Bone Conduction Lock

ECE 445 Mock Design Review Document — Spring 2018

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1 Introduction

1.1 Objective

The ability to quickly enter a locked door without fumbling for keys is an issue the car industry has recognized and worked to eliminate with features like keyless entry. Home and apartment locks on the other hand, have lagged behind in this field. Even so-called 'smart locks' on the market today often require consumers to fumble through their belongings to find a phone and interact with an app [1]—assuming they have remembered to budget enough battery power to keep their phone alive, that is—all the while exposing themselves to cold, rain, or potentially dangerous persons they would rather have on the other side of a locked door. If not dependent on a smartphone, alternate mechanisms are either expensive or vulnerable. Keypads are simple to crack with the aid of fingerprinting dust or an infrared camera [2]. Fingerprint locks can be fooled by pictures of secretly-gathered prints [3]. Iris scanners are impractically expensive for the average household. Facial recognition poses the risk of allowing those who use it to be identified in a crowd without their consent if the data is ever compromised or sold to advertisers [4]. Card-swipe or RFID proximity card locks suffer from the same fumbling problem as keys, and a lost or stolen wallet can render the locks as good as shut.

The Bone Conduction Lock System (BCLS) provides an efficient way to lock/unlock a door while laying the groundwork for further investigation of cheap and secure biometric access to be developed atop the platform in the future. The BCLS consists of two parts: a wearable wristband (hereafter, band)—far more resistant to loss than wallet—and a door-mounted lock. When the user wants to unlock a BCLS-secured door, they press a button on the band and touch their finger [1] to the lock. A haptic motor inside the band will then use the bones in the user's hand as a channel to transmit vibrations to the lock. An amplitude-modulated signal at a carrier frequency signal capable of being conducted through bone will carry a vibration signal to the receiver in the lock. The signal itself will also be perturbed by the channel: the user's hand. If the signal received at the lock is correct, the lock opens. While not a requirement of the project, this method lays the groundwork to investigate using the specific perturbations imparted by the user's hand as a form of biometric identification.

1.2 Background

Smartphone dependence of existing smart locks is an issue due to minority populations. The National Federation of the Blind reports there are 1.3 million [5] legally blind Americans. While there are accessibility features for the vision impaired available on smartphones, a system that is entirely haptic such as the BCLS would be more accessible to those populations. It will also be more convenient for the sighted, who will not have to fumble through their pockets for their keys or phone to unlock their doors. Additionally, the elderly or those making too little to afford smartphones could also gain access to the ease and security of smart locks without being required to purchase a phone or take the time to learn to use one. Unlike smartphones, the BCLS

[1] The specific finger is arbitrary.

band would not have to perform all the battery-draining features of phone, and so would be less prone to running out of battery when it may be needed to enter a locked door.

Previous research also indicates there is enough difference in skeletal structure to potentially warrant unique identification via bone conduction. German researchers undertook a Google Glass based project called Skullconduct, which used vibrations conducted through the skull to identify users correctly with a 97% success rate [6]. The BCLS lays the groundwork for similar applications based on users' hands. Another interesting area to investigate is whether the channel distortion is affected by hand or finger position. If so, users being forced to replicate hand or finger positioning could be another layer of the 'password' when entering a BCLS-secured door.

1.3 High-level Requirements List

- The only communication channel from band to lock must be vibrations conducted through the user's hand.
- When the correct "key" is successfully transmitted from the band to the lock, BCLS must operate with a 90% success rate.
- We must be able to lock/unlock the BCLS in 10 seconds or less.

2 Design

The BCLS is lock/unlocked using vibrations conducted through the user's hand. BCLS is composed of two independent modules: the band and the lock. The user wears a band on their wrist connected to a ring containing a haptic motor worn on their finger. The user presses a button on the band and the haptic motor in the ring generates a vibration signal that acts as the "key" to the lock. The haptic motor is a linear resonant actuator (LRA) motor. The LRA motor generates a vibration by using AC power to move a mass back and forth along an axis. When the user presses their finger to the lock, the vibration signal is conducted through the user's hand to their fingertip and is received at the lock. If the lock receives the correct "key", it locks/unlocks depending on its current state. Status LEDs on the lock indicate the state of the lock and whether an attempt to lock/unlock the lock was successful or unsuccessful. When the lock is in its locked state, the red LED is on. When the lock is in its unlocked state, the green LED is on. If an attempt to lock/unlock the lock is successful, the green LED will blink. If an attempt to lock/unlock the lock is unsuccessful, the red LED will blink. The lock also keeps a log of all the attempts to lock/unlock it.

