
# Double Phononic Crystal Lens-Based Enhancement of Underwater Power Transfer

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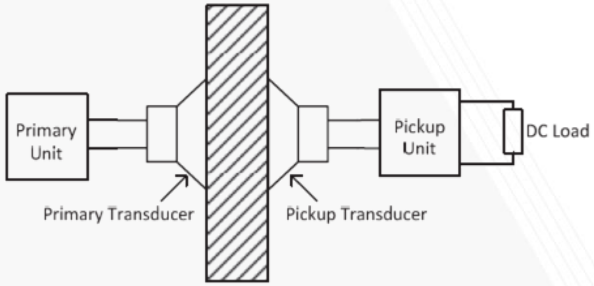
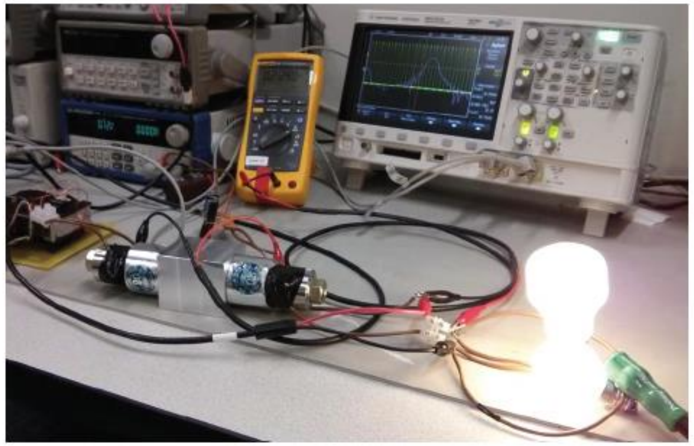
ASA ACOUSTICAL SOCIETY OF AMERICA

181st ASA meeting, Seattle, WA

# Motivation for Acoustic Power Transfer (APT)

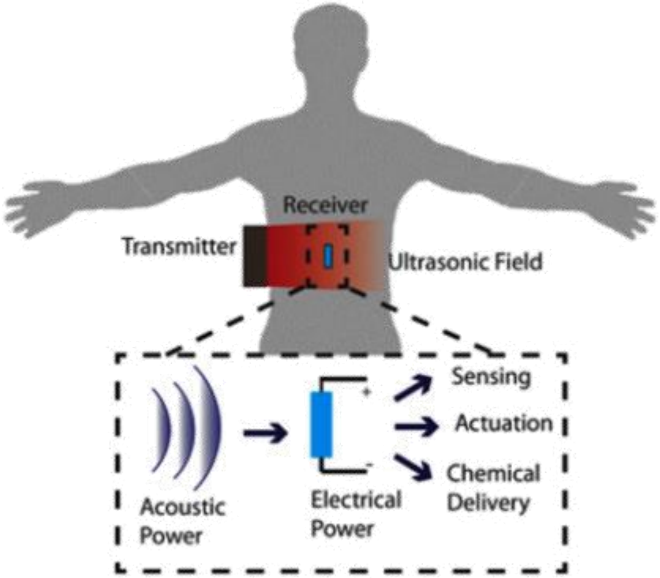
## Power and data transmission through metallic walls



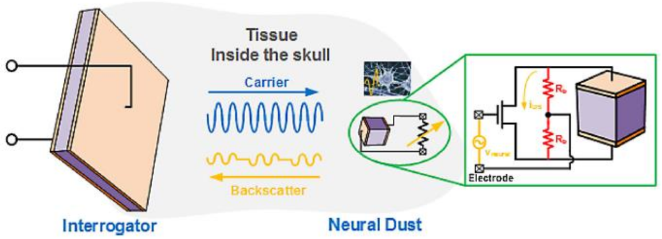



Leung *et al.*, in *9th IEEE Conf. on Ind. Elec.& App.* (2014).

## Biomedical implants

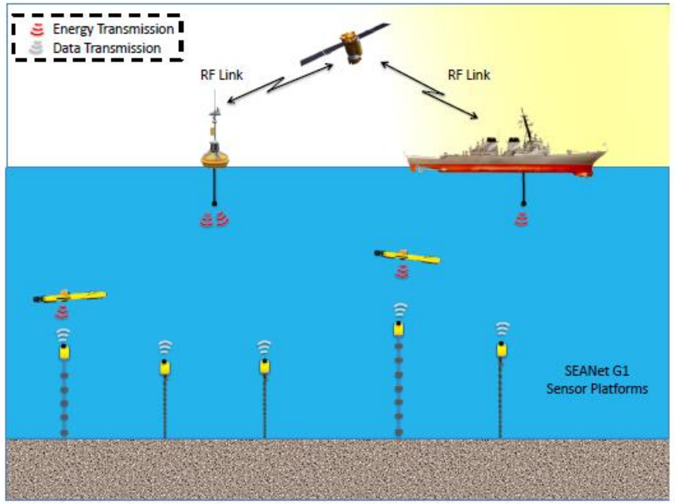



Song *et al.*, *IEEE Trans. on Biomed. Eng.* (2015).

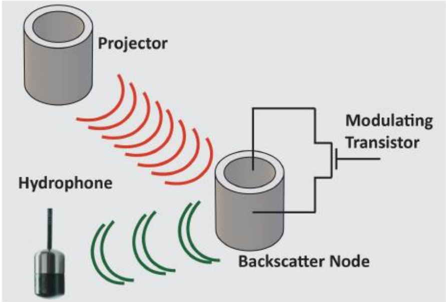



Seo *et al.*, *J. Neurosci. Methods* (2015).

## Ocean monitoring and navigation




Guida *et al.*, in. *IEEE Trans. on Mob. Comp.* (2020).




Ghaffarivardavagh *et al.*, in *SIGCOMM.* (2020).



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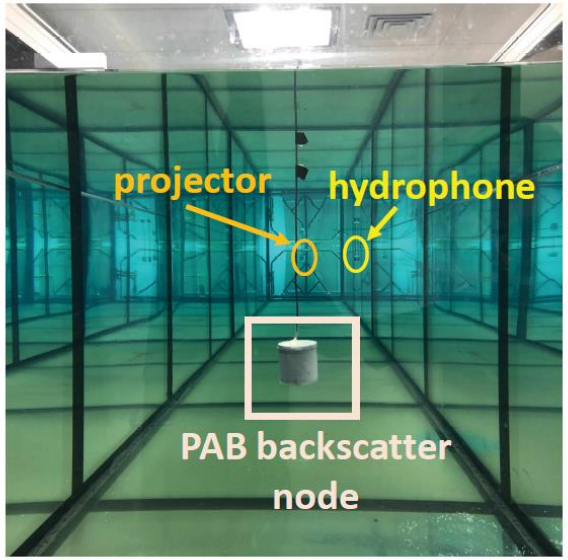
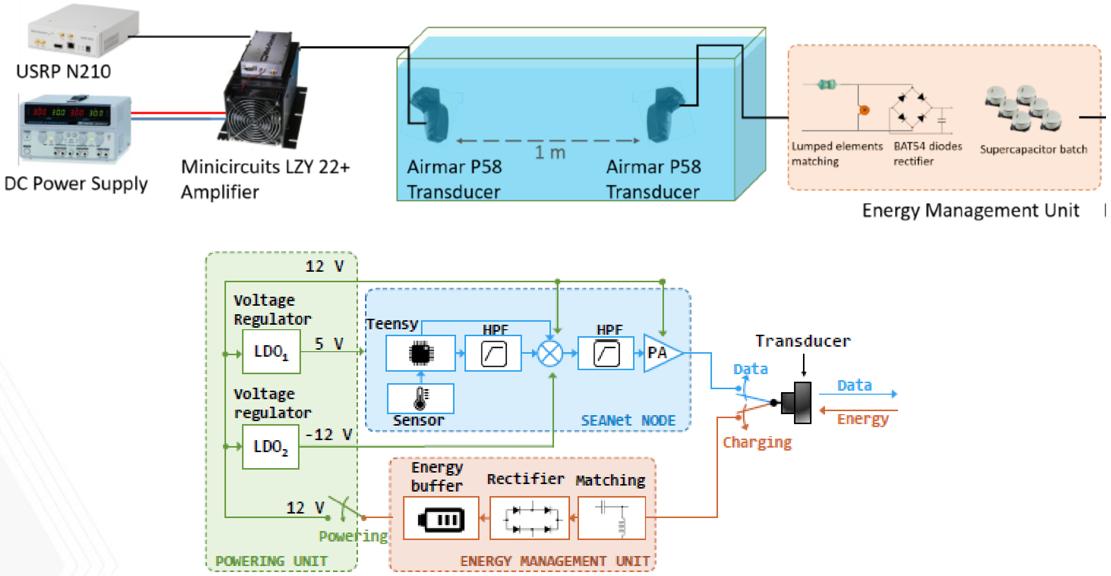
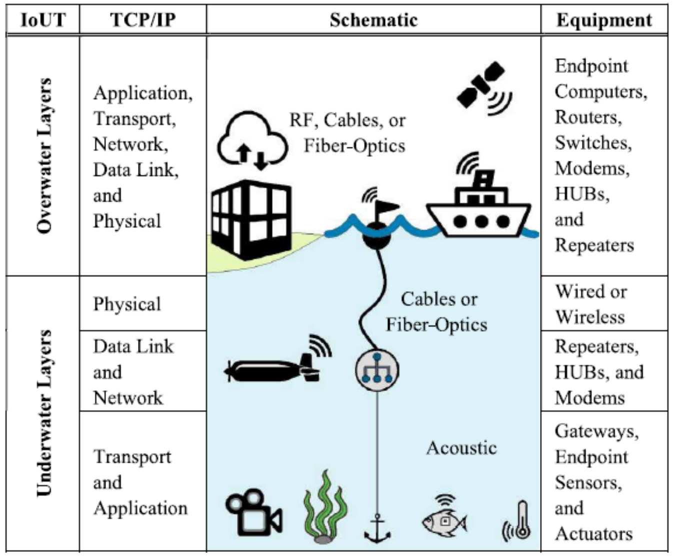
# Underwater Power Transfer




