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A Directional Dogbone Flextensional Sonar Transducer

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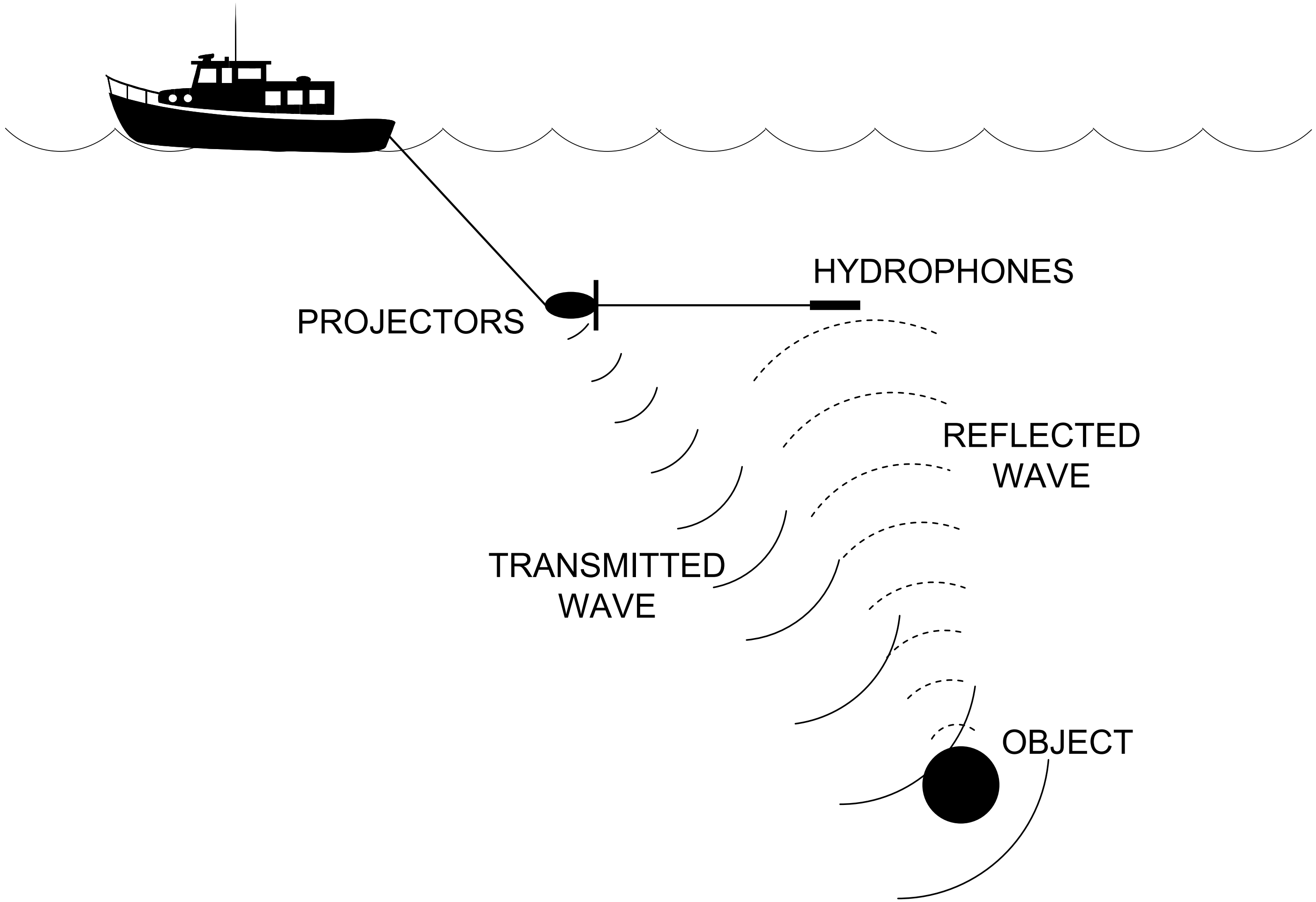
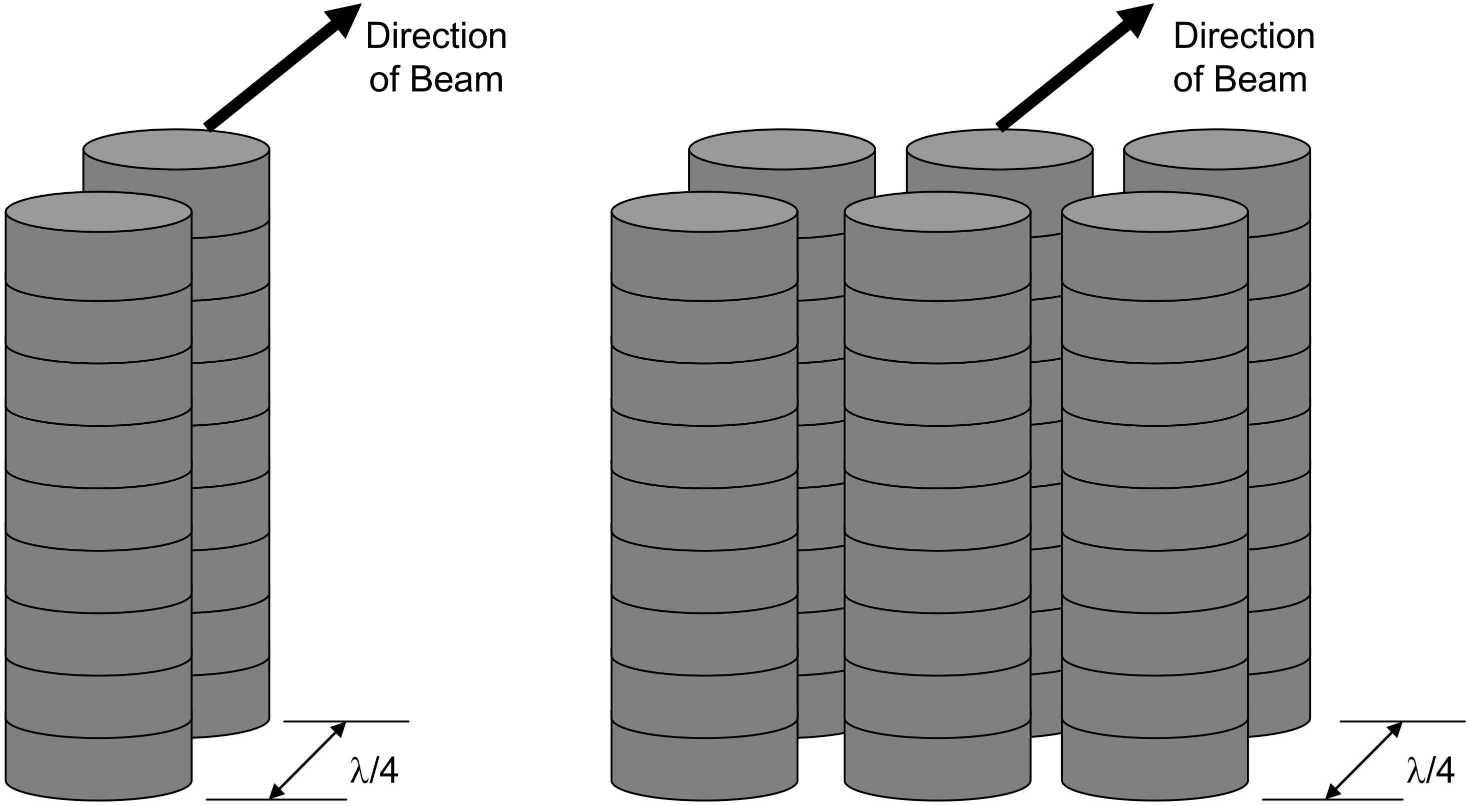
Introduction

- Sonar transducers are electro-acoustic devices used for transmitting and receiving acoustic energy for the purpose of detection and location of underwater objects.
- In order to transmit energy in one direction, sonar Class IV flextensional transducers are combined into arrays of elements that are spaced a 1/4 wavelength apart. The directionality (front-to-back pressure ratio) in practice is a modest 6 dB due to diffraction.
- A new class of transducer the Directional "dogbone" flextensional transducers which generates cardioid beams could replace these dual line array. This will reduce weight, cost and increase front-to-back ratio greater than 20 dB.
- COMSOL with Acoustics Module is used to predict in-water electro-acoustic performance and is compared with experimental data. COMSOL is then used to calculate the complex drive coefficients used to drive the transducer into the directional mode.

