PASSIVE AMPLIFICATION FOR WILDLIFE RECORDING

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Abstract

Backyard Brains, in conjunction with previous MDP projects, has developed a device to collect and store audio data from the wild to detect and differentiate between birdsongs, insects, and rainfall. My MDP team is currently working to optimize the device to make it more manufacturable, user friendly, and ready to ship to Ecuador for field trials. During device testing in the first half of 2021, it became evident that the enclosure solution used to house the PCB was significantly dampening audio waves, causing recordings made with the device while housed in the enclosure to be muted and difficult to identify. The team, in conjunction with Backyard Brains, decided to pursue passive sound amplification to remedy this problem, using a design process to produce a final recommended amplifier shape for the prototype.

Executive Summary

Over the course of the Winter 2021 semester, it became evident that the enclosure solution used to house the PCB was significantly dampening audio waves, causing recordings made with the device while housed in the enclosure to be muted and difficult to identify. The benefits of the enclosure outweighed this issue, however, and the team looked to various alternatives to amplify audio waves to make recordings clearer and easier to identify, without having to increase device costs by purchasing a new microphone.

While discussing the possibilities of amplifying sound waves for clearer recordings, it was mentioned and agreed upon that passive sound amplification - similar to the function of a human ear - would be a plausible alternative to purchasing a new microphone. With the team focused on optimizing the rest of the enclosure, I pursued passive sound amplification and the design of a viable amplifier for the prototype as an independent study within the MDP team. More specifically, my individual contribution involved the following, which will be discussed in this report:

1. Passive audio amplification research that will help inform concept generation for potential solutions, providing vital background information and in depth specifics regarding the best execution of passive sound amplification for various frequencies.

2. Concept generation of numerous potential solutions for passive sound amplifiers that can be attached to the current enclosure, using best practices of design, ensuring creative and innovative solutions can be generated.

3. Rapid prototyping of multiple concepts to be used for evaluation and data collection. Prototypes will be created using CAD in SolidWorks, and manufactured to be functional in field testing that will coincide with a wider testing session for the team.

4. Develop a testing plan for the passive sound amplifier prototypes to allow for accurate data collection that will be used later in concept evaluation. In addition, this testing plan will provide a standardized method for testing passive sound amplifiers, should any testing be needed at a later date this semester, or any time in the future.

5. Concept evaluation using collected testing results and best practices of concept evaluation with a decision matrix to document and utilize a process for evaluating each passive amplifier design.

6. Finalize top designs and make any modifications necessary for manufacturing and best functionality. Each top design will be manufactured for use with the team deliverables at the end of the semester.

While the project is displayed here in stages, each stage will not end with a hard stop on the process or concept that is used during a given stage. Throughout the semester, the process will be iterative and cyclical during each stage. I independently lead the work on these stages of the development of passive sound amplification for the Backyard Brains device, working to complete a thorough design process following best practices over the course of the semester, resulting in finalized designs and recommendations provided to the sponsor.

Project Background

More than half of U.S. bird species are threatened by climate change. In order to track migrations and monitor population numbers, there is a need for large scale data collection on songbirds both in the U.S. and in remote regions of the world. Documenting the activity of songbirds remains a challenge, given the high cost of accurately collecting and storing song data. There are options for affordable, high-quality, and inexpensive microphone systems on the market. What is missing, however, is a system that will autonomously perceive, identify, store and report bird song from its native environment. Backyard Brains has sponsored multiple MDP projects in the past to design and develop a device to collect and store audio data from the wild to detect and differentiate between birdsongs, insects, and rainfall.

Backyard Brains, in conjunction with previous MDP projects, has developed a device to collect and store audio data from the wild to detect and differentiate between birdsongs, insects, and rainfall. My MDP team worked to optimize the device to make it more manufacturable, user friendly, and ready to ship to Ecuador for field trials.

Due to the damping effect seen during device testing, this device will also include a passive sound amplifier that is effective in amplifying recordings. The Backyard Brains MDP team delivered a minimally viable product (MVP) for an audio recording device housed within a waterproof enclosure, utilizing a passive sound amplifier, capable of long-term deployment in the wild while attached to a tree, to record bird calls within a range of both audible and ultrasonic frequencies. The MVP also includes a mobile application for communicating with the recording device, as well as a web-based system for analyzing recorded data with AI to identify bird species based on their calls.

Project Scope

The scope of this project is contained to the interaction between the environment and the device. Initially, the device solely included an acoustic membrane in this scope - a component that allows sound to pass through the case more while keeping the enclosure water-resistant. To visualize the scope of this project within the greeted Backyard Brains MDP project and device, the Interface Control Document is shown below in Figure 1. The specific scope covered in this project and report is contained within the red box.

