Project 21: Wall Of Sound

Alpha Demo

Vectorized Acoustic Deterrence of Elephants Research

Team Members: Arpad Voros, Greyson Fitts, HunterGCook, Morgan Pyrtle, Nwaf Alamro

Sponsors: Army Research Office: Paul Reid, Stephen Lee

Mentors: Dr. Pitts, Dr. Gupta, Dr. Schiefele

Project Background

- Create a passive deterrence system which inhibits elephants from trespassing on farmland, reducing the number of casualties of humans and elephants.

- To broadcast 10Hz - 15kHz (range of elephant hearing).
- Not cause any physical or psychological harm to any organisms.

- Have to accomodate for terrain, vegetation, weather patterns, and animal interference.

Pre-Alpha Timeline - Expected

	Week 1	Week 2	Week 3	Week 4	Week 5
Group	Schematic Design	PCB Action	Debug	Assembly and Debug	Alpha Demo
Nwaf	Schematic/Modeling	Microphone circuit design	Behaviour Research	Behaviour research/ Implementation	Implementation
Hunter	Determine IC for second or third stage amp	Test/debug second stage IC	Test/debug total amplification circuit	Test/debug overall schematic with all pieces	Further needed debugging for demo
Greyson	Assist with PCB development	Finalize PCB design and order from appropriate vendor	Assist with PCB debugging, reorder PCB if needed	Continue to debug PCB/working on physical housing unit	Ensure PCB is ready for demo/3D print casing
Morgan	Work on mechanical details, help find ICs and SPICE models for amplifier circuits	Test/debug circuit models for PCB, start constructing 3D printed casing	Debug PCBs, do more testing with 3D-printed casing	Continue to debug, work on mechanical assembly	Make sure everything is set up for the demo, particularly mechanical
Arpad	Model transducer - Flesh out complete circuit design, test and retest	Model transducer - Flesh out complete circuit design, test and retest	PCB layout of both circuits (multiple amp circuits per module, single mixing circuit)	PCB layout of both circuits (multiple amp circuits per module, single mixing circuit)	PCB ordered/printed, debug and move onto MCU/3D modeling of encasing

Pre-Alpha Timeline - Expected

→ not done
→ done but not working
→ done but little/no contribution/effort from team member
→ being worked on
→ done and working

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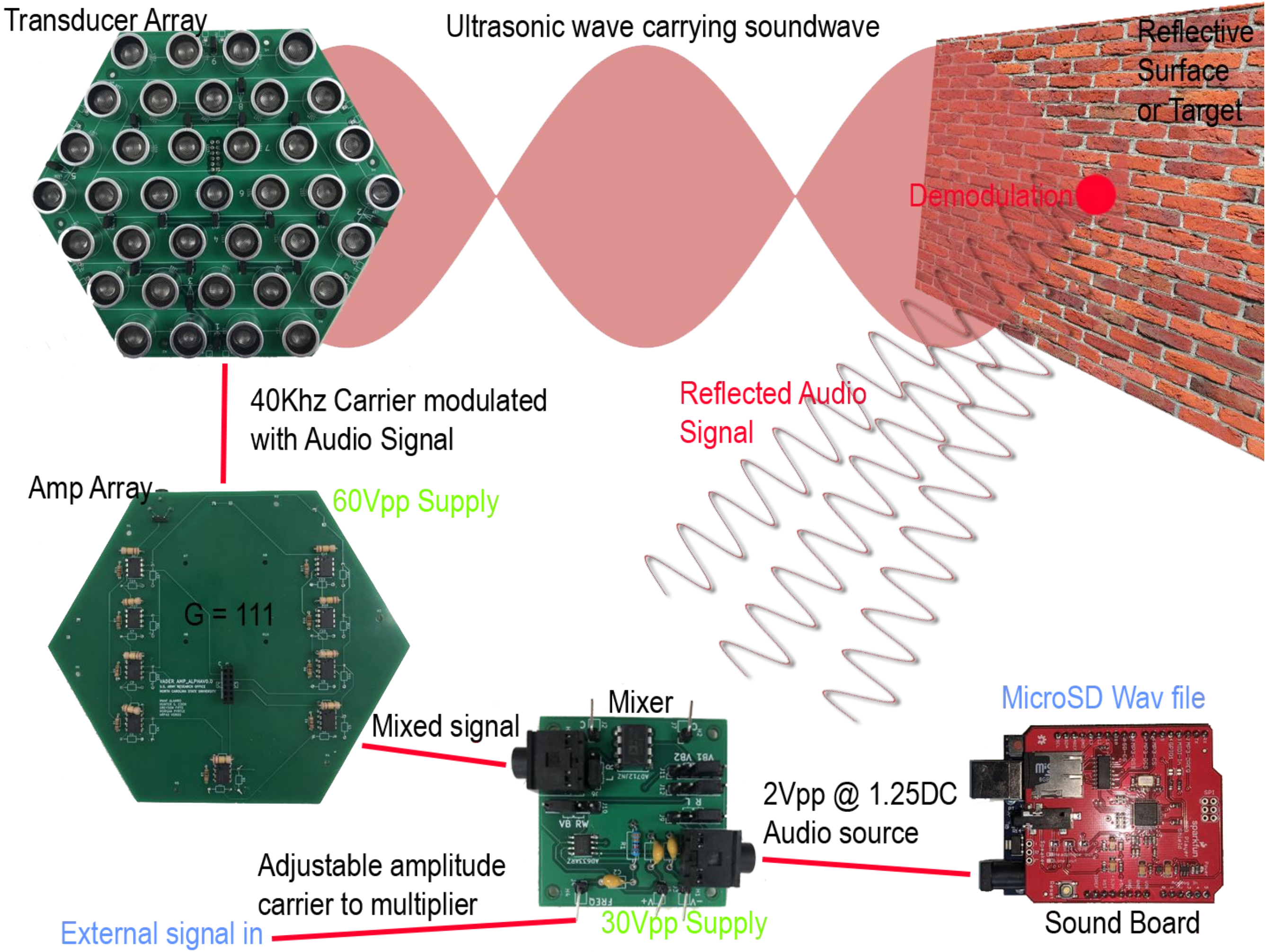
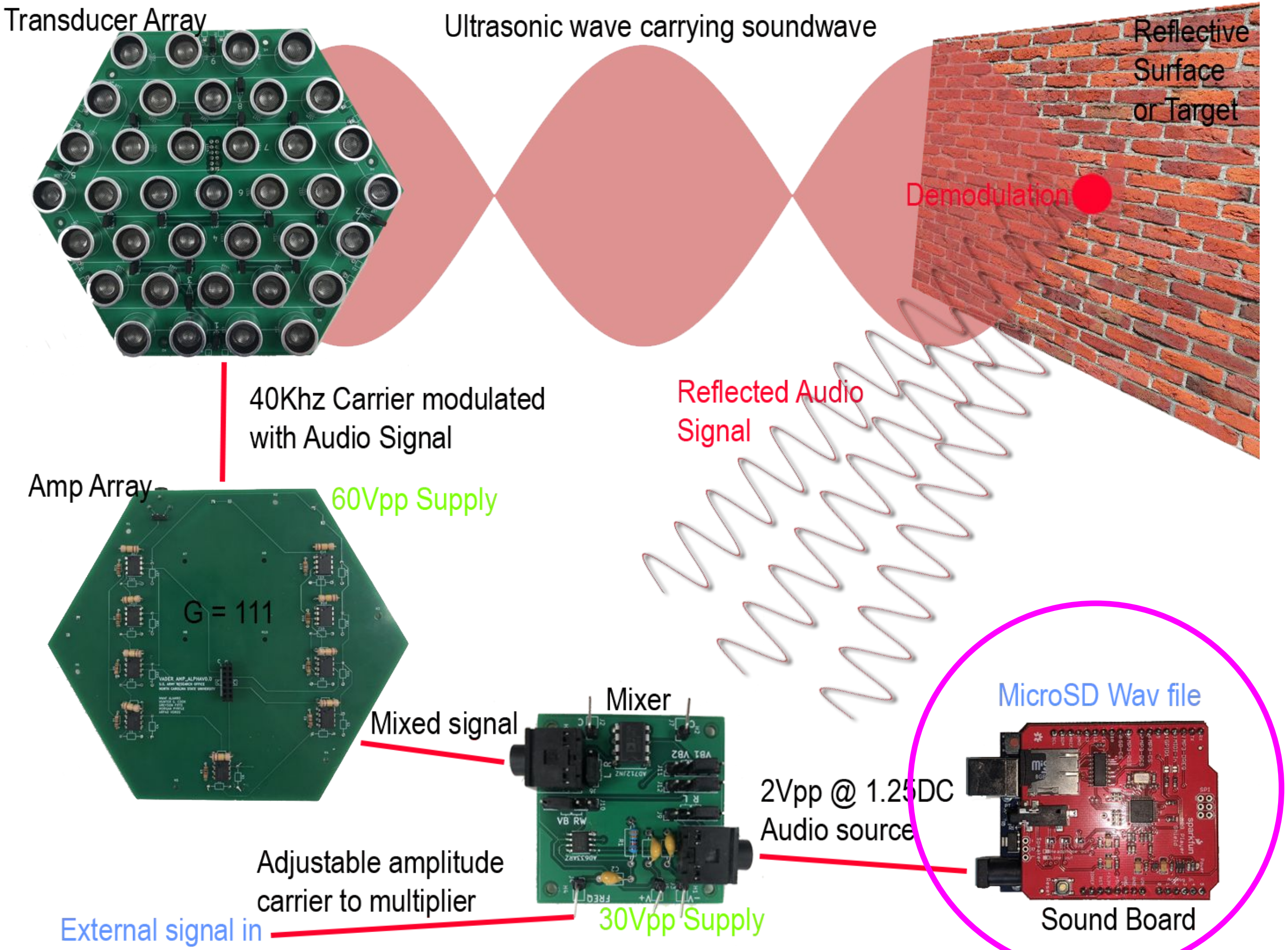
Pre-Alpha Timeline - Actual

	Week 1	Week 2	Week 3	Week 4	Week 5
Nwaf	Amplifier PCB	Amplifier PCB	Getting familiar with Arduino IDE, learning about the sound shield	Hooking up the sound shield parts and prove that a sound can be sent to a pair of headphones	Debugging the sound shield, testing different sound files
Hunter	Determine IC for Amp	Simulate OPA552 bias and power needs	Test/debug total amplification model with load	Assemble/Test/debug amplifier PCB	Find problems with overall amp subsystem, Dr. Garner contact
Greyson	Multiplier PCB	Order Components for PCB	Nothing	Looked into alternative sound shields (not utilized)	Set up microphone
Morgan	Basic mechanical prototype	Amplifier PCB	Work on design for 3D-printed enclosure	Revise enclosure design	Work on mechanical prototype and revise enclosure design
Arpad	Circuit design, transducer modeling, simulation, transducer array PCB	Re-do multiplier PCB, Amplifier PCB, order PCBs	Nothing	PCB preparation (gather misc components), populate multiple PCBs, test & debug	More test & debug, ask for anechoic chamber access, prepare list of to-do items for Beta


Transducer Array
Ultrasonic wave carrying soundwave
Reflective Surface or Target
Demodulation
40Khz Carrier modulated with Audio Signal
Reflected Audio Signal
Amp Array
60Vpp Supply
G = 111
Mixer
Mixed signal
MicroSD Wav file
2Vpp @ 1.25DC Audio source
Adjustable amplitude carrier to multiplier
External signal in
30Vpp Supply
Sound Board

Subsystems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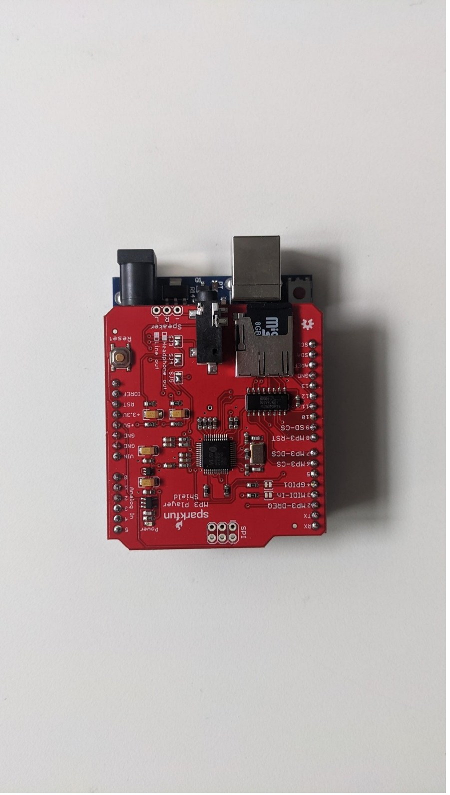
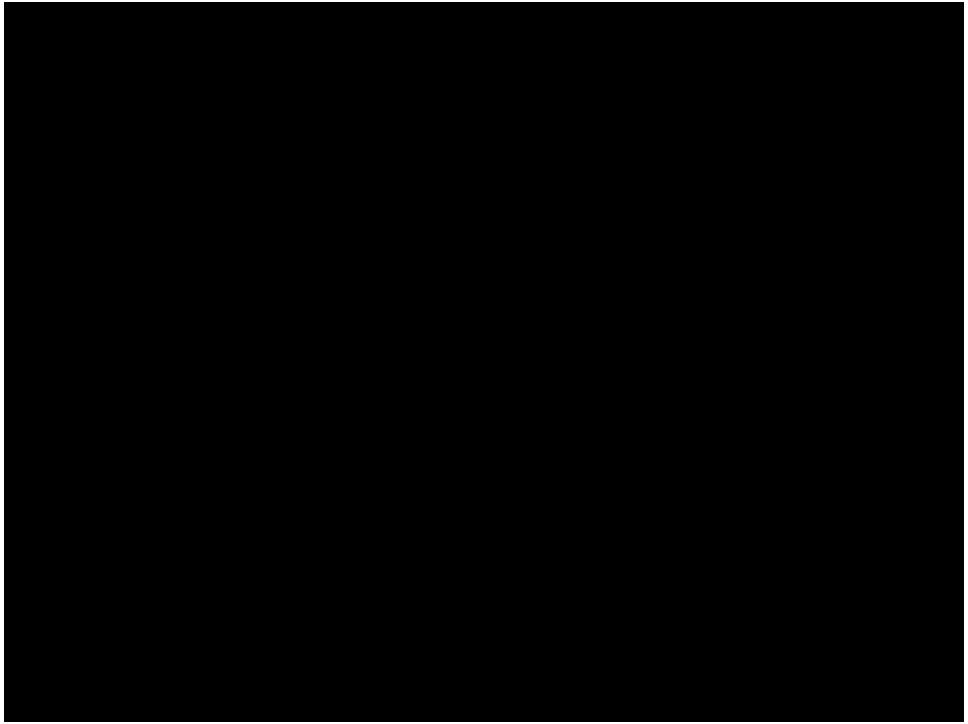
Subsystem - Sound Shield

- 2Vpp at 1.25 DC audio source
- Uses VS1053 IC on an Arduino Uno
- Sound files are uploaded on a 16GB micro SD card.
- The micro SD card is inserted into the sound shield, and the sound files are visible on the Arduino IDE serial monitor.
- Files can be in WAV, MP3, VMA, AAC etc..
- Using the Arduino IDE, you can play, stop, and change the volume of the tracks.

