Formi: A New Age of Music Listening

ECE 445 Design Document

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10/1/19

1 Introduction

1.1 Problem and Solution Overview

With Americans spending on average 4.5 hours per day listening to music, it is no doubt that we love music. [1] In fact, it has been used as a stress reliever for hundreds of years yet each modern speaker, headphone, etc optimizes for a limited range of music dictated by its sound signature.[2] [3]

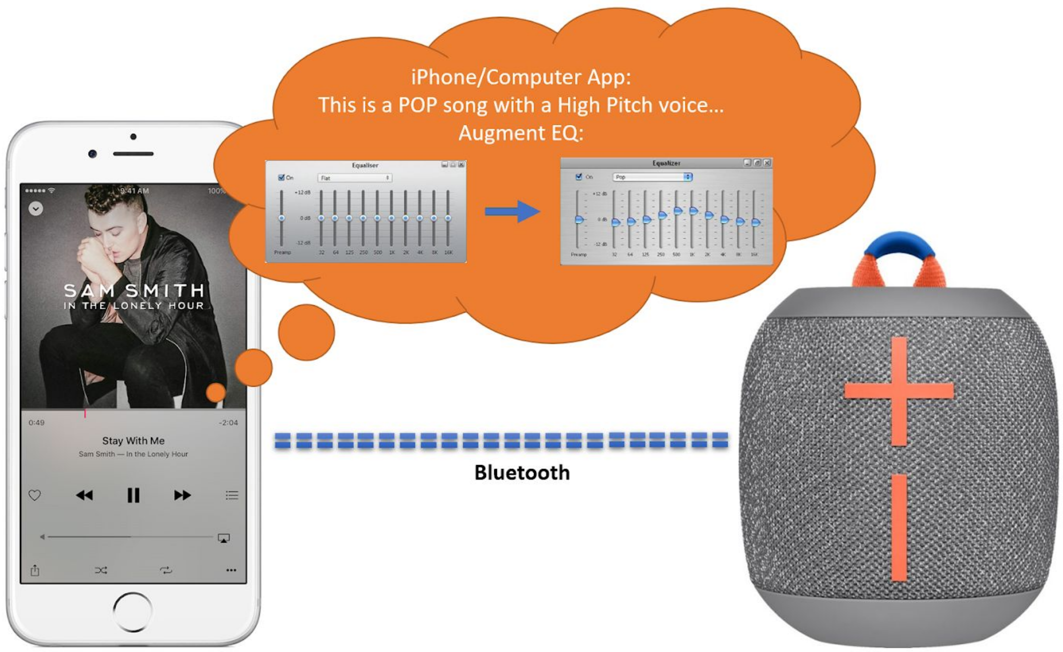
Sound signature emanates from two elements:

1) Programmed equalization in the DACs (Digital to Analog Converters)
2) Circuit Components

As avid music listeners, we recognized this common problem that many musicians and music lovers alike have faced. In order to enjoy a wide and varied range of music genres, people have to buy multiple high-end headphones. This can become quite costly with the price of high end headphones ranging from eighty dollars to over three-hundred dollars. With every headphone having different sound signatures, each one works best for a specific genre or use case and may even cause fatigue when mismatched. This is especially troubling if you love multitudes of music genres, compose or record music. Concurrently, modern pop music is incorporating multiple genres into one. With artists like Lil NasX, Billy Eilish, and Twenty One Pilots all in one genre, the differences in sound can be quite extreme.

Our solution targets all of these elements by optimizing circuit components for adaptability and utilizing a baseline/neutral DAC equalization setting. Building on this, we will create a computer/phone (with Bluetooth connectivity) application that augments equalization based on the music playing. For example, it would analyze *Old Town Road* and make certain EQ parameter decisions based on the musical/signal qualities of the song itself in this case the vocal range. [4] The goal of the hardware portion is to create a Bluetooth based music reproduction system that is uniquely adaptable to a wide range of genres. Concurrently, the goal of the software portion is to create an application that can make EQ decisions dynamically based on song attributes such as genre and characteristic such as a singer's range driven by ML. With a successful POC, our solution has the potential to shape the music listening industry by helping audiophiles, artists, producers,etc. save money(no need for multiple headphones) and enhance the music listening experience for all music lovers. Concurrently, this technology has additional prospects in enhancing tangential experiences such as movies to immersive ones such as AR/VR.