2.1 Block Diagram

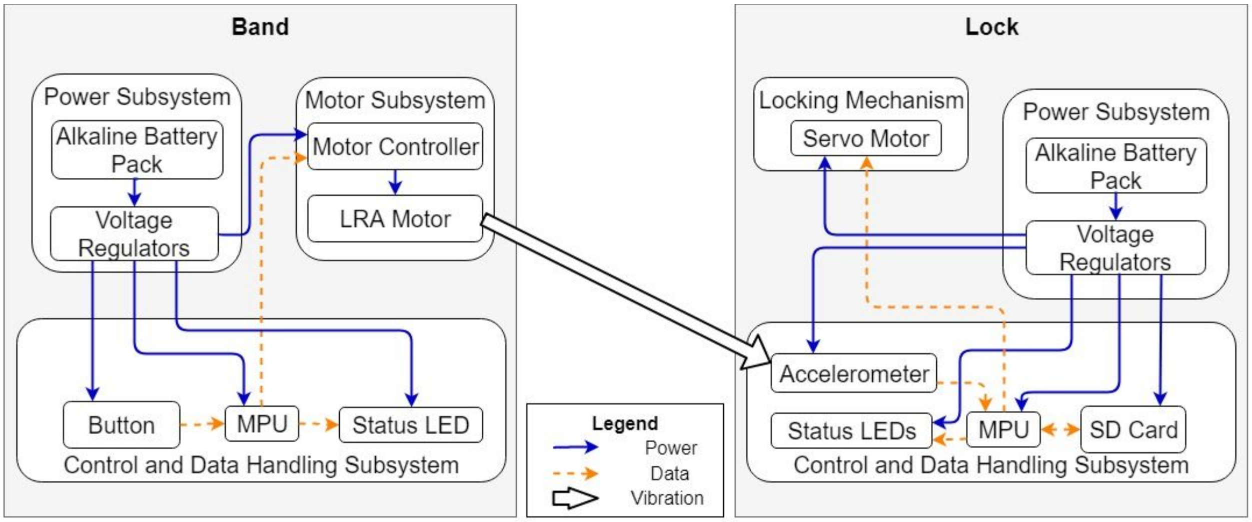

Figure 1: BCLS Block Diagram

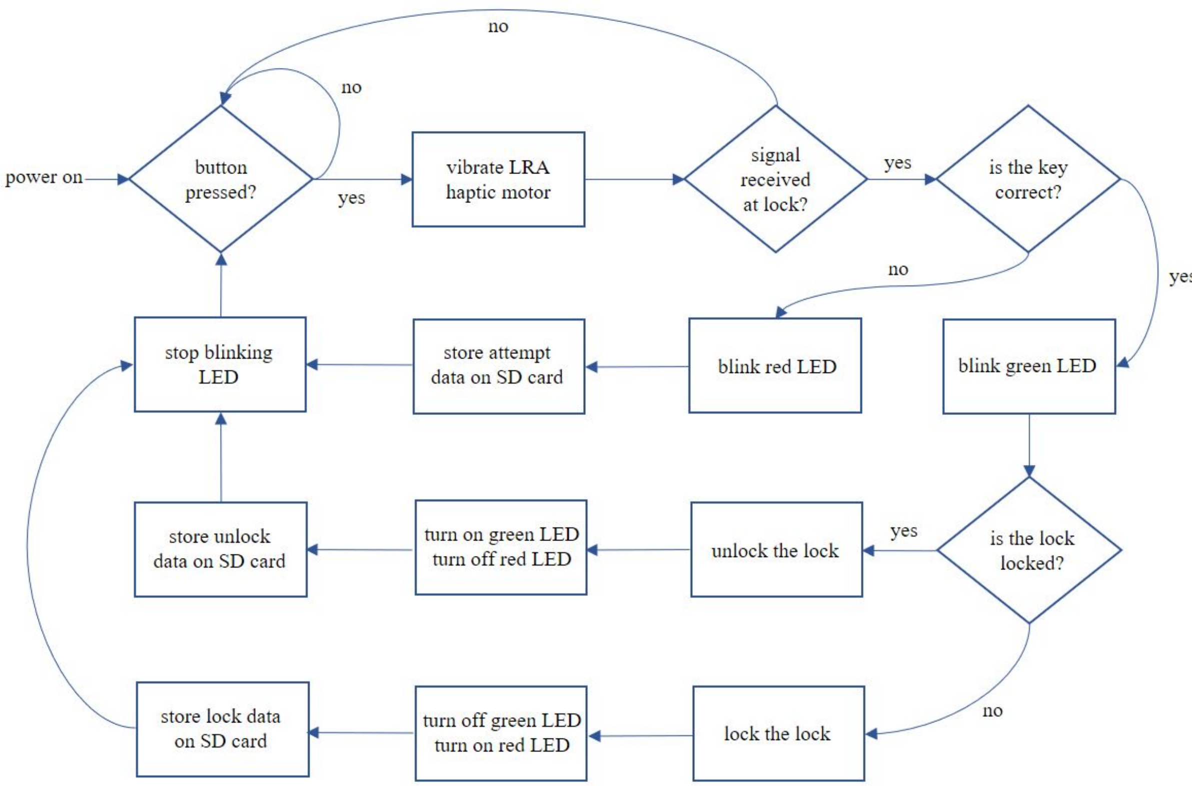

Figure 2: BCLS operation flow chart

2.2 Physical Design

2.2.1 Door Lock Module

For the physical design of the lock module, we want to mimic the HID module on the doors in UIUC's Electrical and Computer Engineering Building (ECEB). The HID module is the black rectangle located above the door handle as seen in Figure 3. To operate the door lock, an I-card is placed in close proximity (1- 3 cm) allowing the HID module to read the identification number associated with the I-card. If the identification number is approved, the lock unlocks.

Our lock module will be a close approximation of the HID module in appearance. However, unlike the HID module which uses a wireless communication protocol, we will be using a physical vibration signal protocol. Our lock module is comprised of four main components: the control unit, locking mechanism, status LEDs, and battery.

