Wireless Bluetooth Music Player

ECE 445 Design Document

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1. Introduction

1.1 Problem and Solution

Current music playback devices are increasing in size to meet the demand for larger and larger screen sizes. Phones are now averaging with a screen size of 5.5 inch and increasing each year[1]. The weight of these devices is rather large, the result of using metals and glass to give users a 'premium feel' and increasing battery size to maximize the charge life of the device. These factors are integral to making good smart devices; however, they also lead to bulky/inconvenient device profiles for physical activity, especially for exercises like running and rock climbing.

Our proposed solution is a compact wireless music player that is capable of storing and playing the user's music through wireless headphones via Bluetooth. It will be lightweight and convenient to wear while exercising (clipped onto shirts or joggers). Our device will be simple and affordable. It will store audio files on the device and play them back via Bluetooth.

1.2 Visual Aid

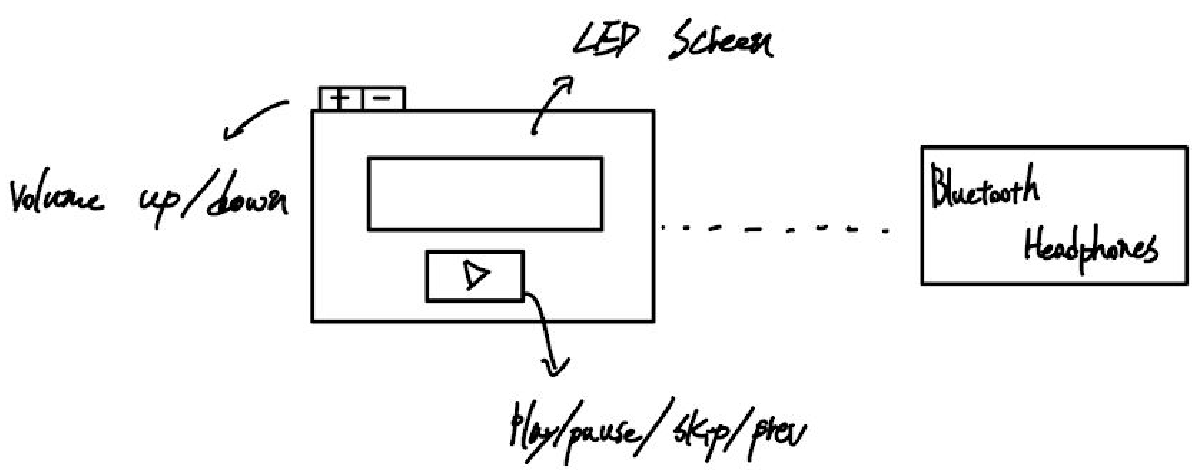


Figure 1. Visual Representation of the Device

1.3 High-level requirements list

- The device must be able to play as many songs users can listen to in a workout session.
- The device must have enough battery life to last a workout or run, for at least 3 hours.
- The PCB of the device must be small enough to fit in a 25 cm^2 profile.
- The final price tag on bulk production of the device must be less than $35.

