Bone Conduction Lock

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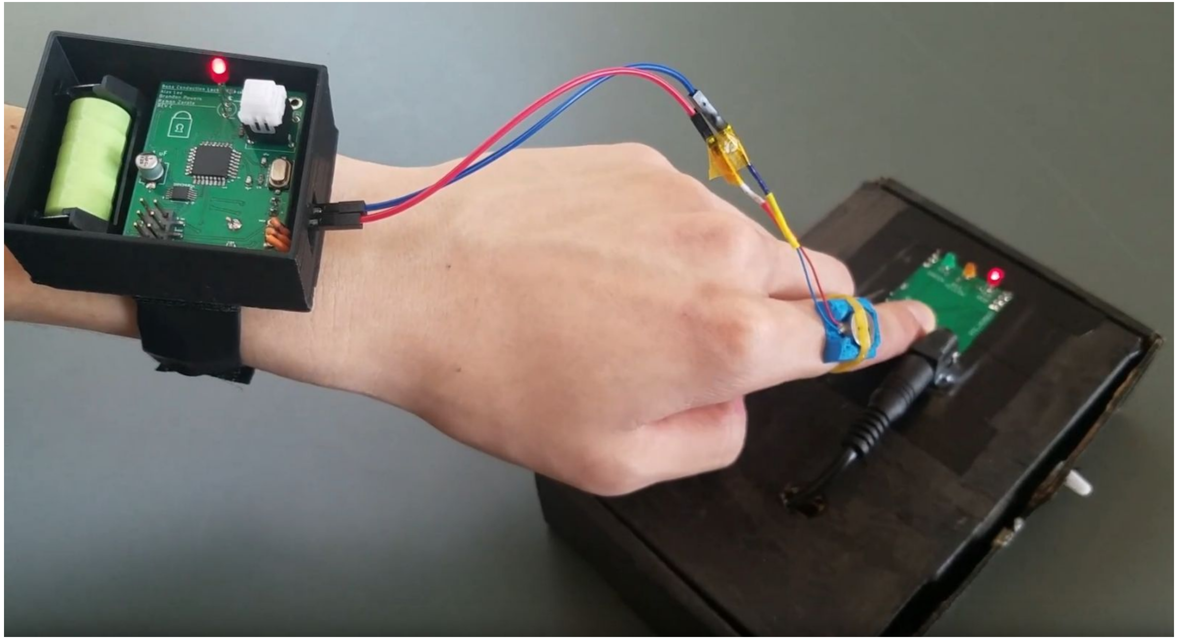
Project Overview

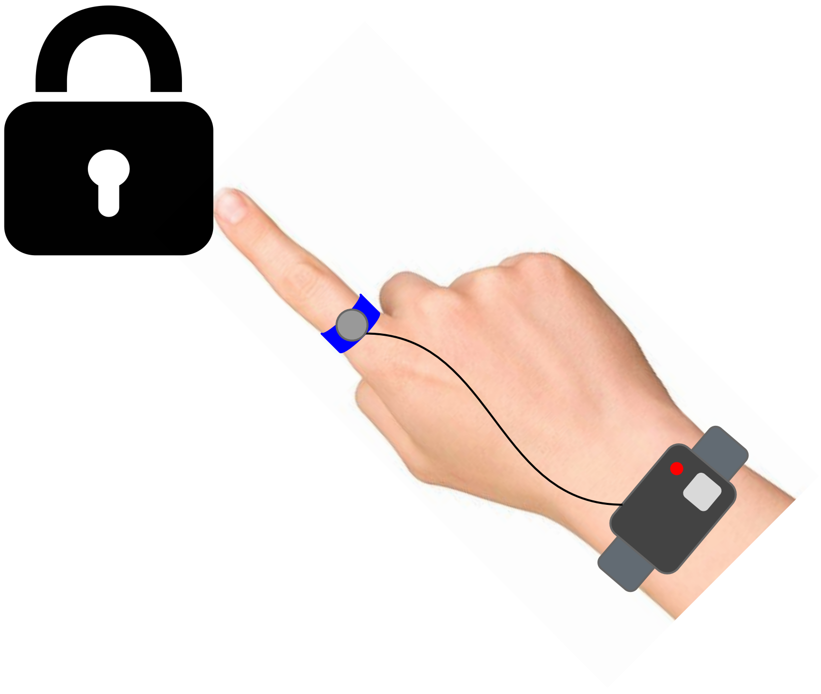
A lock that is unlocked by vibrations conducted through the user's bones.



Objective

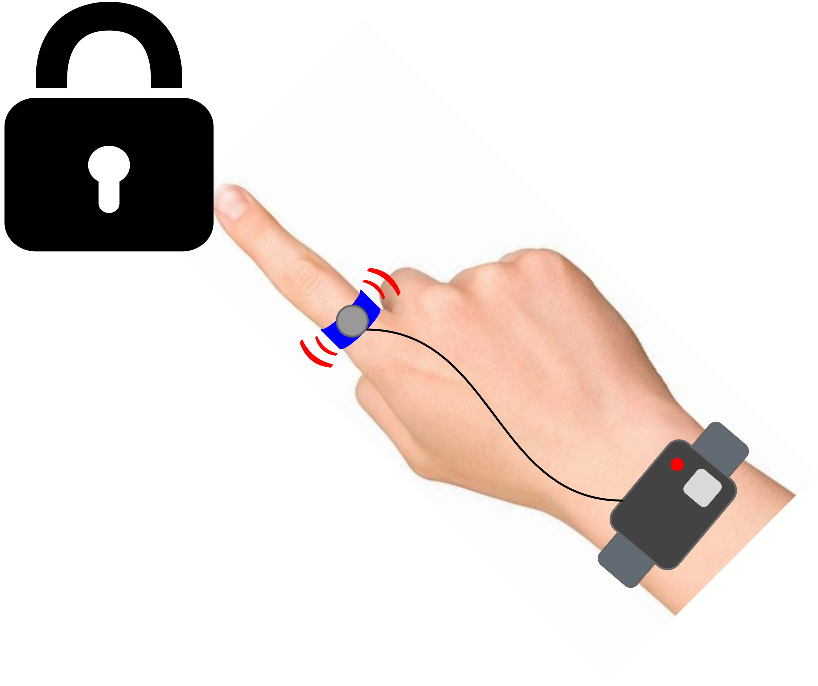
- Prove human bone conduction is a viable communication channel
- Provide an efficient and secure way to unlock a door
- Investigate the use of human bone for biometric authentication

Bone Conduction Lock Operation (Basic)



User presses their finger to the lock

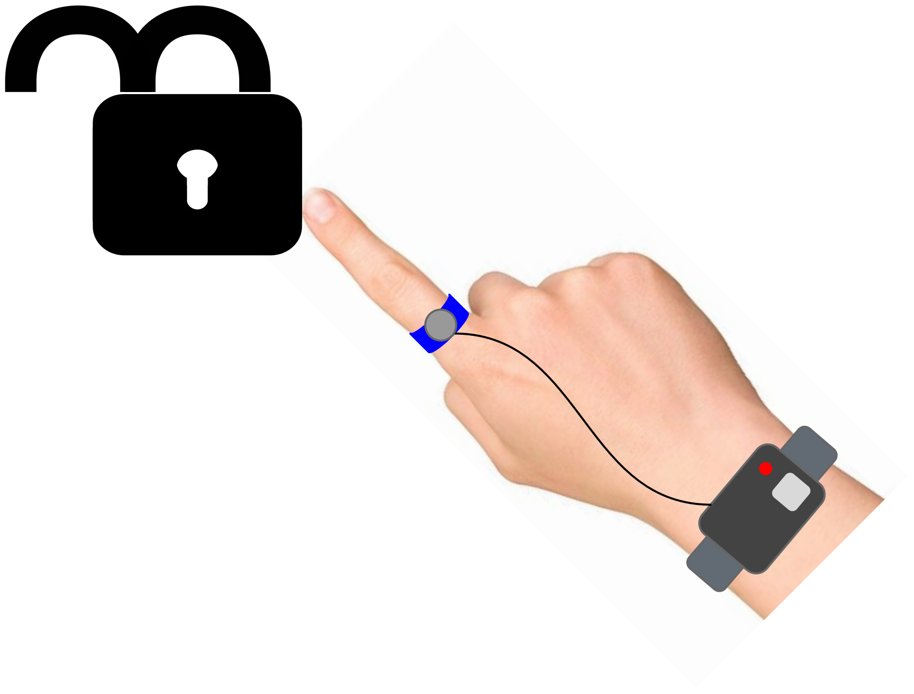
Bone Conduction Lock Operation (Basic)



User presses their finger to the lock

User presses button on band to generate vibrations

Bone Conduction Lock Operation (Basic)



