NC STATE UNIVERSITY

Project 21: Wall Of Sound

Critical Design Review

Vectorized Acoustic Deterrence of Elephants Research

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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.

Description of Key Components

Power Supply - Provides power to all systems and components.

Frequency Generator - Creates a sinusoidal tone at 40kHz to be modulated by the sound source.

Sound Source - Laptop/MCU that send analog tone or sound. What the final and unmodulated sound should be at the target.

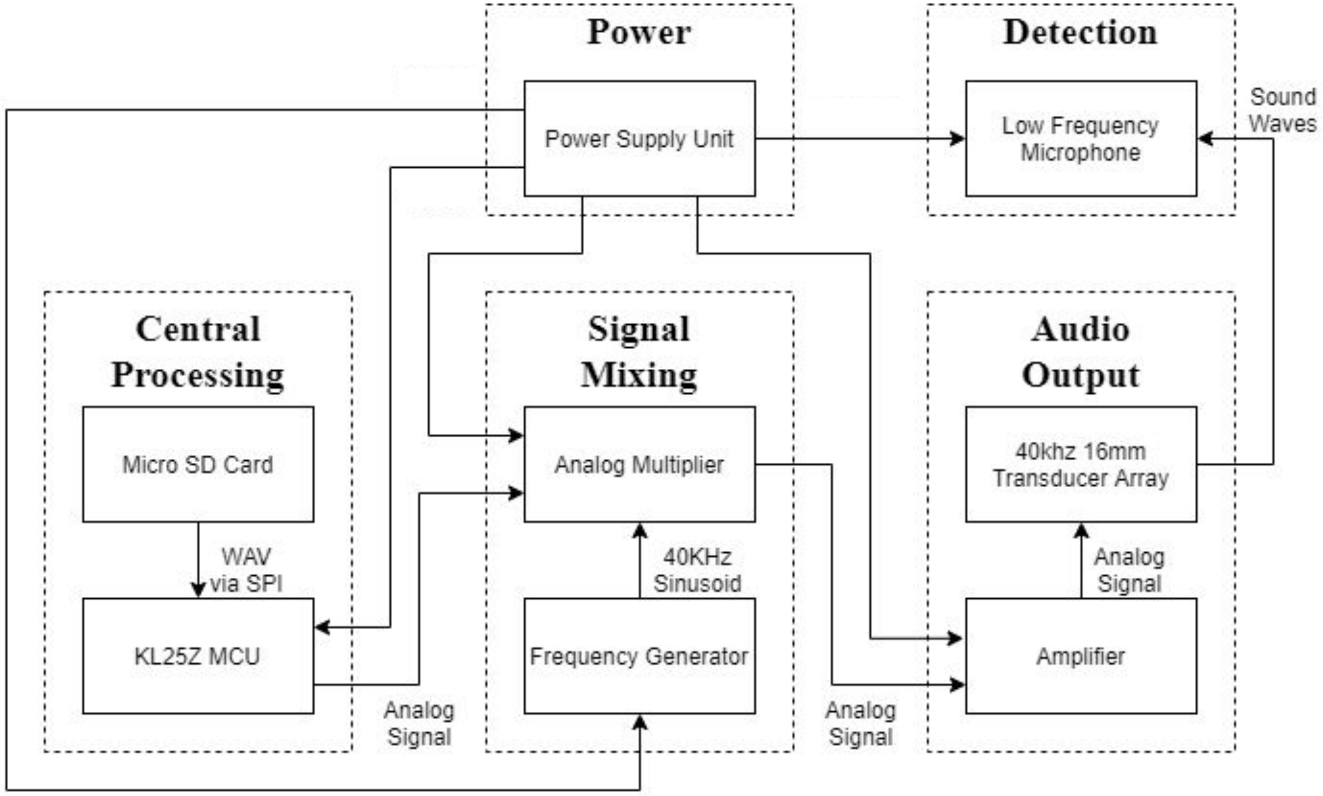
Analog Multiplier - Modulates sound source onto carrier via amplitude modulation.

Amplifier - Apply gain to modulated signal and provide power for transducer array.

Microphone - Verifies system functionality with frequency spectrum.

Transducer Array - 40kHz 16mm transducers in an array configuration to help propagate the ultrasound at longer distances.

System Architecture Overview



Design Changes Since PDR

Removals

- Removed all motor instances design
- Decreased size of single hexagonal panel (331 transducers)
- Lowered priority of functioning UI
- Lowered priority of MCU & software-side of the project
- Decreased the range from 20kHz to 15kHz to target elephant specifically.

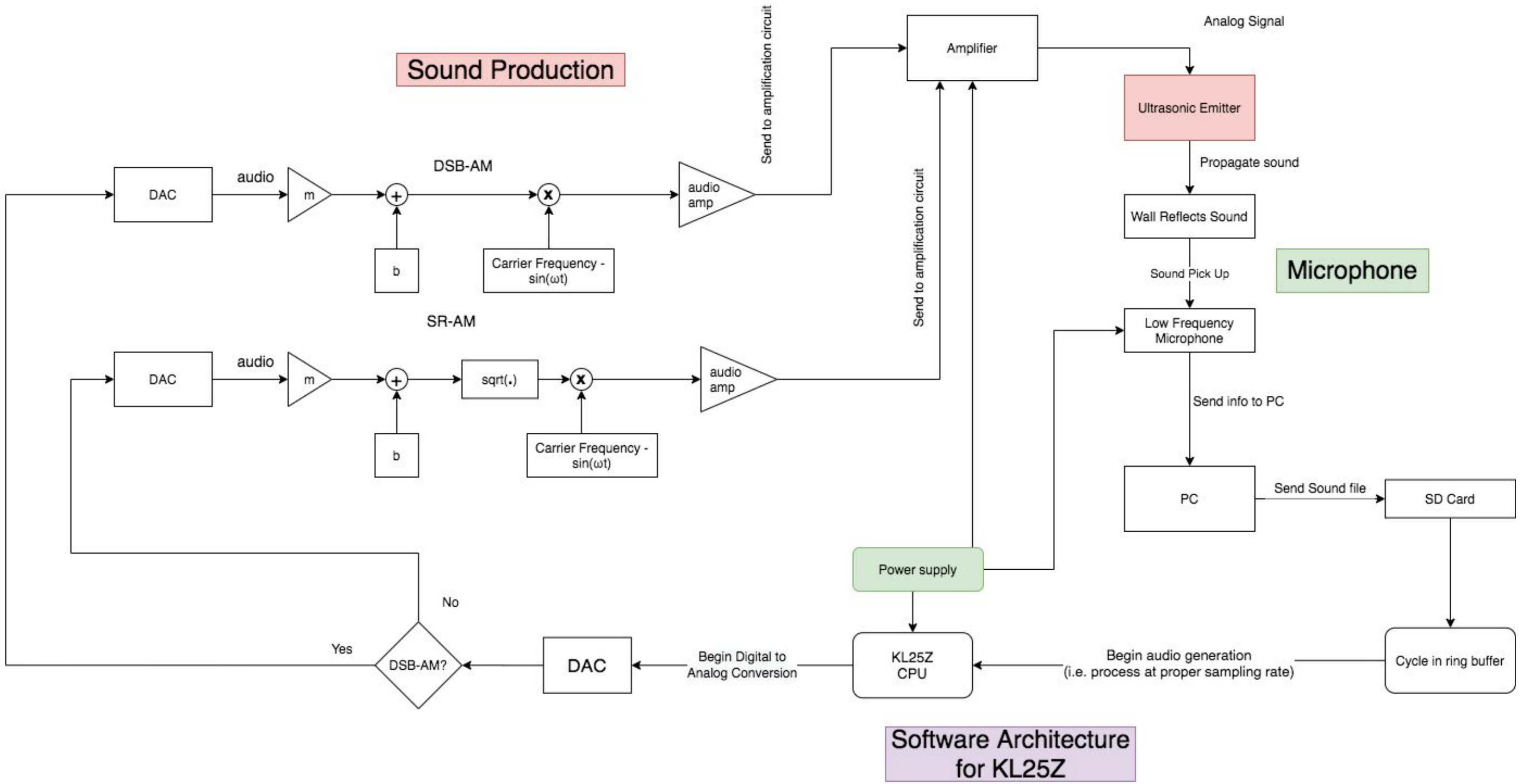
Additions

- New modular design with smaller hexagonal panels (19 transducers)
- Multistage amplification
- Amplifier to transducer ratio (1:~20 → 1:~4-5)
- New PSU, higher wattage as well as higher voltage range