2. Design

2.1 Block Diagram

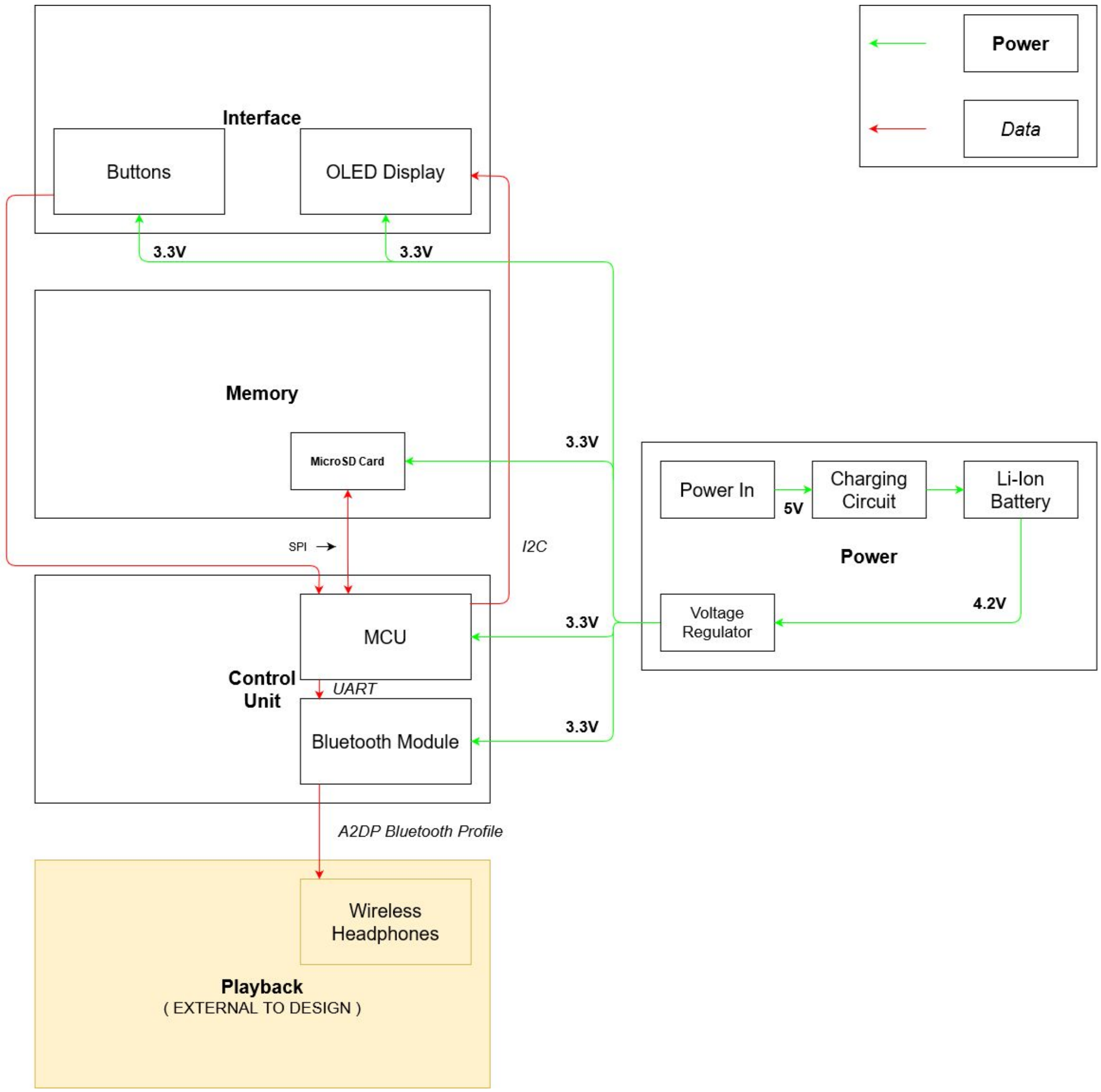


Figure 2. Block Diagram

2.2 Block Descriptions

2.2.1 Power

Block Requirement: The power block is responsible for supplying power to all the components in the device, must last at least 3 hours and prevent overcharging.

Lithium Ion Charging Circuit

The lithium ion charging circuit will receive power from the USB input to the device, and manage the charging process of the battery to prevent damage to the battery, and ensure longevity of the device's charge life. The charging IC we are using is the MCP73831T from Microchip, as it meets our device requirements and is quite inexpensive. Below is our charging circuit modeled in EAGLE.

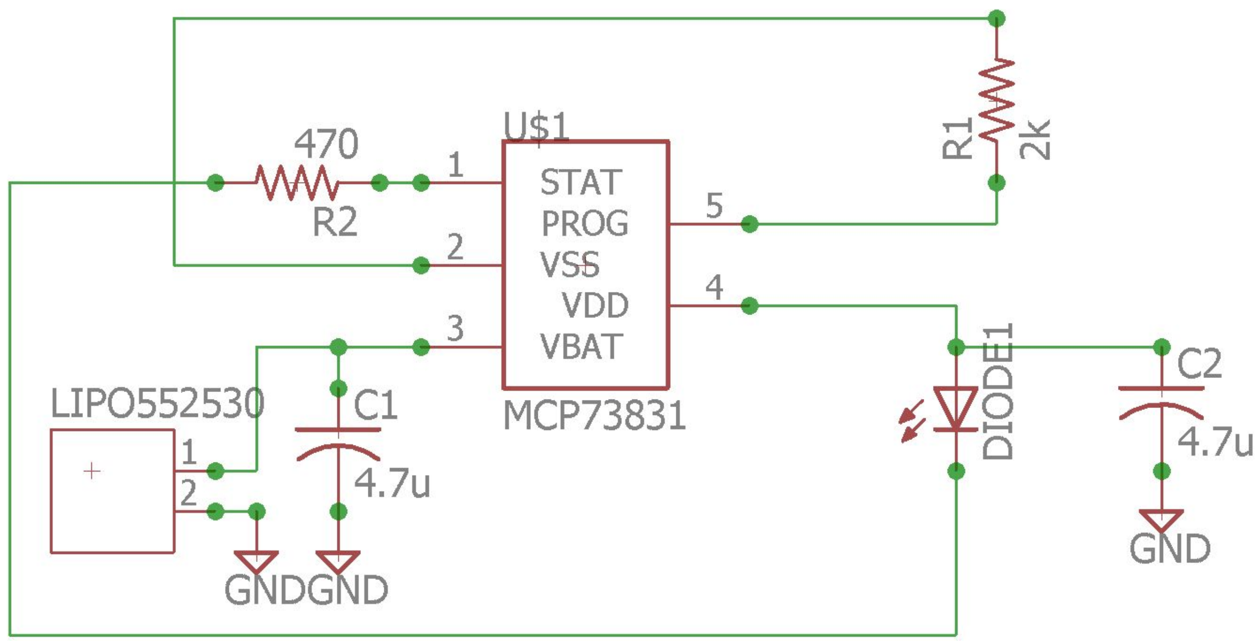


Figure 3. Charging Circuit using MCP73831T in EAGLE

Battery

We will be powering our device with a Lithium Ion Polymer Battery as they are the established standard for safety and size. There are some safety considerations, which we will cover in the Safety section, but Lithium Ion batteries are the best option available to us. The option we are currently considering is the LIPO552530 rated at 3.7V with 350mAh, a reasonable amount of power for a system as small as ours. This option is expected to easily meet the power demands of our device for more than the duration of average use.