User presses their finger to the lock

User presses button on band to generate vibrations

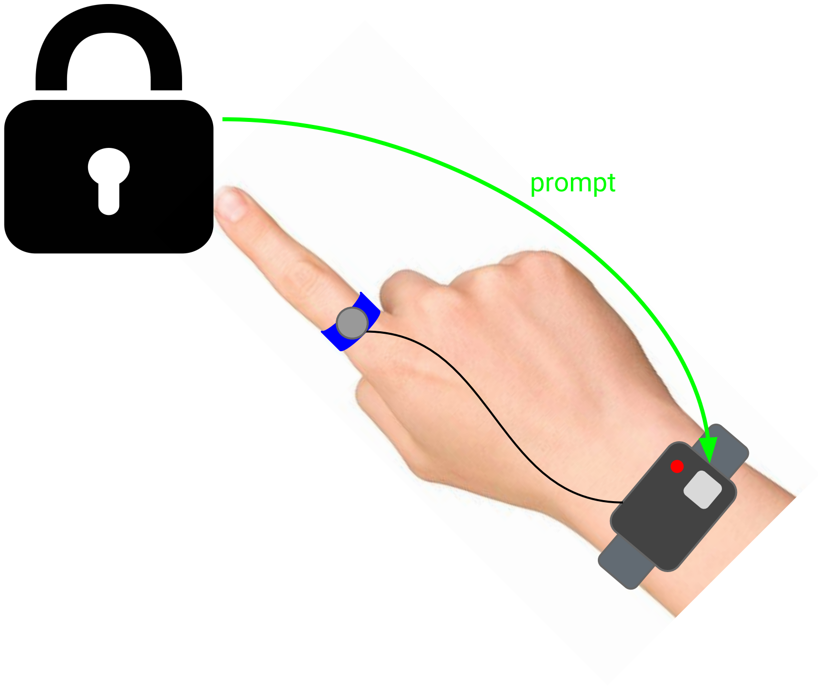
Lock detects and verifies signal

- if signal is correct, lock unlocks

After predetermined time, lock locks itself

Lock is now ready for the next attempt

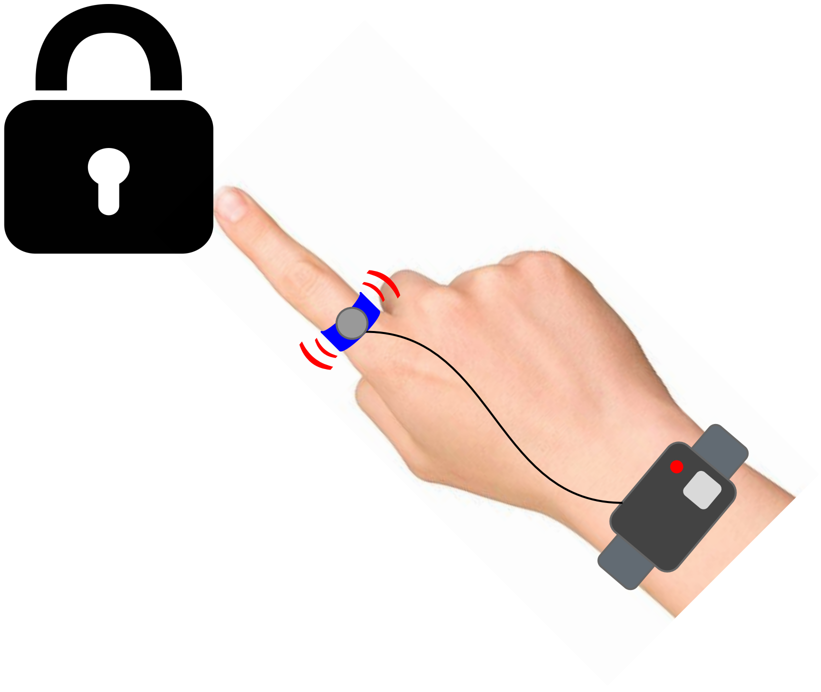
Bone Conduction Lock Operation (Advanced)



User presses their finger to the lock

Lock detects finger and sends prompt to band wirelessly

Bone Conduction Lock Operation (Advanced)

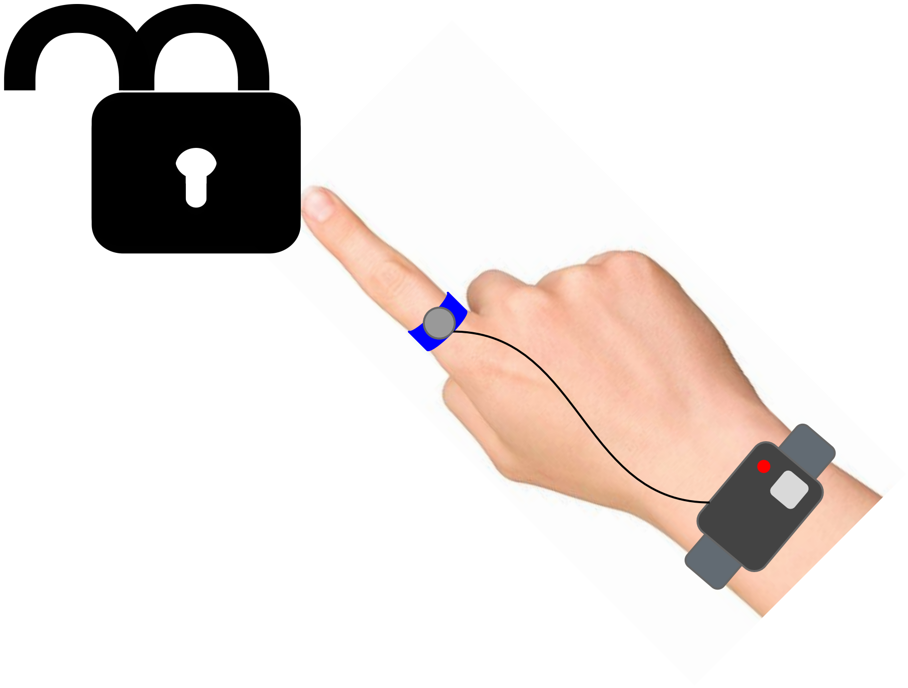


User presses their finger to the lock

Lock detects finger and sends prompt to band wirelessly

Band generates vibrations corresponding to prompt

Bone Conduction Lock Operation (Advanced)