1.2 Visual Aid



1.3 High-Level Requirements

- [1]The device must take musical data in through bluetooth signals and transform it into analog signals that must be played on the POC speaker.
- The software must be able to dynamically change EQ based on file embedded (basic) genre and [2]ML derived genre/characteristics at 70% accuracy.
- [2]The software must exhibit an equalization change through means of a dB vs frequency or a spectrogram (must be transferred to our device).

Footnotes:

[1] Characteristics can differentiate types of genres. (i.e. high pitch vs low pitch singers)

[2] EQ or Equalization augmentation can be detected as change in decibels over frequency.

2 Design

2.1.1 Hardware Block Diagram

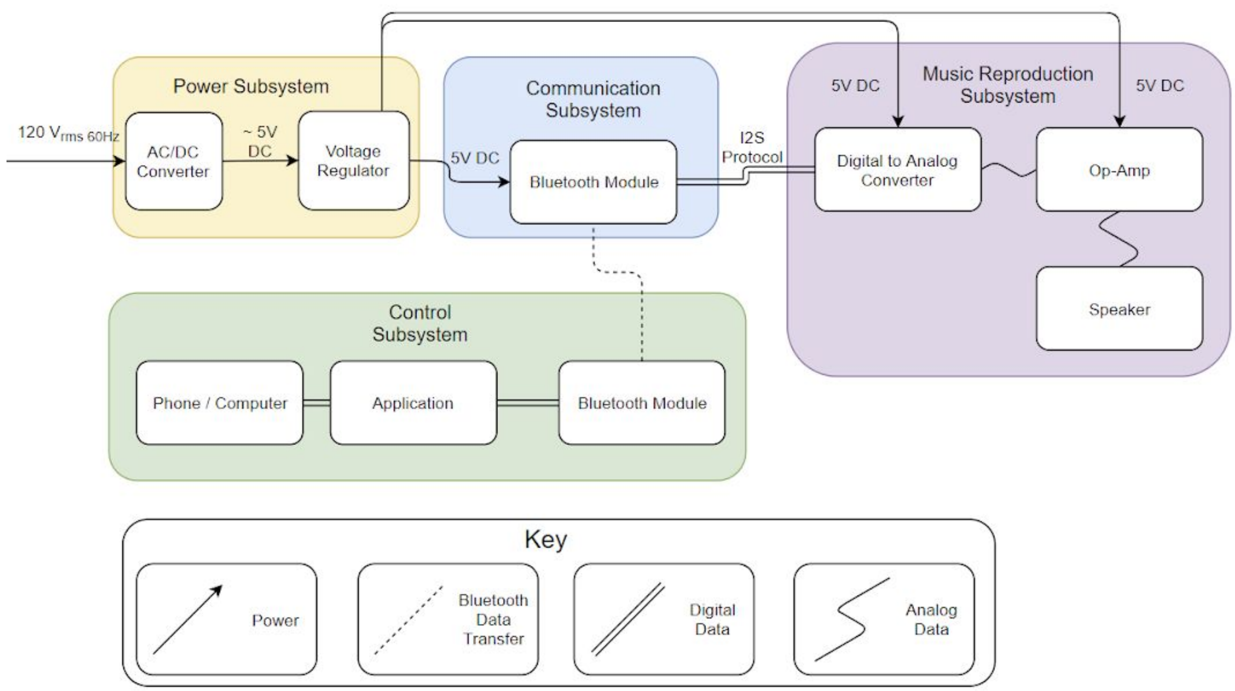


Fig 1. Hardware Block Diagram

Above, we can see that wall power is sent to the AC-DC converter (power subsystem) and, subsequently, the voltage regulator ensuring a safe 5V DC to power subsequent components. After conversion, power is sent to all other PCB components (including Communication and Music Reproduction Subsystem(sans Speaker which will be connected to terminals on the PCB)). The song is chosen, analyzed and augmented with chosen EQ within the control subsystem. Then, it is sent digitally to the Bluetooth module, converted to an analog signal through the DAC, and finally sent to the Op-Amp/Speaker.