Figure 3: Door Lock Unit at ECEB

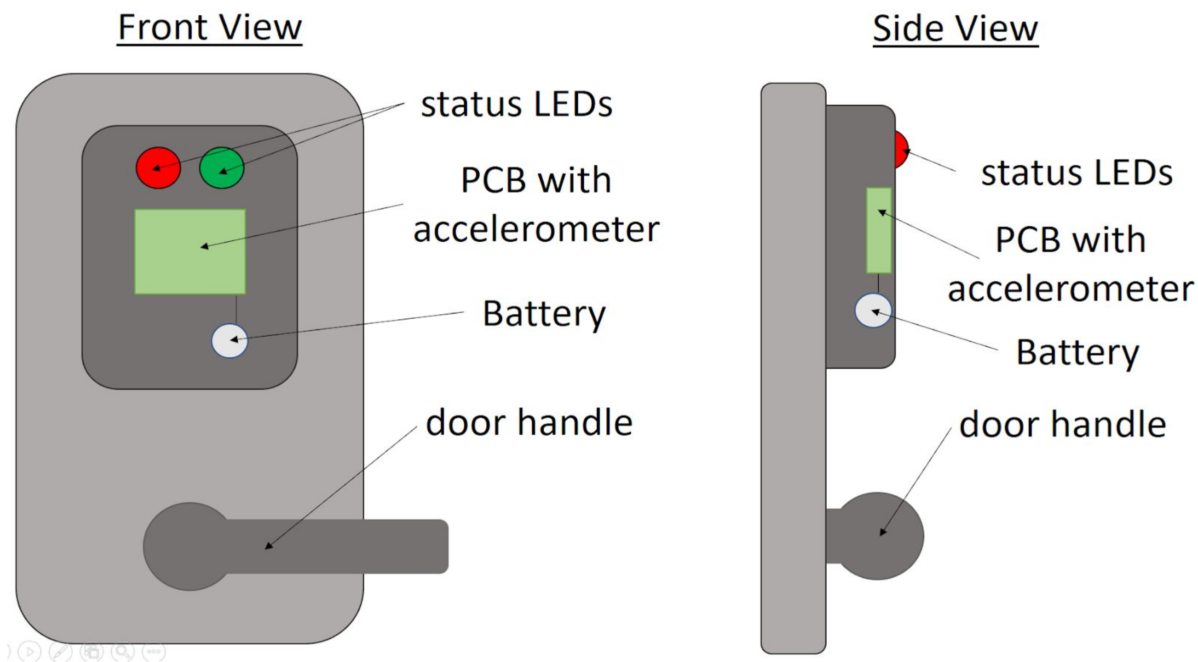

Figure 4: Physical Design of Lock Module

As seen in Figure 4, all the components are housed in a rectangular module located above the handle. Looking at the module, the only exposed components are the status LEDs. The rest of the components will be hidden inside the casing of the module. Since an accelerometer is a microelectromechanical system, to get the best signal to noise ratio, it is crucial to minimize the distance between the accelerometer and the point of contact where the finger touches the module. Because the accelerometer is surface mounted on the PCB, the PCB needs to be located as close to the point of contact with the finger as possible. A marking on the outside of the casing will indicate the optimal place for the user to touch their finger to ensure the strongest signal possible.

2.2.2 Band Module

The band module is responsible for generating the vibration signal. The band will have a similar form factor to a Fitbit with the exception of coming in two connected parts: the main band and the ring. Preliminary tests showed the signal amplitude from the LRA motor mounted on the ring was far greater than when the motor was mount on the band. This form factor can be seen in Figure 5 and Figure 