

Portable Bluetooth Stereo Backpack Speaker System

ECE4011 Senior Design Project

Team Big Type D Energy

Project Faculty Advisor: Dr. Allen Robinson

Connor Brothers - CmpE - cbrothers3@gatech.edu

Jack Glennon - EE - jglennon7@gatech.edu

Alex Mathis - EE - amathis37@gatech.edu

David Rogers - EE - drogers62@gatech.edu

Andrew Verneti - CmpE - avernetti3@gatech.edu

Submitted

November 18, 2019

Table of Contents

Executive Summary (5 pts)	3
1. Introduction (10 pts)	4
1. Objective	4
2. Motivation	4
3. Background	5
2. Project Description and Goals (15 pts)	6
3. Technical Specification (15 pts)	7
4. Design Approach and Details (20 pts)	8
1. Design Concept Ideation, Constraints, Alternatives, and Tradeoffs	8
2. Engineering Analyses and Experiment	12
3. Codes and Standards	14
5. Schedule, Tasks, and Milestones (10 pts)	15
6. Project Demonstration (5 pts)	15
1. Bluetooth Control	16
2. RGB Lighting	16
7. Cost Analysis (5 pts)	16
8. Current Status (5 pts)	18
9. Leadership Roles (5 pts)	18
10. References (5 pts)	20
Appendix A: QFD Diagram	22
Appendix B: Gantt Chart	23
Appendix C: PERT Chart	24

Executive Summary

The Portable Bluetooth Stereo Backpack Speaker System is a mobile, durable, and quality speaker system that can connect over Bluetooth to any mobile device and be controlled from a mobile app while also retaining analog inputs. The system consists of a subwoofer box and two satellite speaker boxes which will each have two speaker cones for a woofer and a tweeter. The subwoofer box houses the amplifier for the system, a microcontroller and Bluetooth module for app connectivity and signal processing, and the power supply consisting of both power-tool batteries and a 120V rectifier. The app allows the user to control the volume level of the speakers as well as adjust signal processing function settings such as equalization and time alignment.

The main constraints and subsequent tradeoffs arise from a desire for the system to be portable, efficient, durable, cheap and to have the best sound quality possible. The system will have its own internal amplifier so that any input can be amplified to take full advantage of the system's frequency response and volume output safely. In this way, the system is fully standalone and can be used without any external systems minimizing complexity and maximizing user experience.

The working prototype will cost \$500 and should be able to be carried on a backpack frame, be durable enough to withstand multiple loadings/unloadings, last for at least four hours on battery power, amplify any source given over Bluetooth or line-in, have multiple equalization settings controlled via the mobile app, and produce great sound quality.

Portable Bluetooth Stereo Backpack Speaker System

1. Introduction

The Portable Bluetooth Stereo Backpack Speaker System is a mobile, durable, and quality speaker system that can connect over Bluetooth to any mobile device. The system consists of a backpack rig to carry the speakers, subwoofer, two satellite woofer/tweeter mid-range speakers, and a mobile app to control the equalization and input of the system. Big Type D Energy is requesting \$500 in funding to develop this system.

1.1 Objective

The goal of this project is to create a portable backpack sized system of speakers including a subwoofer to fill the need of a portable but loud and high quality speaker system. The system should have a sufficient battery life and have a user interface that is easy to use as well as providing decent sound quality and volume while also being able to be controlled through its companion app connected over Bluetooth. Additional features include the ability to connect to up to 4 aftermarket Bluetooth speakers, RGB lighting that changes based on the volume and frequency of the music being played, line level input via a 3.5 mm jack or RCA, and additional equalization settings and other signal processing. See Appendix A for QFD with further details on customer desires versus engineering requirements.

1.2 Motivation

Currently in the speaker market, there aren't any portable speaker systems that are easy to carry around except for on a cart, and those that are portable are too small to produce meaningful

sound pressure and/or have a poor frequency response. This backpack speaker system will allow the user to have a decently portable and high quality sound source for whatever event they would need it. It also is being designed to be user-friendly, so that the equalization makes up for any shortcomings in the design as a result of adhering to portability, lower energy consumption, and lower cost constraints.

This design seeks to fill a hole that our team has identified in the speaker market for complete systems that are portable enough to be carried around and used on battery power, but provide high enough quality to be able to replace normal high-end speaker systems.

