An Acoustic Beamforming Device For Personalized Audio Experiences

STUDENTS: Connor Bowers, Abdikafi Hersi, Joseph Concepcion, Yuan Li, Tyler Pippin

An Acoustic Beamforming Device

- Sends arrays of ultrasonic sound with audible audio signals modulated into them, which demodulate to audible sounds in the air.
- Creates very narrow beams of sound, that is controllable in both direction and magnitude.
- We were tasked with miniaturizing the existing prototype for more convenient transport and usage.
- As a team with a diverse set of skills, we also explored other possible improvement of the device and its capabilities.

Beamforming & Demodulation Principles

- The beamforming device transmits amplitude modulated audio content through a parametric acoustic array (PAA) [1].
- The PAA is made up of 112 ultrasonic transducers, arranged in 8 columns.
  - Individual columns are interleaved, to minimize side lobe effects.
- Phenomena called “medium and motion nonlinearities” in the air cause the ultrasonic carrier wave to demodulate [1].
- The result is a highly directional beam of sound.
  - The PAA has lower off-axis response than a conventional speaker.
- The acoustic beam can be steered by manipulating the phase of the signal being sent into each of the 8 columns in the PAA.
  - Phase manipulation is performed in software.

Prototype

- The prototype was developed by Juan Pampin and Michael McCrea.
- It used a rack-mounted DAC and amplifier board, as well as a bench power supply.
- The DAC required a thunderbolt connection to computer running the sound generation software.
- The setup was heavy and roughly 4 cubic feet in size, and the DAC was very expensive, making it inconvenient to transport.

Fig 1. The prototype electronics

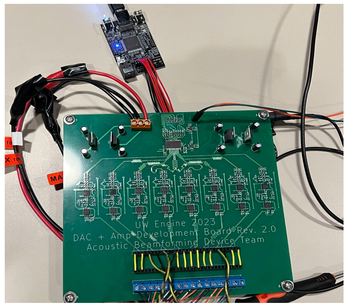
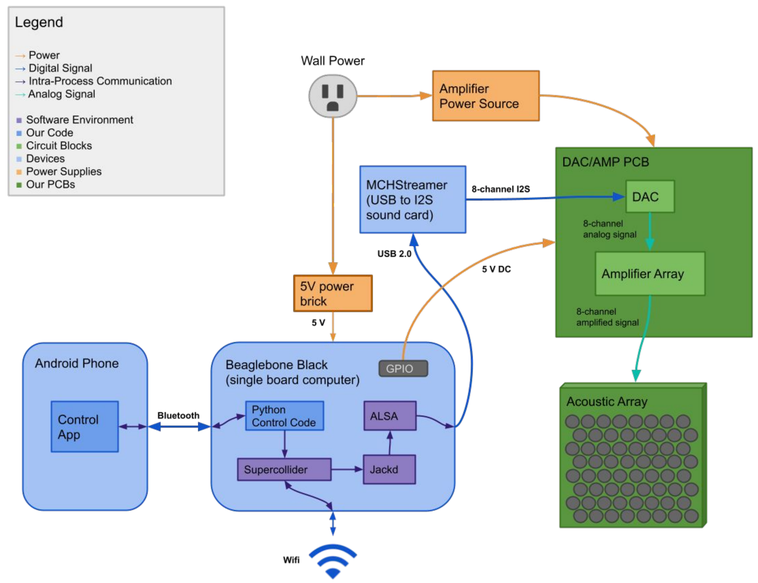


Fig 2. New DAC+Amp board

Overall System Design



Hardware

- **PAA**
  - Ole Wolff Electronics Inc OWS-081528TA-6 Surface-mount speaker
- **DAC**
  - Texas Instruments PCM1690 Integrated Circuit
  - Flexible Control Modes and Audio Interface, we’re using I2S
- **AMP**
  - Custom 3-stage Class AB amplifier
  - Butterworth LPF, First-Order Gain Stage, and a single-ended to differential converter.
- **Power supplies**
  - Pre-built power supply module which will be mounted into the enclosure
- **Enclosure**
  - All hardware except the PAA will be mounted in a 3d printed box which is light and has a size of one eighth of the prototype rack.

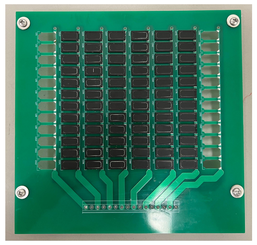


Fig 3. New PAA board with six columns of transducers soldered.

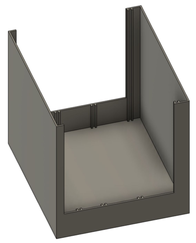


Fig 4. New 3D printed box for all the SBCs and PCBs except PAA board.

Software Controls and Sound Generation

- Pampin and McCrea’s prototype already had software for generating the modulated signals.
- We integrated it with a python script to enable remote control.
- A single board computer (SBC) runs the sound generation software and python script.
- The SBC is connected to an android app over bluetooth
- We created a JSON API to communicate between the app and the SBC.

- The app can:
  - Scan for wifi networks and connect to them
  - Play and pause sound output

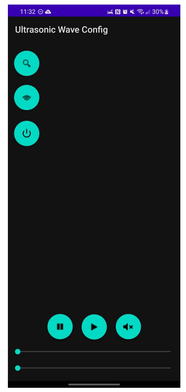


Fig 5. The app user interface

Results

- We successfully minitrarized the size and weight of the whole device. The box containing the SBCs and PCBs has a size of only one eighth of the prototype rack.
- The new transducer requires lower voltage and the PAA board is thinner because the new transducer is surface-mount. However it performs too poorly to be a suitable replacement.
- Although more testing would be needed to evaluate the performance of the whole device, we’ve paved the way for future development and optimization.

Future Work

- Use universal plug-in connector on AMP and PAA boards.
- Test different parametric acoustic arrays with different layouts and transducers.
- Polish the android app and add more remote control features.
- Add sound file playback and input selection to the SBC.
- Integration with advanced technologies such as sensing systems to allow automatic steering.

Acknowledgements and References

- Thank you to the Chameleon Capstone Team for loaning us an MCHstreamer Lite to use during our product development!
- Thank you to Katherine and SQRLab for loaning us the soldering heat gun.

[1] H. Zhou, S. H. Huang, and W. Li, “Parametric Acoustic Array and Its Application in Underwater Acoustic Engineering,” Sensors, vol. 20, no. 7, p. 2148, Apr. 2020, doi: https://doi.org/10.3390/s20072148.
[2] C. Howard, C. Hansen, and A. Zander, “A Review of Current Ultrasound Exposure Limits,” School of Mechanical Engineering, University of Adelaide, Australia, Sep. 2004.

ELECTRICAL & COMPUTER ENGINEERING
UNIVERSITY of WASHINGTON

ADVISERS: Juan Pampin, Eric Klavins

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