6. The electrical components of the band are the PCB, the push button, LRA motor, battery, and status LED. The components are housed in the portion of the band located on the top side of the wrist. This connects via a cable to a ring housing the motor. All other components will be contained entirely inside the band's housing with the exception of the push button and status LED, which will stick out above the surface. The user will be able to push the button to generate the vibration signal. The status LED indicates when the battery is low, prompting the user to change the battery.

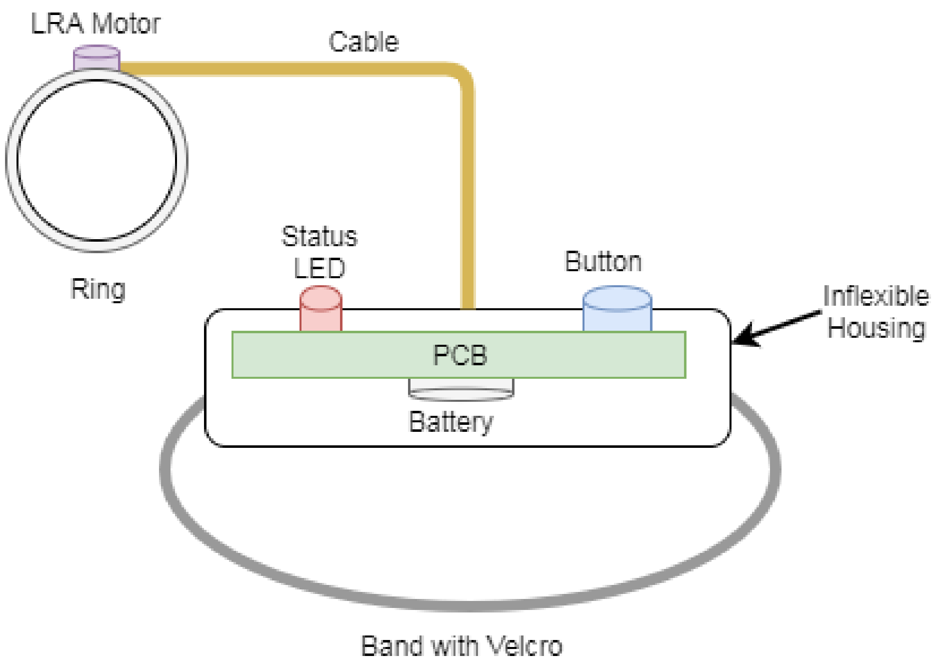

Figure 5: Physical Design of Band Module

2.3 Block Design

2.3.1 Lock Module

2.3.1.1 Power supply subsystem

The the lock module's power subsystem drives the control unit subsystem and locking mechanism. Specifically, it supplies power to the MPU, accelerometer, status LEDs, SD card reader, and servo motor. The power subsystem is comprised of a 7.5 V Alkaline battery pack and two voltage regulators. The lock module is battery powered so the lock can be independent from the door it's securing. The regulators output 5 V and 3.3 V respectively. This makes installation of the lock module easier and ensures the lock will continue to work in the event of a power outage.