User presses their finger to the lock

Lock detects finger and sends prompt to band wirelessly

Band generates vibrations corresponding to prompt

Lock detects and verifies signal

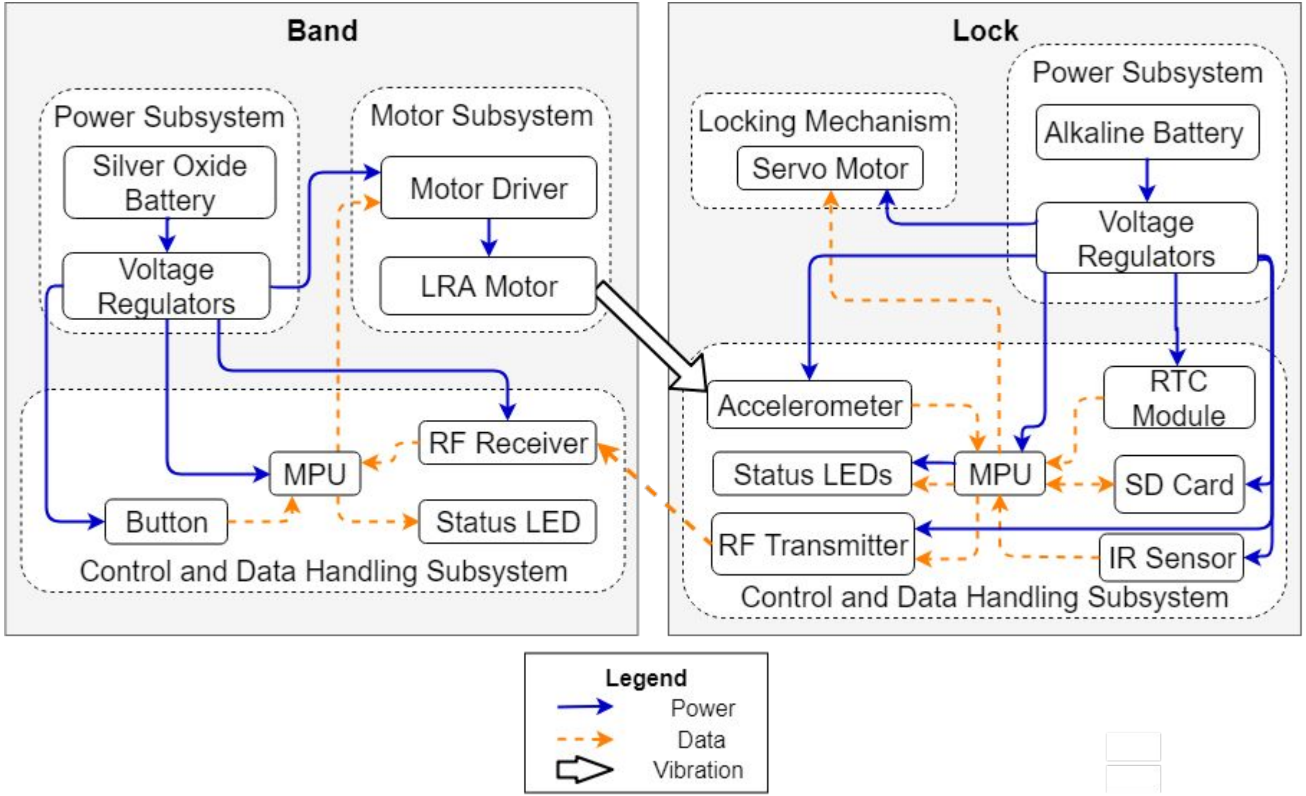
- if signal is correct, lock unlocks

After predetermined time, lock locks itself

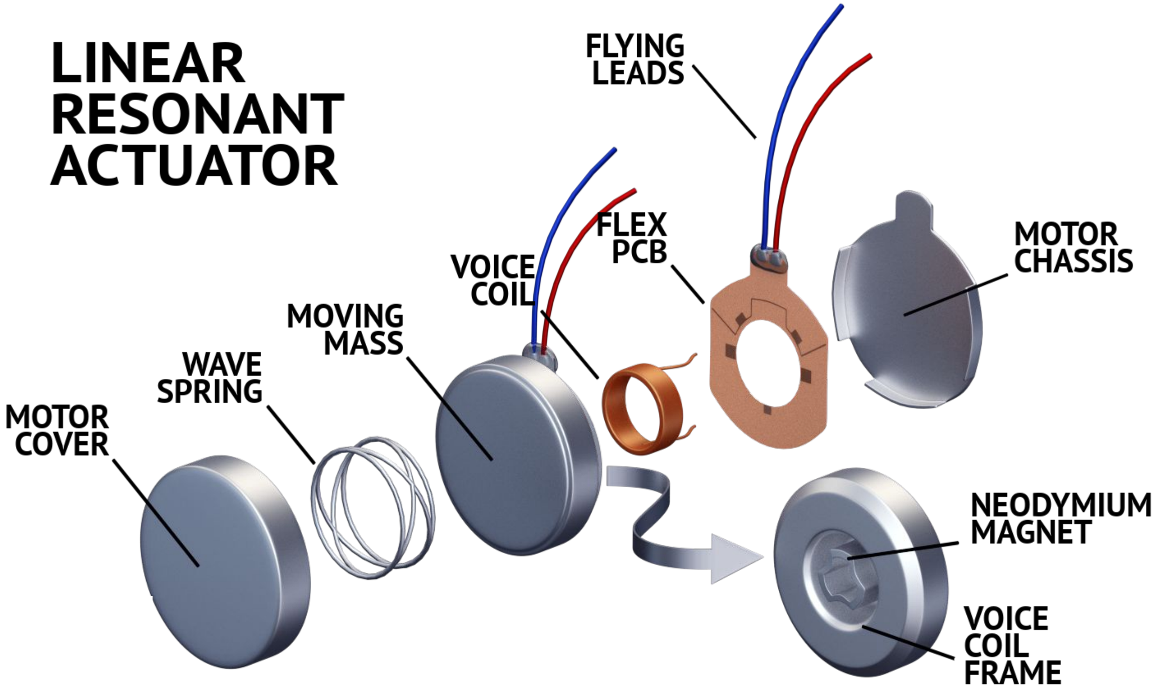
Lock stores activity in activity log

Lock is now ready for next attempt

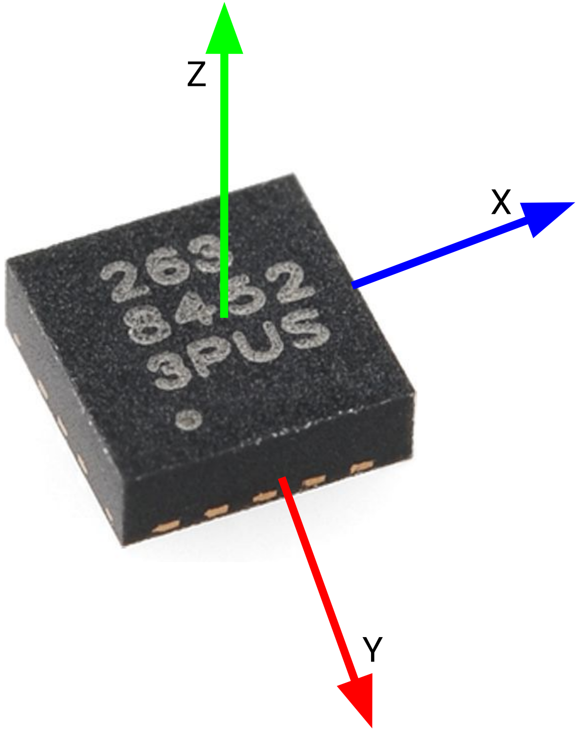
Block Diagram



Motor


LINEAR
RESONANT
ACTUATOR
FLYING
LEADS
FLEX
PCB
VOICE
COIL
MOVING
MASS
WAVE
SPRING
MOTOR
COVER
MOTOR
CHASSIS
NEODYMIUM
MAGNET
VOICE
COIL
FRAME

Accelerometer

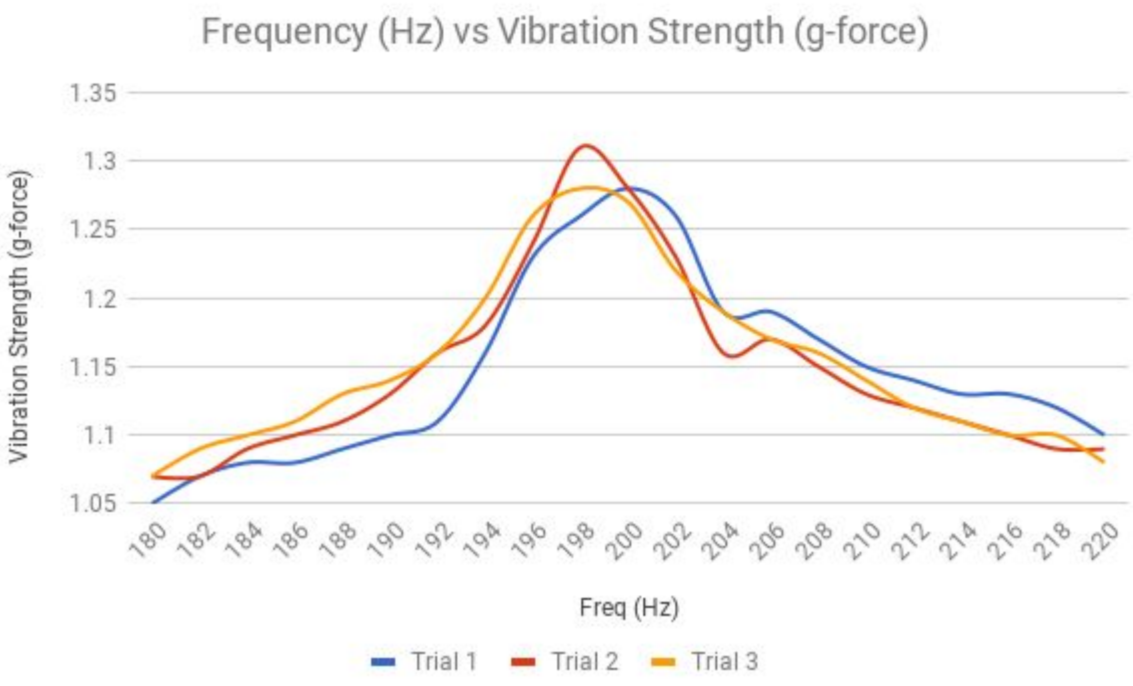


MMA8452 3-axis accelerometer:

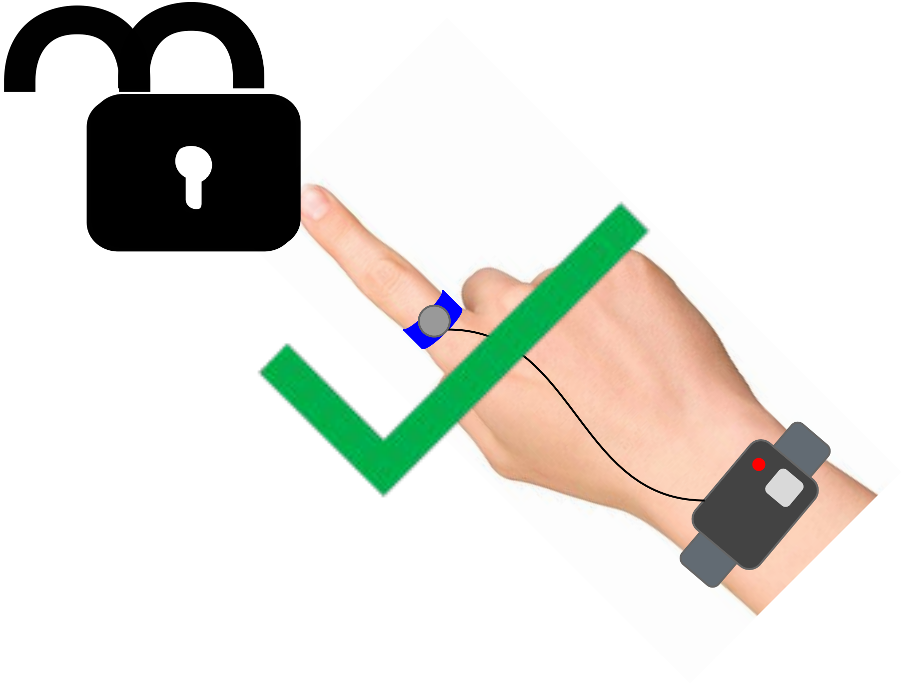
- MEMS accelerometer with 12-bit resolution
- Selectable full-scale range: ±2g, ±4g, or ±8g
- Selectable sampling rate: 800, 400, 200, 100, 50, 12.5, 6.25, or 1.56 Hz

We initialized accl with **±2g** full-scale range and **800 Hz** sampling frequency.

Resonant Frequency



Efficiency: Unlock with one motion



Security

- keys made up of 10 bits transmitted in 3s
- bit = 0 or bit = 1
- total number of possible bit sequences:

2^10 = **1024 possible keys**

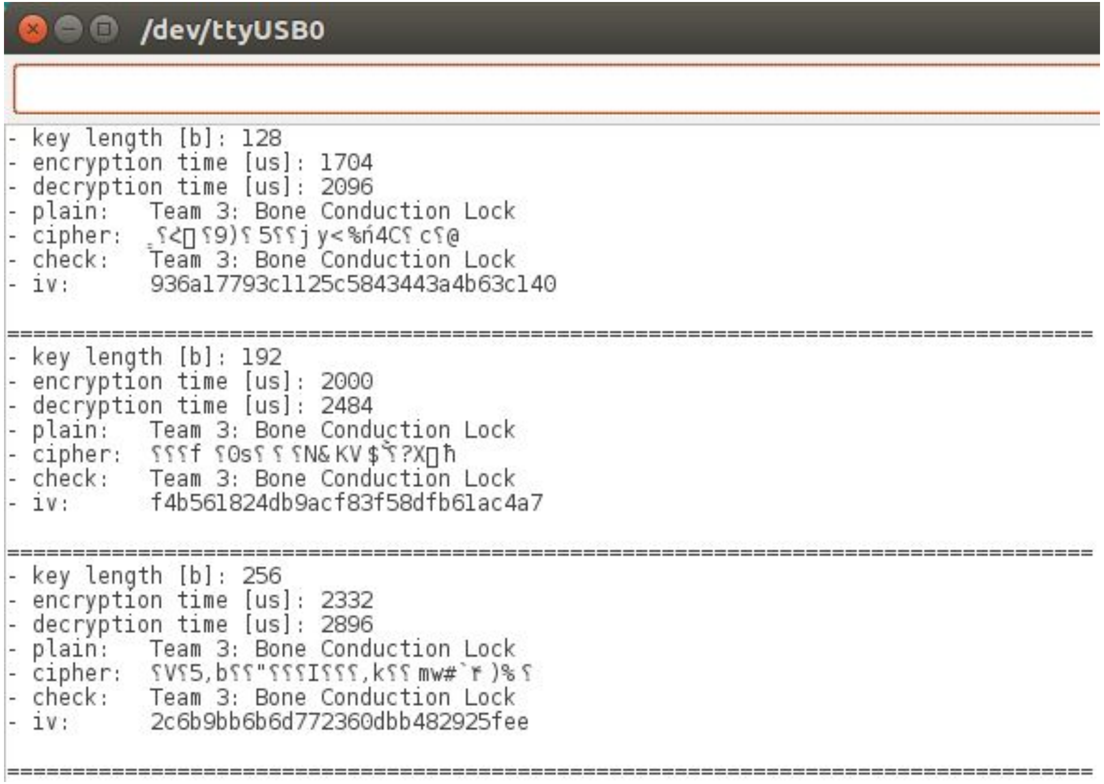
Security (cont.)

Dynamic prompts:

- For every attempt, the bone conduction lock is expecting a different key

¯_(ツ)_/¯

Security (cont.)



Security (cont.)

Time penalty:

- penalized for consecutive incorrect keys received by the lock
- Penalty for *n* consecutive incorrect key:

$n = 2 \rightarrow$ wait 10 seconds

n = 5 --> wait 30 seconds

$n = 10 \rightarrow$ wait 60 seconds

$n > 10 \rightarrow$ wait $60(n\text{-}10)+60$ seconds

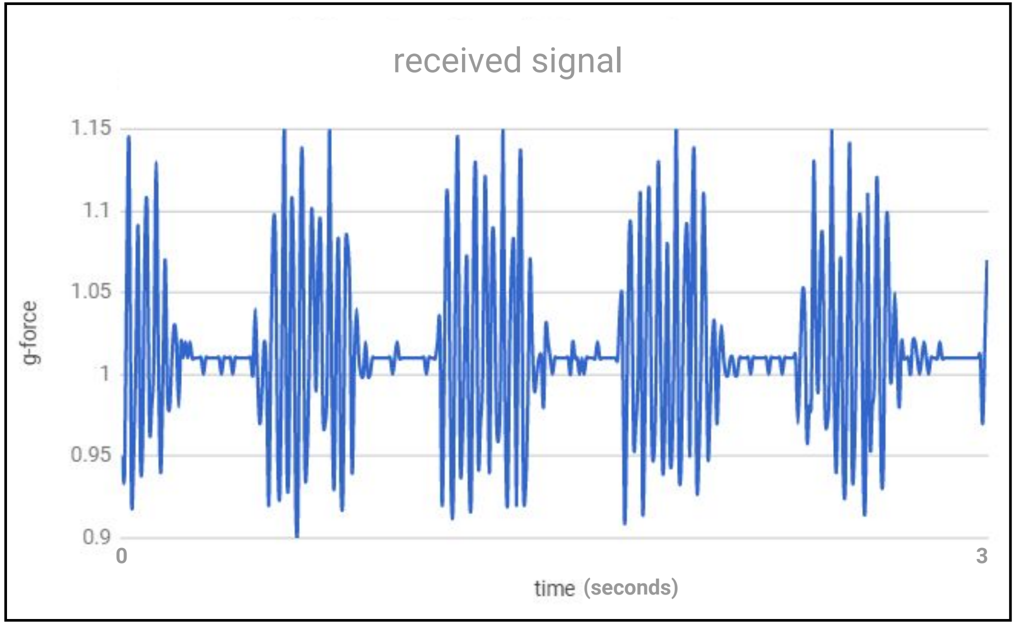
To bruteforce all possible keys, ignoring the dynamic prompts, it would take **30916970 seconds** = **375 days**

Security (cont.)

```
11:08:29 | Tuesday - 2/27/18  LOCK ACTIVITY LOG

11:08:47 | Tuesday - 2/27/18  finger detected
11:08:57 | Tuesday - 2/27/18  correct key;      lock UNLOCKED
11:09:01 | Tuesday - 2/27/18  finger detected
11:09:10 | Tuesday - 2/27/18  correct key;      lock LOCKED
11:09:14 | Tuesday - 2/27/18  finger detected
11:09:20 | Tuesday - 2/27/18  incorrect key;    do nothing
11:09:25 | Tuesday - 2/27/18  finger detected
11:09:29 | Tuesday - 2/27/18  finger removed
11:09:30 | Tuesday - 2/27/18  imcomplete key;   do nothing
```