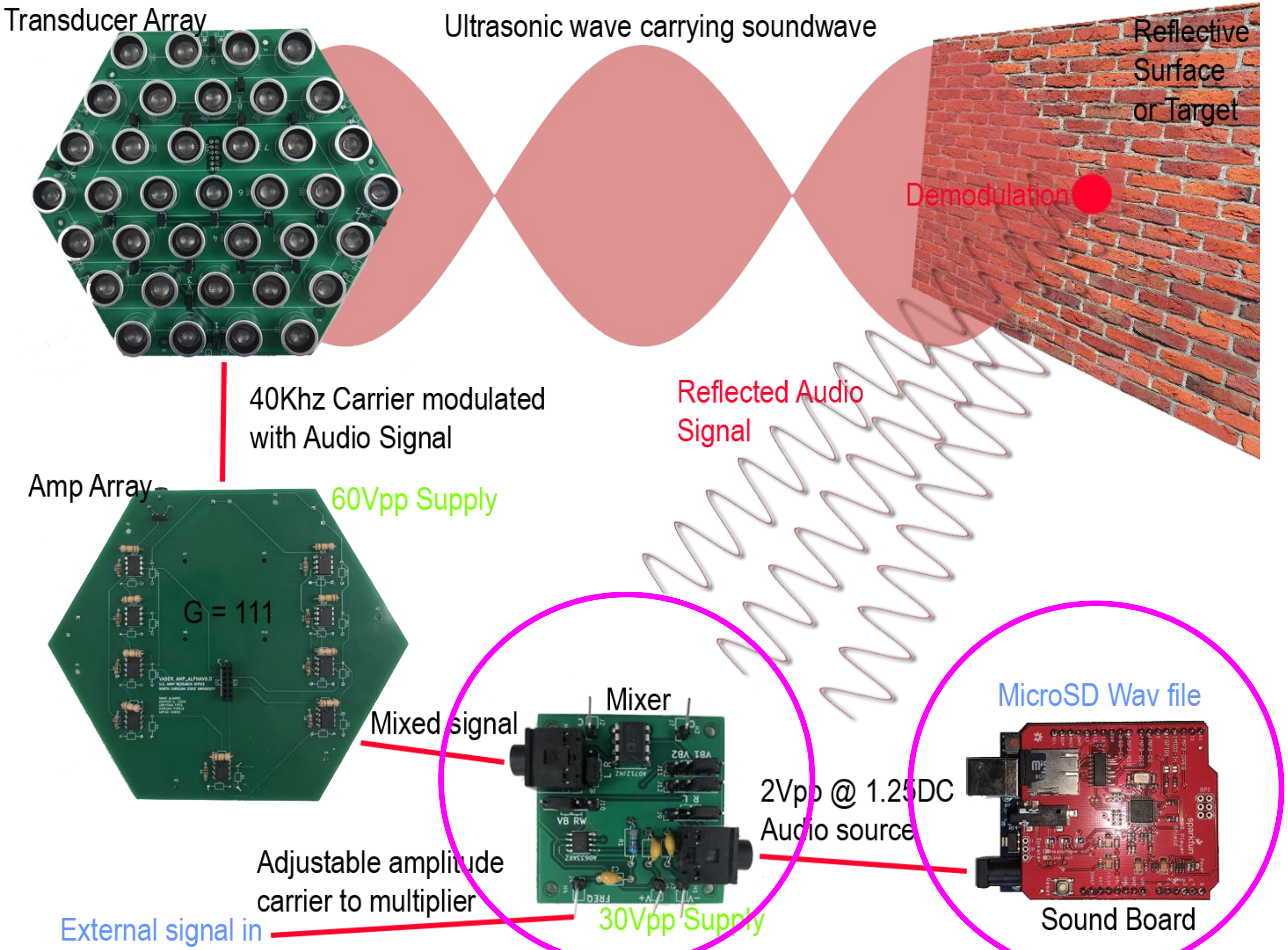


Sound Shield Functionality



Sound Shield - Beta Plan

- Connect the sound shield to the whole system.
- Create UI interface that allows a user to play, stop, and shuffle through sound files using a small screen (utf character screen).
- Work with Dr. Scheifele and add sound files that are designed for our project purposes.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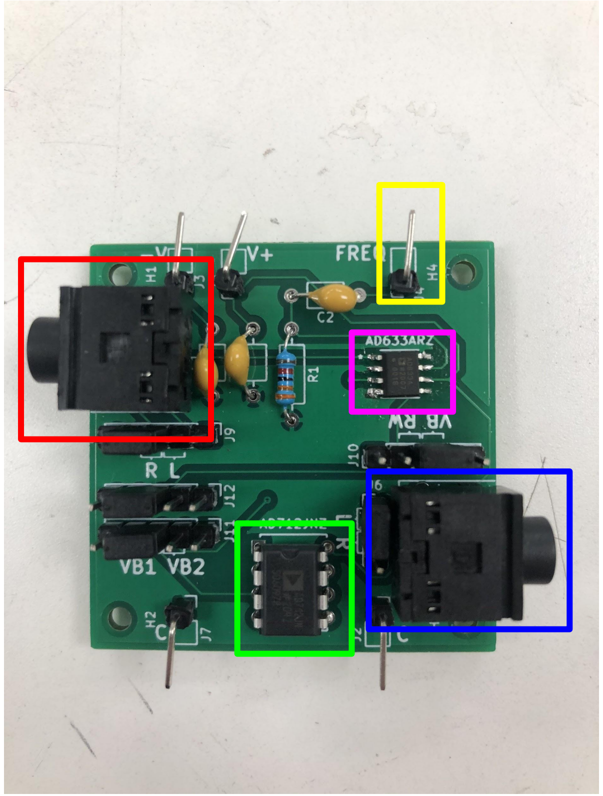
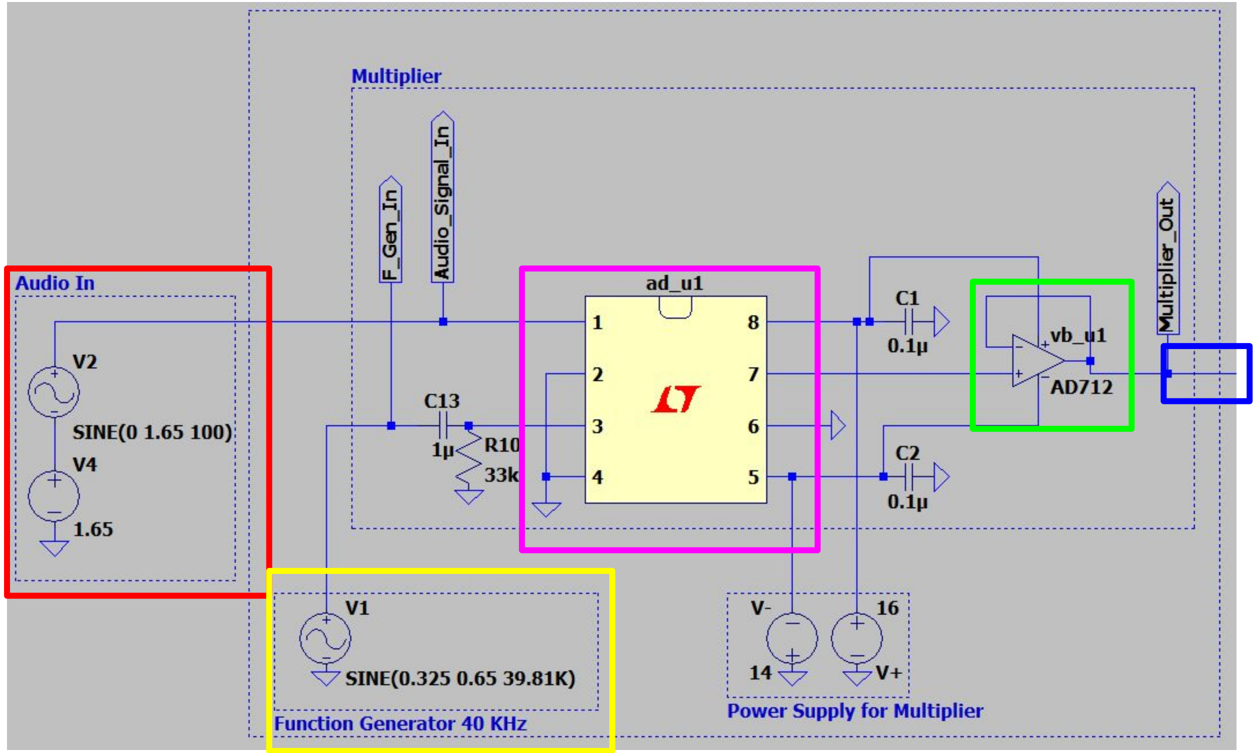
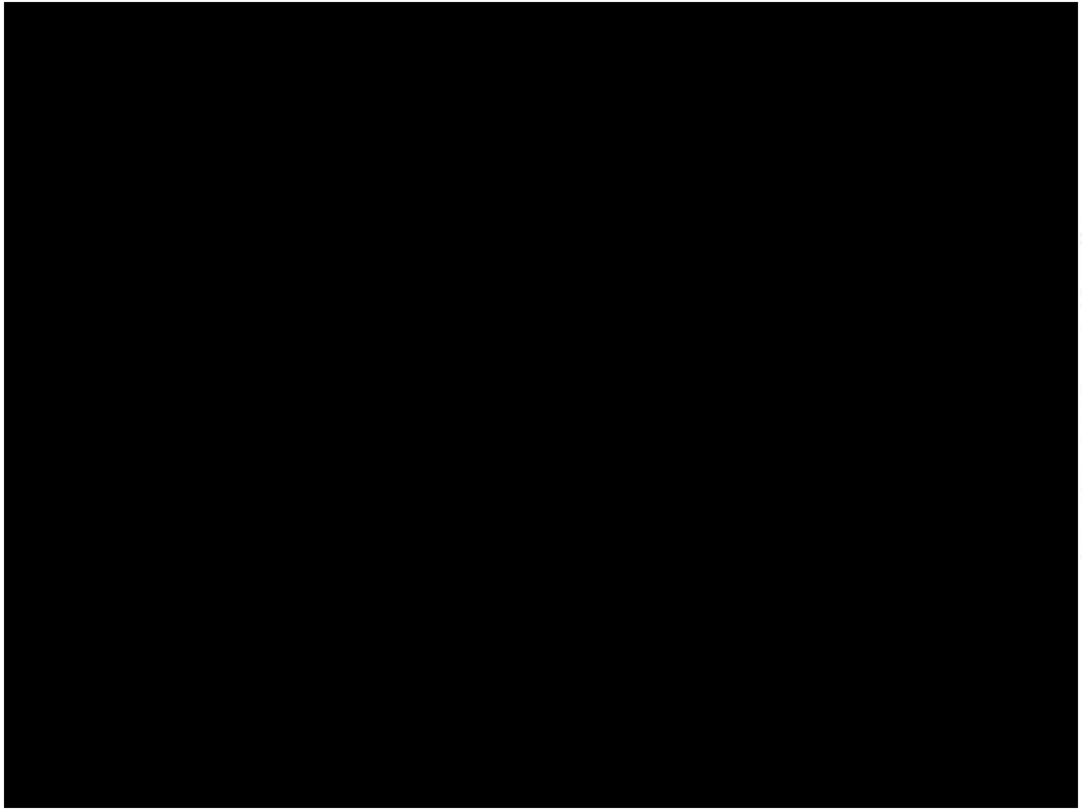
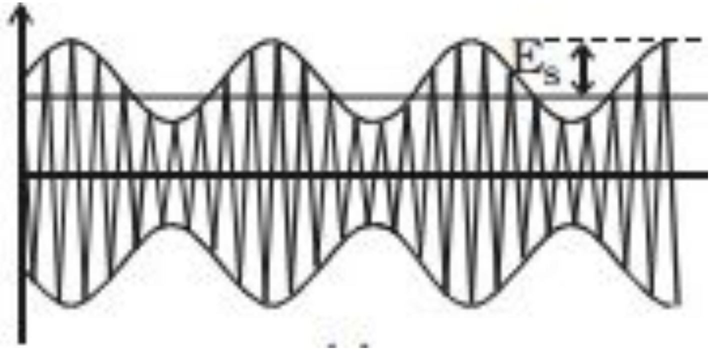
Subsystem - Master Multiplier





Master Multiplier Functionality





Master Multiplier Functionality & Beta Plan

Observation(s)

- Voltage buffer is effective. Amplifier board sometimes has feedback
- Incorrectly implemented input audio - no DC offset. Luckily, with a large enough voltage on the frequency input & a purely sinusoidal wave, the mixed output mimicked an AM signal to a degree.