(a) Alkaline Battery Pack

The alkaline battery pack provides power to the other subsystems of the lock module. We chose a battery pack of 7.5 V because it resulted the lowest amount of power dissipation in the regulators. The battery pack has a capacity of 15.25 Ah which provides a total battery life of ~50 hours.

(b) Voltage Regulators

The 3.3 V regulator drives the accelerometer. Meanwhile, the 5 V regulator supplies power to the microprocessor, SD card reader, and servo motor.

Requirements	**Verification**
1. Must output 3.3 V +/- 5% to with a current load of up to 100 mA	a. Measure the output voltage using a multimeter. b. Sweep the load current. Show that voltage stays constant as current is varied.
2. Must output 5 V +/- 5% to with a current load of up to 300 mA	a. Measure the output voltage using a multimeter. b. Sweep the load current. Show that voltage stays constant as current is varied.
3. Maintain a temperature below 120°C	a. Use a IR thermometer when the IC is in operation to show that the temperature stays below 120°C

Table 1: RV Table for the Lock Module's Power Subsystem

2.3.1.2 Control unit subsystem

The control unit is tasked with detecting the vibration signal transmitted from the band and determining what action to take: lock/unlock the lock or do nothing. The control unit also keeps a log of all the attempts to lock/unlock the lock. The control unit is powered by the power supply subsystem and is comprised of the MPU, accelerometer, status LEDs, and SD card reader.

(a) Microcontroller

The microcontroller is connected to all the components in the lock module. The microcontroller processes the output from the accelerometer and determines what the other components of the lock module should be doing.

(b) Accelerometer

The accelerometer constantly outputs data to the microcontroller corresponding to the vibration it experiences.

(c) Status LEDs

The status LEDs serve as a visual representation of the state the lock is in. When the lock is unlocked, the green LED is on. When the lock is locked, the red LED is on. When a correct “key” is received at the lock, the green LED blinks. When an incorrect key is received at the lock, the red LED blinks.

(d) SD card reader

The SD card reader is connected to the microcontroller and stores the activity of the lock. It logs when a “key” was received at the lock, if the “key” was correct or not, and if the lock was locked or unlocked.

Requirements	**Verification**
1. Accelerometer output has full-scale range of +/- 2 g with minimum sampling rate of 800 Hz.	a. Sweep frequency range using function generator to capture frequency response. Show that frequency response does not get clipped.
2. Microcontroller needs data rate of at least the accelerometer bit resolution per 1.25 ms.	a. Send accelerometer output to microcontroller. Show data resolution is the same.
3. Keeps log of attempts to lock/unlock the lock.	a. Transmit correct “key” to the lock. Read the log on the SD card to show successful attempt to lock/unlock the lock. b. Transmit incorrect “key” to the lock. Read the log on the SD card to show unsuccessful attempt to lock/unlock the lock.
4. Status LEDs give visual feedback on attempts to lock/unlock the lock.	a. When correct “key” is received at the lock, green LED blinks. b. When incorrect “key” is received at the lock, red LED blinks.

Table 2: RV Table for the Lock Module’s Control Subsystem

2.3.1.3 Locking Mechanism

(a) Servo

The servo receives its rotational position from the microcontroller and is responsible for locking and unlocking the physical lock mechanism.

Requirements	Verification
1. Lock has two clear states: locked and unlocked.	a. Perform sweep of designated servo motor range. Show the range allows the lock to be in two distinct positions. - Locked state - Unlocked state
2. Status LEDs correctly correspond to the state of the lock.	a. When lock is in locked state, red LED is on. b. When lock is in unlocked state, green LED is on.

Table 3: RV Table for the Lock Module's Physical Locking Mechanism

2.3.2 Band Module

2.3.2.1 Power Subsystem

The band module's power subsystem is responsible for powering the control unit subsystem and motor subsystem. Specifically, it supplies power to the MPU, push button, and motor driver. The power subsystem is comprised of a 7.5 V Alkaline battery pack and two voltage regulators. The band module is battery powered so it can be worn on the wrist with the LRA motor secured to the finger in a ring. The regulators output 5V and 3.3 V respectively. The status LED will indicate to the user when the battery is low.

(a) Alkaline Battery Pack

The alkaline battery pack provides power to the other subsystems of the band module. We chose a battery pack of 7.5 V because it resulted in the lowest amount of power dissipation in the regulators. The battery pack has a capacity of 7.55 Ah which provides a total battery life of ~25 hours.

