Enhancing and Redirecting Sound Wave Propagation Utilizing Metamaterials

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Introduction

A technology demonstrator called the "acoustic hyperlens", constructed using metamaterials, can transform near field waves into far field waves. It is the inherent anisotropic properties of this metamaterial that facilitates the transformation. Prior "acoustic hyperlens" research has focused on sound wave propagation along air gaps between radial fins made of heavy material such as brass. Our research changes the fin geometry to further explore the effect of different anisotropic properties on sound wave propagation. Using the COMSOL acoustics module, re-orientation of the fins perpendicular to the sound source was explored. We observed amplitude enhancement of the original sound source through redirection of the sound wave propagation. The benefits of our research can potentially improve noise reduction solutions and enhance signal to noise ratio through redirection of the sound waves back to the transducer.

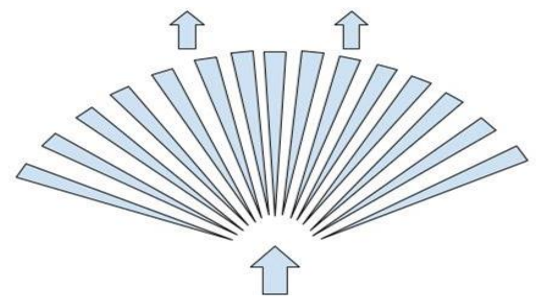

Figure 1: Existing Radial Geometry of Acoustic Hyperlens

Anisotropic properties of metamaterials are manipulated by varying mass density and bulk modulus [2]

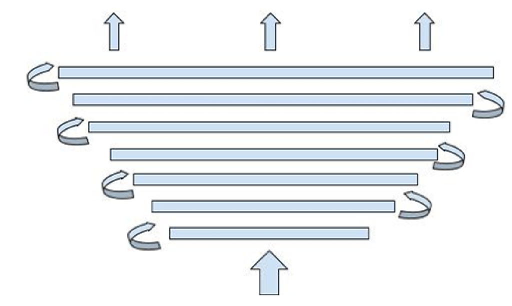

Figure 2: NEW Re-oriented Perpendicular Geometry

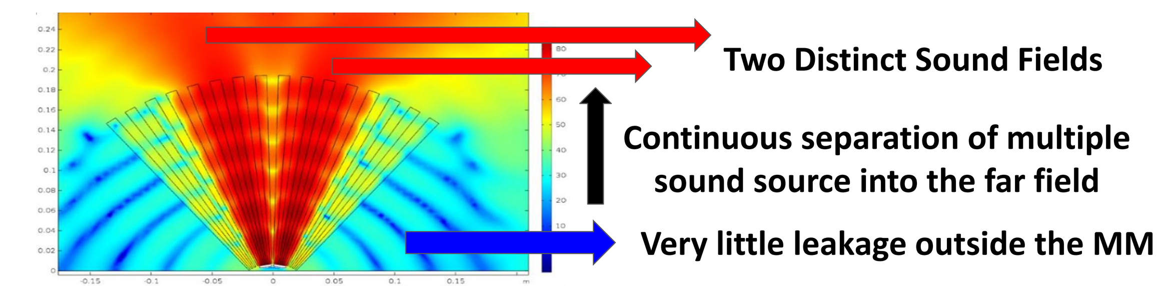

Figure 3: COMSOL simulation of existing Acoustic Hyperlens improving the resolution of the acoustic image [3]

Materials & Methods

Phase 1: Design Prototype

- Using COMSOL Acoustics with LiveLink for SolidWorks to manipulate the parameters and optimize the fin design.

