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Sport Alert System for the Audibly Impaired

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ABSTRACT

The purpose of this project was to create an alert system for audibly impaired athletes. As most alerts to stoppage of play are tonal, this severely limits athletes with a hearing deficiency. The project aims to correct this by providing all athletes with a comfortable, easy to use device that provides immediate and noticeable haptic alerts whenever there is a stoppage of play. The haptic device will be placed within an armband. Whenever the device receives a signal via the custom transmitter, it will produce a noticeable haptic vibration to alert the athlete. The custom transmitter uses low frequency radio waves to send the signal. The haptic alert system will allow athletes with hearing deficiencies to participate more broadly in sports with lower risk of injury due to hearing impairments.

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1 INTRODUCTION

To further improve upon accessibility in the athletic world, a transmitter and receiver haptic feedback system was developed to alert athletes, especially those with hearing deficiencies, to stoppage of play. Most sports use purely tonal signals, such as whistles, to indicate when play has been stopped. This puts otherwise capable athletes with hearing deficiencies at a disadvantage and increases the amount of risk that may result from continuing play after play has been stopped. The haptic engine module is intended to be worn in conjunction with the armband and will emit a noticeable haptic vibration whenever the transmitter is activated. Current solutions often try to improve an individual's hearing capabilities by using hearing aids or some other method to improve hearing. This is an effective method, but often hearing aids are not practical for excessive physical movement or contact during sports. To better accommodate hearing impaired athletes in sports, this project develops a non-tonal to alert athletes of stoppage of play.

To efficiently address each area, work was divided between the three project members. The major areas were material consideration and electronic housing design (led by Kyle Wade), printed circuit board design and transmitter/receiver interfacing (led by Cauy Thomas), and signal conditioning, code structuring, and main logic (led by Brenden Bittner).

1.1 PROJECT PURPOSE

Creating equal opportunity for athletes and the general populace is one of society's largest tasks. Persons with physical impairments have been a target for receiving aid and access to more equal opportunities. Of these physical impairments, hearing loss proceeds all others in volume. According to the World Health Organization (WHO), an estimated 1.5 billion people, which are predicted to rise to 2.5 billion by 2050, suffer from a hearing impairment of 20 decibels (dB) or greater [1]. With almost a quarter of the world's population suffering from some form of hearing loss, there is a need for more ways to make their lives more inclusive. Hearing loss can be broken down into six categories: mild hearing loss (20-34 dB), moderate hearing loss (35-49 dB), moderately severe hearing loss (50-64 dB), severe hearing loss (65-79 dB), profound hearing loss (80-94 dB), and complete hearing loss (greater than 95 dB). For reference, an individual with mild hearing loss will not be able to hear or understand another person in a loud or noisy place, while a person with moderately severe hearing loss would not be able to hear or understand someone even in a quiet place [2]. In sports, a referee's whistle ranges from 50-120 dB. For an individual with a hearing impairment, this can be extremely difficult to hear, especially in a loud environment such as a soccer stadium.

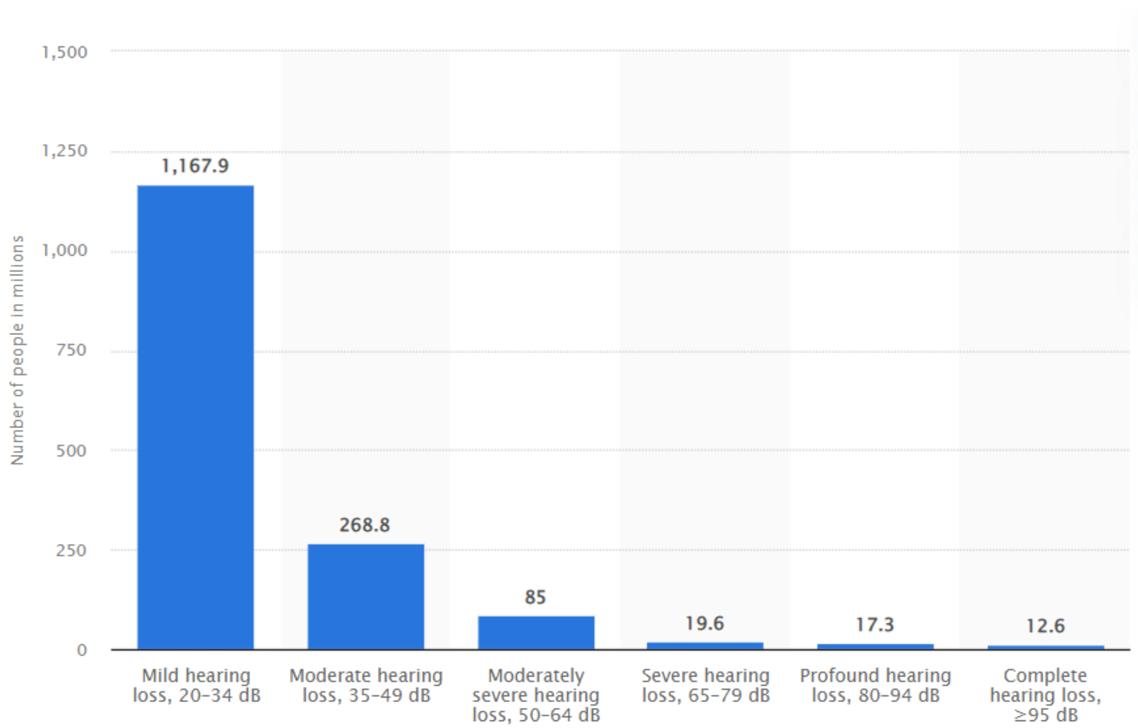

Figure 1.1: Worldwide; IHME (Global Burden of Disease Study) [3]

The device consists of a wireless transmitter, wireless receiver, and haptic engine module. The transmitter will emit a low frequency radio wave when its button is depressed. The wireless receiver will then pick up that signal and command the haptic motor to vibrate. Since the haptic engine module will be on the athlete's person, the device will have to be robust enough to withstand impact while also being energy efficient to last the duration of the entire game. The haptic engine module will be connected to the armband's power supply, and it will have a button to adjust the level of haptic feedback based on user preference. The device will also need to be discrete enough to be unnoticeable to the athlete until it emits haptic feedback. The "Electronic Whistle Transmitter and Receiver" project inspire this project [4] completed by Wyat Harmon, Erica Schmidt, and Presley Warren in spring of 2022. This project will allow people who are unable to hear tonal alerts effectively to participate in sports and not have to rely on a tonal alert that the "Electronic Whistle Transmitter and Receiver" project provided.

2 ECONOMIC CONSIDERATIONS

This section will discuss environmental, public health, safety, and welfare, global/political, social and cultural, teamwork, and professional standards engineering design considerations. The scope of this section is to design the device with regards to the set of considerations listed earlier. The receiver and transmitter designs should reflect the boundaries put in place with the consideration. The table in Appendix D displays where each one of these conditions was met in the overall design.

2.1 ENVIRONMENTAL

The device will need to be recharged regularly to be able to last the full length of the game. This will require a significant amount of energy consumption over time. This device will come with a low power solution to cut back on energy usage and will allow the device not to be charged as often. The batteries, circuit boards, and wiring could be recycled at the end of its life. The circuit boards could be recycled and used again for other devices if they were not damaged. The case is made from a biodegradable plastic, allowing for the case to not harm the environment in any way after disposal.

The haptic alert system may be subjected to moisture, both from the athletes and due to environmental conditions, such as rain or snow. Therefore, a protective waterproof covering may be added to the transmitter and haptic alert system. The design must also be robust due to the inherent physical nature of a contact sport.

2.2 Public Health, Safety, and Welfare

This product was designed with the health and safety of the athletes in mind. This device will alert the audibly impaired of the stoppage of play, which helps let the user know when to stop and pay attention to what is happening on the field. This can prevent athletes from getting run over or if there is an injury on the field, play can be stopped immediately. The physical design of the haptic alert system is taken into consideration as well. Since the haptic alert system will be used the entire duration of the game, it needs to be comfortable for the athletes to wear. The housing for the electronics needs to be smooth and robust in the event of direct contact. Also, the system needs to be moisture resistant to prevent electronic shorts, as well as electrical shocks to the athlete.

2.3 Global/Political

The haptic alert system is being prototyped for contact sports. While the design for the haptic alert system is primarily focused on soccer, a special consideration is being made to make the design universal for other non-contact sports, or for other industries such as construction. Implementing this design in other countries outside of the United States is not in the current plan.

2.4 Social and Cultural

The intended users for this system are the audibly impaired athletes that play contact sports. Benefits of this sport alert system allow the athletes on the field to have safer play and allows the audibly impaired athletes to play with anyone. Risks associated with the device could be not alerting the player, the battery on the device not maintaining charge, or the player not feeling the haptic feedback. Haptic feedback is used in many devices and aspects of life. This would integrate well into the intended user's lifestyle because many have experienced haptic feedback with current cellular or watch devices.

2.5 CODE OF ETHICS

According to IEEE's code of ethics, it is the mission of its members and the communities they serve to:

1. to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment. [5]

This professional standard closely aligns to this project's goals as this device will let hearing impaired athletes compete where they could not before. This project also greatly reduces the risk of injury by implementing a new stoppage of play alert that is not dependent upon sound. This project will allow audibly impaired athletes to participate in sports in a safe manner.

2.6 TEAMWORK

The team was organized into three different assigned parts. Each team member was assigned a part of the project. Communication was performed in class, over the phone, and over email. Tasks were assigned based on who felt the most comfortable with each major part of the project and it was divided accordingly. The major areas that were focused on were material consideration, project construction, and electronic housing design (led by Kyle Wade), transmitter/receiver interfacing and printed circuit board design (led by Cauy Thomas), and signal conditioning, code structuring, and main logic (led by Brenden Bittner). Disagreements with design ideas and component selection were solved by addressing the advantages and disadvantages of each idea and the one with the most advantages were chosen.

3 CONCEPT GENERATION

There were many different avenues that could be pursued when attempting to create a sport alert system for the hearing impaired. During the preliminary design phase there were a few different options that were considered, each yielding a different finished product. These designs go over the type of alert system, how the device will be mounted to the user, and what type of signal communication the transmitter and receiver will require. The design aspects are in greater detail below along with the decisions of the desired method.

3.1 Type of Alert System

There are many different methods that can be used for designing an alert system to stop play of the game. The system must be able to alert the player in many different playing atmospheres, based on the sport being played. For this design, two of the five senses of the human body, the sense of touch and hearing, were considered. The options discussed involved electrical stimulation, vibration using haptics, and utilizing an earpiece.

3.1.1 Electrical Stimulation

To provide a more noticeable level of stimulation to alert the athlete, electric stimulation was considered. This method would apply electrodes in the location of the e-stim pads which would create a slight tingling sensation. The advantage of this method is that it would be more noticeable for the athletes to register as the sensation may be uncomfortable, but it should never cause pain.

Some disadvantages of the electrical simulation include accidental jerking from overstimulation, changing moisture levels throughout play affecting the effectiveness of the device, and there was very little research found in this area for this project's application. There are limited mobile options for these devices, and they often require large power sources. These power sources are not practical or fit the athlete comfortably. The disadvantages of electrical stimulation outweighed the benefits, so a different approach was considered.

3.1.2 Haptic Feedback Engines

Another option that is based on the players sense of touch is the use of haptic feedback engines. Haptics are in many devices such as watches, gaming controllers, and cellphones. These devices are small enough and the level of vibration can be adjusted based on the intensity of the sport and the comfortability of the athlete [6]. Haptics are used in numerous devices and the research on haptics is extensive. Haptic engines range in all shapes and sizes which make them easily integrated into existing systems. Another benefit to using a haptic engine is it can alert deaf athletes along with the audibly impaired athletes. This system could be used for athletes at all stages of hearing impairment from total hearing loss to fully healthy.

A disadvantage, however, could be when being involved in high contact sports a method that uses vibration may not always be the most suitable. The vibration of the haptic engines may not be strong enough to alert players in the appropriate time after stoppage of play given the size parameters to attain. Given that one of the overall goals is to be able to apply this system across as many sports as possible, this is a viable option. With the availability and the accessibility of haptics, this was chosen for the final design.

3.1.3 Tonal Alert via an Earpiece

One of the other options considered for the design was a tonal alert system utilizing an earpiece. This design would use a transmitter and a receiver like the other options. The device would be used to amplify whistle like tone or create a new tone entirely to alert the players to stoppage of play. It would be an earpiece which housed the receiver, battery, and was able to be adjusted to fit different size ears. This device would resemble a modern-day hearing aid in size and functionality. The practicality of the earpiece staying on an athlete who does not wear a helmet, like football, is very slim due to the physical contact often occurring in sports. Being able to design an earpiece small enough to fit on an ear and not fall off the ear during sports with higher rates of physical contact is not a viable option. It is important that the device stays on the athlete the entire duration of the game. Tonal options would also not meet the needs of an athlete that is diagnosed with total hearing loss. The main target of the project is to include options for all severities of hearing impairments or total hearing loss. For these reasons, the option for a tonal alert system was not chosen considering the target consumer of the device.

3.2 WEARABLE DEVICE CONSIDERATIONS

This portion of the design also had many different routes that could be taken. First, multiple wearables were compared based on location and type allowing for the most advantageous to be selected. With this selection in mind, platforms considered were an armband around the upper bicep or a sports vest that is worn under the jersey of the athlete.

3.2.1 Wearable Armband

The first design option that was considered was an armband. This design would be worn on the bicep and would look as if the players were wearing a captain armband in soccer. The electronics of the device would be on the underneath portion of the bicep closest to the rib cage. This would allow it to be better protected from the ball and any rough play experienced. The electronic casing would need to be as small as possible to prevent it from being of any bother to the player wearing it. For most athletes in sports, their arms are always in motion, so the design will ideally not interfere with the player in any way. The armband would be able to fit male and female players universally with size adjustment capabilities. For these reasons, the armband was selected to house the receiving device.

Figure 3.2.1: Armband [7]

3.2.2 Sports Vest

The other concept that was considered was a sports vest. Sports vests have many different uses for athletes in sports as well. Vests can help prevent athletes from getting skin abrasions, track the athlete's movement, speed, heart rate, sprints, etc. These vests can help athletes improve in whichever sport is being played. Sports vests have all the electronics stored on the back of the vest, which is very important for the sport of soccer [8]. The chest is important because many players "chest" the ball to help settle it down after a high kick. If the electronics were on the front of the vest, it would be at a high risk of being damaged considering it is a high impact area. It is also important to not impair the players in any way during the game. It is vital that the electronics are as small as possible and out of the way. The idea is to place two haptic engines on each side of the vest. These will be placed in the lower band of the sports vest along the ribs to alert the players through haptic feedback. When the play is started and stopped, the vest receives a transmission from the transmitter on the field and this will trigger the vests to provide haptic feedback to the players.

Some disadvantages to the vest are integrating wires and connecting the haptic feedback to the receiver. Athletes typically sweat a lot and are exposed to the elements as well, which would cause the vest to stink and need to be washed. The haptics and the wires would not be able to be taken out very easily to be washed. This would cause an issue with the overall aesthetic and functionality of the design. For these reasons, this option was not selected due to the washing difficulties and possible electrical complications.

Figure 3.2.2: STAT Sports Vest [9]

3.3 WIRELESS COMMUNICATION

After the selection of the alert type and wearable device type, a form of wireless communication was discussed and chosen. The options discussed include Wi-Fi, Low Energy Bluetooth, and low frequency radio waves. Within sports, there are several different communication interfaces between coaching staff and players that are already used. This device must be engineered to not interfere with these current systems. The wireless communication used in this project is designed to work in all environments - from rural areas to sports arenas - without interfering with other pre-existing systems [10].

The frequency the device will operate at is 418MHz. Based off Federal Communication Commission (FCC) standards, this is within the public domain, as it is a license-free band [11].

3.3.1 Wi-Fi

One of the options discussed for wireless communications was the Wireless Local Area Network (WLAN), more commonly referred to as Wi-Fi. Wi-Fi devices use radio waves to communicate. The Wi-Fi radio waves are transmitted and received at a frequency of 2.4 GHz or 5 GHz [12]. A connected device will transmit a signal to a router, where the router will convert the data into a signal and send it to the intended device.

For the project design, the Wi-Fi router would be used as an intermediate break between the transmitter and the receiver used to turn on the alert system. The advantages of the system are that it allows rapid data transfer, so this intermediate step would not decrease the response rate. Wi-Fi is also easy to use and is readily available on large scales. Disadvantages of the system include, but are not limited to, black spots where signal is not available, high installation costs, and low security [13]. If a signal is not available in certain areas or ranges, then it would make the alert system useless. High installation costs also make it difficult for a rural sports team or single customer to afford the device. Wi-Fi routers also require a wired connection to work properly, and this will impose prohibitive costs or unpractical installation for rural fields. For the Wi-Fi system the disadvantages outweigh the advantages, so this option was not chosen for the design.

3.3.2 Low Energy Bluetooth (BLE)

Another option discussed was the Low Energy Bluetooth (BLE) system. This system divides the Industrial, Scientific, and Medical (ISM) radio band into forty channels with 2 MHz spacing between the bands. A BLE single mode device uses extremely low energy, significantly reducing the power supply requirement. BLE is also a much thinner stack of data allowing for the reduction of both the firmware and overall electrical footprint [14]. Even with low power consumption, BLE is still able to use high transmission rates with a low error factor.

Advantages of the system include the small firmware required for the system to operate, lesser power supply requirements, and a small electrical footprint. Disadvantages of the BLE system include a reduced range, complex implantation, and the frequency can also be disrupted between the transmitter and receiver by individuals passing between the devices. The low range of the system is a problem because it may not reach across an entire field of play. This will cause the players to not receive an alert in certain situations, making the device ineffective. The disadvantages of the BLE system outweigh the advantages, so this system was not chosen.

3.3.3 Low Frequency Radio Waves

The final option discussed was the transmission and reception of the system using low frequency radio waves (AM and FM). This system can range from kHz to MHz allowing for multiple transmission frequencies. These systems are already being used in sports for one way communication between coaches and players. The infrastructure and research for these systems are already in place. It allows for easier implementation into stadiums without worrying about interference along with rural areas.

An advantage of this system is there are an abundance of open frequency channels that can be used to allow one transmitter to alert multiple receivers. It also has a long range and can be used in many fields – from the largest sports complexes to small rural fields - without intense infrastructure. The devices will be equipped with their own power supplies allowing for the devices to transmit and receive without an external power supply or LAN cable [15]. This creates a highly mobile device that can be used in any sized sports field or arena with little to no difficulty.

There were a few disadvantages to this system, the main disadvantage being the security of the signal. With the frequency range of this device operating in an open band, many different devices also use this band. This has the potential to create discrepancies, such as false alarms, between the transmitter and receiver devices developed in this project whenever foreign devices use this open band. This may lead to players starting or stopping play prematurely. With this being the only disadvantage to the system discovered thus far, this option was selected.

3.4 CONSTRAINTS

Constraints regarding this project include size, dust and water resistance, battery life, range of transmission, and cost. A major constraint for this project was the size of the device. This device needed to be as small as possible to not impede the athlete in any way during a game. The size of the device should be smaller than 3” (W) x 4” (L) x 1.5” (H). The device also needed to be dust and water resistant due to the varying field and weather conditions experienced on a soccer field. The battery life of this device was important because it is critical to last the duration of a soccer game at a minimum. Soccer games typically last 2.5 hours at the most, therefore the battery life must last 4 hours minimum. Range of transmission was another constraint considered due to varying field sizes across the country. The transmitter and receiver needed to be able to communicate at a minimum of 450’. The idea behind this project was to keep it as low cost as possible to keep it affordable for athletes to purchase and not to further prevent them from participating in sports. The device must cost less than $250. Another constraint was making the device removable from the armband. This allows the athlete to wash the armband after a long day of tournaments or after a muddy practice during a rainstorm. The final constraint for this project is durability of the device housing. The device housing needs to withstand a significant impact and not have the electronics damaged. This is for when the athlete falls on the device, or if the device gets stepped on by a cleat during a game.

4 SYSTEM ARCHITECTURE

The system architecture details how the system will operate. The official will press a button on the transmitter, and the haptic engine on the player’s receiver will activate. Several intermediate steps are made in that process, and the following subsections detail the signal flow.