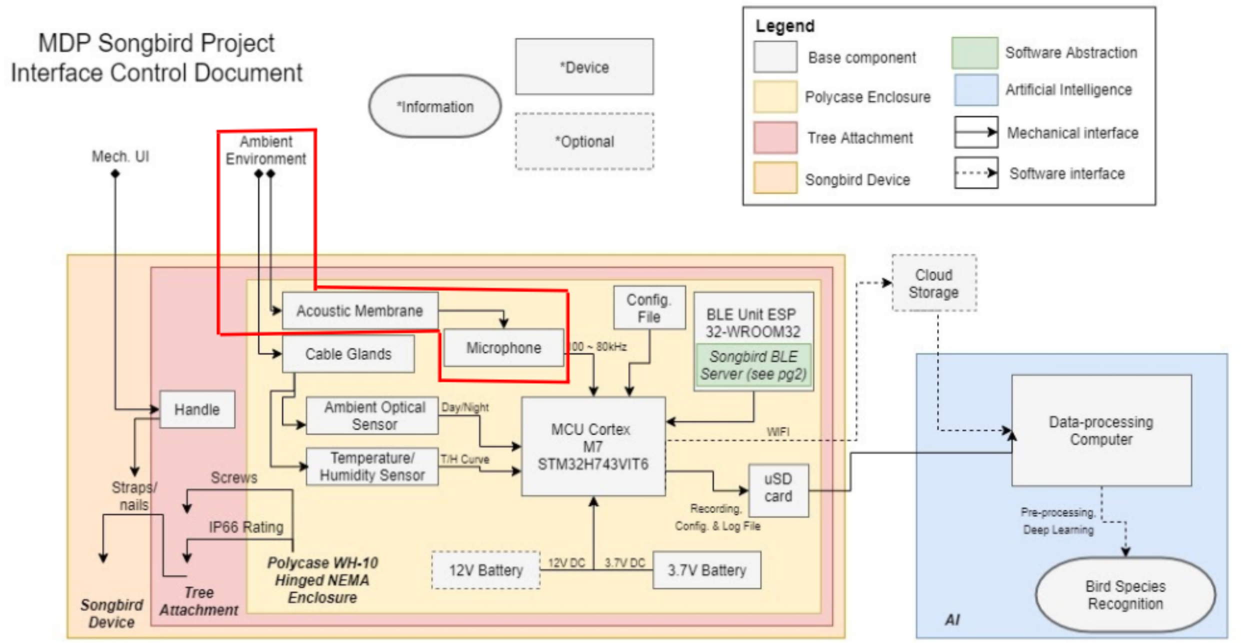


Figure 1. Interface Control Document with project scope denoted within the red box.

In addition to the project scope detailed above, the design process created for this project and informed by experiences in ME499 and ME450 provides valuable insight into the scope and flow of the project. Each major stage of the design process is shown in the diagram below, with solid arrows denoting linear flow, while dashed arrows indicate the major iteration at stages. The purple lines indicate iteration that would occur if given more time. The process is shown in Figure 2 on the following page.

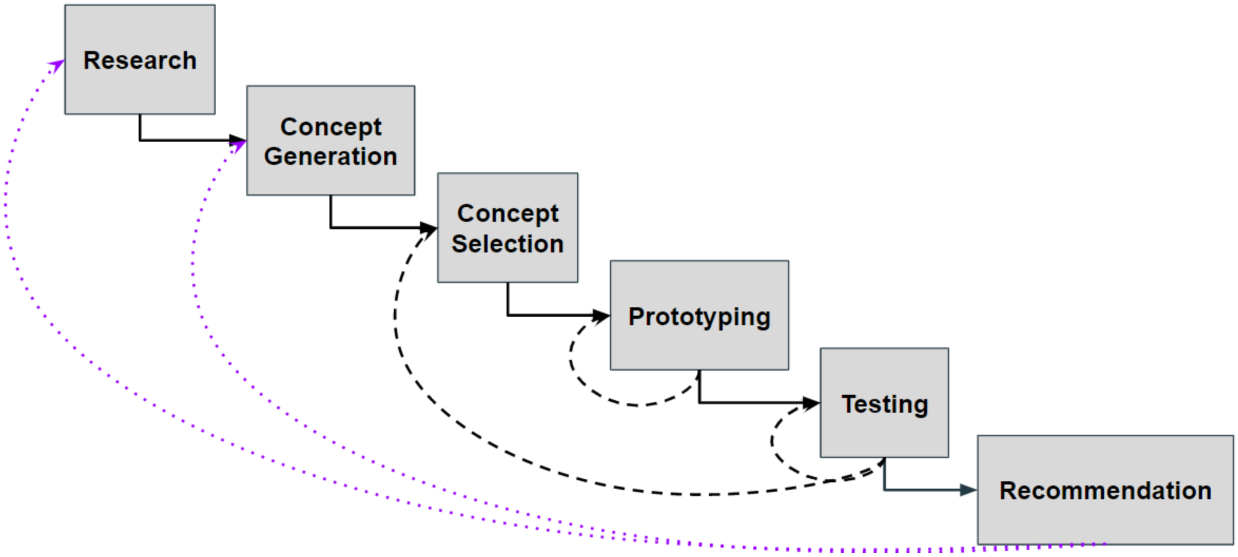


Figure 2. Project-specific design process followed during the independent study

The design process in Figure 2 also provides a high-level outline of this report, as the flow of the project is best represented by the stages followed throughout the design process of the project.

Amplifier Research

At their core, passive amplifiers increase the amplitude of audio recordings, and importantly do not require electrical power and work by increasing or focusing the sound pressure levels [1]. The main passive amplifier that is currently used, especially for wildlife recording, is the parabolic microphone. This is done by recording audio with an ordinary microphone that's boosted by a parabolic dish by positioning the microphone at the focus of the parabola [2] as the special shape of the parabolic dish collects the incoming sound waves and focuses it onto a single point (at the focus of the parabola) [3]. This reflection and focusing effect is demonstrated in Figure 3 below.

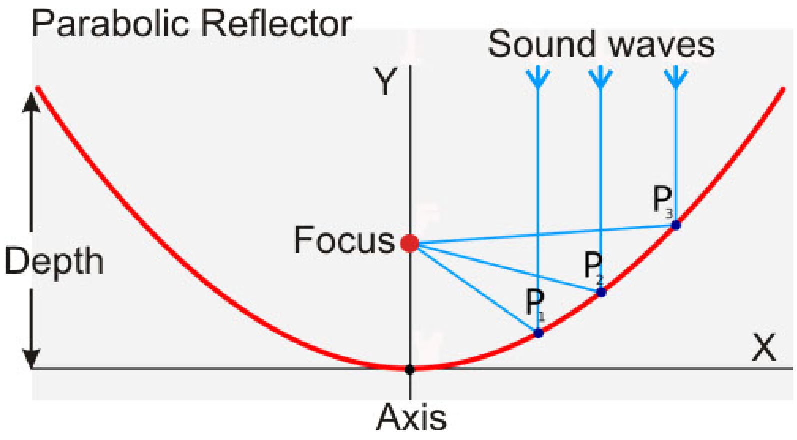


Figure 3. Diagram of the reflecting and focusing functionality of a parabolic microphone [4]

Generally, the performance of a parabolic microphone depends on its physical diameter, specific shape, focal point and depth, and microphone quality. It is crucial that the microphone is located at the parabola's focal point as shown above, to maximize gain and frequency response [4]. This position can be calculated by comparing the parabola equation with the equation of the focus: $y = ax^2 + b$ and $focus_y = \frac{1}{4}a$. Proportionally, the larger the parabola, the lower the frequency response while smaller parabolas will have a higher frequency response [4].