Areas of Increased Emphasis

- Amplifier IC selection

Final System Design



Main Parts List

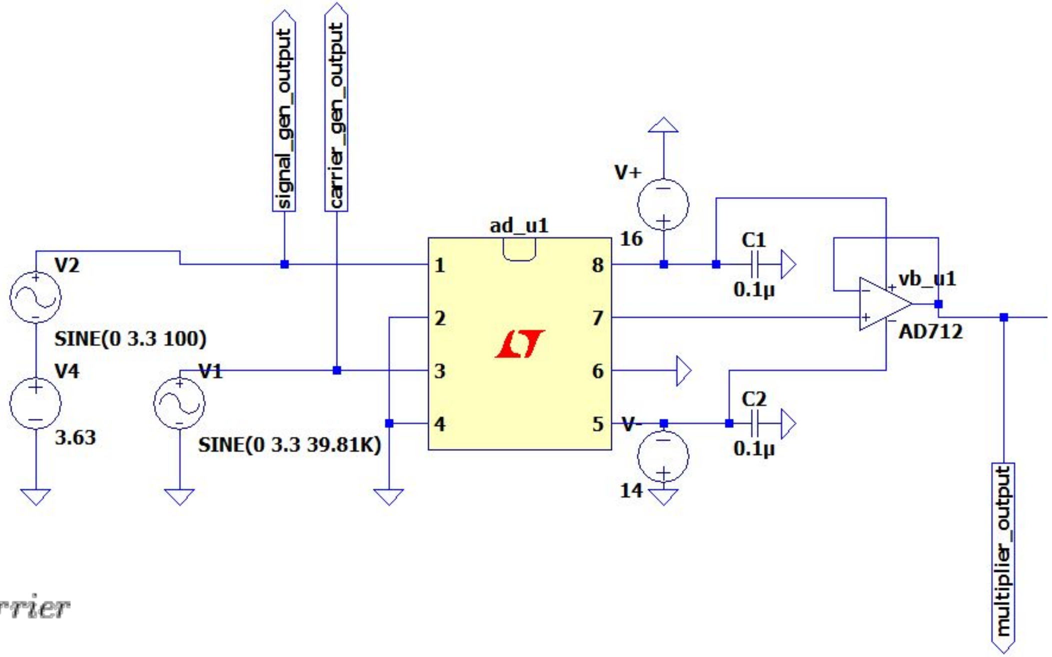
Part	Quantity
16mm 40kHz ultrasonic transducers (MSO-A1640H12T)	100
Analog multiplier (AD633)	6
Frequency generator (AD9833)	6
Extended low frequency microphone (ICS-40300)	4
Miscellaneous amplifiers (low voltage audio amplifier, operational amplifiers, etc.)	10
Miscellaneous thru-hole and SMT components	~
MCUs (KL25z, MSP4030, Arduino, etc.)	15
Plywood	5 - 6 sq. ft
2 x 4"	11 - 12 ft
8020	~

Power Budget

Item	Current (mA)	Power (mW)	Quantity Needed	Total Power (mW)	URL
Frequency Generator	50mA	889mW	1	889mW	https://datasheets.maximintegrated.com/en/ds/MAX038.pdf
Microcontroller (Laptop)	~	~	1	~	
Multiplier	40 mA	500 mW	1	500mW	https://www.tme.eu/Document/ce5356ac4efb480c752b9e53289e2634/AD633ARZ-Analog-Devices.pdf
Amplifier - 1	23.695 mA	426.51mW	Many (equal to 4-5x the amount of modules we end up having)	Not sure yet	https://www.ti.com/lit/ds/symlink/lm386.pdf?ts=1613132995005&ref_url=https%253A%252F%252Fwww.google.com%252F
Microphone	<220 µA	~1mW	1	~1mW	https://invensense.tdk.com/wp-content/uploads/2019/02/DS-ICS-40300-00-v1.3.pdf?ref_disty=digikey

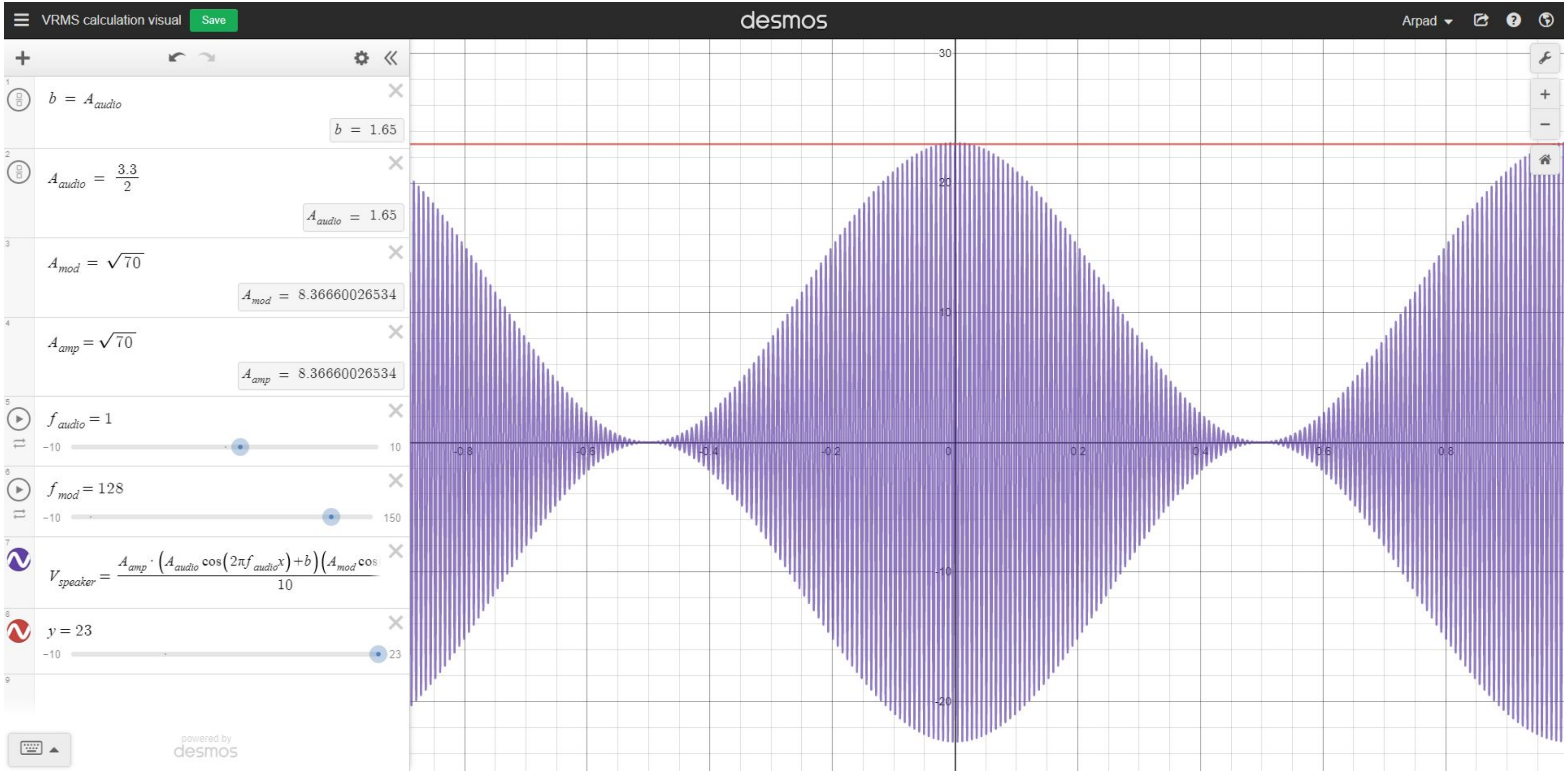
Schematic - Multiplier (AD633)