Jang and Adib, in *Proc. of the ACM* (2019).

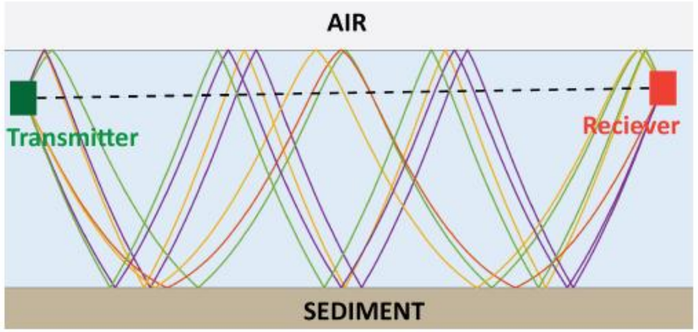



Guida *et al.*, in. *IEEE Trans. on Mob. Comp.* (2020).



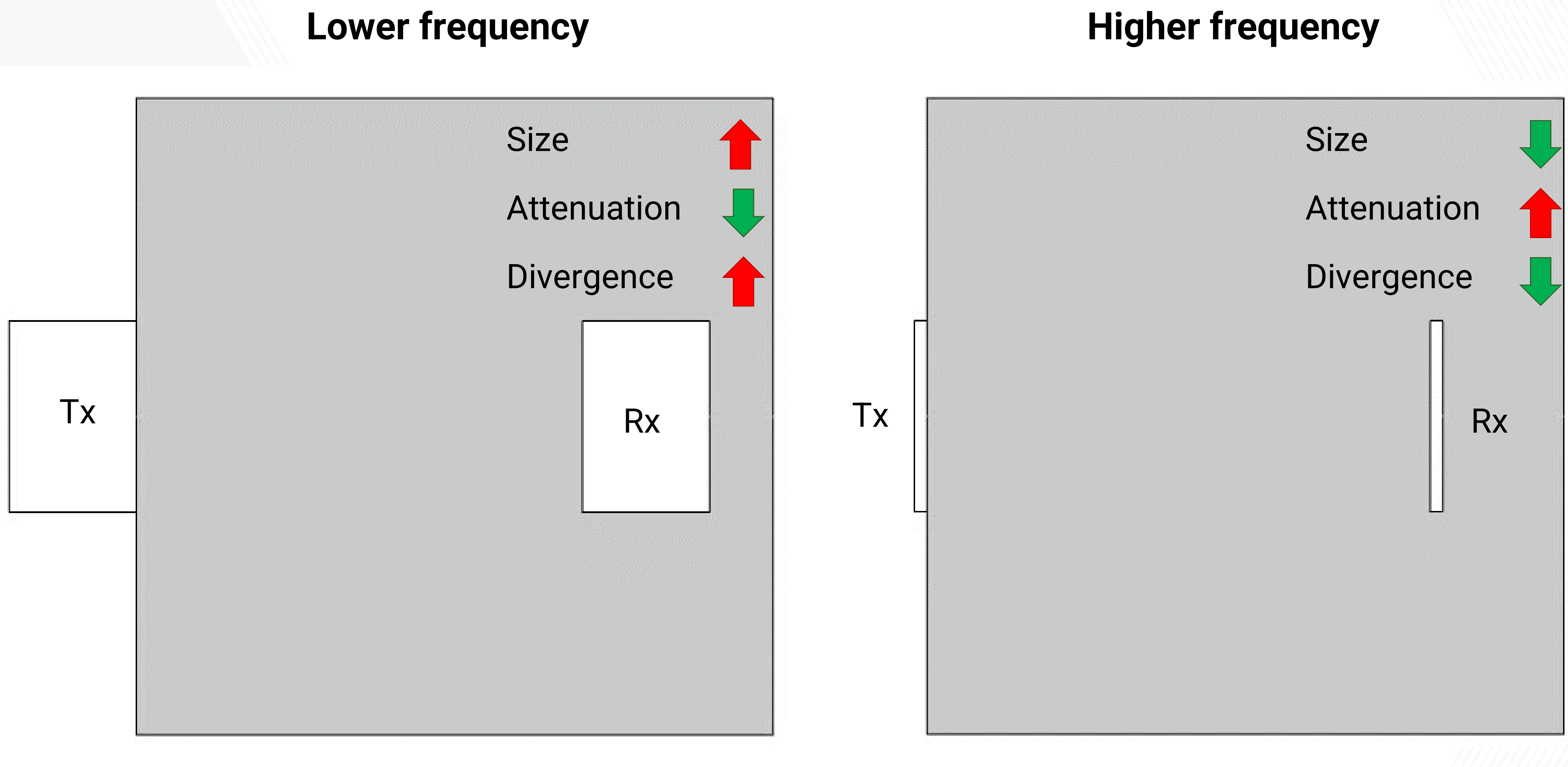

Jahanbakht *et al.*, *IEEE Comm. Surv. Tut.* (2021).

- 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.



