BaseRock Bluetooth

Bi-directional Bluetooth & 3.5mm Headphone Jack Compatibility Device

Built for:

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Senior Project

ELECTRICAL ENGINEERING DEPARTMENT

California Polytechnic State University

San Luis Obispo

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Table of Contents

List of Tables and Figures

Acknowledgements

Thanks to my Mother and Father for giving me life and instilling in me the mindset of an Engineer by allowing me to take apart various items around the house. Thank you to my family for allowing me to grow in a positive atmosphere. Thank you to my great Uncle Doug, for giving me tools to facilitate my education as an Engineer. Finally, thank you to my professors for being generous enough to impart their knowledge and life skills to me. I leap from the foundation you have provided, into the future as a hopeful Electrical Engineer.

Abstract

This project was proposed by a startup company from downtown San Luis Obispo called BaseRock. BaseRock sells a backpack containing subwoofers to allow the user to feel low frequencies of music. It is intended for concerts or personal use, listening to songs on an MP3. The main way the BaseRock backpack communicates with MP3s is via the headphone jack. With the introduction of the Apple iPhone 7 in September of 2016, BaseRock realized it was at a disadvantage. Millions of iPhone 7 owners and potential customers around the globe would no longer possess a headphone jack. BaseRock needs a Bluetooth-to-headphone jack adapter for its product to be competitive in the post iPhone 7 market. The module described by this report is able to pair to both an MP3 and to Bluetooth headphones. The device takes music data from the phone/MP3, passes it to the backpack subwoofers, and also to user headphones. Design challenges include compact size, internal power, and simultaneous signal outputs.

Background

In September of 2016 Apple announced the release of the iPhone 7. In a push to go wireless, except for the charging/data port, Apple removed the headphone jack from the new version of the phone (see Figure 1). People love listening to music and consumers were disgruntled with Apple when the headphone jack was designed out of the iPhone 7, forcing them to buy only Bluetooth compatible devices.

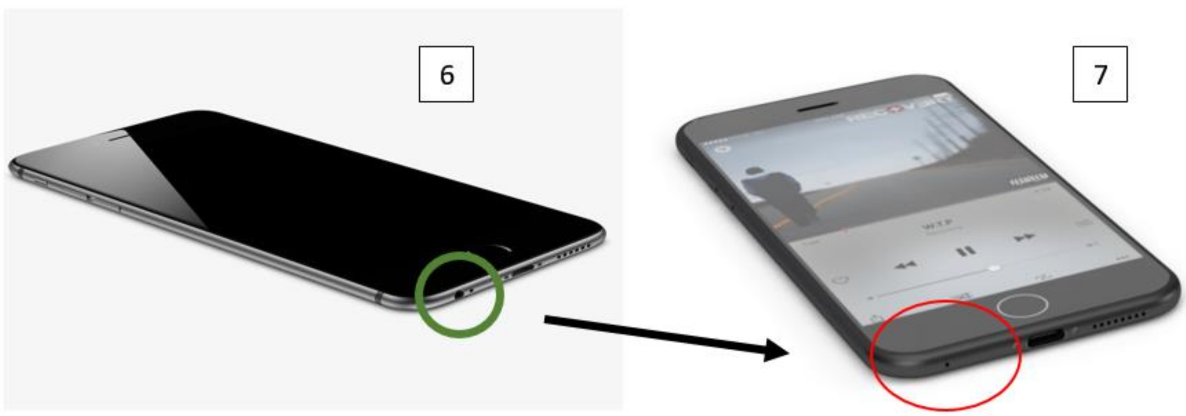

Figure 14: iPhone 6 and iPhone 7 Juxtaposed
http://www.buyiphone7.org/wp-content/uploads/2016/08/iphone-7-no-headphone-jack.png

Many music-centric companies, whose business depended heavily on headphone jacks had to adjust their products so they could stay relevant in the post-iPhone headphone jack market. One such company, a startup called BaseRock (formerly known as Spectrvm), utilized the headphone jack to allow users to connect to its backpack (see Figure 2). The BaseRock backpack was built for adventurers, audiophiles, concert goers, and the hearing impaired. The backpack has two transducers in it to allow the user to feel lower frequencies of music.

Figure 15: BaseRock Backpack
https://twitter.com/getbaserock?lang=en

BaseRock needs a way to be compatible with the new wireless iPhone 7. Previously, an audio signal traveled through two sequential wired connection ports to reach both backpack and user's headphones (see Figure 3).

Figure 16: BaseRock Control Module

BaseRock needs a device that will take a Bluetooth signal from the iPhone 7, duplicate it, send one copy via wired connection to the backpack, and send the other copy via another Bluetooth connection to wireless headphones. Figure 4 shows a rendition of what the device could look like. It is from this need for a device that this Senior Project formed.

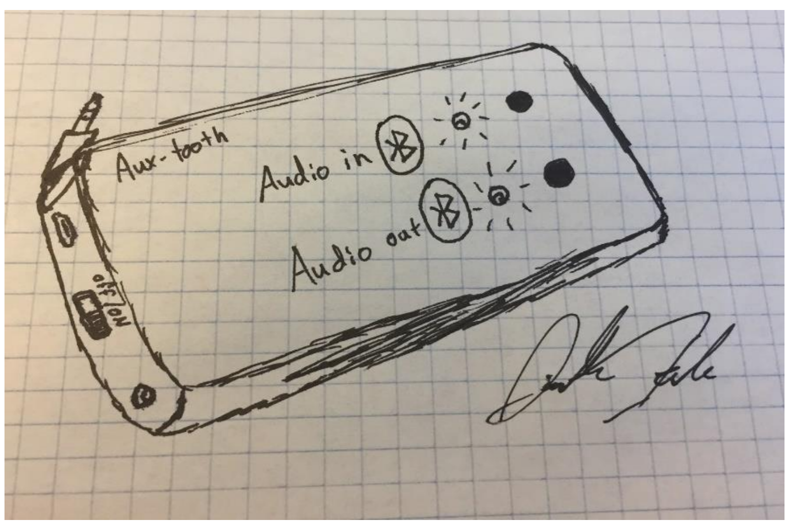

Figure 17: Artist's Rendition of BaseRock Bluetooth

Product Description:

Figure 18: Audio Signal Flow Chart

"BaseRock Bluetooth" takes an incoming Bluetooth signal, copies it, and outputs to both a wired connection and another Bluetooth connection (see Figure 5). It runs on battery power and does not use power from the BaseRock backpack or the audio signal producer. The battery life lasts at least as long as an average music concert, around four to five hours. Battery life information is also displayed on the music signal producer's display. It has high signal fidelity to maintain audio quality. Users with a non-technical background can use the device with ease. It also controls latency, so the low frequency baseline the backpack produces matches up with the full spectrum audio the headphones are generating. BaseRock Bluetooth is small enough to fit into the "control unit" of the BaseRock pack and compatible with any software installed inside the BaseRock pack. A secondary goal for the BaseRock Bluetooth is compatibility with most Bluetooth devices, so customers can purchase the device for more applications than just the BaseRock pack.

Market Research

There are many readily available solutions on the market which are currently being used to solve the problem of the missing headphone jack. A simple search of "aux to Bluetooth" on online retailer Amazon produced 5,000 results of small devices that are Bluetooth to aux connections (see Figure 6). Searching on Google with the query "wireless headphone converter" produced 828,000 results. However, none of the top ten results are anything like BaseRock Bluetooth.

Figure 19: Devices already on the Market
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https://images-na.ssl-images-amazon.com/images/I/51hH0TSFcqL._SL1000_.jpg

None of the available online products have audio signal duplicator functionality. Most devices have only a male headphone jack connector. BaseRock Bluetooth has both a male headphone jack connector and a simultaneous Bluetooth out. Many devices are designed for automotive applications and plug into a 12 Volt cigarette lighter port for power. Again, the BaseRock Bluetooth runs off of its own battery power so it can be more portable. BaseRock Bluetooth is intended to be an innovative product with little competition in its market segment.

Customer Archetype

Anyone with an iPhone or MP3 capable device, aged 18-50, male or female, and a fan of listening to music is a potential customer. A day in the life of a typical customer could look like this:

- Wake up and get ready for work listening to music.
- Get in a car or public transportation for a commute. During the commute the consumer uses this product to connect their phone to their car's audio system or listen via their cell phone.
- The customer would then use the product again on the commute back.
- During exercise, after work or pre-work, the customer could connect their phone to workout headphones via BaseRock Bluetooth.

Another scenario is use at concerts wearing the BaseRock backpack. The customer needs to connect both backpack and headphones simultaneously. This product solves the problem customers now have of owning wireless headphones, or of owning three devices that all need to connect via Bluetooth. This product would solve the nuisance of not being able to listen to music on the iPhone 7 because of the missing headphone jack. BaseRock Bluetooth provides the benefit of easily connecting three devices seamlessly.

This niche market is growing rapidly. However, there are a few competitors that have been making this kind of product before the announcement of the iPhone 7. They are:

- Logitech
- Griffin
- Kinivo
- iKross
- AmazonBasics

This market is small but growing rapidly. A quick Google search of “Bluetooth-to-aux” brings up thousands of results, including lists of what product is the “best” on the market. For example, BuytheBest10.com details ten products that purport to solve the Bluetooth-to-aux problem. Thankfully, none of them have Bluetooth to Bluetooth/aux functionality this product has.

This niche market can be fully addressed with features BaseRock Bluetooth employs, from simple Bluetooth to aux capability, to the extra copied signal outputting simultaneously via wired connection.

BaseRock Bluetooth began as a project intended to connect the BaseRock pack to the iPhone 7. It is conceivable that BaseRock Bluetooth can work with other music playing devices. Any customer that listens to music on the go or prefers wireless connections will benefit from the functionality BaseRock Bluetooth offers. The four main consumer groups this product will target are: BaseRock users, iPhone 7 users, other smartphone users, and wireless preference users.