Using a parabolic microphone has its advantages and drawbacks. They can provide significant amplification of a target sound with the potential for creating high-quality recordings with a high signal-to-noise ratio. Effectively, parabolic mics bring a target brid closer when it is impossible to be physically near the bird [5].

Challenges with a parabolic microphone include difficulties with size while attempting to generate a low frequency response in addition to an inherent amplification of higher frequency sounds slightly more than lower frequency sounds.. Additionally, parabolic microphones are extremely directional and can be difficult with moving subjects, producing inconsistent signals when a target bird moves frequently. It is also difficult with a parabolic microphone to equally record all members of a group of vocalizing birds [5].

This research was used to inform concept generation and a general understanding of passive sound amplification, especially with wildlife recording.

Concept Generation

Due to the extensive use of parabolic microphones in the field currently, this information was used to generate concepts that utilized the parabolic equation. However, with the challenges as noted in the previous section, various other concepts were generated that attempted to utilize the idea of channeling sound waves to a specific point. Due to the short timeline between concept generation and a desire to begin testing, nine concepts were generated in an individual brainstorming session. Figure 4 on the next page displays sketches of all nine concepts, with three examples that are labelled and discussed further below the figure.

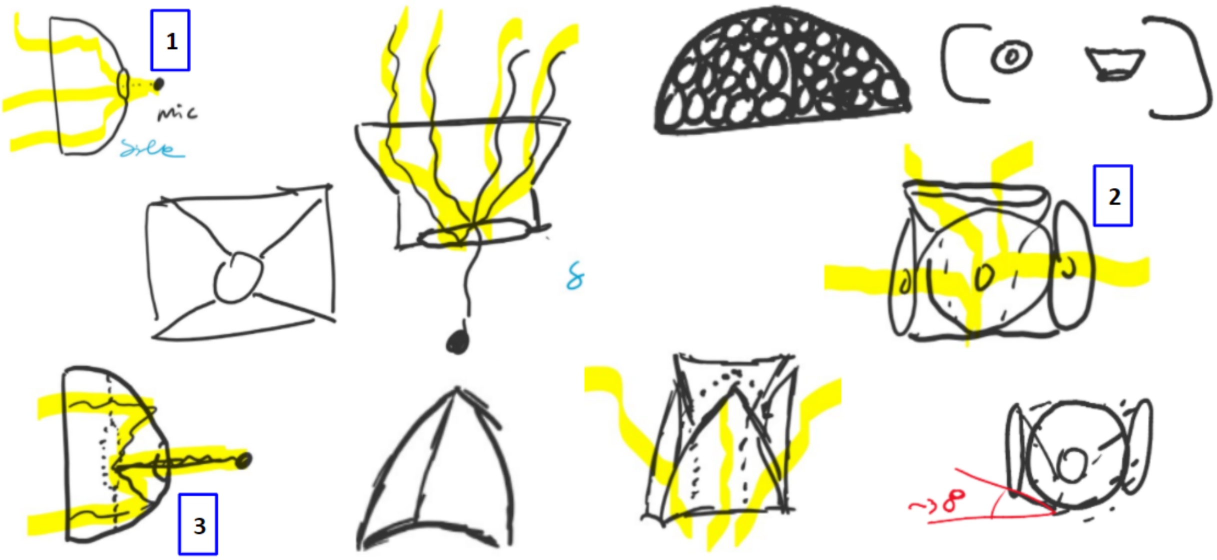


Figure 4. All nine concepts generated for the first round of concept filtering

Concept (1) → This concept is based off of the parabolic microphones that were heavily prevalent in passive audio amplification research. It is designed to have the focus of the parabola at the location of the microphone inside of the enclosure to maximize the reflecting and focusing effect of the parabolic shape.

Concept (2) → This concept is essentially a cover for the acoustic membrane with a round funnel on four sides and on the top. The intention of this design was to minimize the extreme directionality of normal passive amplifiers by placing amplifiers at multiple angles and directions to capture and focus sound waves from all around the device.

Concept (3) → This concept is also based on the research into parabolic mics, but it aims to direct sound waves with two points of reflection. Since the microphone is inside of the enclosure, the intent with this concept is to reflect sound waves to the reflector at the focus of the parabola, which will then direct the sound waves back to the microphone.

Concept Filtering

Once the nine concepts had been generated, the process moved to concept filtering with the aim of limiting the number of concepts that needed to be manufactured. This would help keep development costs low and keep the time for testing on schedule. To evaluate each concept, they were scored on a weighted scale of four criteria: Research Functionality, Complexity, Creativity, and Design Preference. Research functionality was scored based on research done at the beginning of the project to evaluate the potential of each concept based on significant findings. Researched functionality was weighted at 3 being critical for success. Complexity was scored based on the material and time required to manufacture the concept, with a high score having low complexity. Complexity was weighted at 2 for being an important contributor to success and the project goals. Creativity and design preference were aimed to create a design that stood out amongst competitors and taking into account Backyard Brains preferences respectively, with both weighted at 1 for not likely contributing to success. The scoring and results for all nine concepts can be seen in Table 1 below, with the highlighted concepts moving on to be manufactured for prototyping and testing.