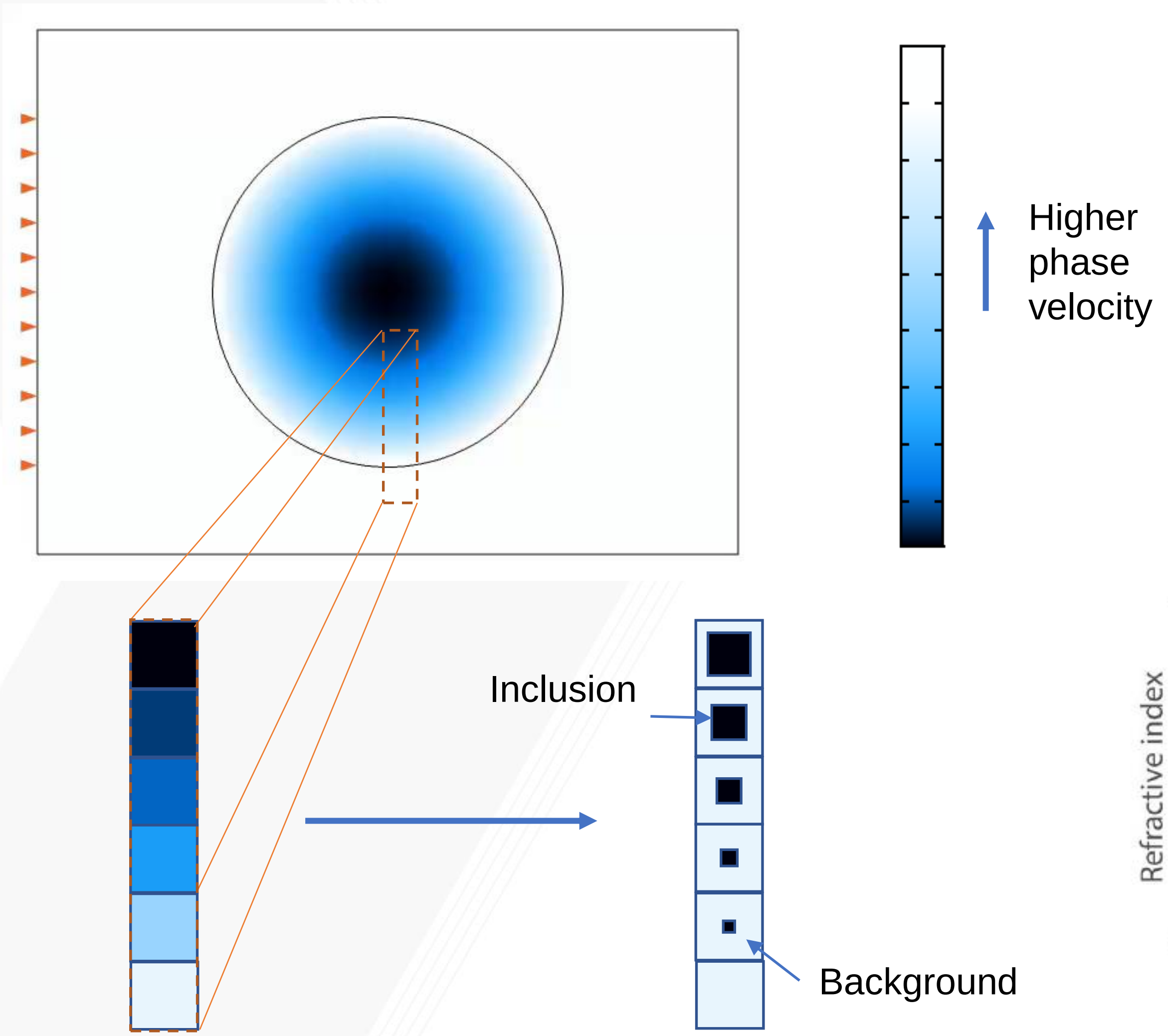

Ghaffarivardavagh *et al.*, in *Proc. Of 19th ACM Workshop on Hot Topics in Networks* (2020).

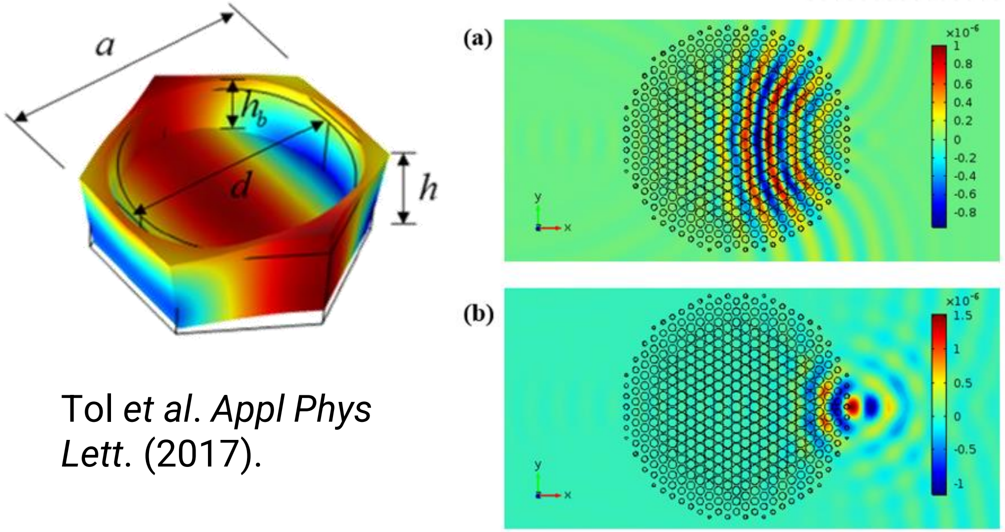
# APT Challenges: Divergence, Attenuation and Reflection



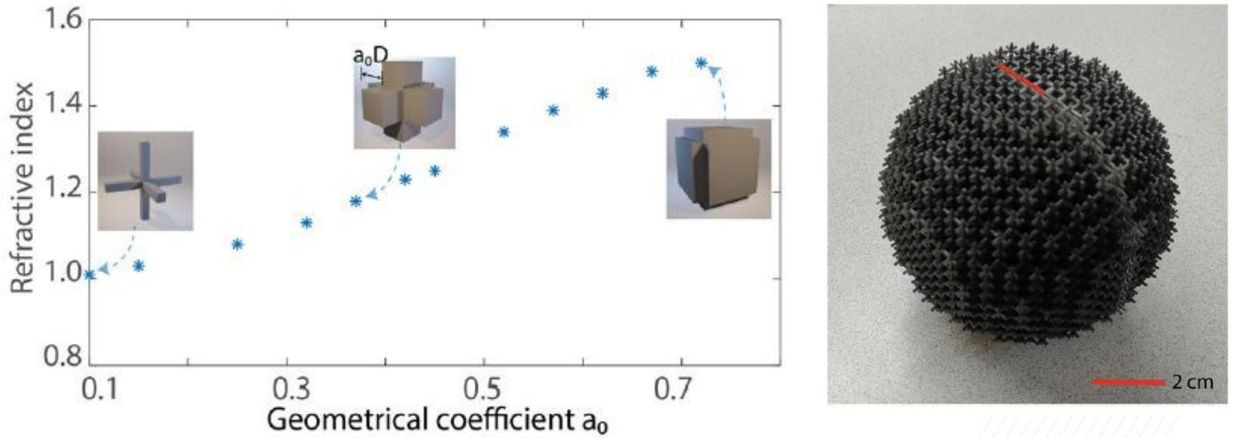

- Operating at lower frequency reduces attenuation but increases divergence losses.

# Gradient Index Phononic Crystals (GRIN-PCs)




Tol *et al. Appl Phys Lett*. (2017).




Xie *et al. Sci. Rep.* (2018).