- 40kHz sinusoidal signal from function generator
- 100Hz sinusoidal signal from signal controller
- 30V supply, oscillation absorbing capacitors
- Voltage follower to final output, ***multiplier_output***



$$MulitplierOutput = (Signal + DC) \times Carrier$$

10Vrms Visual

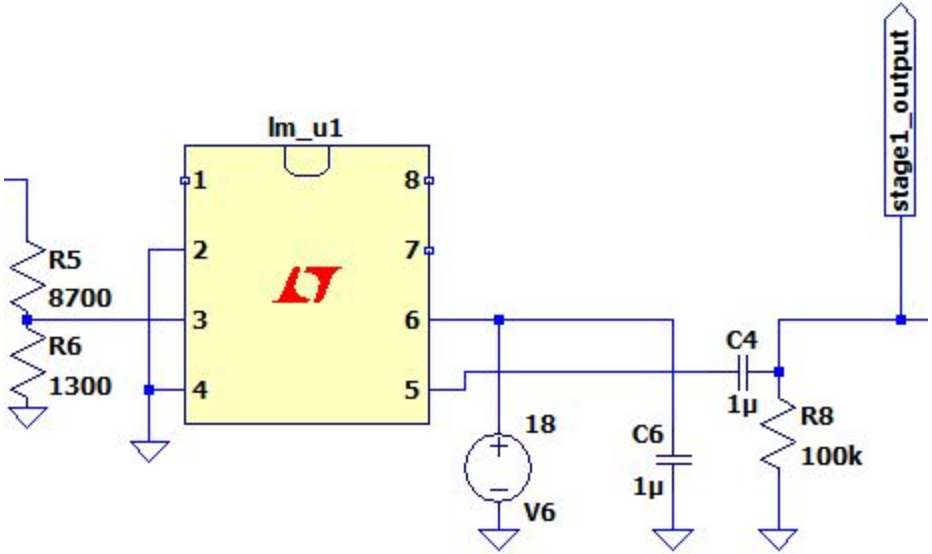


Schematic - Amplifier

- HPF at ***multiplier_output*** to remove any DC offset
- Potentiometer to adjust gain on pin 3
- Pins 1, 7, 8 are NC
- 18V supply, oscillation absorbing capacitor
- HPF at pin 5 toward ***stage1_output***

Will need second stage to get to voltage required by transducer

- Differential to negate common noise
- Frequency response

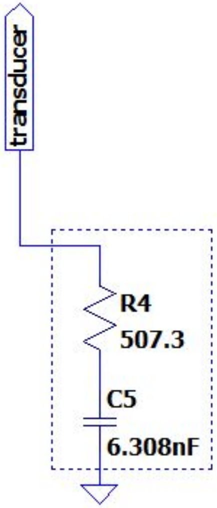


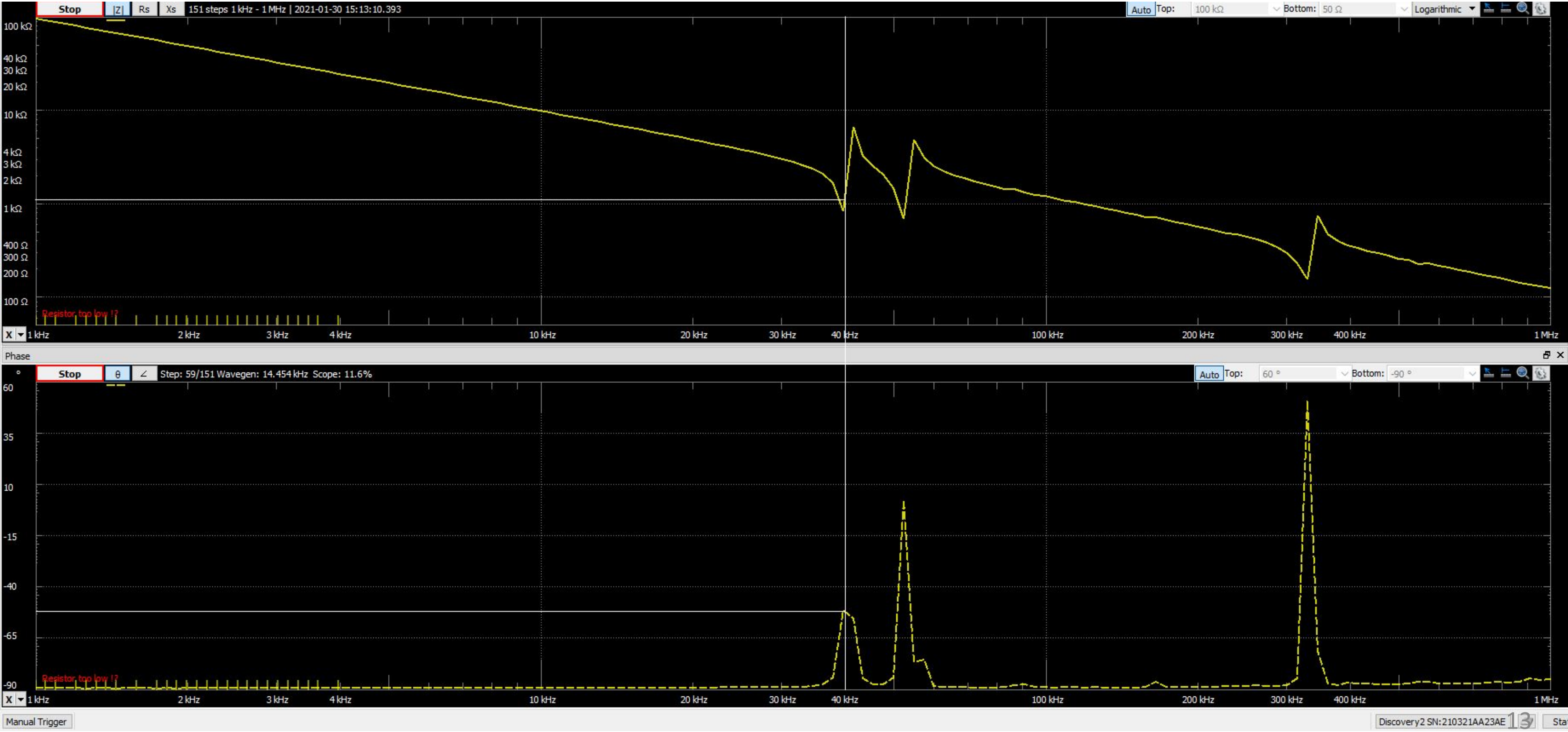
$$Stage1Output = MultiplierOutput \times 3$$