1.3 Background

Generally, speaker systems contain 2 mid-range speakers and a subwoofer. The purpose for the two mid-range speakers is to create stereo sound from two different sources of left and right channels, which is how almost all music is recorded. Each of these speakers will typically consist of two different speaker cones. The first is the woofer, which is the main workhorse of the mid-range frequencies. The second is the tweeter, which provides the best frequency response at higher frequencies. The subwoofer is responsible for the booming bass of the lower frequency notes. Typically, these speakers would all connect to an external amplifier, where the input from a different source would come in, be equalized and boosted, then be filtered to the different output speakers depending on frequency range. In our system, we instead propose to have an internal amplification system that is housed inside of the subwoofer box, that is able to take an input via a 3.5mm line-in or via Bluetooth. In this way, there are no auxiliary cables that run from each speaker to a separate amplifier system and then the input also being connected to the

amplifier. Our system is fully self-contained and is able to be used as a standalone system with minimal complexity of parts and subsystems.

2. Project Description, Customer Requirements, and Goals

The team will design a system consisting of three main components: a mobile app, mid-range speakers, and a subwoofer. The mobile app will allow, via Bluetooth connection, the user to control the source input to the speakers, as well as what equalization settings are desired. The mid-range speakers will each have a woofer and tweeter and will take a ¼” cable in from the subwoofer box as their input. The subwoofer will contain not only the large subwoofer speaker cone, but also the amplifiers, microcontroller, and battery power system that feeds the whole system. The subwoofer will have two ¼” cables out, one for each of the mid-range speakers.

The main constraints and subsequent tradeoffs arise from a desire for the system to be portable, efficient, durable, cheap and to have the best sound quality possible. See Appendix A for a QFD diagram detailing tradeoffs with regards to customer desires and engineering requirements.

Project goals include the following:

General

- Speaker system should be lightweight enough to reasonably be carried on a backpack frame
- Cost less than \$500
- System should be weather resistant and durable to withstand frequent unloading/carrying

Mobile App

- Control source input via Bluetooth to the speakers
- Choose different equalization settings/digital signal processing functions to run on the microcontroller inside the speaker system
- Send commands to turn control the volume of the speaker system

Speakers

- Should be able to produce high quality sound with low frequency response
- Contain their own amplification system
- Can be powered for a reasonable time from portable power tool batteries

3. Technical Specifications

Table 1. Acoustic Specifications

Feature	Specification
Maximum frequency response ripple	0.5 dB
Speaker/box combo alignment	Butterworth (B2 or B4)
Power output	200 W
Driver sensitivity (at 2.83 V)	>90 dB
Frequency range	20-20,000 Hz

Table 2. General Specifications

Feature	Specification
Total weight	<40 lbs
Processing & Bluetooth power	.5 W
LED lighting power	1.5 W

Processing delay	<100 ms
Setup time	<1 min
Startup time	<5s
Maximum dimensions	2' x 1.5' x 3.5'
Cable length	6'
Auxiliary simultaneous bluetooth devices	1-4
Power supply voltage	24 V
Analog input	2 RCA, 1 3.5 mm
Battery life @ 200 W	4 hrs

4. Design Approach and Details

4.1 Design Concept Ideation, Constraints, Alternatives, and Tradeoffs

System Overview

The Big Energy Backpack Speaker will consist of two bookshelf style loudspeakers and a subwoofer integrated into a backpack frame. Figure 1 shows a block diagram of the system. The amplifiers, audio processors and batteries will be contained within the subwoofer housing. The speakers will be removable from the backpack using a system of hooks and a securing strap. Figure 2 shows a conceptual rendering of the speakers and subwoofer on the backpack frame.