Problem(s)

- Problem 1 - Forgot to implement DC offset of incoming audio
- Solution 1.1 - Either audio jack sleeve connected to DC rail
- Solution 1.2 - Apply negative potential to pin 2 of the AD633ARZ

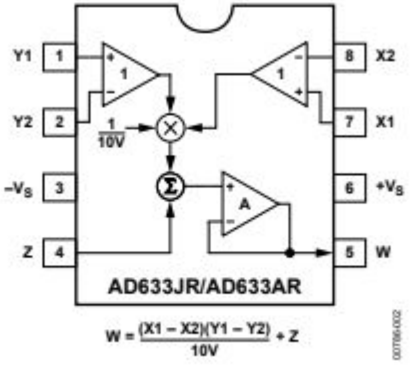
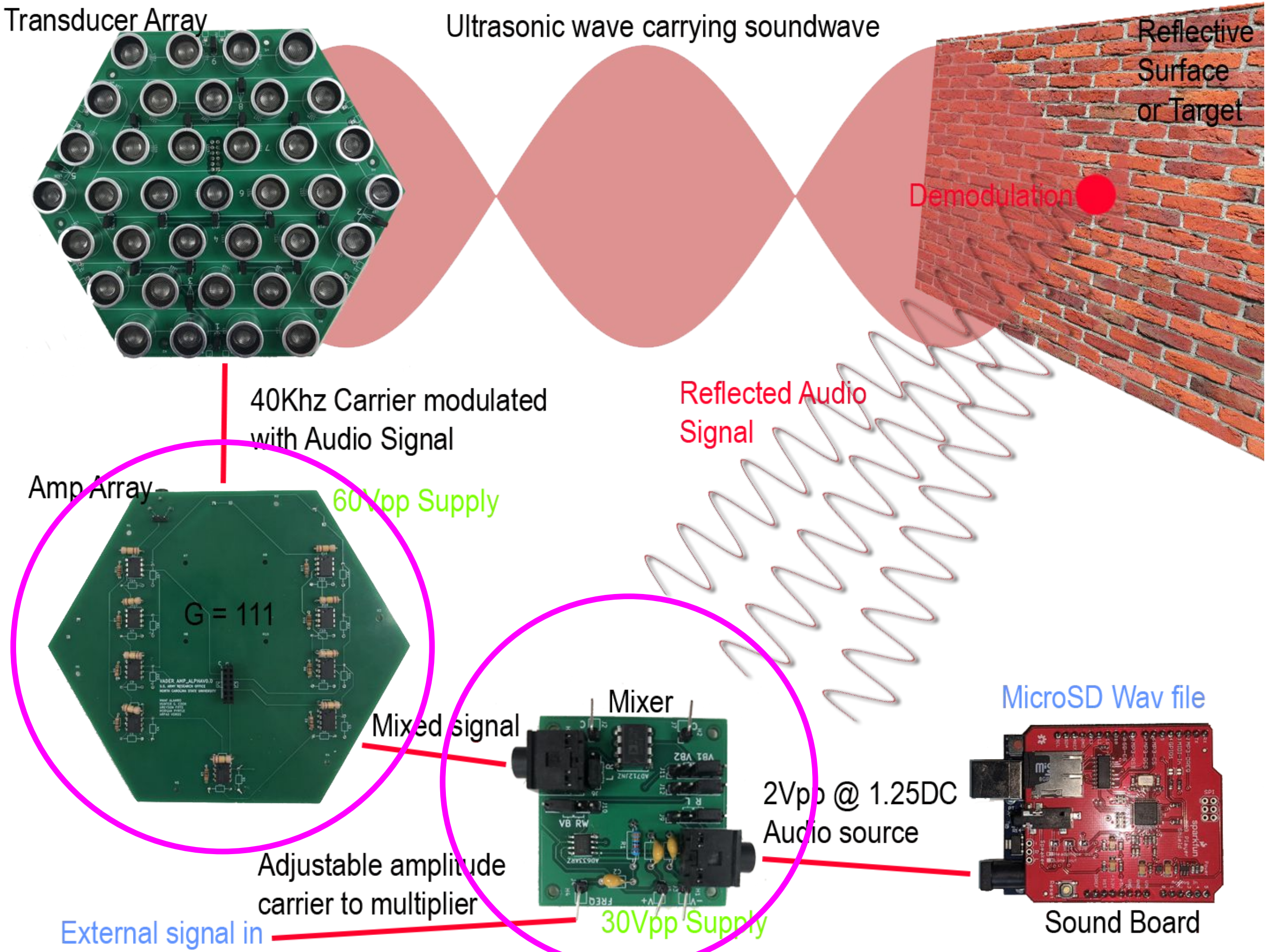


Figure 3. 8-Lead SOIC

Improvement(s) for Beta

- Incorporate stand-alone frequency generator IC
- Other AM techniques (SQRT-AM) to decrease THD
- Power connector
- Add variable amplifier to output (and/or every port)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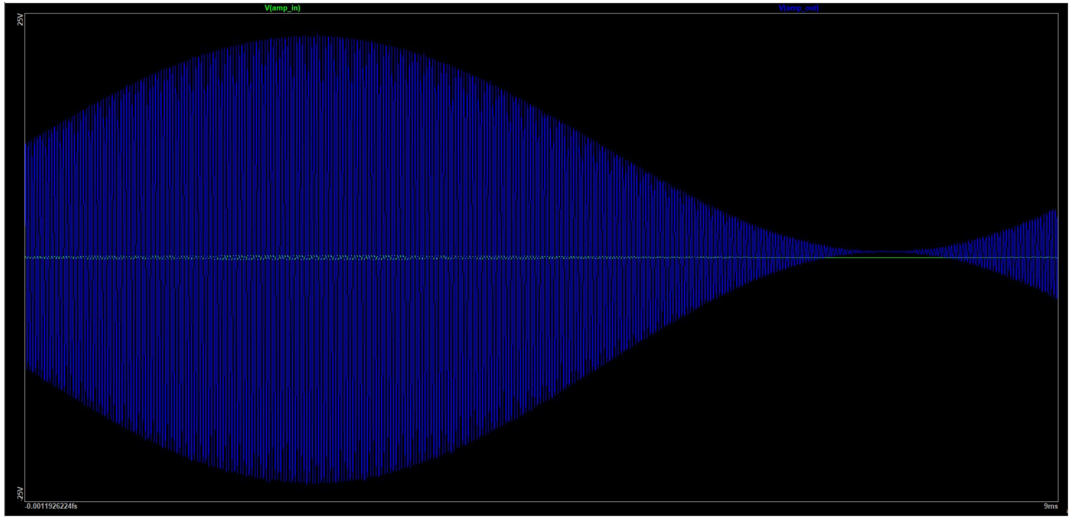
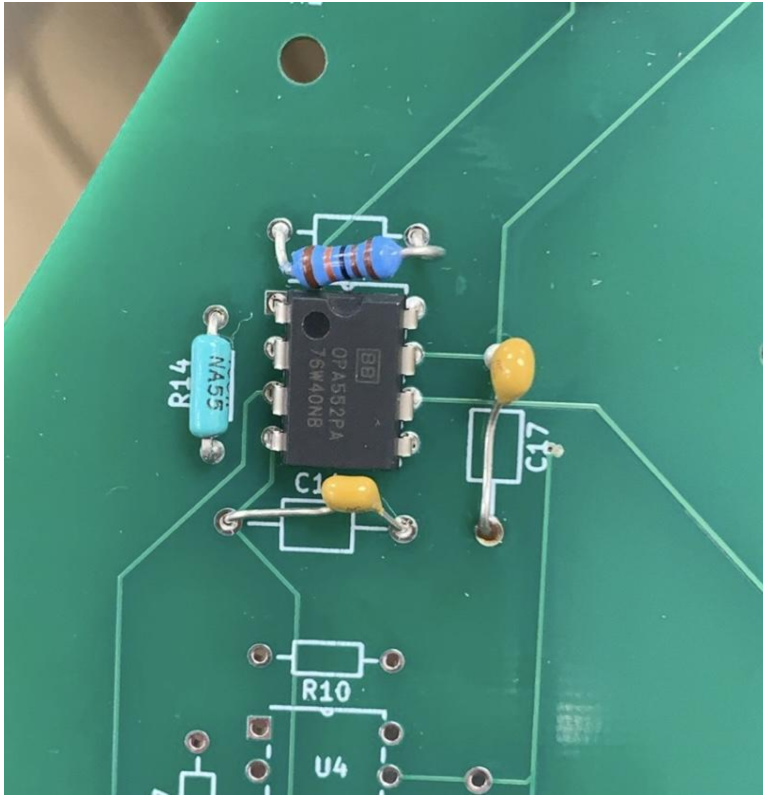
30Vpp Supply
External signal in

Subsystem - Amplifier Circuit

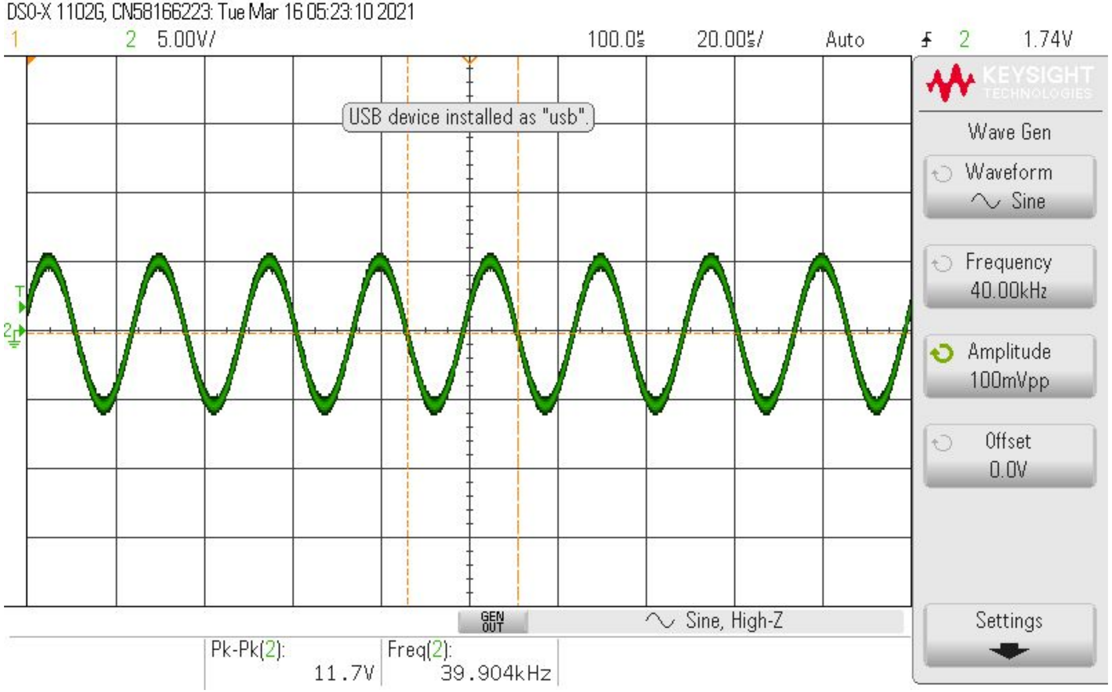
- Trying to achieve 45Vpp (±22.5V)
- Linear gain across audible spectrum. Simulated to be 111 to achieve with conventional DAC
- Should behave this way with the load of multiple transducers
- Simulated behavior below





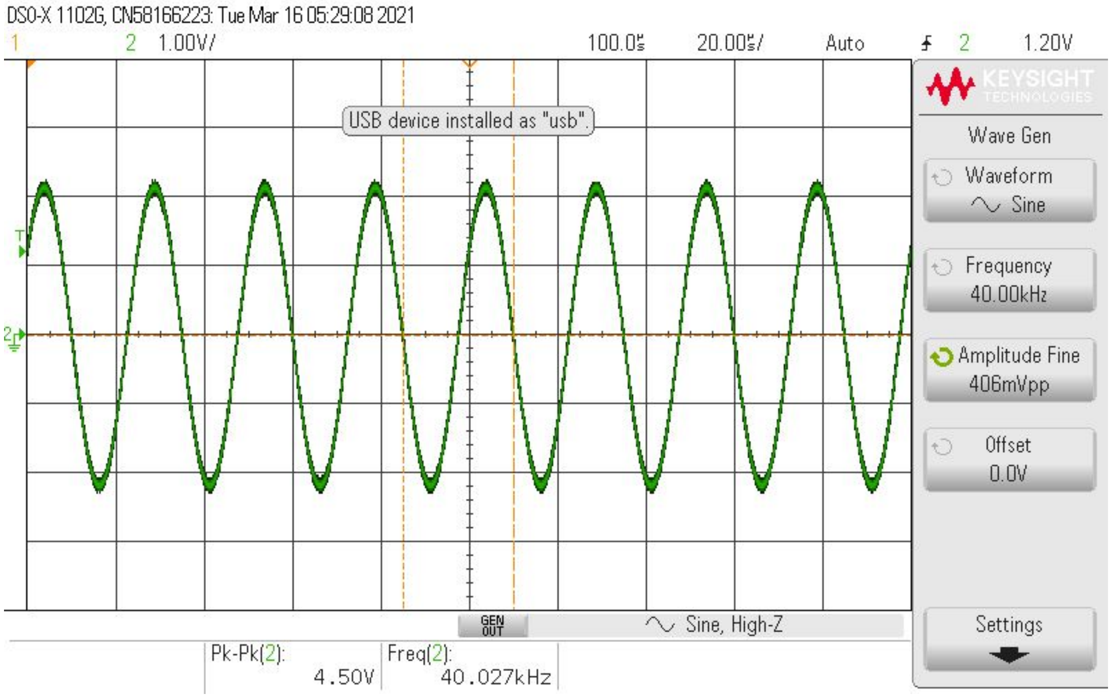
Amplifier Functionality - General

- Single 40kHz sinusoidal input of 100mVpp. Not mixed, Unloaded
- Output of 11.7Vpp, Gain of over 111. This is due to using a 113kΩ resistor instead of 110k so there is a slightly higher gain here
- Frequency bounces between 39.9kHz and 40.1kHz
- Test case was verified with this as presented in CDR.