(b) Voltage Regulators

The 3.3V regulator drives the motor driver IC in the band module. Meanwhile, the 5V regulator supplies power to the microprocessor and push button. The status LED is connected to the microprocessor and which will keep track of battery level.

Requirements	Verification
1. Must output 3.3V +/- 5% to with a current load of up to 100 mA	a. Measure the output voltage using a multimeter.

	b. Sweep the load current. Show that voltage stays constant as current is varied.
3. Must output 5V +/- 5% to with a current load of up to 300 mA	c. Measure the output voltage using a multimeter. d. Sweep the load current. Show that voltage stays constant as current is varied.
3. Maintain a temperature below 120°C	a. Use a IR thermometer when the IC is in operation to show that the temperature stays below 120°C

Table 4: RV Table for the Band Module's Power Subsystem

2.3.2.2 Control Unit Subsystem

The control unit takes user input and determines when to generate the vibration signal. The control unit contains the microcontroller, push button, and status LED.

(a) Microcontroller

The microcontroller is the specific component tasked with handling the user input and initiating subsequent tasks. It gets its power from the battery and is connected to the push button, status LED, and the motor driver.

(b) Push button

The push button is the method the user will use to communicate with the band. The push button is connected to the microcontroller. When pressed, the push button will send a signal to the microcontroller to initiate the vibration signal.

(c) Status LED

The status LED acts as a visual representation of the battery level of the wristband.

Requirements	**Verification**
1. Pushing the button results in <u>one</u> successful transmission of the "key."	1. a. Wait five seconds without pressing the button and show that the motor does not generate a signal.

2. Must be able to successfully generate and transmit multiple complete "keys."	b. Push the button and observe the motor generate the correct signal. c. Push the button while the motor is generating a signal and show the successful completion of the current signal. 2. a. Transmit two consecutive signals by pressing the button once, wait for the signal to transmit completely, then press the button again to transmit the second signal.

Table 5: RV Table for the Band Module's Control Subsystem

2.3.2.3 Motor Subsystem

The motor subsystem is responsible for generating the vibration signal. It contains the motor driver and the LRA motor.

(a) Motor driver

The motor driver drives the LRA motor. The motor driver is connected to the microcontroller and the LRA motor. When a vibration signal needs to be generated, the motor driver receives a signal from the microcontroller that tells the motor driver what frequency the motor needs to run at. With this information, the motor driver drives the LRA motor appropriately.

(b) LRA motor

The LRA motor is the actual mechanism that produces the vibration signal. The LRA motor receives AC power from the motor driver. The frequency the motor runs at is dependent on the waveform of the AC power it receives.

Requirements	**Verification**
1. Motor has resonant frequency in the range of 150-300 Hz (intersection of human bone conduction range and typical LRA motor resonance frequency range).	a. Conduct frequency sweep from 150-300 Hz to get frequency of the motor. b. The peak of the frequency response is the motor's resonance frequency.

	Show that the resonance frequency lies within the required range by using an accelerometer to show the change in vibrational signal amplitude during the frequency sweep in real time.
2. Vibration signal generated by the LRA motor conduct through the hand to the fingertip has an amplitude that exceeds the accelerometer noise floor.	a. Generate a vibration signal from the motor. b. Conduct the signal through the hand to the fingertip. c. Use accelerometer to show the vibration signal being received from the fingertip. Vibration signal's amplitude is greater than the accelerometer noise floor if the change in the accelerometer output is a function of the vibrations of the motor.