BaseRock Logo, used with permission

Market Description

BaseRock Bluetooth to headphone jack/Bluetooth device is a signal duplicator and signal splitter. An incoming Bluetooth signal is paired by a Bluetooth module in the device. The Bluetooth module then takes the signal and splits it. One copy of the signal is passed to a headphone jack module which sends the signal to an auxiliary device via 3.5 mm headphone jack connection. The other copy of the signal is sent to another Bluetooth module that pairs with Bluetooth capable headphones. This is especially useful for customers purchasing the BaseRock pack with the introduction of the iPhone 7 because there is no headphone connection port. This device facilitates seamless and simultaneous wireless usability of the BaseRock pack with iPhone 7 and wireless headphones.

Table 1: Competitor Deficiencies and BaseRock Bluetooth Strengths

Limitations of Competitors	BaseRock Bluetooth Strengths
• Built for automobile use • Requires external power • Low audio fidelity • Unidirectional audio path • Single output method • Non-portable	• *Built for many applications* • *Internally powered* • *High audio fidelity* • *Multi-directional audio path* • *Dual and simultaneous output method* • *Portable*

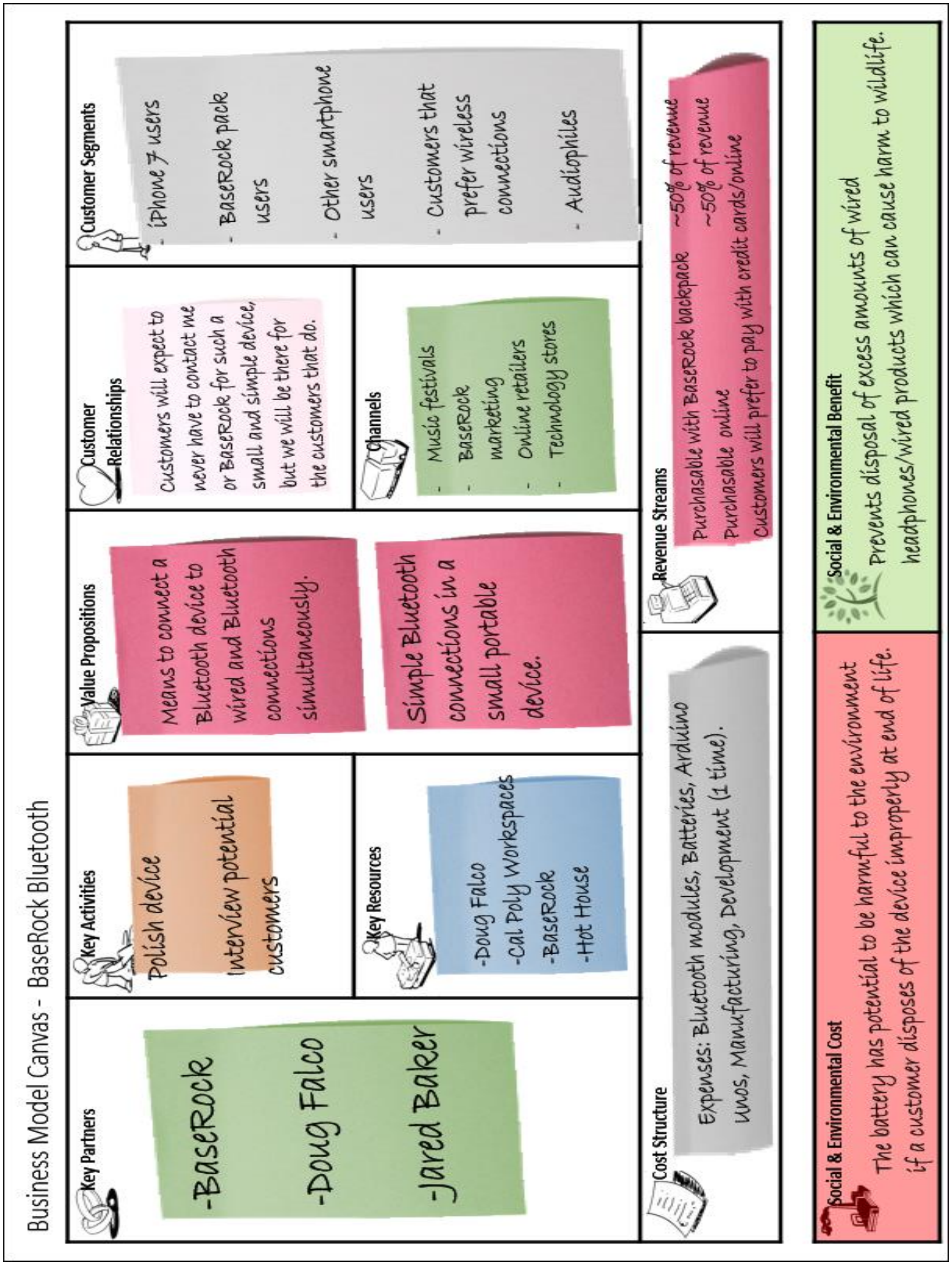
With all the strengths that BaseRock Bluetooth has over its competition, steps should be taken to impede copy-cat products. BaseRock Bluetooth benefits from the relationship it has with BaseRock and can collaborate to create protection of its IP. An area of the market that is not well served is devices with headphone jack capability that cannot connect to a Bluetooth only device. In addition, the market for portability and battery power are not served well. The window of opportunity for this market is closing fast, as it is highly likely audio companies are presently in the stages of developing products that will rival BaseRock Bluetooth. Once developed, BaseRock will already be ready with marketing and sales to push BaseRock Bluetooth to the correct customers.

Table 2: BaseRock Bluetooth Advantages and Disadvantages

Advantages	Disadvantages

• Dual outputs
  ○ 3.5 mm wired connection
  ○ Bluetooth wireless connection
• Simultaneous output capability
• Portable
• Battery powered
• High audio quality
	• Needs to be charged
	• Bluetooth audio signals could become corrupted from time to time

Business Model Canvas



Marketing Requirements

The manufactural BaseRock Bluetooth should be 6.5 cm x 3 cm x 2 cm to fit snugly onto the control module of the BaseRock pack. This small size will also accommodate portability and interoperability with other products on the market. The battery will be chosen to last as long as possible; eight hours of operation on one charge is a good target and definitely attainable if low power modules are used. A goal of zero latency is desired. However we can allow up to 10 ms of latency as humans just barely notice leading or lagging of audio in that amount of time.

Table 3: Marketing Requirements Notes

Customer Need	***Importance High(1-5)Low***	***Weight***	***Notes***
Size	5	3%	Size won't really matter to customers without the BaseRock pack. The ability to fit into the control module is an ideal outcome but not imperative to product success.
Portability	3	9%	The ability to take this product to most places on earth is not of utmost importance in the first iteration of design. Versatility in typical living environments is important. This product should work in a variety of conditions but does not need to be waterproof, freeze proof, etc.
Battery Powered	4	7%	To the customer, it is not critically important that the device be battery powered, as long as it is able to easily be powered by a phone or some convenient source, the customer will be satisfied.
Battery Life	2	13%	If the battery is included, customers will expect it to be top of the line. It will be very important to customers that they do not have to keep charging the device after a short durations of use.
Audio Quality	1	22%	This may be the single most important aspect of this product. If our device degrades the quality of the audio signal being passed to it, then customers will believe it is a low quality product. Audiophiles especially will get angry at signal degradation and will hate the product.
Ease of Use	2	13%	Customers don't want to learn about how Bluetooth works or how audio signal processing works in order to use this product. Customers are most happy when a very technical device is plug and play. It makes them look smart and tech savvy for being able to use a handy piece of equipment.

Durability	3	9%	The ability of this product to survive drops from a standing height is important to most customers. But the ability to survive a hammer strike or getting run over by a car, etc. is not something customers would reasonably expect.
Simultaneous Outputs	1	16%	Simultaneous outputs is one of the selling points and if this device didn't offer this capability, customers will feel cheated and reasonably get angry and hate the product.
Aesthetics	3	9%	While it is not imperative for the device to look as slick as the new iPhone 7, if the device looks ugly, customers won't want to purchase or use it.

Table 4: Engineering Specifications

Customer Need	***Notes for Minimum Viable Product (MVP)***
Size	The device will not tailor to this specification in the initial phase. It is more important to create a working MVP than a small product that does nothing. Towards the end of the development process the device will have to be shrunk to fit inside a 6.5 cm x 3 cm x 2 cm cavity.
Portability	Again, not important for a MVP. Once a prototype has been successfully tested, the BaseRock Bluetooth can be made to be portable. For this specification to be met, the device should be able to operate without any cords, and have the ability to be brought most anywhere. Adding a clip to the back of the product may greatly improve portability; a user could clip the device onto a backpack and not have to worry about losing it while running or jumping. This specification overlaps slightly with durability; the ability to be brought most places comes with the caveat that the device must be durable enough to operate in various environments.
Battery Powered	Imperative for an MVP. The device must have all operations powered by an on device lithium-ion battery.
Battery Life	Not important for MVP but of huge importance towards end of design process. Battery must have enough milliamp hours to supply operation of two Bluetooth modules, for a minimum of 4-5 hours.
Operating Range	The device is expected to be close to the music source and the Bluetooth speakers it is transmitting to. It should work without problem in a range of 4-5 meters.
Audio Quality	Audio quality is of the highest importance at all stages of the development process. If BaseRock Bluetooth does not provide high quality audio, then it becomes a near useless hunk of circuits. The full range of the audible spectrum including some subsonic frequencies should be able to be passed into the device without any clipping, latency, or signal degradation. Frequency range goal of about 10 Hz to about 20,000 Hz is desired.