4.1 FIRST LEVEL SYSTEM ARCHITECTURE

The first level system architecture details the general inputs and outputs to the system, as well as the general process flow. This architecture was used when constructing the project. There are three inputs to the system, a push button on the transmitter, a power switch to turn on the haptic engine module, and a button that adjusts the level of haptic feedback for the user. The transmitter will send a low frequency radio wave to the receiver, which then sends a signal to the microcontroller. The microcontroller then produces two separate outputs: a haptic motor vibration and an LED illumination that indicates battery life. Both the transmitter and receiver will require two separate battery sources to operate. Figure 4.1 visually details the first level system architecture.

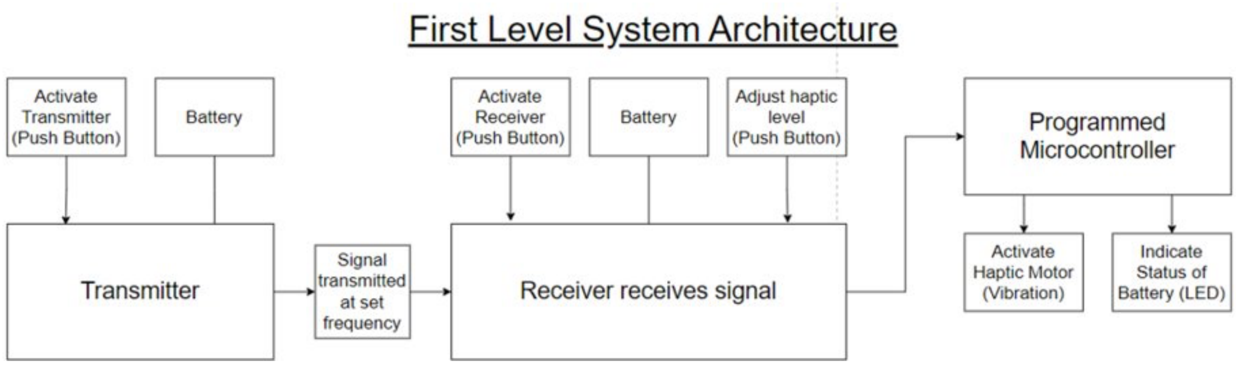

Figure 4.1: First Level System Architecture

4.2 SECOND LEVEL SYSTEM ARCHITECTURE

The second level system architecture details the power requirements and signal flow of the system. The system is powered with two different power supplies, a 3.3V coin battery for the transmitter and a 3.7V rechargeable LiPo battery for the receiver. The signal flow is as follows for the receiver. When the button is pressed, the Encoder will receive a 3.3V signal, and will address a signal and send it to the transmitter. The transmitter will then modulate the signal and send it to the antenna, where the signal will be sent out into free space. The receiver antenna will then pick up the signal and send it to the receiver, where it will demodulate the signal. The demodulated signal will then be sent to the decoder, where the decoder will decide whether to continue the signal if it is addressed properly. The microcontroller receives the signal from the decoder and activates the haptic motor. The microcontroller will also monitor the energy level of the LIPO battery and activate the low battery level LED when below a certain threshold. Figure 4.2 visually details the second level system architecture.

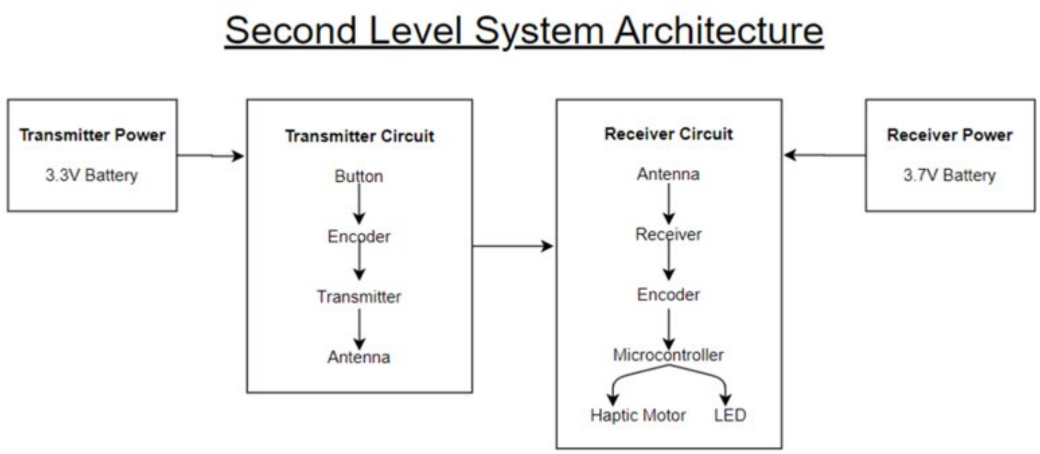

Figure 4.2: Second Level System Architecture

4.3 Operation Architecture

Figure 4.3 details how the system is operated. A referee will have possession of the transmitter and press the button whenever it is determined that play needs to stop. The transmitter will then send out a signal at 418MHz, and the receiver will receive that signal. Upon reception and decryption of that signal, the receiver will activate the haptic motor. The athlete will then notice the vibrations and stop playing. The same process is followed when the referee determines that play needs to start. In this manner, it is possible to safely and completely alert players when play starts and stops throughout an entire game.

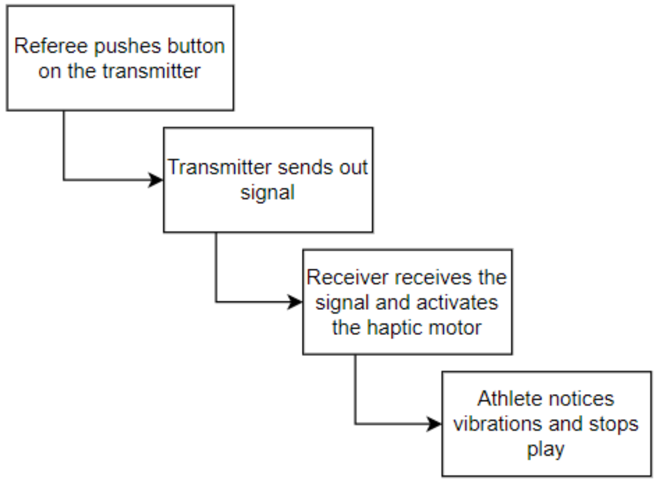

Figure 4.3: Operation Architecture

5 EVALUATION KIT

This section describes testing done for the evaluation kit and lessons learned from it. A LINX Evaluation Kit was used to test the type of transmission for the project. The evaluation kit was used to gain critical insight into how a communication system worked.

5.1 EVALUATION KIT COMPONENTS

The LINX Evaluation Kit is made up of 2 transmitters (key fobs), 1 receiver board, and 1 antenna. The kit uses an LR Series 433MHz transmitter and receiver for communication. The transmitters and receiver also use a LINX Encoder/Decoder module to encode/decode the signal packet. When the button is pressed, the encoder will send an addressed signal packet to the transmitter. The transmitter will then modulate the signal and send it to the antenna, which will broadcast the signal at 433MHz. The receiver side antenna will receive the 433MHz signal and send it to the receiver. The receiver will then demodulate the signal and pass it to the decoder.

The decoder will check to make sure the signal packet is addressed properly, read the signal packet, then activate the proper LED or buzzer.

Figure 5.1: DigiKey Evaluation Kit Components

5.2 TESTING OF EVALUATION KIT

The LINX Evaluation Kit was run through a series of tests to determine its capabilities. The kit was taken to the USI Men and Women's soccer field to be tested. The receiver was placed on the far side of the soccer field, and the transmitter was slowly moved away from the transmitter. Once the transmitter was approximately 1200' away from the receiver, it slowly started to lose communication with the receiver, becoming hardly operational. The signal from the transmitter was reaching the receiver through thick trees, bleachers, and other obstacles at approximately 1200’. There will be very little interference on soccer fields between the referee who will hold the transmitter and the players who will be wearing the receiver.

Test	Pass/Fail (P/F)
Communication between single transmitter and receiver	P
Communication between both transmitters and receiver	P
Receiver activates upon simultaneous transmission signals	F
All buttons work at max range	P
Signal duration matches	P
Range	P

Table 1: Evaluation Kit Test Results

As seen in Figure 1, the evaluation kit passed most of the tests. The only test the evaluation kit did not pass was activating upon multiple transmission signals - as in both transmission fobs were pressed at once. The receiver failed to activate during this test. This is due to signal corruption. When the two transmitted signals overlap, they cause the decoder to receive a distorted signal that it cannot decode into a signal packet. Thus, the signal is lost, and the receiver does not activate.

The main purpose of this test kit was to help conceptualize the main communication system that is being used in the project. This helped with the circuit board design and sourcing the necessary components for communication between the transmitter and receiver. It also gave insight into how the LINX receiver/transmitter communicate together.

6 DEVICE HOUSING

6.1 DESIGN PROCESS

For this device to be implemented onto an athlete, the housing must be able to properly hold the electronics and withstand repeated impact throughout the duration of the game. The first iteration of the design housing was a 3”x 4” casing that would enclose the device electronics. The thickness of the housing was one inch. The device housing consisted of two halves that snapped together to form a protective shell over the electronics. The base was 3D printed to get a general idea of how big the device needed to be. Once the device was printed, it was decided that the housing could be much smaller. The goal of this device is to not bother the athlete wearing this device, and it was decided this iteration was too big. Being 3D printed out of the material Polylactic Acid (PLA) plastic, it proved to be very strong and protective of any wear and tear it may experience during the play of the game.

6.2 RECEIVER HOUSING

The receiver housing was made smaller to better fit on the athlete’s arm. The casing still needs to be big enough to fit the printed circuit board, battery, and haptic inside. This iteration includes holders for the printed circuit board to be placed in so it will hold it securely. The device housing has two holes – one for a button that adjusts the haptic feedback, and one for a button to toggle device power. The housing also has a hole in it to allow for an LED indicator to be seen to monitor battery life. The housing is also water and dust resistant. The overall dimensions of the receiver housing are 2.60” x 3.30.” The thickness of the housing is 0.78.”

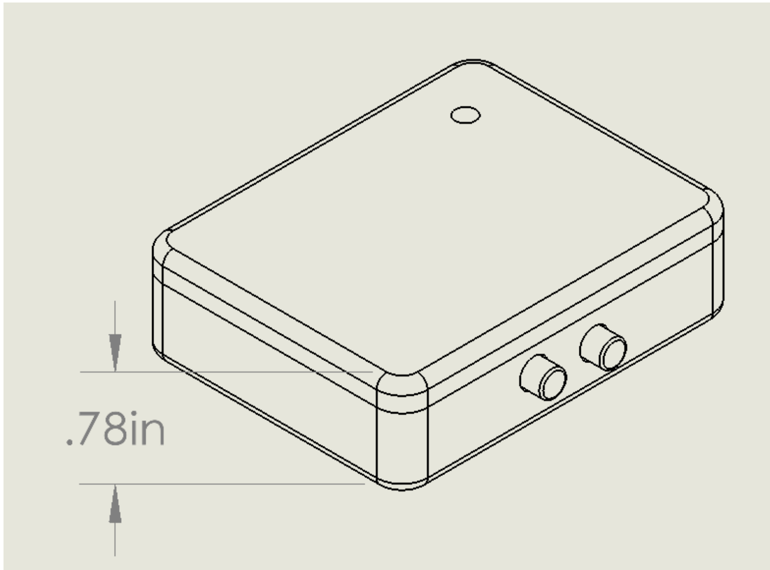

Figure 6.2.1: Receiver Housing

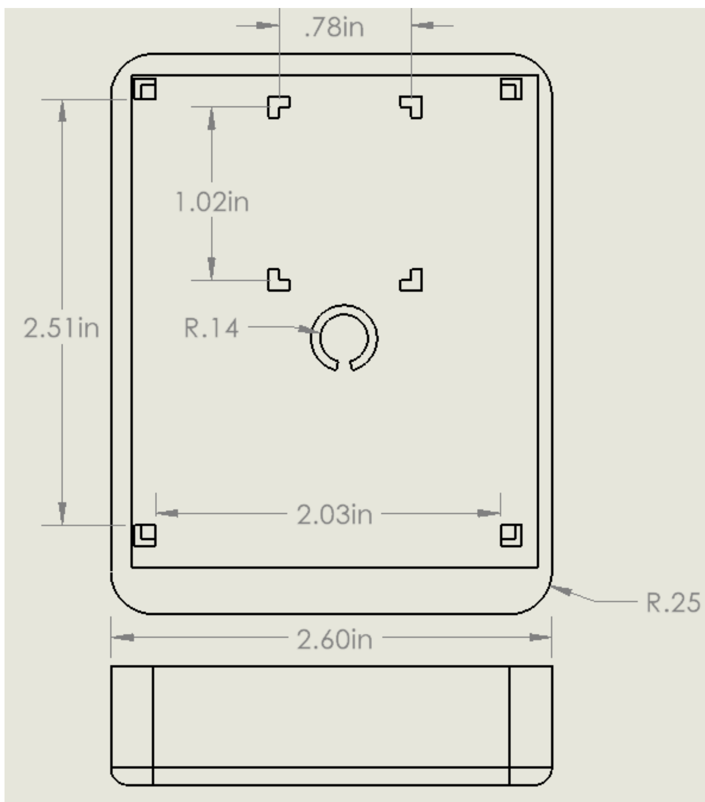

Figure 6.2.2: Base of Receiver Housing

The base of the receiver housing features a slot for the haptic motor to be placed in. This is centered in the middle of the base of the housing. There is also a spot for the battery to be secured in, so it does not slide around while it is being used. Once the housing is opened, it will allow the athlete to remove the PCB, disconnect the battery, and charge the battery. When removing the PCB, the haptic motor will have to be removed but can be easily replaced in its slot. The PCB is raised in the base of the device to allow the battery and haptic to be stored underneath the PCB.

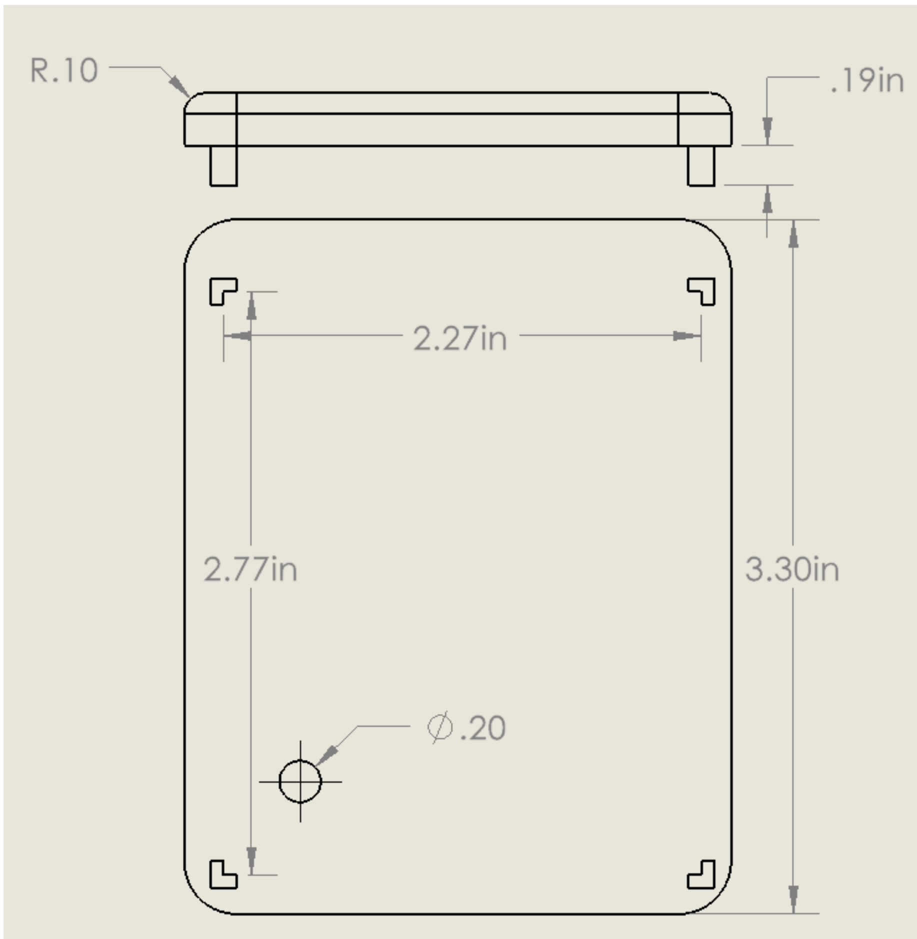

Figure 6.2.3: Lid of Receiver Housing

The thickness of lid is 0.25.” It has a radius of 0.10” around the edge of the lid for aesthetics. The lid has 90-degree corners on each side that are 0.19” tall to securely snap into the base of the receiver.

6.3 TRANSMITTER HOUSING

The transmitter housing was made to be as small as possible to easily fit the palm of a hand. The housing will feature the same two-piece design as the receiver housing. There will be holders in the bottom part of the casing to hold the PCB into place. The overall dimensions of the transmitter housing will be 2.25” x 3.30.” The overall thickness is 0.90.” The housing is also water and dust resistant. The PCB will be able to be easily removed from the device housing to replace the battery when needed.