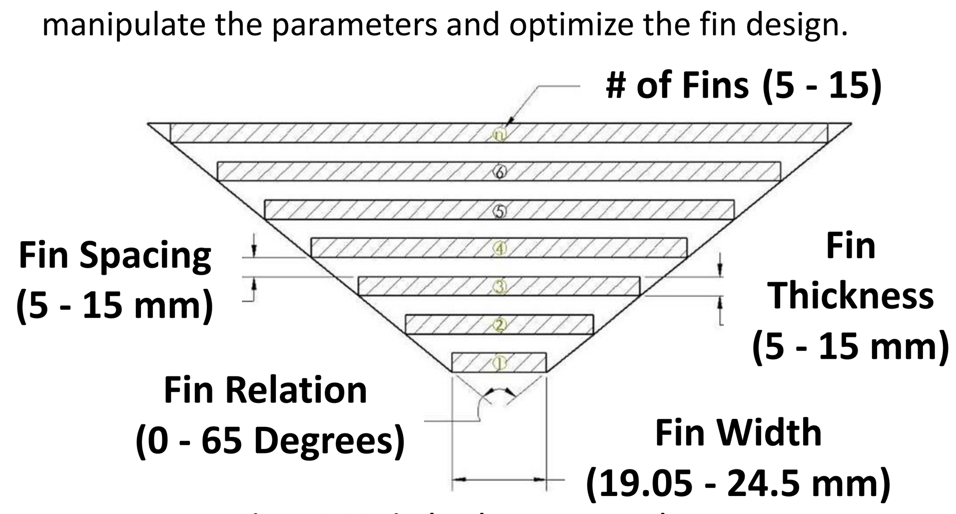

Figure 4: Manipulated parameters and ranges

Phase 2: Manufacture Prototype

- Brass prototype manufactured in house at Jabil using CNC Milling machine.

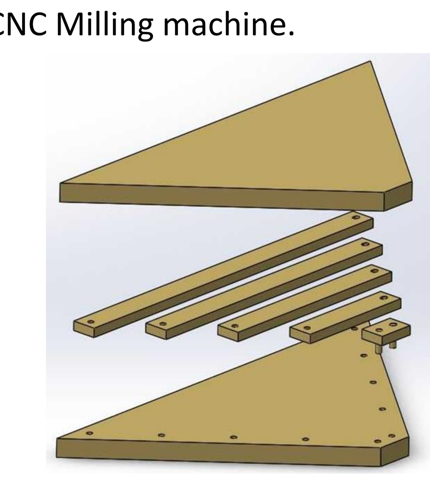

Figure 5: Exploded view of optimized design

Phase 3: Validate Test Setup

- Validate test setup on Klippel's Near Field Scanner (NFS) using existing hyperlens.

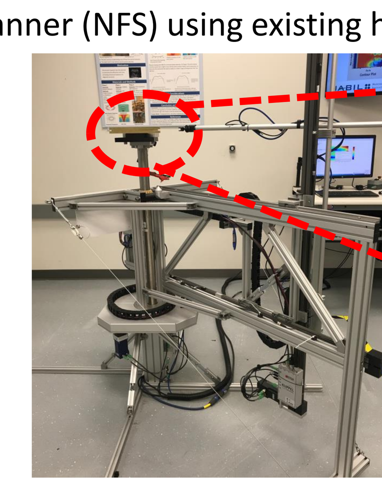

Figure 6: Prototype mounted on Near Field Scanner

Phase 4: Prototype Performance

- Establish baseline for speaker standalone.
- Assemble prototype and measure performance.