Ease of Use	Not important for MVP, but very important for an end product. Many customers will not be tech savvy, thus the easier the product is to use, the better. A goal for this product would be for the first operation of the device to require only four inputs from the user. Switch the power on, pair to it with a music source, press the button that tells the device to search for a speaker or headphones to pair with, and finally power off when the user is finished with it. Subsequent operations would only require the user to power the device on and off.
Durability	Overlapping with portability, durability requires the device to withstand operation in adverse environments. Durability is not important in the MVP. But, the final design is expected to meet these durability requirements: survive a drop from 6 ft onto concrete, function in temperatures ranging from 120 ^{o}F to 20 ^{o}F, survive constant jumping motion, crushproof up to 50 lbs, resistant to dust, salt, humidity up to 80%, rain and water, vibration, and thermal shock.
Simultaneous Outputs	This design requirement is also of utmost importance for every iteration of the design process. This requirement is part of the devices functional description, and without it, the device would be no better than a $20 device a user could purchase online. Instantaneous synchronization of the device should reach a maximum of 10 ms difference between the two outputs. Humans are unable to hear difference in audio signals less than 10 ms.
Aesthetics	Also, not important for a MVP. For an end product, it will be very important. One of the tests that consumers perform subconsciously is whether or not a device looks good. In general, excess wires, circuit boards, and many colors produce unappealing aesthetics. The trend for digital device aesthetics presently follows a minimalist style, where the device should be one solid dark color, with little to no wording on the façade, and buttons/switches that are not prominent.

Marketing Data Sheet

Product/Project Name: BaseRock Bluetooth

Unmet Customer Need: A simultaneous multiple output audio splitter that takes Bluetooth signal and allows a wired output with a Bluetooth repeater.

Unique Value Proposition: Allows customers with the iPhone 7 to use wired headphones/wireless headphones + wired aux device like the BaseRock backpack.

Target Customer: BaseRock backpack owners, Customers who want simultaneous wired/Bluetooth outputs.

Positioning: Connect and listen ®

Pricing and Availability: ~<$50, Spring 2017.

Product Objectives: This product tries to create a market where the iPhone 7 created one with the removal of the headphone jack.

Customer Benefits: Able to use wired headphones with the iPhone 7, Able to split 1 audio signal to 2 outputs, able to choose wired or wireless outs/ins

Sustainable Differentiation: ease of use, swiss army knife of audio ins/outs, small, battery powered

Disruptive Go-to-Market: Music Festivals, Social Media, Bundled with BaseRock backpack

Block Diagram, Requirements, and Specifications

Figure 20: Level 0 Black Box Diagram

As seen in Figure 7, the device takes in a Bluetooth signal and outputs a Bluetooth signal and a simultaneous 3.5 mm wired analog connection. The Bluetooth signal is 2.4 to 2.485 GHz, frequency hopping, full-duplex at a nominal rate of 1,600 frequency hops/sec.

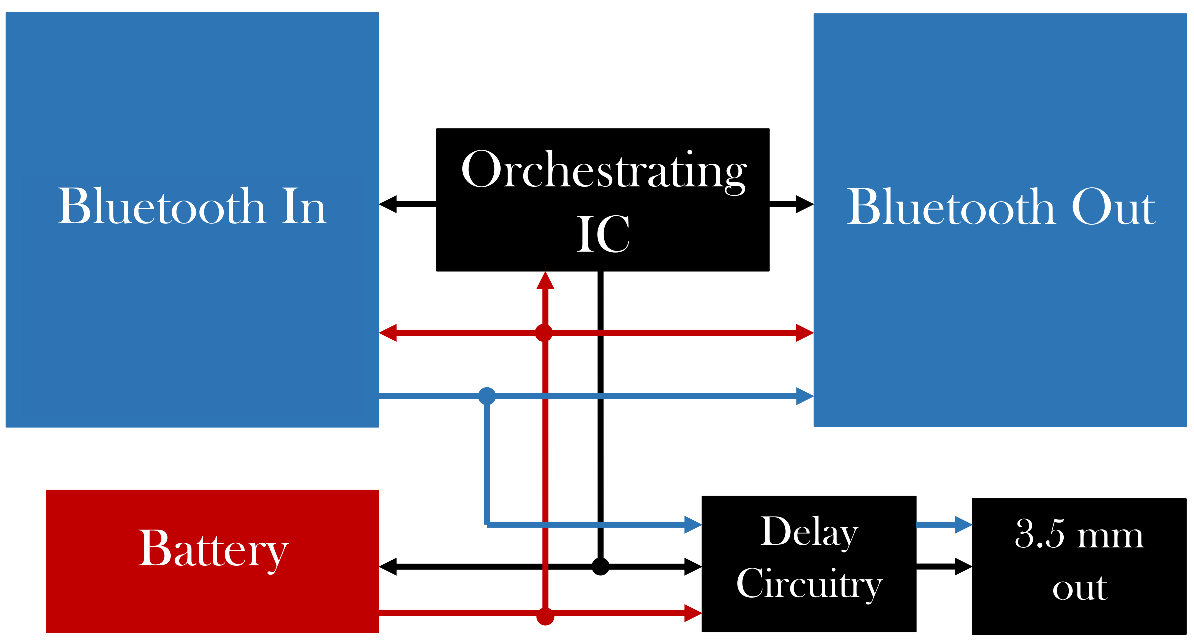


Figure 21: Level 1 Black Box Diagram

Table 5: Module Functional Requirement

Module	***Specification***
User Interface	Consisting of an On/Off button or switch, two buttons that cause the outgoing and incoming Bluetooth modules to begin pairing, battery indicator light, Bluetooth connection status lights, and a micro USB charging port.
Aux-out to 3.5 mm jack	This module contains circuitry that drives the output of the 3.5 mm headphone jack which will connect to the BaseRock pack and other wired connection devices.
Bluetooth in Module	This module is in charge of receiving the incoming Bluetooth signal from the signal producer. It will be in charge of maintaining a handshake with the other device and taking incoming wireless signals and converting them into a wired signal.
Brain Circuitry (Arduino Uno)	This module will contain the IC of the project that will control things like the illumination of the connection status indicator lights and the process of connecting to the Bluetooth devices. It will talk with the latency control, the user interface, the output selector, and the battery monitoring circuitry.
Latency Control	This module will control any latency between the two outputs by staggering a few milliseconds of signal so the other output can "catch up" to the stored output.
Bluetooth out Module	This module is responsible for taking a wired signal in and converting it into a wireless Bluetooth signal and sending it to the Bluetooth dependent device. It must maintain handshake with the device that is receiving the Bluetooth signal.
Charging Circuitry	This circuitry provides some protection to the battery to prevent damage to the battery from surges or problems in the power source.
Battery Monitoring Circuitry	This circuitry will protect the battery from any module drawing too much power. It will also track the life of the battery and relay that information to the brain circuitry.
Battery	The powerhouse of the project, it will provide power to all modules. It will be able to provide power for a minimum of 4-5 hours of continuous operation.

Table 6: Testing and Verification Requirements

Customer Need	Desired Results for MVP
Low Latency	Difference between simultaneous outputs is <10 ms.
Battery Life	Full operation for minimum of 4-5 hours. Rechargeable.
Audio Quality	No clipping or signal degradation when comparing output signals to input signals. Frequency passband of 10 to 20,000 Hz.