Table 1. Concept filtering scoring and results - highlighted concepts moved to prototyping stage

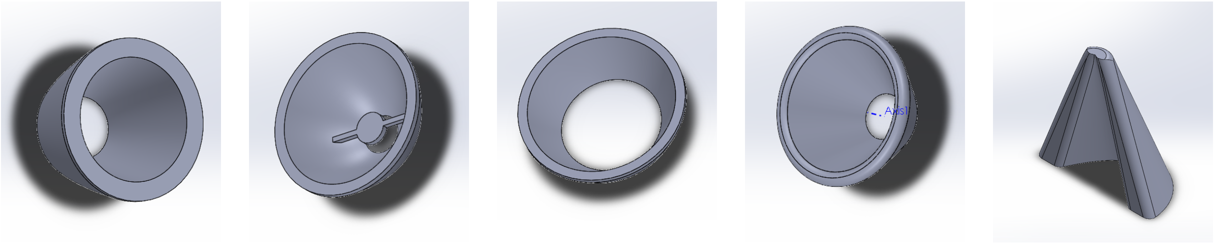
Name		**Researched Functionality**	**Complexity**	**Creativity**	**Design Preference**
	Weight →	3	2	1	1
Parabolic Mic		3	3	1	1
Parabolic Mic w Reflector		2	2	3	1
Funnel		2	3	1	0
Square Funnel		1	3	2	0
Dog's Ears		2	2	3	1
Quad Funnels		1	1	2	0
Cube Funnel		2	1	2	1
Funnel + Dog's Ears		1	0	2	0
Pockmarked Mini-Funnel		0	0	3	0

Prototyping

To begin the prototyping process, CAD models were created in SolidWorks for each amplifier. At this stage, there was also one additional concept that was added for prototyping and testing. This concept was added based off of the AudioMoth enclosure - a competing product. The basis for the design - named "Parabolic AM" for short - can be seen boxed in Figure 5 below that shows the amplifier as part of the AudioMoth case.

Figure 5. AudioMoth case with passive amplifier callout

Each of the five concepts was developed in SolidWorks with each model approximately 20mm in height. Images of the CAD models can be found in Figure 6 below.



Parabolic | Parabolic Reflector | Parabolic AM | Funnel | Dog ear

Figure 6. SolidWorks CAD models of all concepts used for prototyping

Each concept was initially manufactured using PLA with a 3D printer to confirm dimensions and the interface between the amplifier and the enclosure. An image of the prototypes produced with PLA can be seen in Figure 7 below.

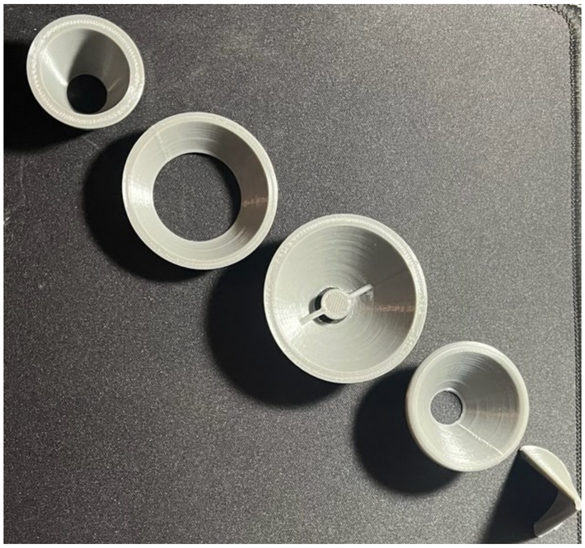


Figure 7. PLA printed prototypes of selected concepts

Once the PLA prototypes had been manufactured, concerns were raised about potential interference between the layers created during the 3D printing process and the reflection of sound waves for amplification. Due to these concerns, Kaylla Cantilina with the Center for Socially Engaged Design provided consultation for additional materials that could be used for manufacturing prototypes as well as the final design for amplifiers. All options considered were materials that were generally harder, to better reflect sound waves and limit sound absorption. These options included concrete (cast with a silicone mold), aluminum, and SLA (resin printing). As SLA is accessible and cost-effective for UM students through the Duderstadt Fabrication Studio, the next iteration of prototypes were manufactured using SLA (resin) printing. These

SLA prototypes were of the same CAD as pictured in Figure 7 above, with the only slight modification of adding fillets at the outward-facing rim of each amplifier.

Bird Call Testing

The first round of audio testing that was performed to begin concept selection was completed under the conditions described in Appendix A - Computer Testing. In this first round of testing, four different bird calls were played through the computer speakers in Duderstadt Multimedia Room 3 - olive warbler, robin, blue jay, and parrot. The first comparison was made between the peak amplitude (in dB) of the bird call recording with the device outside of the case versus the device inside of the case. The results of this comparison can be seen in Table 2 below.

Table 2. Comparison of peak amplitude (in dB) of bird call recording with/without the enclosure

	No Case	**Case (No Amp)**
Bird Call	Peak Amplitude (dB)	Peak Amplitude (dB)
Olive Warbler	-17.32	-27.01
Robin	-11.73	-22.68
Blue Jay	-20.95	-25.69
Parrot	-15.27	-24.21

As is demonstrated in Table 2 above, there is a clear amplitude difference when recording bird calls without the case and while the device is inside of the case. These results acted as further proof for the necessary development of passive sound amplification. Once this classification had been made, each amplifier was then tested with the four bird calls. The peak amplitude (in dB) recorded for each bird call with a specific amplifier was then compared to the test scenario of the case without any amplification. Then, the percent difference was calculated, and the amplifier that produced the highest, positive percent difference was determined as shown in Table 3 below.

Table 3. Amplifier used for the highest percent difference change in amplitude (dB)

Bird Call	**Max Positive %Change**	**Amplifier Used for Max**
Olive Warbler	31.14%	Funnel
Robin	42.77%	Dog Ear (Vert)
Blue Jay	14.25%	Parabolic
Parrot	17.72%	Parabolic Reflector

As is clear from the results, there was not an amplifier that clearly outperformed the others - a different amplifier performed the best for each bird call used for testing. This allowed for the determination that the bird call testing was inconclusive for concept selection but successful for verifying the functionality of each concept and the damping effect of the case. The full data for this round of testing using bird calls can be found in Appendix B - Bird Call Testing Data. To complete concept selection, the next round of testing was performed as detailed in the next section of this report.

Speaker Sweep Testing

The second round of audio testing that was performed for concept selection was similarly completed under the conditions described in Appendix A - Computer Testing. In this second round of testing, an audio sweep from frequencies of 20Hz - 20kHz was through the computer speakers in Duderstadt Multimedia Room 3. Once the recording had been made, the audio file was analyzed to yield a frequency response for each amplifier for the range played in the audio sweep. The frequency response of each amplifier compared to both the no case scenario and the case without amplification scenario can be seen in Figures 8a-f.