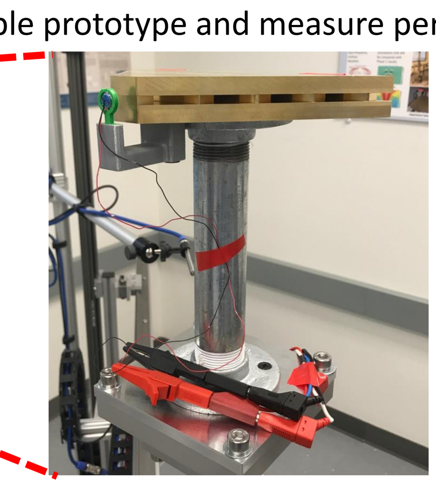

Figure 7: New prototype with support fixture

Results

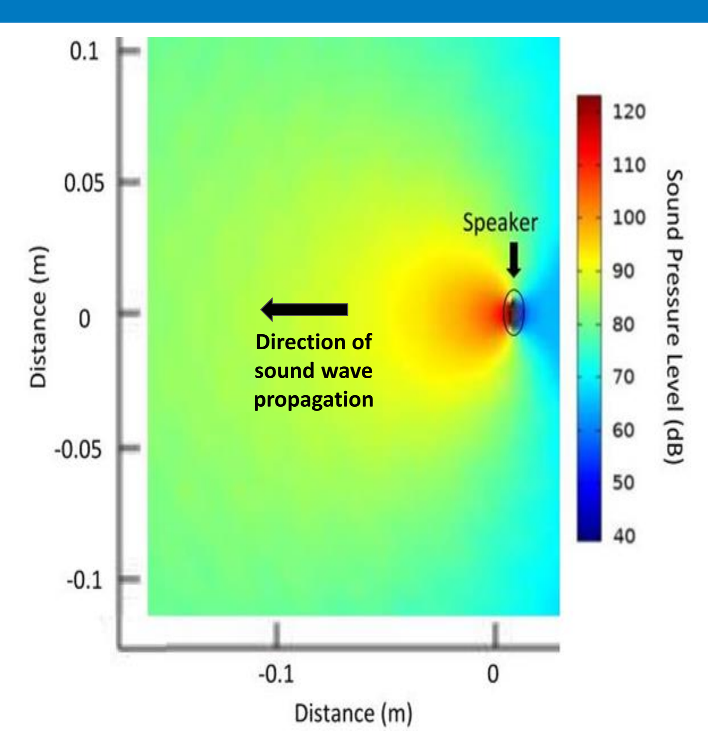

Figure 8: Simulation of Speaker Standalone at 9 kHz