2.1.2 Software Block Diagram

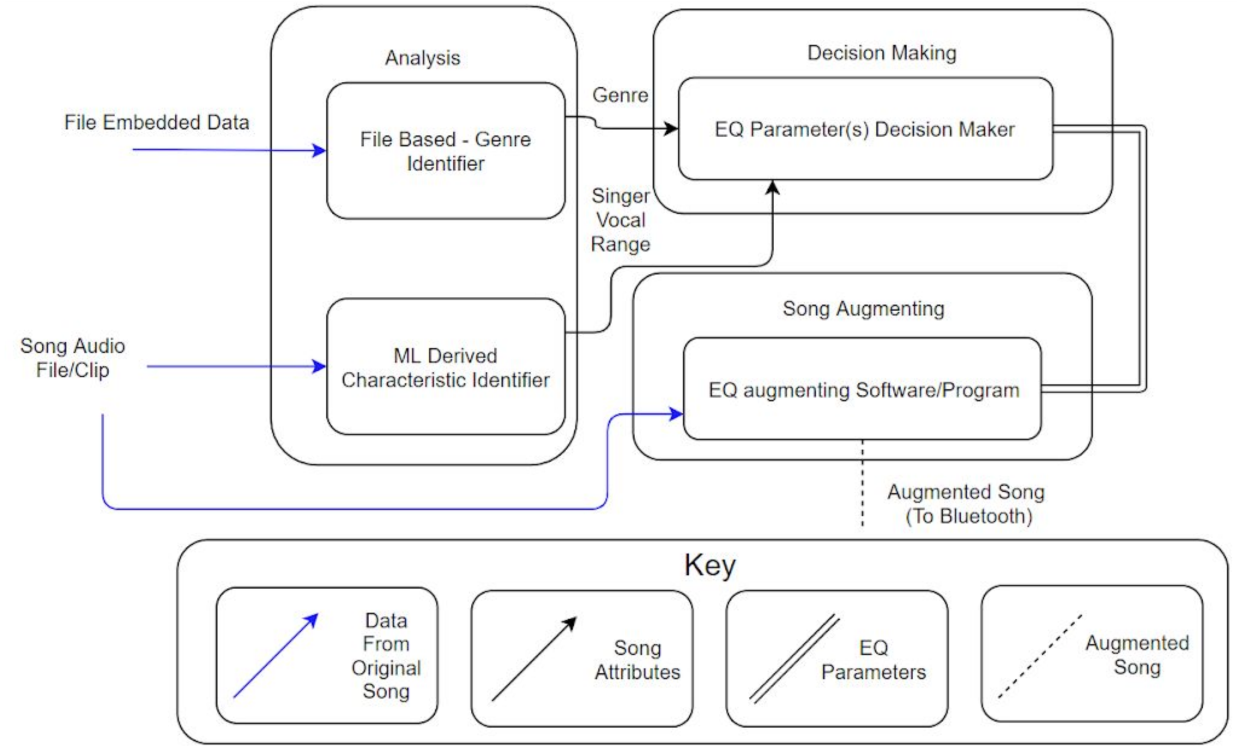


Fig 2. Software Block Diagram

*Above, we can see the high level outline of the software portion of the project. There are two key data elements from the song we want to play that are required: 1)Song/Audio Clip 2)file embedded data. The file embedded data is run through the "File Based - Genre Identifier" to output a genre to the "EQ parameter decision maker." Concurrently, the song's audio is analyzed by the ML algorithm to determine the vocal range of the singer. With both these inputs, the "EQ parameter decision maker" makes decisions on the EQ parameters and outputs it to the "EQ augmenting Software/Program" where the EQ parameters are applied to the original song clip and outputted to the Bluetooth module for playback.

Footnotes:

[1] This block diagram only refers to the end result of the software portion of the project and does not make any inferences on programs or software needed for creating, analyzing the data set or training the ML Algorithm.