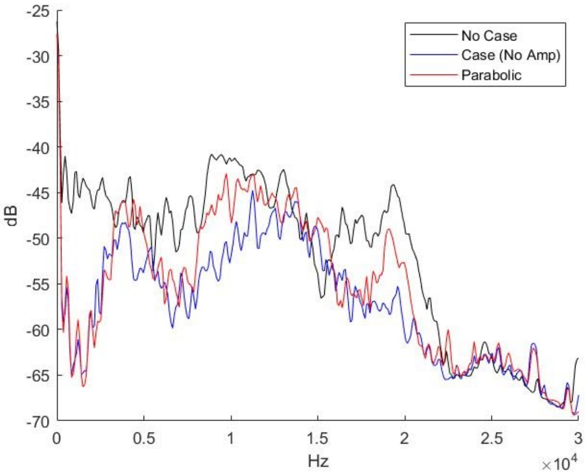


Figure 8a. Parabolic frequency response

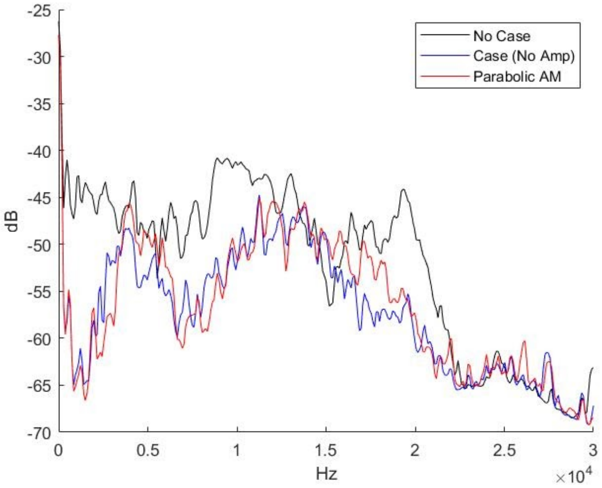


Figure 8b. Parabolic AM frequency response

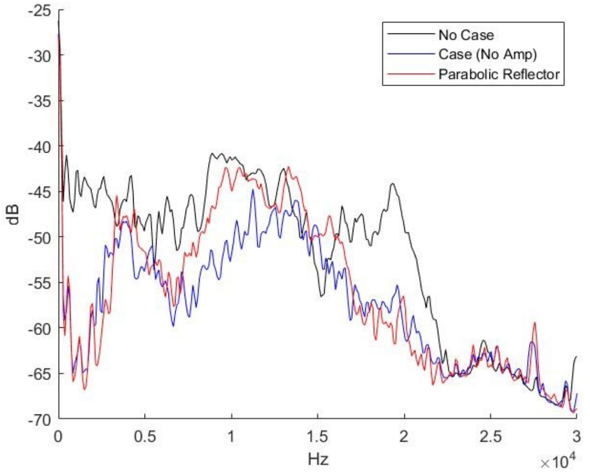


Figure 8c. Parabolic reflector frequency response

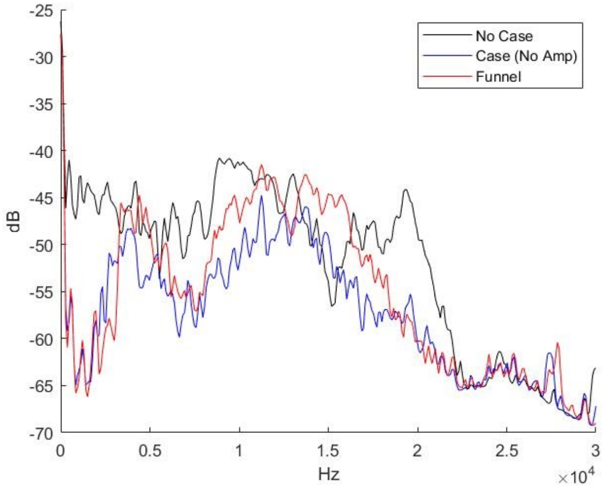


Figure 8d. Funnel frequency response

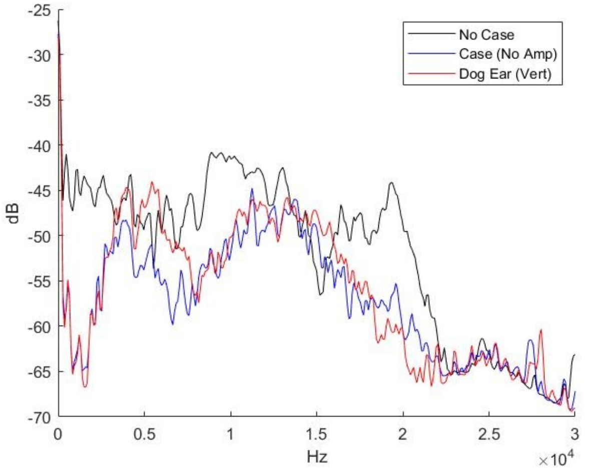


Figure 8e. Dog Ear (vertical) frequency response

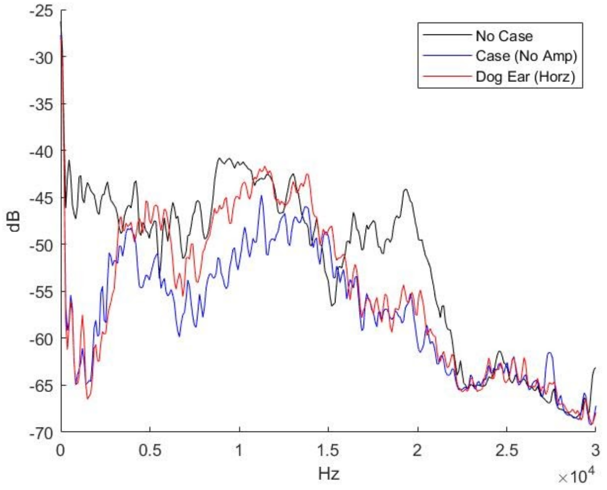


Figure 8f. Dog Ear (horizontal) frequency response

Once the frequency response of each amplifier had been generated as seen in the figures above, the amplifier concepts were then selected based on visual inspection of a concept's frequency response when compared to the scenario with the enclosure and no amplification. Backyard Brains was consulted during this selection process to ensure that the company deemed the performance of the selected amplifiers acceptable. The three concepts that were selected to move on to final testing were the parabolic amplifier, the funnel amplifier, and the dog ear amplifier in a horizontal orientation. An image of each of these selected concepts can be seen on the next page in Figures 9a-c.