Sonar uses Transmitted and Reflected Sound Waves to Locate Underwater Objects



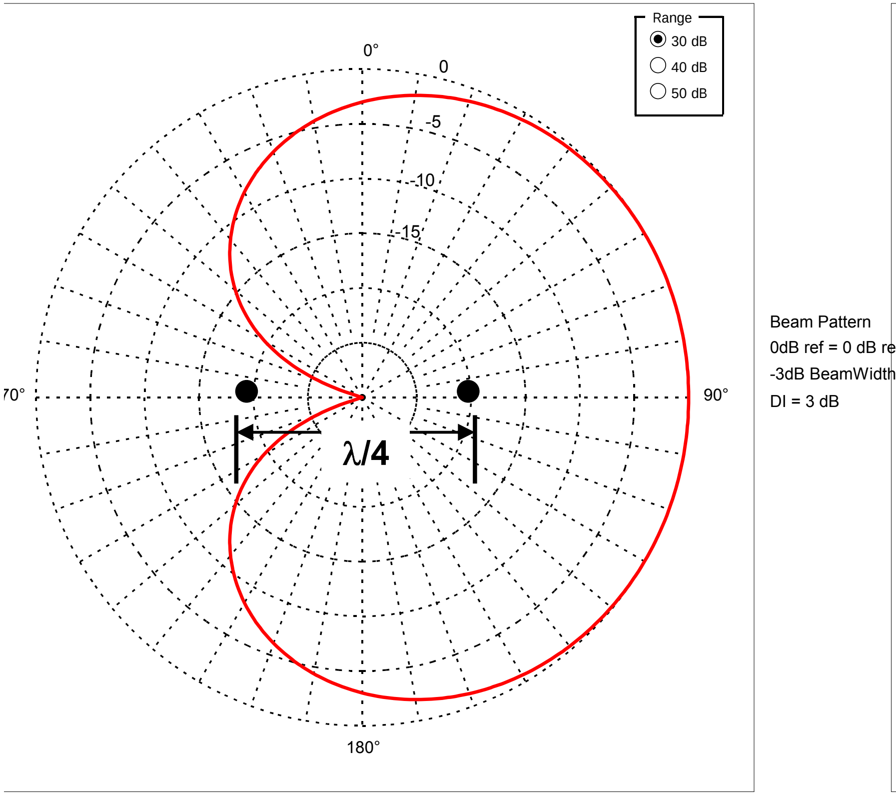
Two Line Arrays and Planar Arrays of Projector Elements that are Several Wavelengths Long and Spaced a 1/4 Wavelength Apart.



a) Two Line Arrays

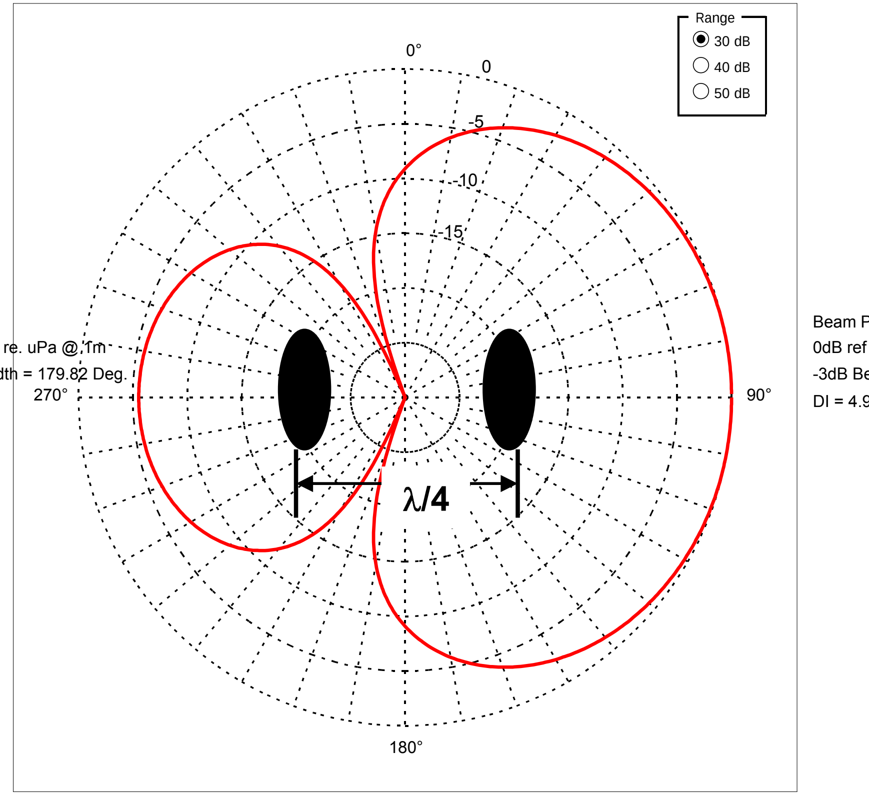
b) Two Planar Arrays

Modeled Beam Patterns for Two sources spaced a 1/4 wavelength apart with one of the sources driven 90 degrees out of phase with the other sources, a) for Point Source Element and b) Real Case Flextensional Elements.