Voltage Regulator

This module takes in the battery voltage, and supplies 3.3V to all components on the board. We are using the LD1117S33CTR from ST Microelectronics to accomplish this. Below is our regulator circuit modeled in EAGLE. The left input is the voltage coming in from the battery, while the wire on the right is the output voltage to the rest of the components in the device.

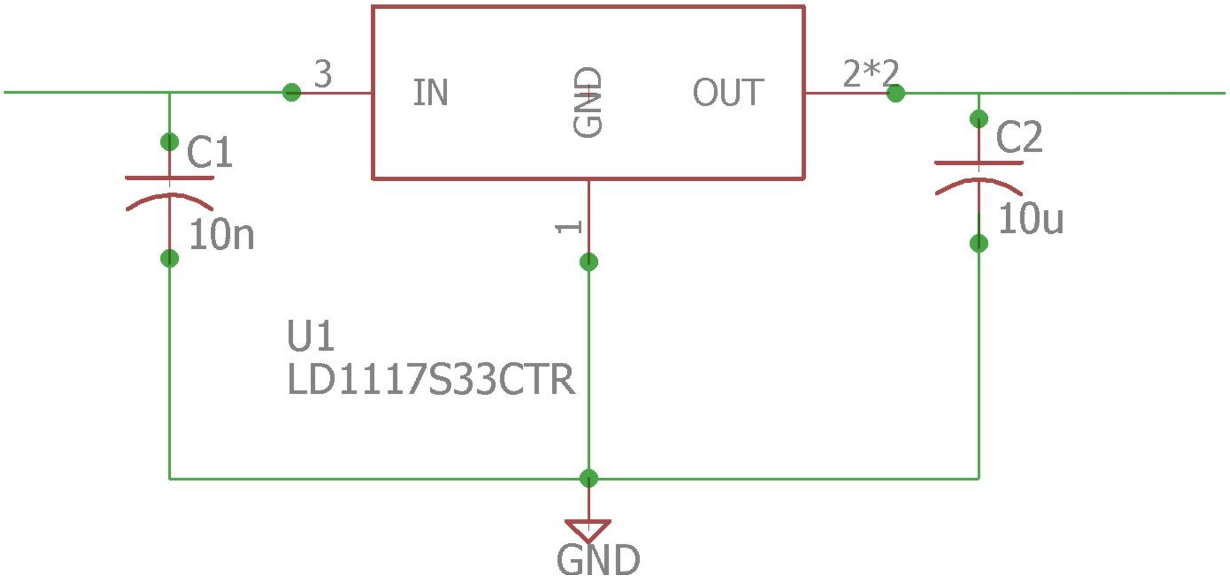


Figure 4. Voltage Regulator Circuit using LD1117S33CTR in EAGLE

2.2.2 Interface

Block Requirement: Buttons must change the playback state of the music (rewind, fast-forward, volume changes). Display must show relevant information.

Buttons

Buttons will act as the user's medium for changing the playback state of the device. We will have separate buttons for changing the volume of the music and pausing/rewinding/skipping through music, as well as powering and pairing the device. By mapping different combinations/timings of pressing buttons, we could simplify the design and have the same functionality while reducing the number of buttons, thereby reducing the size. Our current plan is to use 3 FSM6JH buttons from Tyco Electronics.