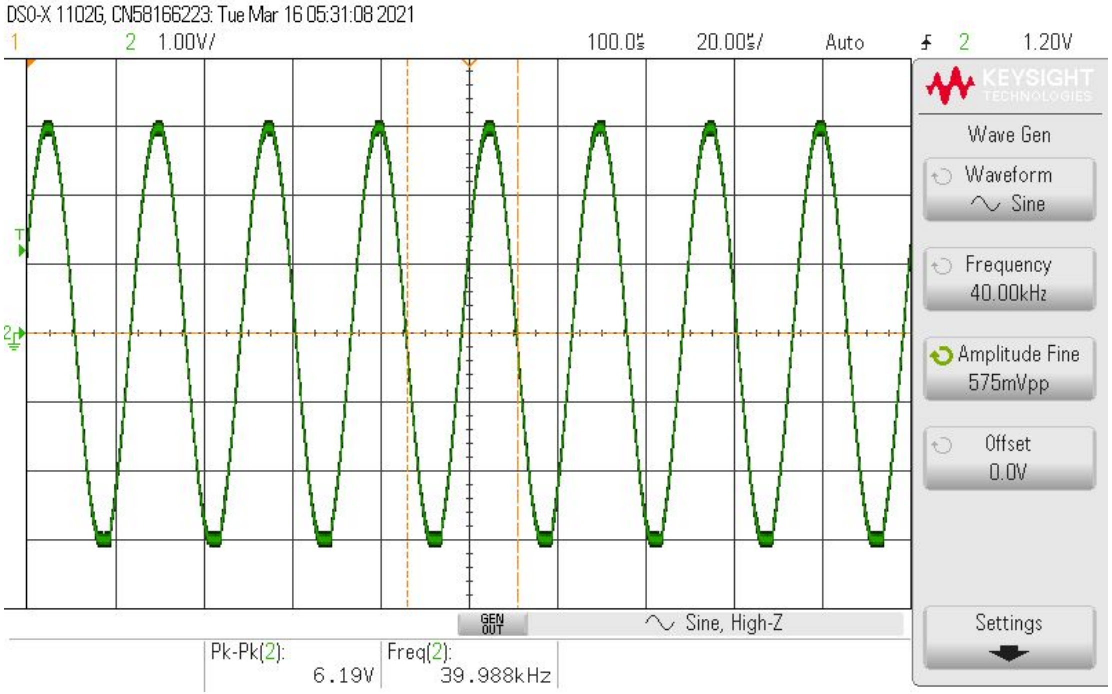
Amplifier Functionality - Desired

- Single 40kHz sinusoidal input of 406mVpp. Not mixed, Unloaded
- Output of 45Vpp (Probe is 1:10)
- Frequency bounces between 39.9kHz and 40.1kHz still.
- This was a test to see what our input would need to be with the current gain to achieve 45Vpp.
- This leads to understanding that whatever comes out of the mixer should be 406mVpp to achieve our desired output to the transducers.



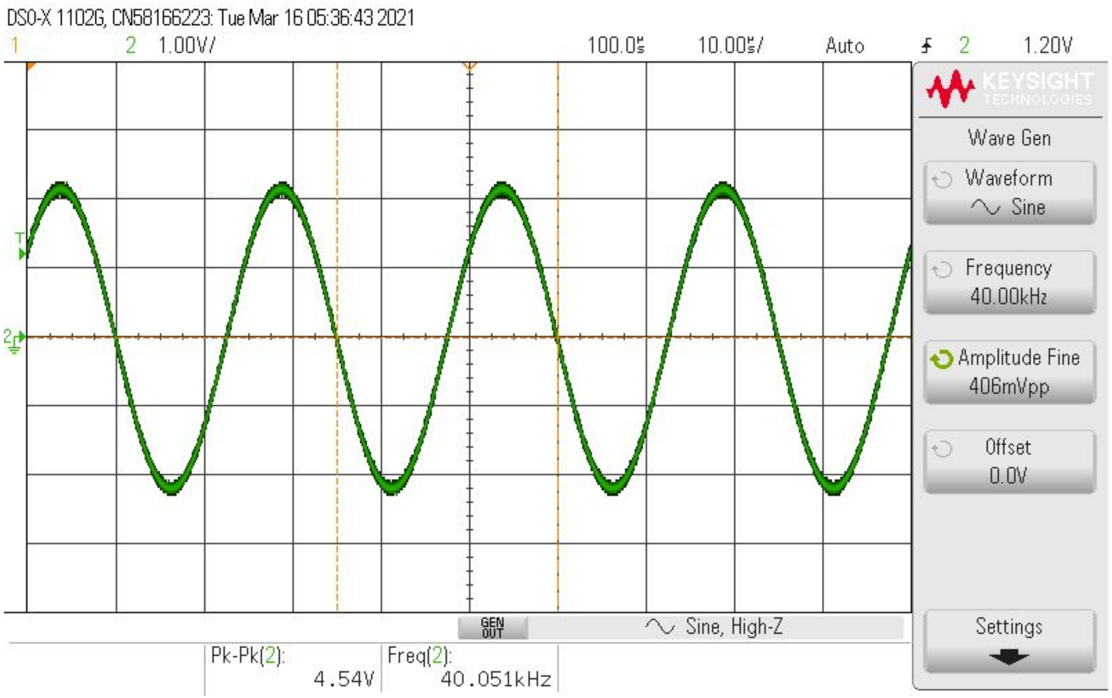
Amplifier Functionality - Clipping

- Single 40kHz sinusoidal input of 575mVpp. Not mixed, Unloaded
- Output of 61.9Vpp (Probe is 1:10)
- This was a test for clipping. We would expect it to occur at 60Vpp due to power supply limitation.
- Any mixer output above 575mVpp will lead to clipping



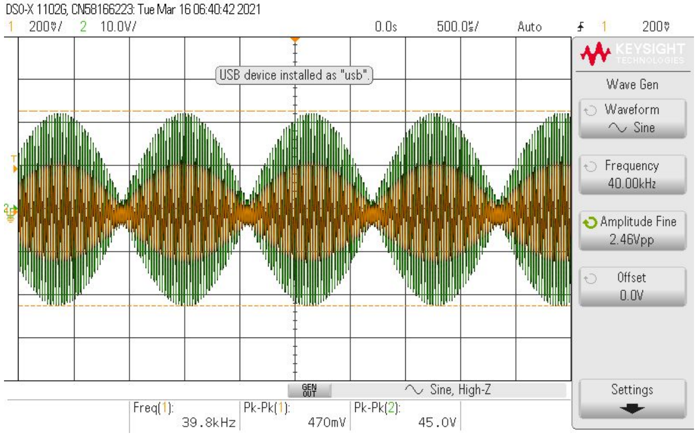
Amplifier Functionality - Loaded

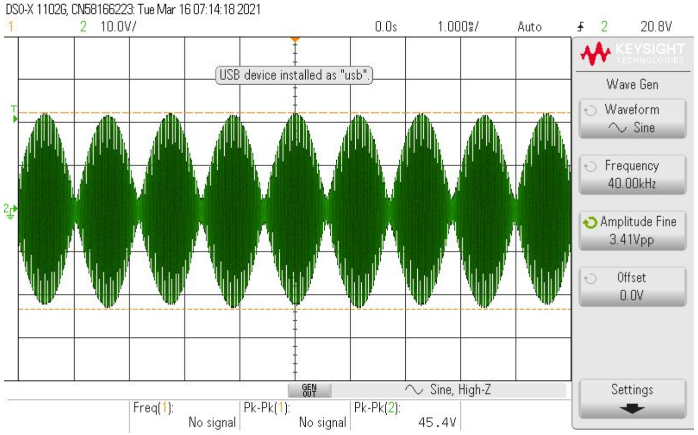
- Single 40kHz sinusoidal input of 406mVpp. Not mixed, Loaded
- Output of 45.4Vpp (Probe is 1:10)
- With the load of 4 transducers we get the same gain and behavior from the amplifier with a single tone.



Amplifier Functionality - Loaded

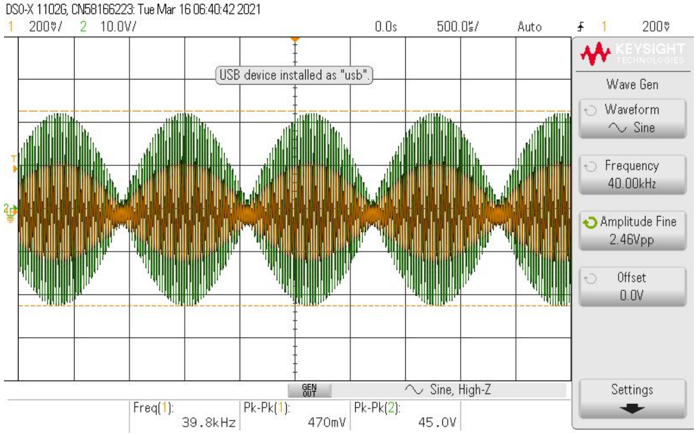
- Now mixed and loaded
- 40kHz coming in at 2.46Vpp to achieve the aforementioned voltage required out of mixer.
- But was not enough, like earlier test had showed so bump up input again
- Output of 45.4Vpp when 40kHz is set to 3.41Vpp
- More on this when discussing transducers

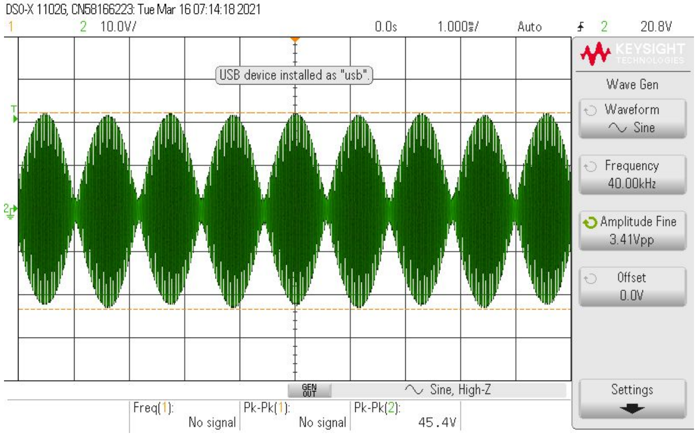




Amplifier Functionality - Overall

- What does this mean?
- Non-linearity in the amp was the first guess. This would explain some of the issues we had when trying to play music. Some frequencies do not get amplified as well as others.
- The fix for this is pre-distorting the music in the opposite way that the amp does.

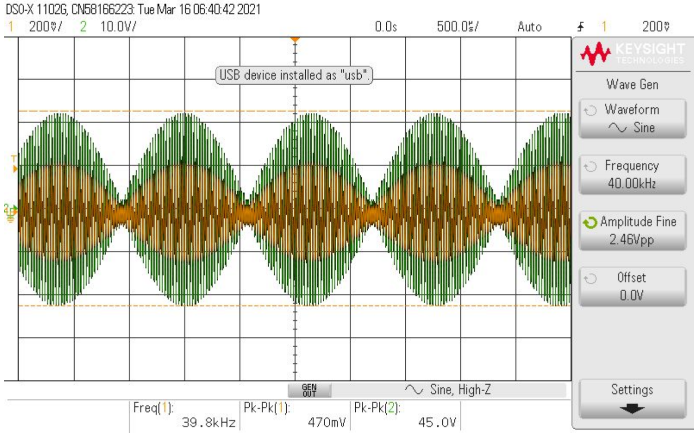


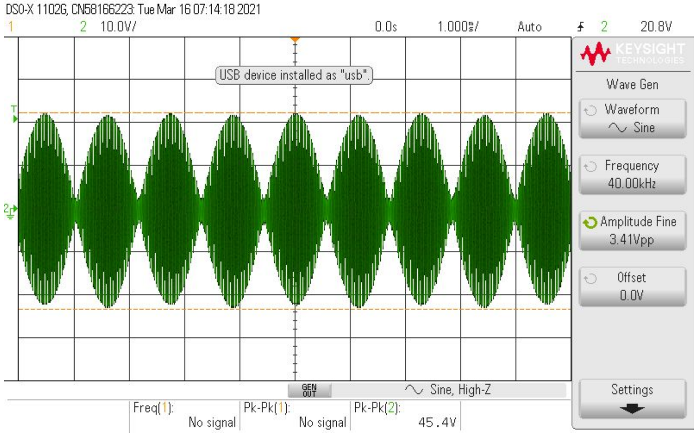


Amplifier Dysfunctionality

- Amplifier changes in gain depending on not only current frequency, but also other factors. Can confirm previous frequency is one of those factors.