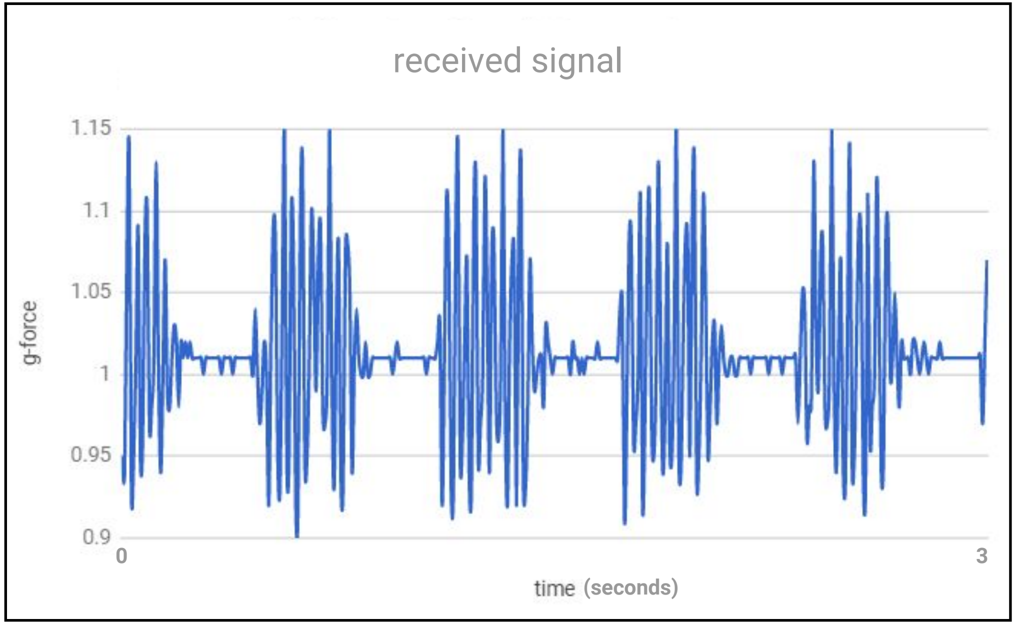
Stability



For bit extraction, must consider:

- sampling rate
- downsampling
- ramp up/down of LRA motor

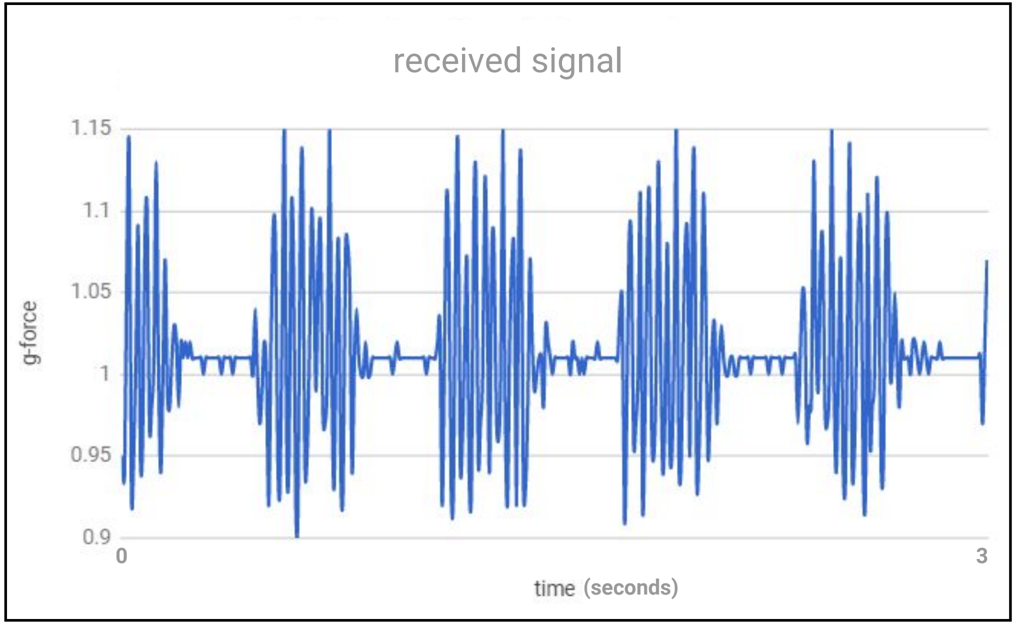
Stability (cont.)



To decrease the time per vibration, implemented following algorithms with the **TI DRV2605L** motor driver:

- resonance frequency finder
- overdrive
- assisted braking

Stability (cont.)



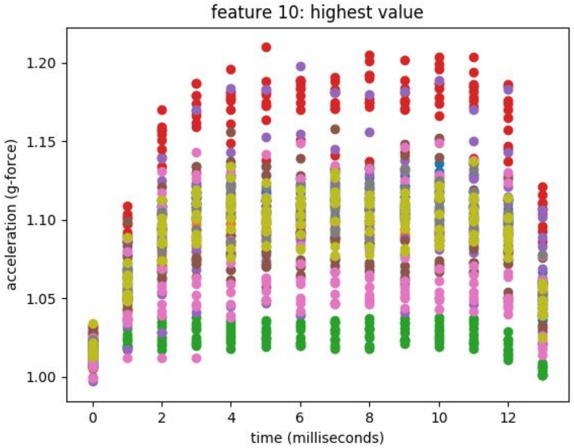
fastest vibration → 100 ms

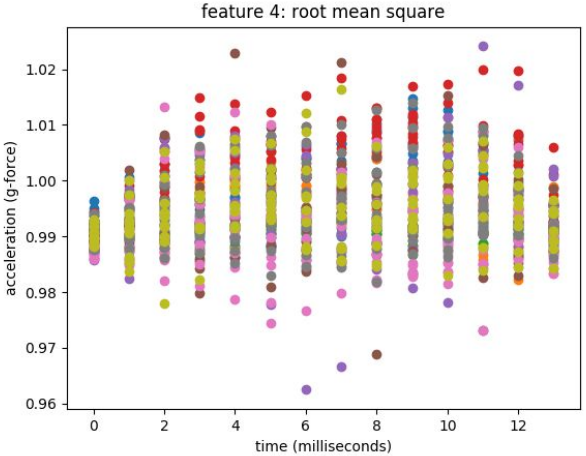
↑ number of bits = ↑ bit extraction error

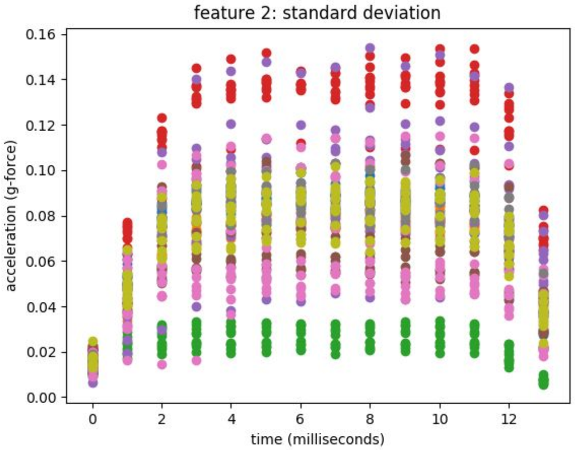
false negative < 5% of trials

- use 290 ms vibrations

Biometric Authentication (time domain analysis)



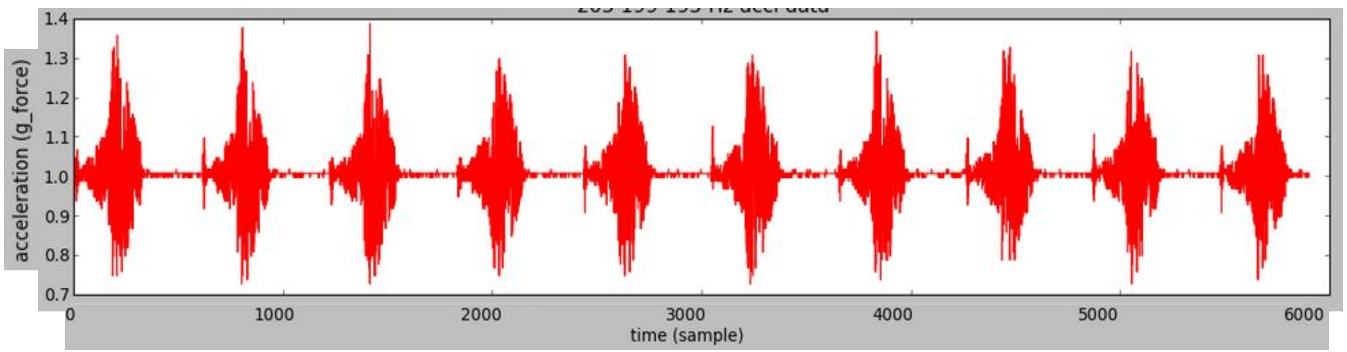




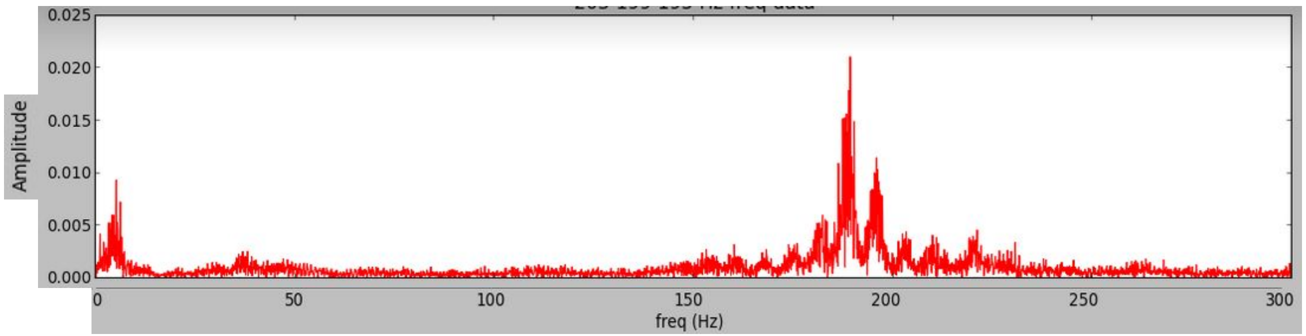
Other features: mean, variance, average deviation, zero-crossings, skewness, Kurtosis, lowest value