OLED Display

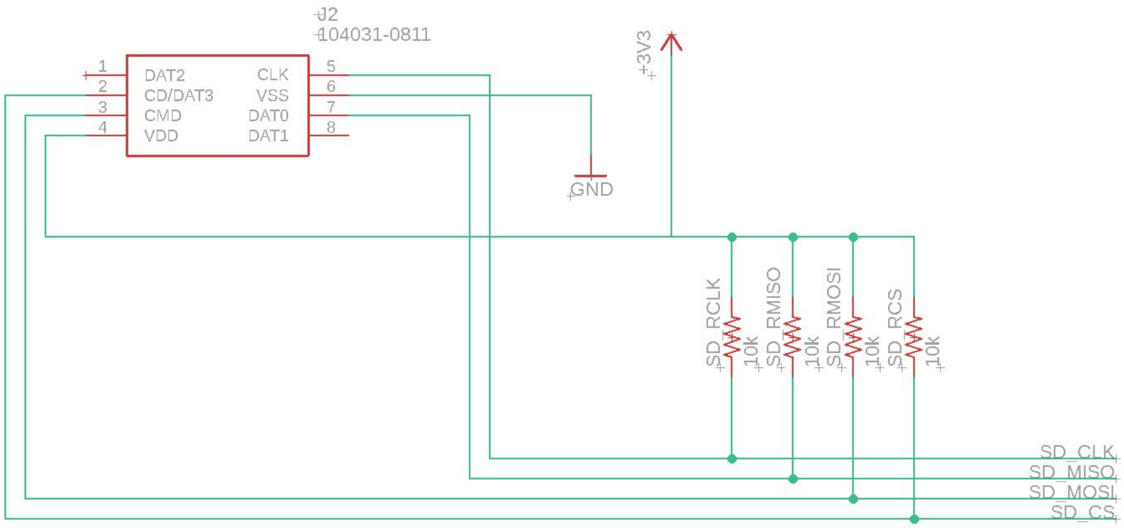
The display will be a small monochrome OLED, interfacing with the MCU via I^2C, allowing for pairing information to be displayed to the user when setting up the Bluetooth connection to a pair of wireless headphones. The display will be small, and should use as little power as possible (this is why a monochrome OLED display will be used, as power will only be consumed for illuminated pixels). The MakerFocus B0761LV1SD has all of these features.

2.2.3 Memory

Block Requirement: Must be capable of storing the minimum requirement of 2 GB of data, to store a sizable amount of playback audio to last an entire workout session.

Micro SD Card

The Micro SD Card will be used to store the audio files for later playback, with fast read and write times, along with a small footprint. The Micro SD interfaces with the MCU over SPI, transmitting data along the SD_MOSI and SD_MISO lines.



2.2.4 Control Unit

Block Requirement: MCU must communicate and relay instructions to various components on the device in accordance with button inputs. The Bluetooth module must communicate in a Data/Co-Processor mode over UART communication protocols, and use minimal power.

MCU

Because the uniqueness of the device lies in its small profile and affordability, the microcontroller we use will have to be low cost and power efficient. The K32 L2 (K32L2B31VLH0A) MCU, the chip we plan to use, meets these conditions. It also has native 2.0 USB hardware, simplifying the design process and ensuring that the device will handle USB communication [9]. The K32 L2 has a sufficient amount of GPIO pins along with the required DMA to access the flash IC, as well as I^2C pins to handle communication with the remaining peripherals, such as the Bluetooth module and a small monochrome OLED display.

Bluetooth Module

The Bluetooth communication will be handled by a Bluetooth transceiver module, interfacing with the MCU over UART, while still not consuming large amounts of power. Bluetooth communication will in all likelihood be drawing the largest amount of power, so our selection of a power efficient module is key. Our current bluetooth module selection is the Microchip RN4871.

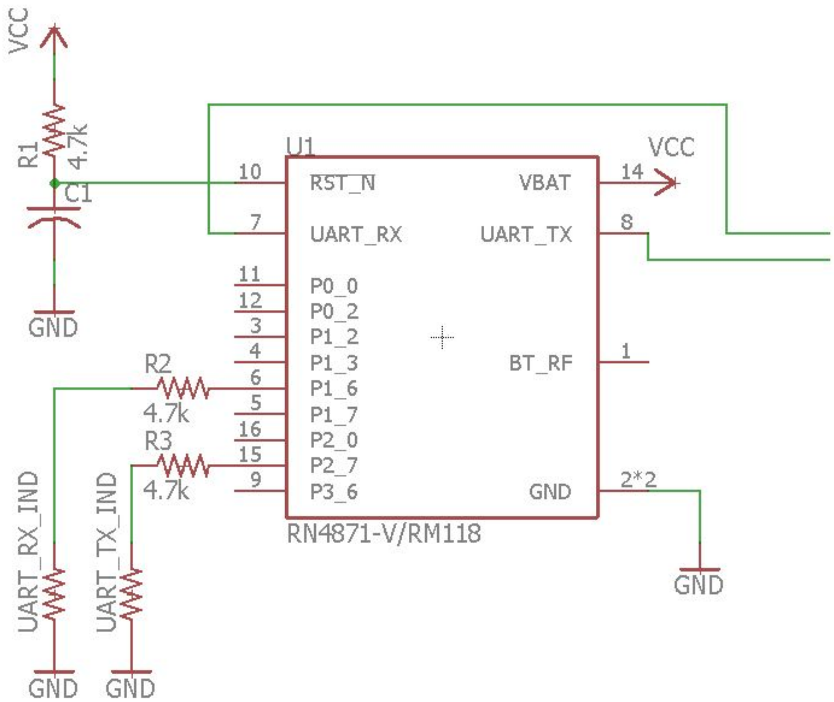


Figure 5. Bluetooth Module using RN4871 in EAGLE

2.2.5 Playback (External)

Block Requirement: Wireless Earbuds must support Bluetooth and be able to play music from the device.

Wireless Earbuds

The wireless earbuds are the final destination of the data from the device. There are a variety of earbuds available on the market, but as long as they support Bluetooth they will be able to receive data from the device. We output music data into the earbuds using the A2DP Bluetooth profile.

