Double Phononic Crystal Lens-Based Enhancement of Underwater Power Transfer

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Motivation for Acoustic Power Transfer (APT)

Power and data transmission through metallic walls


Biomedical implants


Ocean monitoring and navigation


Leung et al., in *9th IEEE Conf. on Ind. Elec.& App.* (2014).

Ghaffarivardavagh et al., in *SIGCOMM* (2020).
Recent interest in creating the underwater internet of things for ocean monitoring, underwater navigation, and marine life tracking.

Proposed systems use SONAR frequencies below 100 kHz for transmitting power.


Ghaffarivardavagh et al., in Proc. Of 19th ACM Workshop on Hot Topics in Networks (2020).
APT Challenges: Divergence, Attenuation and Reflection

- Operating at lower frequency reduces attenuation but increases divergence losses.
Gradient Index Phononic Crystals (GRIN-PCs)

- GRIN-PCs reduce divergence losses through wave focusing.


- We recently developed an underwater GRIN-PC lens for focusing ultrasonic waves around 100 kHz.
- Our main concern was to focus the energy at the receiver.

Wave Collimation

• Dolphins use a point source to generate their echolocation clicks.
• The melon acts as a gradient index lens to collimate the generated beam from a point source (the phonic lips).

Wei et al., PLOS ONE.(2020).

Using Two Lenses to Enhance Power Transfer (Ideal Case)

• Our proposed Power Transfer system leverages:
  1. A GRIN-PC lens at the transmitter to collimate the waves towards the receiver.
  2. A second lens focuses incident waves at the receiver.

• Raytracing assumes waves travels as rays which is only valid when the lens aperture is much larger than the wavelength.
Using Two Lenses to Enhance Power Transfer (Practical Case)

• Using a frequency domain finite element model to simulate the pressure field:

• The source lens improves the directivity of the source.
• The finite aperture of the lens limits the directivity of the beam.
Effect of Lens Aperture on Collimation

- Larger lens aperture yields a more collimated beam.
- The source/lens is approximately a piston radiator with the same aperture.
Experimental Results
Power Enhancement for Omnidirectional TX and Rx

• The double lens system is characterized using an acoustic tank.
• The Tx hydrophone is excited by a wide band pulse centered around 90 kHz.
• The Rx hydrophone is connected to an oscilloscope for measuring the output voltage.

• The power output of the system is enhanced by almost two orders of magnitude.
Enhancing Power Transfer for Low Directivity Transducers

- The GRIN-PC lens enhances the directivity of transducers with small apertures.
Power Enhancement for a Practical System

- The distance between the lenses is limited by the tank size to 19 cm (~11\(\lambda\)).
- The output voltage is measured on the optimum resistance of the receiver (2.8 \(k\Omega\)).

- The peak output power of the system increased from 480 \(\mu W\) to 5.7 mW when the lenses were introduced.
Conclusions and Future Work

- GRIN-PC lenses enhance the efficiency of acoustic power transfer systems by:
  - Collimating waves generated from TX
  - Focusing waves on RX

- Wave collimation was limited by the finite aperture of the lens.

- The GRIN-PC enhanced system transmitted 5.7 mW of electric power compared to 480 μW without the lenses.

- **Future Work:** explore a broader parameter space in terms of distances, mediums, and geometry with respect to wavelength.

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Thanks!
Questions?