School of Electrical and Computer Engineering
Opportunity Research Scholars' Program

Acoustic Metasurfaces for Personal Acoustic Spaces

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Introduction

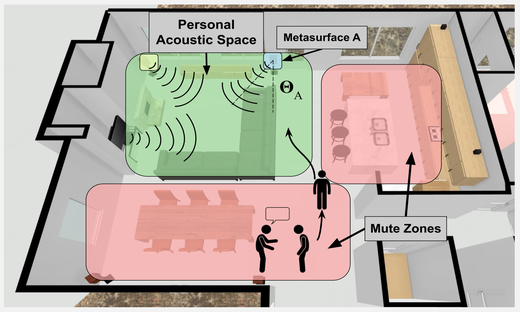

Fig. 1. Personal Acoustic Space (PAS) in the context of a living room. Figure adapted from [1]

Motivation

- Phased speaker array to create PAS is costly
- 3D printed MS → easy, low-cost & reconfigurable
- Previous research focuses on wideband MS at high frequencies [2]
- Achieving subwavelength wideband acoustic MS difficult because:
  - $\lambda \propto 1/f$ → low frequencies require massive metasurfaces
- Additionally: existing MS completely static [2, 3]
  - Most reconfigurable MS require active elements; not user friendly
  - Difficult to create PAS without adjustable elements (different needs = different PAS)
- Goal: explore reconfigurable, wideband acoustic MS to create PAS

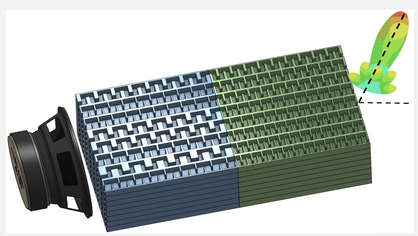

Fig. 2. Cascaded MS illustrating reconfigurability to beamform at sharper angles

MS Development and Simulation

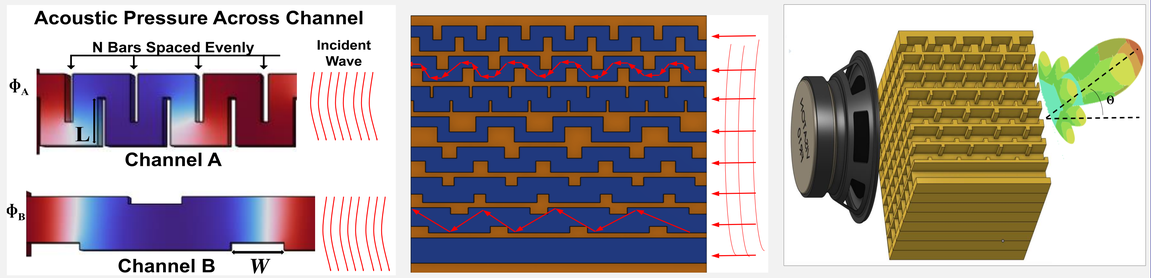

Fig. 3. Metasurface development process. From left to right: Single cell time delay; Single layer of MS cells; Layers abutted together

KEY TAKEAWAYS

1. Changing channel properties (bar spacing, dimensions L & W) has resulting effects on acoustic pressure
2. More bars → longer path length → larger time delay of outgoing wave
3. Each layer contains an array of differing waveguides with different lengths → beamform at different angles