2.3 Requirements and Verification Table

2.3.1 Power Supply Unit

Requirements	Verifications	Points (8)
Lithium Ion Battery 1) Supply 3.7V at 300mAh draw on the PCB	Verification Process: 1) Hook up to an oscilloscope to ensure voltage and currents are steady at specified values	2
Voltage Regulator	Verification Process:	3

1) Handle up to 4.0V battery voltage 2) Supply up to 200 mA current draw	1) Use a multimeter to measure the potential difference and ensure it is within range 2) Use the oscilloscope or multimeter to measure the current is close to our specified value	
Charging Circuit 1) Accept an input voltage of 5V through a usb input from a computer 2) Output a voltage of 3.3V that is passed through to all the components	Verification Process: 1) Use a multimeter to measure the potential difference and ensure it is as desired	3

Table 1. Requirements and Verification for Power Component

2.3.2 Interface

Requirements	Verifications	Points (8)
Buttons 1) Be small enough to fit on the device 2) Change the playback state of the music	Verification Process: 1) Use an oscilloscope to verify a signal is being passed to the microcontroller when each button is pressed 2) Press each button to ensure it performs its assigned task	3
Display 1) Be compact 2) Communicate using the I2C protocol 3) Operating Voltage V_o is in range: $0 \leq V_o \leq 4$ [V] 4) Operating Current I_o is in range: $.18 \leq I_o \leq .3$ [mA]	Verification Process: 1) Ensure audio metadata matches with information on display 2) Verify that changing songs changes the information on screen 3) Use a multimeter to ensure the component is operating within the specified voltage range 4) Use an oscilloscope to ensure current is within given range	5

Table 2. Requirements and Verification for Device Interface

2.3.3 Memory

Requirements	Verifications	Points(15)

Micro SD Card 1) Be capable of storing the minimum requirement of 2 GB of data 2) Operating Voltage V_o is in range: $2.7 \leq V_o \leq 3.6$ [V] 3) Operating Current I_o is in range: $25 \leq I_o \leq 50$ [mA]	Verification Process: 1) Begin communication with SD card via SPI interface, issuing CMD0 until a 0x01 flag bit is received, indicating the card is in an idle state. 2) Verify SD card version using CMD8 3) Initialize SD card using CMD1 command, and verify 0x00 response from card to ensure initialization is complete 4) Set the read/write block size using CMD16, and issue CMD24 to write a block with test data. 5) Issue CMD17 to read the same block and verify the written data	15

Table 3. Requirements and Verification for Memory

2.3.4 Control Unit

Requirements	Verifications	Points (15)
Microcontroller 1) Must quickly access peripheral memory 2) Be capable of communicating over I2C and UART. 3) Integrated USB hardware 4) Operating Voltage V_o is in range: $1.71 \leq V_o \leq 3.6$ [V]	Verification Process: 1) Press buttons on device and make sure they change the state of the music within a half second 2) Connect device to a computer and transfer music 3) Use a multimeter to ensure the component is operating within the specified voltage range	8
Bluetooth Module 1) Ensure MCU could communicate with Bluetooth module via UART 2) Operate under data transfer mode with	Verification Process: 1) Able to toggle between command and data transfer mode 2) Press buttons on the device and make sure our Bluetooth device receives signal 3) Use a multimeter to ensure the	7

Bluetooth device via UART or I2C 3) Operating Voltage V_o is in range: $1.9 \leq V_o \leq 3.6$ [V] 4) Operating Current I_o is range: $I_o \approx 13$ [mA]	component is operating within the specified voltage range 4) Use an oscilloscope to ensure the current through the module is steady near the specified value	

Table 4. Requirements and Verification for Control Unit

2.3.5 Playback (External)

Requirements	Verifications	Points (4)
Wireless Earbuds 1) Support Bluetooth A2DP communication profile 2) Be able to play music from the player	Verification Process: 1) Click buttons on the device and make sure that earbuds will receive the signal 2) Wear earbuds and listen to ensure there is an audio output	4