Gantt Chart

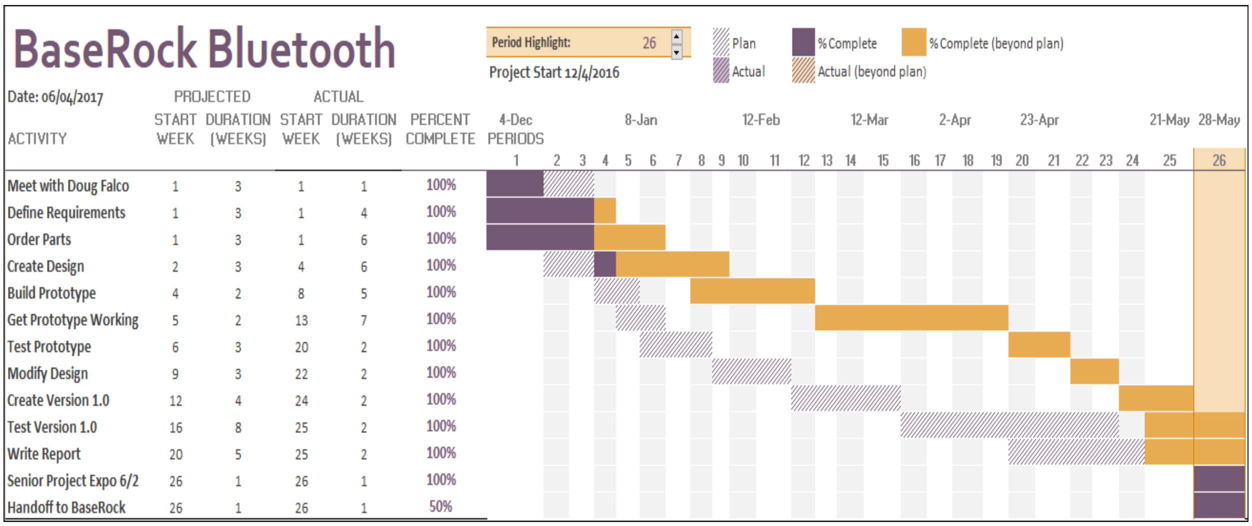


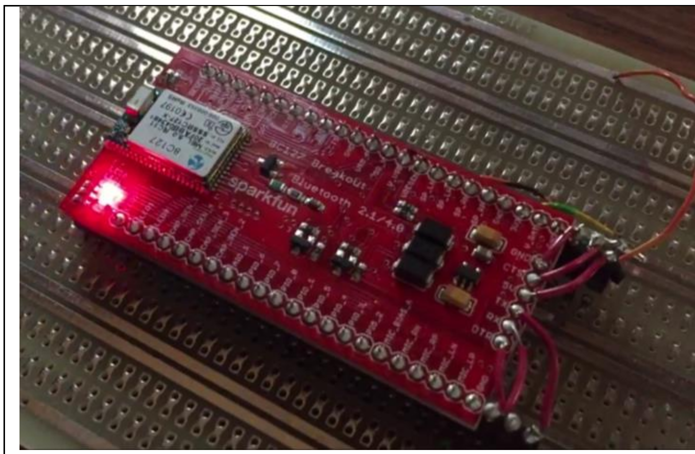
Table 7: Bill of Materials

		Senior Project: BaseRock Bluetooth					
		TEAM: Jonathan Falco					
		DATE/REV: 6/2/17 VERSION V 1.0				USA	Total
Sub	**Sub**	**Description**	**Qty**	**MFG**	**MFG P/N**	**Price (USD)**	**Cost (USD)**
First	Build -	Model A - Prototype Design	1			0	0
1	Unit	<BaseRock Bluetooth>	1			0	0
	1	SparkFun Bluetooth Audio Breakout - BC127	2	Digikey	1568-1263-ND	44.95	89.90
	2	Lithium Ion Polymer Battery 3.7V 1200 mAh	1	oddWires	LP503562	4.50	4.50
	3	Headphone Jack Male	1	oddWires	CWJ-0000011	0.90	0.90
	5	Tactile Micro Button Switch	10	Sparkfun	-	0.15	1.50
	6	Princeton Technology Corp. Echo Processor	2	Amazon	PT2399	1.60	3.20
	7	Arduino Uno	1	JamesCo	A000073	21.95	21.95
	8	Switch	1	Sparkfun	COM-00102	1.50	1.50
	9	2X5.5 mm Power Jack	1	Digikey	CP-102A-ND	0.64	0.64
						Total	124.09

Hardware Development

Two “SparkFun Bluetooth Audio Breakout - BC127” boards were ordered from Digikey.com. The BC127 chip was selected because it comes preloaded with BlueCreation Melody software, and is ideal for smartphone controlled audio systems and high quality audio streaming.[1] It is compatible with many Bluetooth connection profiles including AVRCP (Audio/Visual Remote Control Profile), A2DP (Advanced Audio Distribution Profile), HFP (Hands Free Profile), and many other Bluetooth classic profiles.

The boards had many operations already pre-configured, from battery charging circuity to LED indicators to UART communication. These helped facilitate many of the features planned in the engineering specifications (see Figure 9).



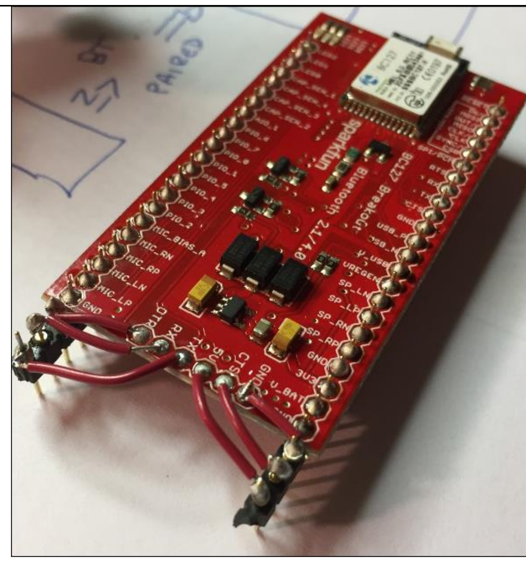


Figure 22: SparkFun Bluetooth Audio Breakout BC127

The melody software on chip is very easy to communicate with. Serial data received on the Rx port is interpreted as a commands for the BC127. Any command will elicit a response by the module in the form of a string composed of ASCII characters, terminated by both a new line ‘\n’ and a carriage return ‘\r’. The two most common responses are “OK\n\r” and “ERROR\n\r”.

The BC127 is connected to the breakout board according to the following schematic (see Figure 10).

[1] https://cdn.sparkfun.com/datasheets/Wireless/Bluetooth/DataSheet-BC127.10.pdf

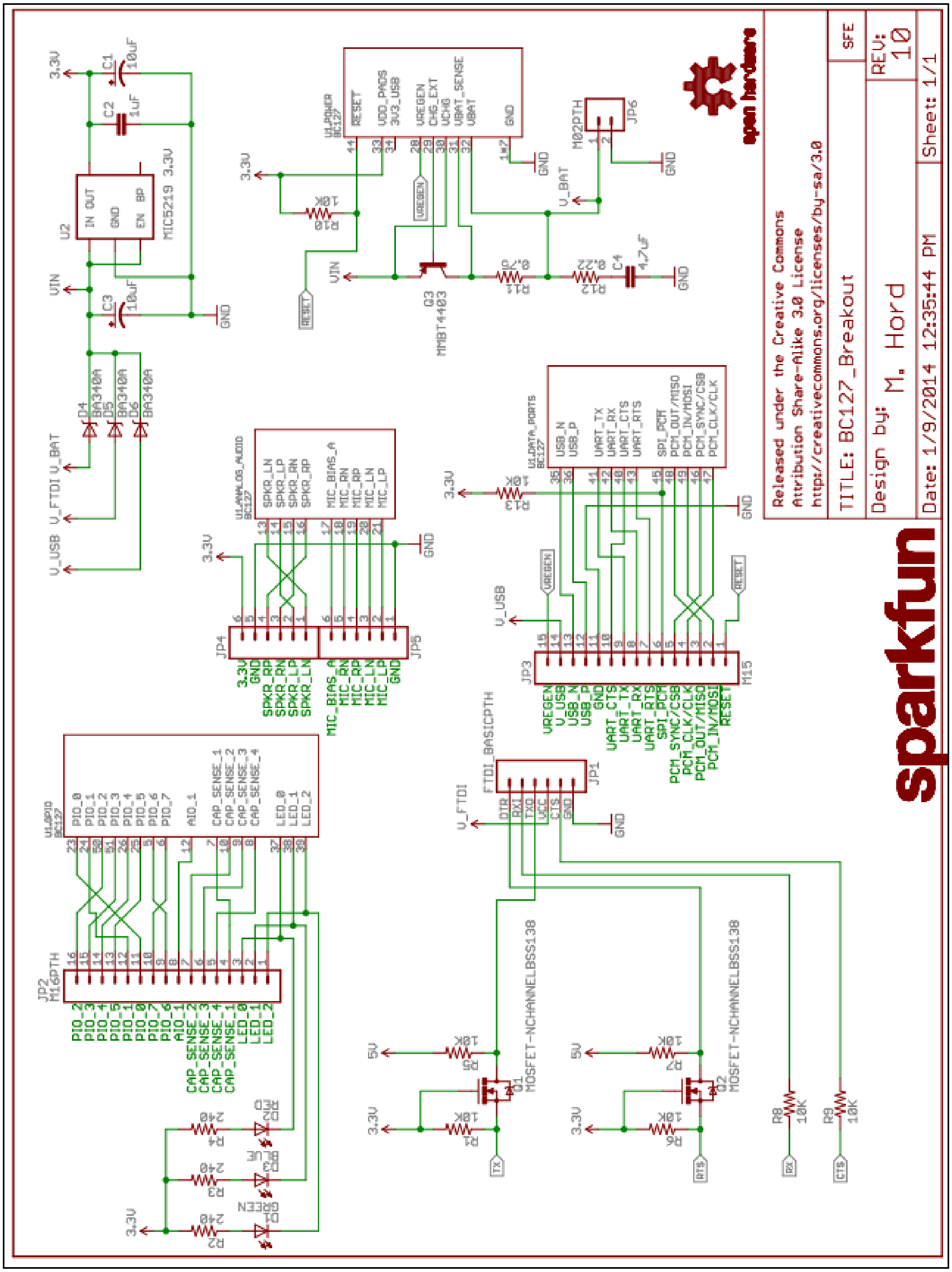


Figure 23: BC127 Breakout board Schematic[2]

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[2] "[BC127 Breakout]" by [M. Hord] is licensed under [CC BY 3.0]

Once BC127 modules were prepped, remaining steps were to figure out battery storage, connect analog audio headphone jacks to the inputs and outputs, create software for an Arduino to orchestrate the two chips, and correct any audio latency between the Bluetooth and the headphone jack output.

Battery Storage

In order to calculate necessary battery storage, a Rigol DP832 Programmable DC Power Supply was used to provide 5V and an Agilent U3606A Multimeter connected in series with the V_{DD} wire to measure the current in milliamps. A feature on the Agilent multimeter recorded maximum, minimum, and an average of 50 current readings. These values were recorded while the device was in the following modes: searching, connected with no music playing, and connected with music streaming (see Table 8).

Table 8: BC127 Power Consumption Measurements

Operating Mode	Max value (mA)	Average (mA)	Min value (mA)
Searching	11.903	7.568	5.178
Connected/Standby	22.227	12.354	11.712
Music Streaming	66.004	60.239	58.259

BaseRock wants the backpack to run for 8 hours before needing a charge. 60 mA is the average current the device draws while in music streaming mode, which is the mode it will be in for the majority of the time.

$$60\ mA\ x\ 8\ hrs = 480\ mAh$$

BaseRock Bluetooth will have capability to take Bluetooth signals in while simultaneously outputting Bluetooth signals which requires two separate Bluetooth chips. This doubles power consumption.

$$480\ mAh\ x\ 2 = 960\ mAh$$

A 1.2 Ahr battery was purchased from Oddwires.com, well above the 0.96 Ahr need. The battery came with charging functionality and overdraw protection and was implemented using the following schematic (see Figure 11).

Note: The Arduino module in the version 1.0 is not factored into the power consumption because it is only needed during assembly. Once the BC127s have their commands set, they can store the commands in flash memory and perform simple operations on their own.