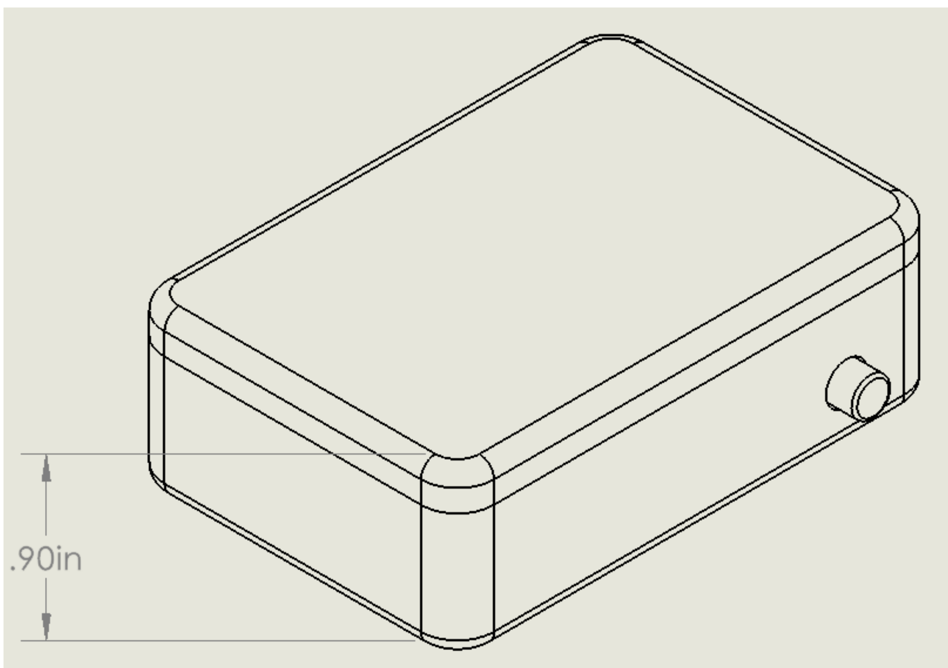

Figure 6.3.1: Transmitter Housing

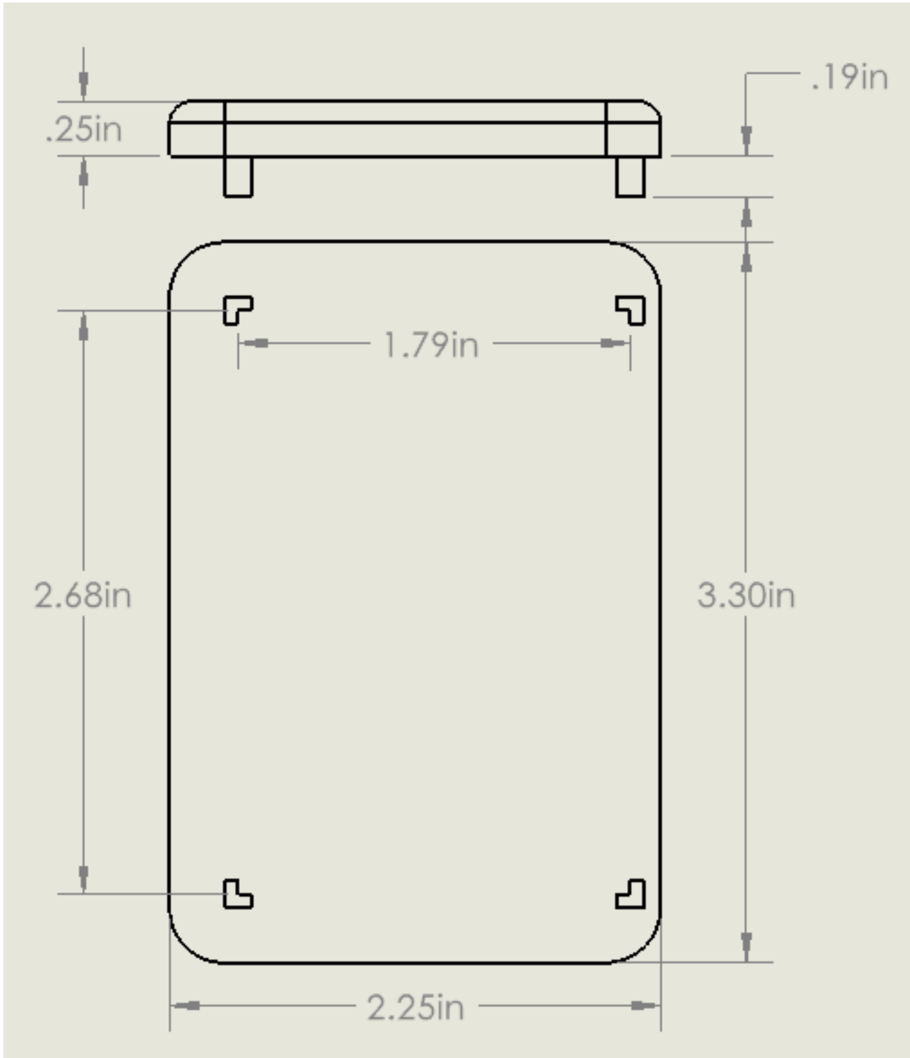

Figure 6.3.2: Lid of Transmitter Housing

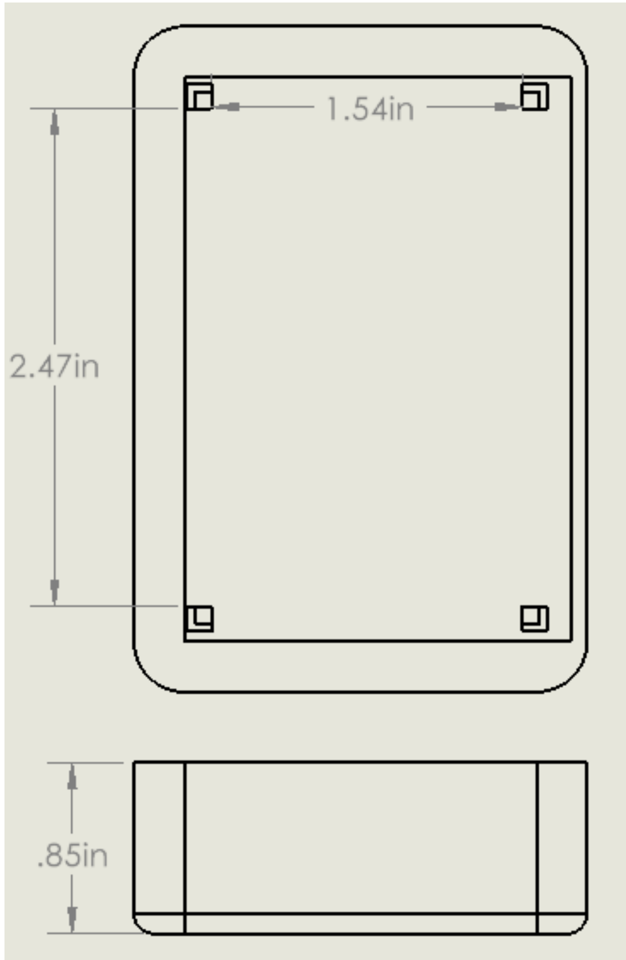

Figure 6.3.3: Base of Transmitter Housing

The lid of the transmitter housing is 0.25” thick. The lid has 90-degree corners on each side that are 0.19” tall to securely snap into the base of the transmitter. The lid also has a 0.10” radius around the lid to match the receiver housing.

7 RECEIVER PCB DESIGN

This section outlines the development and revisions of the receiver PCB schematics, fabrication, and testing. There were several revisions to each design and sections outlined the revisions made and why they were necessary. The goal for the final revision of the receiver and transmitter communicating wirelessly and activating the other peripheral components.

7.1 RECEIVER REVISION 1.0

The first iteration of the receiver was developed to get formulated ideas onto a PCB to visualize future steps. There was a significant amount of research done to determine what the best type of wireless transmission would be for the design. Originally the design planned to use a 433 MHz frequency with select addressing pins. The 433 MHz frequency is also in the legal public accessible range determined by the FCC [16]. However, due to part shortages the 433 MHz receiver and antenna splatch were not available for purchasing. To complete the project in the allocated time, the design was changed to a 418 MHz receiving system. This is a minor change, but the lower frequency theoretically reduces the range between the receiver and the transmitter. This frequency is also in the legal public use range allocated by the FCC.

7.1.1 Receiver 1.0 Schematic and Board

The receiver module was originally designed to have the smallest electronic footprint possible. It was thought that to do this the receiver would\have to be able to directly communicate with the microcontroller. The signal would flow through the antenna, to the receiver, then to the microcontroller. The components used for this would be a LINX ANT-418-SP (418 MHz antenna), LINX RXM-418-LR (418 MHz receiver), to a Seeeduino Xiao Arduino Microcontroller. It was believed that the microcontroller would be able to decode the receiver and address the signal at the same time. This would significantly reduce the overall electrical footprint and size of the PCB. The schematic for the first receiver iteration can be seen in Figure 7.1.1 in Appendix A. The first iteration of the receiver board can be seen in Figure 7.1.2 below.

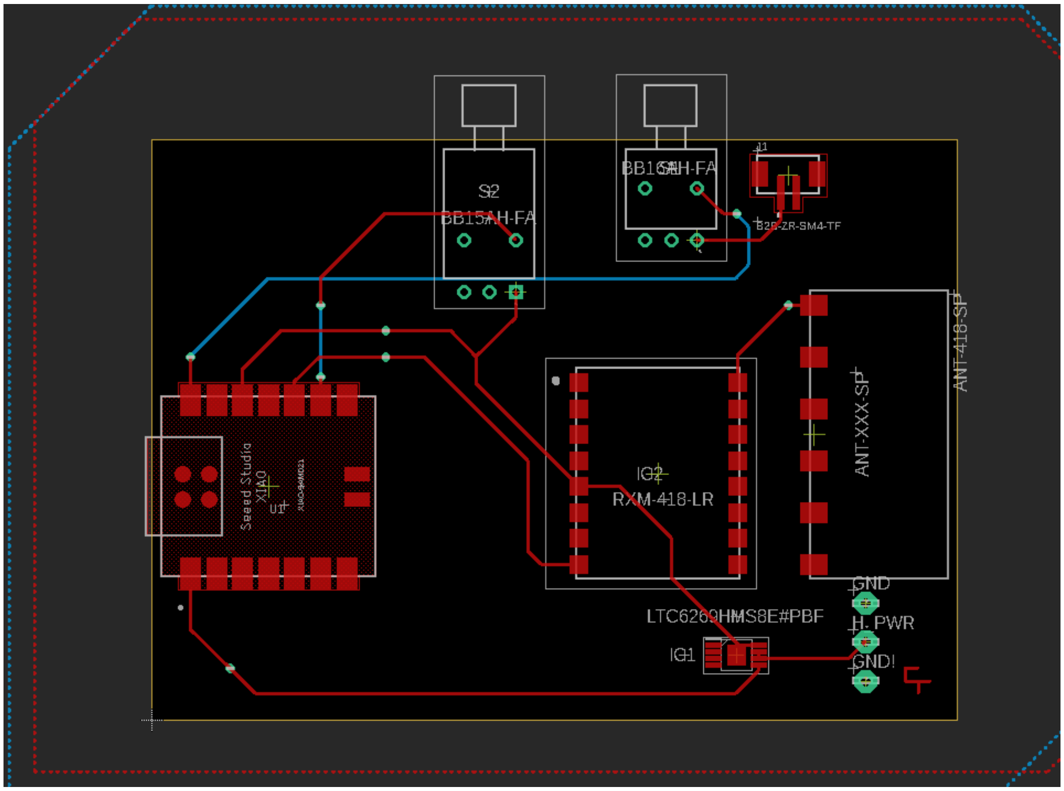

Figure 7.1.2: Receiver 1.0 EAGLE Board

The schematic and board design where made using a software called EAGLE. It is an ECAD software created by Autodesk to design and model hardware and PCBs. In the top right corner of the board design is the lithium polymer (lipo) battery connector. This is so the battery can be easily taken in and out of the design to be charged. The power button is directly to the left of the battery plug. The power button is a single pole, double throw (SPDT) momentary switch (BB15AH-FA). The button will stay locked down until pressed again to turn on and off the device. This will allow the user to physically see whether or not the receiver is turned on. The next button to the left is a SPDT on-on push button switch (BB16AH-FA). This is connected to the Seeeduino Microcontroller to change the level of haptic feedback. Each click of the button will change the intensity of the haptic feedback. The microcontroller will output three different voltages to regulate the strength of the haptic motor.

Pin 1 on the microntroller is refered to as the digital-to-analog converter, otherwise known as the DAC. This allows the voltage output to be regulated by the microcontroller with out the need of external voltage regulators. Before the DAC output is sent to the haptic motor it is sent through an op-amp (LTC6269HMS8E-10#PBF) that is wired as a buffered op-amp. The op-amp is configured as a buffered op-amp in order to reduce possible signal interference. Without the buffer the haptic engine could be exposed to signals that would cause the system to operate at in adequate times. This would confuse or possibly put an athlete at risk of injury if the haptic feedback occurs at an unprompted time. The buffered op amp is also configured as a unity gain op amp to provide the adequate amount of current necessary to drive the haptic motor.

The reciever is connected to the microcontroller via the trace labeled DATA in Figure 7.1.1 in Appendix A. As discussed earlier, the original idea was to address and receive the signal directly from the receiver. It was believed that the receiver would already output the signal as a string of bits as 1's (high) or 0's (low). With this, the microcontroller would be used to process the data and use the high value to turn on the haptic motor. Attached to the input of receiver was the LINX antenna splatch listed earlier. This would increase the range and improve the ability of the receiver to detect the corresponding transmission signal.

This EAGLE model was then milled out in the PCB Lab at the Applied Engineering Center at the University of Southern Indiana. The PCB Lab uses a copper FR-4 material without a soldermask. Soldermasks are extremely useful in eliminating shorts from soldering on componenets. The soldermask aids in stopping the solder from running from pad to pad. Revision 1 of the in-house milled PCB can be seen below in Figure 7.1.3.

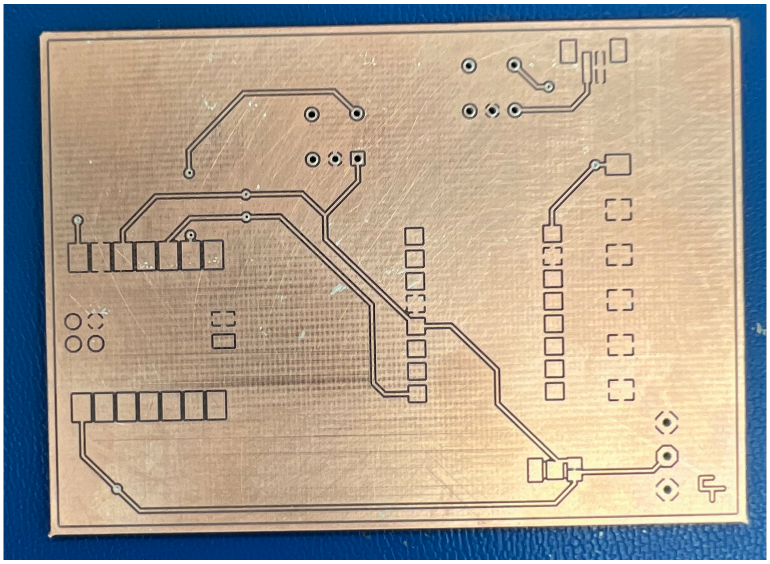

Figure 7.1.3: Receiver 1.0 In-House PCB Fabrication

After the fabrication of in-house receiver board there were several issues that were noticed within the orginal circuit design. It was later learned that while the receiver did output a string of 1's and 0's, the microcontroller did not have any communication portocols available that could decode the data. Given that the current microcontroller could not be used for this design, either a new microcontroller with radio capabilites, or a decoder before the current microcontroller, would need to be added to the system for it to function as intended.

7.2 RECEIVER REVISION 2.0

The second revision of the receiver PCB was updated based on the issues highlighted above. It was established that the Seeeduino Microcontroller would still be used, and the decoder would be added to the design. The decoder has the communication protocols necessary for the system to communicate. For this design, the encoder/decoder component (LICAL-EDC-DS001-T) would be configured as a decoder and added before the microcontroller to decode the data from the receiver. There are a couple other minor changes from the first revision that will be discussed later in this section.

7.2.1 Receiver 2.0 Schematic and Board

As previously mentioned, added to the second revision of the receiver was the encoder/decoder component. This component, also being manufactured by LINX Technologies, is easily implemented with the other LINX components on the receiver. The decoder is equipped with 28 pins allowing for data transfer, signal decoding, power pins, and addressing pins to attune the system to a unique signal. The decoder takes the output signal of the receiver and strings it as a series of ones and zeros. This can now be processed by the microcontroller using PIN 12 as the DATA input pin, which can be viewed in Figure 7.2.1 in Appendix A. The battery terminal, pushbuttons, op-amp, receiver, antenna splatch, and the haptic motor are all orientated the same as the first revision. The locations of these components changed a little to try and minimize the board size while leaving enough room for board testing. The EAGLE board can be seen below in Figure 7.2.2.

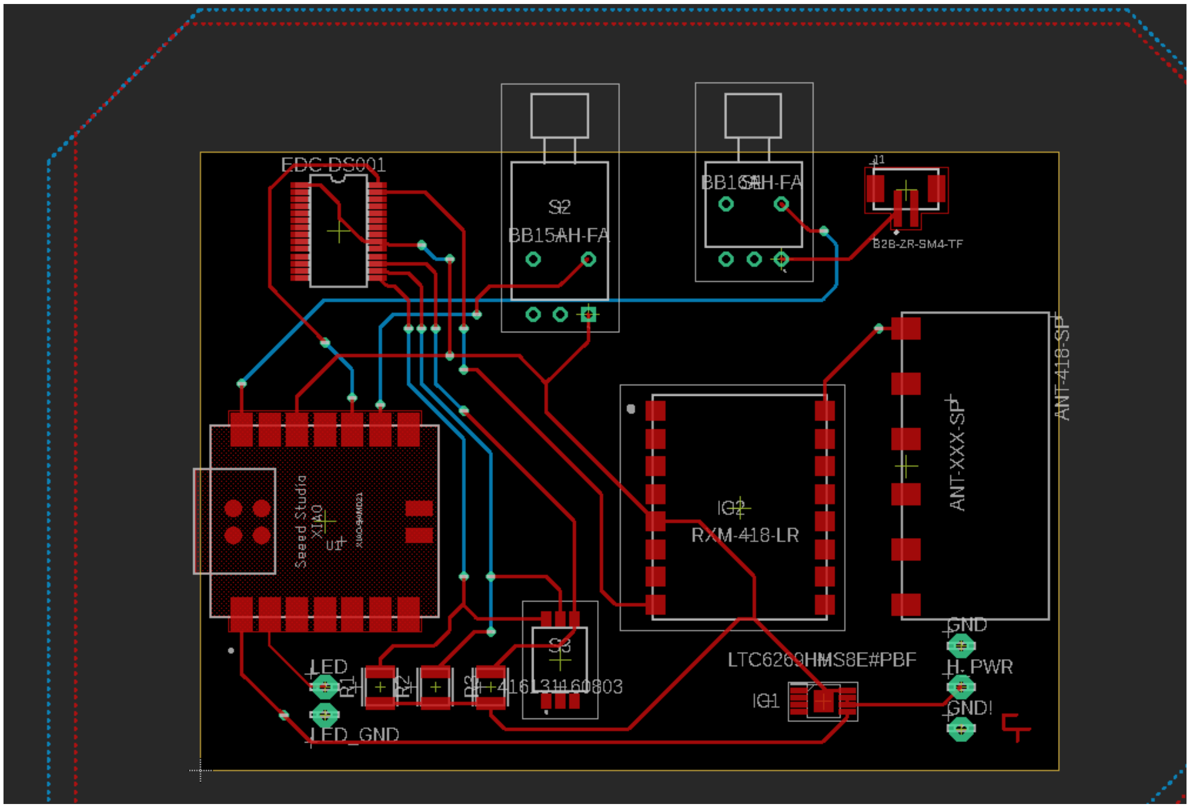

Figure 7.2.2: Receiver 2.0 EAGLE Board

The decoder can be seen added to the board in the top left corner in Figure 7.2.2 labeled EDC-DS001. The output of the receiver is connected to the input pin on the decoder. Connected to the DATA pin on the microcontroller is now the output pin of the decoder rather, than the output pin of the receiver. Also attached to the decoder is a 3-switch DIP switch (416131160803) and three 100kΩ resistors. These switches were used to address the signal to a specific frequency. The bottom side of the three resistors are connected to VCC. The top side of the resistors are connected to the traces that run from the positive terminals of the switch to the respective decoder address pin. When the switch was closed the address would be pulled high and when the switch was open the pin was pulled low. This switch combination was modeled after the common configuration given in the LINX Decoder Module datasheet [17]. This model can be seen below in Figure 7.2.3.

Another component added to the system was a pink, through hole LED. This LED is programmed to flash after the voltage supplied by the battery drops below a certain threshold. The pads for this can be seen in the bottom left corner of the PCB drawing depicted above.

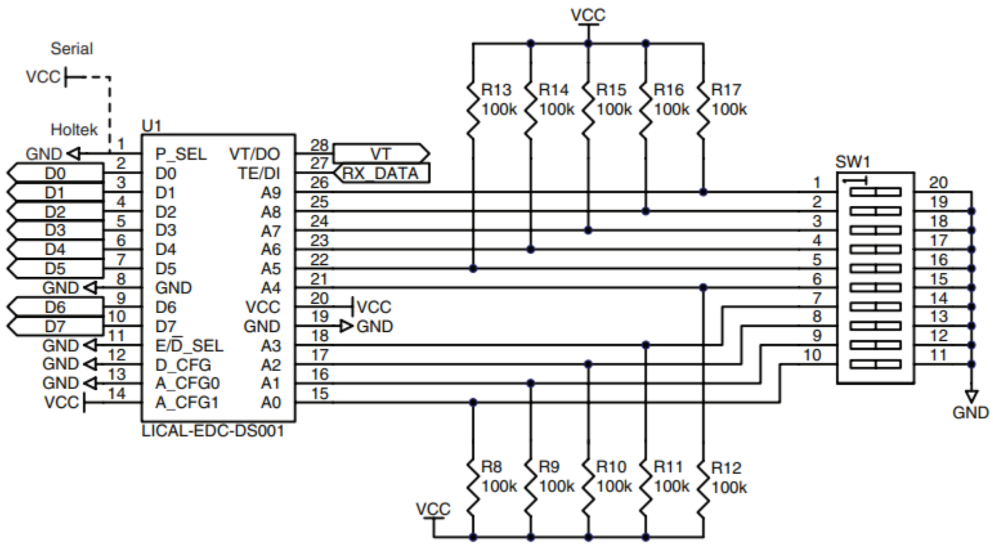

Figure 7.2.3: DS Series Typical Application as a Decoder [17]

Due to the 11-mil spacing between pins on the decoder it would not be practical to fabricate an FR-4 board with the in-house milling machine without a solder mask option available. Without solder mask the odds of having shorts between the decoder pins would be extremely high. To get a solder mask, the EAGLE files were sent to JLCPCB [18] to be fabricated professionally with solder masks applied. This would allow the board to be soldered together with lower chances of shorting traces on the ground pad. The completed model can be seen below in Figure 7.2.4. The solder mask is the green film applied on both sides of the PCB.