Table 5. Requirements and Verification for Playback Device

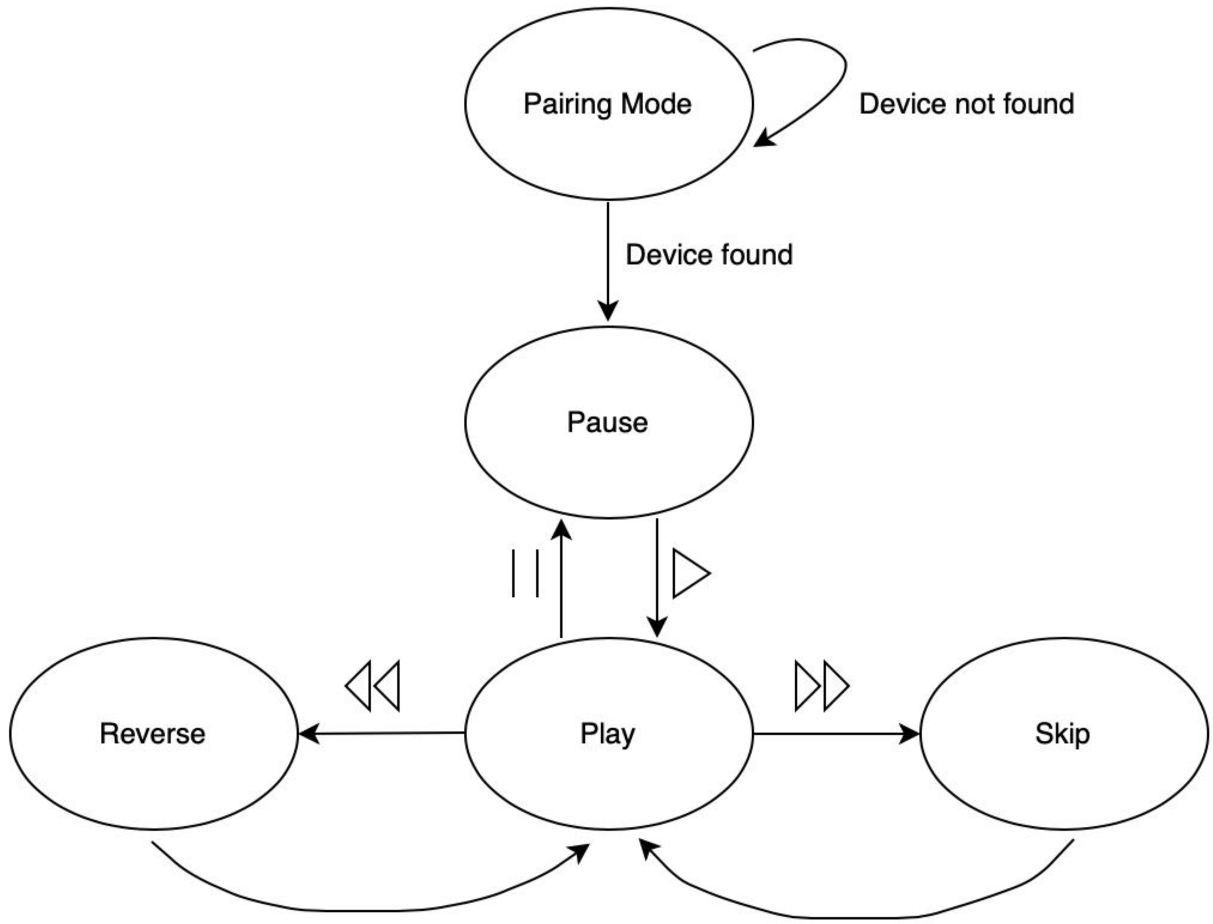


Table 6. Operation FSM

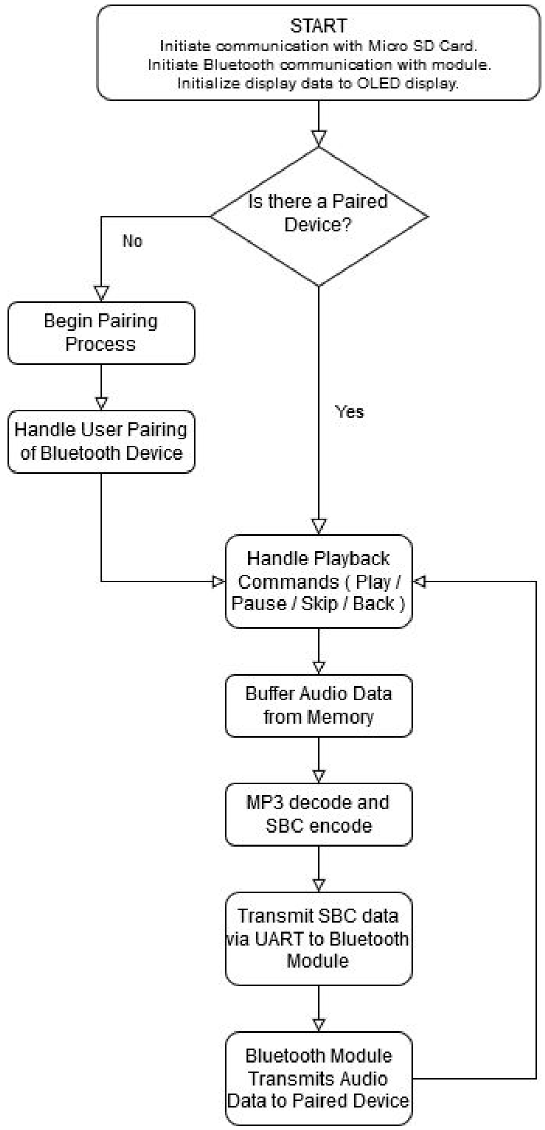


Figure 7. Software Flowchart

2.4 Tolerance Analysis

The compactness of the device is the primary aspect of the device that distinguishes it from alternative products. This also presents the greatest challenge, as attempting to fit the components into as small a profile as possible very well could be very difficult while maintaining the functionality of the device. Fitting the components into a 25 cm^2 profile will be difficult, as the largest components are large enough to lead to concerns about the most efficient placement of devices while not creating added difficulty to the assembly of the device, while still allowing for proper functionality.