2.2 Physical Design

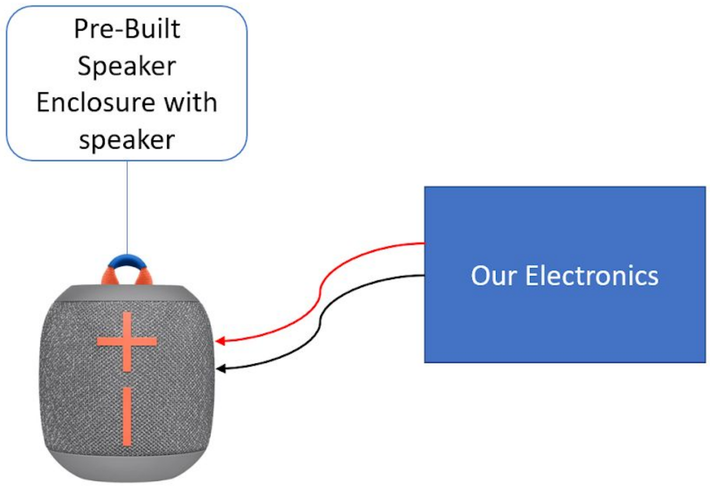


Fig 3. Physical Design Sketch

To alleviate the demands of fine-tuning the physical speaker design, we will use a pre-existing speaker and speaker enclosure setup with pre-tuned acoustics which will connect to our PCB (Printed Circuit Board). Our PCB will be connected to wall power to optimize current powering the speaker and long testing cycles when fine-tuning EQs. Since the control subsystem is a preexisting digital device, i.e. phone or computer, which communicates through Bluetooth to our PCB/electronics, we have not included it in our physical design.

2.3.1 Power Subsystem

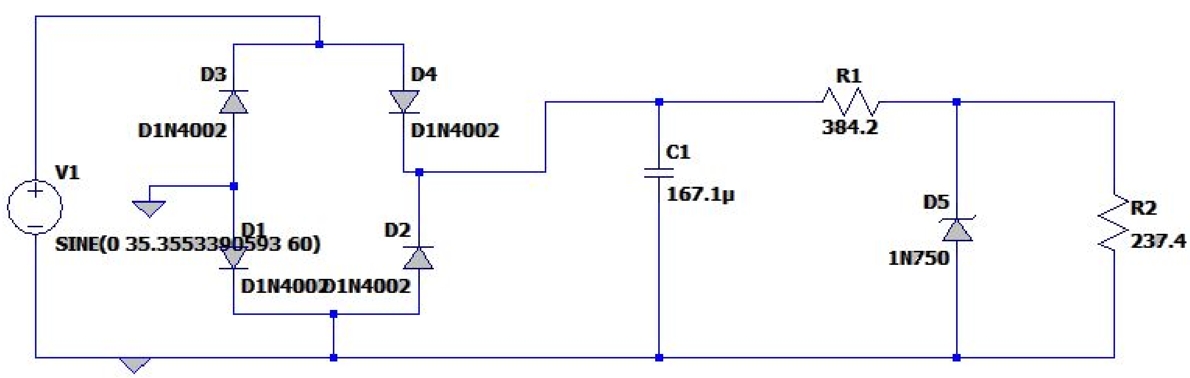


Fig 4. AC-DC converter and Voltage regulator

In figure three is our design for both the AC-DC converter and voltage regulator. What should be noted as well is there is a 5:1 transformer between the input from the wall source and the input to the circuit shown above. This circuit takes a 120 V at 60 Hz and successfully transforms it into anywhere from 4.7 to 4.95 VDC depending on the load resistance. This is mandatory because the DAC, Bluetooth and OP-AMP can be all powered by 3.3 VDC - 5 VDC.

Requirements	Verification
1. Output voltage must be regulated from 4.5 V to 5 V. 2. Output Current cannot exceed 57.5 mA.	1. Observe output voltage on an oscilloscope to ensure voltage remains between 4.5 and 5 V. Change output load from 100 ohms to 1000 ohms in increments of 100 ohms. 2. Observe output current on the oscilloscope to ensure current does not exceed 57.5 mA. Change output load from 1000 ohms to 100 ohms in increments of 100 ohms.