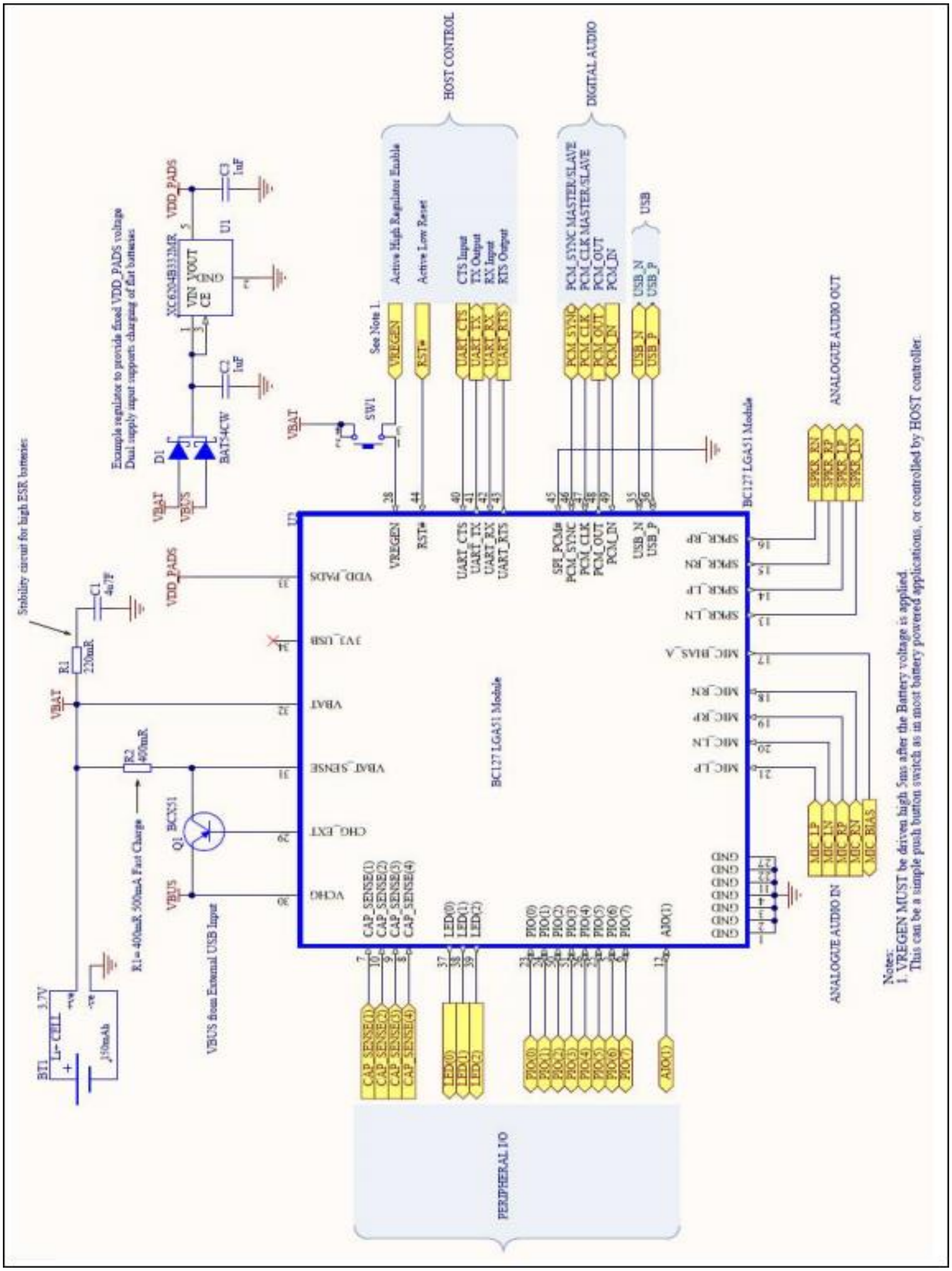

Figure 24: BC127 Battery Hookup Diagram[3]

3 https://bluecreation.com/fdownload.php?file=bc127-harddesign-003-1429770877.pdf

Analog Audio Input/Output

The BC127 chip makes it easy to implement analog audio. An on chip ADC and DAC allows for either streaming audio from an analog headphone jack to a Bluetooth connection or streaming audio from a Bluetooth connection to an analog headphone jack. The first chip establishes a Bluetooth link with a music source. The on chip DAC converts the audio stream into an analog signal. Output of the first chip is then connected to the Microphone input of the second chip. An ADC on the second chip then converts the analog audio signal into a digital audio signal and sends that via Bluetooth to headphones. The analog audio signal sent to the backpack is spliced off wires that connect the input and outputs of the two chips (see Figure 12).

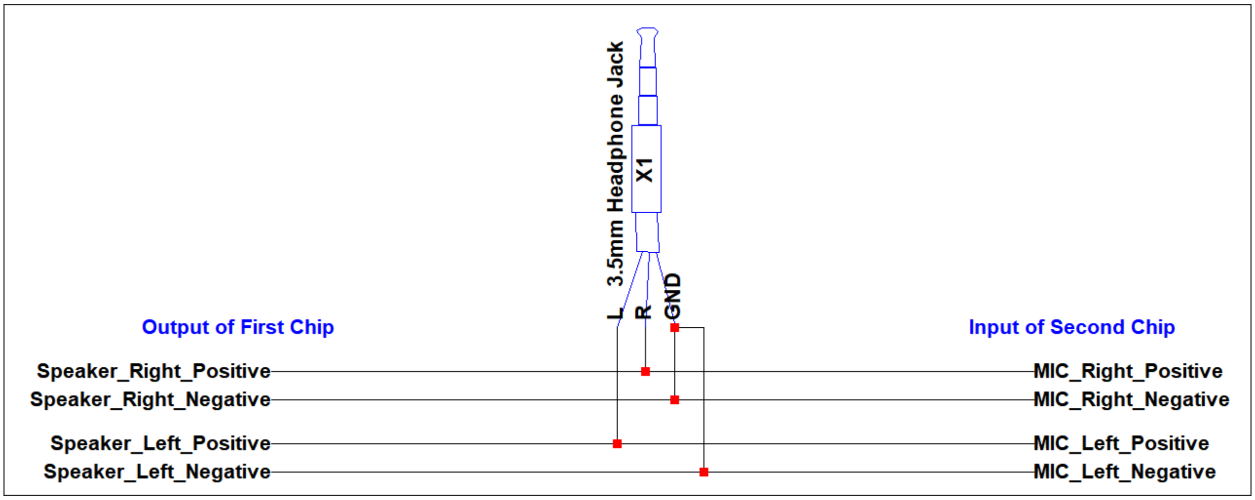

Figure 25: Analog Audio Signal Hookup Diagram

Orchestrating Software

There are many coding examples online showing how to operate the BC127 modules. Open source code from Sparkfun.com was used to get a foundation on how the modules operate.

After powering on, an Arduino UNO restores two modules to factory default settings, then advertises the first chip for a Bluetooth music source to connect. On successful connection, the first chip plays a tone through its speaker wires, although the tone can only be heard if the headphone jack output is connected to a speaker.

The Arduino then commands the second chip to look for a speaker to connect. When the second chip finds a speaker or multiple speakers, it is instructed to connect to the device with the highest signal strength. The user can be certain it is the speaker they want by minimizing the physical distance between the project and the desired speaker. When the second chip forms a connection, both chips open their streaming channels and music is channeled through.

While the connection is established the Arduino periodically checks both the connection statuses for errors and the battery level. Upon disconnection of the second Bluetooth connection, the first chip will continue to stream while the second chip will attempt to reconnect five times. After five attempts, the second chip will enter power save mode until the user prompts it to create a new connection or reconnect. Upon disconnection of the first chip, the second chip will enter power save mode until the first chip re-establishes connection. The first chip will try to reconnect five times. After five attempts, the first chip will enter power save mode until the user prompts it to reconnect or to advertise.

If the battery should reach a 3.2 V threshold the device will play a low battery tone once every minute for five minutes. After five minutes the product will shut itself off pending recharge by the user. The product will indicate with tones to the user when the battery level is half and three quarters empty (see Appendix B for the code).

Audio Latency Correction

When the product first played music, there was a significant audio delay between the signal from the headphone jack and the second chip Bluetooth output. The data sheet says it takes about 20 ms for the incoming audio signal to be converted and sent via the Bluetooth link. To attempt to correct the latency problem, Professors Prodanov, Smilkstein, and Pilkington were consulted for advice. There were many solutions for analog audio signal delay that were no longer being made due to the prevalence of digital signal processing. A promising solution was the PT2399 Echo Processor. This chip has an ADC, a 44K shift register array, and a DAC. It claimed to allow the implementer to delay audio signals up to a second. The chip even has the ability to adjust the delay by trimming a potentiometer connected to pin 6 (see Figure 14). The attempt to rectify the delay between the two signals by utilizing the PT2399 encountered some problems.