- GRIN-PCs reduce divergence losses through wave focusing.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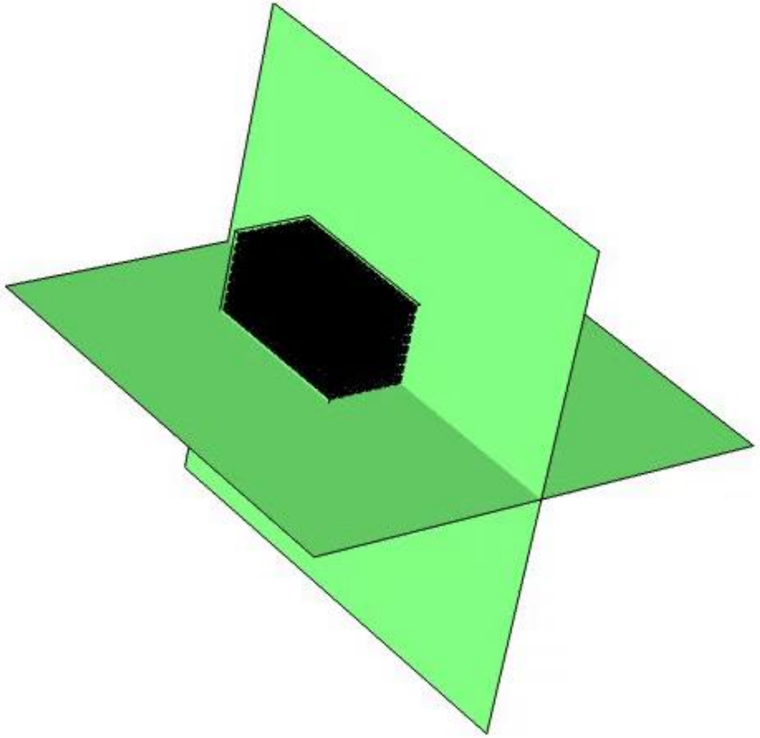
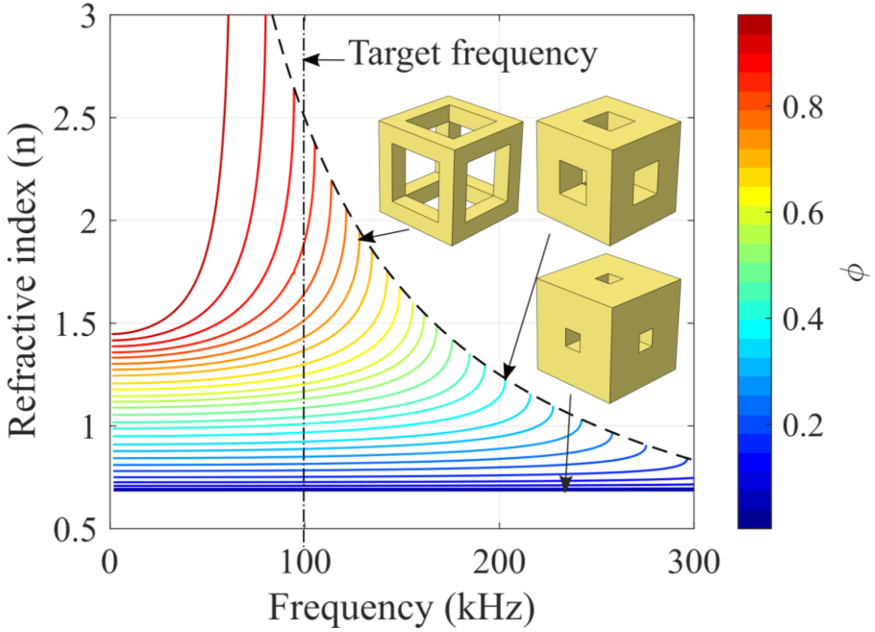
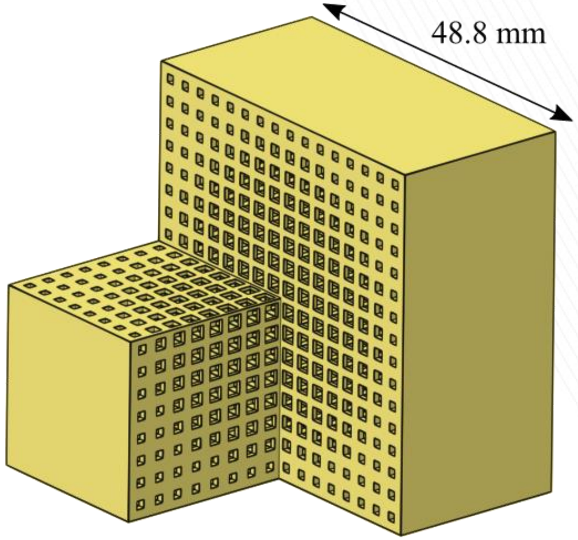
# GRIN-PCs for Focusing Ultrasonic Waves under Water

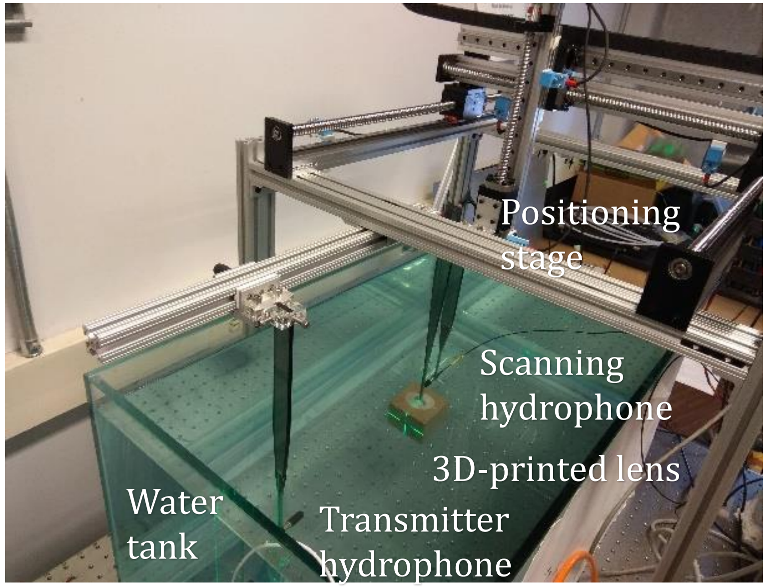
- We recently developed an underwater GRIN-PC lens for focusing ultrasonic waves around 100 kHz.
- Our main concern was to focus the energy at the receiver.

Allam, Sabra, & Erturk , Phys. Rev. Applied (2020).