2.3.2 Communications Subsystem

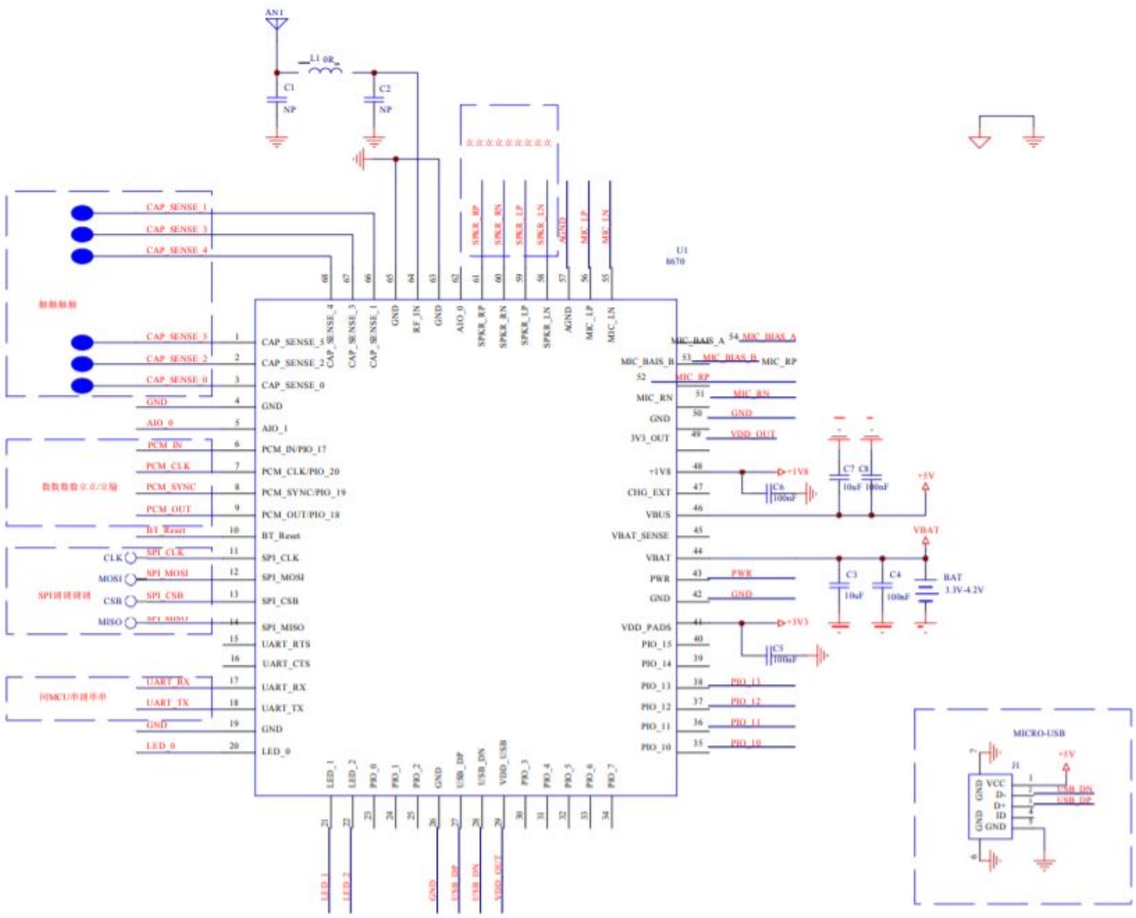


Fig 5. Bluetooth IC

The bluetooth module takes a signal from a computer or phone and then send a digital signal to the DAC. This module allows for wireless signal transferring and as a bonus allows us to bypass the DACs on computers and phones ensuring that the signal is unaltered by any other components other than ours.

Requirements	**Verification**
1. This module has to be able to take a signal from a phone and/or computer and then send that signal from its output.	1. This can be verified using a single tone signal from either a computer or a phone and then using an oscilloscope to measure the output of the bluetooth module allowing us to see if the signal

	was transferred correctly.