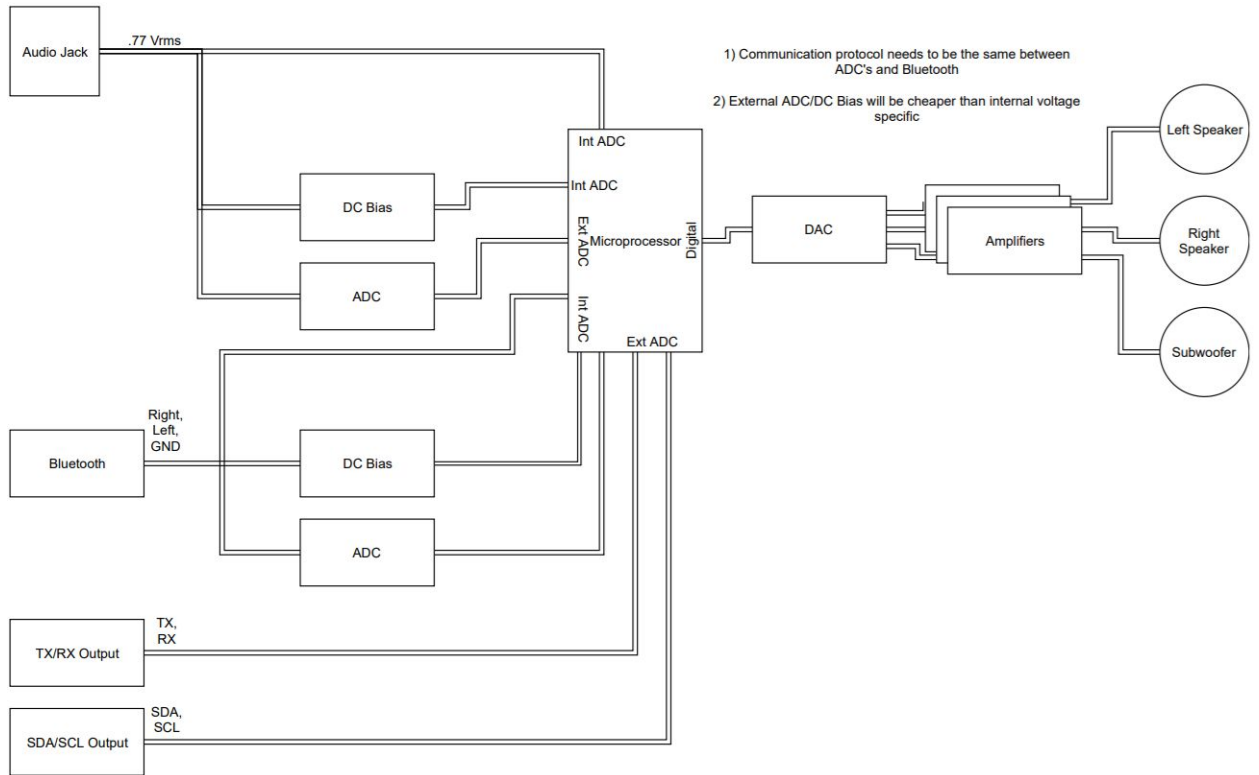


Figure 1. Block diagram of the system.

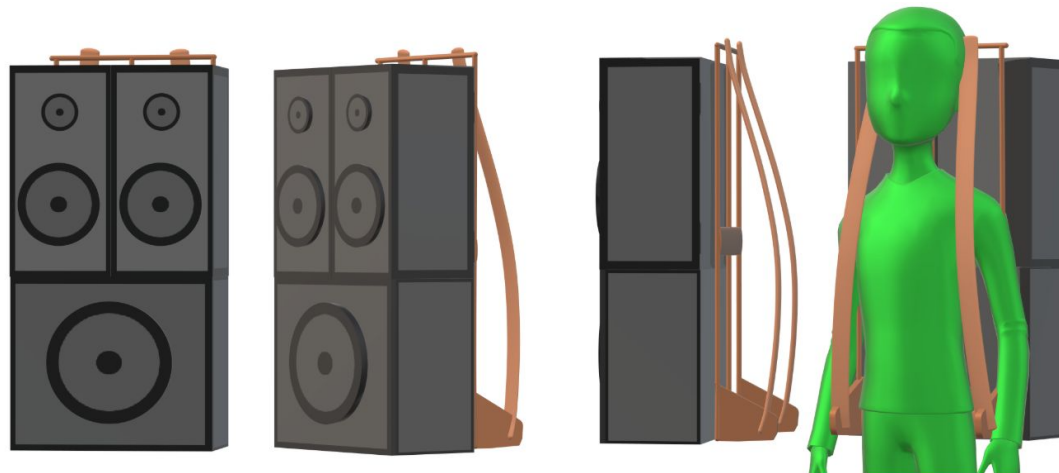


Figure 2. Conceptual rendering of the Big Energy Backpack Speaker.

The audio stream is delivered through bluetooth, aux, or RCA into the subwoofer housing. It will then be decoded by the microprocessor and converted to a digital signal by the analog to digital convertor. Once digital, the signal will be routed to the correct amplifier and each will be converted to an amplified analog signal. These amplified analog signals will be sent to the left and right speakers and the subwoofer, producing sound.