- Not systematic
- Current issue being addressed, not fully functional at the moment

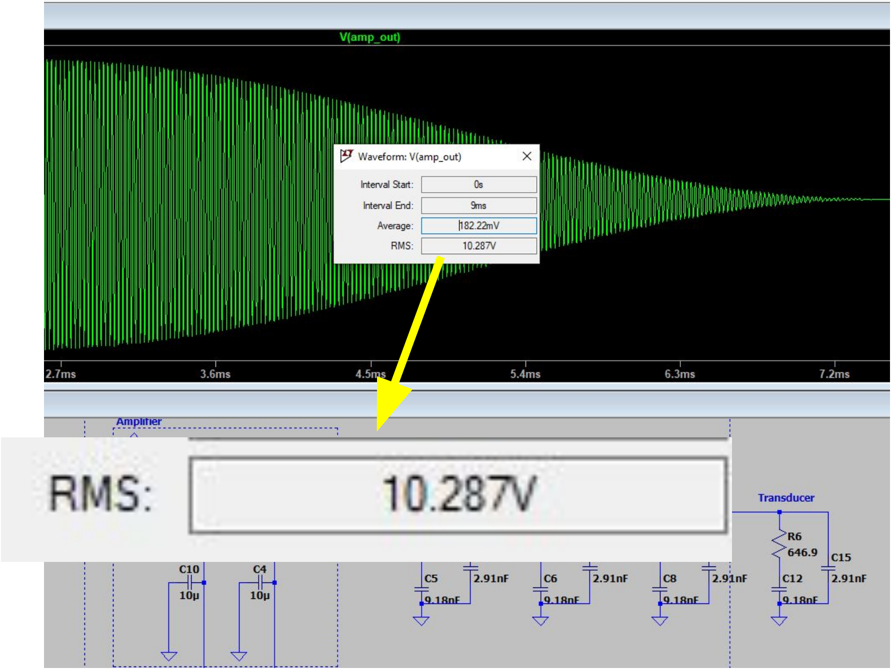




Driving Voltage

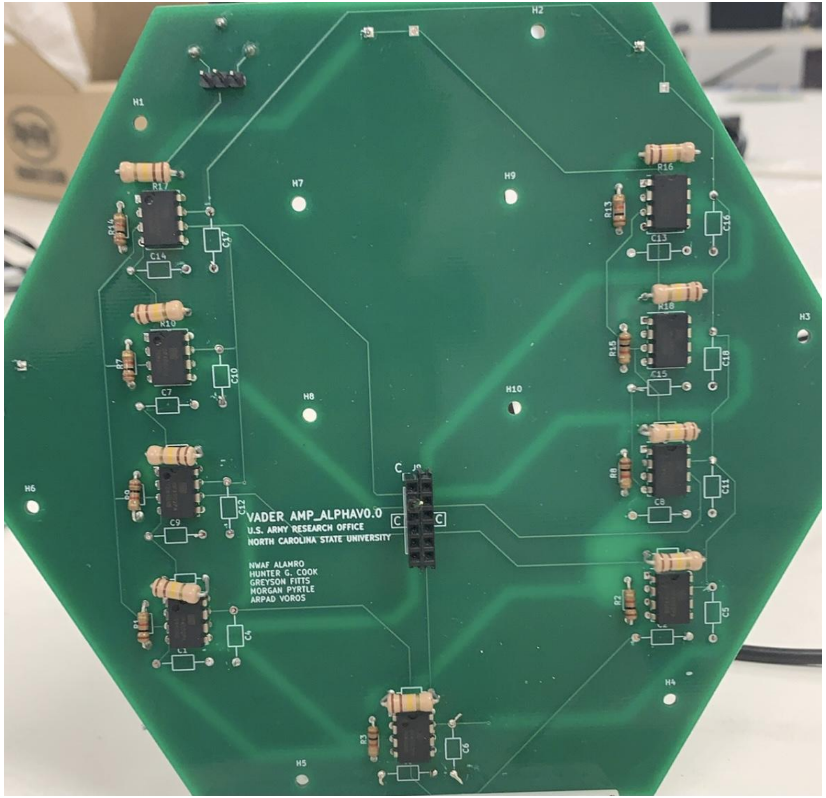
- As mentioned before, trying to achieve 45Vpp (±22.5V)
- This is due to the fact that our transducers were said to be nominal at 10Vrms. Calculation shown in CDR that given modulated signal, we need 45Vpp to achieve 10Vrms
- Is confirmed in screenshot to the right

- But is 10Vrms really nominal? After looking at datasheet, we are unsure
- Maximum input can go as high as 150Vpp
- Anything greater than 60Vpp is loud/non-directional, but this statement could be biased because we tested in an enclosed space with lots of reflections
    - Test outside
    - Test in anechoic chamber
- Can and probably will go higher for Beta



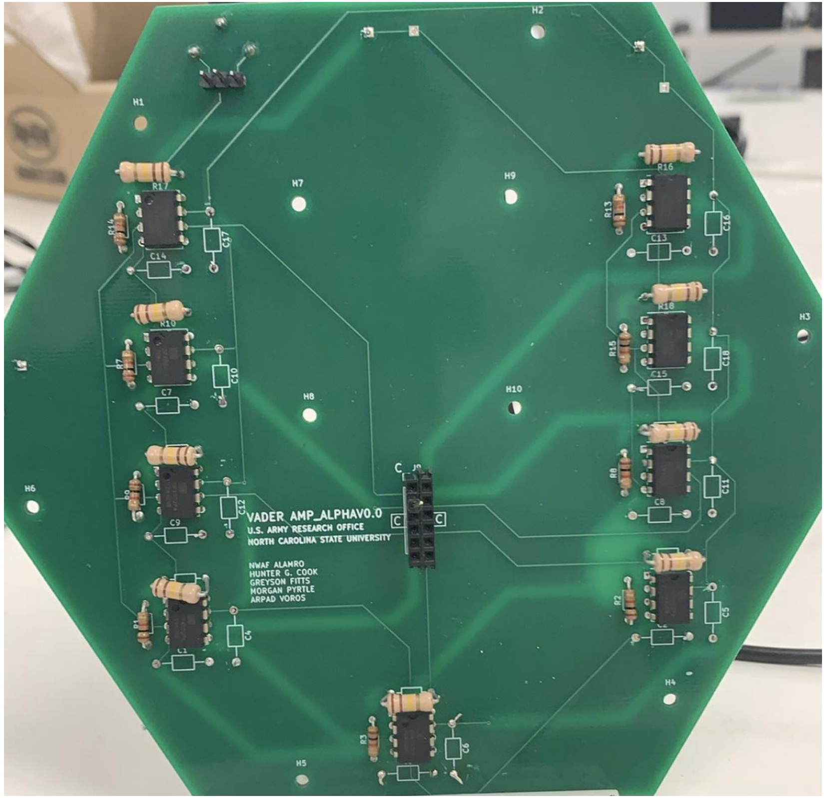
Amplifier Functionality - Physical Implementation

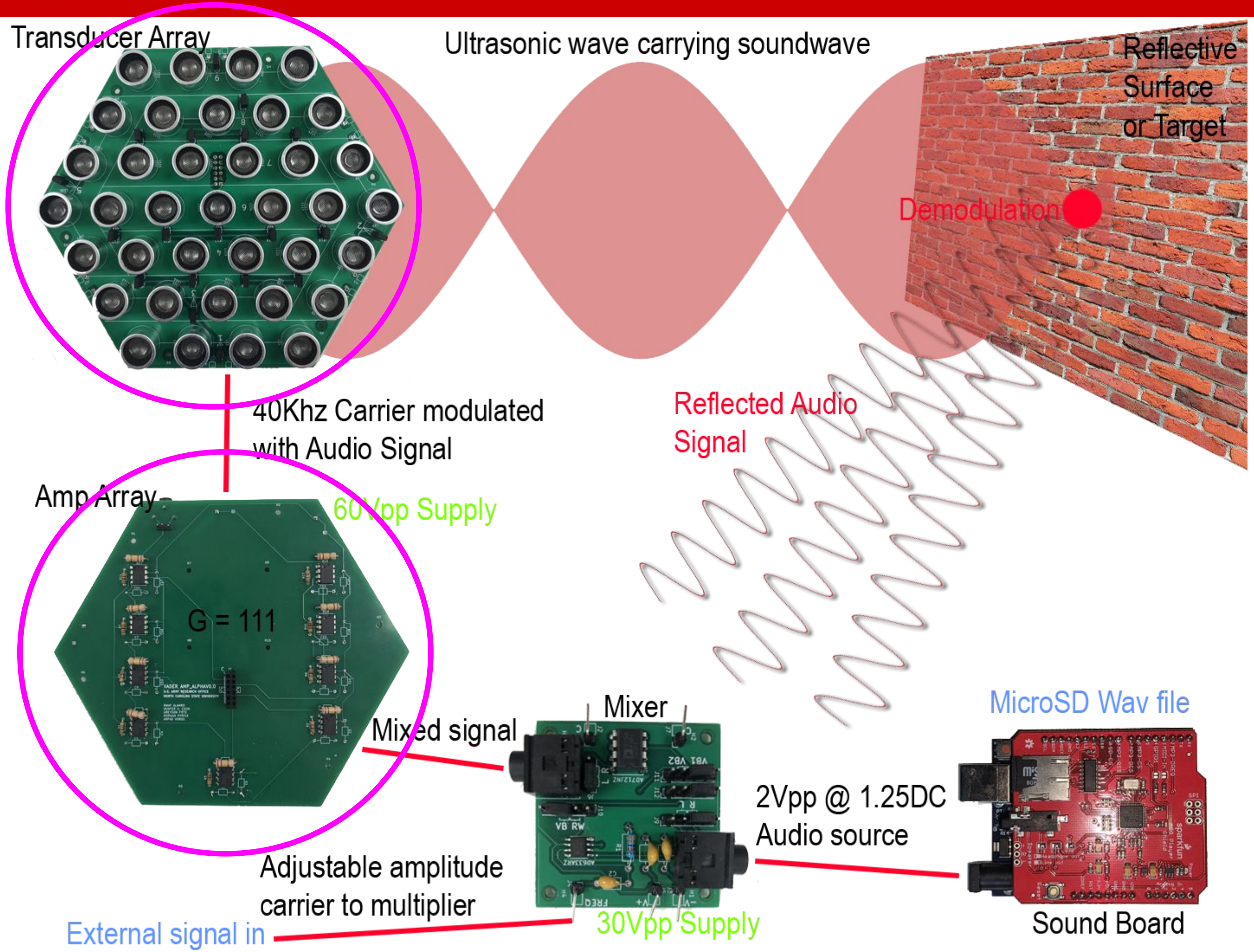
- Outputs of the 9 amplifiers feed into 12 pin female connector in the middle. 3 connections are ground
- Capacitors are removed in this photograph. A mistake with polarization resulted in removing all of them and replacing all these parallel capacitances with two large capacitors
- Most important board, and the board which needs the most work. Many unknowns. Need more debugging & human resources to determine behavior for Beta



Amplifier Board Redesign - Beta Plan

- Re-structure and configure entire board to place pieces in a more linear & systematic fashion. Right now, board physically resembles schematic, which it should not for efficiency
- Larger traces to match the transducer board (9.8mil → 27.5mil). Large current carrying wires are better than small default ones
- Power connector, similar to that of the multiplier board
- Possible changes to fix nonlinearity effect

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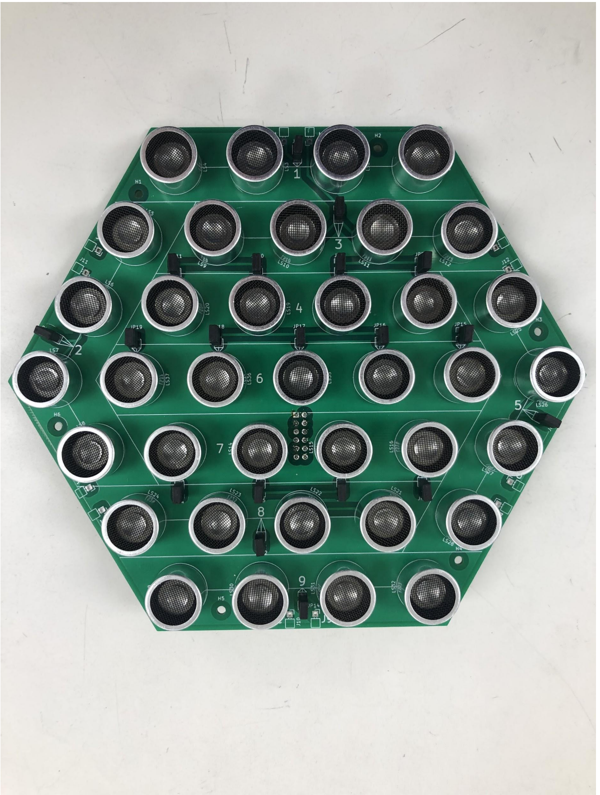
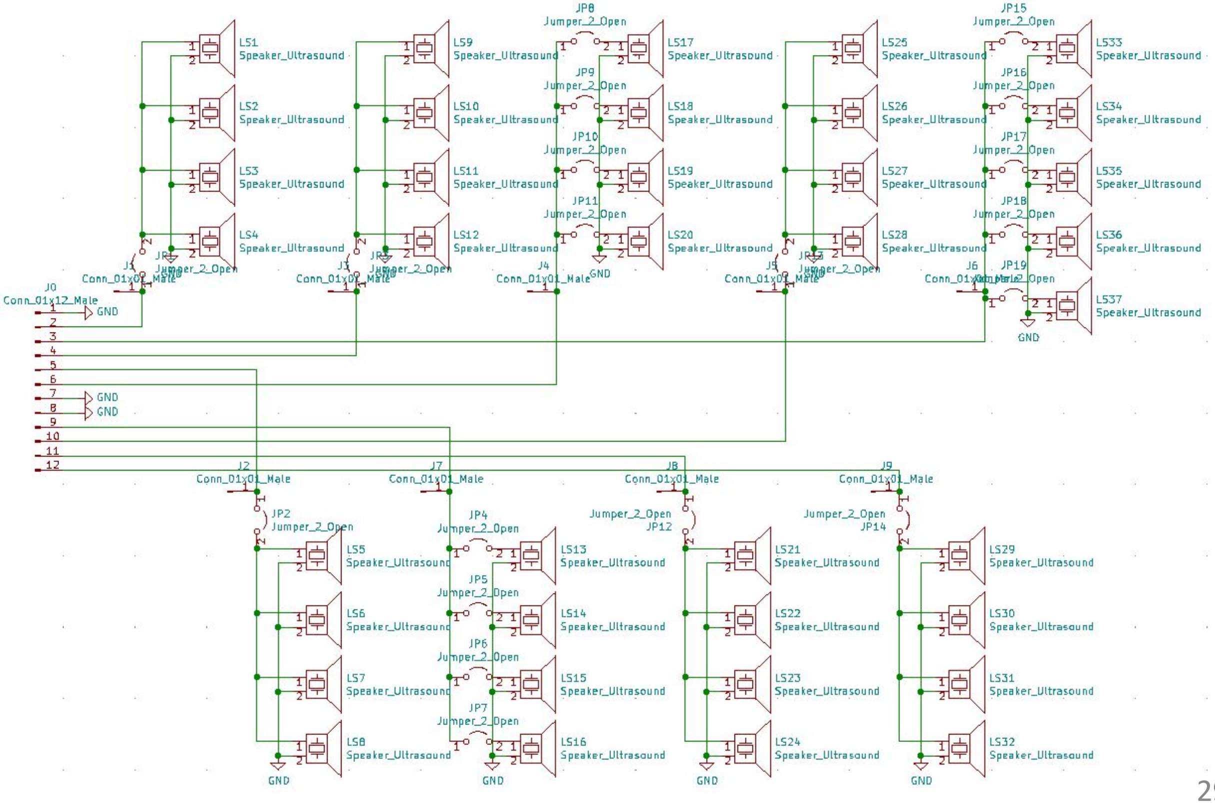
Subsystem - Transducers