Biometric Authentication (frequency domain analysis)

Continuous time domain signal reconstructed as discrete signal. Increasing frequency sweep to drive LRA motor.



Frequency response.



Conclusion:

- Proved human bone is viable channel for communication
- Built hardware platform to use human bone as communication channel
- Showed hardware platform is stable and can operate as a lock
- Used hardware setup for explorations into biometric authentication

Future Work

Integration with commercial devices

Use biomarkers to generate key

Ethics

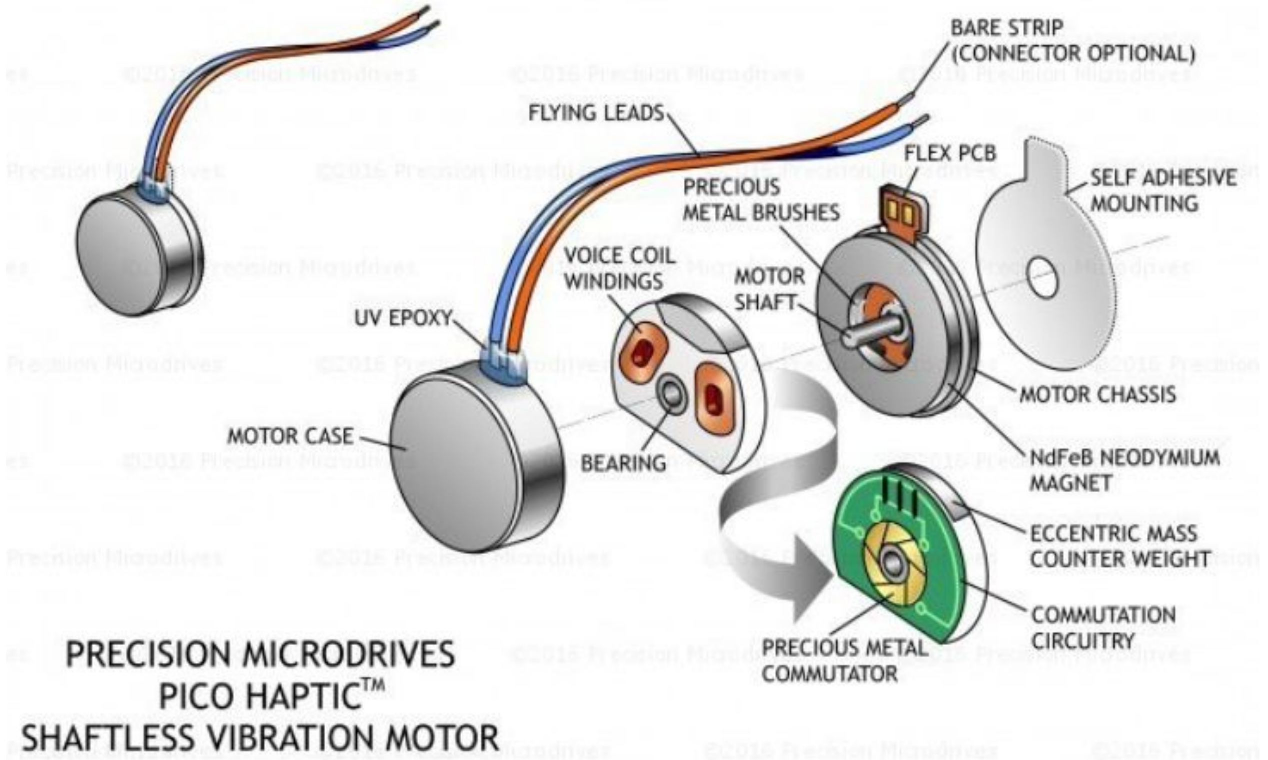
HIPAA

Health Insurance Portability
& Accountability Act

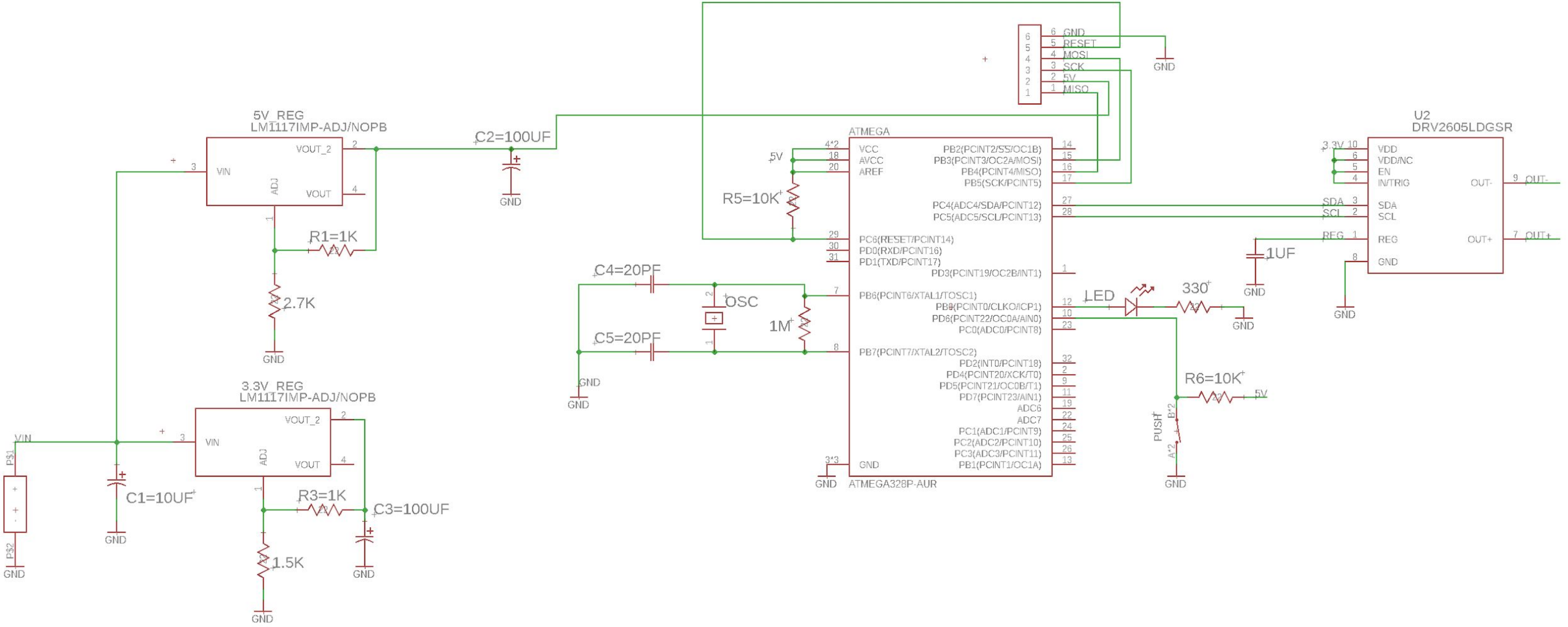
Thank You!

Questions?

