Controlling underwater sound propagation using 3D-printed phononic crystals

Ahmed Allam, Karim Sabra and Alper Erturk

G. W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology

178th meeting, San Diego, California
Background


Underwater implementations

- Use heavy metallic scatterers
- Limited to 2.5D designs
- Difficult to extend to 3D designs due to manufacturing limitations


Objectives

• Design a 3D gradient index phononic crystal capable of achieving a large variation in the effective refractive index compared to water.

• Use this phononic crystal to design a 3D Luneburg lens for focusing underwater acoustic waves.

• Use common 3D printing techniques to manufacture the lens.
Unit cell design

Using a Comsol finite-element model of the unit cell is used to estimate the dispersion.

\[ c_{\text{eff}} = \frac{2\pi f}{k} \]

\( \phi \): volume filling fraction

**Cell design 1:**

**Cell design 2:**
Effect of inclusion height on the refractive index

- The refractive index of the material ($n$) is given by:

$$n = \frac{c_w}{c_{eff}}$$

$c_w$: Speed of sound in water
$c_{eff}$: Effective wave speed in the crystal
Luneburg lens in 3D

- Luneburg Lens can be constructed by varying the refractive index of the material gradually in space according to the profile:

\[ n(r) = \sqrt{1 - \frac{r^2}{R^2}} \]

- \( r \): position in space
- \( R \): radius of the lens
Time domain numerical model

- A 3D coupled elastic-acoustic FEM model of the lens is simulated in the time domain
Lens fabrication

- Identified material properties:
  \[ E_{PLA} = 3200 \pm 50 \text{ MPa}, \quad \rho_{PLA} = 1117 \text{ kg/m}^3 \]
  \[ \eta_{PLA} = 0.021 \pm 0.003 \]

- Unit cell size: \( a = 3 \text{ mm} \)
- Lens Dimensions:
  16 cell x16 cell x16 cell = 48 mm \( \times \) 48 mm \( \times \) 48 mm \( \sim \) \( 3 \lambda \)
- Printing time:
  16-40 hours
Experimental setup
Lens performance (Time domain)

- Exciting the lens with a Gaussian pulse centered at 100 kHz with 30kHz bandwidth
Lens performance (RMS pressure)

Without lens

Experimental

Numerical
Lens performance

Focal plane

Propagation plane

Normalized pressure

X [mm]

Normalized pressure

Z [mm]
Conclusions

- Air inclusions in a polymer matrix phononic crystals can be used to direct ultrasonic waves underwater.
- A novel phononic crystal-based Luneburg lens has been designed, analyzed, 3D-printed, and experimentally validated.
- The realized lens achieves a power gain 8 dB at the focal point.
- The introduced lens can find potential applications in acoustic wireless power harvesting/transfer as well as signal enhancement in underwater sensing.
Acknowledgment

• This material is based upon work supported by the National Science Foundation under Grant No.(1727951)
Thanks!...

Questions?