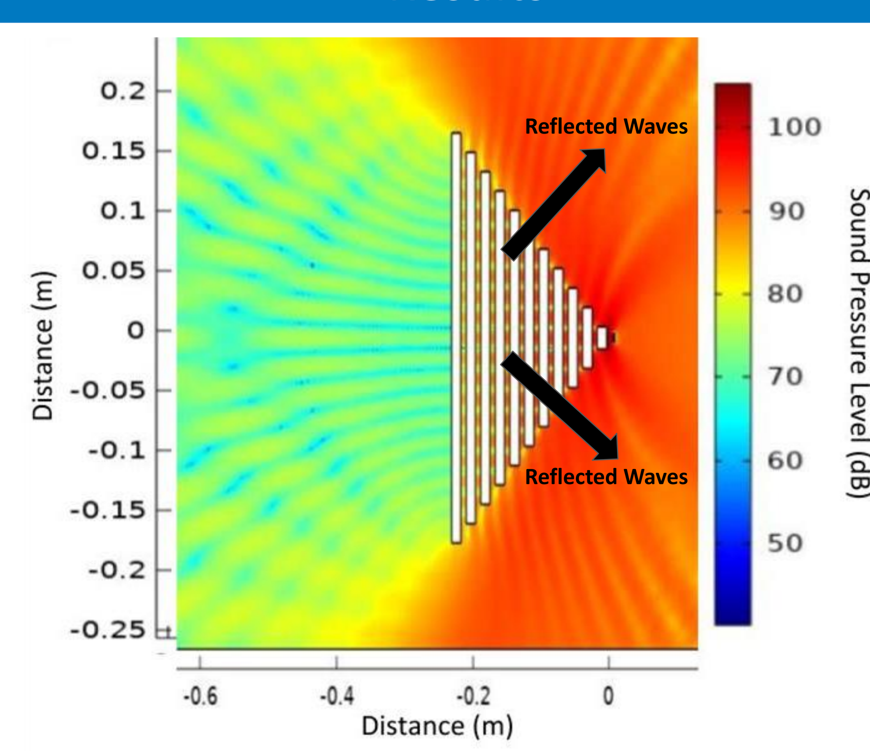

Figure 9: Simulation of Prototype at 9 kHz

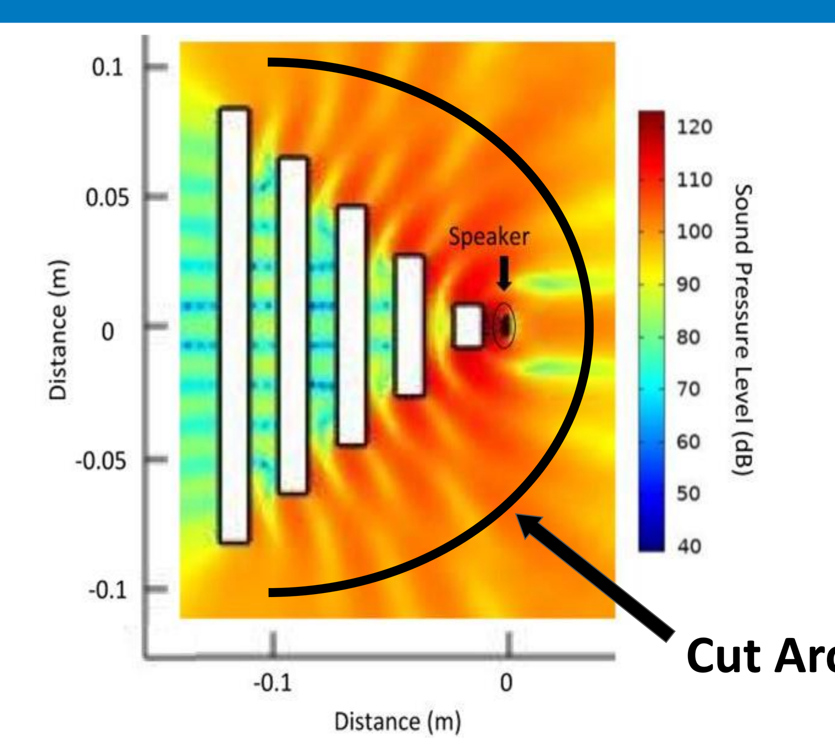

Figure 10: Optimized Model: 5 fins, 45⁰, 21 mm width of first fin, 14mm spacing, 14mm thickness, 9 kHz