Design: ERM Motor

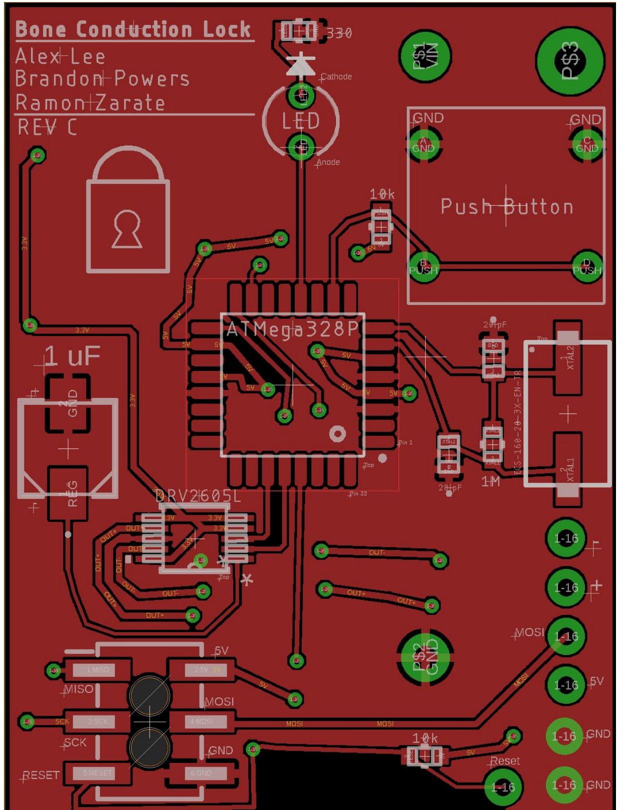


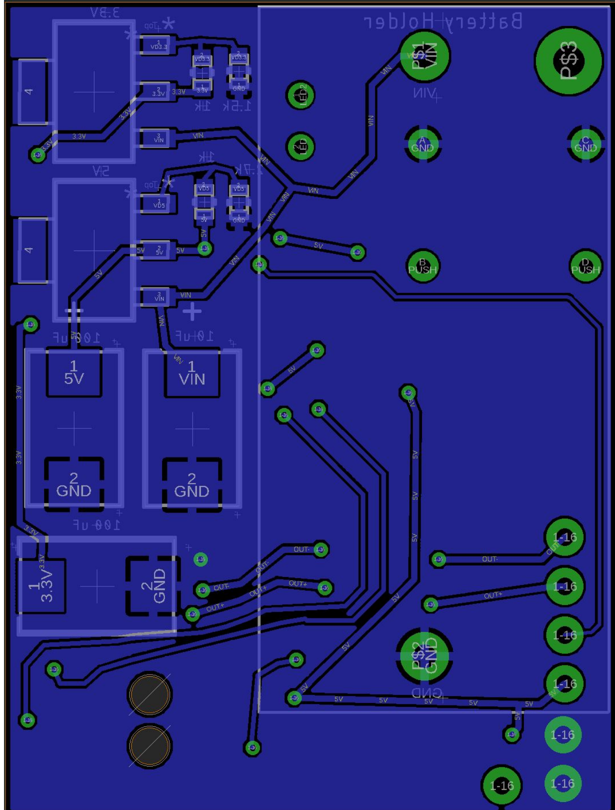
Design: Band Module Schematic



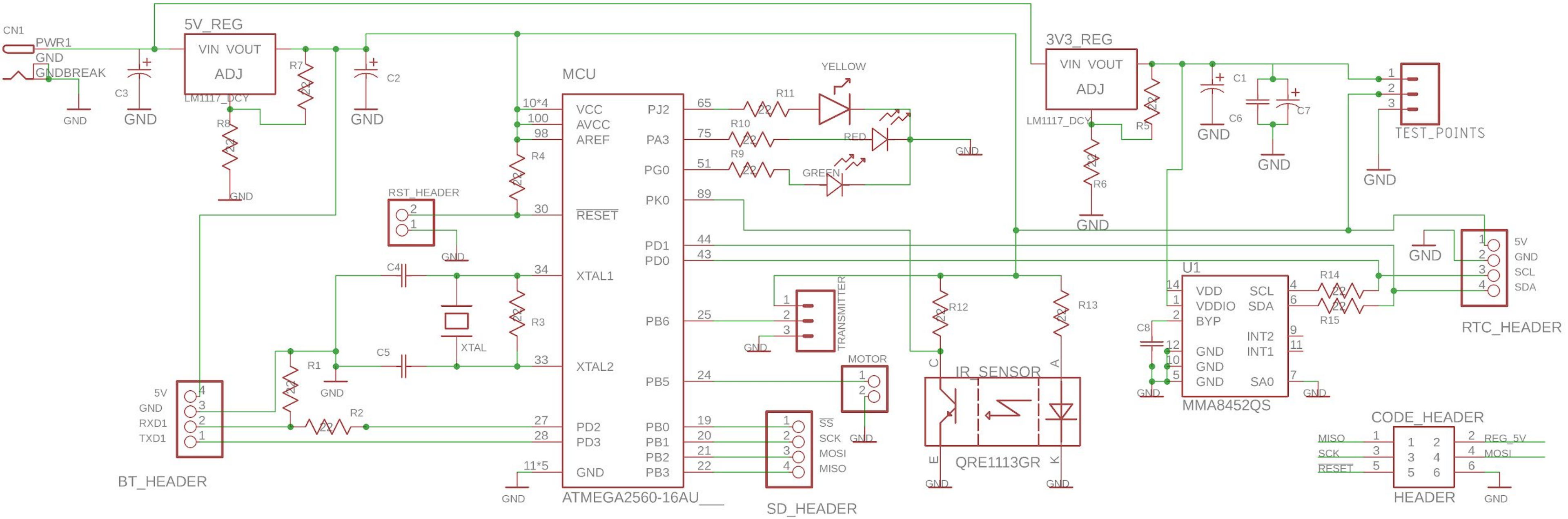
Design: Band Module PCB Layout

- 30 mm x 40 mm
  - Size of Apple watch
- Power on bottom



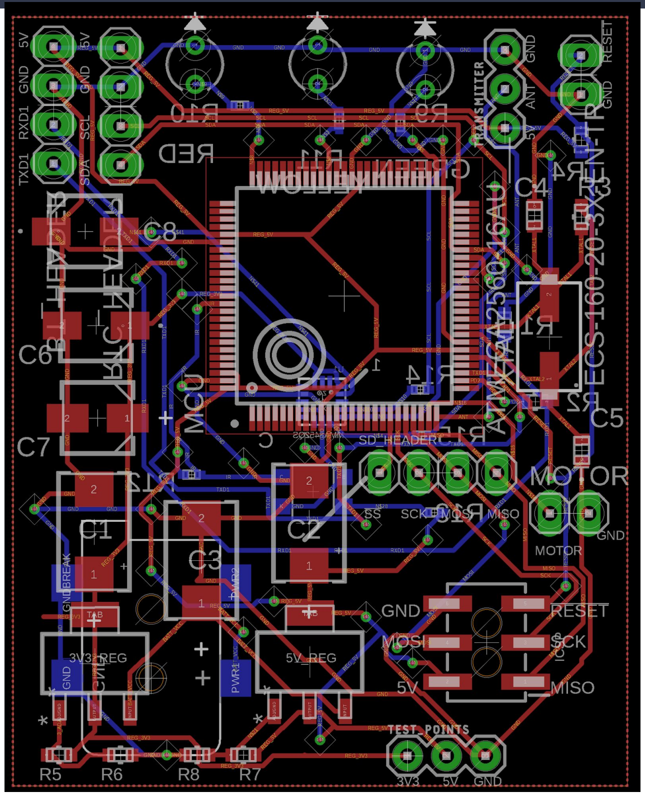


Design: Lock Module Schematic



Design: Lock Module PCB Layout

- 40 mm x 50 mm
- Mostly clear on bottom except for IR sensor, accelerometer
- Too dense to effectively display via powerpoint. Evidence visible on right