Back is an ideal Null

a) Ideal Case



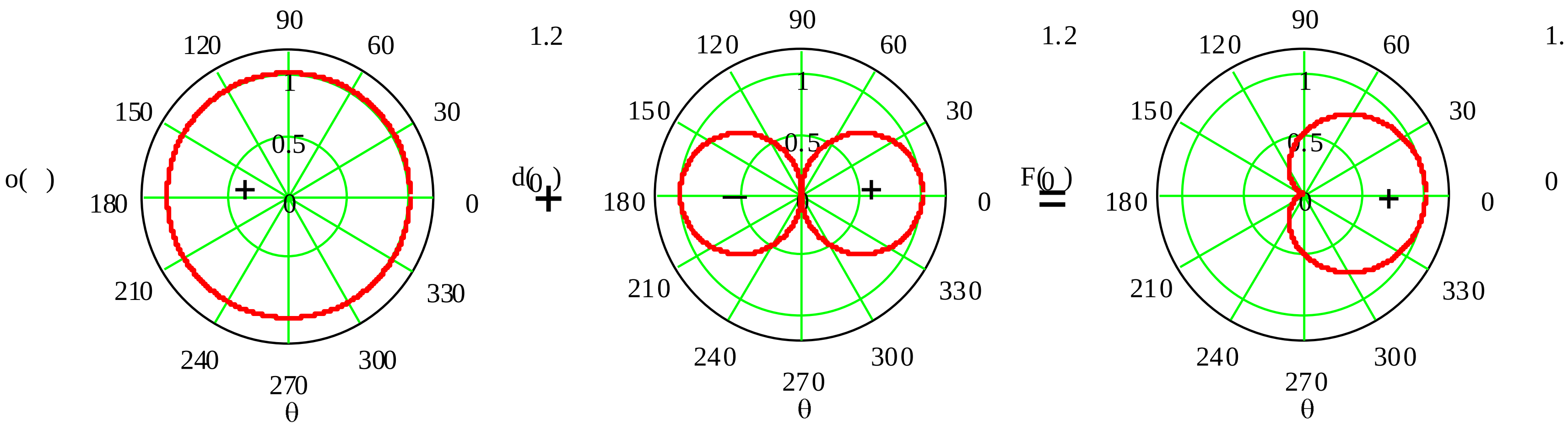
Front/Back = 6 dB

b) Real Case

caused by diffraction

Synthesis of a Directional Flextensional

Omni	Dipole	True Cardioid
1	cos(θ)	[1+cos(θ)]1/2



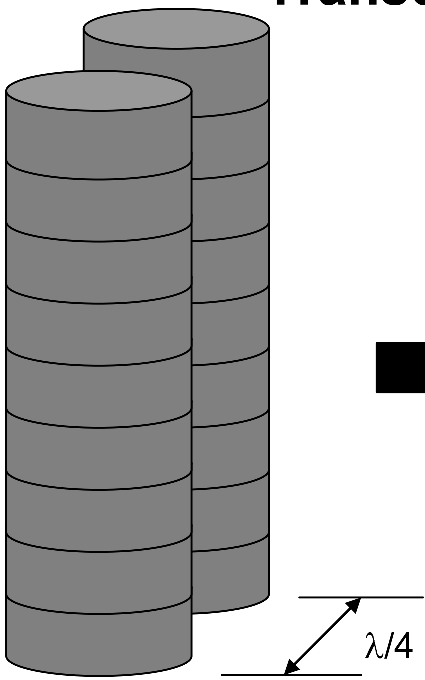
a) Omni

b) Dipole

c) Cardioid

An other way to generate a directional cardioid Beam

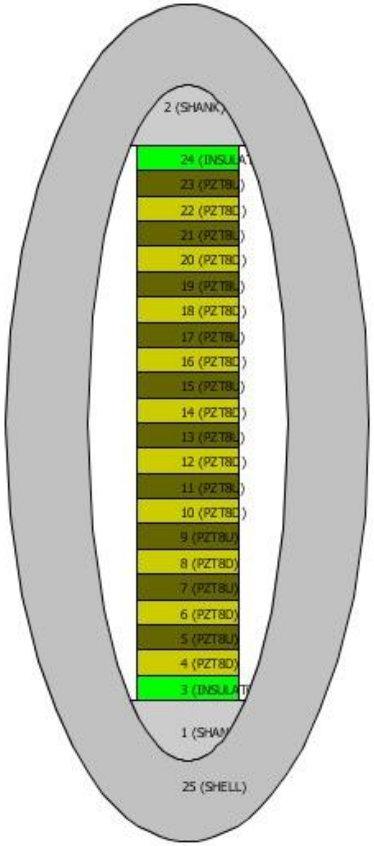
Two Line Arrays of Projector Elements that are Several Wavelengths Long and Spaced a 1/4 Wavelength Apart Replaced by One Line Array of Directional Dogbone Transducers



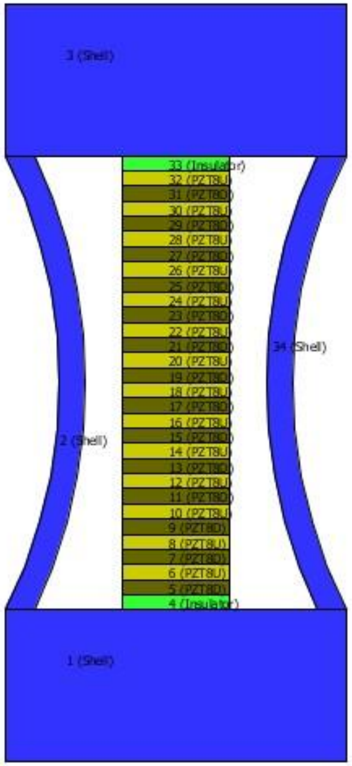
a) Conventional
two lines
F/B < 15 dB

b) Directional
one line
(Replacement)
F/B > 20 dB

Class IV Flextensional Transducer and Class VII "Dogbone" Flextensional Transducer



a) Class IV Flextensional



b) Class VII Flextensional

Model Verification Procedure

- **Validate COMSOL Model with Measured Results of a standard Omni Mode Dogbone Flextensional Sonar Transducer**
- **Then predict the directional operation mode**

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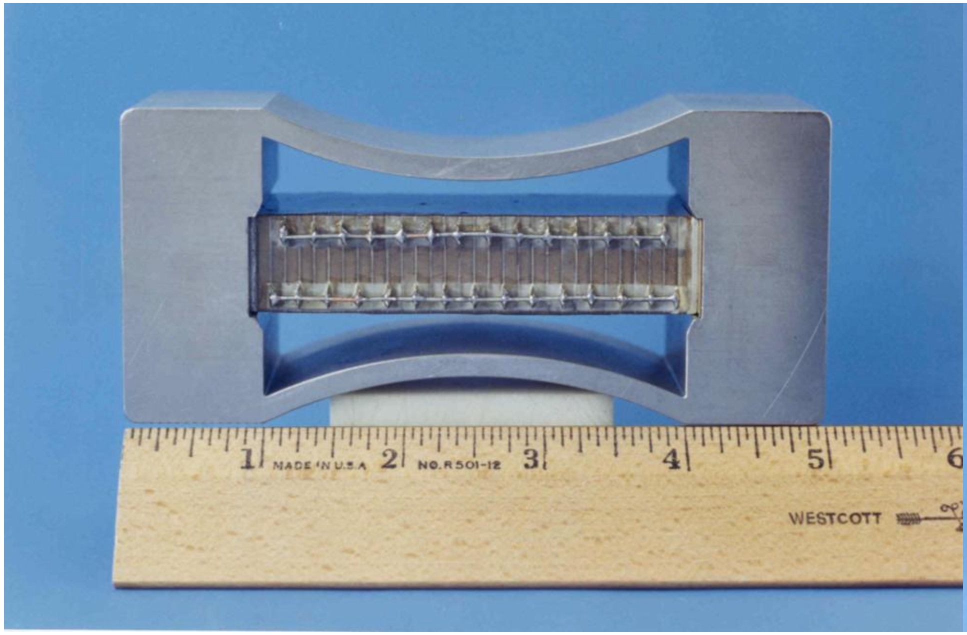
ONR Revolutionary Research . . . Relevant Results

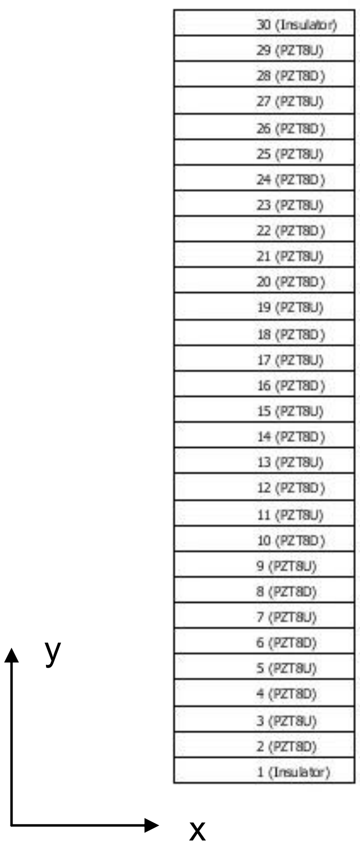
Class VII "Dogbone" Flextensional Sonar Transducer, a) Shell and Ceramic Stack and b) Encapsulated



a) Shell and Ceramic Stack

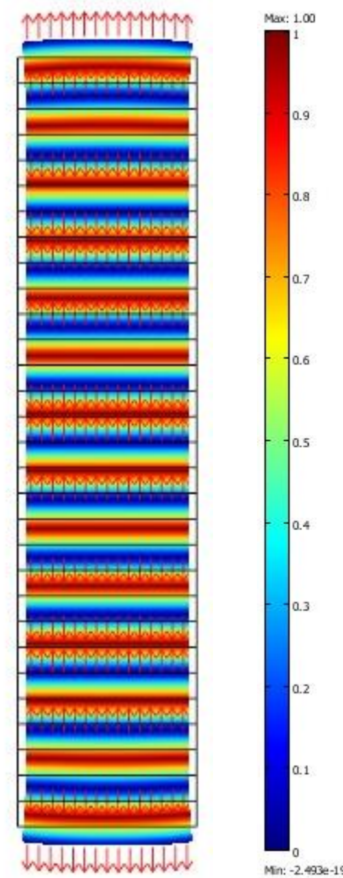
b) Encapsulated

COMSOL Stack a) Subdomain Settings and b) Boundary Settings for Piezo Plane Strain (smppn) application and c) Electric Potential and Field Arrows results



a) Subdomain Settings

b) Boundary Settings



c) Electric Potential and Field Arrows

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Electrical Input Impedance

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Integrate Displacement Current Density for Input Current