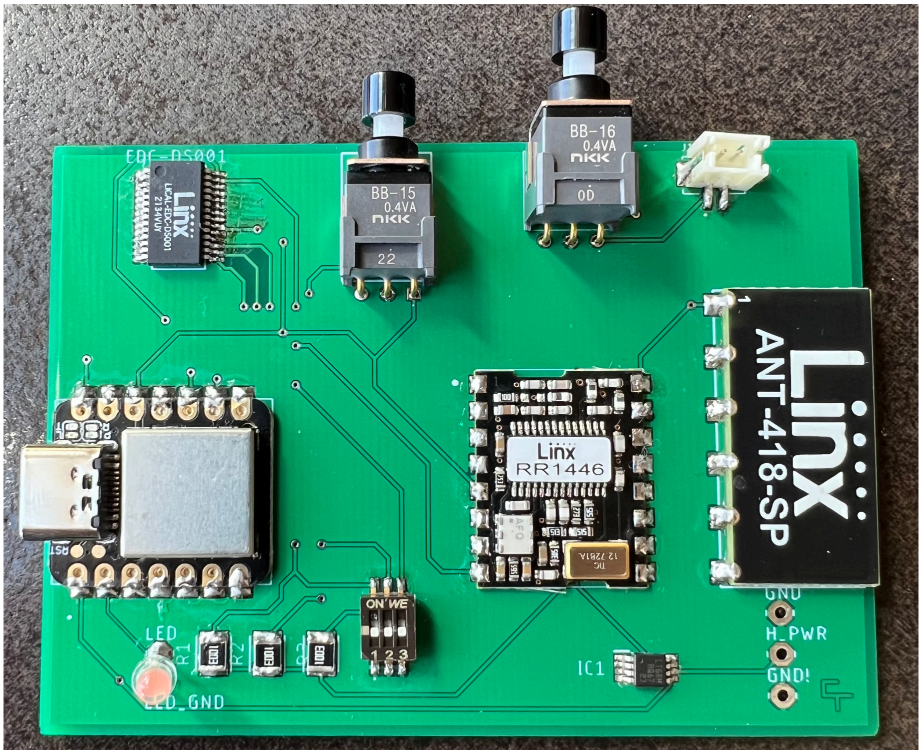

Figure 7.2.4: Receiver 2.0 JLCPCB Fabricated Board

7.2.2 Receiver 2.0 Testing

The first round of testing was to see if there were any shorts in the system after all components were soldered in position. This was completed using a multimeter to check connectivity between traces and from pin to pin. The only issues after soldering were completed were a couple shorts between the decoder pins. These were fixed using a solder wick and by lightly running a scalpel blade between contact pads.

The footprint of the BB-16 pushbutton also showed the button being smaller than the BB-15 pushbutton. To get the pushbuttons at the same level for the housing, the BB-16 pushbutton was moved closer to the edge of the board. However, after the components were received it was noticed that the two types of pushbuttons were the same size. This created and offset in the pushbuttons after being soldered to the board which can be observed in Figure 7.2.4. This would complicate the housing design in later steps if the buttons were offset.

Another issue was found when attempting to connect the lithium polymer battery to power on the board. The battery terminal in the upper right-hand corner of the board does not match the terminal on the battery. There is a small difference in the locking mechanism between the connection terminal and the battery itself. This prevented the planned 3.7V power supply from being used during the initial testing of the receiver.

The addressing switch being used to address the system was found to be obsolete. It was originally thought that the DIP switch would need to be used on the receiver to address the system. During testing and reducing the electronic footprint on the board it was established that the microcontroller would be able to provide this addressing. The microcontroller would be able to address the encoder by setting three output pins to either LOW or HIGH. This would eliminate the DIP switches, resistors, and extra wire traces to reduce the footprint and size of the board.

Reviewing the antenna splatch datasheet also revealed another issue present within the design [19]. The antenna is supposed to be placed on the board where no traces or ground planes are present. This is to ensure the antenna is working to its full potential with as little interference as possible. The antenna also calls for a 50-ohm microstrip line. This isn’t a necessity for this project, but for the best signal transfer the wire trace must be at least 20 mil and as short as possible. This reduces the resistance in the wire, effectively increasing the power of the reception strength. Revision 2.0 of the board does not take this into consideration, which could significantly impede the performance of the design. Shortening the distance between the receiver module and antenna will allow the system to be less susceptible to interference as well.

7.3 RECEIVER REVISION 3.0

The third revision of the receiver PCB was updated based on the issues found while testing Revision 2.0 of the receiver. It was established that the Seeeduino Microcontroller would be used to address the system to attune to the transmitter frequency, thus eliminating the DIP switches. There are also some small orientation changes of components to reduce the chances of signal interference and improve other board functions.

7.3.1 Receiver 3.0 Schematic and Board

Mentioned previously, the battery terminal did not match the connection to the battery itself. To fix this, a through hole battery plug-in replaced the current surface mount battery terminal. This would allow the battery to operate as the power source of the receiver system. The quick connect battery terminal allows the battery to be disconnected for charging. The BB-16 pushbutton was also moved down to match the same alignment as the BB-15 pushbutton. This allows for the housing design to easily align the pushbuttons with the PCB.

The DIP switches were also removed allowing the system's address to be programmed with the microcontroller. The three microcontroller pins are connected to the same pins as the DIP switches were to use the correct addressing pins. The schematic showing Revision 3.0 of the receiver can be seen below in Figure 7.3.1 in Appendix A. The schematic shows the addressing pins did not change on the decoder by using the microcontroller.

A voltage regulator was also added to the system. Revision 2.0 of the receiver was going to read the voltage from the power pin of the microcontroller to determine the battery level. The microcontroller is unable to read and perform tasks directly from the power pin due to the high input power. To compensate for this, a voltage regulator was added to PIN2 of the microcontroller. This uses two resistors to change or regulate the voltage and current being applied to PIN2. These are 0402 sized resistors to minimize the area of the board. The microcontroller will read a certain threshold of the regulated voltage and calculate the battery level. After the voltage drops below the threshold the pink LED will begin to flash meaning that the device will need to be charged soon. The addition of the voltage regulator can be seen below in the EAGLE board drawing in Figure 7.3.2 below.

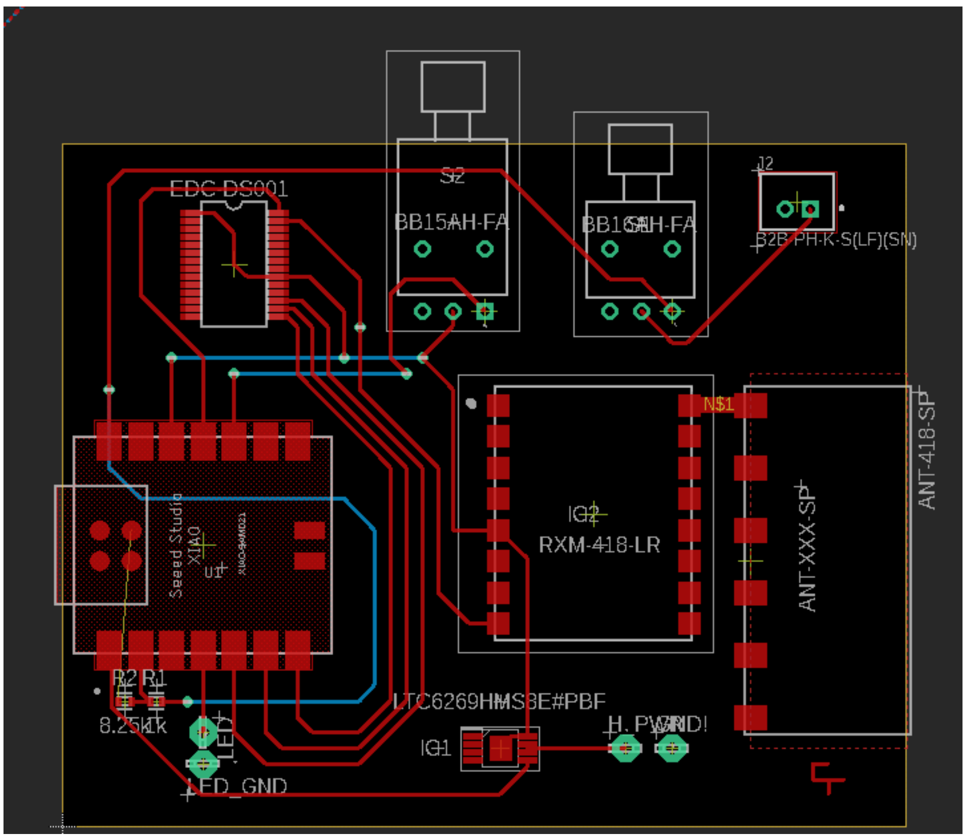

Figure 7.3.2: Receiver 3.0 EAGLE Board

The receiver module and antenna were also moved. The receiver was moved to line up the input pin (PIN9) to the output pin of the antenna (PIN1). This is to decrease the length of the trace and the resistance of the signal transmission line. The trace was also increased to a 40 mil width to help eliminate the line resistance. This helps keep the signal accurate and reduce the possibility of signal interference. The ground plane was also removed on both layers of the PCB around the antenna to reduce interference and increase the range [19]. Removal of the ground plane can be seen as the dotted red cutout around the antenna splatch in Figure 7.3.2 above. Eliminating the DIP switches and moving the receiver closer to the antenna splatch allows for the size of the receiver PCB to be reduced even further.

The PCB was fabricated using JLCPCB to ensure efficiency and professionalism similar to Revision 2.0 of the board. This completed board can be seen below in Figure 7.3.3. The pushbuttons can also be observed as being the same distance from the edge of the PCB. The contact traces are also a cleaner design with less traces crossing over each other. This also helps eliminate signal interference across the entire system. The output of the system is the same as Revision 2.0. This goes from the microcontroller through a buffered op-amp to the haptic motor to ensure the correct level of haptic feedback is being applied upon the user input.

7.3.2 Receiver 3.0 Testing

The third revision of the receiver was found to have a couple small issues that needed to be corrected. When testing the receiver, the antenna and receiver module registered the 418 MHz transmission signal from the transmitter. The received signal originally did not match the transmitted signal, and the reason for this will be discussed further in the Results section. Once the signal was correctly received, the haptic motor would activate. This was the first working model of the haptic alert system. An issue found was that the negative voltage source terminal (V1- and V2-) on the amplifier were floating and supplied 3.3 volts respectively. This did not allow the buffered amplifier to operate correctly, causing the haptic motor to stay active when not receiving a signal. The issue was resolved by tearing the wire trace to V2- and grounding the two pads. This was accomplished by ripping up the solder mask on the ground plane and soldering the two negative pad terminals to ground. This fixed the haptic alert issue and allowed the system to function as intended. The grounding issue was the main fix for the final iteration of the PCBs that were manufactured.

7.4 Receiver Revision 4.0

This section goes over the fourth iteration of the receiver PCB. There was one functionality change from the third iteration of the receiver. The configuration of the amplifier was changed to operate as the design intended. These changes can be observed in the schematic and EAGLE board, but the testing of this PCB is inconclusive due to time constraints on the project.

7.4.1 Receiver 4.0 Schematic and Board

The fourth revision of the receiver is the final iteration of the receiver PCB. The overall layout of the board and board sizes did not change. The issue with the connection to the amplifier was changed to match the design requirements. On the data sheet for the amplifier, it states that the negative voltage supply could be connected to the ground plane. This was originally missed with the first observations of the data sheet. The negative pins (V1- and V2-) are now grounded to make the buffered amplifier operate as intended. This change can be observed on the schematic in Figure 7.4.1 in Appendix A. The other change on this board iteration was the angles of the VCC connections to the decoder, eliminating any 90-degree bends within the wire. The last change on the board was supplying power to the PDN pin on the receiver module. This helps increase the reception range and keeps the system out of a low power state, which prohibits the receiver from acquiring a signal. This change can be observed on the EAGLE board in Figure 7.4.2 below along with the other changes made during Revision 4.0.

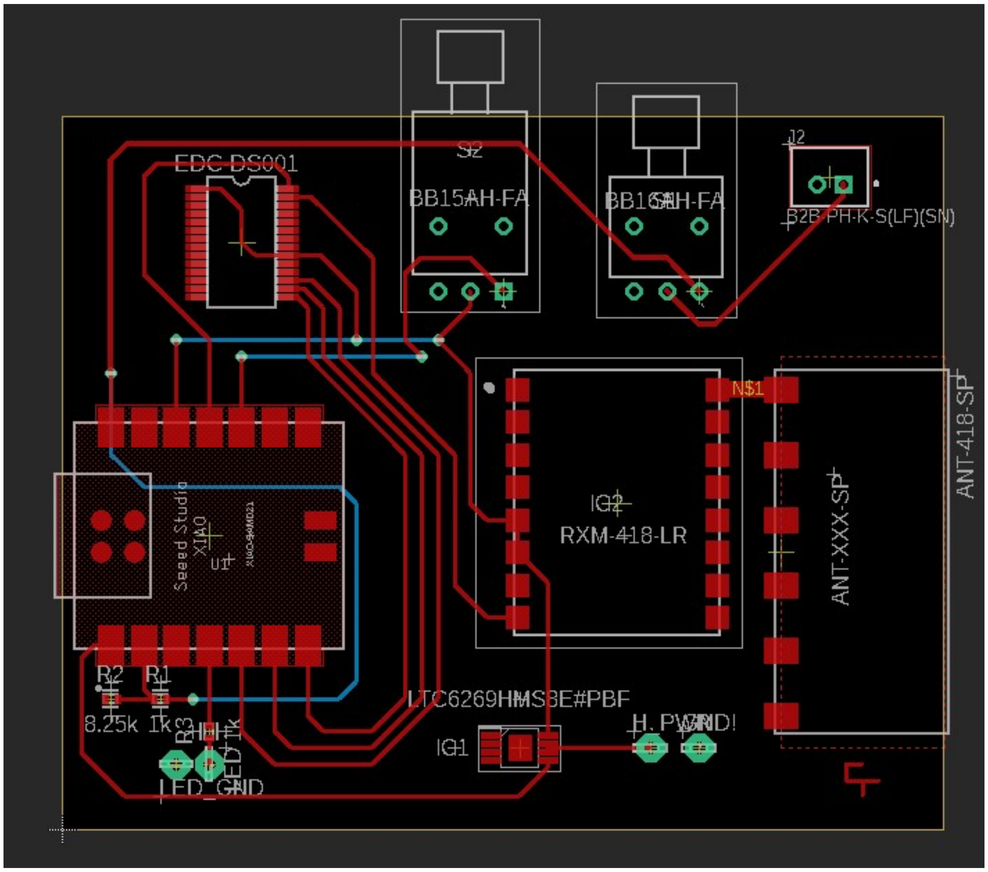

Figure 7.4.2: Receiver 4.0 EAGLE Board

8 TRANSMITTER PCB DESIGN

This section outlines the development and revisions of the transmitter PCB schematics, fabrication, and testing. The transmitter went through several revisions, and this section outlines the revisions made and why they were necessary. The goal for the final revision of the receiver and transmitter is for the transmitter and receiver to communicate wirelessly, and to activate the peripheral components on the receiver.

8.1 Transmitter Revision 1.0

The first design of the transmitter PCB was fabricated to get a version of the transmitter close to the final design. This transmission design reflects a similar design to the "Electronic

Whistle Transmitter and Receiver" project's [4] transmitter whistle. For this design, the transmitter is going to be more like a key fob. It is turned on with a power switch, and the transmission signal is activated using the BB-15 pushbutton described in the previous receiver sections. This will allow the referee or coach to easily operate the transmitter. The section will highlight the components and design ideas for the first revision along with the schematic, EAGLE board design, and the testing of the board.

8.1.1 Transmitter 1.0 Schematic and Board

The transmitter was designed with the goal in mind of having the simplest method of transmission possible. This would help ensure that the transmission and receiving portion of the project would be attainable. The transmitter is composed of a 418 MHz antenna splatch, 418 MHz transmitter, a pushbutton, power switch, DIP switches for addressing, an encoder, and five resistors. This was the smallest electrical footprint design thought achievable. The schematic for Transmitter 1.0 can be seen in Figure 8.1.1 in Appendix A. The schematic shows how the components are labeled and where each component is connected. Figure 8.1.2 depicts the common layout for the LINX transmitter module [17] found in the LINX datasheet.

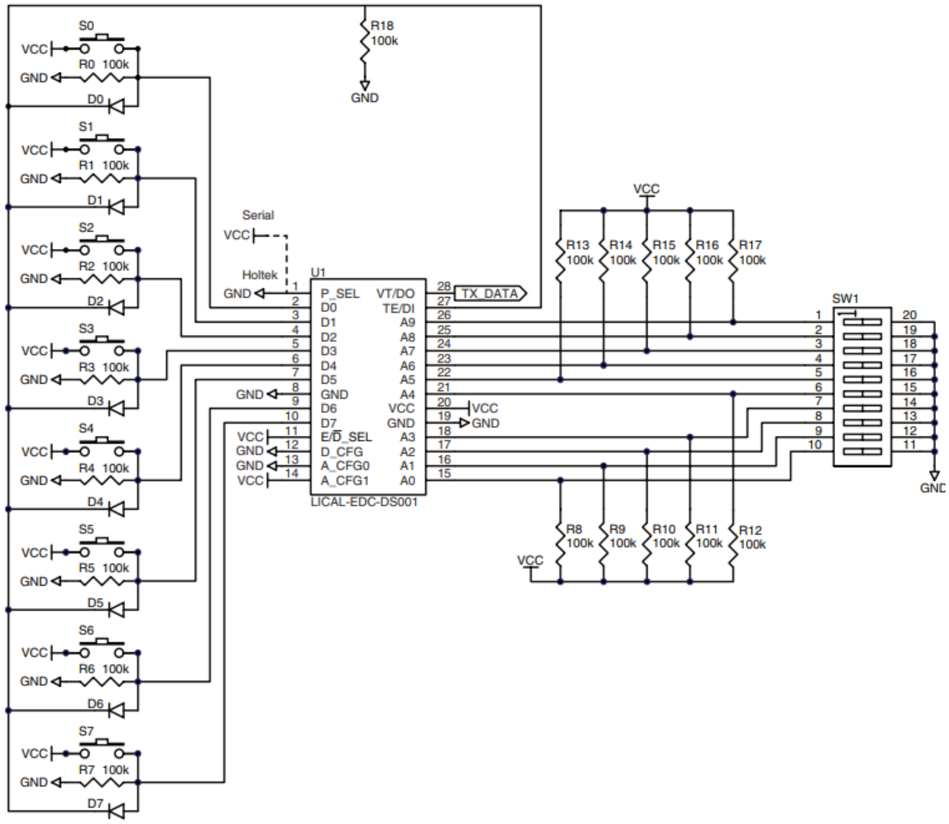

Figure 8.1.2: DS Series Typical Application as an Encoder [17]

The encoder (LICAL-EDC-DS001) is the exact same component that was used in the receiver module. The only difference between the encoder used in the transmitter and the decoder used in the receiver is how the component is connected. Pulling the E/D_SEL pin high turns on the encoder protocol. Addressing the encoder/decoder is the same process for both applications. The main difference is the signal is outputted as an encoded data packet instead of being received as an encoded data packet. Digital pins on the encoder are all set to turn on the transmission signal if any one of the buttons or switches are activated. This ensures that the signal will always be transmitted if any one of the digital input pins are activated. The EAGLE CAD layout of the board can be seen below in Figure 8.1.3. This shows the connections of the device and the physical layout and size of the printed circuit boards.