Modeling Transducer

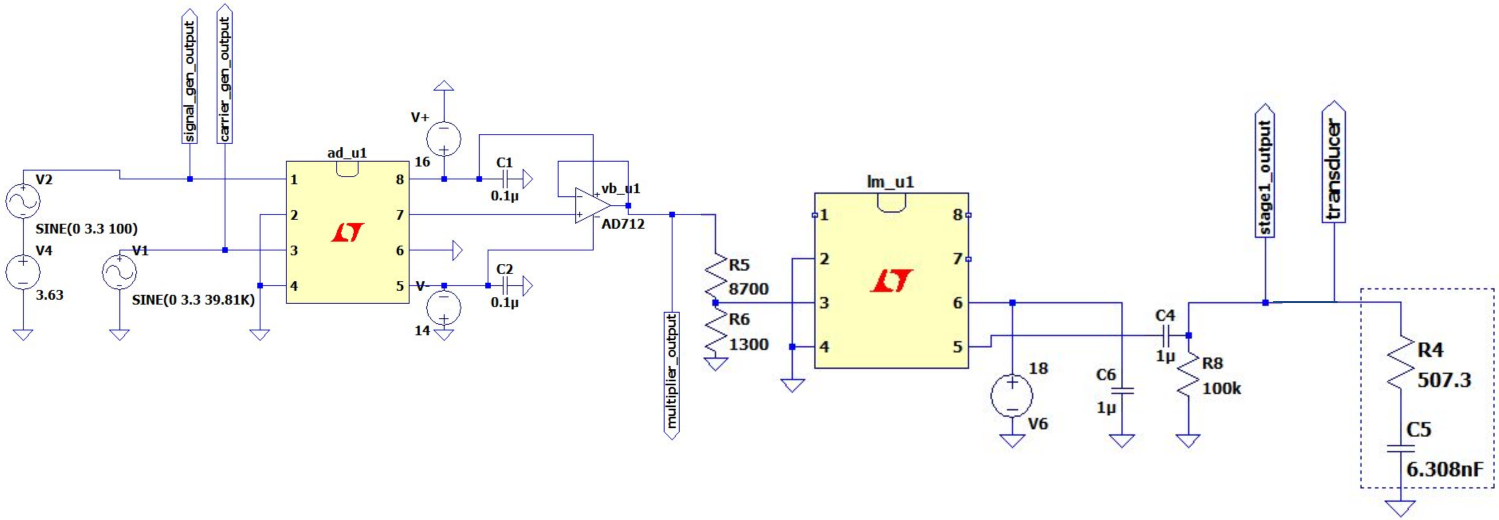
Cs: 6.308 nF	Rs: 507.3 Ω	@: 39.81 kHz	θ: -51.3251 °	Q: 1.249323
|Z|: 811.7 Ω	Xs: -633.7319 Ω	∠: -50.3832 °	D: 0.8004334	

- Model of single transducer from AD2 measurements
- Software-calculated impedances, similar to LCR meter
- Have ONLY accounted for series capacitance/resistance. There are parallel ones that have measurements for, but have not modeled them (at the time of this presentation) - current task
- Transducer model on right is for 39.81kHz, hence why some of these LTspice models show that frequency rather than 40kHz

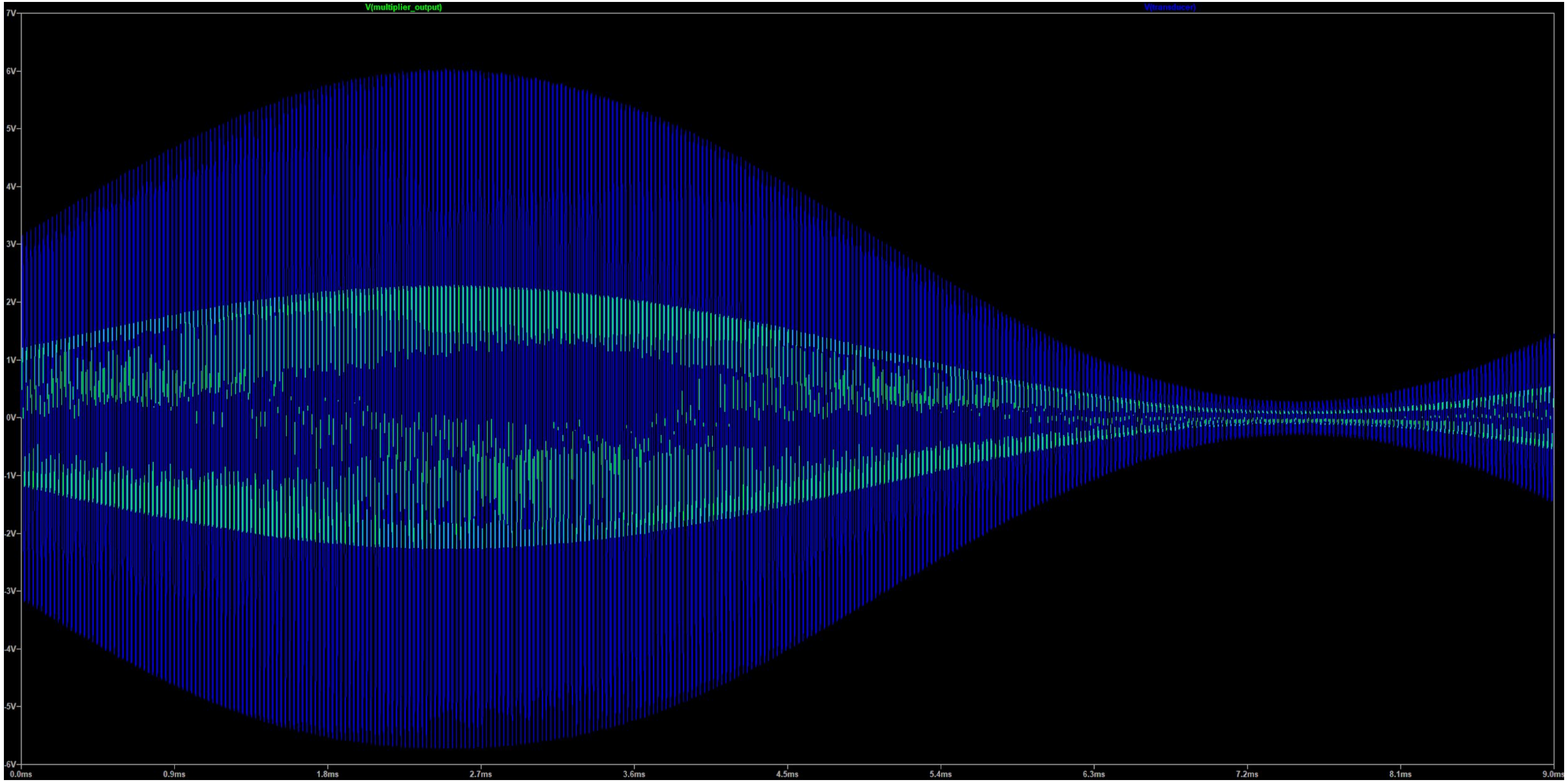



Stop
|Z|
Rs
Xs
151 steps 1 kHz - 1 MHz | 2021-01-30 15:13:10.393
Auto
Top: 100 kΩ
Bottom: 50 Ω
Logarithmic
100 kΩ
40 kΩ
30 kΩ
20 kΩ
10 kΩ
4 kΩ
3 kΩ
2 kΩ
1 kΩ
400 Ω
300 Ω
200 Ω
100 Ω
Resistor too low !?
1 kHz
2 kHz
3 kHz
4 kHz
10 kHz
20 kHz
30 kHz
40 kHz
100 kHz
200 kHz
300 kHz
400 kHz
1 MHz
Phase
Stop
θ
Step: 59/151 Wavegen: 14.454 kHz Scope: 11.6%
Auto
Top: 60 °
Bottom: -90 °
60
35
10
-15
-40
-65
-90
Manual Trigger
Discovery2 SN:210321AA23AE