IU =-(up(Jdy_smppn))*z — Current into upper plate

ID =-(down(Jdy_smppn))*z — Current into down plate

Admittance is: Y=1/Z — Z = Impedance

|Y|=I/V=abs(ID)+abs(IU) — Magnitude — For V = 1

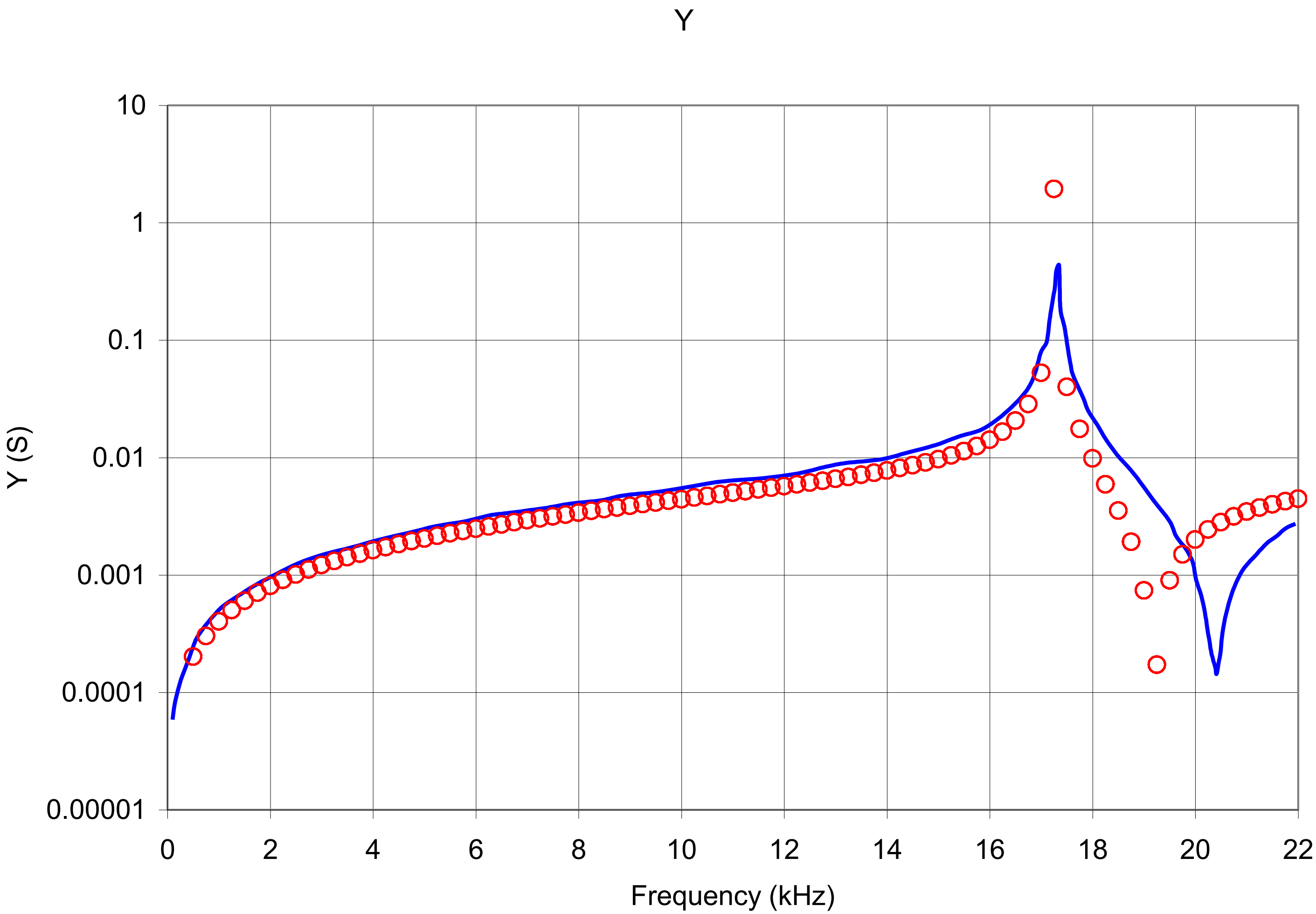
G= real(ID)-real(IU) — Real Part

B= imag(ID)-imag(IU) — Imaginary Part

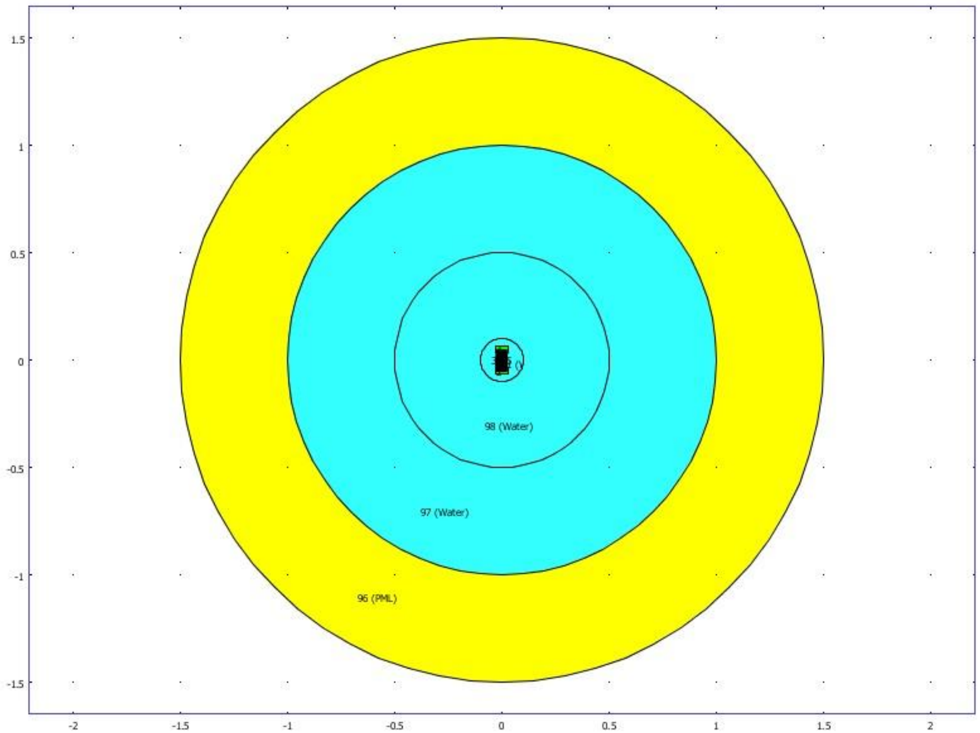
Capacitance is: B/ω

C= (imag(ID)-imag(IU))/(2*pi*freq)

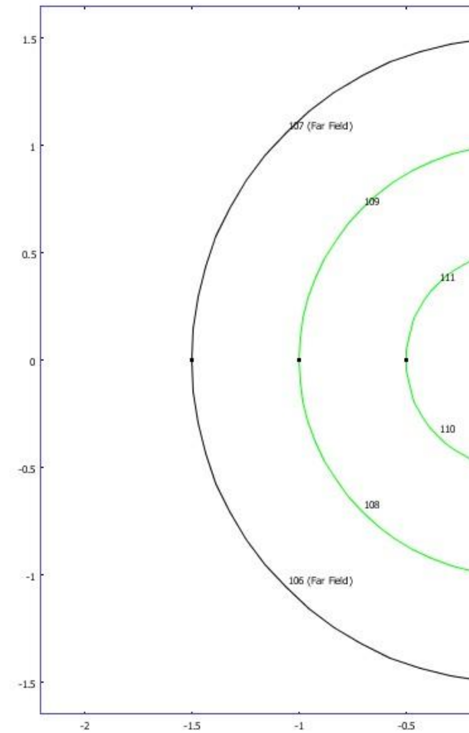
Piezoelectric Stack
In-air Admittance Magnitude Response
Measured (____) and COMSOL Modeled (oooo)



