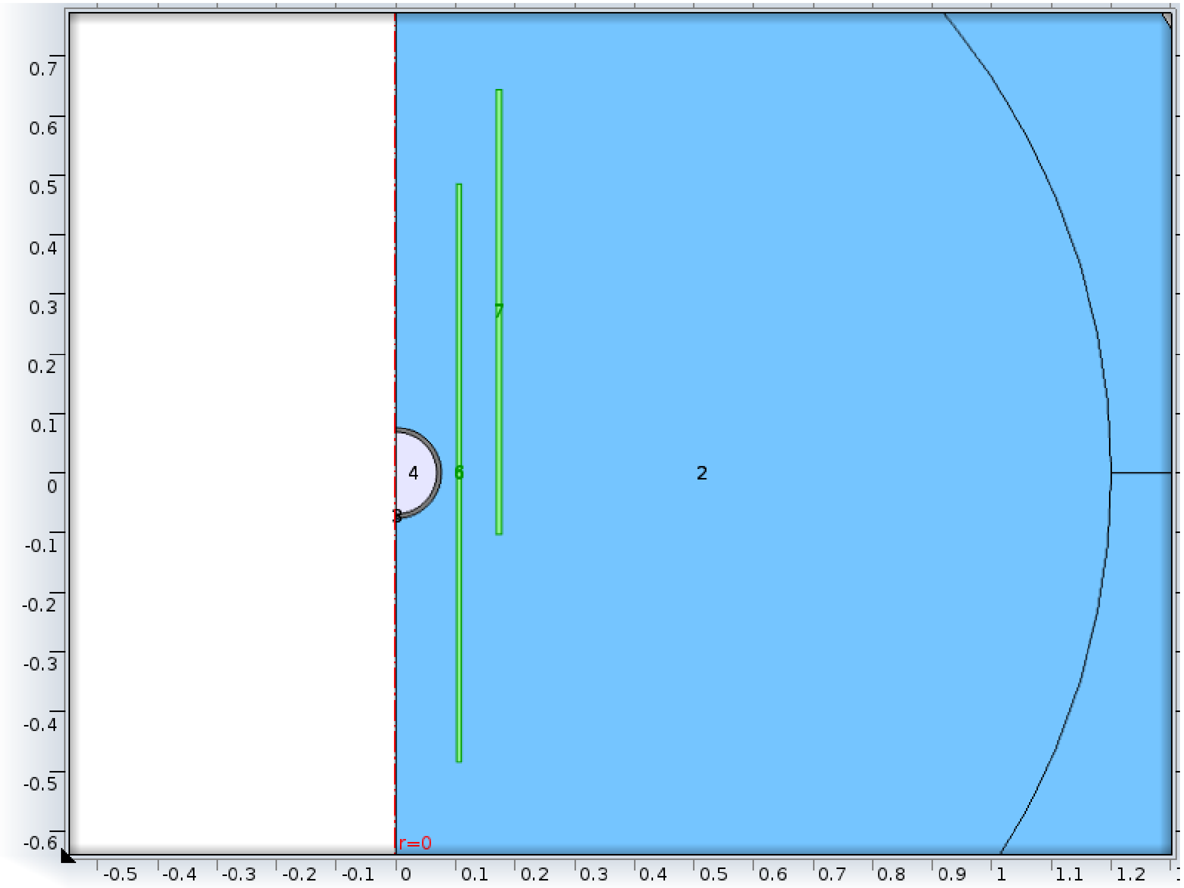
Possibly KV Svalbard at 100km

RAFOS 1.5Hz sweep
@ 260Hz @ ~80km
400m Depth



Single-channel PSK equalization results at 40 km using a 12 bps. The 12 bps that was successful to 80 km when 4 hydrophones were utilized with a multi-channel decision-feedback equalizer. At ranges past 80 km additional coding gain is necessary, and the estimated data rate using all 4 hydrophones at 90 km is 6 bps.