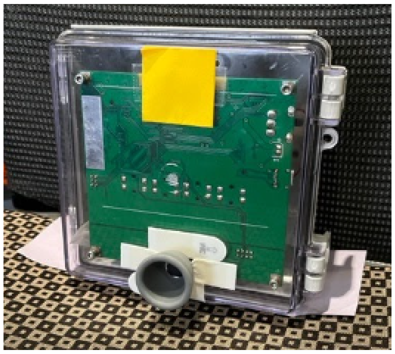


Figure 9a. Parabolic amplifier

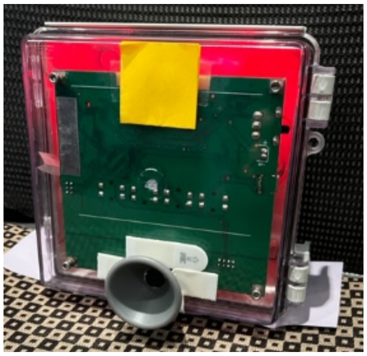


Figure 9b. Funnel amplifier

Figure 9c. Dog Ear amplifier in horizontal orientation

Function Generator Testing

The three selected concepts were then used to perform a third and final round of audio testing completed under the conditions described in Appendix C - Function Generator Testing. An audio sweep was played from a speaker connected to the function generator that swept from 10Hz - 40kHz. This range was requested by Backyard Brains and allowed for a full classification of the amplification performance for a wide range of frequencies. The audio files from this round of testing were again used to produce a frequency response for each amplifier, however the data used to compare amplifiers was the change in dB between each respective amplifier and the scenario using the enclosure without amplification. This allowed for the amplifiers to be compared directly to one another on the same graph - seen in Figure 10 below.

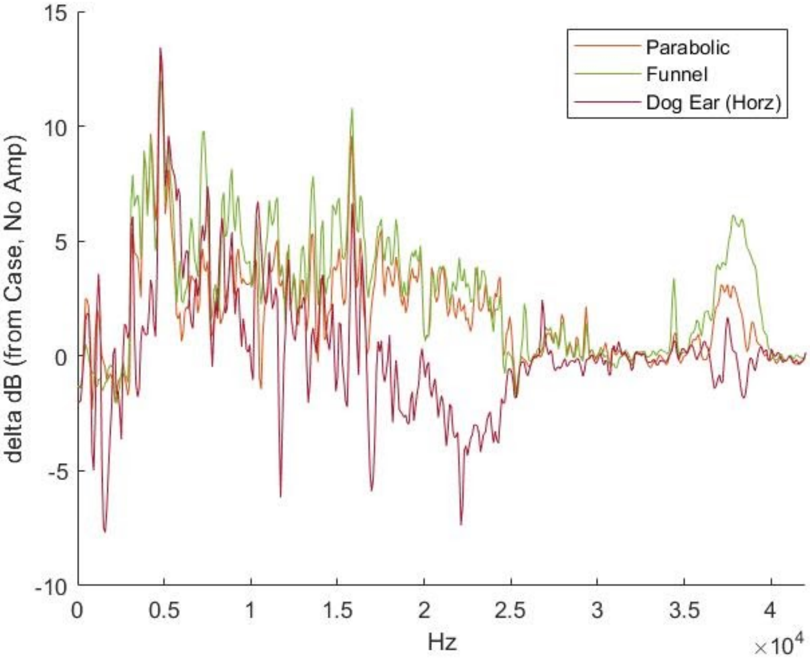


Figure 10. ΔdB between each amplifier and the case without amplification

The comparison seen in the figure above provided sufficient information to perform a visual comparison between the ΔdB response of each amplifier, with agreement from Backyard Brains that the funnel amplifier was the concept that performed the best during the function generator testing, and therefore was the best performing amplifier. For reference, the frequency response of the testing scenarios can be found in Appendix D - Function Generator Testing Frequency Response Graphs.

Conclusion and Recommendations

After following the design process displayed in Figure 2 on page 5 with the culmination of function generator testing displayed in Figure 10 on page 13, I can confidently recommend that the funnel amplifier be used for the Backyard Brains recording device. The funnel amplifier is the highest performing concept that was manufactured and tested during the timeline of this project. The funnel amplifier can be seen attached to the final deliverable in Figure 11 below.

Figure 11. Final MVP with the funnel amplifier that was delivered to Backyard Brains

If given more time with this project, I would advise to first investigate additional amplifier concepts, specifically testing multiple iterations of a parabolic amplifier with different values in the parabolic equation. Along with further concept generation, I would be extremely interested to classify the performance of multiple amplifiers during field testing with various environments and target bird species. Finally, I would investigate attachment methods for the amplifiers to be easily removable. Adhesive 3M Command Strips were used in testing and for the MVP, however this method may not be viable for extensive use in the field. The development of attachment methods for the amplifier was not completed due to time constraints.

Although there are further stages and additional iteration that can be completed for this project, the main goals of the project as listed on pages 2 and 3 of this report were accomplished.

Acknowledgements

I would first like to thank Professor Shanna Daly for her mentorship throughout the semester. Additionally, I would like to thank Robert Loweth for his weekly help with each step of the Passive Sound Amplification Project.

Thank you to Lin Van Nieuwstadt for her mentorship during the entire Backyard Brains Project and her consistent feedback and assistance throughout the independent study.

Thank you to my MDP Team - Andrew Cao, Noah Lichtenberg, Kane Sweet, Igor Veklenko, Kefan Zhou - for their assistance with this independent study as well as their incredible work with the entire Backyard Brains project.

Finally, I would like to thank the Backyard Brains team - Greg Gage, Wenbo Gong, and Miroslav Nestorovic - for their support, assistance, and trust in the work of students.