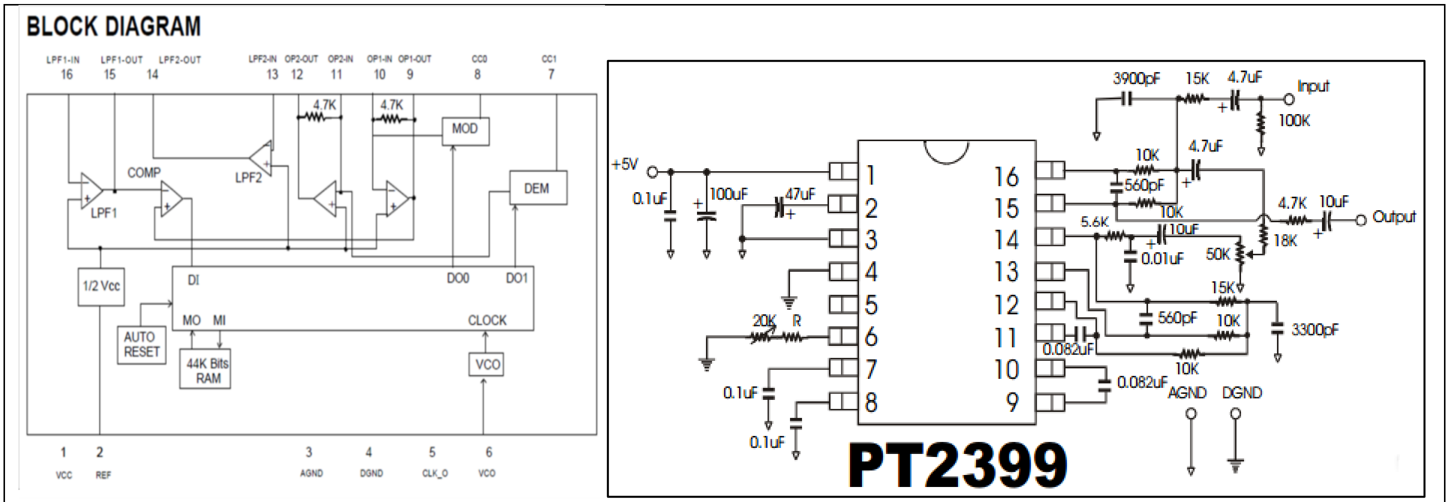

Figure 26: PT2399 Block Diagram and Delay Circuitry

Taken from PT2399 Datasheet

When hooking the PT2399 to the same power source as the BC127 modules. A strong buzzing noise signal appeared on the output of the PT2399 circuit. This was likely feedback from the BC127 on the ground plane. The problem was fixed by placing large capacitances in-between the power rail and the ground plane. A second and more serious problem was inherent to the chip. When implementing the circuit in Figure 14, the output did not produce the desired result. Instead of delaying the signal, it created an echo effect. Attempts to fix the latency problem are still in progress as of June 5th, 2017, and with the help of peers and/or professors, the latency should be taken care of before the project is handed off to BaseRock.

Testing Procedures

Table 9: Testing Results

Customer Need	***Criteria for Pass***	***Result***
Size	Can the device fit inside a 6.5 cm x 3 cm x 2 cm cavity?	*Conditional Pass* The Bluetooth modules are 11.8 mm x 18 mm x 6.4 mm if stacked one on top of the other which would take up only 3.4% of the allowed volume. If the battery can be designed into a custom shape and the wiring can be done in an efficient manner, the device will easily pass this requirement.
Portability	Can the device operate without cords?	*Pass* The device is fully operational without any wires connected.
Battery Powered	Can all operations of the project be battery powered?	*Pass* A Li-Po battery provides adequate power to all modules
Battery Life	Does battery support full operation of the device for 4-5 hours?	*Pass* Device ran on battery power streaming music for 6 hours on 5/13/17 without depleting the battery.
Audio Quality	Can an audio range of 10 Hz to about 20 kHz pass through the device without clipping, latency, or signal degradation?	*Conditional Pass* Music sent into the device was reproduced with no noticeable signal degradation, or clipping. However, significant latency was present. The DAC resolution is 16 bits and the DAC Output Sample Rate is 90 KHz as per data sheet. The SNR of the DAC is 96 dB. Pass is conditional upon the fixing of the latency.
Ease of Use	Upon first operation of the device, and subsequent operations, does the total actions the user must perform equal four or less?	*Pass* Upon first operation, the user is required to switch the power on, pair a music source with the product, and press a button to pair the device with a speaker or headphones. Subsequent operations would only need the user to power the device on and off.
Range	Does the device operate without signal loss in a range of 4-5 meters?	*Pass* Device was able to operate without loss when both the source and the speakers were about 20 feet away (~6 meters). 5/13/17
Dual Outputs	Can the device produce two simultaneous outputs, one wired, one Bluetooth, capable of less than 10 ms difference?	*Conditional Pass/Fail* The device produces two outputs, but they are not synched below the 10 ms threshold. This is a conditional pass if the latency can be made less than 10 ms.

Implementation of the engineering requirements was mostly satisfactory. Two factors that prevent this project from being a total success are size and latency. The size can be addressed with the knowledge that this project is not a final product and as it develops, it will become smaller and smaller until it reaches its specification. Latency is the biggest threat to the success of this product. As long as the audio streams are not synched, the product will be

unmarketable. Hopefully, this problem can be solved in the coming weeks. Should the problem not be fixed, there are a few options for BaseRock to consider.

Conclusion and Recommendations for BaseRock

BaseRock Bluetooth was the most ambitious project I have ever undertaken. I do not consider it a 100% success at the present time but remain very proud of the hard work I put into the project. It was an interesting experience and I gained knowledge about Bluetooth communication, and also confidence in my own abilities by designing a product from scratch.

Although, the project is not 100% finished, I do have some recommendations for the company that commissioned me. The BaseRock backpack is a new and inventive product that has gathered great attention worldwide as the world's first wearable subsonic woofer system. Even when I was showing off my senior project at the Senior Project Expo, the BaseRock name attracted many people to my booth, asking questions about the backpack. The purpose of my senior project was to provide the BaseRock backpack with Bluetooth connectivity. This goal has been achieved but I have some points I'd like BaseRock to consider before implementing my solution:

1.) It may be a good strategy to wait and see what develops in the mobile phone market in the next few years before rushing to make the backpack Bluetooth compatible. While it turns out the lack of the headphone jack did not hurt Apple's US sales, Bluetooth tends to cost significantly more and provides poorer quality than wired connections. The plethora of dongles on the market today proves that people who are into audio prefer wired connections.

2.) Instead of providing another device for customers to purchase with the BaseRock, it may be smarter to implement Bluetooth compatibility inside the BaseRock backpack. Considering the minimum amount of cost required to manufacture the small device, it may be hard to make a profit. A BC127 module costs $20 and having two Bluetooth modules and a battery would make the device cost at least ~$60. A possible solution to the Bluetooth problem could be to add a single Bluetooth chip to the backpack itself. An additional $20 tacked on to the BaseRock backpack price may be more competitive than an additional device costing $60. Also, it is much simpler to implement one Bluetooth chip than implementing two.

I stand by the product I've created and am happy to present BaseRock with the results of a year of work. I hope the BaseRock Bluetooth serves the company well, and I wish everyone at BaseRock the best of luck for the future!

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Appendix A: Analysis of Senior Project

Project Title: BaseRock Bluetooth
Student: Jonathan Falco
Advisor: Jeff Gerfen

1) Summary of Functional Requirements
    a) The project serves as a way for customers to create Bluetooth connectivity for non-Bluetooth devices. The device takes a Bluetooth signal from an audio source, duplicates it, and simultaneously outputs the signal at both a wired 3.5 mm headphone jack and a wireless Bluetooth stream. Its primary function is to help customers who have the BaseRock pack, a non-Bluetooth device, and the iPhone 7, a Bluetooth only device.
2) Primary Constraints
    a) The biggest challenge for this project was selecting a Bluetooth module well suited for "simultaneous" output. This module will have to be able to operate with an identical module broadcasting the exact same signal in very close proximity, which could be a source for infinite loops, noise, feedback, and loss of connection. The second major challenge was in making the outputs simultaneous. The problem lies in the nature of the device itself. Making an audio signal go from analog to digital to broadcasting it via Bluetooth takes time as each conversion has specific operations associated with it. That time, although very short, creates latency detectable enough for an average listener to notice. The third biggest constraint was power. Running two Bluetooth modules on the same battery has the potential to put a huge strain on a small battery and perhaps even ruin the battery lifespan. I researched how to preserve battery life and made sure that I found low power Bluetooth modules which were still robust enough to accomplish all that I asked of them.
3) Economic
    a) What economic impacts result?
        i) Human Capital: The development of this product could create jobs in engineering, sales, accessibility for disabled persons, manufacturing, and distribution. However, I doubt if the product does take off, the amount of jobs created will exceed 50.
        ii) Financial Capital: Customers in our target market will receive a huge gain. Many people would love to pay a nominal amount for a device that allows their old devices to be easily retrofitted instead of having to buy completely new products. In the existing market, this product will add big competition as it allows the Bluetooth connectivity of two devices for the same price that the competitors are charging for connectivity for just one device.
        iii) Natural Capital: The product utilizes many electrical components, as well as an IC and a battery. Proper disposal and electronic-waste recycling of the project is important to prevent environmental destruction as the materials the components are made of can be toxic to both humans and the environment.

iv) Costs / Timing: The main cost of this project will be in the Bluetooth modules. The BC127 modules cost $20 each. Foreseeably in the far future, it may be beneficial to develop a custom Bluetooth module to cut costs, and improve performance.

Table 10: Prototype Cost

Part	Quantity	Provider	Cost ($)
BC127 Modules	2	Digikey	89.90
LiPo Battery	1	oddWires	4.50
Buttons	10	oddWires	1.50
PT2399s	2	Amazon	3.20
Switch	1	Sparkfun	1.50
Headphone jack male	1	oddWires	0.90
Arduino Uno	1	JamesCo	21.95
Switch	1	Sparkfun	1.50
2x5.5 mm Power Jack	1	Digikey	0.64
Total			125.59

4) If manufactured on a commercial basis:
- **a)** ~100 products sold in the first year.
- **b)** Estimated manufacturing cost: ~$126 as per table 8. Future manufacturing costs must be driven lower as price for the device is targeted for <$50.
- **c)** Estimated purchase price for each device: $150. Again, preliminary devices will be much more expensive than mass manufacture devices.
- **d)** Estimated profit per year: (100 * $150) - (100 * $126) = $2,400
- **e)** Estimated cost for user to operate device, per unit time: Maximum use would require the user to charge the device two times a week. If the battery houses 1,200 mAh with a operating voltage of 3.7 V, 3.7 V x 1.2 Ah = 4.44 Wh. If power is priced at 50¢ per kWh, 4.44/1000 * 0.5 = 0.00222¢ per charge. 52 weeks * 2 charges per week * 0.00222¢ per charge = 0.12¢ per year. Operating the device for three years with maximum usage costs less than a dollar.