Conception of Doubly Resonant Sound Source



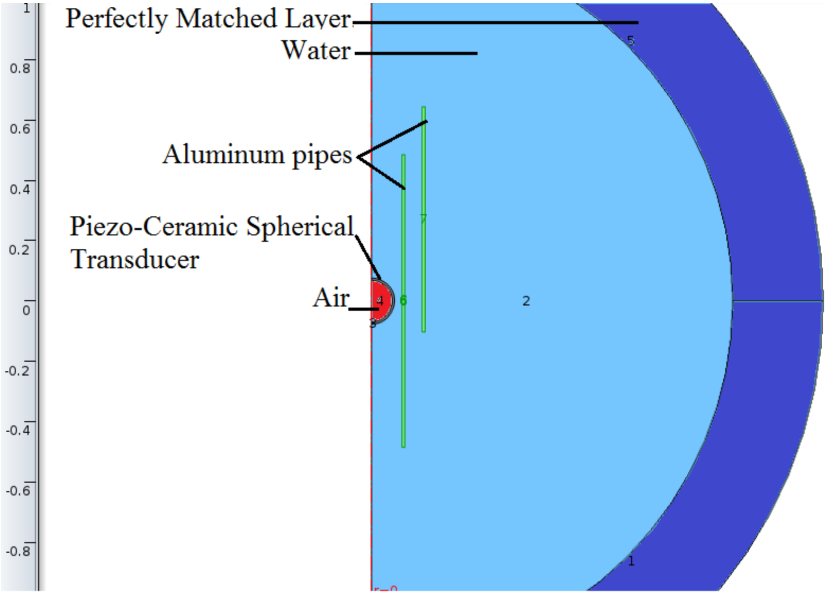
Light carbon-fiber composite pipes materials and doubly resonant broadband organ pipe resonator.

Research plan

1.Simulate, design and build aluminum variant of resonator with the standard ITC1007 acoustical driver.
2. Test aluminum variant of resonator and compare results with COMSOL simulation.
3.Replace aluminum resonator with carbon-fiber with the same stiffness of pipes
4.Test carbon-fiber resonator and compare results with the aluminum variant and with COMSOL simulations.
5.Build attachment, paint and make final test.

COMSOL simulation

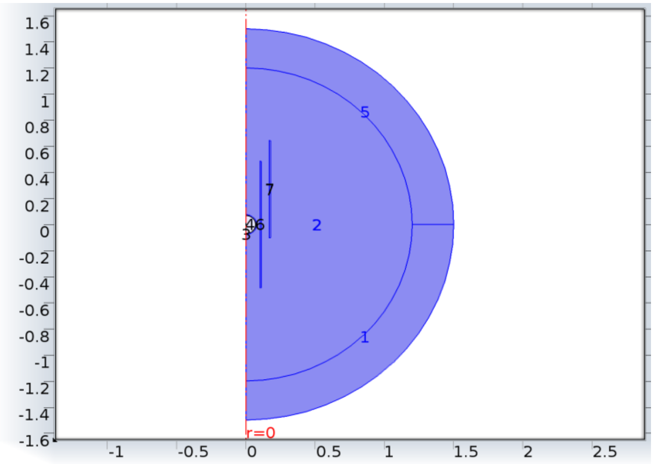
COMSOL Multi-Physics Acoustic-Piezoelectric Interaction module, Frequency Domain.
Geometry: 2D axi-symmetric (cylindrical) approach. The geometry of model is shown in Fig. 1.



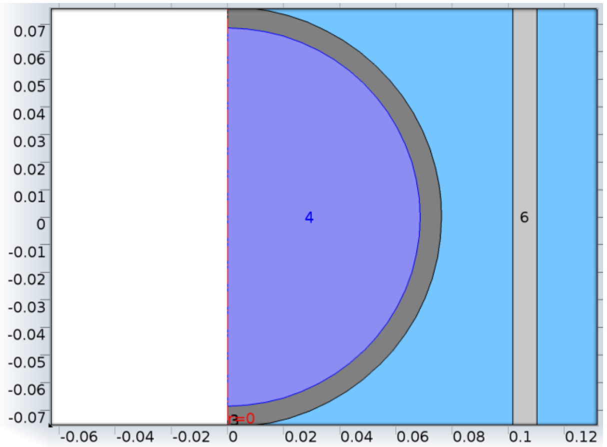
The geometry of the model.

Aluminum pipes are shown in green, water in blue, piezo-ceramic spherical transducer in the center in grey, and air inside the sphere in light grey. The sound source was surrounded by a Perfectly Matched Layer sphere with a spherical wave propagation condition. The Acoustic Structure Boundaries are the surfaces of the spherical transducer and the aluminum pipes. The Electric Potential boundary condition, 100 V, was initiated on the external surface of the pieze-ceramic sphere.

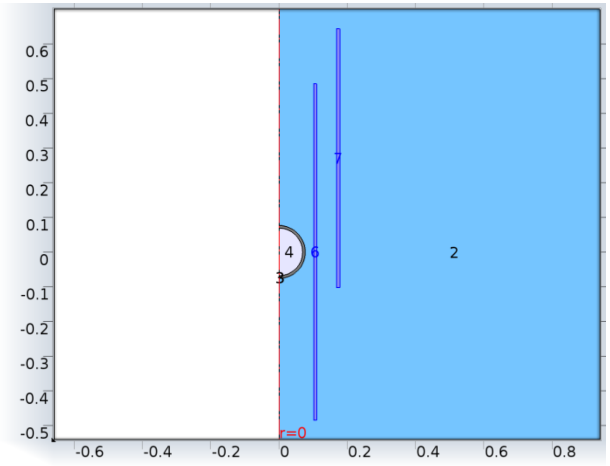
Materials:
Water, Air, Aluminum, Piezo-ceramics