References

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Appendix A - Computer Testing

The computer testing - bird call and 20Hz - 20kHz audio sweep - was completed in the Duderstadt Library Multimedia Room 3. The testing conditions and images of the testing setup are compiled in this appendix. Each amplifier was attached to the enclosure using 3M Command Strips. An example of this enclosure setup is seen below in Figure A1.

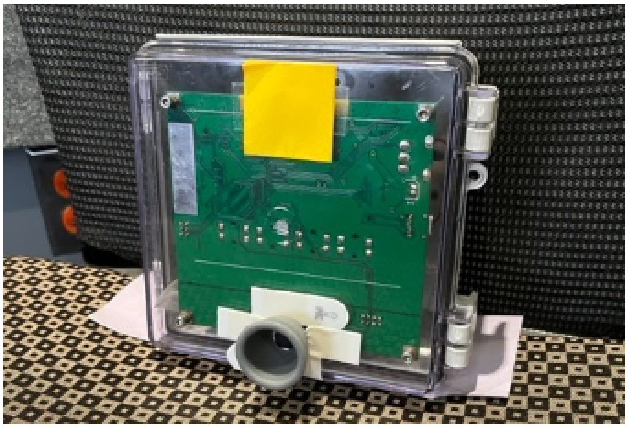

Figure A1. Example enclosure setup for parabolic amplifier

Table A1. All device settings for computer testing

Device Settings	*Computer Settings*	*Speaker Settings*
- Sampling rate = 96kHz - 1 SD card used	- Volume 50%	- Volume -18dB

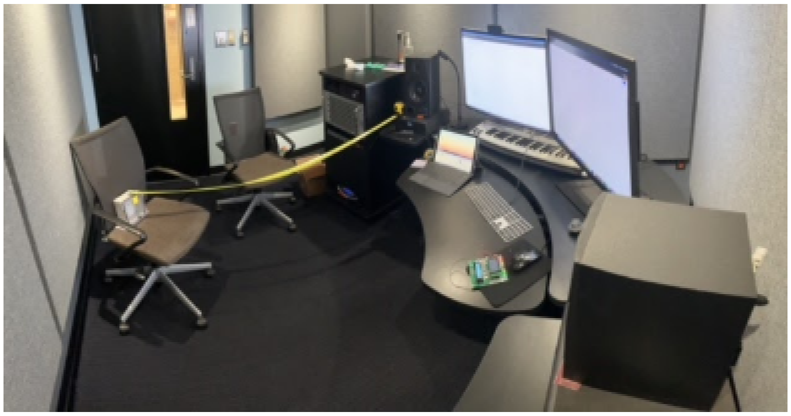

Figure A2. Full testing setup in Multimedia Room 3 - distance between speakers (69 in.)

Figure A3. Enclosure distance from left speaker (68 in.)

Figure A4. Enclosure distance from right speaker (66 in.)

Appendix B - Bird Call Testing Data

The full bird call testing data and values are reproduced below in this appendix. The values were utilized to calculate the maximum positive percent change that is detailed on page 10.

Table B1. Comparison of peak amplitude (dB) with no case versus case without amplification

	No Case	**Case (No Amp)**
Bird Call	Peak Amplitude (dB)	Peak Amplitude (dB)
Olive Warbler	-17.32	-27.01
Robin	-11.73	-22.68
Blue Jay	-20.95	-25.69
Parrot	-15.27	-24.21

Table B2. Peak amplitude (dB) matrix for all amplifiers tested with each bird call

	Parabolic	**Parabolic AM**	**Parabolic Reflector**	**Funnel**	**Dog Ear (Vert)**	**Dog Ear (Horz)**
Bird Call	Peak Amplitude (dB)	Peak Amplitude (dB)	Peak Amplitude (dB)	Peak Amplitude (dB)	Peak Amplitude (dB)	Peak Amplitude (dB)
Olive Warbler	-19.56	-21.01	-22.9	-18.6	-18.97	-20.43
Robin	-15.54	-18.03	-18.14	-16.2	-12.98	-15.83
Blue Jay	-22.03	-23.78	-23.57	-23.39	-23.81	-25.3
Parrot	-21.73	-24.45	-19.92	-21.96	-23.03	-21.4

Table B3. Maximum positive percent change for each bird call and amplifier used for result

Bird Call	**Max Positive %Change**	**Amplifier Used for Max**
Olive Warbler	31.14%	Funnel
Robin	42.77%	Dog Ear (Vert)
Blue Jay	14.25%	Parabolic
Parrot	17.72%	Parabolic Reflector

Appendix C - Function Generator Testing

The function generator testing with the 10Hz - 40kHz audio sweep was completed in the Duderstadt Library Multimedia Room 3. The testing conditions and images of the testing setup are compiled in this appendix. Similar to computer testing, each amplifier was attached to the enclosure using 3M Command Strips, an example of which is shown below in Figure C1.