COMSOL Fluid, Shell and Stack Subdomain Settings and Boundary Settings for Pressure Acoustics (acpr) application



a) Subdomain Settings



b) Bounda

Blue - Water fluid two wavelength at 3 kHz
Yellow - PML one wavelength

Mesh 16312 Triangular Element

Sound Pressure Level

COMSOL SPL is given by,

[illegible]

p_{ref} **= 1 μPa for Water**

2 in denominator indicates pressure is a peak value,
Therefore Voltage Potential on transducer should be a peak value V = 1.414

The more common form of SPL in terms of rms pressure is given by,

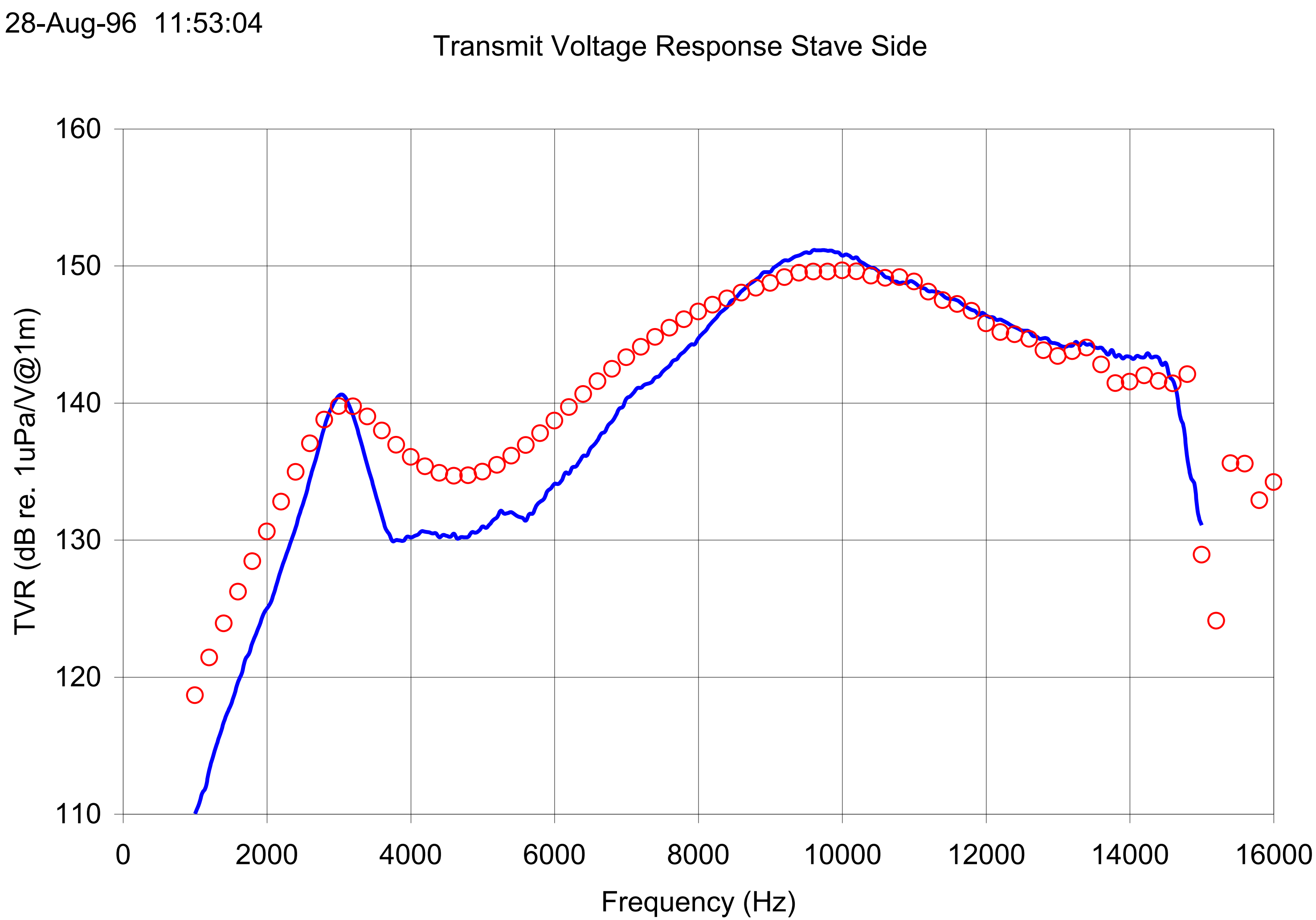
[illegible]

Transmit voltage response for 2-D model is given by,

TVR = SPL-10log10(1/h)-10log10(1/r) ***dB ref 1μPa/Vrms at 1m***

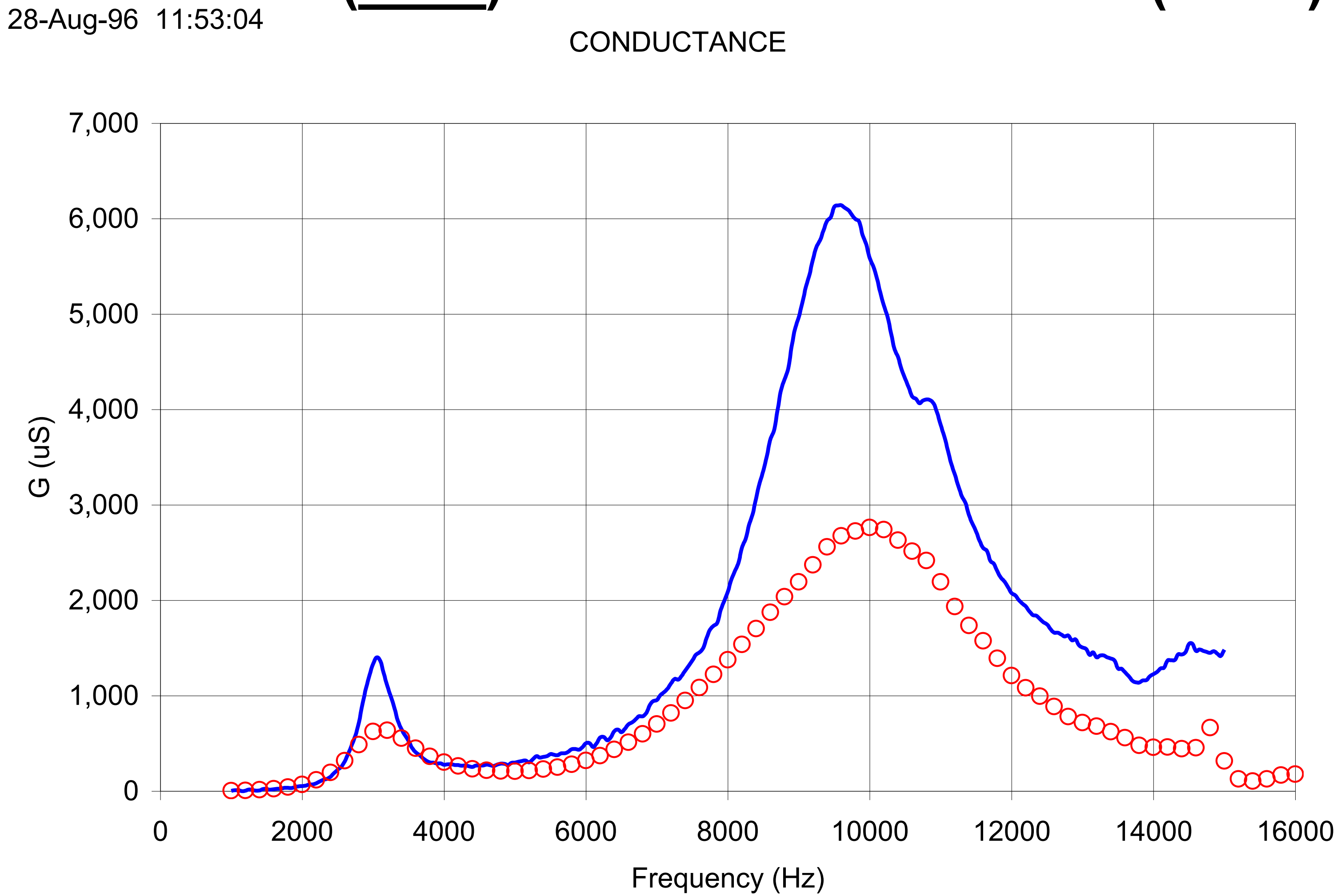
h **is the transducer height in the z-direction**
r **is the radial distance pressure point**