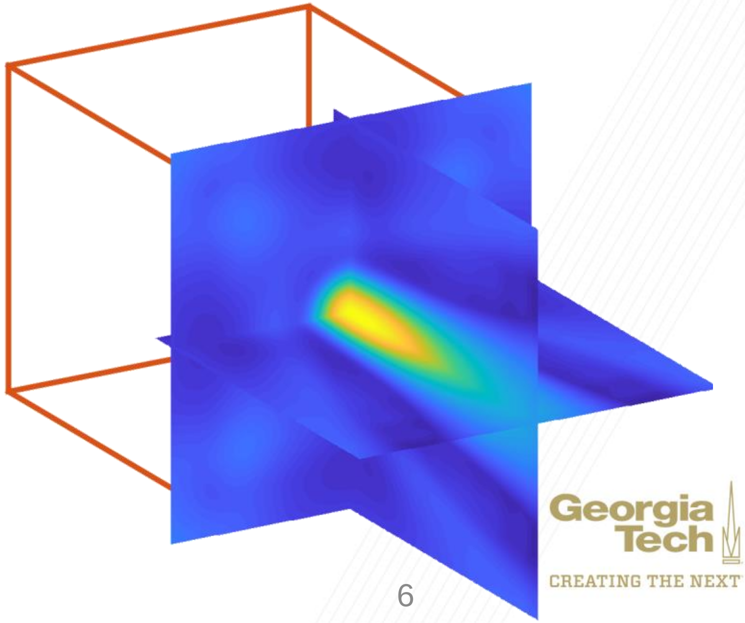





Experimental pressure field





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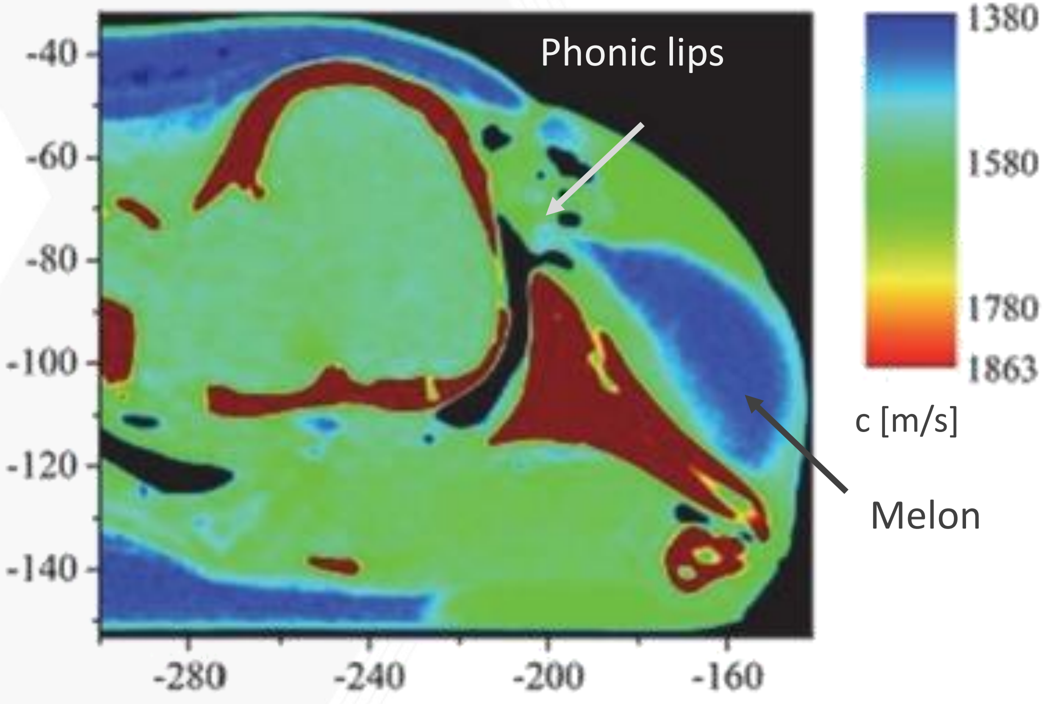
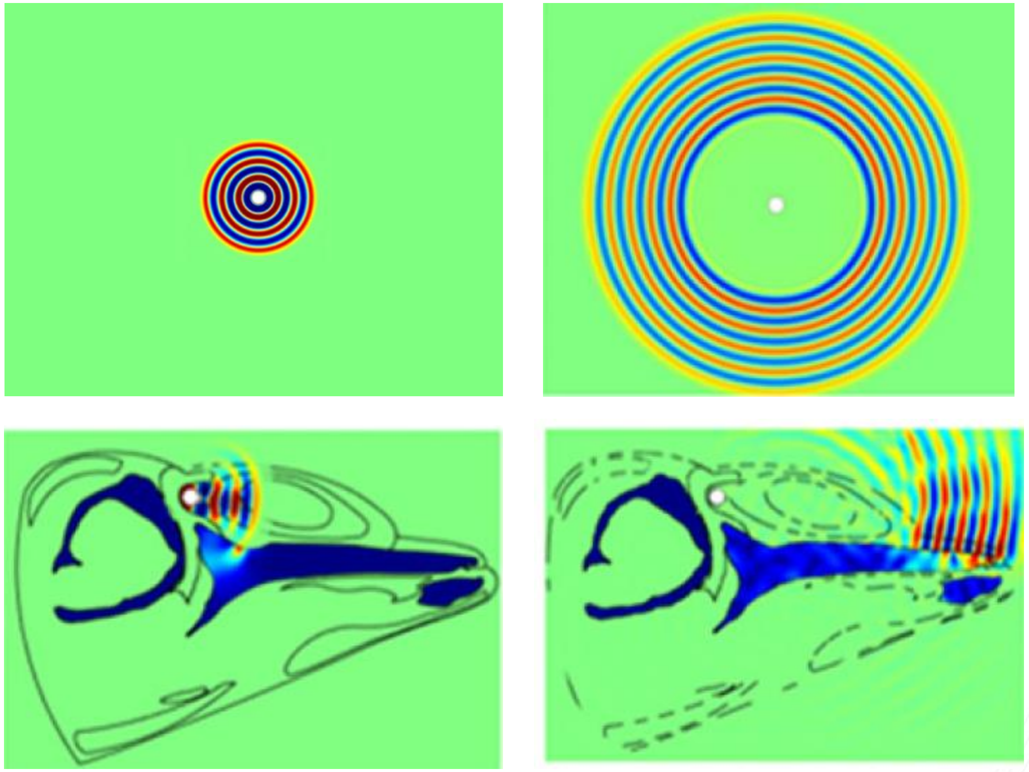
# Wave Collimation

- 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).



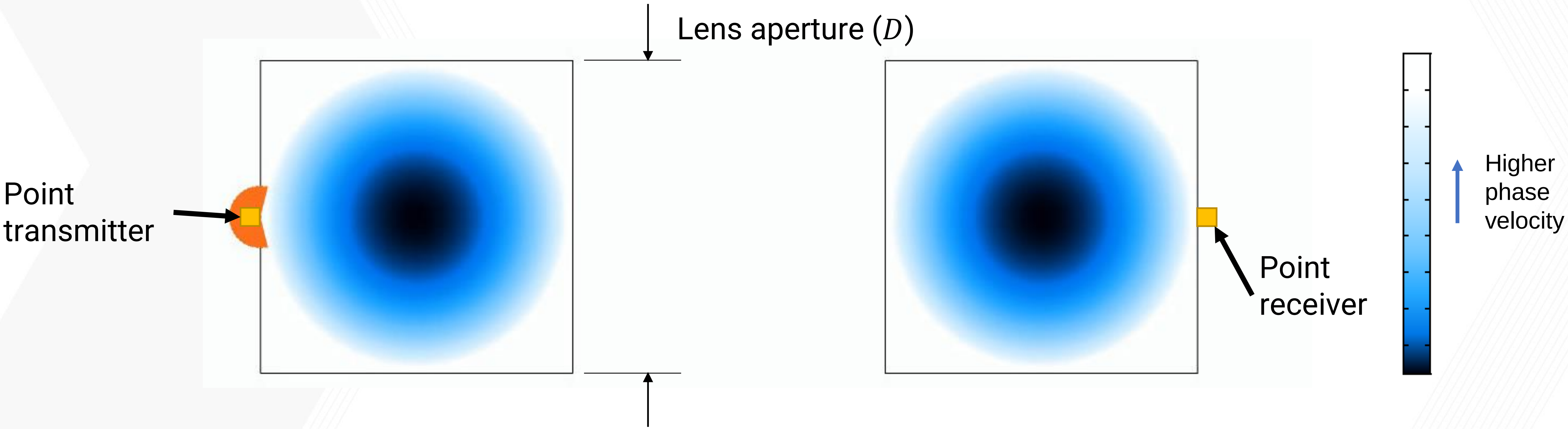

Wei *et al.*, PLOS ONE.(2020).



Song *et al.*, Appl. Phys. Lett.(2020).

# Using Two Lenses to Enhance Power Transfer (Ideal Case)

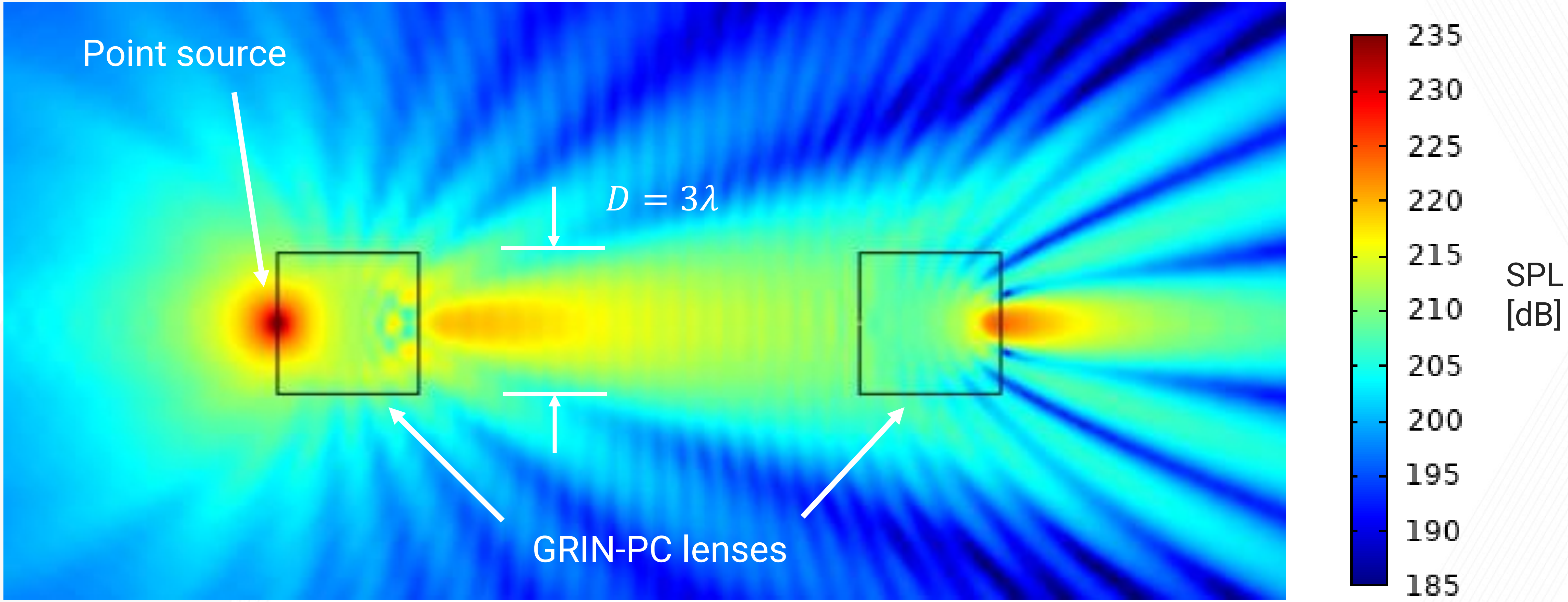
- Our proposed Power Transfer system leverages:
  1. A GRIN-PC lens at the transmitter to collimate the waves towards the receiver.
  2. A second lens focuses incident waves at the receiver.