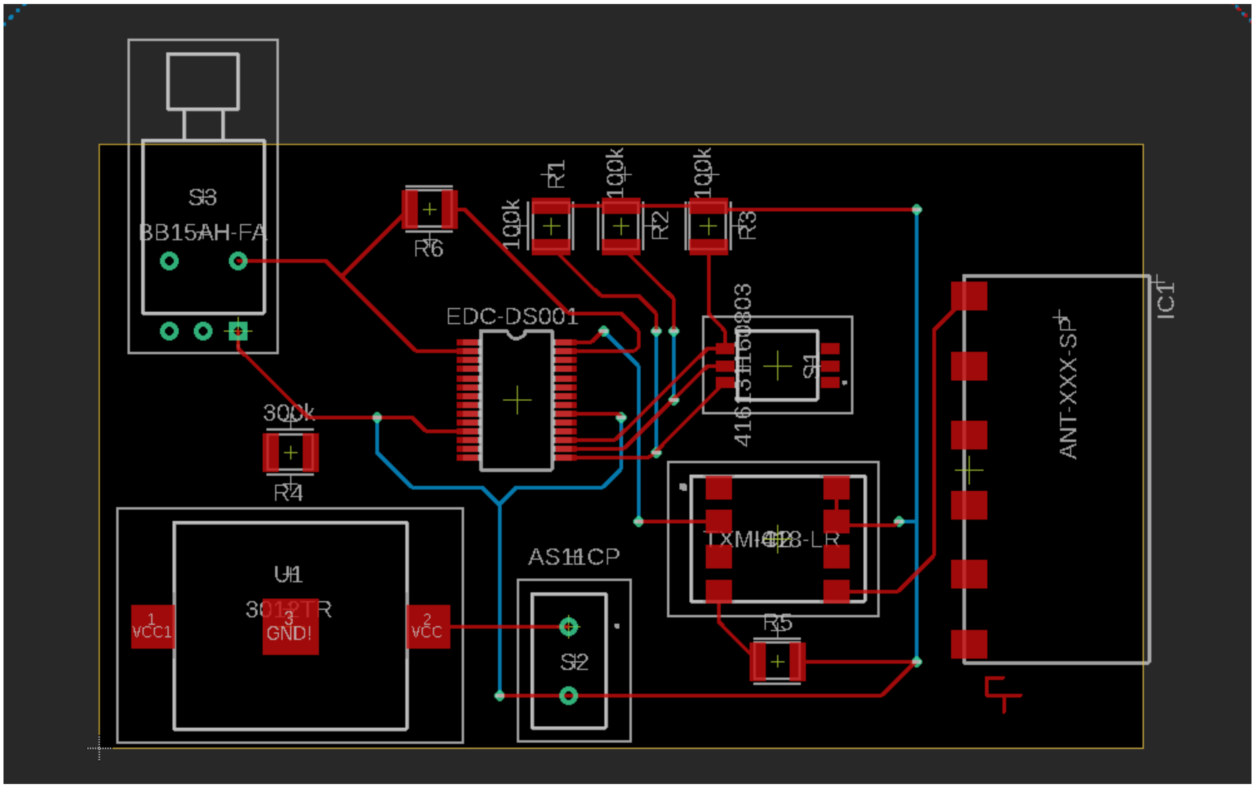

Figure 8.1.3: Transmitter 1.0 EAGLE Board

The splatch antenna is placed on the opposite side of the board of the battery and other analog components to reduce the possibility of creating a false transmission. A false transmission would cause the athletes wearing the device to receive a false signal making them susceptible to an unpredicted collision or continuation of play resulting in an injury. This would have the opposite effect for the desired goal of the project. The antenna is attached to the transmitter module to amplify the signal. The transmission signal is received from the encoder in the center of the board. There are several traces crossing in this design on the top and bottom layers. The bottom layer traces are blue while the top layer traces are in red. The encoder is addressed using the three dip switches setting the pins to pull high or pull low. Each of the 100k resistors are used for this process. In the current position of the transmitter and dip switches, the resistors cross the input signal to the transmitter. This overall is not good design practice and will need to be changed in future designs.

The transmitter board was never milled using the in-house capabilities due to the use of the encoder. Soldering the encoder pins requires high precision with low clearance and without a solder mask this is extremely difficult to accomplish. The FR-4 PCB was fabricated at JLCPCB to ensure the traces and solder mask is held at professional standards in a manufacturing facility. As mentioned above this allows the solder to be more easily applied without causing a short in the system. This PCB fabricated by JLCPCB can be seen below in Figure 8.1.4. The board pictured is soldered together with all the components to test functionality.

8.1.2 Transmitter 1.0 Testing

Testing for Transmitter 1.0 began with checking the JLCPCB fabricated board for shorts between traces and solder pads. This was done by testing continuity across trace wires and the ground planes to across the entire system. One lead was placed on one side of the trace or solder pad and then the other lead was placed on the other in the desired location. To check for ground shorts one lead was placed anywhere on the wire trace being checked and the other would be connected to anywhere on the ground plane. If the trace was grounded it would call a closed circuit and an alarm/buzzer would go off. The JLCPCB board connections passed the correct continuity test for each given component layout.

The second phase of testing came after the board was soldered together with the components. After the board was soldered the components and wire traces were tested for proper continuity. The first error in continuity was found at the push button. When the pushbutton was pressed to the on position, the continuity on the multimeter did not change and continued to read open. This was not from an error with the pushbutton or trace wires, but from the misreading of the pushbutton data sheet causing the pushbutton to be connected to the board with the wrong pins. To fix this problem for this iteration of the board, the pushbutton trace connections were shorted using a jumper wire. This would cause the system to be constantly transmitting whenever the power switch was toggled on.

The second error in continuity was found between the transmitter and antenna. These connections were shorted to ground at some point during the soldering process. This issue had not yet been resolved in the current revision and will be addressed in the next iteration. The short to ground does not let the system transmit a signal since the short occurred between the transmitter pin and the antenna data pin.

8.2 TRANSMITTER REVISION 2.0

There were multiple issues from the first revision of the transmitter printed circuit board. These issues were highlighted above, but the biggest change is the overall layout and size of the PCB. This section will go into detail about the second revision of the transmitter discussing the schematic and board, changes that were made, and testing of the PCB.

8.2.1 Transmitter 2.0 Schematic and Board

The second revision of the transmitter PCB addresses the issues found in the previous section, but also improves the layout and functionality of the board itself. There were a couple changes made to the schematic - adding components and fixing the pushbutton connection issue. The pushbutton that activates the transmitter is now connected in the proper orientation to complete the circuit when the button is pressed. The two components added to this transmitter module were a 1k ohm resistor and a pink LED to show when the button is pressed on the transmitter. The pink LED was added so it could be observed when the system is transmitting data. This would be beneficial for the functionality of the system and the schematic showing this can be seen in Figure 8.2.1 in Appendix A below.

The other changes in this revision are in the layout of the board and changing various trace sizes to improve functionality of the system. When soldering the battery terminal on the first revision of the PCB there was only one trace attached. There was difficulty soldering the terminal on the pad, and whenever the terminal was being adjusted the single wire trace was ripped up. To prevent this happening on this design, the battery terminal was rotated, the traces were connected to both positive leads on the terminal, and the wire trace thickness was increased from 10 mil to 16 mil to decrease the possibility of having an issue at the battery terminal. This change can be seen below on the EAGLE CAD board design in Figure 8.2.2 below.

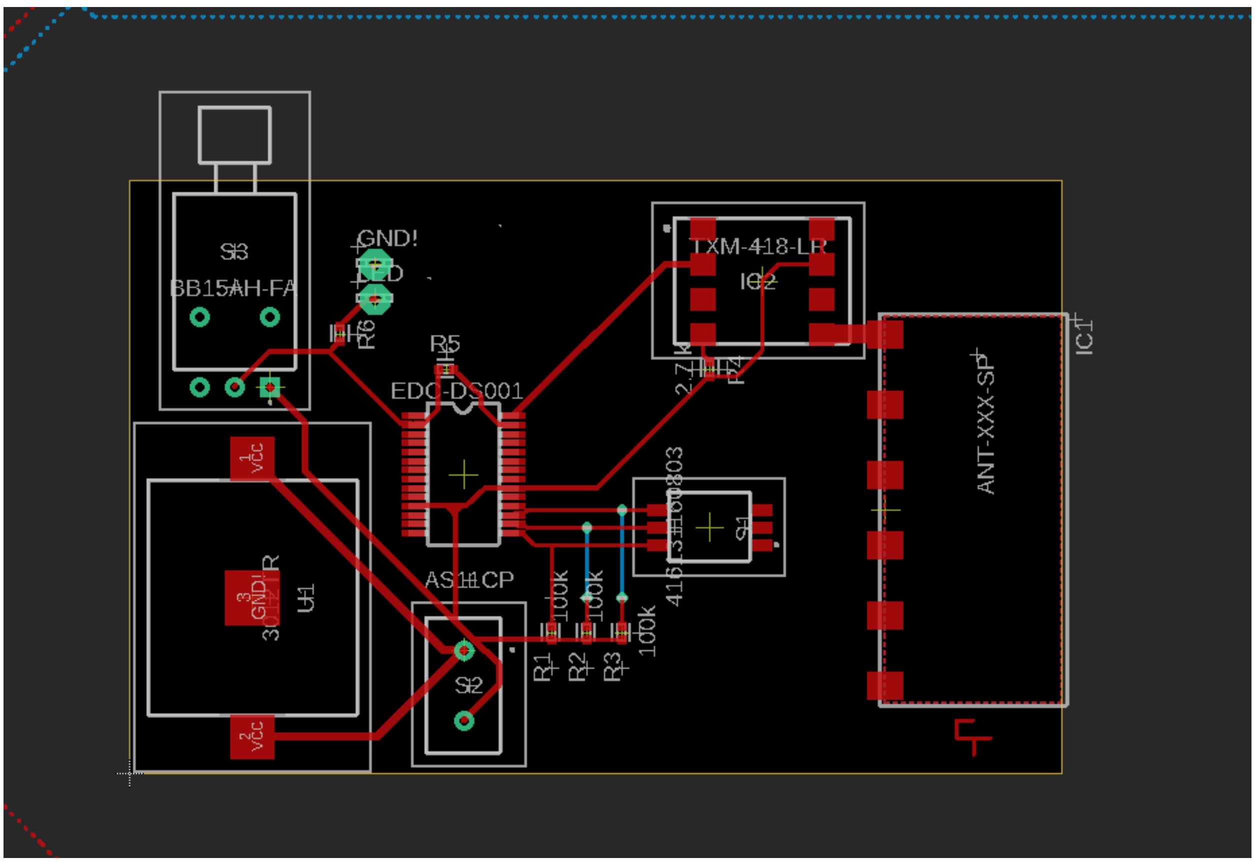

Figure 8.2.2: Transmitter 2.0 EAGLE Board

To decrease the chance of having a transmission error, the transmitter component and splatch antenna locations were altered. The analog components were moved further away from the transmission line between the transmitter and the antenna to also reduce the possibility of signal interference. Moving the transmitter and antenna as close together as possible reduces the trace length between the two components. The wire trace was also increased to a size of 50 mil to decrease the resistance of the wire. The antenna splatch recommended a 50 mil microstrip to increase the functionality, but the 50-mil wire trace is sufficient for this design. The antenna also called for the removal of all traces and ground planes beneath it. This is to ensure the transmission signal can be broadcast with as little interference as possible.

8.2.2 Transmitter 2.0 Testing

Overall, Transmitter 2.0 PCB was a fully functional board. There were a few errors that were discovered while debugging the system. The first issue discovered was that the LED would not light up due to a grounding issue. There was an error with the grounding pad was not actually grounded to the board for the LED causing the LED not to light up. It was also observed that there was a better way to loop the LED with pins connected to the encoder to make a more streamlined process. This fix will be described in more detail with the third revision of the transmitter. Another issue was the 2.7 kOhm resistor, R4, was placed on the board too closely to the TXM-418-LR transmitter module and could not be soldered on due to the pads being covered once the transmitter module was soldered to the board. This issue will be fixed with the third revision of the transmitter. It was also observed that the transmitted signal did not match the received signal on the bit level. The very first bit was transmitted a 0 and the received signal began with a 1. This meant that the first pin, P-SEL, on the encoder for the transmitter was pulled low instead of high. Pulling the P-SEL into low turns on the Holtek data structure protocol and pulling P-SEL high turns on the serial protocol. The transmitter and receiver were supposed to both be in serial protocol and were orientated to do so. This will be explained in more detail in the Results section along with the solution that makes the transmitter operate correctly.

The Transmitter 2.0 could send the encoded 418 MHz transmission signal which was observed using the Agilent E4402B Spectrum Analyzer. This transmission signal can be seen in Figure 8.2.3 below. To view the signal the spectrum analyzer was set to have a center frequency of 418 MHz to appear in the middle of the screen. When the transmission signal was received by the Spectrum Analyzer the graph displays the peak observed below at 418 MHz. There is a minor noise being picked up around the 418 MHz frequency which is represented by the minor peaks on either side of the 418 MHz peak. This is why the signal was addressed, so the receiver would not be activated by this noise.

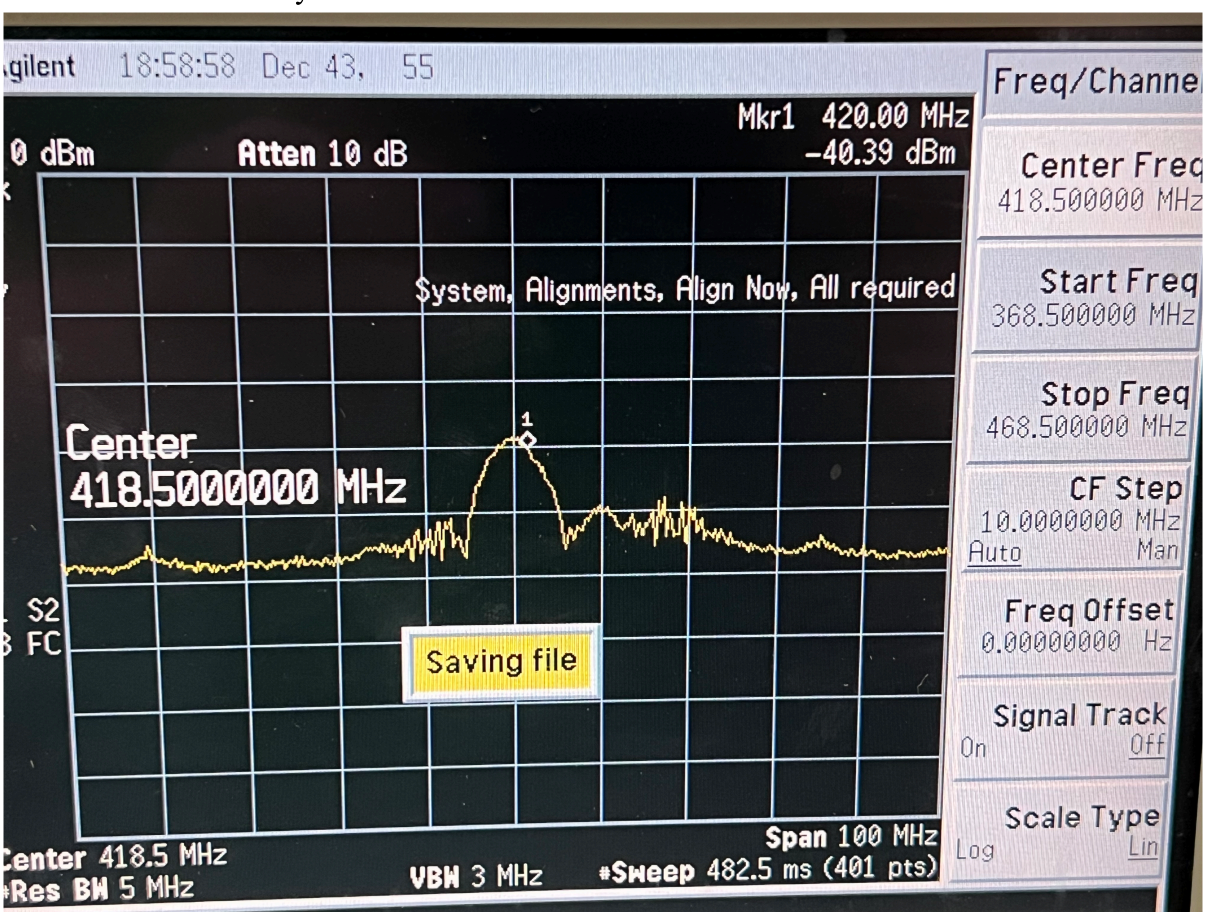

Figure 8.2.3: Transmission Signal from Spectrum Analyzer

8.3 TRANSMITTER REVISION 3.0

There were a couple issues from the second revision of the transmitter printed circuit board. These issues were highlighted above, but the biggest change is the design of the LED and how the system is wired from the pushbutton to the encoder. This section will go into detail about the third revision of the transmitter, discuss the schematic and board, and highlight changes that were made. Testing of the board was not completed due to not receiving the manufactured boards within the project deadline.

8.3.1 Transmitter 3.0 Schematic and Board

The third revision of the transmitter PCB addresses the issues found in the previous section, but also improves the layout and functionality of the board itself with regards to the LED and how it is connected to the encoder from the pushbutton. Transmitter 2.0 ran the ground of the LED directly to ground and the other trace to the D0 pin on the encoder. Transmitter 3.0 has three different trace routes off the pushbutton, to the LED, to a 100 kOhm resistor to ground, and the D0 pin on the encoder. Unlike Transmitter 2.0, the negative side of the LED is sent to the DE/TIN pin on the encoder and branches off across a 100 kOhm resistor to ground. This will optimize the functionality of the initial transmission activation signal to the encoder. There is also another 300 kOhm resistor added to the other input pins of the encoder (D1-D7) that is ran to ground on the other end. This is to ensure that there is no possibility of a false signal through the ground plane could activate the transmitter. These changes can be seen along with the added resistor in the schematic depicted in Figure 8.3.1 in Appendix A.

There were no other components added to the system besides the 300 kOhm resistor. The orientation of the other components on the PCB were not changed in any way. This can be observed in Figure 8.3.2 of the EAGLE CAD model below. The overall size of the board was not changed for the third revision since the components were not in a different orientation. The 2.7 kOhm resistor (R4) was moved down farther away from the transmitter module to ensure that it could be soldered onto the board without interfering with the installation of the transmitter module. As mentioned above, after the push button is pressed the wire trace branches off into three directions. This allows the system to operate more effectively by regulating current and voltage irregularities while powering on the LED when the transmitter is activated. The P-SEL pin on the encoder was also pulled high to activate the Serial Protocol so the receiver and transmitter can communicate. This solved the problem where the transmission signal was not perceived as a valid data packet when decoded by the receiver board.

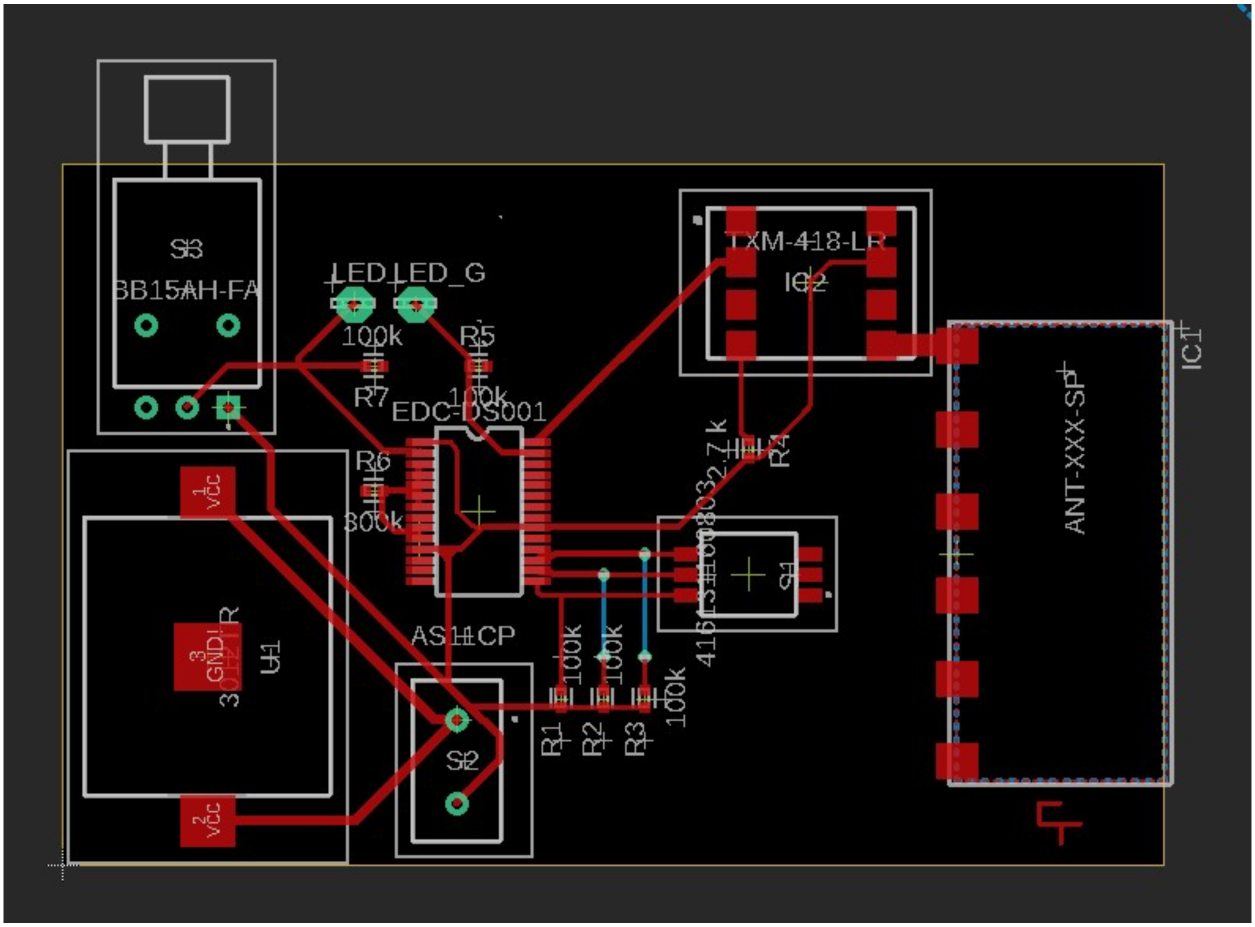

Figure 8.3.2: Transmitter 3.0 EAGLE Board

9 CODE LOGIC

9.1 Overview

The main goal for this code is to detect when a signal comes in from the Decoder pin, then activate the Digital-to-Analog Converter (DAC) pin which the haptic motor is wired to. Whenever the DAC pin activates, it will stay on for a period of 10 seconds, then shut off again. This can easily be adjusted in the code.