2.3.3 Music Reproduction Subsystem

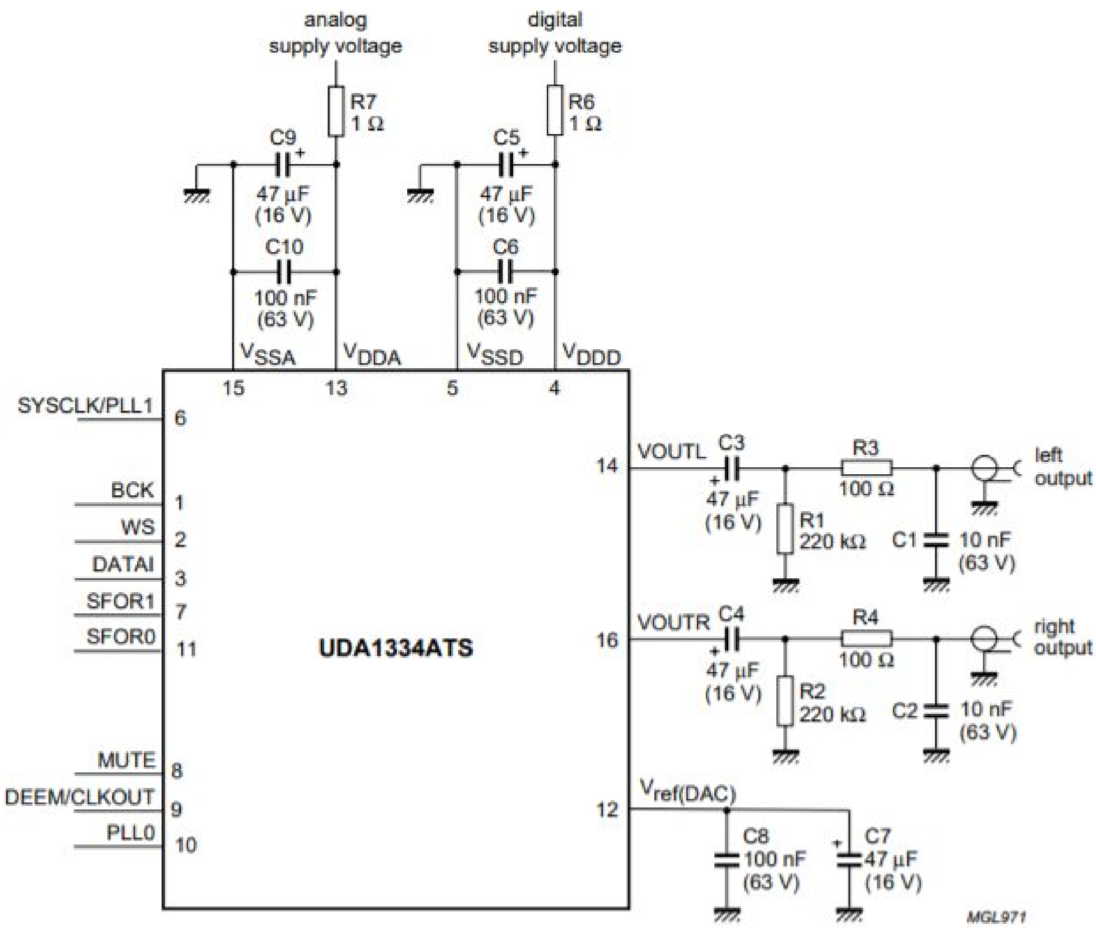


Fig 6. DAC

This component takes into its input the digital signal from the bluetooth module and outputs the analog data to be sent to the amplifier. This is important because in order for music to be played from the speaker it has to be changed from digital data into analog since the speaker will only play the analog signal correctly. [10]