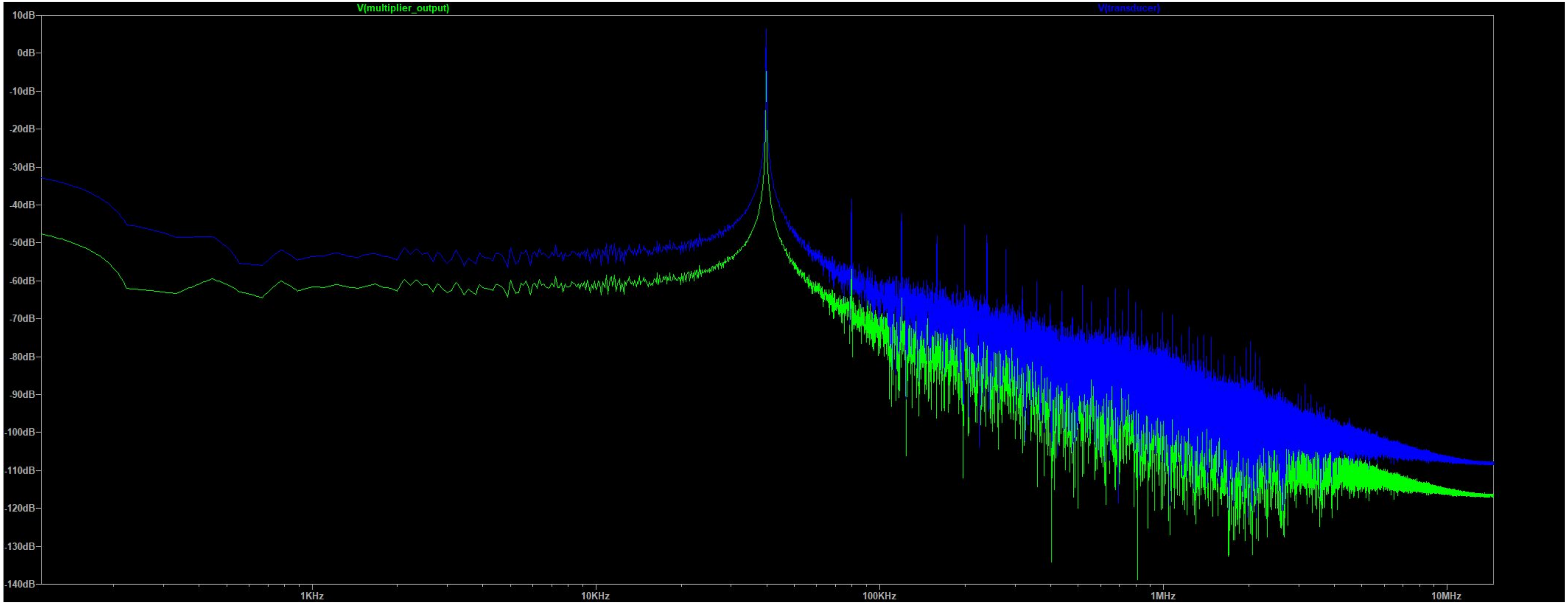
Final Detailed Schematic Diagrams



Simulation Results - Waveform

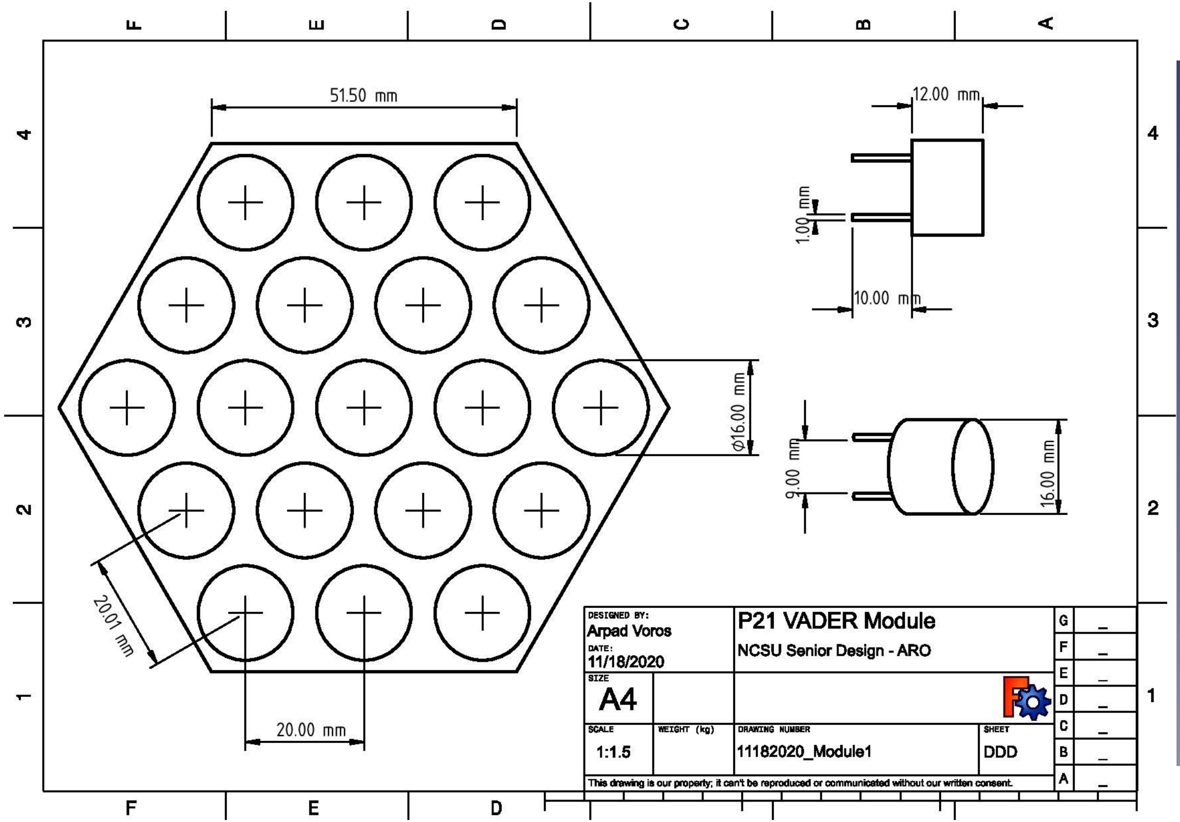


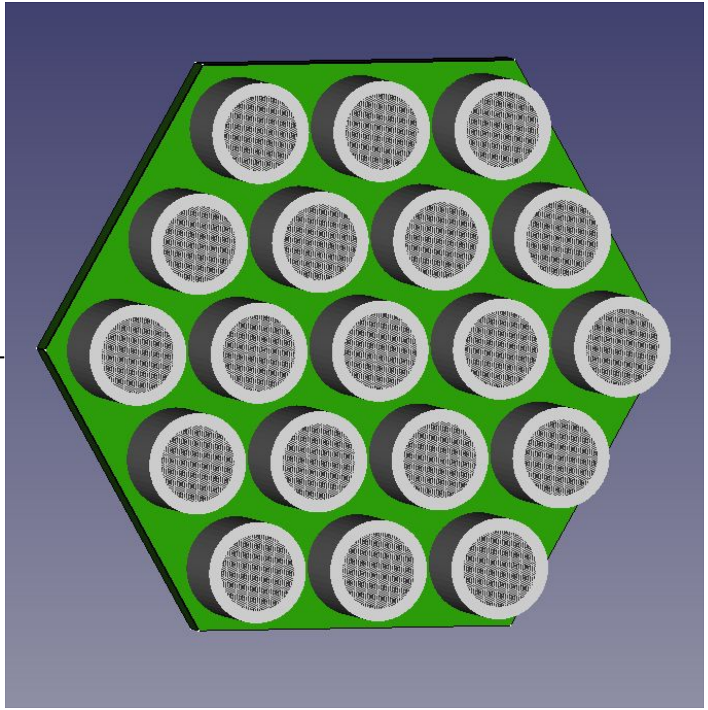
Simulation - Spectrum



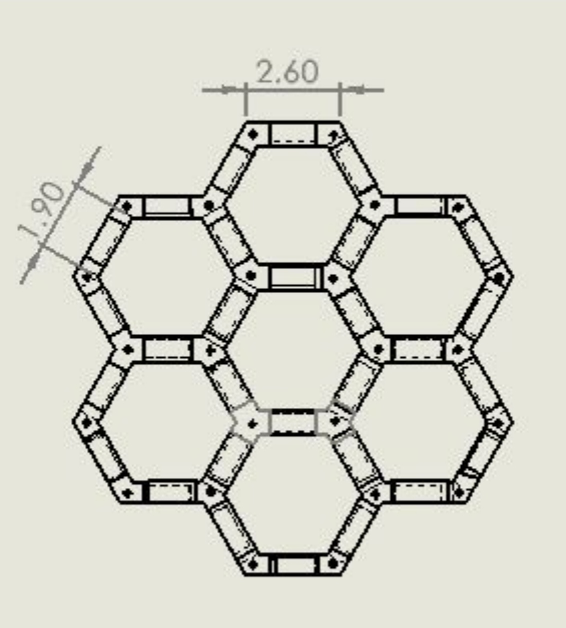
Large amount of power at 40Khz

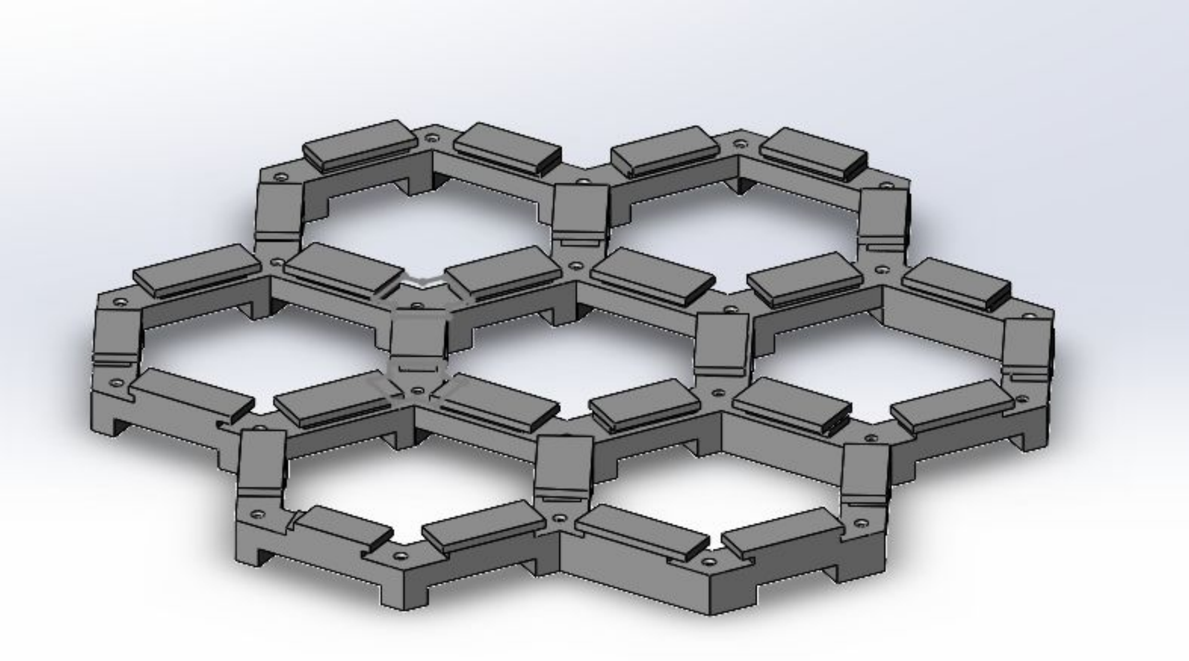
Hexagonal PCB Structure

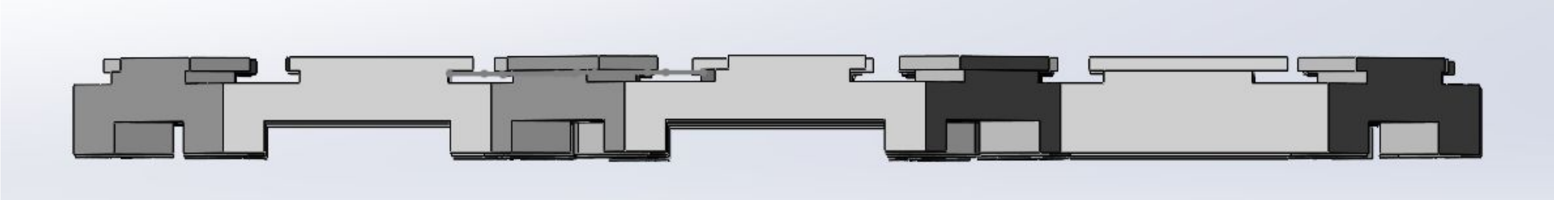




Hexagonal PCB Housing







Final Software Overview

Goals:

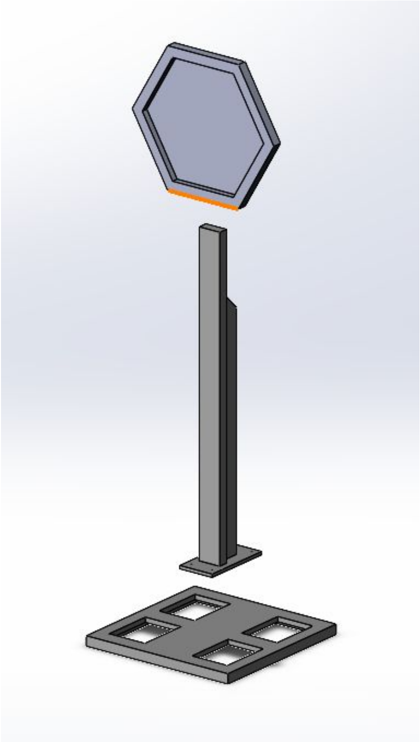
- Read sound file from SD card
- Output to DAC, 3.3V
- GUI and other processing

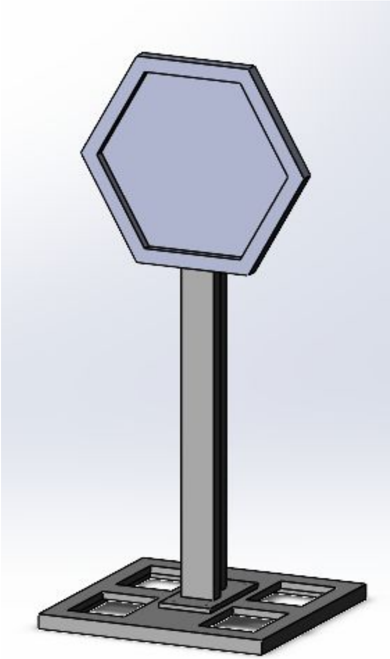
HOWEVER

- Put on backburner for time being
- Current testbench works more effectively with a laptop
  - Quicker to change settings for tone generation
- User Interface is not as important in the proof of concept

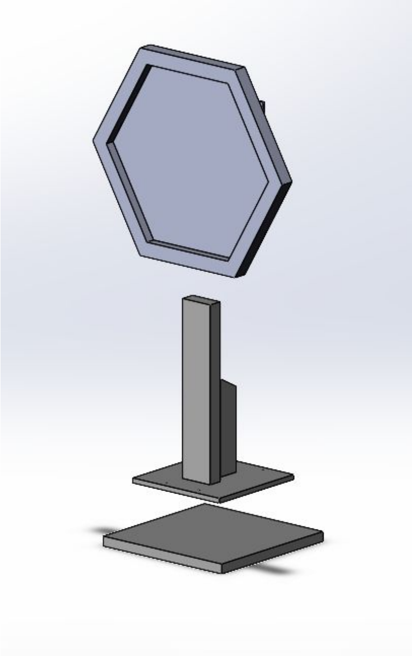
Final Mechanical Design

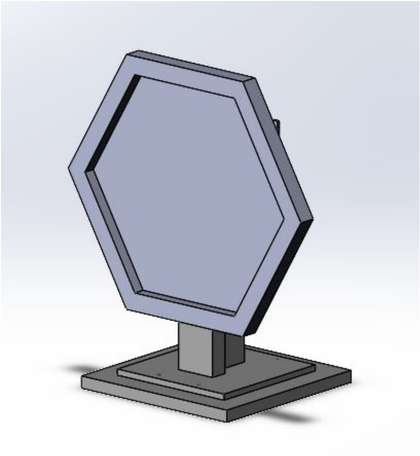
Tall Version:



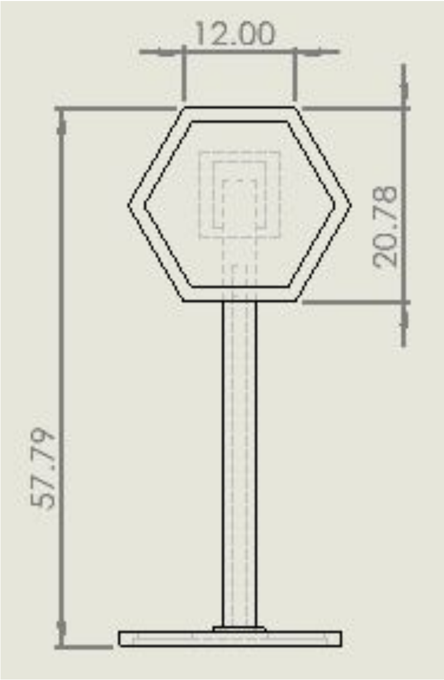


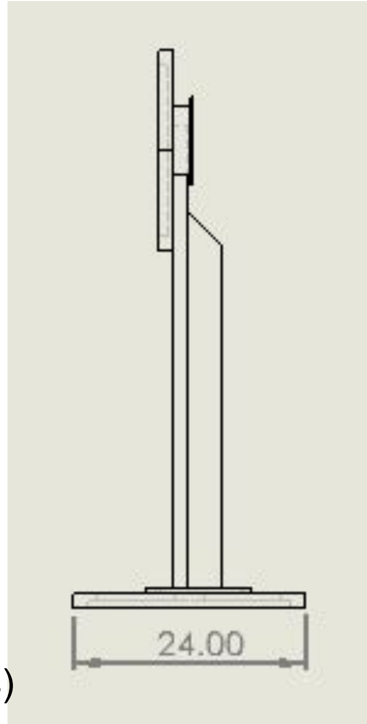
Short Version::





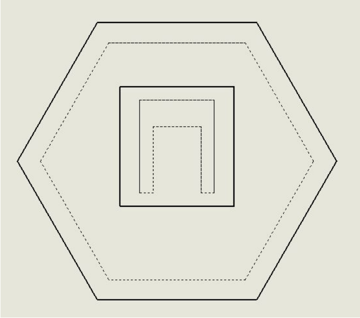
Final Mechanical Design

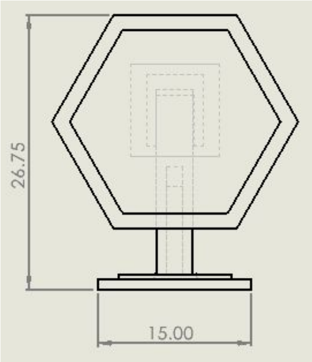




Tall Version (~45 lbs with wheels)

Constant Hexagon Plate:





Short Version (~10 lbs)

Testing And Verification for Subsystems

Test Case Amplifier	Determine the efficacy of the amplifier at every stage to insure no clipping or distortion with proper gain at both the 40kHz carrier and the tone signal frequency.
Method	Simulate in LTspice to get these desired results. Afterward connect transducers and probe at every stage. Looking at the spectrum will determine if the simulations prove to work in a desired way.
Test Case Transducer Modeling	Modeling the transducer in such a way that it behaves identically to the physical transducer itself in simulation and testing that to be true.
Method	Measuring LCR characteristics with AD2 and adapting the transducer model. Taking a known working circuit output (Sins of varying amplitude), running it through the model and in reality until we are satisfied with both behaviors being close to each other.
Test Case Structural integrity	Ensure that housing component is structurally sound and that base is able to support array.
Method	Asses base oscillations prior to array/PCB installment and make adjustments accordingly. Reassess after 3D casing is printed and PCB array is installed. Make any necessary adjustments. Analyze brittleness of 3D casing to ensure that array will not be damaged during transport.

High-level Test and Verification

Test Case	Method
Length and Intensity from source	Using a microphone, measure distance away from source that sound can be identified and determine intensity at specific distances.
Multidirectionality using splitting sound waves	Using a microphone, ensure that the sound wave is split correctly upon contact with surface
Play sound files from memory storage device	Device should produce any sound file or frequency which we desire and can be tested with frequency analysis software
Physical durability	Basic tests for brittleness
Power draw	Measure current draw from subsystems and components. Change some things to accomplish a reasonable power draw.

https://docs.google.com/spreadsheets/d/1B-i2YPVe5rdnIJbTUB8mwCOv8Y-YYvgo1uZOVVaxF_Y/edit?usp=sharing

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Pre Alpha Plan

	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

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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

Team VADER PCB Design Timeline

February 12th	February 19th	February 19th-26th	February 26th – March 17th	March 18th
Begin PCB Layout of Mixing Circuit	Finalize Initial PCB Design and Order from Vendor	Anticipated wait time for PCB order. Continue to work on design and make improvements/ debug	Test PCB, analyze errors/bugs, make any necessary design changes, reorder PCB	Audio test with PCB should be completed prior to Alpha Demo

PCB redesign

We anticipate that we will need to redesign our PCB at least once, this time has been factored into the design process.

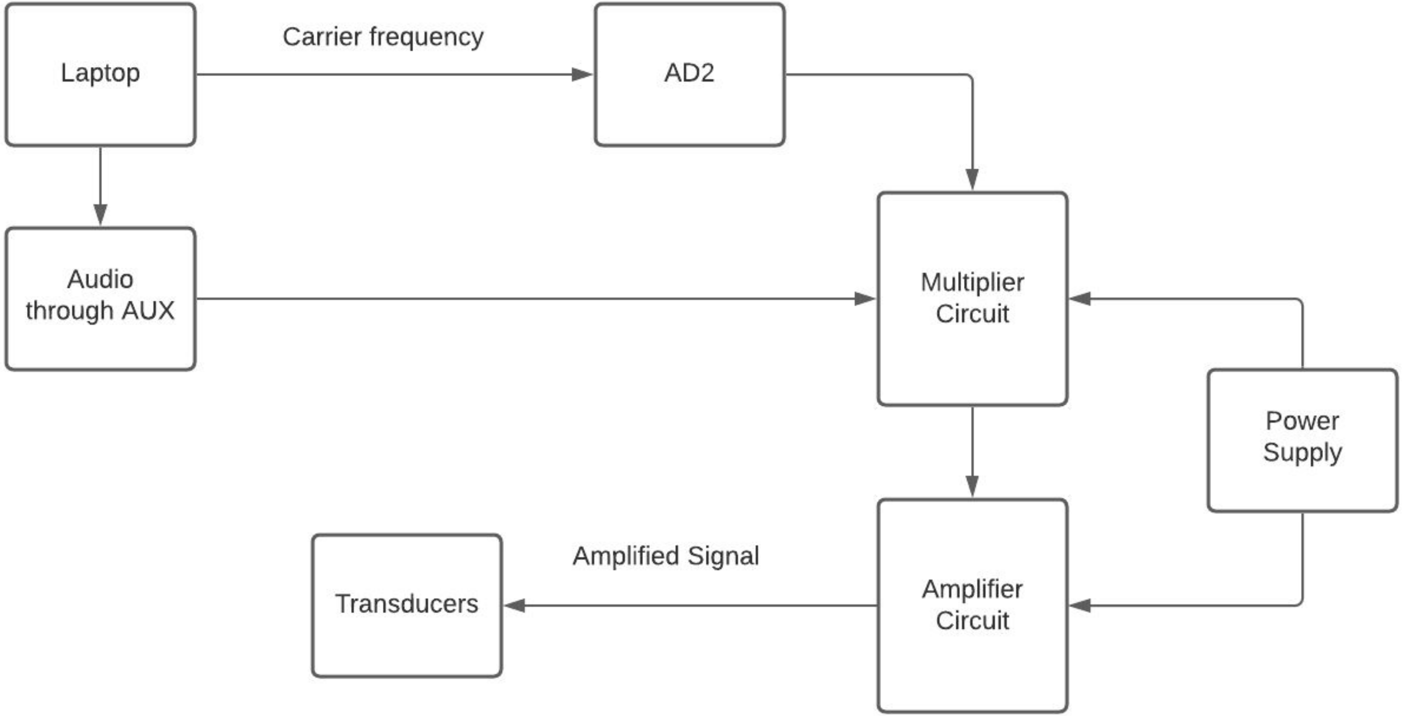
PCB Ordering

We will be utilizing JLCPCB to order our PCBs. We anticipate that it will take 5 business days to complete and receive our order. This wait time has been anticipated