Mounting

The system used to mount and secure the system to the frame will be integral to its portability.

The back of the speakers will have two J-hooks each that are able to securely grab the crossbar of the backpack frame. The subwoofer will have four J-hooks to support its extra weight and maintain stability. There will also be a strap that secures the speakers to the backpack frame ensuring the speakers do not bounce off of the hooks or shift during transport. One strap will go around the two loudspeakers and one will go around the subwoofer. There will be guides built into the speaker casings to ensure that the strap does not damage the speaker cones.

An alternate method to securing the speakers to the frame and subwoofer enclosure is through the use of rubber hook latch as is typically used in insulated coolers. This would provide a simple, yet secure alternative if the above J-hooks don't prove to be reliable enough.

Communication

Having easy communication with the system will be required to change relative speaker levels as well as the overall volume of the music. A simple system of three buttons will be integrated into the subwoofer housing allowing the user to change the volume up or down in addition to having

a play and pause function. These settings as well as advanced equalization will be possible through an Android app that communicates with the audio processor through a bluetooth module. This will allow the user to easily equalize the system, add delays for time alignment, and control/correct the frequency response through equalization and possibly equal-loudness curves.

The app GUI will be relatively simple and have a series of sliders based on nine ranges of frequencies split logarithmically from 20 Hz to 20 kHz (the range of human hearing). Sliding up on a specific frequency will increase the level of that frequency while sliding down will decrease said level. In addition to the custom sliders there will be several presets that automatically adjust the sliders to enhance the intended type of music being played. The app will also have a play/pause button, a volume slider, an input drop down, a skip, and a sleep button. The sleep button will turn off all systems with the exception of the bluetooth which is waiting for the wake signal. Other options will be accessible via an advanced settings button.

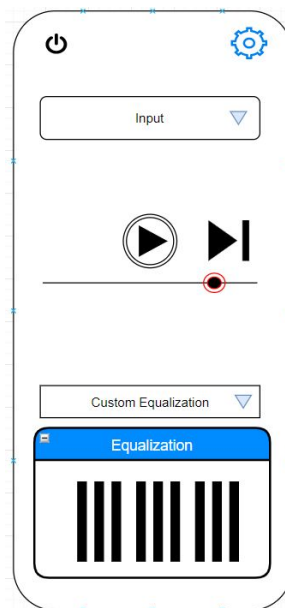


Figure 3. Layout of main functions of application

Audio Input

The three methods of audio input are bluetooth, RCA, and auxiliary. This combination of inputs will be able to accommodate nearly all sources of audio outputs. The microprocessor will switch to the input that was most recently connected or paired automatically. The bluetooth input will support multipoint pairing which allows multiple devices to be connected at the same time. This will allow one device to pause their music and allow the other device to play without having to disconnect and pair.

In the worst case scenario there would be a major flaw in the processor or bluetooth signal chain. As long as the analog converters function, the amplifiers could still be used to amplify analog input signals for the speaker outputs..

4.2 Engineering Analyses and Experiment

Every module of the system will be designed to be independently testable through either the use of a debugger probe or externally available test probing locations for the inputs and outputs of every section. This will allow for both quick debugging and modularity making it so that if one module is tested to be dysfunctional it can be exchanged for another that is a new version without having to remake large sections of the system.

Other modules will be based off of the central microprocessor of the system, which will be one of the first things needed. It will need to be tested first using known-working auxiliary modules such as GPIO expanders for working out the I2C protocol, and breakout audio amplifiers for

working out the I2S protocol. First in the audio signal path is the bluetooth modules which can be tested using example code provided by the manufacturer via a breakout board and an Mbed microprocessor then the code will be ported over to the primary processor code allowing for parallel workflow.

Second in the chain is the microprocessor which will be doing many digital signal processing tasks as well as managing the amplifiers, Bluetooth modules, battery management systems, and audio signal multiplexing. The total delay of the microcontroller (MCU) signal processing and bluetooth transmission decoding will be measured using another microprocessor that can broadcast a known bluetooth audio signal and also receive the I2S output then comparing the input and output signal timing directly.