Transmit Voltage Response Measured (_____) and COMSOL Modeled (oooo)



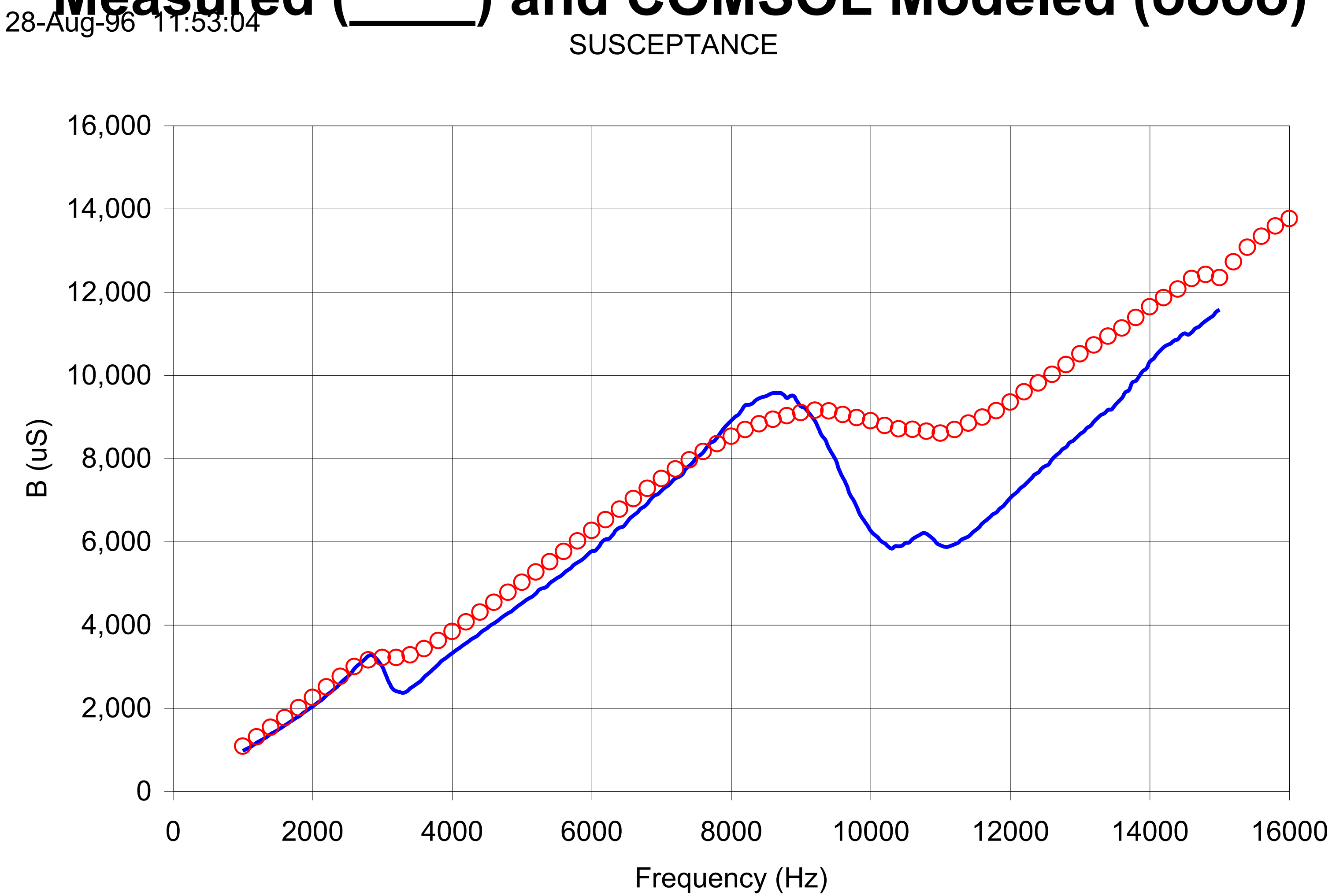
In-water Conductance Response

Measured (_____) and COMSOL Modeled (oooo)

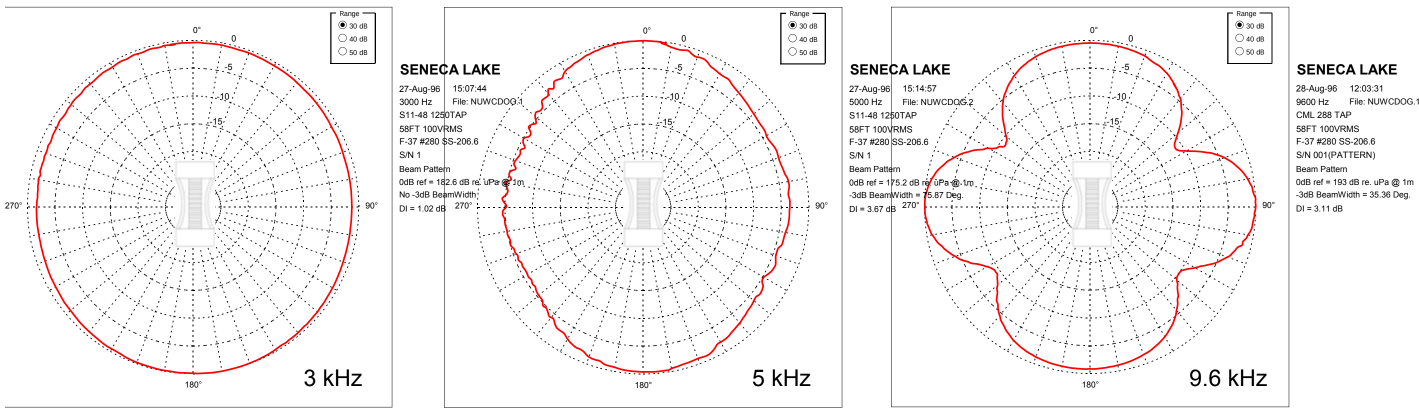


In-water Susceptance Response

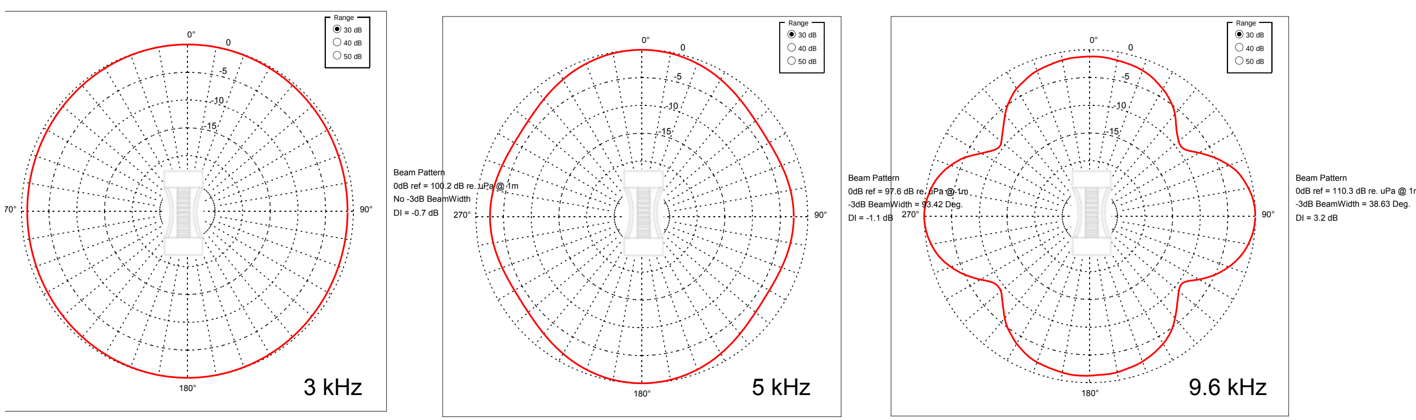
Measured (_____) and COMSOL Modeled (oooo)