- Raytracing assumes waves travels as rays which is only valid when the lens aperture is much larger than the wavelength.

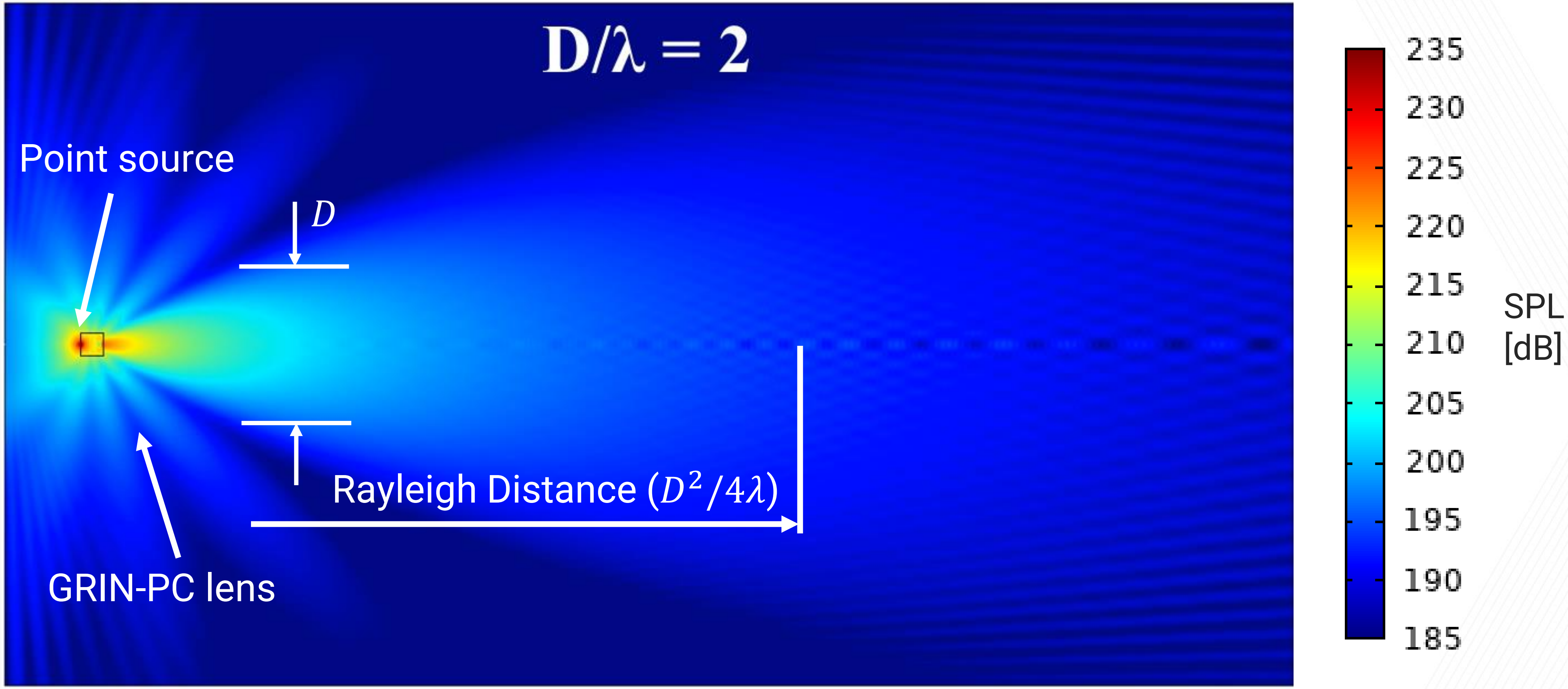
# Using Two Lenses to Enhance Power Transfer (Practical Case)

- 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

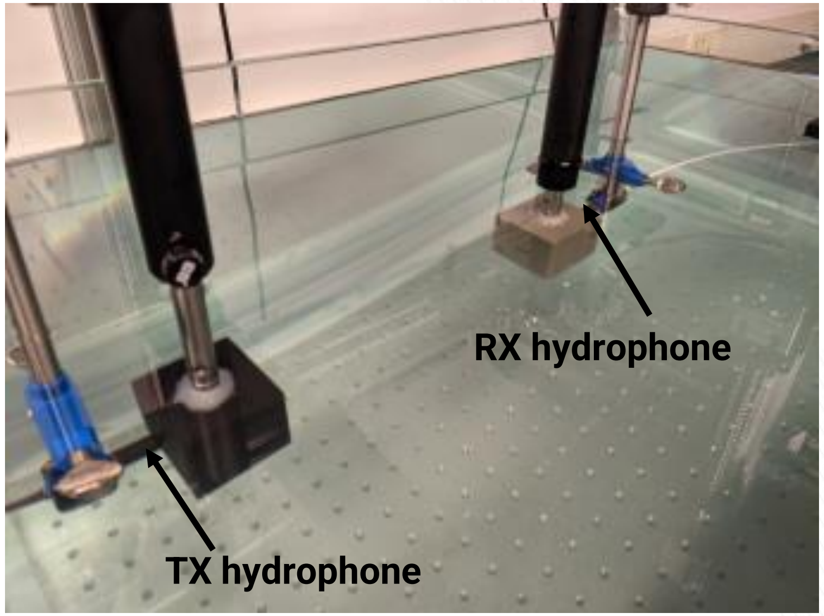


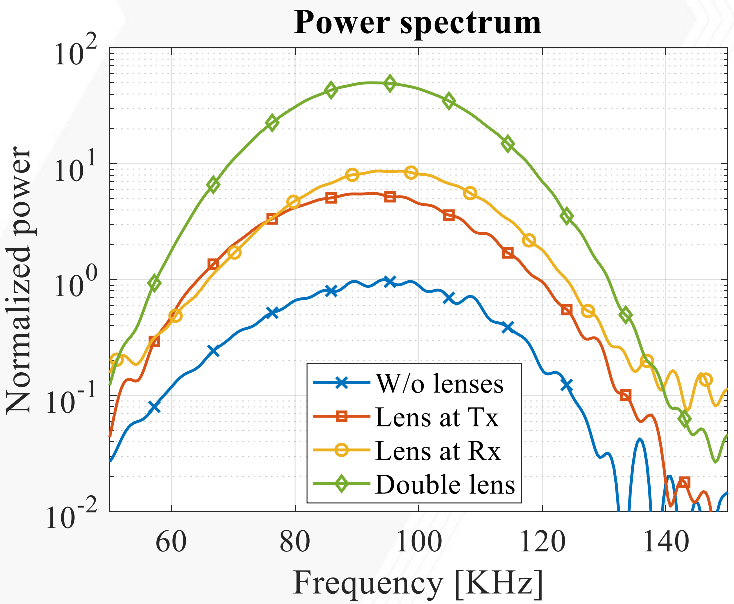

- Larger lens aperture yields a more collimated beam.
- The source/lens is approximately a piston radiator with the same aperture.