When a signal is detected from the haptic adjustment push button, the voltage level of the DAC output pin is adjusted to one of three different levels. Since the haptic motor is rated to operate within a voltage range of 2.7V-3.3V, the determined voltage levels are 2.7V, 3.0V, and 3.3V for low, medium, or high feedback. Since the haptic motor is a DC motor, the output level of the motor is directly proportional to input voltage. In this manner, the user has control over the output level of the haptic motor. Whenever the push button is pressed, the system delays for a second for simple button debouncing.

9.2 Low Power

To meet the battery life constraint, a low power solution had to be implemented. This was accomplished by using the ArduinoLowPower.h library [20]. The Low Power library uses interrupt programming to detect when a signal is received. When waiting for a signal, the microcontroller powers down to a sleep mode, where most of its higher-level functions are disabled. This increases battery life. The microcontroller enters sleep mode for a period of 10 seconds, where it wakes up to check the battery level, or until it detects a signal from the decoder or push button. After completing the task at hand, it again enters sleep mode.

9.3 Battery Level

To alert the user when the battery is below a certain threshold, the microcontroller will check the battery every 10 seconds when it exits sleep mode. The microcontroller will read the analog value on the Battery Level pin using the Analog-to-Digital Converter (ADC) and check if the value is below a certain threshold. The signal from the ADC pin is then converted to volts and compared to the minimum threshold [21]. If the threshold is met, nothing happens, and the microcontroller resumes sleep mode. If the threshold is not met, the microcontroller will activate the LED output pin for 3 seconds, then resume sleep mode. In this manner the user can determine if the battery needs to be charged or not.

9.4 Addressing for the Decoder

Although the decoder uses 10 pins for addressing, only the first three pins are adjustable in this design. Full adjustable addressing is excessive for the project's needs. The microcontroller provides the addressing for these pins by pulling the pins high. The address of the encoder can easily be configured in the code.

9.5 Alternate Solution

To test the device's capabilities more thoroughly, two different versions of code were developed. One solution utilizes the ArduinoLowPower.h library and is described above, and the other does not. The non-low power solution had significantly better performance on the range test when compared to the low power solution, suggesting that the performance of the overall system depended just as heavily upon the code solution used as the mechanical parts' performance. Upon further testing, it was found that the low power solution performed poorly with the Pulse Width Modulation (PWM) signal that was necessary when using the DAC peripheral, leading to subpar performance. Even though both solutions use PWM signals to operate the DAC, the ArduinoLowPower.h library does not work properly with PWM. Therefore, an alternative solution was developed that did not use the ArduinoLowPower.h library. Both solutions are included in the appendix.

10 RESULTS

This section discusses the results of the project. The testing metrics were determined from the given constraints. Each testing metric will be further expanded upon in consequent subsections. Figure 10 depicts the final working boards and casings of the design. The working boards were from the Transmitter 2.0 and Receiver 3.0 design. The most current Transmitter 3.0 and Receiver 4.0 boards did not arrive soon enough for testing.

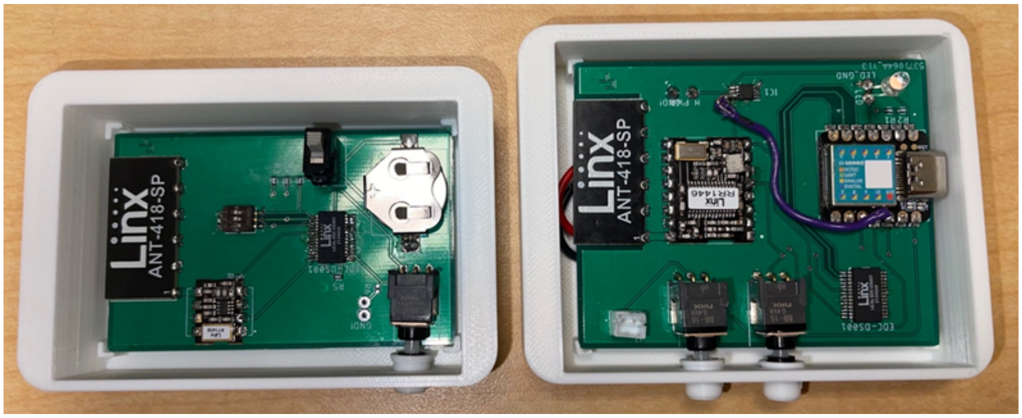

Figure 10: Final System Design

Test	Pass/Fail (P/F)
Communication	P
Adjustable Feedback	P
Range over 450'	F
Battery Life over 4 hours	P
Smaller than 3" (W) x 4" (L) x 1.5" (H)	P
Housing can withstand 170lb of force	P
Cost Less than $250	P
Water and Dust resistant	F

Table 2: Final Test Results

10.1 COMMUNICATION

The most important aspect of this design was ensuring that both the transmitter and receiver were able to communicate with each other. To meet this metric, both the transmitter and receiver signals were analyzed using a spectrum analyzer and oscilloscope. The spectrum analyzer was able to detect if a signal was transmitting at 418MHz and was essential to determine if the transmitter was functioning as intended. The oscilloscope was used to look at both the transmitter and receiver individually and compare the 1's and 0's in each signal.

Before the devices were communicating, it was necessary to compare the 1's and 0's in both the transmitter and receiver signal in order ensure the signals matched one-to-one. If the signals did not match, the decoder on the receiver board would not perceive the signal packet as valid, and the haptic motor would not activate. By examining the signal packet, it is possible to determine how the encoder and decoder are configured. In this manner, the signal packet can be used to determine if the encoder is soldered to the board correctly.

Both the transmitted and received signals matched one-to-one, and the boards communicated. Whenever the transmitter button was pushed, the haptic motor on the receiver activated. Therefore, the devices communicate with each other and pass this test.

10.1.1 Transmitter Signal

The transmitted signal is comprised of 41 bits. The shorter and wider peaks constituted 0's, while the taller and slimmer peaks constituted 1's. In the first half of this data packet, the encoder describes the configuration of the encoder, the communication protocol it is using, the state of each of the inputs, and the address it is using. The signal is then inverted and added to the second half of the data packet.

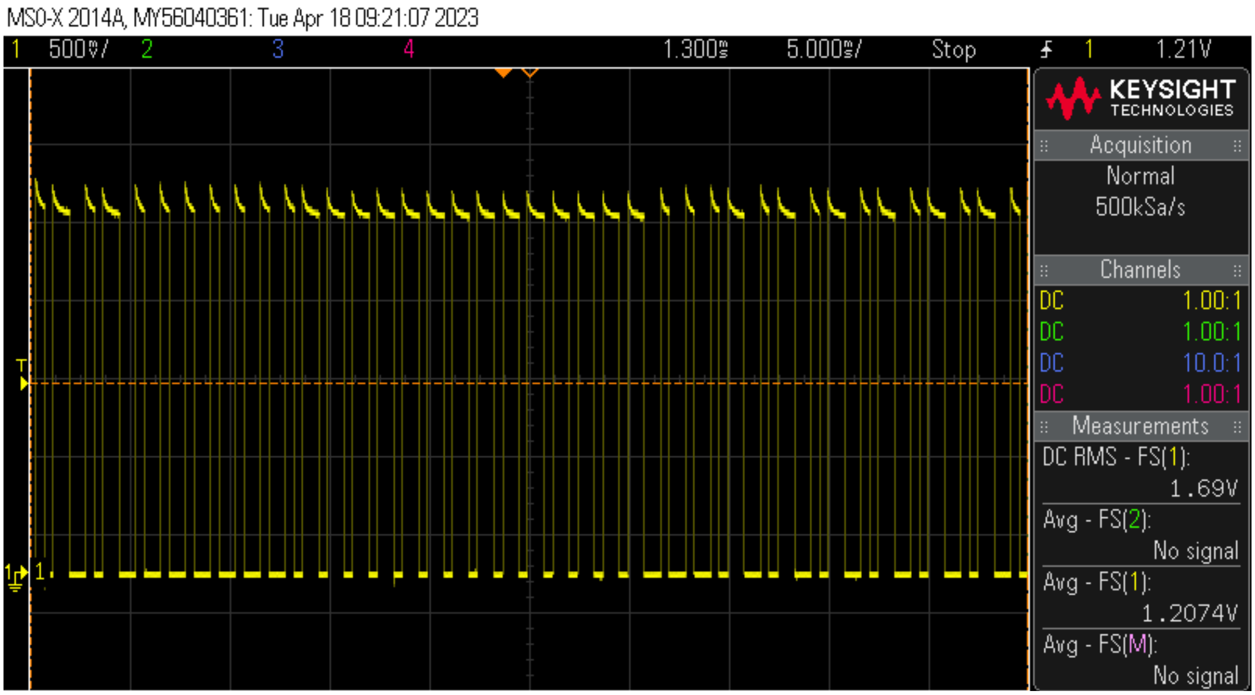

Figure 10.1.1 Transmitted Signal

10.1.2 Receiver Signal

The received signal is also comprised of 41 bits. The decoder reads both the inverted and non-inverted halves of the data packet then matches them together. If the halves do not match, it disregards the entire data packet. If the halves do match, the decoder will read the configuration, communication protocol, state of the inputs, and address. If the transmitted address does not match the decoder's address, it disregards the entire data packet. If the address matches, both the corresponding output pin and valid transmission received pin on the decoder will activate, thus sending a signal to the microcontroller to activate the haptic motor.

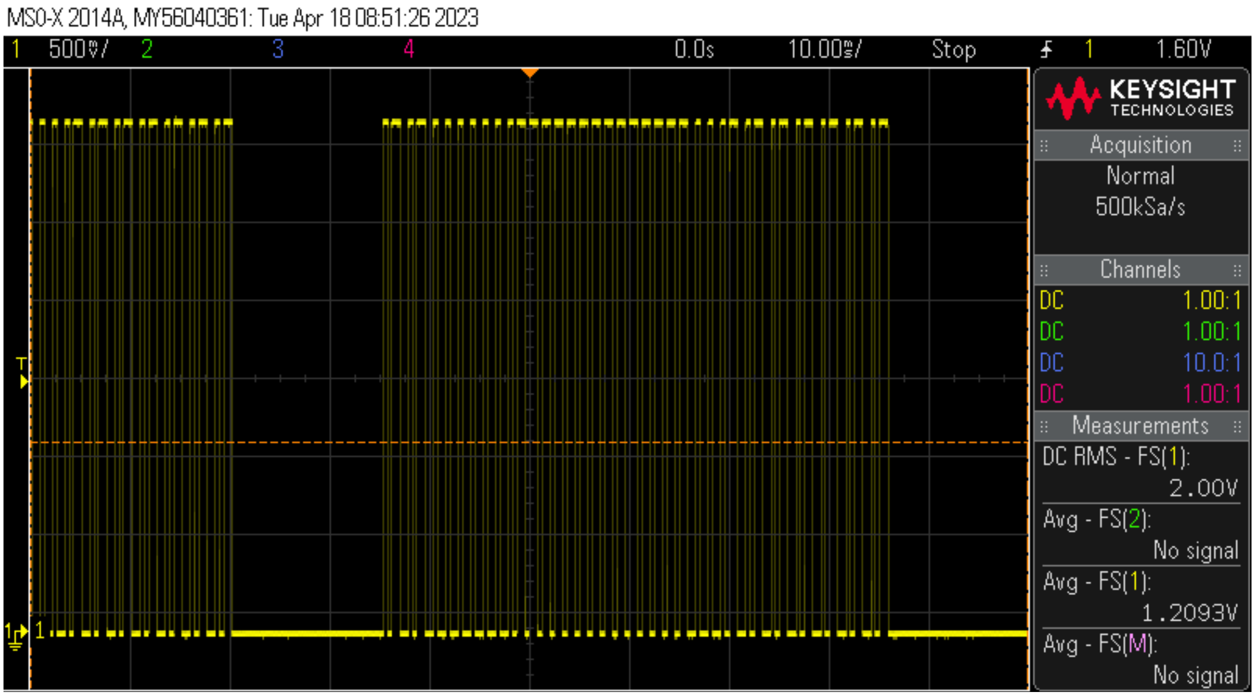

Figure 10.1.2 Received Signal

10.2 ADJUSTABLE FEEDBACK

The device needed to be able to have some level of user interactivity. This was done by implementing a push button that adjusted the level of haptic feedback that the motor output. When the button was pushed, a high was sent to the microcontroller. The microcontroller then adjusted the voltage output of the DAC pin to one of three levels – high, medium, or low. In this manner, the user can adjust the level of haptic feedback and the device passes this test.

10.3 RANGE

A goal for this project was for the device to communicate 450' to account for a soccer field of any size. This will also allow for the athlete to use this device for multiple years as the soccer fields get bigger as they age. However, the transmitter and receiver only communicated approximately 100' and then stopped. Therefore, the device does not pass this test and further design is needed.

10.4 *BATTERY LIFE*

The battery life needed to surpass 4 hours. The minimum battery voltage threshold was designed to be 2.7V for the system to still operate as intended. To test this aspect of this design, the haptic motor was cycled to activate at full power for one second, then deactivate for one second. The haptic motor was cycled on and off every second to simulate the worst-case, highest-power draw scenario, as this is the largest power draw that the receiver would operate under. When the battery was tested at the end of 4 hours, it had a voltage of 3.14V. This voltage level exceeded the minimum requirement of 2.7V while under the highest-power draw scenario, therefore the device meets the battery life requirement and passes this test.

10.5 *SIZE*

The receiver needed to be within a certain size to be reasonable for the athlete to carry during a game. If the device were too large, it would be impractical and even dangerous for an athlete to carry during a game. Therefore, the dimensions of the device needed to be within 3" (W) x 4" (L) x 1.5" (H). The actual dimensions are 2.60" (W) x 3.30" (L) x 0.78" (H). The receiver meets these requirements and thus passes this test.

10.6 *DURABILITY*

While the housing was designed to be as thin and small as possible, it was also designed to be durable. The device needed to be able to withstand a 170lb of force being exerted on it to protect the electronics within. 170lb of force was chosen as this is the average weight of a soccer player. The device housing was able to withstand 260lbs of force and did not break, therefore it passes this test.

10.7 COST

For the system to be cost-effective and an attractive solution, it needed to be below $250 in cost. After calculating the cost of both the transmitter and receiver devices, the final cost came out to be $129.69. Since the device meets this cost threshold, it passes this test.

10.8 WATER AND DUST RESISTANCE

For the system to be as robust as possible and to be able to be used in any state of play, the devices need to be dust and water resistant. The current housing has no designs in place to meet this requirement. To meet this requirement, an O-ring seal would need to be added around each button and LED protrusion from the housing, and a rubber seal would need to be implemented around the edges of the housing base. As the current design does not implement these features, it fails this test.

11 COMPONENT JUSTIFICATION

This section describes the components used to develop the receiver and transmitter modules. It will describe the specifications of the components used, why these components were selected, and how the components are used in the systems. These components were selected primarily for functionality but were also selected or changed based upon availability.

11.1 ARMBAND

The armband was chosen over the sports vest and a captain's band to be more user friendly to the athlete. Some athletes may not be comfortable wearing a sports vest while running and could cause discomfort to the athlete. Depending on the gender and size of the athlete, the sports vest may not fit properly and be able to function as designed. An armband allows for a more universal fit for the athlete regardless of size and gender. An armband versus a captain's band allows the device to be securely placed on the athletes' arm so it does not risk the chance of falling out while in motion. The armband chosen was a traditional armband made to fit a standard size cellphone.

11.2 MICROCONTROLLER

The microcontroller that was chosen is the Seeeduino XIAO SAMD21. This microcontroller was chosen for a few specific reasons. Firstly, the microcontroller was chosen for its small size. As size is a major constraint for this project, each component needs to be as small as necessary. Another reason this microcontroller was chosen is for the familiarity of the Arduino library. The Arduino community is very large and offers much help with examples and libraries. The final reason this microcontroller was chosen was for its low power libraries. As battery life is also a major constraint for this project, the microcontroller needed to be able to be put in a low power mode to preserve power.

Figure 11.2: Seeeduino XIAO SAMD21 Microcontroller [22]

11.3 DS Series Encoder/Decoder Module

The encoder/decoder module is used for remote control and wireless communication applications. A common application for encoders and decoders is wireless garage door openers. This module can operate as either an encoder or a decoder. To configure the system the E/D_SEL pin is pulled high or low, pulling high activates the encoder and pulling low activates the decoder protocol. The module can transfer the status of up to eight inputs at a time (D0-D7) that will turn on each respective pin between the encoder and decoder. This allows for each input on the encoder to have a corresponding unique output on the decoder. There are also ten addressing pins that allow the signal to be unique.

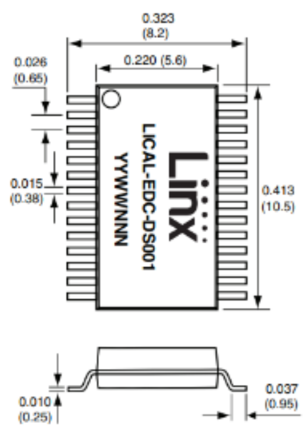

Figure 11.3.1: Encoder/Decoder Module [17]

The 418 MHz is an open broadcasting wave for public use, so there is extra noise for the system when no transmission is being received. This idle noise of 1s and 0s can be seen in Figure 11.3.2 below. With addressing, the decoder will only activate upon reception of a signal with the same address. This eliminates the possibility of the haptic motor activating upon reception of idle noise, thus adding a layer of security to the system. This component was chosen for its small size, built-in communication protocol, compatibility with the transmitter and receiver modules, and the ability to address the signal.