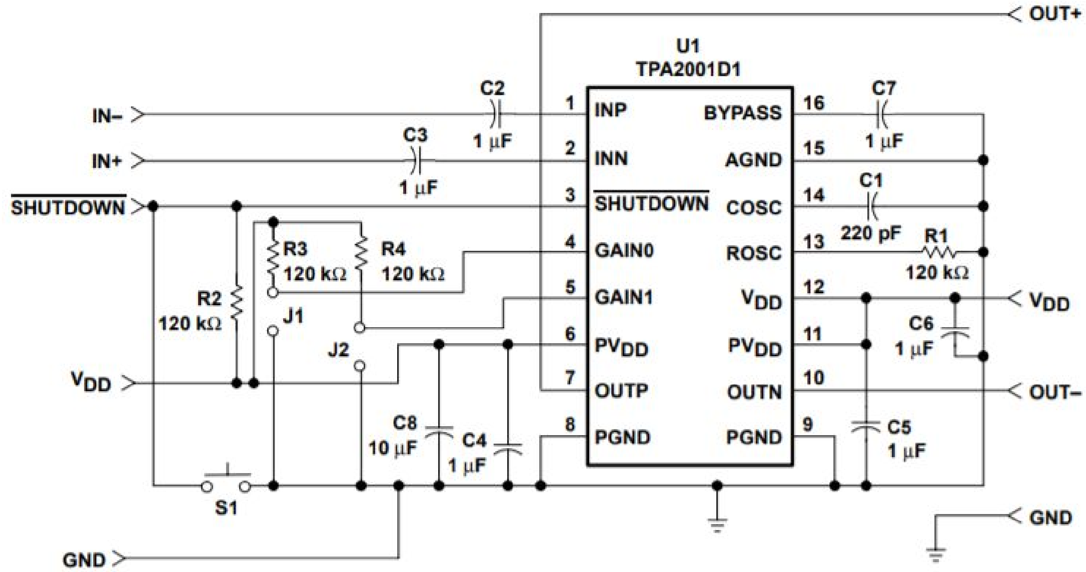


Fig 7. Class D Operational Amplifier

The operation amplifier would take the analog signal produced from the output of the digital to analog converter and then amplify the signal to be sent to the speaker. Without this component, the signal would not be strong enough to produce a recognizable volume from the speaker. The speaker is the final piece. The speaker takes the amplified analog signal from the operational amplifier and then transmit that energy into vibrations that produce sound waves.

Requirements	Verification
1. The DAC has to convert a digital signal into an analog signal correctly. 2. The operational amplifier has to be able to produce 1 watt of power for an 8 ohm load. 3. The speaker has to audibly play sound from an analog signal.	1. Using an oscilloscope on both the input and output of the DAC and sending in a periodic steady state digital signal, we can observe the output and compare to the predicted waveform. 2. Placing an 8-ohm load as the output of the operational amplifier, we can use a wattmeter to measure voltage and current through the load to ensure that 1 watt of power is produced.

	3. Simply sending in a sufficiently powered analog signal should produce an audible result from the speaker.

2.3.4 Control Subsystem

The control subsystem is a software-based subsystem residing as a program on a phone or computer. This subsystem is software that using both basic codes to identify genre in conjunction with machine learning to correctly identify the vocal range of the singer and change the equalization of the signal that is to be sent to the Bluetooth module. As well, this subsection demands high volumes of training data sets in order for the ML to make correct decisions.

Requirements	**Verification**
1. This must correctly identify the vocal range/characteristics of a song. 2. Also, it must change the equalization of the signal depending on the genre. 3. The machine learning aspect of code must be at least 70% accurate.	1. This can be tested by displaying the vocal range/characteristic identified and compared to the range prescribed by determining the highest and lowest notes that the singer sang manually. 2. The software will include a graphing function that will take the output of the program and either plot it in a spectrogram of a dB vs frequency graph to illustrate the change made. 3. Using controlled test cases and using a print function in the code will allow us to use a simple true/false result system and then computing the effectiveness of the system.

2.4 Tolerance Analysis

The subsystem with the greatest risk for failure is the control subsystem/software portion. A huge portion of the risk is the need of using ML to make rapid decisions to augment EQ. The two main concerns are 1) The Data Set and 2) Training the Algorithm.

2.4.1 The Data Set

From a layman level, more data points means the ML algorithm can make more accurate decisions. However, we cannot be sure of the exact amount of data points needed for critical success because of two main factors: the complexity of the decision to be made and the complexity of the learning algorithm. [14]

To create our data set, there are three methods for classifying the audio files. One classifying method is manually labelling all songs by a certain artist as having a certain vocal range. The second method is to programmatically filter and,subsequently, analyze the vocal range from a plethora of songs to label it accordingly. This can be done by a unique trick we call "anti-karaoke" method since it utilizes the opposite of karaoke song creator program to just obtain the vocal elements from a song. Then, we can analyze the vocals and classify the song to as identified vocal range. The third method is simply finding notated music sheets and finding the highest and lowest vocal notes to label song with identified vocal range.

While we will use a combination of all methods, the second method is uniquely formidable for its programmatic nature. However, there are some key hurdles we have identified. For the second method, we tried two programs to isolate the vocals from the rest of the song. One was Audacity and another was an open source python code. The results from the audacity separation were of much higher quality than those from the python program. In this case, quality refers to noise levels in the song as well as the instrumentation that was left in the song after separation. This shows that there can be some error even within creating the data sets needed for the next section.

2.4.2 Machine Learning

In order to ensure that at least 70% of our ML decisions are correct we will use the following formula to determine its accuracy:

(Correct Decisions)/(Total Decisions) x 100% = Success Rate

To ensure we do not design a classifier that overfits to the trained data, our testing songs will not overlap with songs used to train the algorithm.