Third in this path is the amplification stage where the I2S signals from the MCU will be translated into analog signals internally and fed into several different class-D amplifiers for each speaker. These amplifiers will primarily be programmed through I2C commands for setting things like cutoff frequencies and overcurrent protection status which can be fed using a testbed such as an extra Mbed processor if the MCU isn't up and running yet. A test resistor could be used to simulate an acoustic load until confidence is earned for the amplification stage through testing the total power output into a known load, making sure the amplifier is able to provide the required power. A similar test method will be used for the power supply, but it will consist of putting a known load meant to simulate the RMS power draw of 200 W.

The speaker cabinets will be designed based on the available speakers to provide a butterworth alignment allowing for a maximally flat response. This can be measured using testing equipment designed exactly for this purpose. An impedance analyzer will be used to verify the manufacturer datasheets, and the cabinets will be altered accordingly to ensure a perfect final frequency response will be as desired. Once the entire amplifier and speaker system is complete, the total transfer function can be measured using a digital spectrum analyzer on the output while feeding noise to the analog input of the system.

4.3 Codes and Standards

Fuses:

To ensure that the speaker system is safe from shorts and excess heat we will need to regulate the power from both the batteries and the wall power. In order to accomplish this we will need to implement a fuse that will blow and protect our electronics from damage and risk of fire [11].

Bluetooth:

Given the wide variety of encoding and decoding that goes into music compression and transfer, our system must be able to work with a variety of input encodings. Bluetooth data transfer has its own standards that we must adhere to with the receiving module. [9] Most bluetooth chips are able to pair and communicate with each other but we have to ensure that ours is done seamlessly at audio level quality.

I2S encoding:

The host microcontroller must be able to communicate with multiple amplifiers. This communication must be able to be transmitted and read by the amplifier. The most common method for this is using I2S [10].

To remain portable without injuring the wearer, we must adhere to standards of what people can carry. We have some flexibility from backpacking standards as it is not expected the user will hike long distances with the backpack. Using that as a guide we have decided the maximum weight is 35 lbs. This weight is the approximate recommended backpacking weight of a person that weighs 175 lbs [6].

5. Schedule, Tasks, Milestones

Appendices B and C include both a GANTT and PERT chart showcasing the overall timeline for this project, including time estimates for each task. The PERT Chart's critical path(i.e. the longest path of dependent events for the project) is listed in Appendix C. This includes the tasks of modules/block diagram, circuit diagram/PCB Design, and lastly building/testing. The majority of time spent is allocated for programming and testing because these tasks are prone to lots of errors and debugging. The estimated duration for completing the project is about 141 days and there is an 83.4% probability that the team will finish one week before the design expo.

6. Project Demonstration

The demonstration of the backpack speaker will take place at the Georgia Tech Capstone Expo located in the McCamish Pavilion. A group member will demonstrate how portable it is by

wearing the backpack speaker and walking around with it. Also, the speakers can be separated from the backpack frame and can each be driven individually. One of the members will then use his phone to play and control music from the speaker.

6.1 Bluetooth Control

The speaker system will be controlled by someone's phone using Bluetooth technology. An app developed by the team can be used to select what to play, control volume as well as standard pause, rewind, and fast-forward controls, and adjust equalization settings.

6.2 RGB Lighting

LEDs will be installed on the speaker system which will be programmed to change based upon the volume and frequency of the audio being played. Many different songs will be played at different volumes to demonstrate this effect. More intense and vibrant lighting will be showcased during faster and louder songs, while songs that are more relaxed and quiet will display dimmer lighting. This feature can of course be toggled from the phone application in case the user would prefer playing audio without it.

7. Cost Analysis

The project has several components with varying costs, that will be dictated by the technical specifications of each of the parts. So the price range for the tweeter will end up being dictated by the crossover range of midband speaker and the subwoofer, and vice versa. So to better use the budget, the cost priority will be focused on the back pack frame, box enclosures, and internal

circuitry, like the power amps, power supply, Bluetooth module, and microcontroller. For the project's backpack frame, the estimated highest cost is around \$45 for a used model from Amazon [3]. Additionally, the box enclosure would start as an 8.5 feet by 49 inch sheet of .25 inch thickness MDF that costs \$35 from Home Depot with the option of Aluminum bracers to add internal support for the enclosure at around \$15 [4,5] . For, the internal circuitry, the prices range depending on the modules that are used: for the microcontroller, the price range is between \$20 and \$60, depending on the communication methods and number of pins [1,8]. For the power supply, the project will be using 2 Milwaukee M12 3 amp/hour batteries which can be found in a 2-pack for \$80 [7]. Finally, the bluetooth module ranges from \$6 to \$22 with the main difference in price being bluetooth 4.0 enabled, pin in/out, usb port, and aux in/out [2]. The total outcome for the prices before considering the speakers' cost comes out to be approximately \$245, leaving \$255 left in the budget for the speakers and miscellaneous things such as minor circuit parts, wires, parts to hold down the circuitry, and heatsinks. The project is estimating \$150 for speakers on the low side and up to \$350 on the high end, the biggest impact on price will be the size of the subwoofer, as well as the materials for the speaker cones.