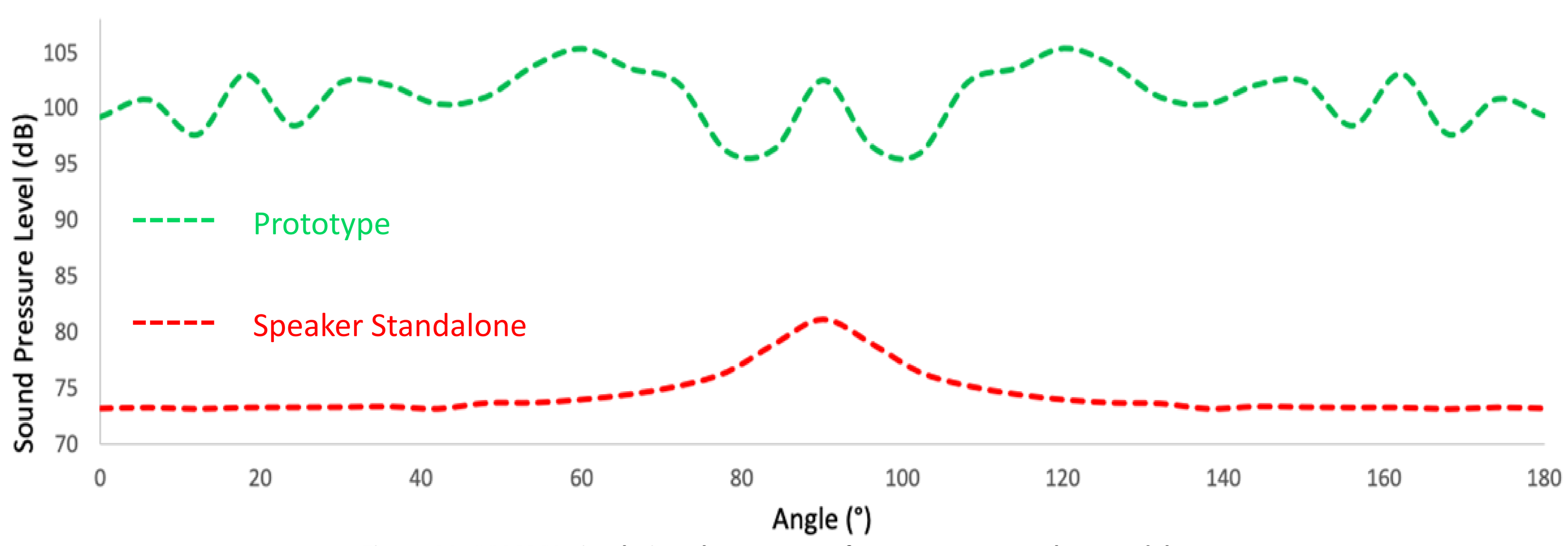

Figure 11: COMSOL simulation along cut arc of prototype vs. speaker standalone

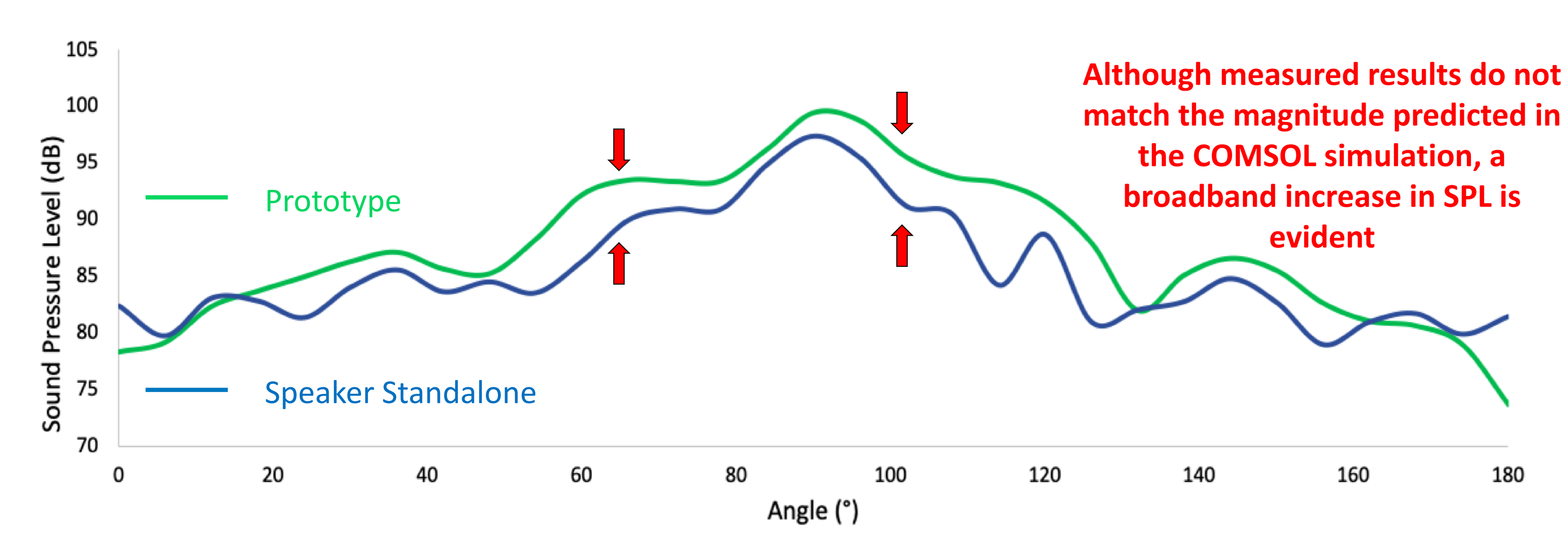

Figure 12: Measurement along cut arc of prototype vs. speaker standalone

2D Structure (Group of 4)