Table 6: RV Table for the Band Module's Motor Subsystem

2.4 Schematics

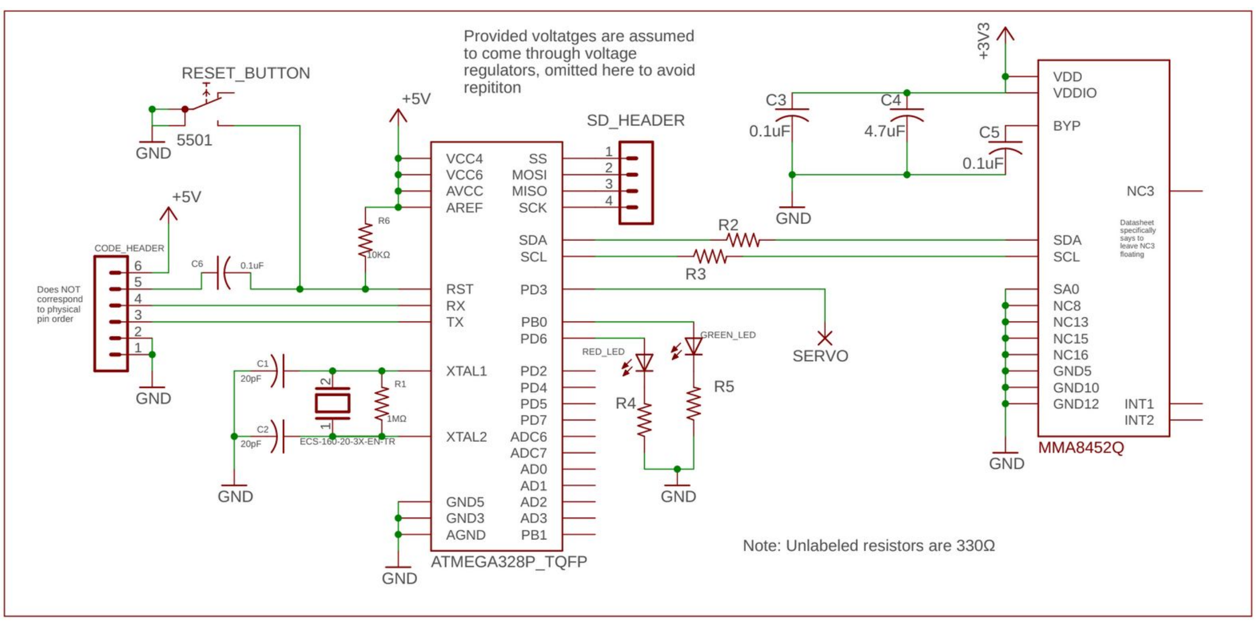

Figure 6: Lock module circuit schematic

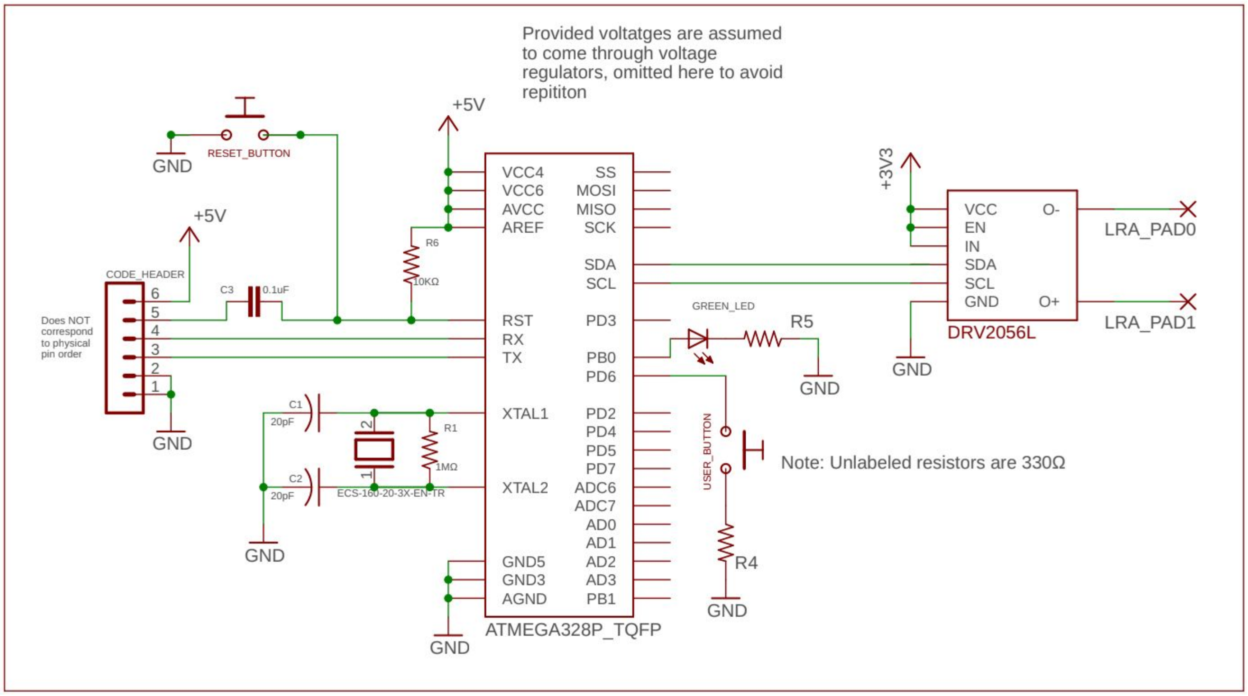

Figure 7: Band module circuit schematic

3 Ethics and Safety

Exposure to vibrations is known by the Occupational Hazards and Safety Administration [8] and the Canadian Centre of Occupational Health and Safety (CCOHS) to be a workplace hazard. According to the CCOHS, exposure of the hands and arms to vibrations can result in Hand-Arm Vibration Syndrome, a disorder affecting blood flow to the fingers and resulting in a loss of touch sensation [9] . A 2002 article in The Journal of Low Frequency Noise, Vibration, and Active Control titled *EU Directive on Physical Agents - Vibration* provides guidelines on the amount of safe hand-arm vibration exposure [10]. It is measured by the RMS magnitude of acceleration normalized by exposure time: a stronger vibration means a shorter exposure time before there is a risk of damage. The shortest time listed in the article was a half hour. Over this time period, the maximum acceleration deemed to be safe was 20 m/s^2 . Preliminary tests of haptic motors of similar size to those we plan to use showed a peak strength below that: 18.04 m/s^2. Additionally, since one goal of ours is to unlock the door in a timely manner, the time of vibration exposure will be on the order of seconds, not minutes or hours.

The operating frequency of the motors to be used in this project also make it unlikely that the vibrating band will cause damage to the user. In Shrawan Kumar's *Biomechanics in Ergonomics: Second Edition* [11], the author proposes damage may be more likely to occur at the resonant frequencies of certain internal organs and structures within the body. Their frequencies are listed in Table 1. Note that some organs and structures have ranges of resonant frequencies. Others have multiple discrete resonant frequencies. The former is notated by a hyphen, the latter with the word “and”.

Internal Organ / Structure	**Resonant Frequency (Hz)**
Spine	5
Pelvis	5 and 9
Abdomen-thorax	3 and 5-8
Lower Intestine (while seated)	8
Heart	7
Head-Neck-Shoulder[2]	20-30
Eyeballs	60-90
Lower Jaw-Skull	100-200

Table 7: Resonant frequencies of various biological structures

These resonant frequencies are outside the range of ~200-250 Hz which our motors will be operating at. The lower jaw and skull, the biological structure whose resonant frequency is closest to our motor’s operating frequency, is located at great distance from the source of the vibrations, making damage to those body parts an unlikely scenario.