The project has an estimated time of 60 hours put into the project so far, with meetings and research taking up most of the time. The project potentially estimates 110 hours intotal to build with some fluctuation depending on errors or difficulties with building the enclosure and the circuits. Additionally, there is an estimated 30 hours that will be put into final testing to verify the final project before the final presentation.

Estimated Hours	Building Estimates
-----------------	--------------------

Meetings	5 hours/person	Enclosure	30 hours
Reports	1 hour/person	Circuitry/Testing	40 hours
Research	6 hours/person	Programming	40 hours
Total	60 hours	Total	110 hours

8. Current Status

The project is currently in the planning phase, consisting of members working on matching data sheets between parts. For example, the microprocessor needs to have the correct communication ports for the power amps that are chosen. Additionally, the processor needs to be able to connect with the Bluetooth Module as well as have access to a Digital Signal Processing Library. Also, the group is meeting with our faculty advisor to learn the process of matching the crossover frequencies of the tweeter, midrange, and subwoofer to optimally produce sound with as minimal distortion from the speakers. Finally, in order to get a better jump on the final preparations and learn more about the overall projects, the group will be testing out some processors and controllers to see the communication requirements for certain modules.

9. Leadership Roles

The leadership roles that are needed for the project are Webmaster, Expo Coordinator, Documenter, Integration Coordinator, and Coding Master. The Webmaster handles the manufacture and design of the website, displaying relevant information about the project including technical details and parts used. The Expo Coordinator is responsible for ensuring all

materials and documentation are ready and present for the expo. The Documenter is responsible for meeting minutes and the final review of all written documents needed for the class and the project. The Integration Coordinator is responsible for establishing the compatibility and connection between the components and systems necessary for the project. Finally, the coding master is in charge of making sure all coding standards are adhered to, including the organization and functionality of the programs needed in the project.

10. References

- [1] (Cortex-M3), m. (2019). *mbed - LPC1768 (Cortex-M3) - DEV-09564 - SparkFun Electronics*. [online] Sparkfun.com. Available at: <https://www.sparkfun.com/products/9564> [Accessed 19 Nov. 2019].
- [2] 10, T., Project, 1. and Qureshi, A. (2019). *10 Best Bluetooth Audio Stereo Module For Your Project*. [online] Wonderful Engineering. Available at: <https://wonderfulengineering.com/10-best-bluetooth-audio-stereo-module-for-your-project/> [Accessed 19 Nov. 2019].
- [3] Amazon.com. (2019). *Deluxe Freighter Aluminum Pack Frame*. [online] Available at: https://www.amazon.com/Stansport-Deluxe-Freighter-Aluminum-Frame/dp/B001RL5PHY/ref=lp_3400481_1_7?s=outdoor-recreation&ie=UTF8&qid=1574103363&sr=1-7 [Accessed 19 Nov. 2019].
- [4] Anon, (2019). *Aluminum Bracers*. [online] Available at: <https://www.homedepot.com/p/Everbilt-1-1-2-in-x-48-in-Aluminum-Flat-Bar-with-1-8-in-Thick-801987/204273937> [Accessed 19 Nov. 2019].
- [5] Anon, (2019). *MDF Sheet Board*. [online] Available at: <https://www.homedepot.com/p/1-4-in-x-49-in-x-8-1-2-ft-MDF-Board-217851/205186604> [Accessed 19 Nov. 2019].
- [6] GearHunts. (2019). *Backpack Weight : How Much Should My Backpack Weigh? » GearHunts*. [online] Available at: <https://gearhunts.com/how-much-should-my-backpack-weigh/> [Accessed 19 Nov. 2019].
- [7] Home Depot. (2019). *Milwaukee M12 Battery*. [online] Available at: https://www.homedepot.com/p/Milwaukee-M12-12-Volt-Lithium-Ion-XC-Extended-Capacity-3-0Ah-Battery-Pack-3-0Ah-2-Pack-48-11-2412/203630471?g_store=159&mtc=Shopping-B-F_D25T-G-D25T-25_9_PORTABLE_POWER-Multi-NA-Feed-LIA-NA-NA-PortablePower_LIA&cm_mmc=Shopping-B-F_D25T-G-D25T-25_9_PORTABLE_POWER-Multi-NA-Feed-LIA-NA-NA-PortablePower_LIA-71700000044155732-58700004615424082-92700048431609705&gclid=Cj0KCQqAn8nuBRczARIsAJcdIfMJdweNG2CwT_Q7FoVTsnOjN5B9MPGFb-lfX842rL_U8_kHrrP1M3caApWJEALw_wcB [Accessed 19 Nov. 2019].
- [8] Industries, A. (2019). *PJRC Teensy 4.0 USB Development Board*. [online] Adafruit.com. Available at:

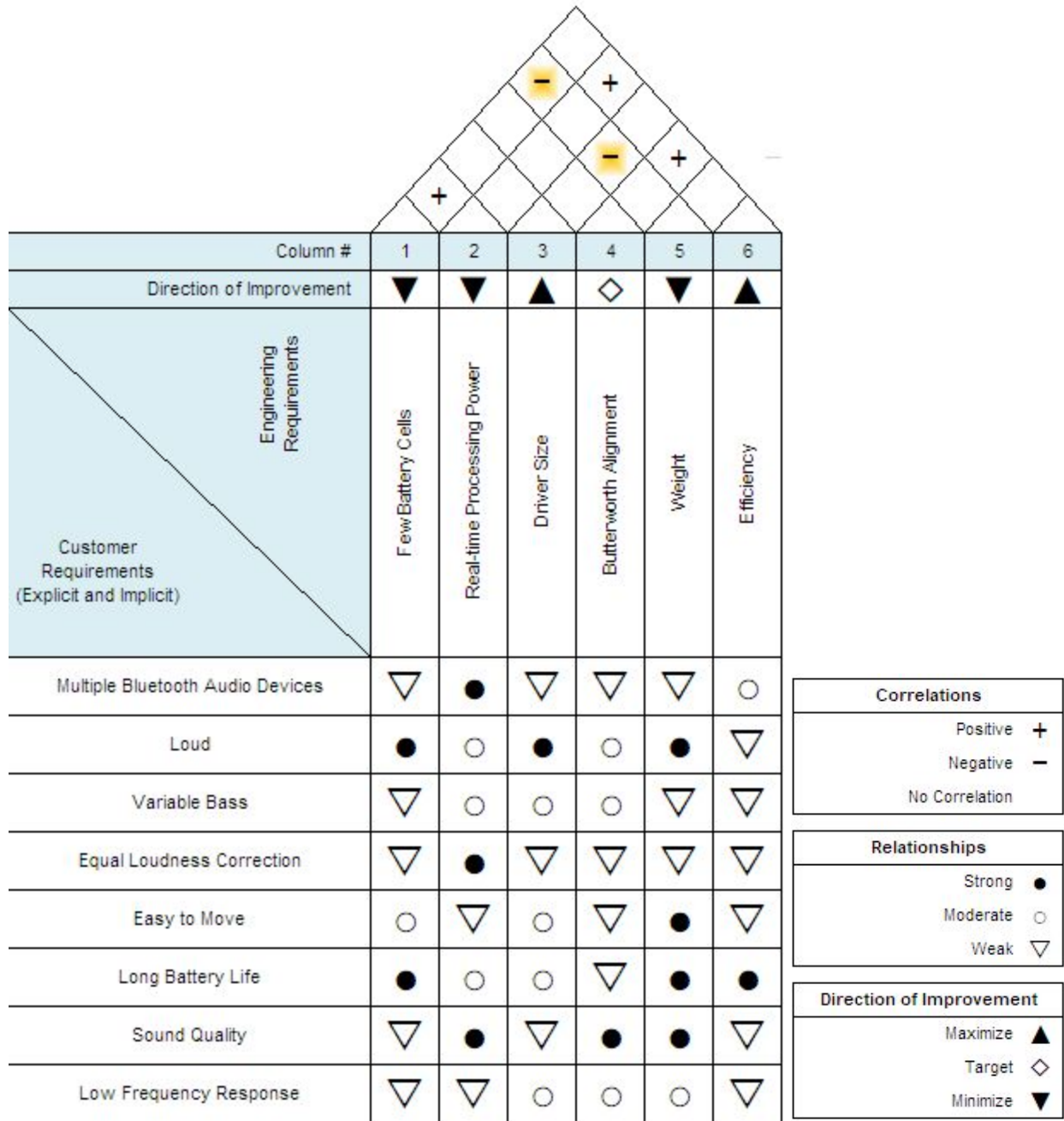
https://www.adafruit.com/product/4323?gclid=EAIaIQobChMI2O6ev7705QIVDZ6fCh3ZHAAa0EakYAiABEgJEZ_D_BwE [Accessed 19 Nov. 2019].