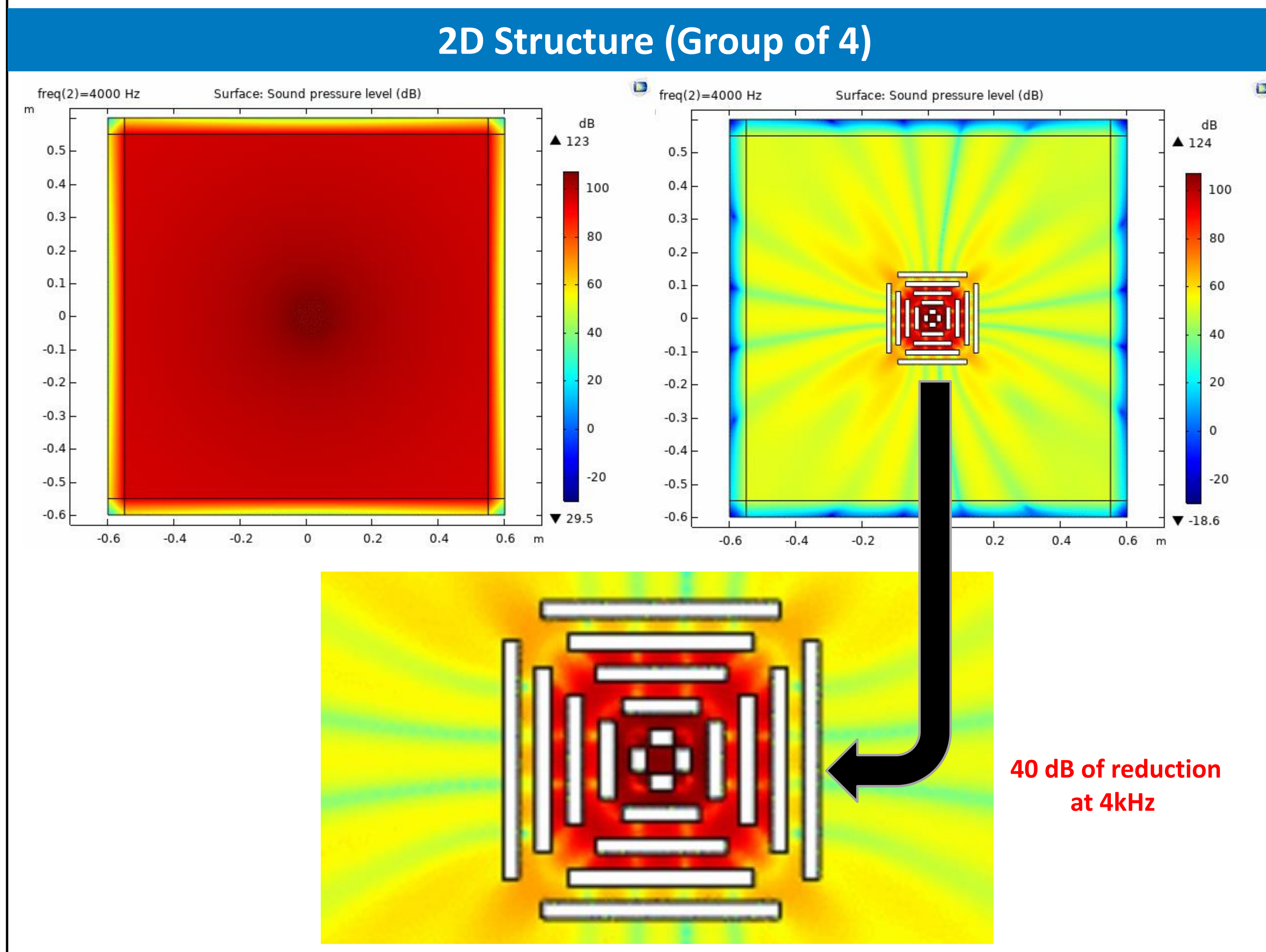

Figure 13: COMSOL 2D simulation consisting of 4 individual structures

3D Structure (Group of 6)