Testing and wearable technology comes with the risk of having dangerously hot or burning electrical components strapped to human testers in the event of a catastrophic failure. If a CO_2 fire extinguisher—the kind typically used on electrical fires—is used to put out a piece of technology being worn by a tester, they are liable to receive cold burns from the extinguisher as well as heat burns from the fire. To counteract this, as many tests as possible will be done without wearing the band while testing. Additionally, we will design the band and ring such that they can be easily removed in the event of an emergency. Using velcro as the band fastener was one proposed way to ensure this.

Ethically, the major issue which concerns this project is user data safety. If our project progresses rapidly enough to get to the biometric identification step, keeping users’ biometric data secure becomes a concern. This issue can be handled by not storing the raw data[3]. The logs which will be written to an SD card inside of the lock do not store information about the signal received, only the time of attempt, bit sequence received, and indication of success or failure.

[2] The odd wording is courtesy of the original author. Whether this refers to all three body parts as separate or the system as a whole is unclear. Regardless, the implication that our motors operate well outside this frequency range is clear.

[3] At least not in the final product. In testing, gathering large amounts of raw signals to process later will be helpful when investigating biometrics, and the SD card provides an easy way to do that.

The calibration data used to judge whether a particular user is authorized for entry will be stored in the memory of the microcontroller. Considering its position inside the physical lock itself, and the relative difficulty of offloading this data in comparison to say, taking an SD card, it is unlikely that this data will be compromised. Other ethical issues—namely those listed in the IEEE Code of Ethics[12]—are not made especially relevant by the nature of the work to be done. There are no exceptional safety risks, conflicts of interest, potential for environmental damage, etc. outside of the risks bound to occur on any electrical engineering project

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