A large concern for the device functionality is the throughput of the MicroSD card to the MCU, as audio output requires real-time access to the data. The minimum sustained read and write speeds of MicroSD cards as per the standard is 17.6 MB/s. This minimum value should be more than sufficient to allow for the MCU to retrieve audio data at a sufficient rate such that the processing and transferring of the data can be achieved in real time to play back audio via the paired bluetooth device. This A2DP profile will use the SBC audio codec, which has a maximum data bandwidth of 320 kbit/s, after processing the audio data by the MCU. The fast transfer speeds from memory will minimize the overhead of loading the data from memory, and allow for more time other processes required for audio playback.

Bluetooth communication could potentially be a blockade for our project. The aim is to have a standalone Bluetooth module that interacts with the MCU over the UART protocol. Although the internal design sounds straightforward, it requires further research in communication between the MCU and Bluetooth module.

The pairing process between the Bluetooth standalone device and our BLE could potentially be complicated. We could either program it while the MCU is connected to the computer or using the device's interface (screen and buttons) to select the device we wish to pair it with. We also have two modes to communicate with our BLE Device: command and data transfer. Both modes could operate up to 10m of distance as explained by figure 4:

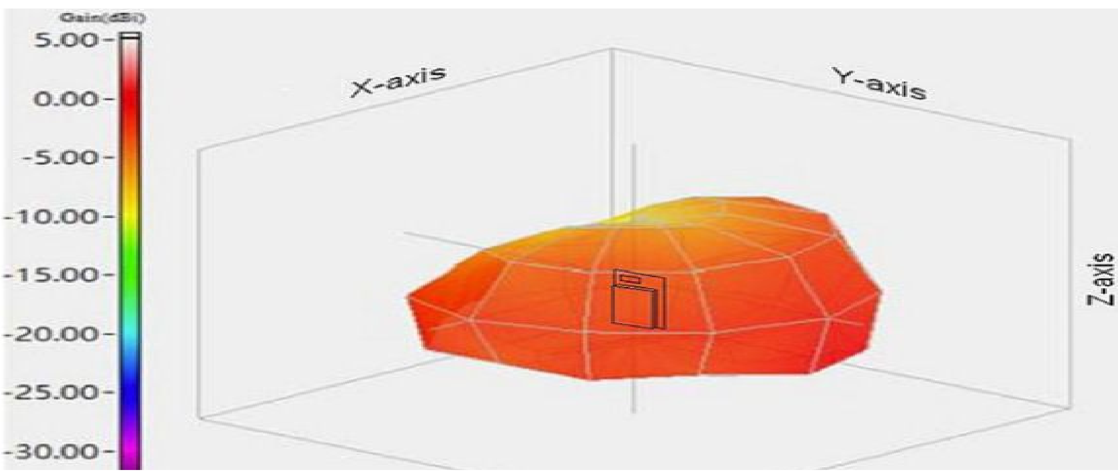


Figure 8. RN4871 Antenna Performance [5]

3. Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

To calculate the labor cost for this project, we will use the equation 3.1 to estimate:

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Labor Cost = Salary * Total Work Time * Number of Members
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Equation 3.1 Labor Cost

According to the Engineering Career Center in UIUC, the average starting salary for a BS graduate is $78,159 per year in 2017-2018 report [2]. Converting to hours, it will be $37.58 per hour per person. As for the total work time, according to the Office of Provost in UIUC, we are expected to put three times the amount of work time in the number of credit hours we receive per week [3]. That is 12 hours of work time per week for Senior Design. Lastly, we have a total of 3 engineers in this group. The total labor cost will sum up to be $21,646.08 for a semester.

3.1.2 Cost

Part #	**Qty**	**Mft**	**Vendor**	**Desc**	**Price/Unit**	**Total**
K32L2B31VLH0A	1	NXP	Amazon	MCU with USB 2.0	$4.60	$4.60
RN4871	1	Microchip	Digi-Key	Bluetooth 5.0 Module	$7.06	$7.06
1040310811	1	Molex	Digi-Key	MicroSD Card Female Connector	$2.02	$2.02
LP-401230	1	Adafruit	Adafruit	3.7-4.2V and 100mAh	$5.95	$5.95
LP2953	1	TI	Digi-Key	Micropower voltage regulator	$5.86	$5.86
B0761LV1SD	1	MakerFocus	Amazon	I2C OLED, res: 128x32	$5.5	$5.5
FSM6JH	3	Tyco Electronics	Mouser	6mm tact switch	$0.13	$0.39
MCP73831T	1	Microchip	Digi-key	Battery Charger IC	$0.56	$0.56

Table 6. Cost for Single Order of Device Components

After adding up all of the components, the device's largest components will cost $31.68. This is assuming we are only making one device. If we order parts in bulks, the cost of components will be a lot less.