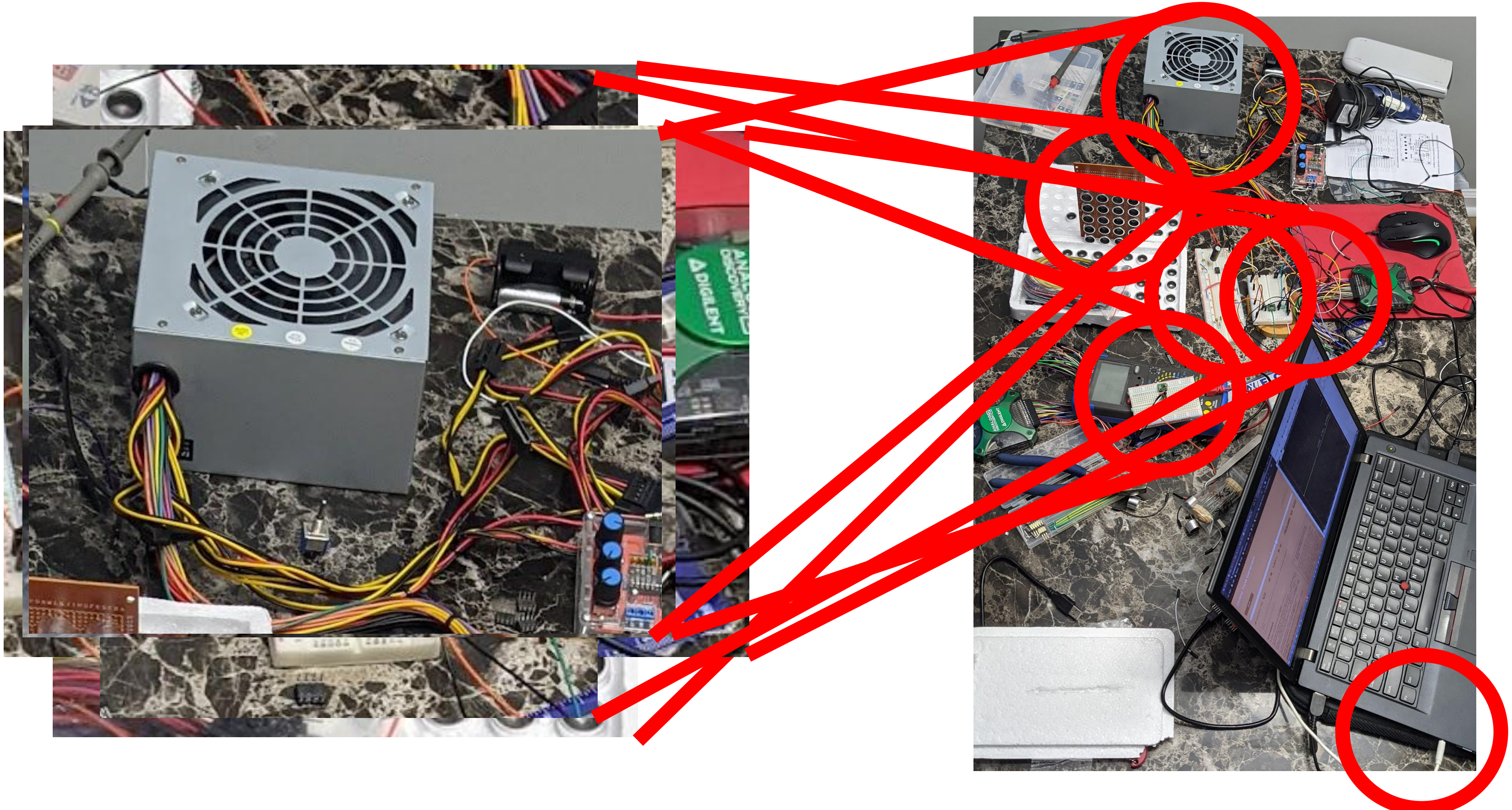
PCB should be completed

Alpha Demo should mark the end of PCB Design

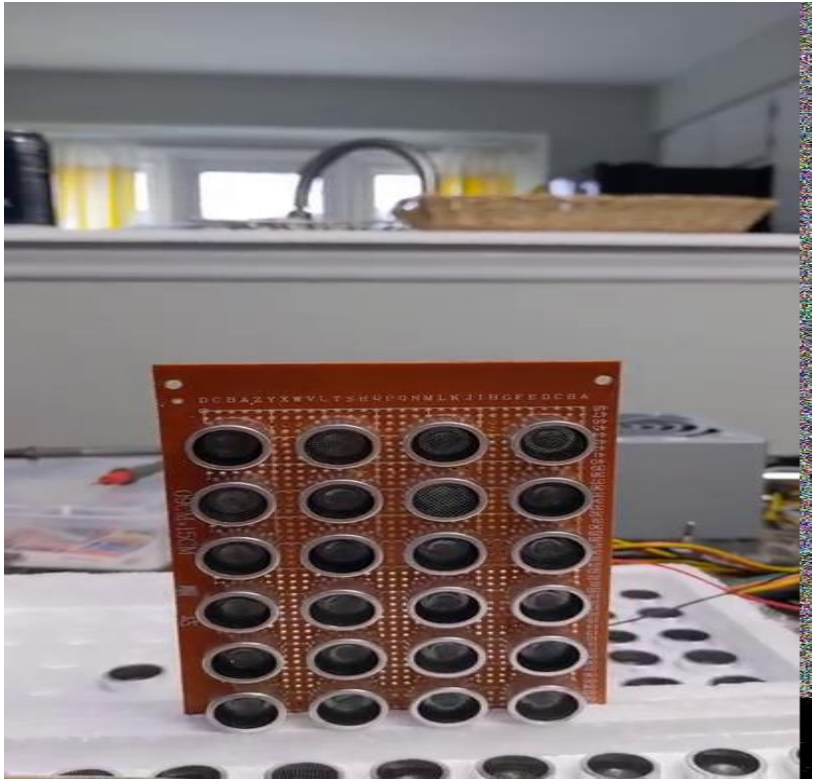
Lab Bench Demo

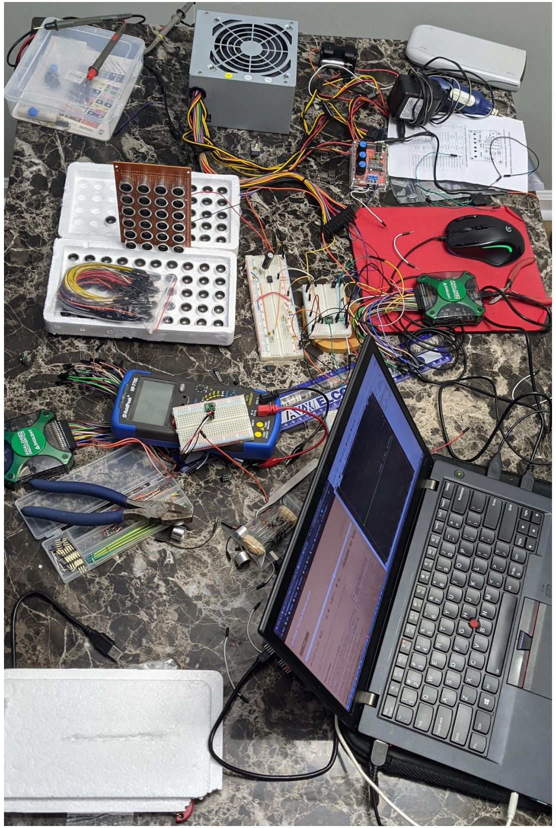


Lab Bench Demo



Lab Bench Demo





Lab Bench Demo

Project Bill of Unordered Materials

- Final Power Supply (Unknown - est.: 100 USD)
  - Renting one from Troxler for free, but will purchase a integrated PSU when the design comes to it

- Post-Stage One Amp(s) (Unknown - est.: 50 - 100 USD total)
  - RF Amps, Piezoelectric Drivers, Ultrasonic Transducer Drivers, Sonar Drivers, etc.