Design: Power Supply Schematic

$R_1 = R_3 = 1\ k\Omega$

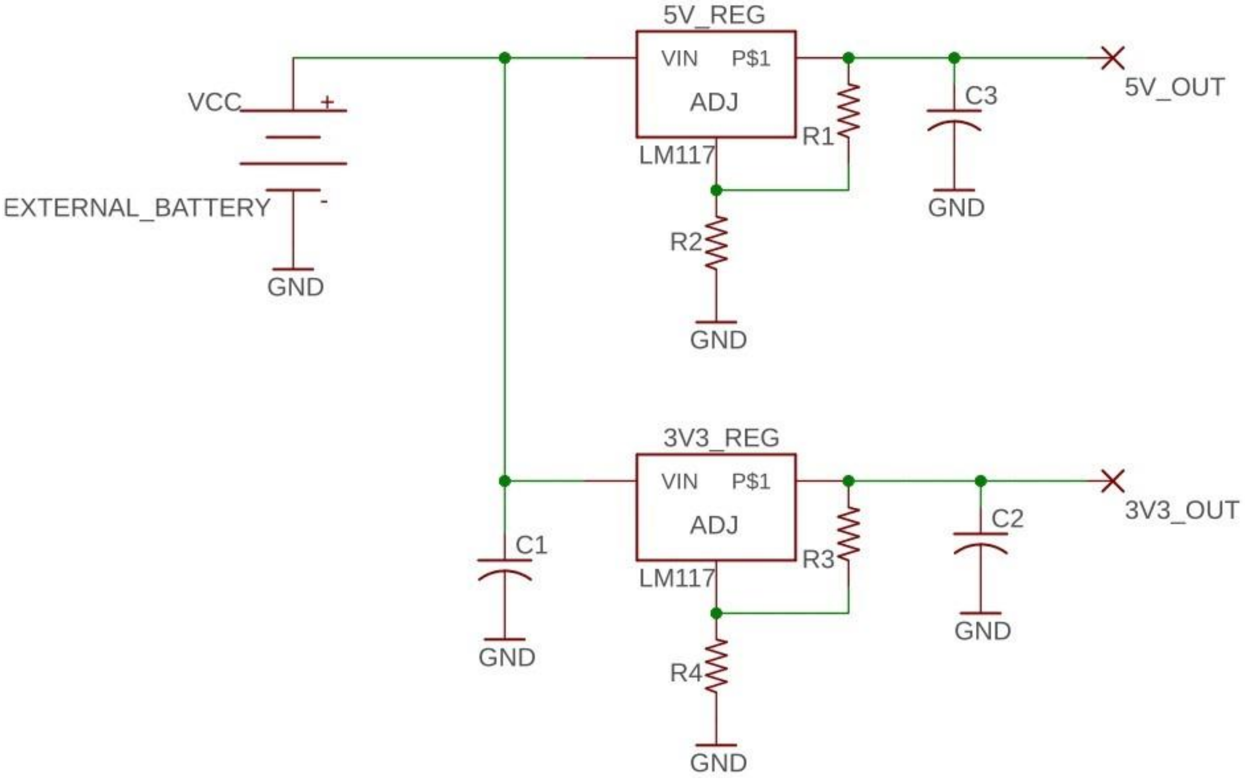
$R_2 = 2.7\ k\Omega$

$R_4 = 1.5\ k\Omega$

$C_1 = 10\ \mu F$

$C_2 = C_3 = 100\ \mu F$

$V_{out} = 1.25(1+(R_2/R_1))$



Design: Power Consumption Results

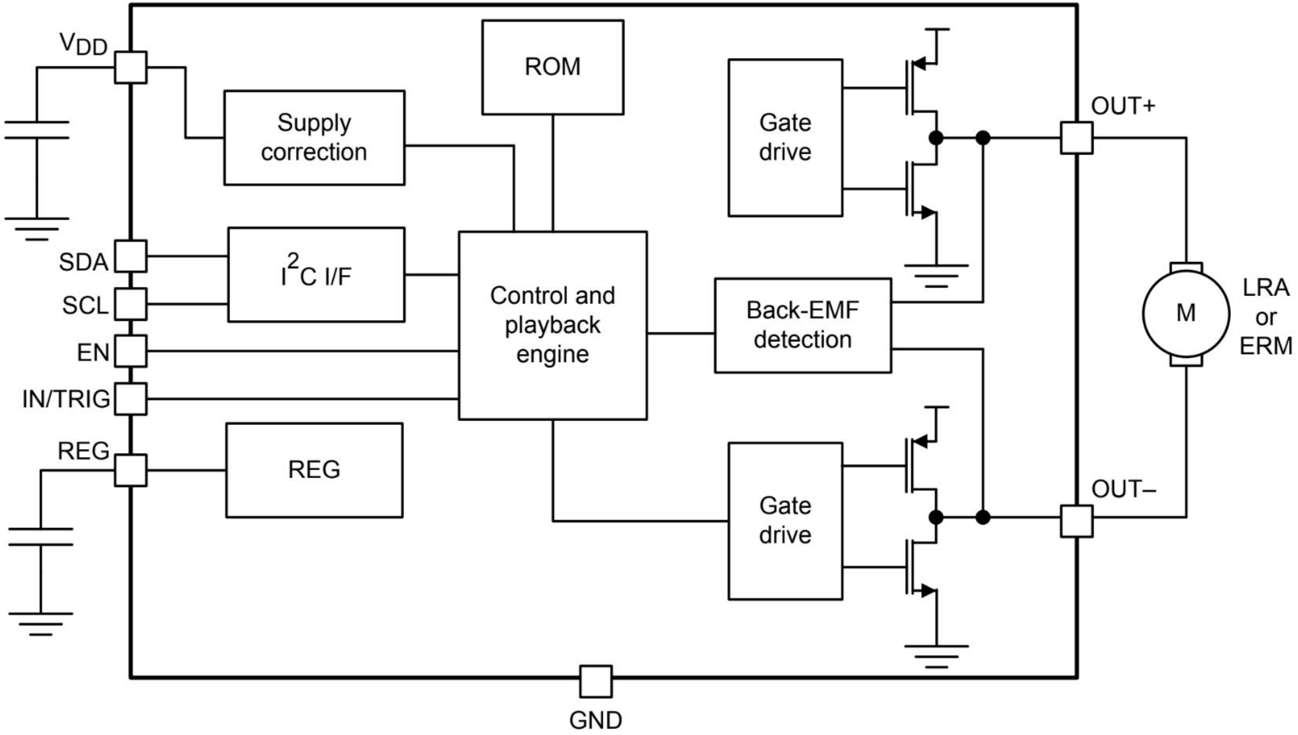
Lock Module

3.3 V Regulator	Output Voltage	Theoretical Idle Current	Input Voltage	9 V
	3.18 V	30 mA	Battery Capacity	310 mAh
5 V Regulator	Output Voltage	Theoretical Output Current	Transmission Time	2 sec
	4.78	100 mA	Battery Life (Idle)	10.3 Hours
			Battery Life (Dynamic)	3.1 Hours
			Transmissions/Battery	5,580

Band Module

3.3 V Regulator	Output Voltage	Idle Output Current	Input Voltage	7.5 V
	5.48 V	20 mA	Battery Capacity	110 mAh
5 V Regulator	Output Voltage	Output Current	Transmission Time	3 sec
	4.75 V	66 mA	Battery Life (Idle)	5.5 Hours
			Battery Life (Dynamic)	1.6 Hours
			Transmissions/Battery	1,920

Design: Motor Driver Supply Correction



Band Module: RV Table Review

Requirements	Verification	Verification Status
1. Signal from push button is momentary	a. Display output from push button on serial monitor b. Show the microcontroller only receives signal when button is pushed.	Yes
2. Pushing the button results in one complete transmission of the “key”	a. Wait five seconds without pressing the button and show that the motor does not generate a signal. b. Push the button and observe the motor generate a complete signal on the serial monitor. c. Push the button while the motor is generating a signal and show that it does not affect the completion of the current signal on the serial monitor.	Yes
3. Must be able to generate and transmit multiple complete “keys”	a. Transmit two consecutive signals by pressing the button once, wait for the first signal to transmit completely, then press the button again to transmit the second complete signal. b. Show two complete signals were transmitted on serial monitor.	Yes

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Lock Module: RV Table Review

Requirements	Verification	Verification Status
1. Accelerometer output has full-scale range of ± 2 g with minimum sampling rate of 800 Hz to be read by microcontroller	a. Sweep frequency range using function generator to capture frequency response. b. Show that frequency response does not get clipped at 2 g on the serial monitor.	Yes
2. Accelerometer output has 0.01 g precision and maximum noise floor of 1.02 g	a. Show the output has 0.01 g precision on serial monitor. b. Show accelerometer has maximum noise floor of 1.02 g on the serial monitor.	Yes
3. IR sensor detects finger when in contact with the lock module target area	a. Send IR sensor output to microcontroller. b. Display sensor output on the serial monitor. c. Show change in IR sensor output is a function of proximity of finger when within one inch of the lock module target area.	Yes
4. Status LEDs show state of the lock	a. When lock is in locked state (0°), the red LED is on. b. When lock is in unlocked state (90°), the green LED is on.	Yes

Power Supply: RV Table Review

Requirements	Verification	Verification Status
3. Must output 3.3 V ± 5% with a current load of up to 800 mA	d. Measure the output voltage using a multimeter. e. Vary the load current by changing load resistance. f. Show on multimeter that voltage stays in its tolerance range as current is varied up to 800 mA.	Yes
4. Must output 5 V ± 5% with a current load of up to 800 mA	d. Measure the output voltage using a multimeter. e. Vary the load current by changing load resistance. f. Show on multimeter that voltage stays in its tolerance range as current is varied up to 800 mA.	Yes
3. Maintain a temperature below 120°C	b. Use an IR thermometer or IR camera when the IC is in operation to show that the temperature stays below 120°C.	Yes