3.1.3 Sum of Grand Total

Summing up the grand total, we estimate the total device's development cost is $21,677.76. However, if we want to put a price tag on this device, we will have to sum the bulk production cost per unit, board assembly fee, as long as revenue cost. This could be better explained with Equation 3.2.

$$\text{Price} = \text{Bulk Production per Unit} + \text{Assembly Fee} + \text{Revenue}$$

Equation 3.2 Device Price Calculation

If we were to mass produce the product and buying the parts in bulks the cost for the components will be a lot cheaper.

Part #	**Qty**	**Mft**	**Vendor**	**Desc**	**Price/Unit**	**Total**

K32L2B31VLH0A	500	NXP	Amazon	MCU with USB 2.0	$2.43	$1,215
RN4871	500	Microchip	Digi-Key	Bluetooth 5.0 Module	$5.06	$2,530
1040310811	500	Molex	Digi-Key	MicroSD Card Female Connector	$0.98	$490
LP-401230	500	Adafruit	Adafruit	3.7-4.2V and 100mAh	$5.95	$2,975
ADP122AUJZ	500	TI	Mouser	Micropower voltage regulator	$0.598	$299
B0761LV1SD	500	MakerFocus	Amazon	I2C OLED, res: 128x32	$3.50	$1,750
FSM6JH	1500	Tyco Electronics	Mouser	6mm tact switch	$0.09	$48.50
MCP73831T	500	Microchip	Digi-key	Battery Charger IC	$0.42	$210

Table 7. Cost for Bulk Order of Device Components

Buying the components in bulk results in a decrease of price for each component. Assuming a batch has 500 units, the total is $9,517.5 for 500 devices, which is about $19.04 per device. If we order a higher volume per batch, the price will decrease even more. For convenience, we will proceed with using $19.04 as bulk production cost to calculate price tag per device.

Using the PCB assembly calculator [7] and preliminary estimates for device requirements, we estimated that the cost for assembling 500 units is $1,621.83, which is $3.24 per device. As for packaging, the cost of the material for packaging will be $255 [8], which is $0.51 per device. Additionally, we estimate it takes a labor a minute to package 3 devices. The total assembly labor cost will be minimum wage multiplied by number of packaging hours, that is $22.9 or $0.0458 per device. In the end, the total cost for bulk production will be $11,417.23 which is $22.83 per device. This leaves a comfortable margin for device cost to fall within our high-level requirements.

3.2 Schedule

Week of	**Task**
2/17	Finalize Parts
	Assign Development Roles
	Send first part request
2/24	Finish Design Doc

	Begin Board Development
3/2	Complete initial PCB Development
3/9	Review Development and Pass Audit
3/16	Assembly of board
3/23	Initial unit testing for individual components
	Think of integration test ideas
3/30	Debug unit test
	Early stage integration
4/6	Complete bulk of integration tests on board
4/13	Debug system(s)
	Begin final verifications
4/20	Final verifications and presentations
	Begin final paper
4/27	Demo and Presentation
5/4	Submit finalized documents

Table 8. Calendar for Project Goals

4. Discussion of Ethics and Safety

There are some safety concerns present in our device. Lithium-ion batteries have the potential to explode and cause fires under certain conditions like puncturing and overheating. In 2015, lithium batteries in hoverboards caused so many house fires that Amazon suspended their sales; e-cigarette batteries have combusted even when not in use; and the fire suppression system on airplanes is often inadequate at extinguishing lithium battery fires so captains must make emergency landings [4]. To prevent batteries from being exposed to these dangerous conditions, we will warn the user of the potential hazards and encase the battery and the device components in a puncture resistant housing. We could also monitor temperatures and suspend operation beyond a certain temperature threshold. Another common cause of lithium battery fires is overcharging. To prevent such a situation, we will ensure the device cannot charge beyond a certain voltage threshold. In order to prevent moisture from entering the device and causing short circuits, the casing will also have to adhere to IP67 guidelines.

When the user is operating the device while running, it is possible that he or she is not paying attention to his or her surroundings. When running on the streets, there is a possibility that the user is unable to hear incoming vehicles if the device is operating at a high enough volume. Although the runner is using the device to facilitate this situation, we believe the responsibility in this scenario lies with the user. This is a potential issue with every device with audio capabilities, but in the end, users do have a degree of responsibility when using any product. It is common practice to monitor one's situation while listening to music in order to avoid accidents or injury.

Our approach to the potential safety issues with our device fall in line with the first IEEE code of ethics: "to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment" [6]. The safety of the user will always be of utmost importance. As discussed before, to combat the dangers of lithium-ion batteries we have put in place features to prevent overheating, overcharging and moisture penetration. We have also made sure to purchase batteries that have undergone safety tests. If we were to produce this product in bulk, we would also warn the user of these potential issues and also to be cautious of their surroundings when the device is in use through a user guide pamphlet.

5. Citations

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