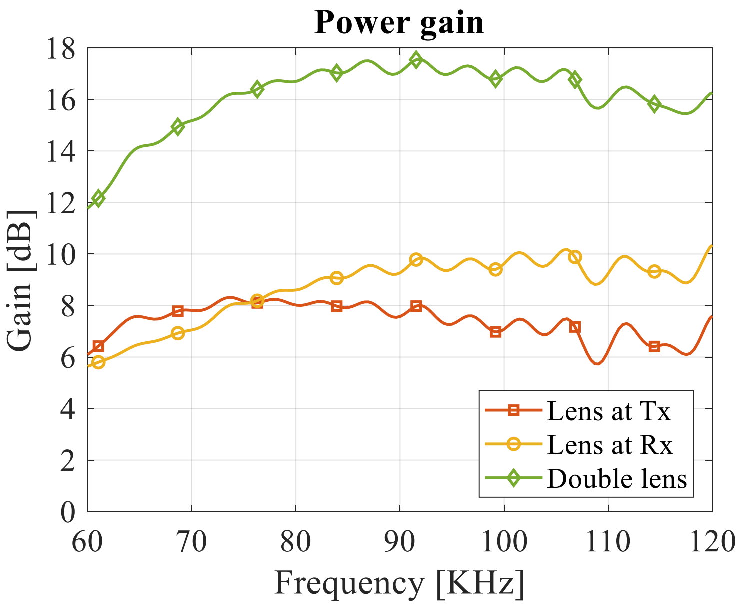

# Experimental Results

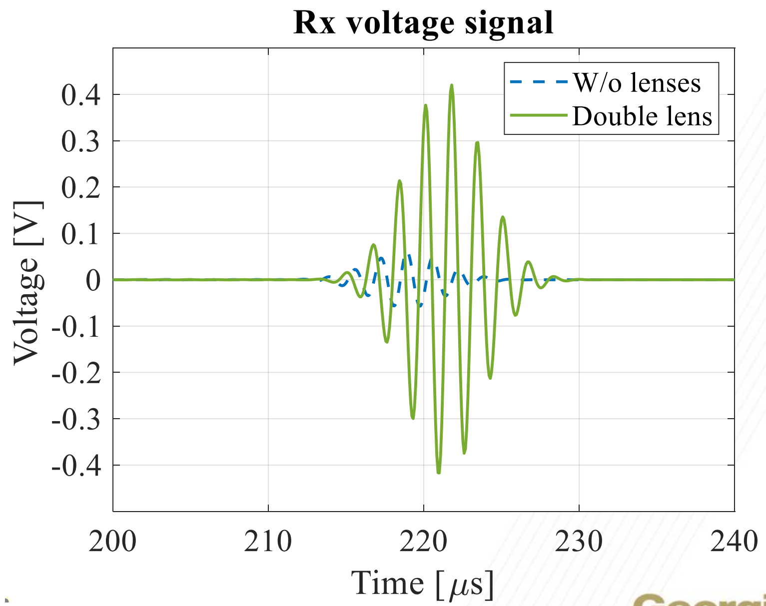
# Power Enhancement for Omnidirectional TX and Rx

- 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.



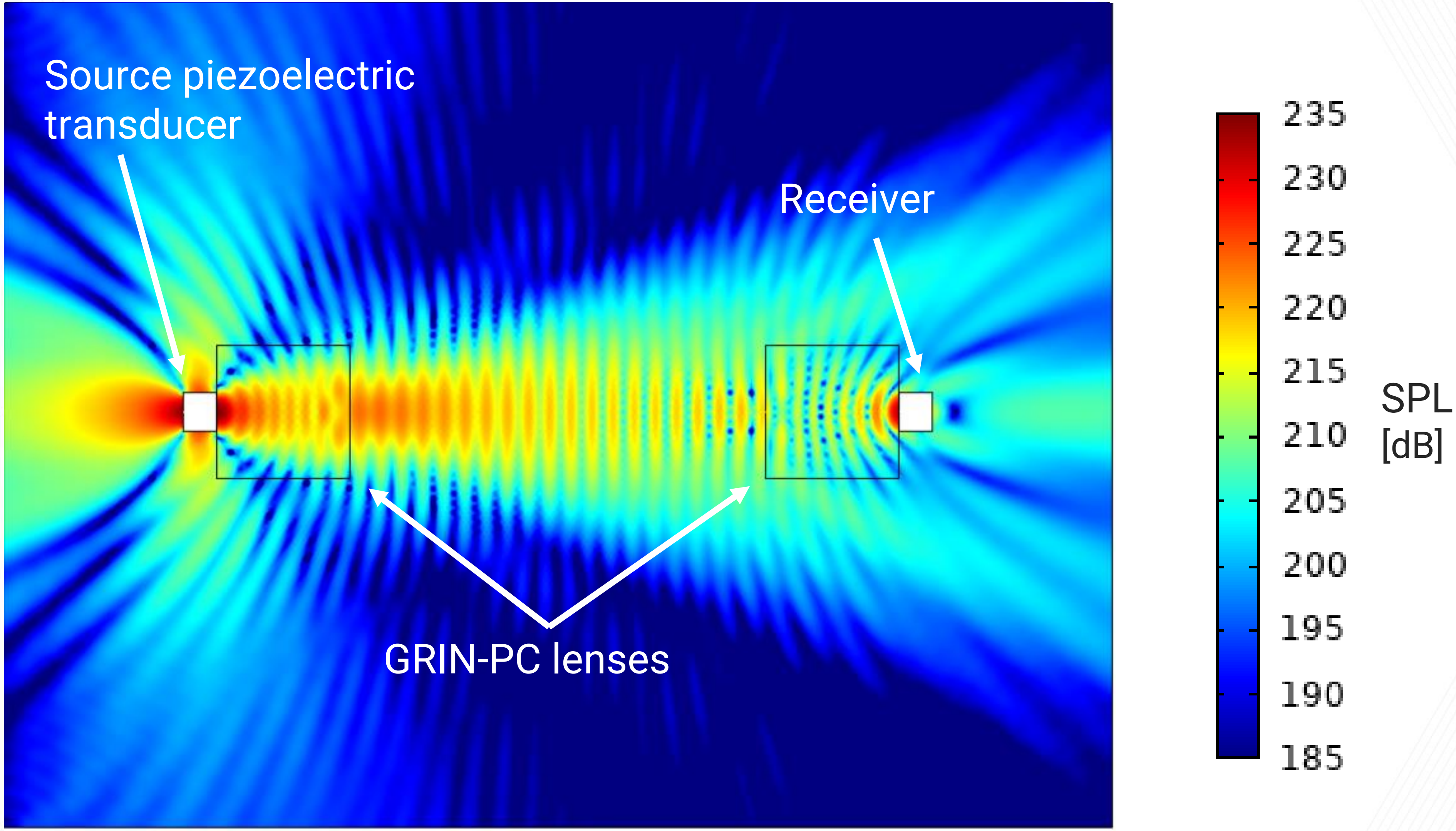




- The power output of the system is enhanced by almost two orders of magnitude.

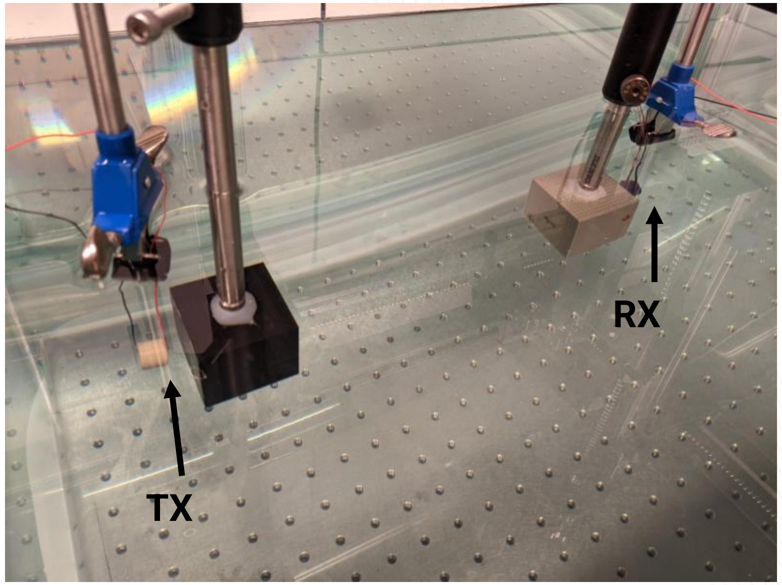
# Enhancing Power Transfer for Low Directivity Transducers