Transducer Modeling

- Measured LCR characteristics of 20 transducers using Analog Discovery 2
- Each transducer was measured 4 times (sample size of 80)
  - 2 times polarized one way
  - 2 times polarized the other way

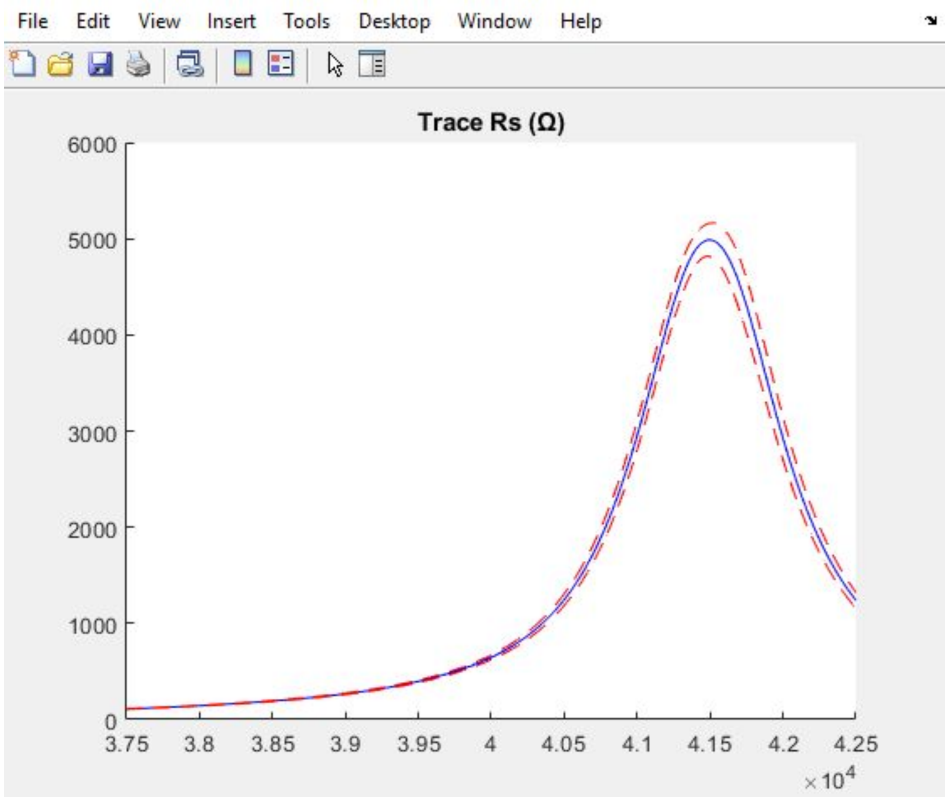
- Characteristics measured:
  - Phase
  - **Series resistance**, impedance
  - Total admittance
  - Parallel conductance, susceptance
  - Series/parallel inductance
  - **Series/parallel capacitance**

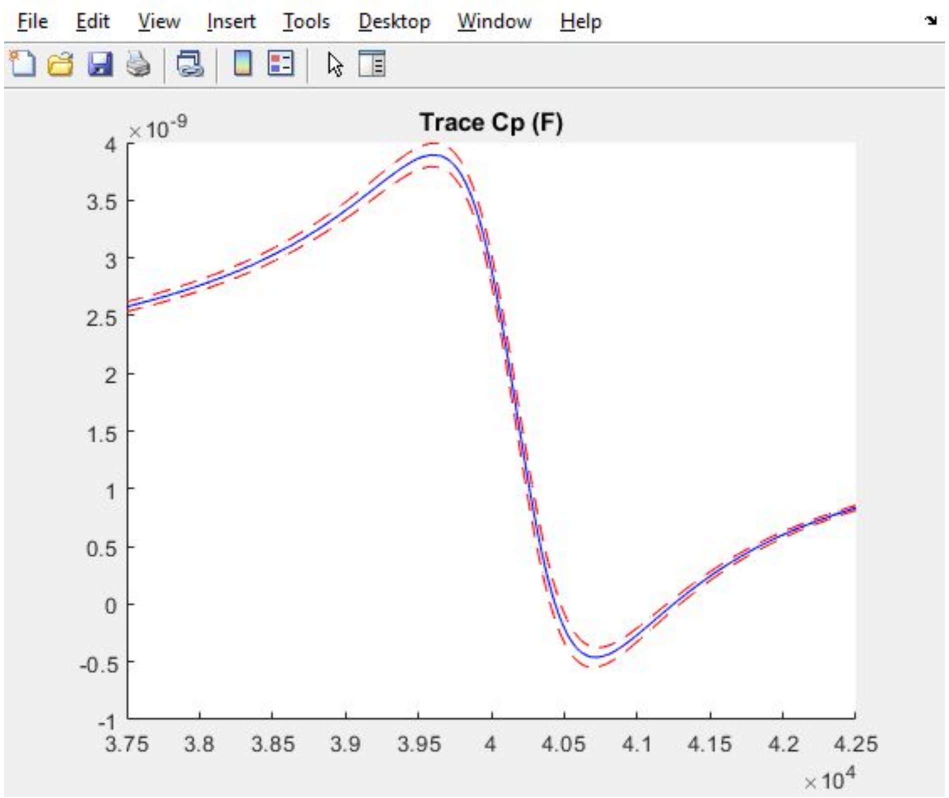
- Statistical tests were run the dataset using Student's t-Distribution to find a simple confidence interval

- The mean of the data approximately maximizes the likelihood function for our unknown transducer characteristic values, so that value was used in simulation

- *Polarization proved statistically insignificant!*

Transducer Modeling - 90% CI's





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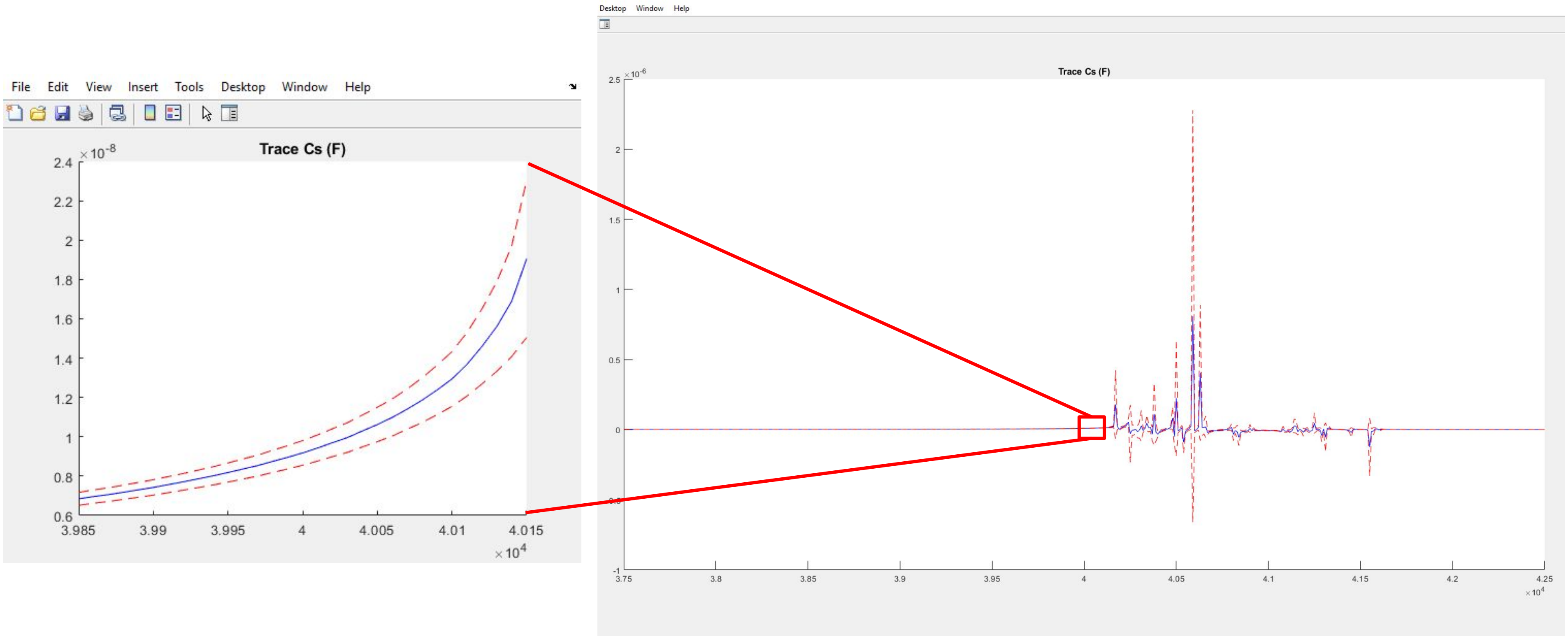
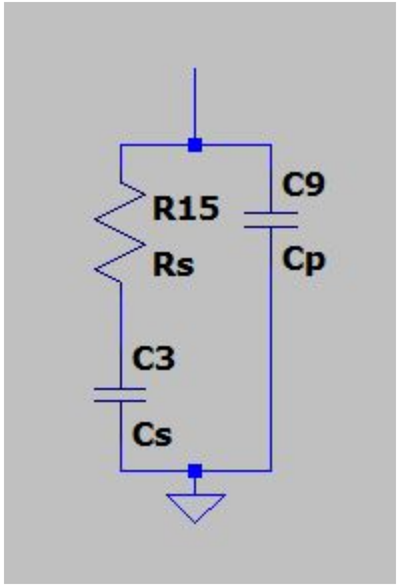


Transducer Modeling - Results

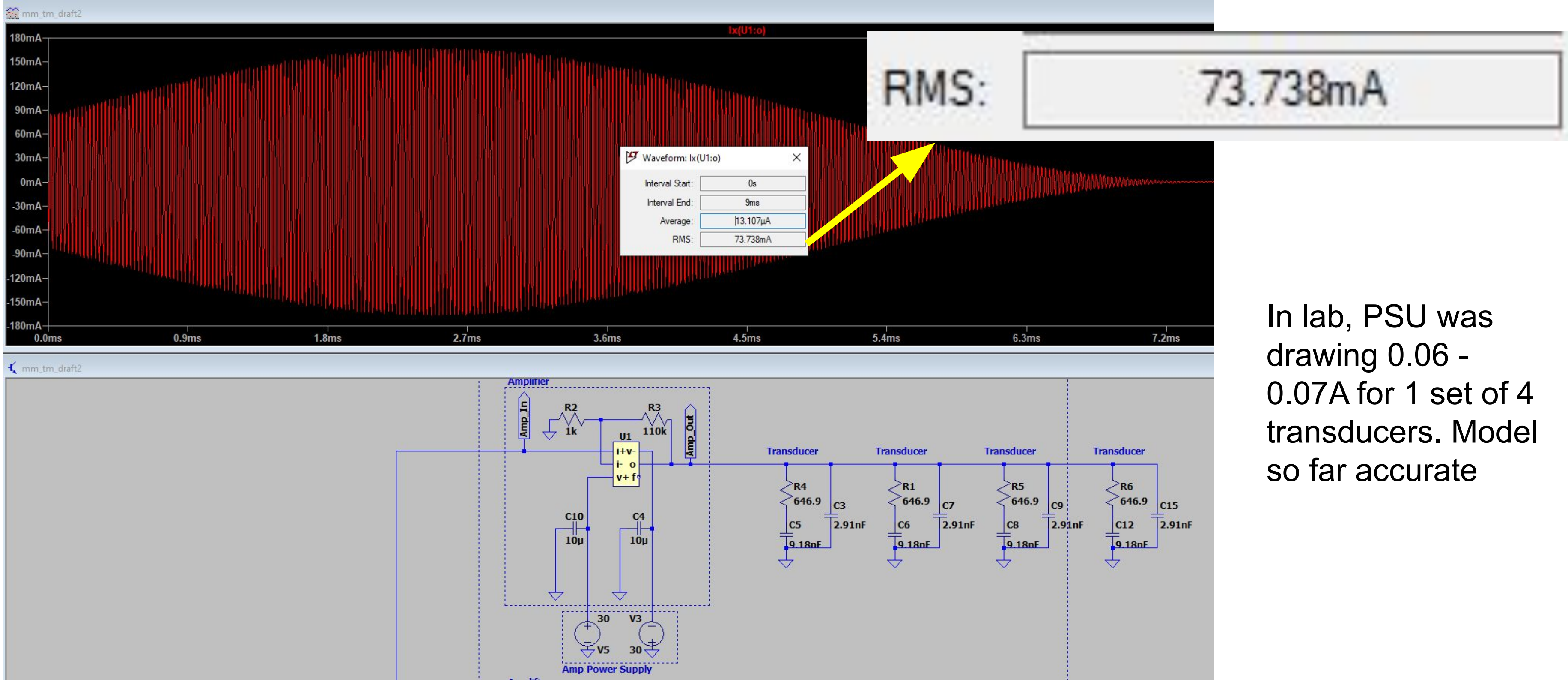
$$R_s = (646.9115 \pm 24.0631)\ \Omega$$