Prior to choosing what characteristics our ML algorithm will use as features, we will examine our data set manually with the following feature extractions and data visualizations:

- Waveform of time vs. amplitude
- Spectogram of time vs. frequency
- Zero crossing rate
- Mel-frequency cepstral coefficients

3 Cost and Schedule

3.1 Cost Analysis

Assuming that a competitive salary would be approximately \$35/hr and that we will spend 12 hrs/week on this project individually, an approximated labor cost can be calculated as such:

2 People x 2.5 x \$35/hr x 12 hrs/week x 16 weeks

= \$33,600

The total cost for our labor for this project can be estimated to be \$33,600. Comparing this the average value for an electrical engineering graduate at \$67,000 and calculating a yearly salary for this project, we would get \$108,387. This is greater than the typical starting salary, but given that we are the engineering, marketing and research team, we feel as though this is a fair salary.

Part	Cost
1-W FILTERLESS MONO CLASS-D AUDIO POWER AMPLIFIER	\$.96
Adafruit I2S Stereo Decoder - UDA1334A Breakout	\$6.95
Bluetooth 5.0 APTX Audio Module - TS8670	\$12.95

Speaker - 3" Diameter - 8 Ohm 1 Watt	$1.76
Assorted Components. E.G. Resistors, Inductors, Capacitors, Transformers, Etc.	$30
PCB	$10

The total cost for this project would come to be $33,662.56.

3.2 Schedule

Week	Drew	Kshithij
9/30	Buy components	Buy components
10/7	Assemble and bench test power subsystem, Bluetooth subsystem, the functionality of operation amplifier, DAC and speaker	Find or Create Music Dataset w/ genre and sound clips
10/14	Circuit schematic and PCB Design (Order PCB)	Start Analyzing Dataset to find patterns; Liason with Musicians, Producers, etc.
10/21	Order PCB	Continue Analyzing Dataset to find patterns; Liason with Musicians, Producers, etc.
10/28	Create custom EQs for genres and test for errors in design (Order new PCB)	[1]Build Rudimentary ML derived genre/characteristic detector
11/4	Test for errors in design. (Order new PCB)	Build iPhone/Computer app that can augment EQ
11/11	Add functionality to augment EQ based on file embedded genre	Add functionality to augment EQ based on file embedded genre
11/18	Miscellaneous / Fine-tune EQs	Add functionality to augment EQ based on ML Algorithm

11/25	Miscellaneous / Fine-tune EQs	Miscellaneous / Fine-tune ML Algorithm
12/2	Miscellaneous / Fine-tune EQs	Miscellaneous / Fine-tune ML Algorithm
12/9	Project Demo and Final Report	Project Demo and Final Report

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Footnotes:

[1] Characteristics can differentiate types of genres. (i.e. high pitch vs low pitch singers)

4 Ethics and Safety

4.1 Concerns and 4.2 Mitigating Procedures

There are numerous potential safety hazards that we may face when executing this project.

Concern	Mitigating Procedure(s)
There are numerous potential safety hazards that we may face when executing this project. There is some risk involved with using wall power since the voltage coming from the wall is 120Vrms.	- [8] To ensure safe practice, someone else should always be present in the laboratory when utilizing wall power. - Accordingly, having a TA check the circuit prior to plugging in or powering the circuit, should be adhered to. - The one-hand rule can be useful in ensuring that the person working on the circuit is never the quickest path to ground.
[ACM 1.2] There is a potential fire hazard if we raise the decibel levels through volume or EQ such that clipping occurs.	- We should place hard upper limits on the decibel levels in the code for the equalization.

	- Listen for signs of clipping and act appropriately. - As well, in case of emergency, a protocol for the laboratory fire emergency must be followed.
Listening to loud music for long periods can damage eardrums.	- Use ear protection when nuanced listening is not imperative. - Limit long periods of music listening.

While the ethical concerns are limited in the scope of this project, there are some key ones to point out.

Concern	Mitigation
[13] Mismatching EQs with Songs or distorting music can cause fatigue or dizziness	- Do not create EQs purposefully to cause harm - Try not to pair songs with non-conforming EQs - Allow for plenty of breaks if the operator starts to feel fatigued or dizzy.

5 Citations

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