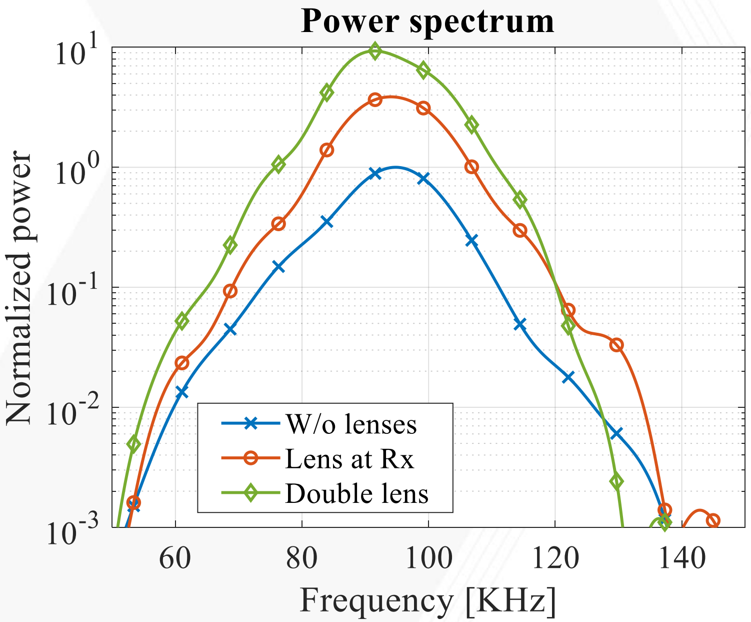


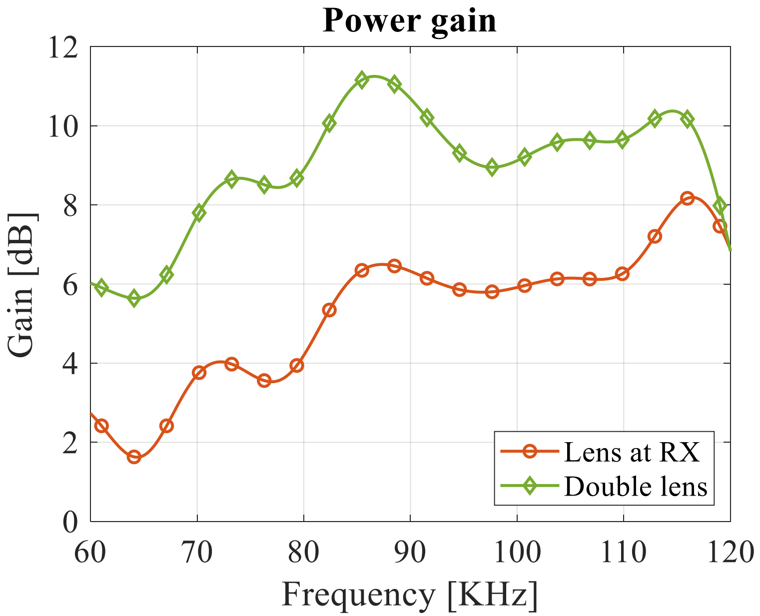

- The GRIN-PC lens enhances the directivity of transducers with small apertures.

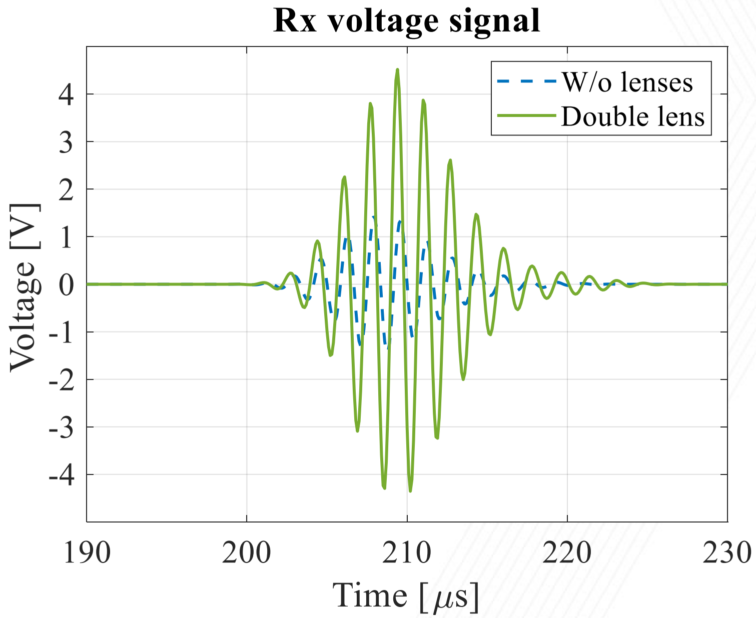
# Power Enhancement for a Practical System

- 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.

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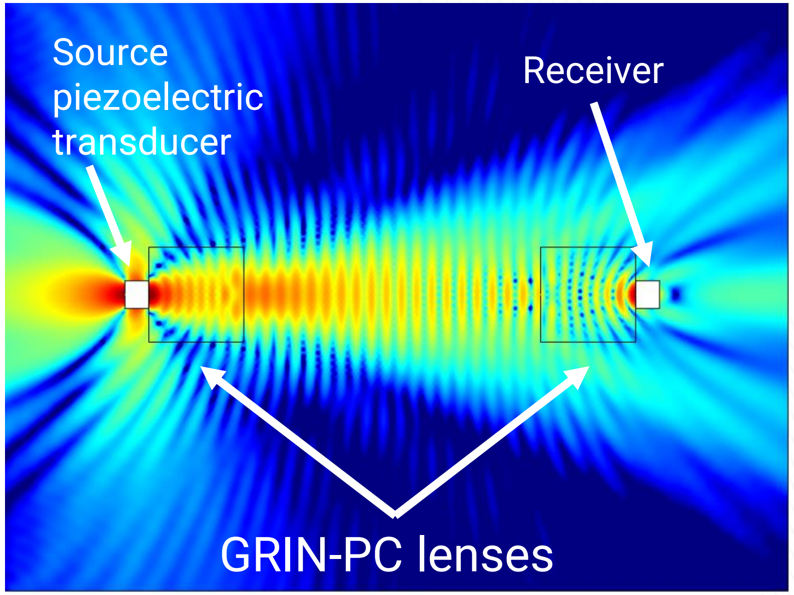
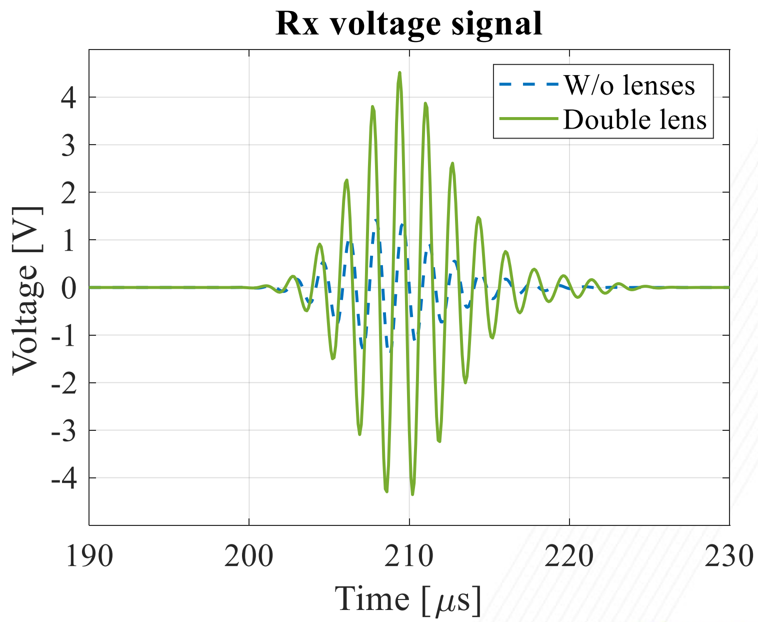
# Conclusions and Future Work

- 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 $\mu$W 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?