$$C_s = (9.1792 \pm 0.62788) \times 10^{-9} F\ (nF)$$

$$C_p = (2.9091 \pm 0.12894) \times 10^{-9} F\ (nF)$$

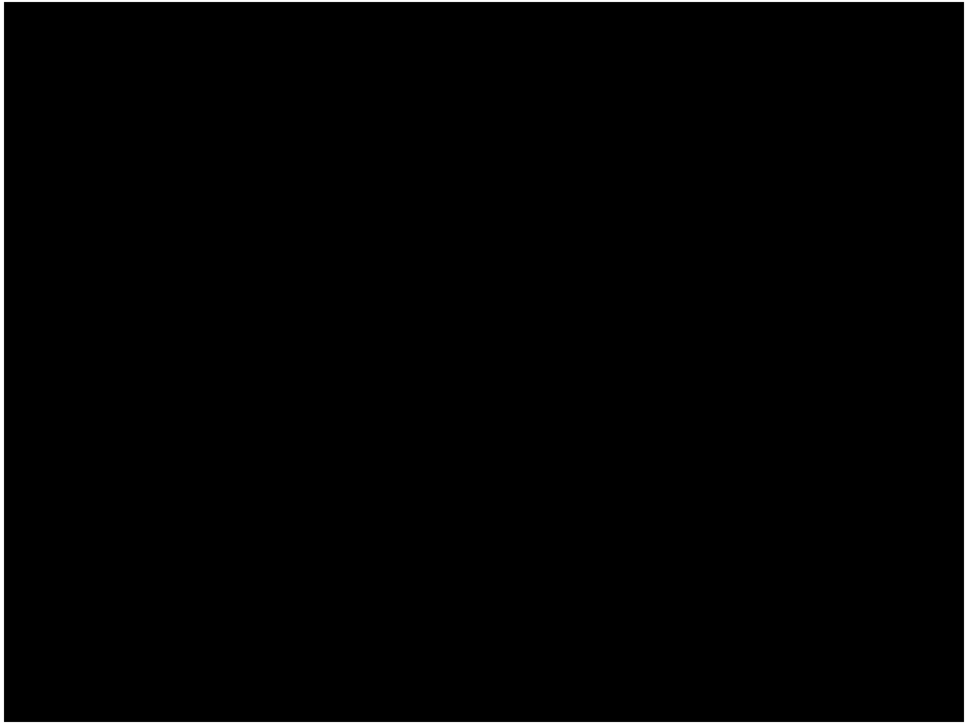


Transducer Modeling - Results (cont.)



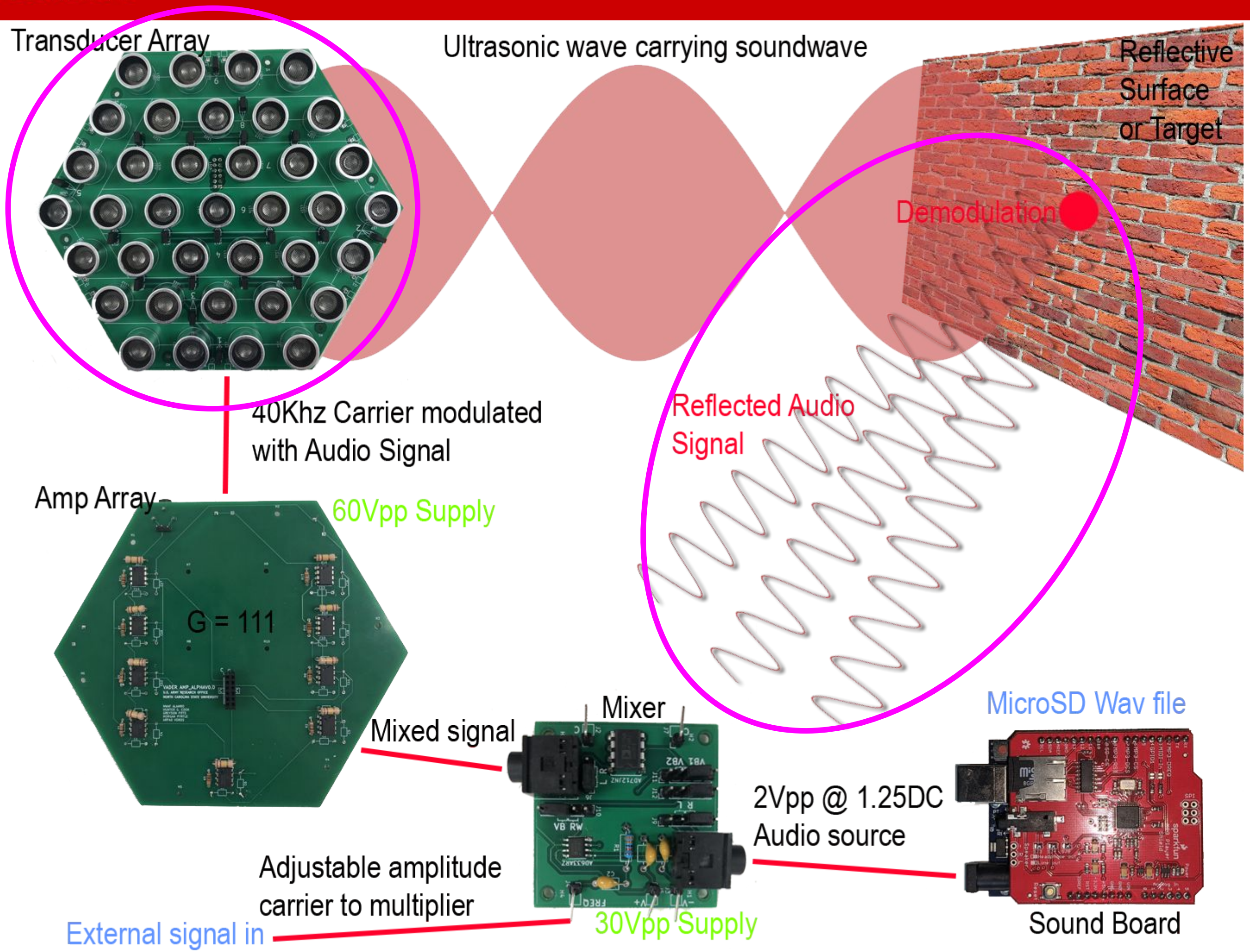
In lab, PSU was drawing 0.06 - 0.07A for 1 set of 4 transducers. Model so far accurate

Transducer Array Functionality & Beta Plan



Improvement(s) for Beta

- Plan to use up to 5 of these modules, therefore remove debugging pins & jumpers
- Maybe add female housing pins for the transducer leads rather than soldering them in. In the case that some are faulty, they can be pulled out and placed in.
- Smaller mounting hole sizes
- That is all! The board for the transducer array is simply a shield with not that many moving parts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Subsystem - Audio Detection

Microphone Schematic:

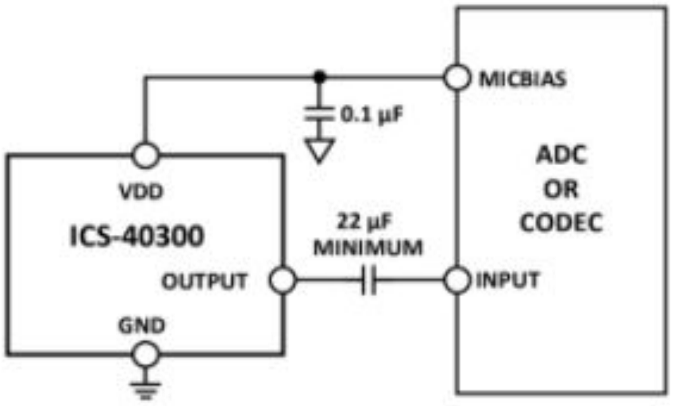
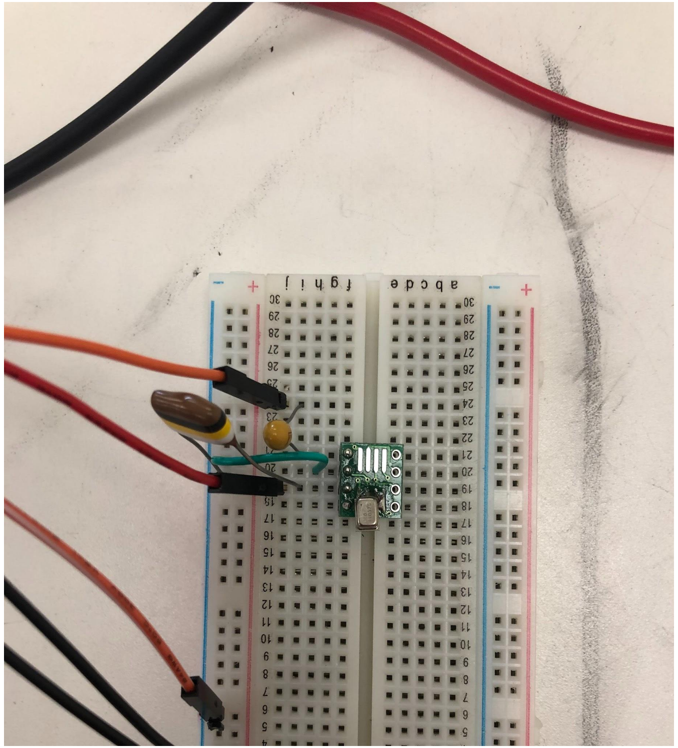
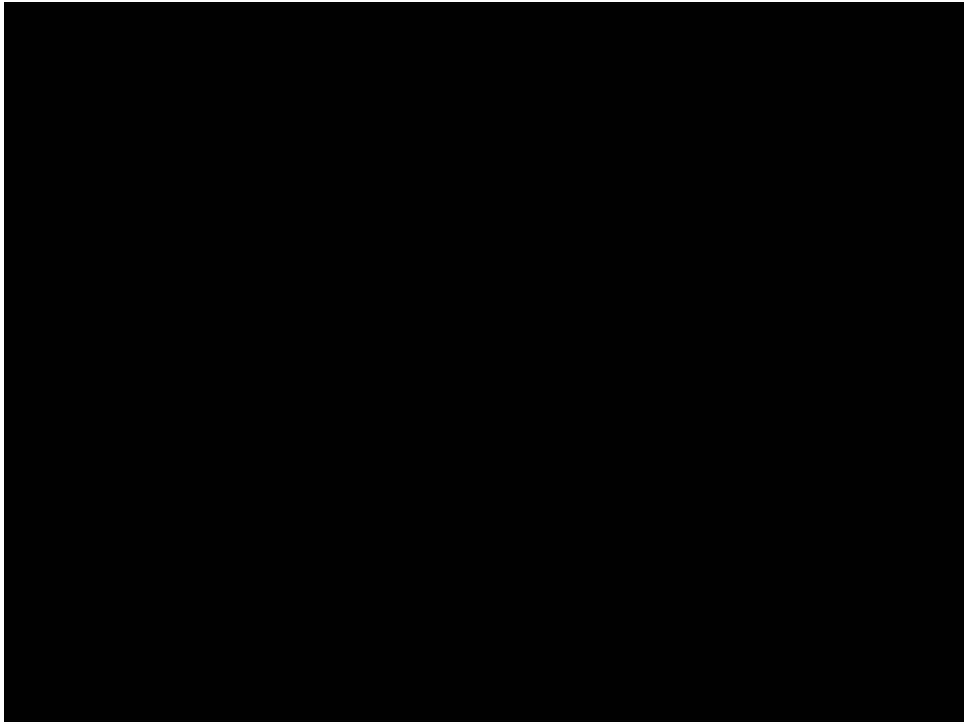


Figure 12. ICS-40300 Connected to a Codec



Microphone Functionality



Microphone Functionality

Product Requirements:

For Alpha:

- Requirement 1.1 - (Detect) Length from Source
  - Pass: **Sound is present**
  - Fail: Sound is not present

For Beta:

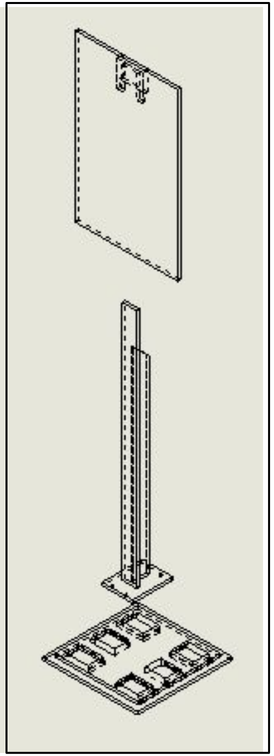
- Requirement 1.2? - Multidirectionality using splitting sound waves
  - Pass: Microphones pick up sound at anticipated location
  - Fail: Microphones do not pick up sound at anticipated location