Experimental Results

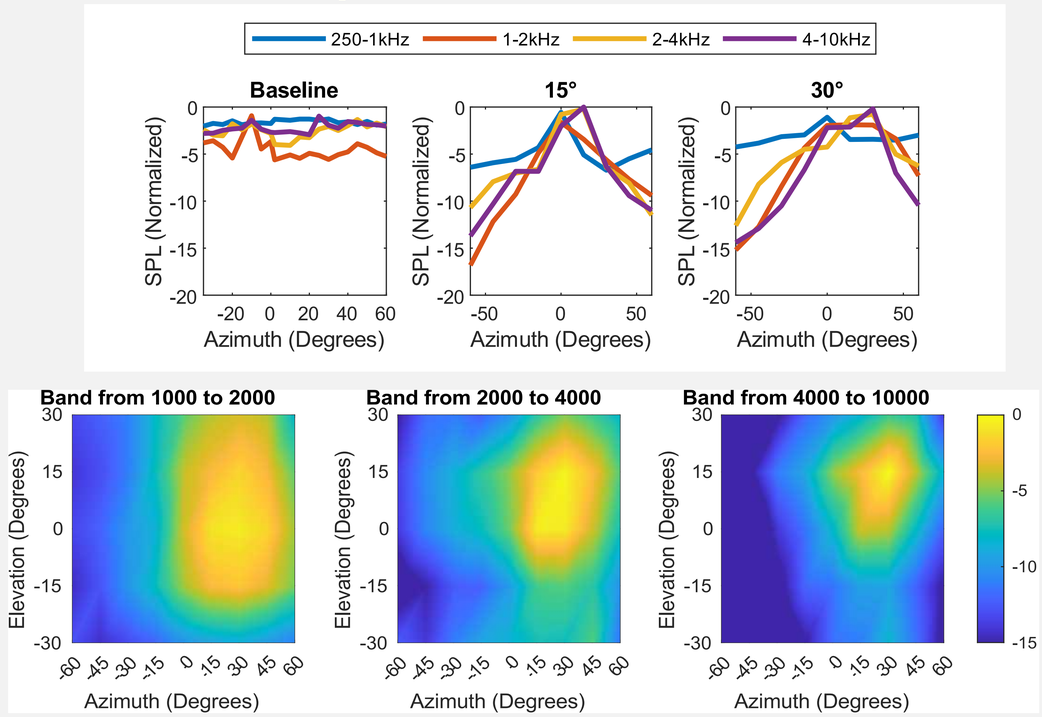

Fig. 4. Results from (a) elevation beamforming testing of 30° MS and (b) elevation beamforming testing of cascaded 30° MS (Azimuth) and 15° MS (Elevation)

Discussion

- Phase delay due to variations in channel length
- 15° MS has best performance for SPL in 2-10 kHz bands
  - ~11 dB attenuation compared to baseline results
- 30° MS operates similarly for 2-10kHz band
  - ~10 dB attenuation compared to baseline mean.
- Cascaded MS:
  - Abutting distinct MS in different configurations can beamform acoustic waves in both in azimuth and elevation
  - Operates well for 1-10k Hz
  - Best results at 4-10 kHz due to higher frequencies and optimized channel size
  - Lower wavelengths:

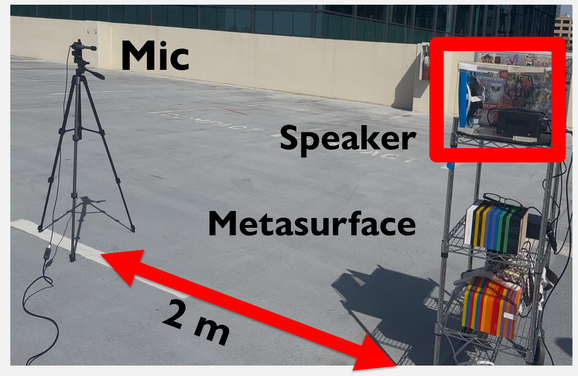

Fig. 5. Experimental Setup

Conclusions

- Developed 2 MS capable of beamforming 1-10 kHz
- Tested indoors and outdoors
  - Performed 2 tests per type: elevation & azimuth
- MS most successful beamforming at 4-10 kHz
- Demonstrated promise for passively reconfigurable MS to create PAS

References

[1] https://tinyurl.com/22h3dsmp
[2] Bansal, S. et al, "Transmissive Labyrinthine Acoustic Metamaterial-Based Holography for Extraordinary Energy Harvesting". Adv. Eng. Mater., 25: 2201117. https://doi.org/10.1002/adem.202201117
[3] Jianxin Z. et al, Phase-Optimized Multi-Step Phase Acoustic Metasurfaces for Arbitrary Multifocal Beamforming" Micromachines. 2023; https://doi.org/10.3390/mi14061176

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