5) Environmental
- **a)** What environmental impacts are associated with manufacturing or use?

- **i)** This project's main environmental impact comes from disposal of the device at the end of life. The components and the battery have the potential to cause toxic harm to the environment if disposed improperly.

b) Which natural resources and ecosystem services does the project use (directly and indirectly), improve, or harm?

- **i)** Lithium ion batteries are dangerous and hard to make. They require a lot of energy and chemical processes to fabricate. Additionally, the services many people do not consider when recycling batteries are not the best. Many times, batteries cannot be recycled and are put in specialized dumps to toxically rot away.

c) How does the project impact other species?

- **i)** Many customers in our target market will use our product for outdoor concerts. These customers will need to be conscious enough to neither break nor lose the product. But, realistically, there will be customers who either don't care about the environment or are too incapacitated by drugs/alcohol to make conscious decisions or both. This product is small enough however, to have small impact on the environment.

6) Manufacturability

a) Describe any issues or challenges associated with manufacturing.

- **i)** The manufacturing of the Bluetooth modules will provide the most difficulty as there are a lot of aspects about them that must be considered when building: frequency hopping, power consumption, handshake to name a few.

7) Sustainability

a) Describe any issues or challenges associated with maintaining the completed device.

- **i)** In terms of product life, the battery and the buttons will be the limiting factors for how long the product will last. Buttons have a large but limited number of presses before they fail. Choosing durable buttons with lots of pushes will improve the life of the product. The battery is a huge constraint as well. Most batteries degrade gradually, decreasing their total capacity by a small amount each charge cycle. Making sure the battery and the charging of the battery are handled with care will be imperative in improving the lifespan of the product.

b) Describe how the product impacts the sustainable use of resources.

- **i)** As mentioned above, lithium ion batteries will be implemented in this design. The development of these batteries must be regulated to insure there are no adverse environmental side effects. Customers must also recycle them responsibly.

c) Describe any upgrades that would improve the design of the project.

- **i)** Improving the Bluetooth modules to be more robust and use less energy would be a huge improvement to the design of the project.

d) Describe any issues or challenges associated with upgrading the design.

- **i)** The biggest challenge in upgrading the project is understanding how to make a Bluetooth module and then fabricating. It would require a lot of research and understanding to come up with a Bluetooth module design and then another huge amount of research to build and implement one, and then another huge amount of research to figure out how to mass manufacture the modules.

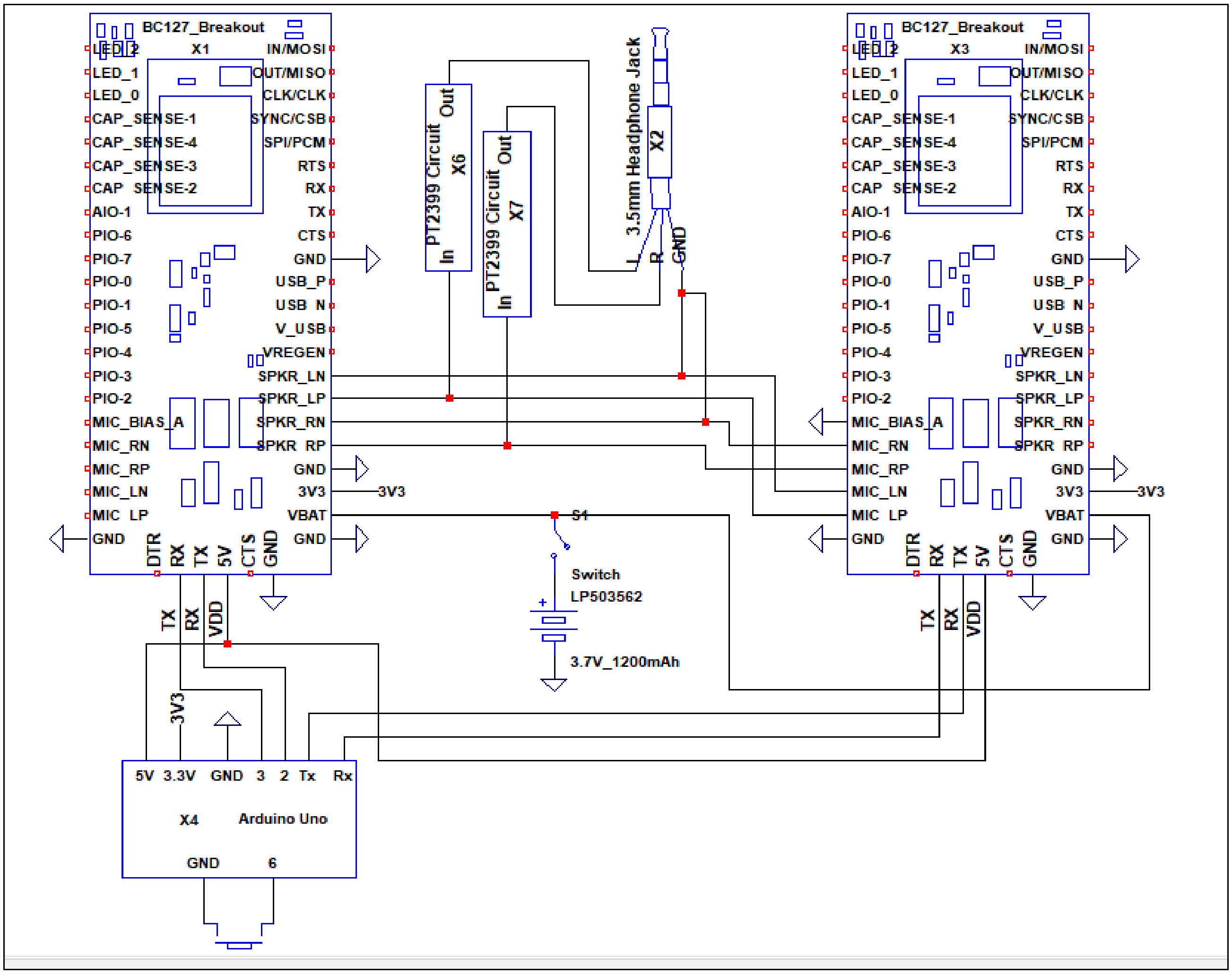
8) Ethical
   a) Ethical implications relating to the design, manufacture, use, or misuse of the project:
      i) This product would have very positive ethical implications as it allows customers to breathe life into older products that aren't Bluetooth equipped. This prevents the useless spending of money to buy new Bluetooth friendly products, the throwing away of old devices to landfills.

9) Health and Safety
   a) Health and safety concerns associated with design, manufacture or use of the project
      i) In the back of everyone's mind with the recent Note 7 battery catastrophe is the health and safety of all customers who use devices that have batteries. With the batteries comes the inherent danger that they could short circuit and or burn the customer. With this concern, this product is engineered with safety in mind so as to protect any human using this product.

10) Social and Political
   a) Social and political issues associated with design, manufacture and use:
      i) To keep ethos and credibility, the product must perform as advertised with little failure at any point in the operation life. In a world where excellence in electronic devices is expected, any failure of the device may cause irreparable damage to its reputation.
   b) Who does the project impact? Who are the direct and indirect stakeholders? How are they affected?
      i) The product impacts the customers and the companies that will sell our product. If something goes wrong, the customers may be physically hurt and the companies will have to recall all the devices causing a huge loss in profits. Again, if anything goes wrong, lots of people, almost everyone involved with the device, will lose money and time.

11) Development
   a) New tools or techniques, used for either development or analysis that were learned during the course of this project:
      i) During the development of this product, I will learn a lot about how Bluetooth works and how batteries work. This will build my knowledge in electrical engineering and help me be a more competitive employee in the future market.