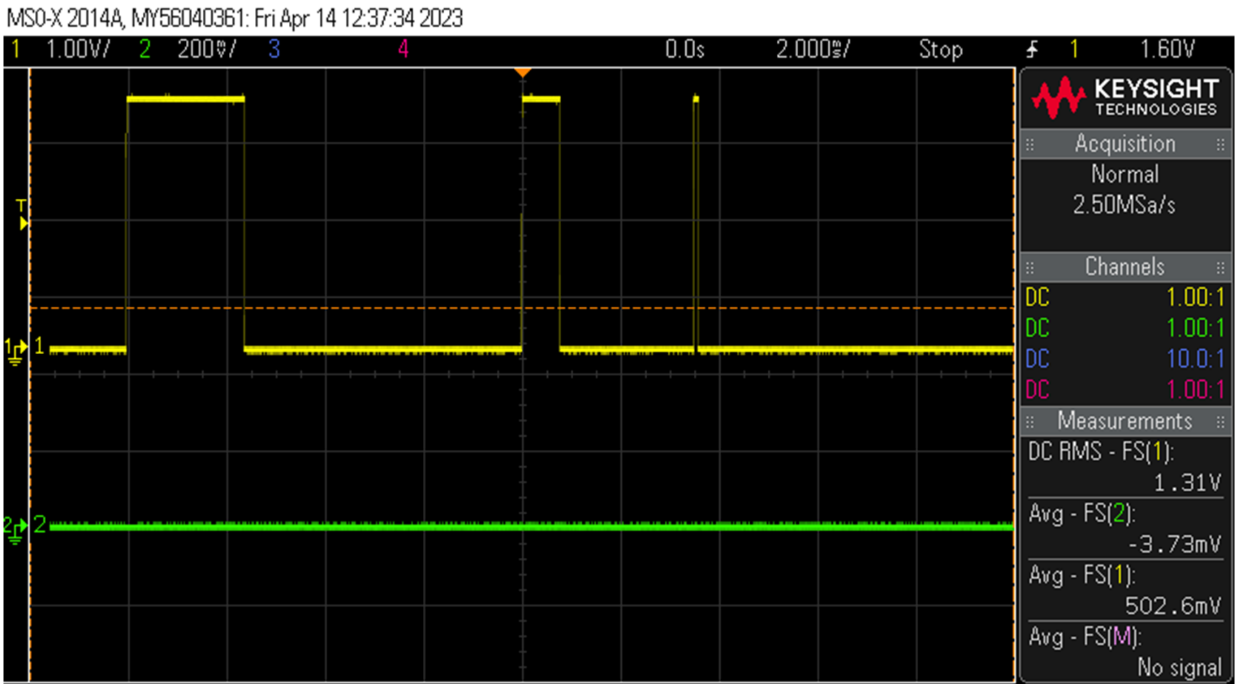

Figure 11.3.2: Received Idle Noise

11.4 LR Series Transmitter Module

The transmitter module is used for remote control applications. It can be used to transmit data in the 260 - 470MHz band. When paired with a compatible receiver, it can transmit serial data up to 3,000 feet. It also boasts superior noise immunity at shorter ranges. This component was chosen for its small footprint, extensive range, and compatibility with the receiver and encoder/decoder modules.

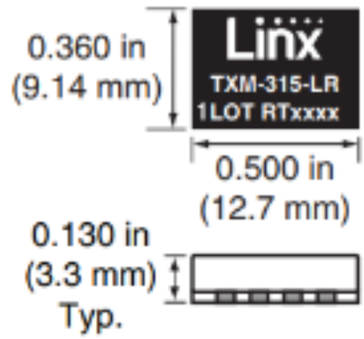

Figure 11.4: LR Series Transmitter Module [23]

11.5 LR SERIES RECEIVER MODULE

The receiver module is used for remote control applications. It can be used to receive data in the 260 - 470MHz band. When paired with a compatible transmitter, it can transfer serial data up to 7,500 feet. It also boasts superior noise immunity at shorter ranges. This component was chosen for its small footprint, extensive range, and compatibility with the transmitter and encoder/decoder modules.

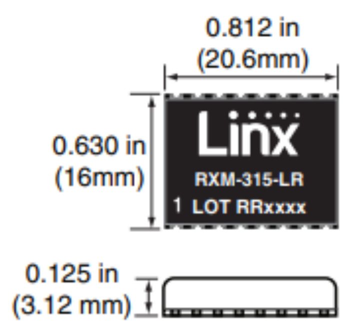

Figure 11.5: LR Series Receiver Module [24]

11.6 SPLATCH ANTENNA MODULE

The Splatch antenna module is used for remote control applications. It is used for both the transmitter and receiver designs. The antenna is surface mount and resistant to proximity effects. The antenna will transmit/receive data at a frequency of 418MHz. It was chosen for its small size footprint and compatibility with the transmitter and receiver.

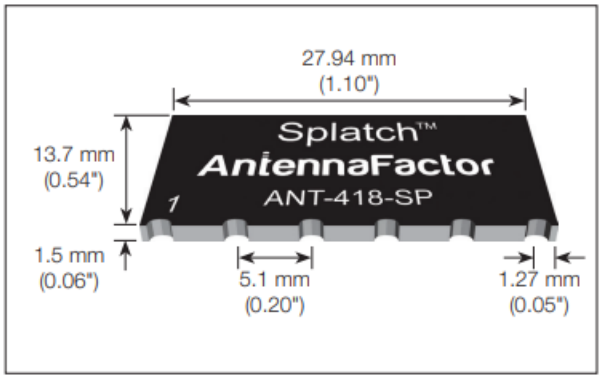

Figure 11.6: Splatch Antenna Module [25]

11.7 HAPTIC MOTOR

The haptic motor chosen for this alert system is a Vybronics Inc. eccentric rotating mass (ERM) 10,000 RPM haptic motor. This haptic motor was chosen because of the intensity of the vibration. It is important that the athlete feels the haptic when it activates so it performs its intended purpose of preventing injuries to the player. Another reason this haptic motor was chosen is because it is already incorporated into many fitness trackers, has a small physical and electrical footprint, and the level of intensity can be adjusted using the operating range of 2.7 – 3.3 VDC.

Figure 11.7: Vybronics Haptic Motor

11.8 BATTERY

The battery chosen for this system is an Adafruit Industries LLC 3.7 V Lithium-Ion Battery. It is a rechargeable battery that has 150mAh. This battery was chosen to allow the device to last the full duration of the game and achieve the 4-hour benchmark as it is very important that the device does not lose power during a game. This could cause bodily injury to the athlete and would prevent an athlete from playing. This battery was also chosen because of the small size and easy implementation. It was important to keep the device as small as possible to not impede the player in any way since the device would be placed on the athlete's upper arm.

11.9 PLA CASING

Polylactic acid (PLA) plastic was chosen for the device housing. PLA is a common filament used in 3D printers and is also made from biodegradable material. A 3D printer was used to produce the electronic casings of both the transmitter and receiver. PLA plastic is water and heat resistant up to a certain point. The lattice structure of the printed material allows for liquids to leak through the plastic after being submerged, but it also creates a strong base given the weight of the material. The casing itself was tested with weight exceeding 170lbs to test the durability of the material, which did not alter the casing's stability in any way. For these reasons the PLA plastic was chosen as the material for the device casings.

12 CONCLUSIONS AND RECOMMENDATIONS

12.1 FUTURE CONSIDERATIONS

One suggestion for future development would be to include more haptic motors in the device. Adding a haptic engine to each corner of the device would be ideal. This would allow the alert to be stronger and more prominent. Another method to boost the vibration strength is by designing the casing to resonate with the haptic vibration frequency. Ideally, the athlete would be able to charge the battery without opening the device and removing the PCB to access the battery. Adding a port to the outside of device housing would allow the athlete to directly charge the battery. Another consideration is making the device thinner and smaller to have less impact on the athlete. The thinner the device, the less the athlete will notice he/she is wearing the device.