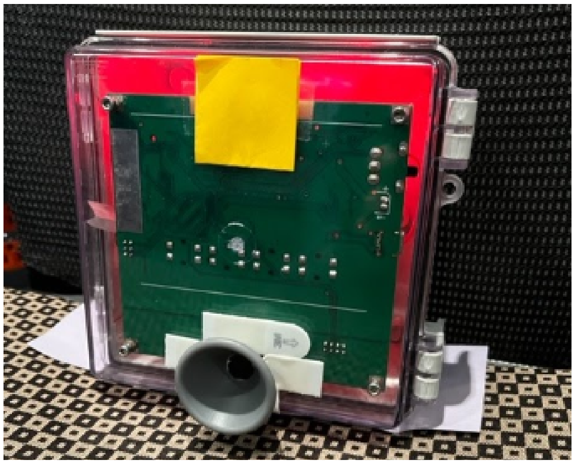

Figure C1. Example enclosure setup for funnel amplifier

Table C1. Function generator settings sued for testing

V_{RMS}	*Frequency Range*	*Sweep Duration*
1.5V	10Hz - 40kHz	15s

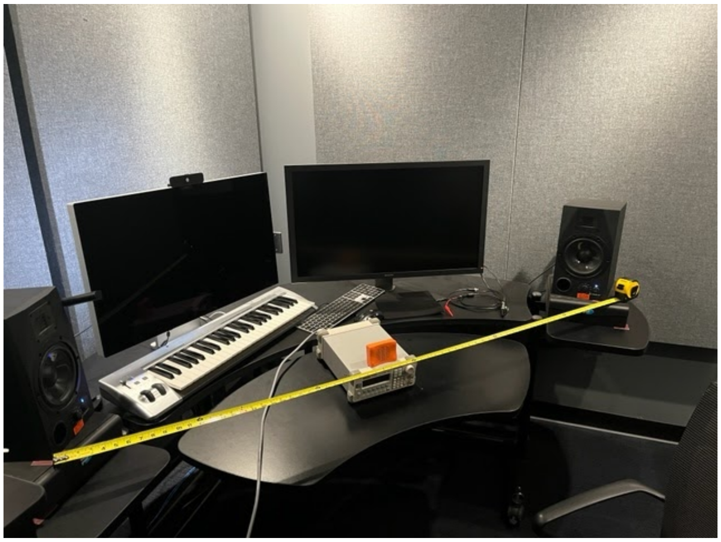

Figure C2. Function generator setup on the desk - 68in. distance between computer speakers and function generator + orange speaker positioned 34in. from right speaker

Figure C3. Enclosure is placed at the location of the tape measure - 64 in. from function generator + orange speaker

Appendix D - Function Generator Testing Frequency Response Graphs

This appendix compiles the frequency response graphs from the function generator testing. The graphs in Figures D1-4 below were used to calculate the ΔdB graphed in Figure 10 on page 13.

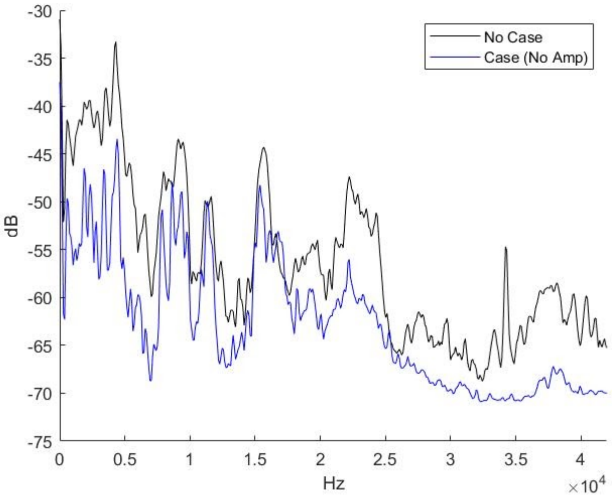

Figure D1. Frequency response of no case versus case without amplification

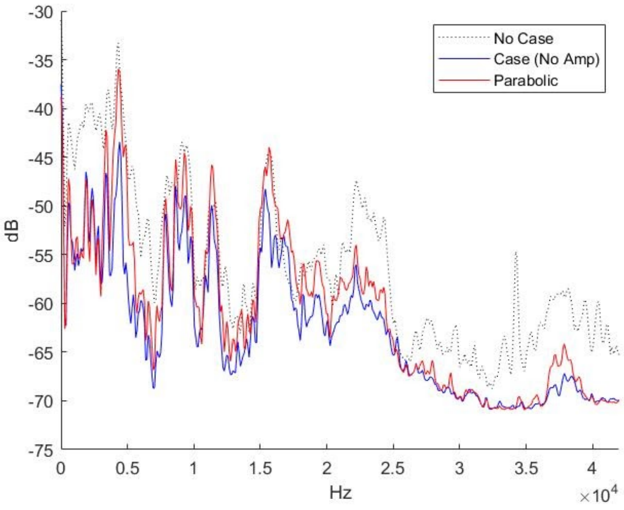

Figure D2. Frequency response of the parabolic amplifier compared to case without amplification

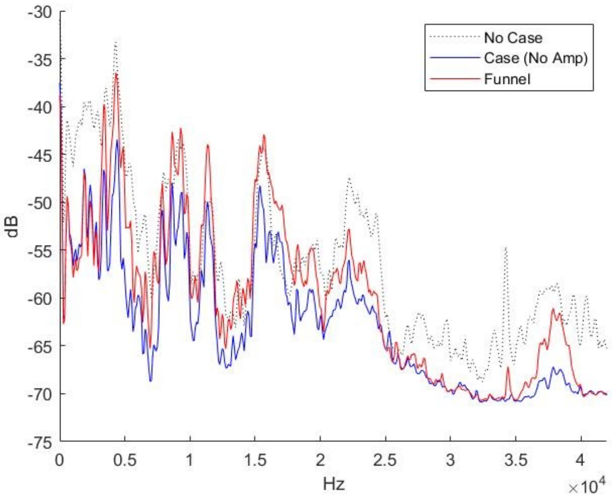

Figure D2. Frequency response of the funnel amplifier compared to case without amplification

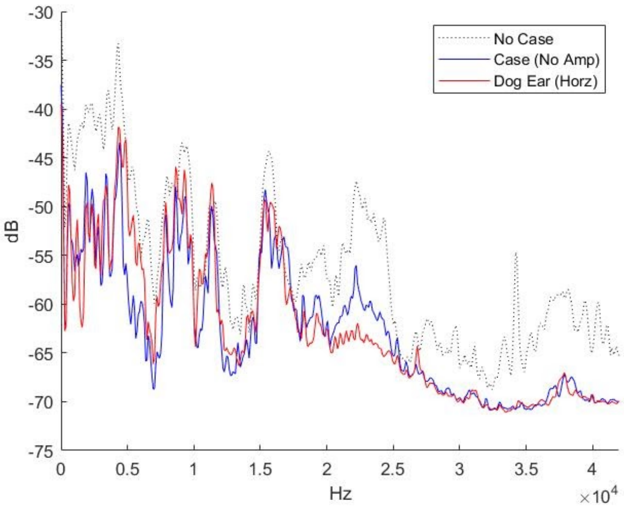

Figure D2. Frequency response of the dog ear amplifier compared to case without amplification