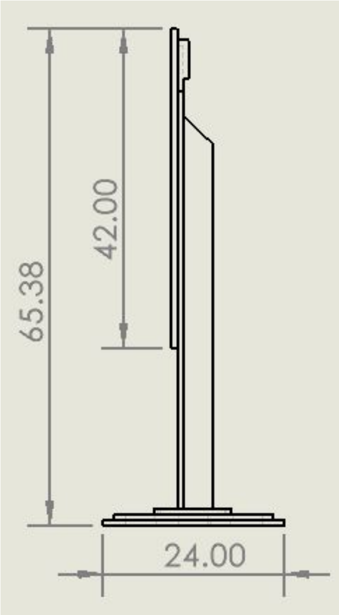
Beta Plan

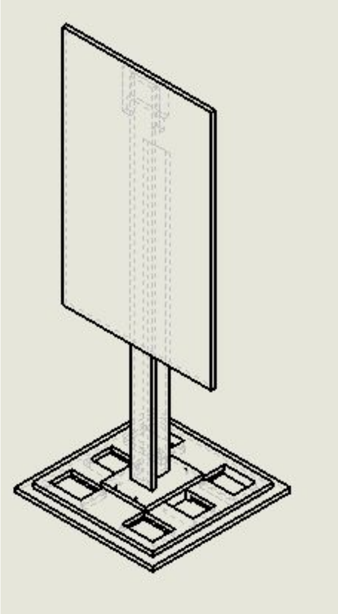
- Create an array using multiple microphones to detect radiation patterns
- Fix issue with oscillating amplitude
- Generate stand-alone circuit (independent of AD2) which can be recognized as a microphone by a PC and capture information about analog signal through AUX/USB

Subsystem - Testbench Stand

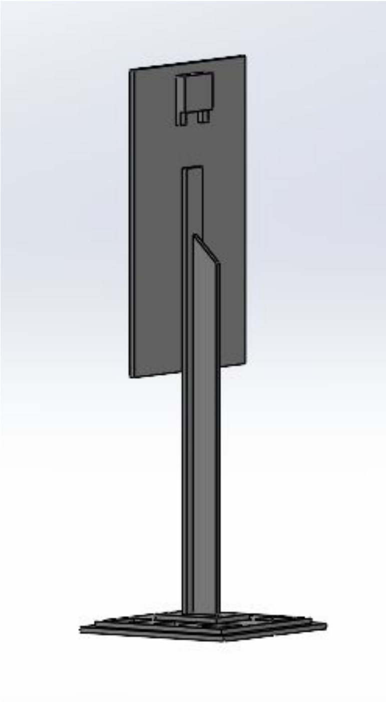
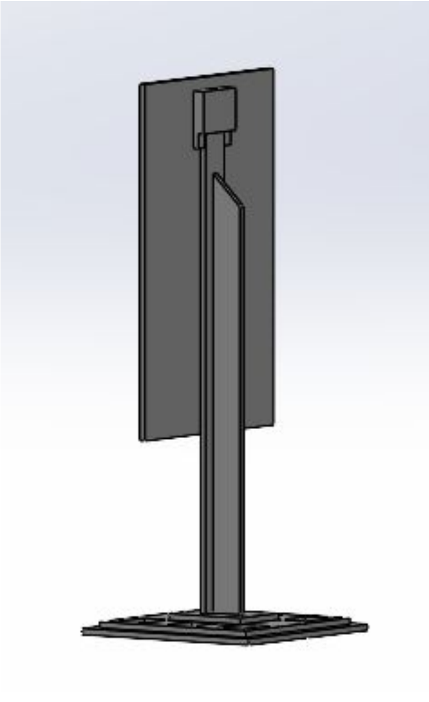
Larger Structure to Hold PCB Enclosure:







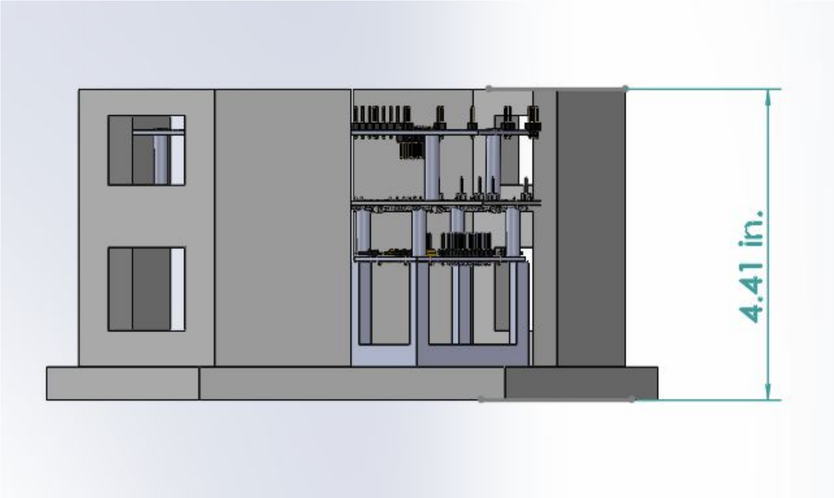
Subsystem - Testbench Stand

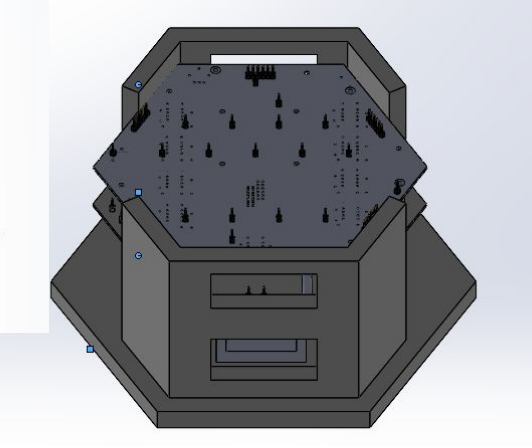



Beta Additions

Subsystem - Housing

CAD Models:

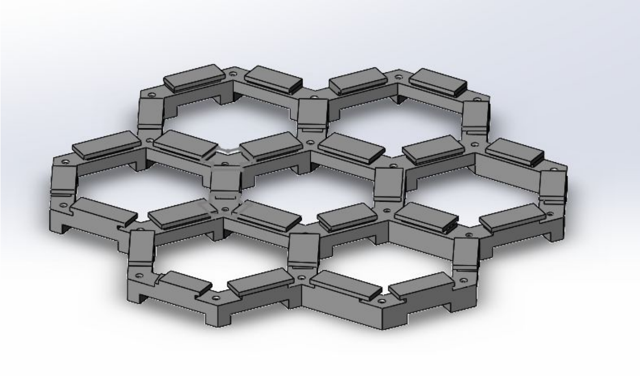


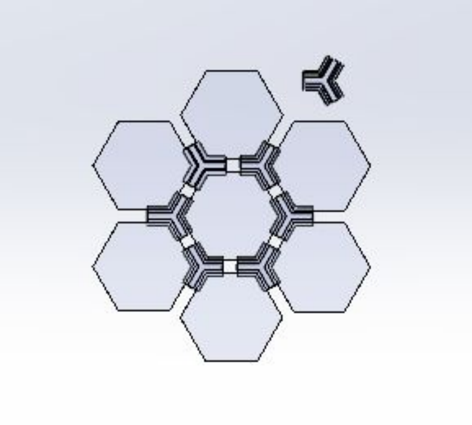


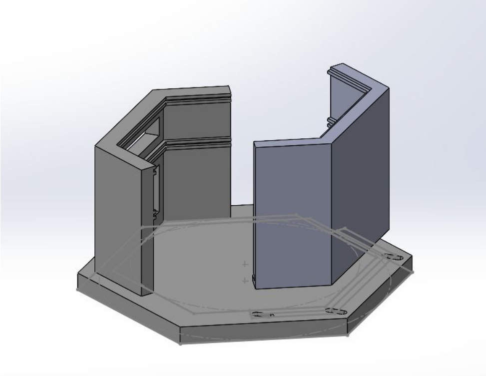
From Collision Testing:

Subsystem - Modular Enclosure

Several Past Models:







Modular Enclosure/Housing Functionality

Product Requirements:

From Alpha:

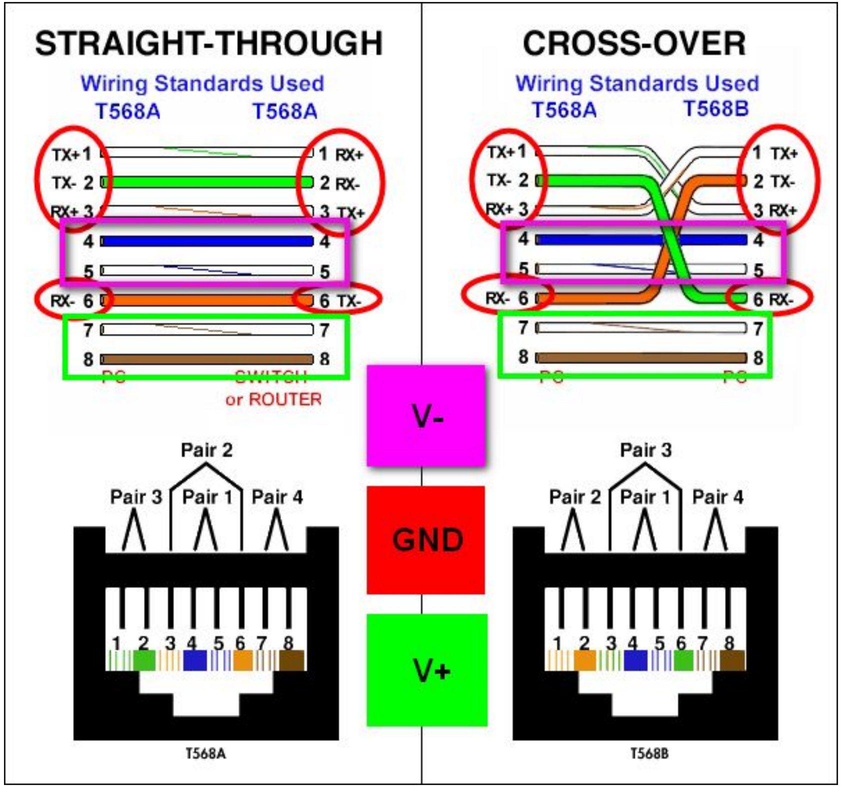
- The larger structure is physically durable.
- The larger structure is easy to assemble; it requires less than 5 major steps for general assembly.
- The current layout of it makes it easier to set up and transport.

Beta Plan

- Interface encasing with the larger structure and other systems
- Ensure that the PCB enclosure meets its requirements of being secure
  - PCBs do not fall out or break (3.3)
  - Array housing is not brittle (4.3)
- Make more modules to support array pattern

Power Connector - Ethernet

- Multiple wiring standards for ethernet cables
- Can find common wires to supply power. Example shown to the right
  - Does NOT have to be done this way, but this is just an example of something that would work
- Simply install an ethernet port to a module to power the whole thing
- Ethernet cable allows for power over long distance
- PSU → ethernet can simply be done via another ethernet port



Project Timeline

CDR February 12th	Post CDR Feb. 12 - 29	Alpha Prep Mar. 1 - 18	Alpha March 18th	Beta Prep Mar. 18 - Apr. 16	Beta April 16th
- Measure characteristics of transducers using LCR meter - Begin designing amplifying circuit with transducer as load - Begin PCB layout of mixing circuit	- Complete amplifying circuit, test and debug - Begin PCB layout of amplifying circuit - Complete and purchase mixing PCB - Begin microphone circuit (no PCB)	- Complete and purchase amplifying PCB - Debug and verify mixing PCB - Begin 3D modeling of hexagonal encasing (LCD billboard) - Ensure encasing includes leads which connects commons, audio source, and power	- Using PCBs, perform audio test - If works, use microphone to begin radiation pattern - If does not work, test and debug, redesign appropriate PCB(s) - Begin software/MCU SD card reading of audio	- Polish PCB(s) and reorder appropriately - Begin 3D printing hexagonal casing, fit flush with hexagonal PCB - Radiation pattern, if not done already - Complete MCU audio reading, start on a simple UI	- Present working product with at least 2 hexagonal faces linked together - Play various audio files from MCU - Simple UI for selecting audio, stopping and playing of sound

Circuit Design | PCB Layout | Purchase PCB | Debug PCB | PCB encasing | Radiation Pattern | MCU/Software | Final Prototype

Beta Plan Summary

Sound Board	- Connect the sound shield to the whole system. - Create UI interface that allows a user to play, stop, and shuffle through sound files using a small screen (utf character screen). - Work with Dr. Scheifele and add sound files that are designed for our project purposes.
Mixer	- Properly input audio signal. Either add DC offset to TRS connector or apply this DC value to an offset pin on the AD633ARZ - Incorporate stand-alone frequency generator IC - Power connector - Add variable amplifier to output (and/or every port)
Amp / Transducer	- Remove caps for each amp, and have one larger cap to reduce complexity. Larger traces to match other board. - Possible changes to fix nonlinearity effect (TBD, communicate with Dr. Pitts). - Maybe add female housing pins for the transducer leads rather than soldering them in. In the case that some are faulty, they can be pulled out and placed in.
Modular Enclosure	- Create arrangement so pieces can easily branch from one to the other
Microphone	- Create an array using multiple microphones to detect radiation patterns - Generate stand alone circuit (independent of AD2) which can be recognized as a microphone by a PC and capture information about analog signal through aux/usb.
Misc	- Order more components to make multiple transducer boards. Power over ethernet to boards to reduce mess. - Connect PCB encasing to larger structure - Smaller mounting hole sizes - Test array outside & anechoic chamber

Conclusion/Feedback

- We have directional propagation of a single tone at loud volume. This is out of a single module we will expand to more.
- Near future steps:
  - Better directionality
    - phasing to a focal point X meters away (physical, electrical)
  - Better sound quality / Support for any sound
    - proper mixing, proper voltage requirements
    - better AM techniques (decrease THD, like SR-AM)
    - predistortion across frequency spectrum
    - filtering
  - a taller “wall”
    - more modules, vertically lined up
- We now need to start worrying more about tuning this device for its purpose: use on elephants as a wall of sound.
- We are currently working on sending sound files into the device. As of now, we don’t have a specific sound that we plan on testing with (bee, construction, humans talking, etc. (?) sounds). More on the behavioural side of things
- Feedback on our system and steps toward potential testing would be appreciated.