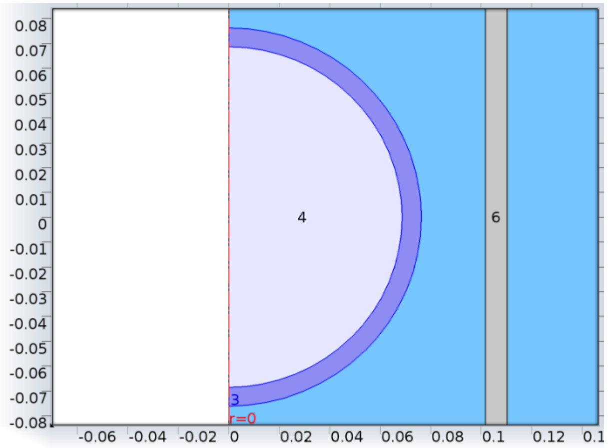
Water, liquid



Air

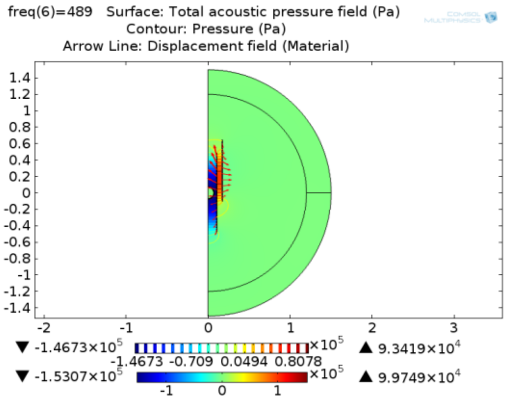


Aluminum 6063-T83

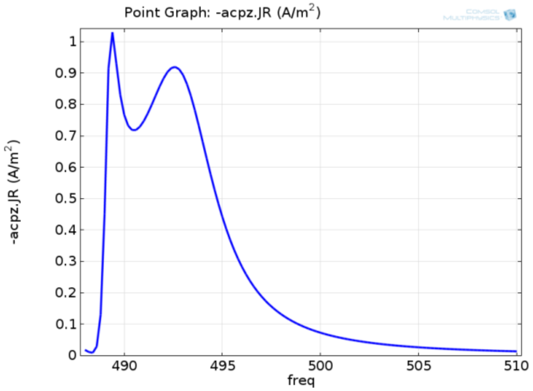


Lead Zirconate Titanate (PZT-5H)

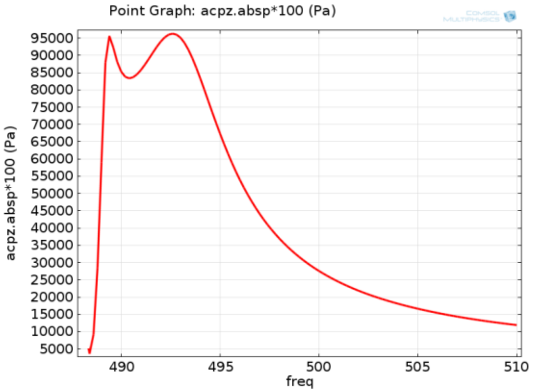
COMSOL Simulation Results



The 2D sound pressure field



Admittance of the transducer.



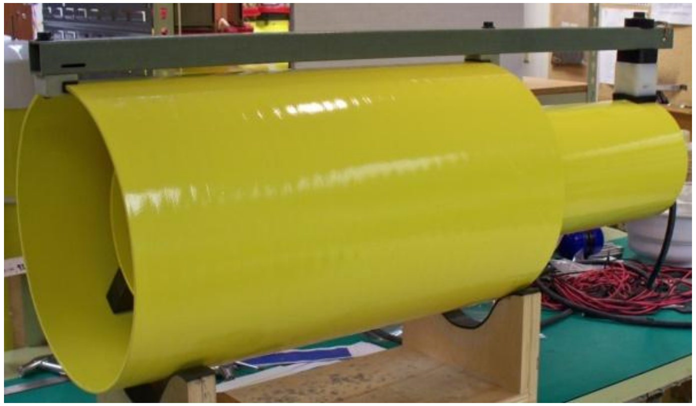
Sound pressure at the distance
1 meter from sound source axis

The results of the simulation were used for experimental testing.
The aluminum pipes were cut in exact accordance with the model and the sound source was tested in the Teledyne Benthos acoustic test pool. The results were similar to the simulation. Two close resonances were found without any adjustment, and only a slight adjustment of shifting pipes along the axis relative to each other was necessary to obtain a good frequency response.