Beam Patterns in Omni Mode Measured and COMSOL Modeled at 3 kHz, 5 kHz and 9.6 kHz

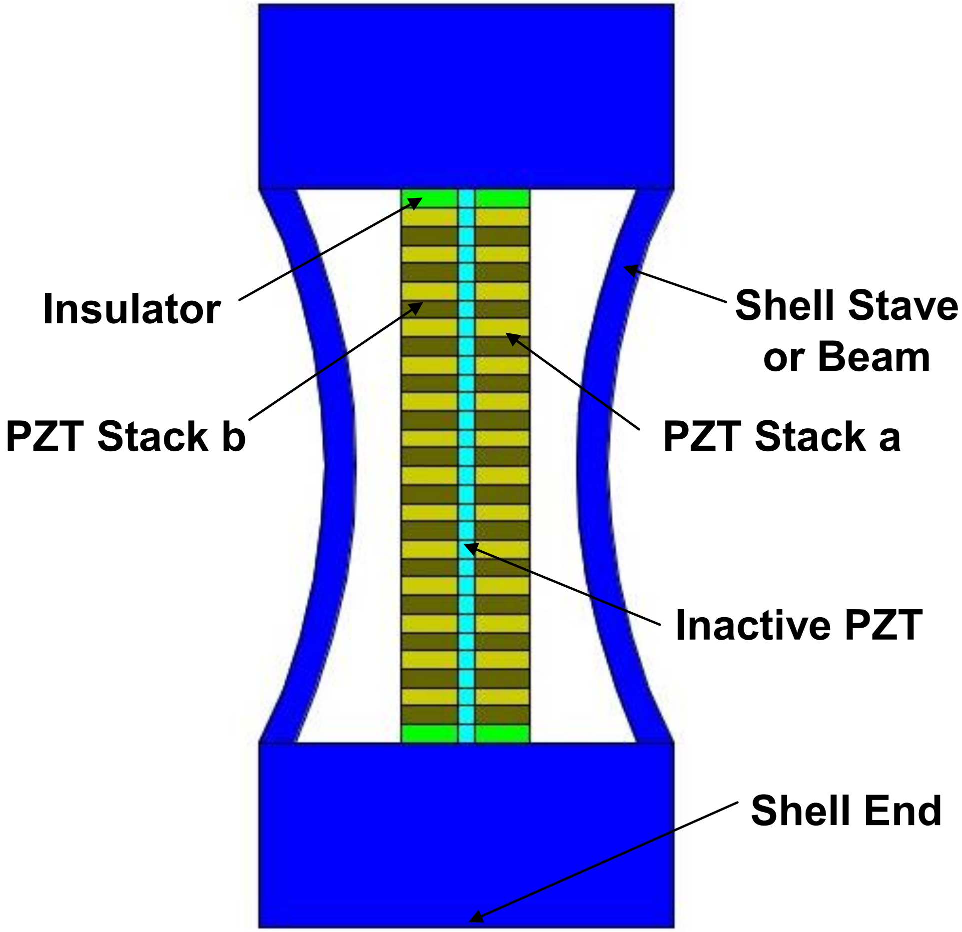


a) Measured



b) COMSOL Modeled

Directional Dogbone Flextensional Sonar Transducer



FEA Shell and Stack Modes

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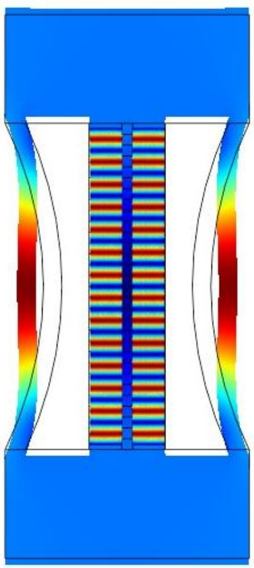
Omni Mode