[9] Learn.sparkfun.com. (2019). *Bluetooth Basics - learn.sparkfun.com*. [online] Available at: <https://learn.sparkfun.com/tutorials/bluetooth-basics/all> [Accessed 19 Nov. 2019].

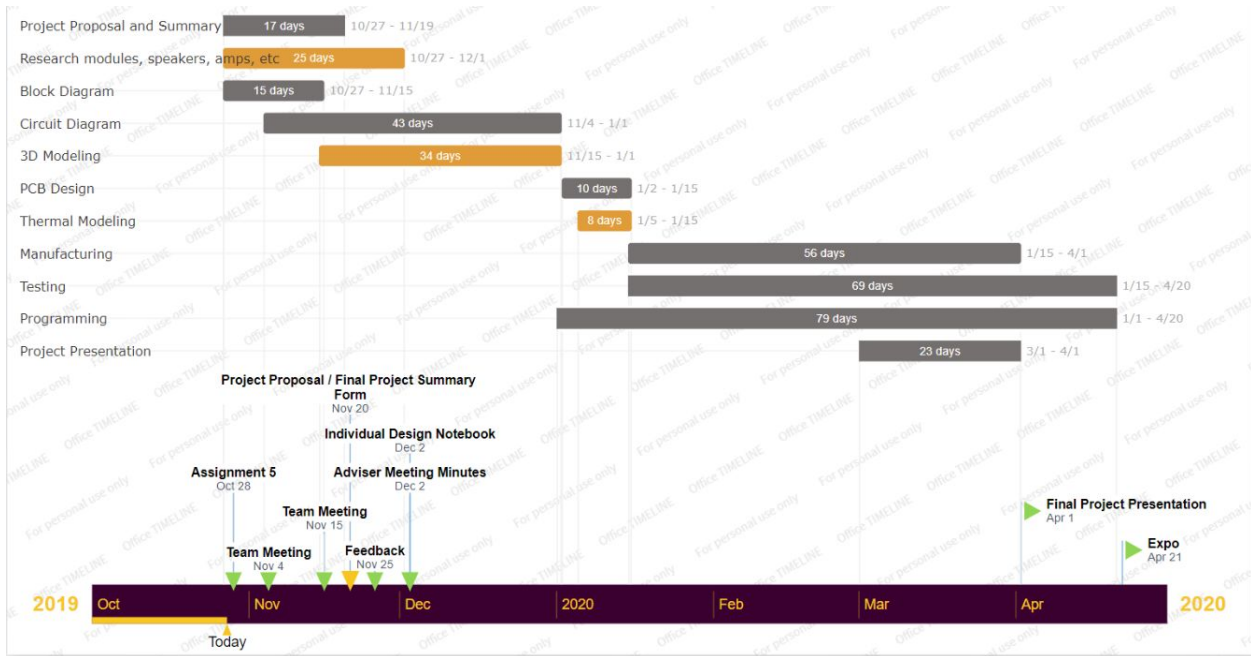
[10] Sparkfun.com. (2019). [online] Available at: <https://www.sparkfun.com/datasheets/BreakoutBoards/I2SBUS.pdf> [Accessed 19 Nov. 2019].

[11] Standards.ieee.org. (2019). *IEEE C37.27-2015 - IEEE Guide for Low-Voltage AC (635 V and below) Power Circuit Breakers Applied with Separately-Mounted Current-Limiting Fuses*. [online] Available at: https://standards.ieee.org/standard/C37_27-2015.html [Accessed 19 Nov. 2019].

Appendix A: QFD Diagram



B: Gantt Chart



Appendix C: PERT Chart