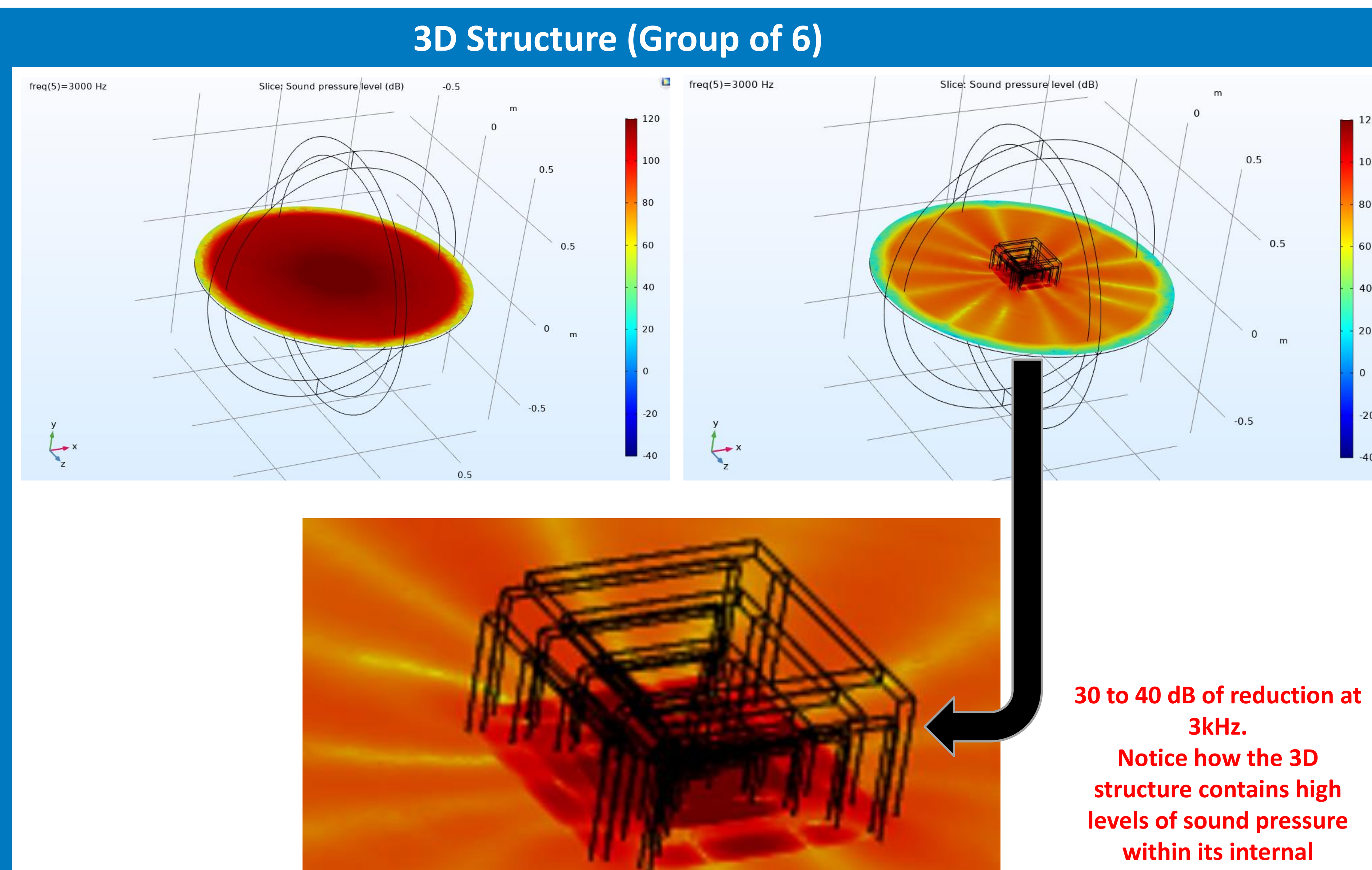

Figure 14: COMSOL 3D simulation consisting of 6 individual structures

Conclusions

- In contrast to the old Acoustic Hyperlens, the new orientation has the ability to enhance and redirect sound waves.
- The anisotropic properties of metamaterials have a major effect on sound wave propagation and directivity.
- Noise reduction applications are possible using acoustic metamaterials as per the 3D structure shown above.

References

1. Chen, Yongyao, et al. "Enhanced Acoustic Sensing through Wave Compression and Pressure Amplification in Anisotropic Metamaterials." *Nature Communications*, vol. 5, no. 1, 2014, doi:10.1038/ncomms6247.
2. A. Cummer, Steven, Christensen, Johan., Alu, Andrea. Controlling Sound with Acoustic Metamaterials. *Nature Reviews Materials volume 1, Article number: 16001 (2016)* https://www.nature.com/articles/natrevmats20161
3. Christensen, K., Nguyen, J., Osuna, A. Final Report: Acoustic Hyperlens. (2018) *San Jose State University: Biomedical Engineering Senior Project II*. Retrieved from Authors.