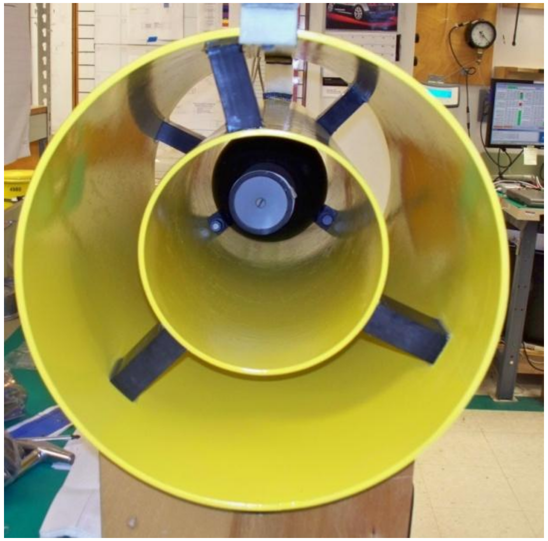
Experimental Prototype

1.Aluminum prototype. The results of the simulation were used for experimental testing. The aluminum pipes were cut in exact accordance with the model and the sound source was tested in the Teledyne Benthos acoustic test pool. The results were similar to the simulation. Two close resonances were found without any adjustment, and only a slight adjustment of shifting pipes along the axis relative to each other was necessary to obtain a good frequency response.

2.Carbon-fiber prototype. The carbon fiber pipes were ordered with the radial stiffness similar to the aluminum prototype. Note that stiffness of the composite pipes in radial and axial directions can be modified by changing the angle of fiber winding relative to the pipes axis. Additionally, the hollow spherical transducer was replaced by an oil-filled pressure compensated transducer. The final variant of the fiber carbon sound source was tested in the Teledyne Benthos pool and then in the Woods Hole Oceanographic Institution dock.



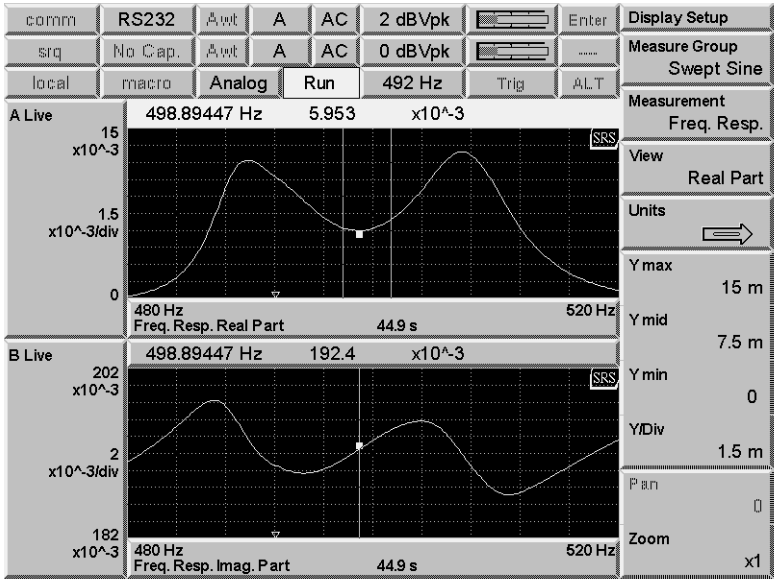
The carbon-fiber variant of doubly resonant sound source



The internal view of the resonator

Final Sound Source Parameters

Central frequency	- 500 Hz,
Frequency bandwidth	- 30 Hz
SPL	- 185 dB
Weight in water	- 10 kg
Weight in air	- 21 kg
Dimensions:	
Central pipe i.d..	-203.2 mm
Length	- 951 mm
Wall thickness	-5.18 mm
External pipe i.d.	-355.6 mm
Length	-650.5 mm
Wall thickness	-6.05 mm
Shift between pipes	-98.425 mm
Maximum amplitude of driving signal	-1500 rms.


Display Setup
Measure Group: Swept Sine
Measurement: Freq. Resp.
View: Real Part
Y max: 15 m
Y mid: 7.5 m
Y min: 0
Y/Div: 1.5 m
Pan: 0
Zoom: x1

Real and imaginary part of the experimental admittance. (scale 0.019 = 1/32000 1/ohm).

Conclusion and Acknowledgements

Conclusion

A multi resonant system usually needs a precise, complicated adjustment of its parameters to get the necessary bandwidth, with limited variability of frequency response inside the frequency range. It can be even more complicated, when the design includes new, never tested, materials. Application of the COMSOL finite element analysis allowed prediction of necessary parameters and avoid a long series of water tests with parameter adjustment.

COMSOL analysis helped design innovative carbon-fiber sound source for long-range sound propagation.

The parameters of the sound source prototype were reasonably close to the COMSOL simulations.

Acknowledgements

Author expresses sincere thanks to Dr. Takuya Shimura from JAMSTEC, Japan for sponsoring the project.