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APPENDIX

APPENDIX A

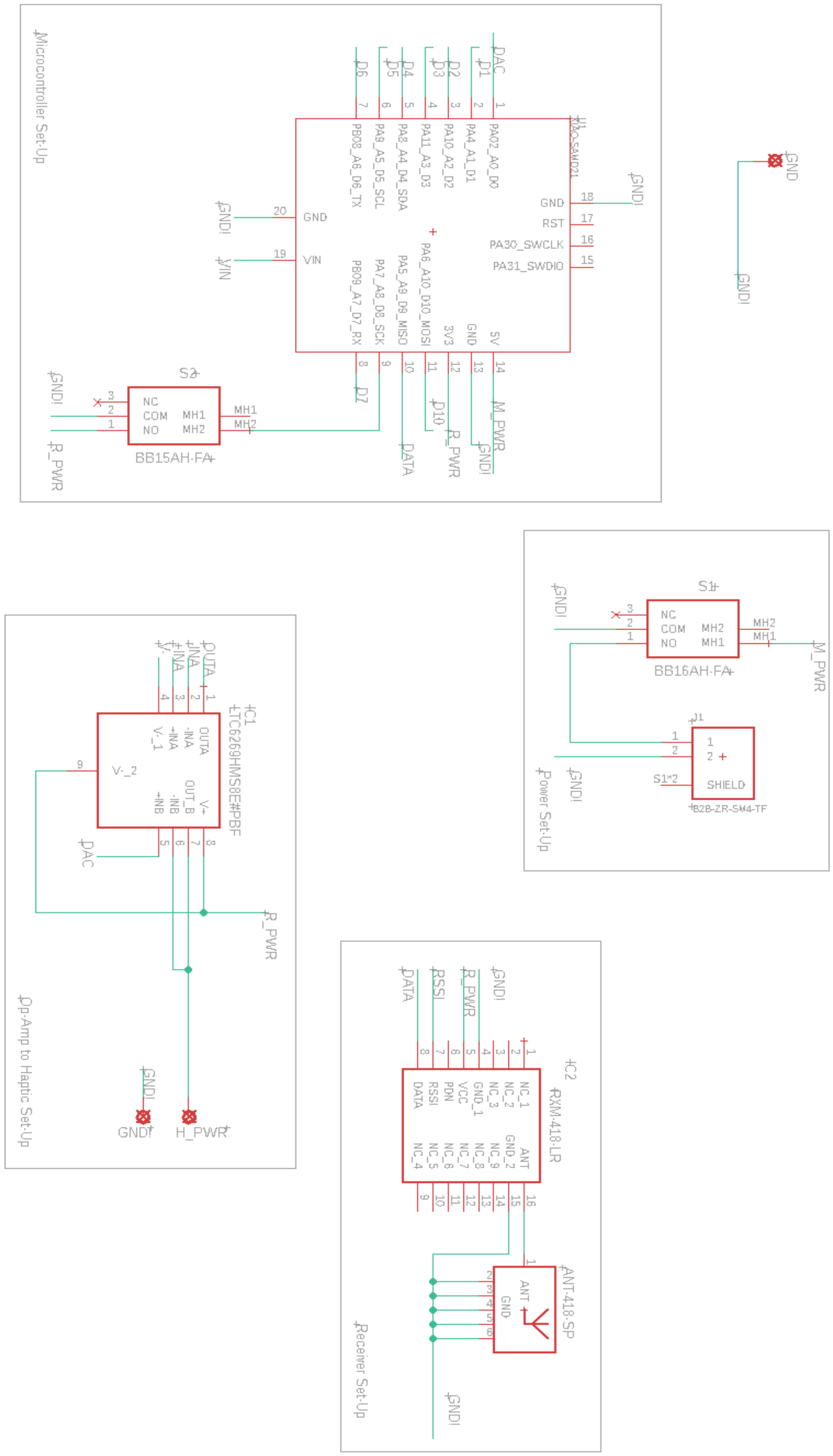

Figure 7.1.1 Receiver 1.0 Schematic

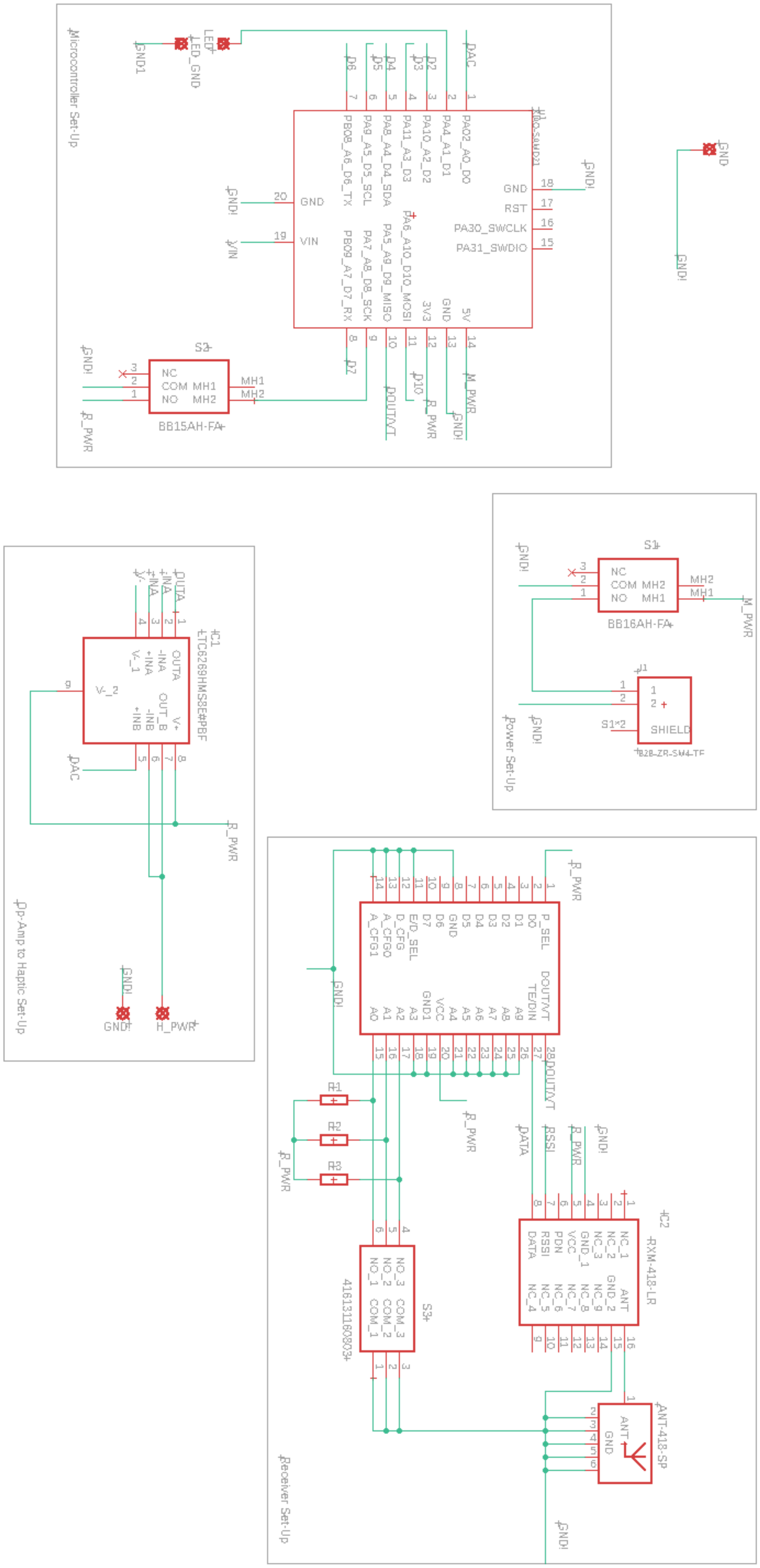

Figure 7.2.1: Receiver 2.0 Schematic

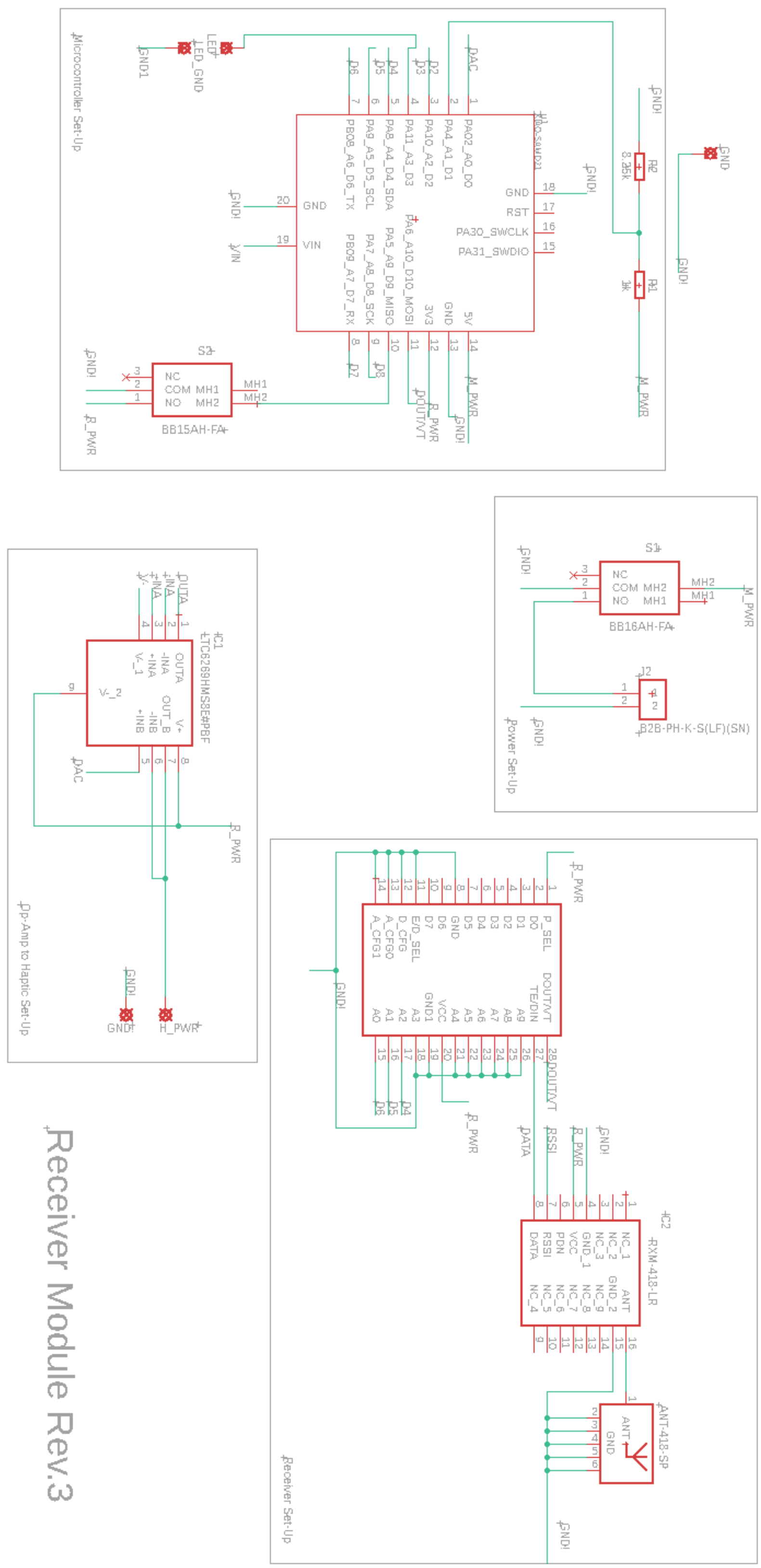

Figure 7.3.1: Receiver 3.0 Schematic

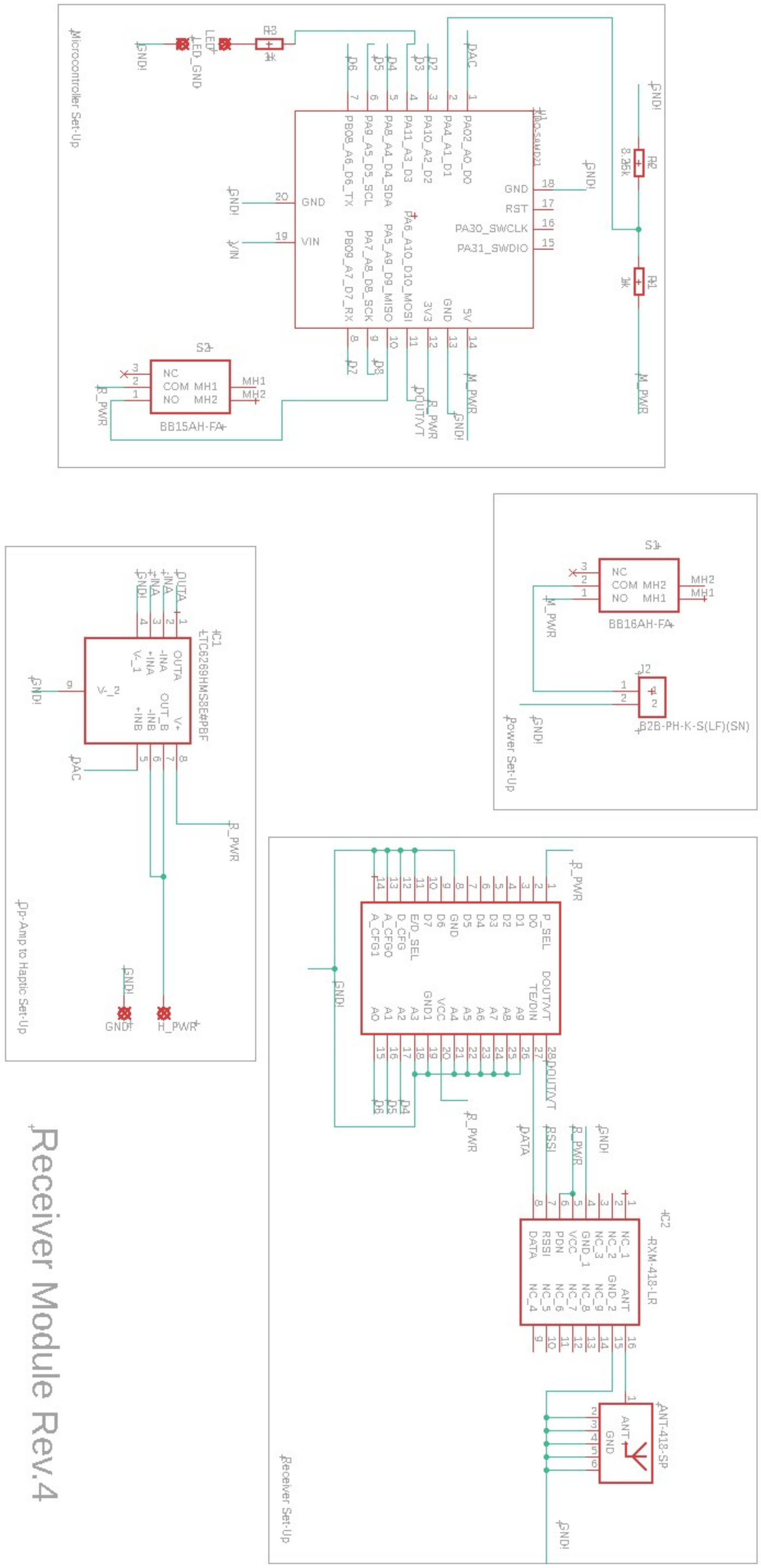

Figure 7.4.1: Receiver 4.0 Schematic

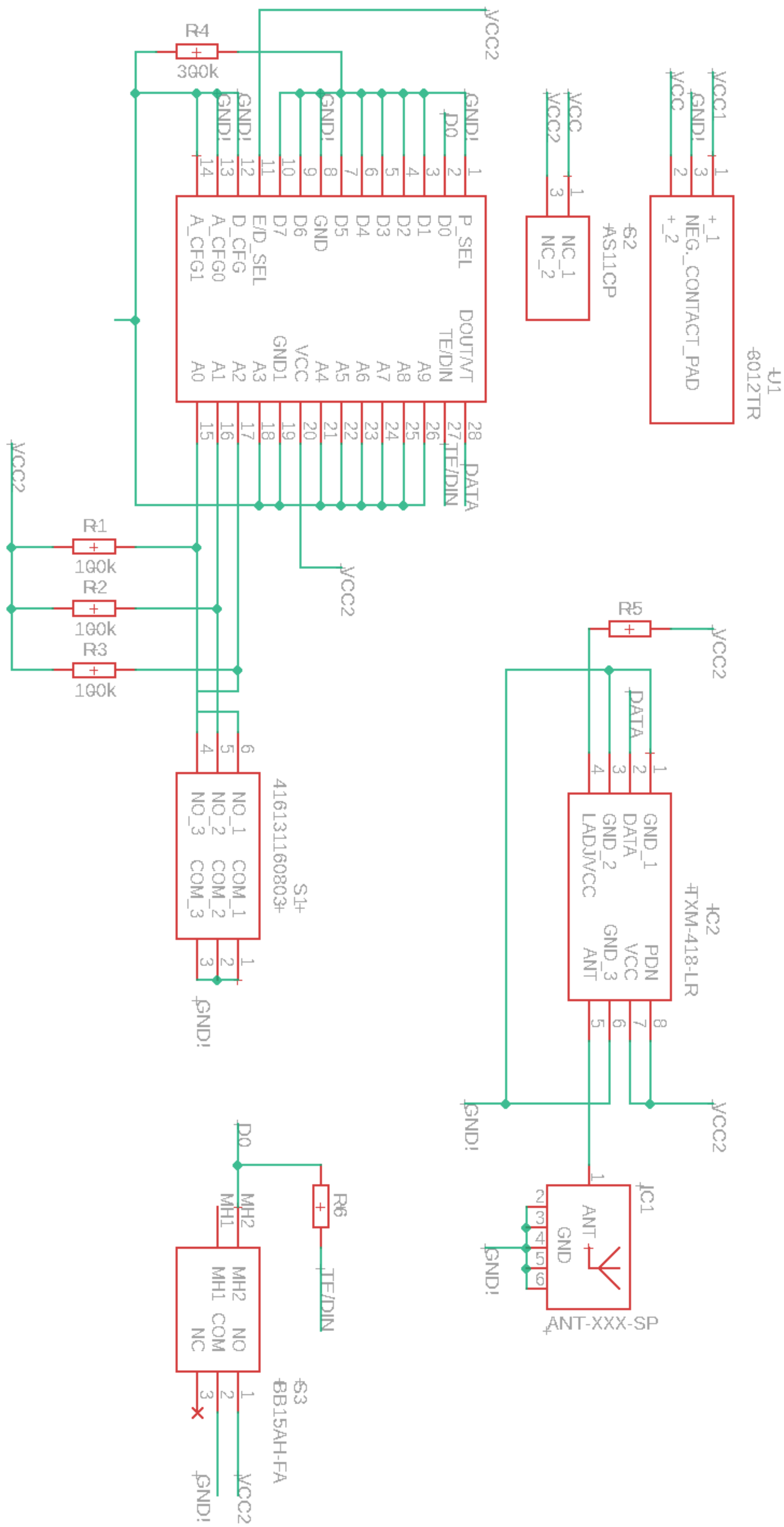

Figure 8.1.1: Transmitter 1.0 Schematic

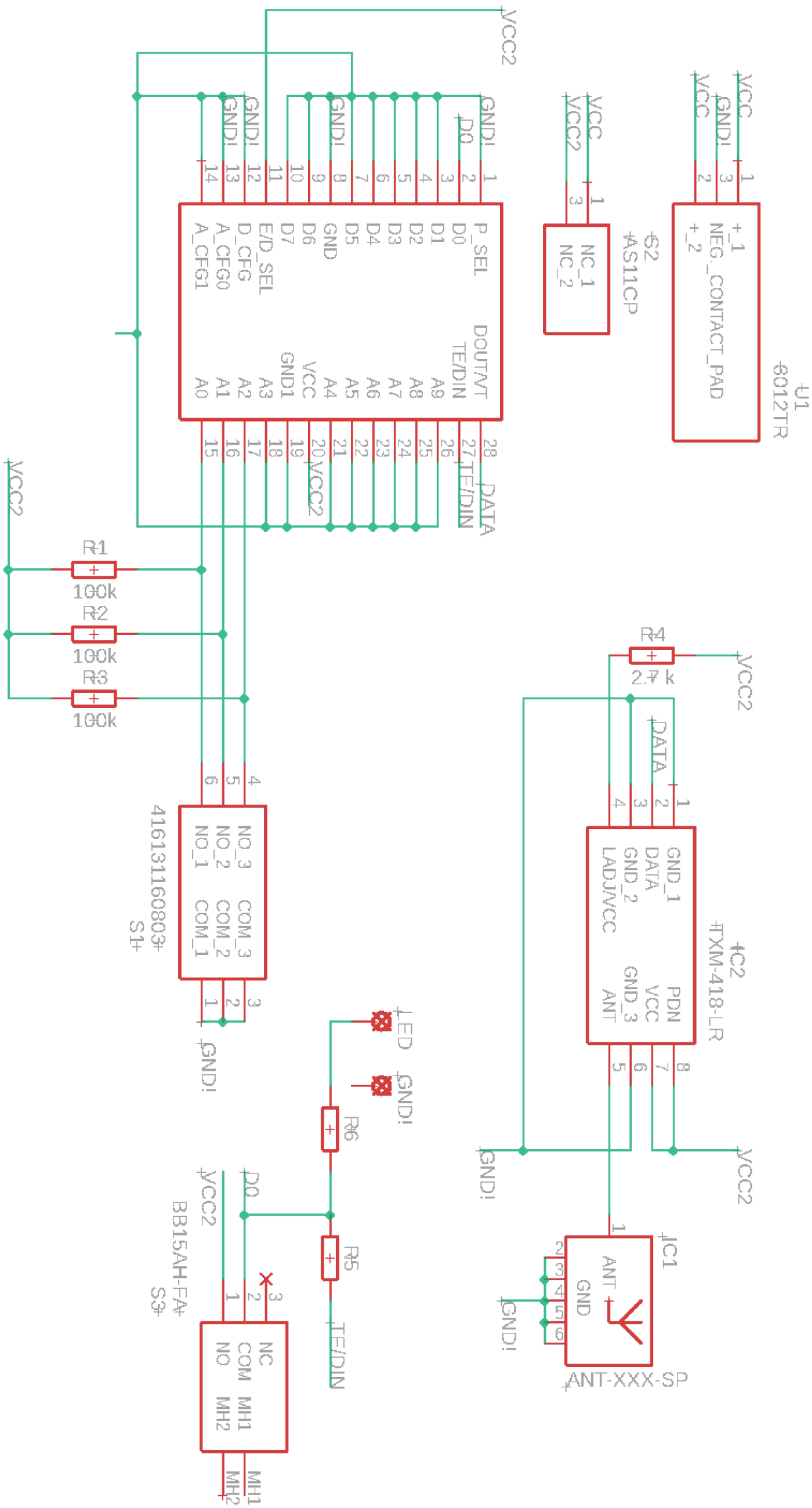

Figure 8.2.1: Transmitter 2.0 Schematic

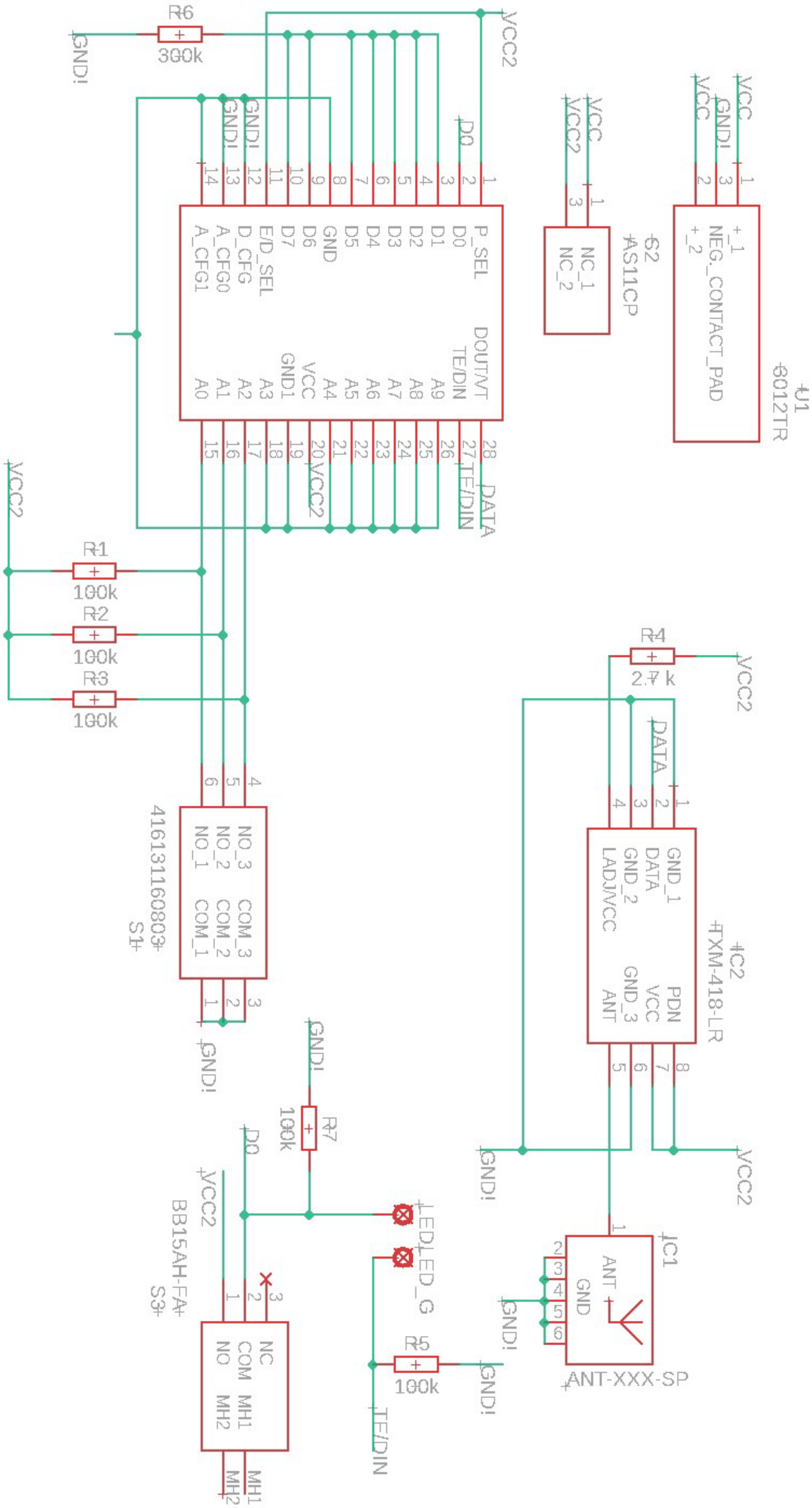

Figure 8.3.1: Transmitter 3.0 Schematic

APPENDIX B

NUM	QTY	Price	Manufacturer	Part Number	DESCRIPTION
1	1	$5.95	Adafruit Industries	1528-1839-ND	BATTERY LITHIUM 3.7V 150MAH
2	1	$20.78	LINX Technologies Inc.	RXM-418-LR	RF RECEIVER ASK/OOK 418MHZ
3	2	$3.85	LINX Technologies Inc.	ANT-418-SP	RF ANT 418MHZ CHIP SOLDER SMD
4	1	$13.60	LINX Technologies Inc.	TXM-418-LR	RF TX IC ASK/OOK 418MHZ 8SMD MOD-Tran
5	2	$12.28	LINX Technologies Inc.	LICAL-EDC-DS001-T	Encoder/Decoder
6	1	$5.40	Seeed Studio	102010328	Microcontroller
7	1	$0.66	Keystone electronics	3012TR	16mm battery holder
8	1	$3.02	Vybronics Inc	VC0720B001F	VIBRATION ERM MOTOR 10K RPM 1.1G
9	1	$17.16	Analog Devices	LTC6269HMS8E-10#PBF	OP Amp, 90mA supply current, 3.1 Vos
10	1	$3.41	Wurth Elektronik	416131160803	Addressing Switch
11	1	$6.05	NKK Switches	BB16AH-FA	PB On-On Switch
12	2	$5.61	NKK Switches	BB15AH-FA	PB On-Mom Switch
13	1	$0.58	JST Sales America, INC	B2B-ZR-SM4-TF	Li-Po battery mount
14	1	$14.39	E Tronic Edge	B074XFRZFD	Armband
15	1	$4.22	NKK Switches	AS11CP	Transmitter Power Switch
16	1	$5.95	Adafruit Industries LLC	1528-4410-ND	LIPOLY BATTERY CHARGER W/USB C
17	1	$0.55	NTE Electronics, Inc	2368-NTE30125-ND	PINK LED
18	3	$0.34	Yageo	RT0402BRE07100KL	100k Resistor
19	1	$0.10	Yageo	RC0402FR-078K25L	8.25kOhm resistor
20	1	$0.10	Yageo	RC0402JR-071KL	1kOhm Resistor
21	1	$0.10	Yageo	RC0402FR-132K7L	2.7kOhm Resistor
22	1	$0.80	JLCPCB	Transmitter Rev:2	Transmitter PCB
23	1	$0.80	JLCPCB	Receiver Rev:3	Receiver PCB
Total	**27**	**$129.69**			

Table 3: Bill of Materials

APPENDIX C

Low Power Solution

```
#include "ArduinoLowPower.h"

// Constants
#define DAC_PIN A0
#define RX_Sig A10
#define Hap_Adj A9
#define Bat_Lvl A1
#define LED_Pin A3
const int R1 = 1000;
const int R2 = 8250;

// Variables
volatile int Adj_Count = 0;
volatile int Hap_Level = 837;
unsigned int i=0;
float voltVal, voltage;
float voltMin = 2.7;

void setup() {
analogWriteResolution(10); // Setup for DAC
analogReadResolution(12); // Setup for battery indication
analogReference(AR_DEFAULT); // Default reference of 3.3V

pinMode(LED_Pin, OUTPUT); // LED output pin
pinMode(RX_Sig, INPUT); // Set up Reciever pin as an input
pinMode(Hap_Adj, INPUT); // Set up Haptic Adjustment pin as an input

// Addressing Pins
digitalWrite(A4, HIGH);
digitalWrite(A5, HIGH);
digitalWrite(A6, HIGH);

LowPower.attachInterruptWakeup(digitalPinToInterrupt(RX_Sig),ReceiveRx,RISING);
LowPower.attachInterruptWakeup(digitalPinToInterrupt(Hap_Adj),AdjustFeedback,RISI
NG);
}

void loop() {
voltVal = analogRead(Bat_Lvl);
voltage = voltVal*(3.3/4095)*((R1+R2)/R2);
if (voltage<voltMin){
  digitalWrite(LED_Pin, LOW);
  delay(3000); // delay 3 sec
  digitalWrite(LED_Pin, HIGH);
}
i=0;
  LowPower.sleep(10000); // sleep for 10 sec
```

```
}

// Functions

void ReceiveRx(void) {
    while (i<5000000) { // ~10 sec delay
      analogWrite(DAC_PIN, Hap_Level); // set DAC voltage
      i++;
    }
    analogWrite(DAC_PIN, 0);
}

void AdjustFeedback(void) {
  while (i<500000) { // ~1 sec delay
    i++;
  } // 1 sec delay for debouncing
    // 2.7V = 837bits, 3.0V = 930bits, 3.3V=1023bits
    if (Adj_Count == 0) {
      Hap_Level = 930;
      Adj_Count = 1;
    }
    else if (Adj_Count == 1) {
      Hap_Level = 1023;
      Adj_Count = 2;
    }
    else if (Adj_Count == 2) {
      Hap_Level = 837;
      Adj_Count = 0;
    }
}
```

Non-Low Power Solution

```
// Constants
#define DAC_PIN A0
#define RX_Sig A10
#define Hap_Adj A9
#define Bat_Lvl A1
#define LED_Pin A3
const int R1 = 1000;
const int R2 = 8250;
const int threshold = 562;

// Variables
int Adj_Count = 0;
int Hap_Level = 837;
float voltVal, voltage;
float voltMin = 2.7;
```

```
void setup() {
  // put your setup code here, to run once:
analogWriteResolution(10); // Setup for DAC
analogReadResolution(12); // Setup for battery indication
analogReference(AR_DEFAULT); // Default reference of 3.3V

pinMode(LED_Pin, OUTPUT); // LED output pin
pinMode(RX_Sig, INPUT); // Set up Reciever pin as an input
pinMode(Hap_Adj, INPUT); // Set up Haptic Adjustment pin as an input

// Addressing Pins
digitalWrite(A4, HIGH);
digitalWrite(A5, HIGH);
digitalWrite(A6, HIGH);

}

void loop() {
  voltVal = analogRead(Bat_Lvl);
  voltage = voltVal*(3.3/4095)*((R1+R2)/R2);
  if (voltage<voltMin){
    digitalWrite(LED_Pin, LOW);
    delay(3000); // delay 3 sec
    digitalWrite(LED_Pin, HIGH);
  }

  if(analogRead(RX_Sig)>threshold) {
    analogWrite(DAC_PIN, Hap_Level); // set DAC voltage
    // 2.7V = 837bits, 3.0V = 930bits, 3.3V=1023bits
    delay(1000); // 1 sec delay
  }
  else {
    analogWrite(DAC_PIN, 0); // set DAC voltage to 0V
  }

  if (analogRead(Hap_Adj)>threshold) {
    delay(1000); // 1 sec delay
    if (Adj_Count == 0) {
      Hap_Level = 930;
      Adj_Count = 1;
    }
    else if (Adj_Count == 1) {
      Hap_Level = 1023;
      Adj_Count = 2;
```

```
    }
    else if (Adj_Count == 2) {
      Hap_Level = 837;
      Adj_Count = 0;
    }
  }

}
```

APPENDIX D

Design Factor	Page Number
Environmental	5
Public Health, Safety, and Welfare	5
Global/Political	6
Social and Cultural	6
Code of Ethics	8
Reference for Standards	8

Table 4: Engineering Design Considerations