Appendix B: BaseRock Bluetooth Schematic



Appendix C: Arduino Programming Code

```
// Jonathan Falco 5/18/2017 BaseRock
#include <SparkFunbc127.h>  //All functions specific for BC127 Chip coded by Sparkfun
#include <SoftwareSerial.h> //<-- Should be included with Arduino Uno libraries.
                            //^Can be tracked down on internet if needed.
                            //This code will probably only work on Arduino Uno.

// create virtual serial port 'cuz time-sharing with uploading code is a pain.
SoftwareSerial swPort(3,2); // Digital port 3 is RX, and port 2 is TX
//SoftwareSerial debugPort(5,4); //used for debugging
//Create a BC127 and attach software serial port to it.
BC127 BTModu(&swPort); //This is transmitting device
BC127 BTModu2(&Serial); //This is receiving device

// Aliases for the input and output pins we're going to use.
#define BUTTONPIN 7

void setup()
{ // Serial port configuration. Default speed for BC127 is 9600 baud.
  Serial.begin(9600);
  swPort.begin(9600);
  //debugPort.begin(9600);
  String buffer = "", buffer2 = "";
  pinMode(BUTTONPIN, INPUT_PULLUP);
  delay(220);//Wait for chips to boot
  BTModu.stdCmd("POWER OFF");   //Turn off BCTX while user connects to the BCRX

  //BC127-Rx Setup
  SetBC127RX();

  //BC127-Tx Setup
  SetBC127TX();

  //Connect to a device
  BC127Connect();
}

String inBuffer = ""; //Arduino complains if this is included in the music streaming loop. It is fine here
String buffer = "";

int SetBC127RX() //Setup for the recieving chip
{
  int BC127RXres = BC127::DEFAULT_ERR;
  String bufferRX = "";
  //Overwright existing settings to factory defaults.
  BTModu2.exitDataMode(1000);  //Exit Data Mode
  //This functions keeps returning a timeout error, possibly due to device not being in data mode in the first place.
  //Clear Device List
  if(BTModu2.restore() == 1)  //Restore
  {
    BTModu2.writeConfig();  //If restore is successful, Write
  }
  BTModu2.reset(); //Reset
  BTModu2.stdCmd("UNPAIR"); //Remove all previous connections
  BTModu2.stdGetParam("AUTOCONN", &bufferRX);
  if (!(bufferRX.endsWith("1")))
    { /*For all statements, second "get command" can be removed if memory low*/
      BTModu2.stdSetParam("AUTOCONN", "1");  //Autoconnect Enabled
      BTModu2.stdGetParam("AUTOCONN", &bufferRX);
    }
  bufferRX = "";
  BTModu2.stdGetParam("BLE_ROLE", &bufferRX);
  if (!(bufferRX.endsWith("0")))
    {
      BTModu2.stdSetParam("BLE_ROLE", "0");  //BLE Protocol Disabled
      BTModu2.stdGetParam("BLE_ROLE", &bufferRX);
    }
  bufferRX = "";

  BTModu2.stdGetParam("DISCOVERABLE", &bufferRX);
  if (!(bufferRX.endsWith("1 0")))
    {
      BTModu2.stdCmd("DISCOVERABLE ON");  //Discovey Enabled
      BTModu2.stdSetParam("DISCOVERABLE", "1 0");
      BTModu2.stdGetParam("DISCOVERABLE", &bufferRX);
    }
  bufferRX = "";
  BTModu2.stdGetParam("DEEP_SLEEP", &bufferRX);
  if (!(bufferRX.endsWith("ON")))
    {
      BTModu2.stdSetParam("DEEP_SLEEP", "ON"); //Deep Sleep Permitted
      BTModu2.stdGetParam("DEEP_SLEEP", &bufferRX);
    }
  bufferRX = "";
  BTModu2.stdGetParam("ENABLE_HFP", &bufferRX);
  if (!(bufferRX.endsWith("OFF")))
    {  //Hands Free Profile Disabled
      BTModu2.stdSetParam("ENABLE_HFP", "OFF");
```

```
      BTModu2.stdGetParam("ENABLE_HFP", &bufferRX);
    }
  bufferRX = "";
  BTModu2.stdGetParam("CLASSIC_ROLE", &bufferRX);
  if (!(bufferRX.endsWith("0")))
    {
      BTModu2.setClassicSink();
      BTModu2.stdGetParam("CLASSIC_ROLE", &bufferRX);
    }
  bufferRX = "";
  BTModu2.stdGetParam("AUDIO", &bufferRX);
  if (!(bufferRX.endsWith("0")))
    { //Audio set to
      BTModu2.stdSetParam("AUDIO", "0");
      BTModu2.stdGetParam("AUDIO", &bufferRX);
    }
  bufferRX = "";
  BTModu2.stdCmd("STATUS"); //Status check for debugging
  BTModu2.writeConfig(); //Write
  BTModu2.reset();   //Reset
  while (1) //Waiting for a device to connect to BCRX
  {
    //Buffer incoming serial data to check if connected.
    if (Serial.available() > 0) buffer.concat((char)Serial.read());
    // Check if it's a full line from the serial port
    if (buffer.endsWith("\r"))
    {
      // If the buffer has a connection message, break out of the loop.
      if (buffer.startsWith("OPEN_OK")|buffer.startsWith("PAIR_OK")|buffer.startsWith("SUCCESS"))
      {
        if (buffer.startsWith("PAIR_OK")) //If pair successful
        {
           delay(500); //wait for connection to establish
           bufferRX = buffer.substring(8,20); //Capture device address
           BTModu2.stdSetParam("REMOTE_ADDR", bufferRX); //Set as autoconnect address
           bufferRX = "";
           BTModu2.stdGetParam("REMOTE_ADDR", &bufferRX); //for debugging
           bufferRX = "";
           buffer = "";
           //BTModu.stdCmd("POWER ON"); //turn on other chip so it's ready for connecting
           //Possibly not getting enough time to boot the device
           BC127RXres = BC127::SUCCESS;
           break;  // Exit this while loop to the music streaming loop.
        }
        buffer = ""; //Reaching here means something has connected
      }
      buffer = "";  // Otherwise, clear the buffer and go back to waiting.
    }
  }
  if (BC127RXres != BC127::SUCCESS) return BC127RXres;
  return BC127RXres;
}

int SetBC127TX() //Setup for the transmitting chip
{
  int BC127TXres = BC127::DEFAULT_ERR; //Assume failure
  String bufferTX = "";
  BTModu.stdCmd("POWER ON");
  delay(200); //Needed for Successful Bootup
  //Overwright existing settings to factory defaults.
  BTModu.exitDataMode(1000);  //Exit Data Mode
  //This functions keeps returning a timeout error, possibly due to device not being in data mode in the first place.
  if (BTModu.restore() == 1)  //Restore
  BTModu.writeConfig();  //Write, if restore is successful
  BTModu.reset(); //Reset:
  BTModu.stdCmd("UNPAIR"); //Clear Device List
  BTModu.stdGetParam("AUTOCONN", &bufferTX); //Check and Enable Autoconnect
  if (!(bufferTX.endsWith("1")))
    { /*For all statements, second "get command" can be removed if memory low*/
      BTModu.stdSetParam("AUTOCONN", "1");
      BTModu.stdGetParam("AUTOCONN", &bufferTX);
    }
  bufferTX = "";
  BTModu.stdGetParam("BLE_ROLE", &bufferTX); //Check and Disable BLE Protocol
  if (!(bufferTX.endsWith("0")))
    {
      BTModu.stdSetParam("BLE_ROLE", "0");
      BTModu.stdGetParam("BLE_ROLE", &bufferTX);
    }
  bufferTX = "";
  BTModu.stdGetParam("ENABLE_HFP", &bufferTX); //Check and Permit Deep Sleep
  if (!(bufferTX.endsWith("OFF")))
    {
      BTModu.stdSetParam("ENABLE_HFP", "OFF");
      BTModu.stdGetParam("ENABLE_HFP", &bufferTX);
    }
  bufferTX = "";
  BTModu.stdGetParam("CLASSIC_ROLE", &bufferTX); //Check and Set Bluetooth as a Source
  if (!(bufferTX.endsWith("1")))
  {
      BTModu.setClassicSource();
      bufferTX = "";
```

```
      BTModu.stdGetParam("CLASSIC_ROLE", &bufferTX);
      if (!(bufferTX.endsWith("1")))
      {
        BC127TXres = BC127::INVALID_PARAM;
      }
      else
      {
        BC127TXres = BC127::SUCCESS; //This is the primary objective of this setup routine,
      }                              //   thus Success is achieved only here
   }
   else if (bufferTX.endsWith("1"))
   {
      BC127TXres = BC127::SUCCESS;   // and here
   }
  bufferTX = "";
  BTModu.stdGetParam("AUDIO", &bufferTX); //Check and set Analog Audio
  if (!(bufferTX.endsWith("0")))
    {
      BTModu.stdSetParam("AUDIO", "0");
      BTModu.stdGetParam("AUDIO", &bufferTX);
    }
  bufferTX = "";
  BTModu.stdCmd("STATUS"); //Can be removed, mostly for debugging
  BTModu.writeConfig(); //Commit changes to flash memory on chip
  BTModu.reset();
  if (BC127TXres != BC127::SUCCESS) return BC127TXres;
  return BC127TXres;
}

int BC127Connect() //Scan and connect
{
  int connectionResult = BC127::REMOTE_ERROR; //Initially assume failure
  int pairRes = 0;
  BTModu.inquiry(20); // Spend ~26 seconds seeking devices. t = 1.28 * input
  String address;
  for (byte i = 0; i < 5; i++)
  {
    if (BTModu.getAddress(i, address) && (address != ""))
    {
      // Now, attempt to connect. Timeouts are enabled.
      //General commands for connecting to music streaming Bluetooth protocols
     if (BTModu.connect(address, BC127::A2DP) > 0)
      {
        connectionResult = BC127::SUCCESS;
        pairRes += 1;
      }
      if (BTModu.connect(address, BC127::AVRCP) > 0)
      {
        connectionResult = BC127::SUCCESS;
        pairRes += 1;
      }
      Serial.println(BTModu.stdCmd("LIST"));
      /*if (BTModu.connect(address, BC127::AVRCP) > 0) //Other Bluetooth profile connections
      pairRes += 1;
      if (BTModu.connect(address, BC127::SPP) > 0)
      pairRes += 1;
      if (BTModu.connect(address, BC127::HFP) > 0)
      pairRes += 1;
      if (BTModu.connect(address, BC127::PBAP) > 0)
      pairRes += 1;*/
      if (pairRes > 1) //Finished connection attempt, check if successful
      {
        Serial.println("pairRes is > 1");
        connectionResult = BC127::SUCCESS;
        break; //If it works, jump straight to streaming music
      }
    }
    buffer = "";  // Otherwise, clear the buffer and go back to waiting.
  }
  if (connectionResult != BC127::SUCCESS) return connectionResult;
  return connectionResult;
}

void loop()
{
  if (digitalRead(BUTTONPIN) == LOW)
   {
     BTModu.stdCmd("UNPAIR"); //Close any previous connections
     delay(500); //Giving it time to complete that operation
     BTModu.reset(); //This seems to help when already paired
     delay(100); //Probably unnessary but kept in because seems to help
     if (BC127Connect() == BC127::SUCCESS) //Initializing Device Search
     {
       delay(2000); //Connection succeeded!
       BTModu.stdCmd("MUSIC PLAY"); //Issue music stream command
       BTModu.stdCmd("TONE TE 400 V 64 TI 0 N C5 L 8 N R0 L 32 N E5 L 8 N R0 L 32 N G5 L 8 N R0 L 32 N B5 L 4 N R0 L 1 N C6 L 
2 TN C6 L 8");
       //Victory tone, seems to only play out of the wired connection and not the Bluetooth
      }
     BTModu.stdCmd("MUSIC PLAY"); //Connection attempt failed. Back to waiting
   }
}
```

Appendix D: Final Project Picture