side B

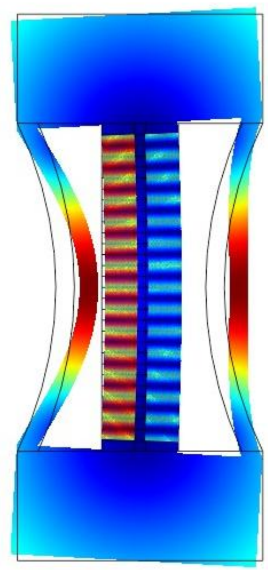


side A

Ea=1V
Eb=1V

+

Dipole Mode

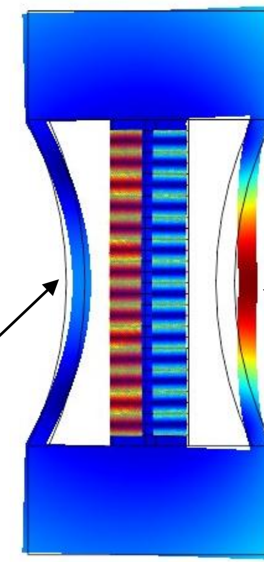


Ea=1V
Eb=-1V

=

Directional Mode

minimized motion

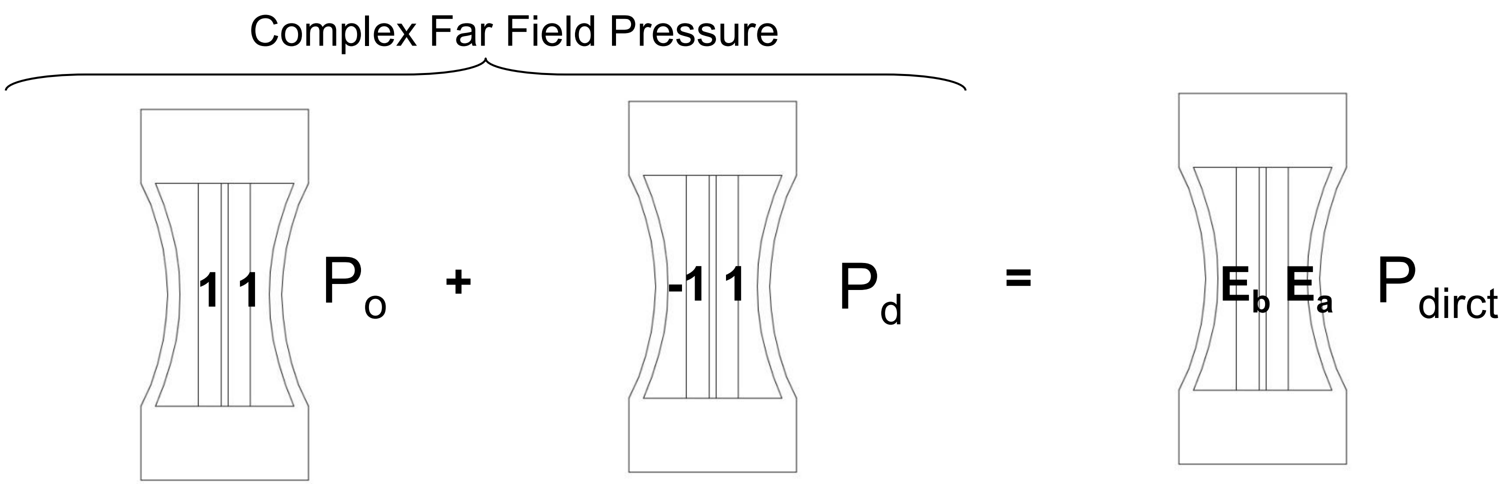


enhanced motion

Ea/Eb = Complex Drive

Displacements and PZT Stack Electric Fields

Voltage Drive Configuration



Complex Drive Voltage Coeff

$$E_a = (P_d + P_o)/P_d = 1 + R$$

$$E_b = (P_d - P_o)/P_d = 1 - R$$

where $R = P_o / P_d$

$$E_a / E_b = 1 + R / 1 - R$$

All Pressures Normalized to Dipole Pressure Field Pd

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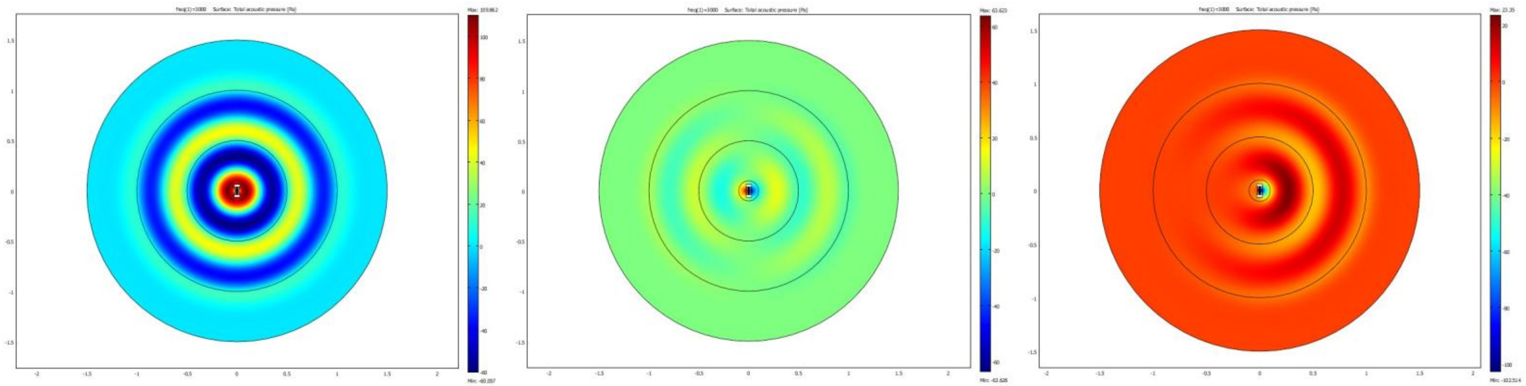
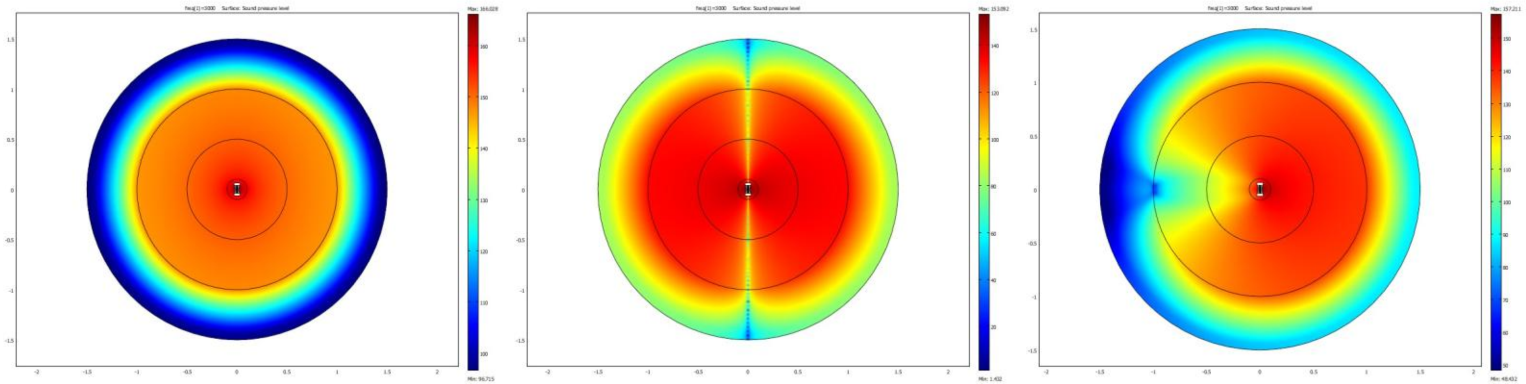
COMSOL Modeled a) Pressure and b) SPL Surface Plots in the Omnidirectional, Dipole and Directional Modes at 3 kHz

Omni Mode | Dipole Mode | Directional Mode



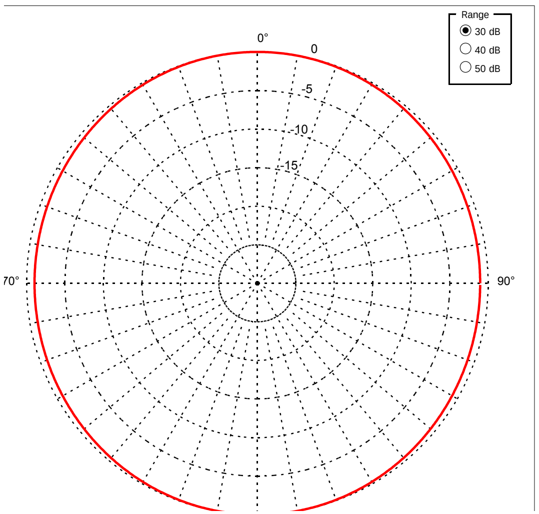
a) Pressure Surface Plots



b) SPL Surface Plots

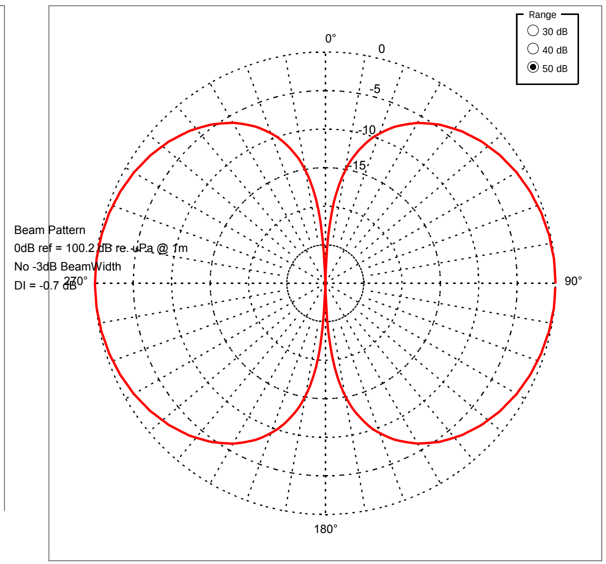
FEA Molded Beam Pattern
at 3 kHz

Omni Mode



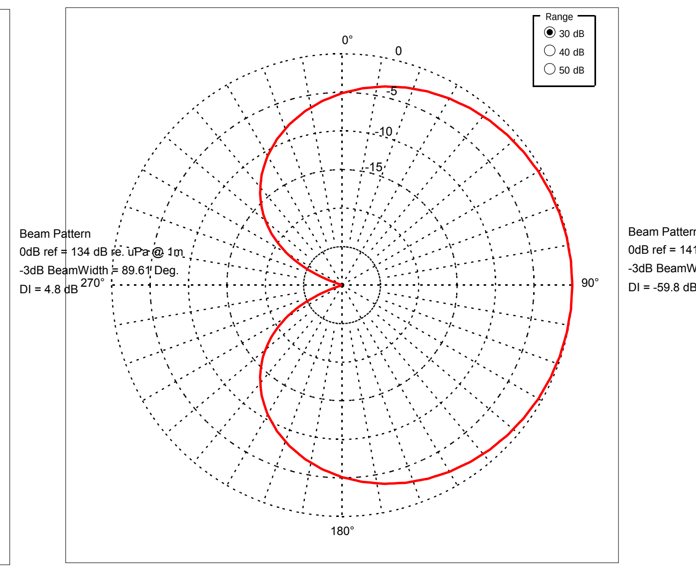
EA=1V
EB=1V

Dipole Mode



EA=1V
EB=-1V

Directional Mode



EA= -0.721-j0.244=
0.761@-161.3 deg
EB=1V
Front/Back ratio = 67.6 dB

Same results obtained from 1kHz – 6 kHz, with Front/Back > 50 dB over Band

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Summary

- The Directional Dogbone Flextensional Transducer
  - **Generates Cardioid Directional Beam Patterns**
    - » ***Front to Back ratio > 50 dB***
    - » ***That can be steered Left or Right***
      - – **Reduces Ambiguity**
      - – **Reduced reverberation**
      - – **Improve detection rates**
  - **Broadband > Octave**
  - **Reduced Size, Weight and Cost**