RFID Lock Final Report

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Abstract

The idea of an RFID door lock that can exist in tandem with current door infrastructure and deadbolts and powered by induced emf is possible. This report details the work done by a team of three University of Illinois Urbana-Champaign senior electrical and computer engineers and findings as they relate to the logistics of the RFID door lock aforementioned.

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1 Introduction

1.1 Problem

The problem this project aims to solve is the difficulty of use of classic door key locks especially when under adverse conditions such as frozen debris, low light levels, inebriation, or disabilities such as Parkinson's or blindness making location and use of these locks a challenge.

1.2 Solution

The solution is to create a renter-friendly system that works in tandem with the current infrastructure on the door and will mount with the deadbolt lock. Since the product will be mounted using the same screw and friction system the deadbolt lock uses, the product will slip into the deadbolt position without marking up or requiring new screw holes to be installed on the door and lose the security deposit after you move out.

The solution will be an RFID scanner mounted on the deadbolt that will be connected to an inner PCB system to ensure the RFID tag is allowed to open this door and will then power a linear actuator to rotate the deadbolt into the unlocked position. The whole system will also be powered by induction where the RFID tag will be housed with a power bank with a remote power transmitter. The door RFID scanner will also have a remote power receiver coil that when the RFID tag is scanned on the door the bank and transmitter will also be in contact to power the system wirelessly. This will ensure the RFID door system will never require a battery change out and only be useful when a proper RFID tag is touching it which is an indirect security measure.

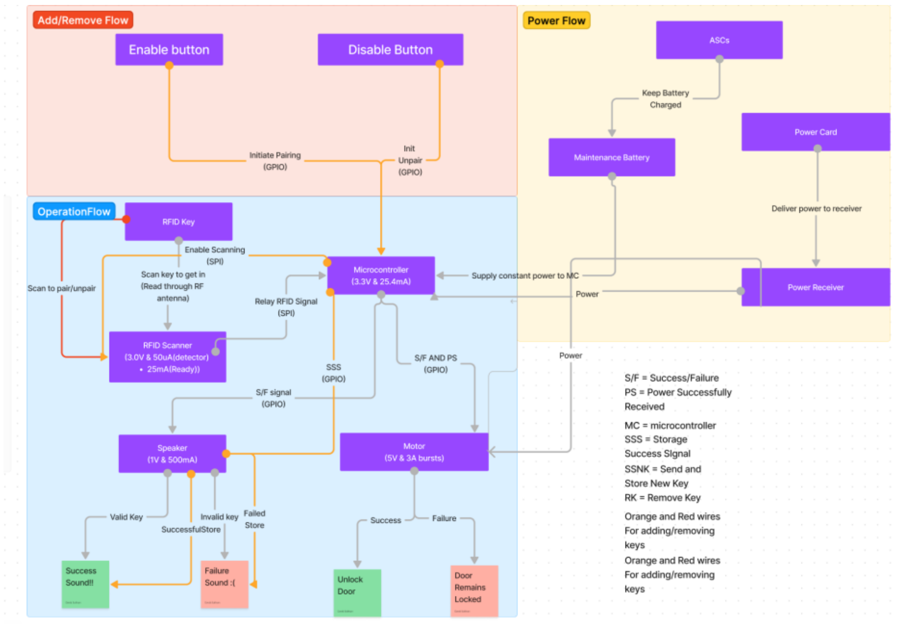

Figure 1.1 shows a block diagram for the initially proposed unit

Within Figure 1.1 is the power card and power receiver which make up only two blocks within the diagram but have their own complexity since they will be providing the power for the entire circuit. Secondly, highlighted in blue is the majority of the operational circuit. These blocks contain the components that will execute the main functionality of the circuit. Examples include the RFID scanner, the microcontroller, and the motor. The diagram is also labeled with voltages and currents, where the maximum voltage is 5 volts (V) so the power components previously mentioned will need to provide sufficient current at 5 V.

The intention behind the design was to provide a system that could get the user into their home within an amount of time that was comparable to the amount of time it would take to use traditional methods. Additionally, the system was not to encumber the user meaning they should not have to hold up the power transfer unit for an extended period of time. These design decisions imposed several requirements. In order for the user to not have to continue holding the power supply unit for an extended period, the power receiver unit would need to be able to maintain a voltage of 5 V for 20-30 seconds.

$$\Delta = 2 \cdot d + h \qquad \textbf{Equation 1.1}$$

The reasoning behind holding 5 V for 20-30 seconds can be seen above in Eq. 1.1. On average, the servo motor took about 3s to turn since the system both unlocks and locks the door, the amount of time for the servo to turn, *d*, must be doubled. Accounting for human factors like adjusting the card and giving the user enough time to close the door make up the "human factor" h.

The servo motor has the biggest power draw within the door management system, pulling 2 amperes (A) to 3 A of current at the peak power draw.

$$P = IV \qquad \textbf{Equation 1.2}$$

Acknowledging standard power draw, for the door to both open and close, the power subsystem must be able to transmit at least 30W of power to both open and close the door. Factoring in the microcontroller, Near-Field Communication, hereby NFC, reader, and antenna the power requirement is even higher. As seen in Fig. 1.1, the microcontroller and NFC reader both require 3.3 V and 25 milliamperes (mA) while operating, meaning the power system would need to generate an additional 82.5 milliwatts (mW) each for those components. All components for controlling the lock on the door are soldered onto the same PCB meaning that maximum power output must be inclusive of all door management components. Therefore, the power subsystem must be able to output ~30.3 W of power at peak conditions.

2 Design

2.1 Design Procedure

The power circuit is going to use induction coils to induce an electromotive force or emf from one coil to another. An induced emf requires the coil that is ‘sending’ power to have an alternating magnetic field which can be accomplished mainly by using an alternating current through that coil ‘sending’ the power. Therefore, the initial idea on how to create this circuit was to use an inverter, or an LC oscillator circuit. An inverter could be more precisely controlled, depending on the part you could select the rate at which the current flips, but these inverters also require power to operate and could be a strain on the power system. An LC oscillator circuit has a frequency based on the inductance value of the coil as well as the capacitance values of the capacitors used in the circuit which can still be controlled but is now much more dependent on the components used and the current inverting rate will switch on the use of new components in the circuit and can be highly variable. Figure 1.2 shows the final version of the LC oscillator circuit used in the project.

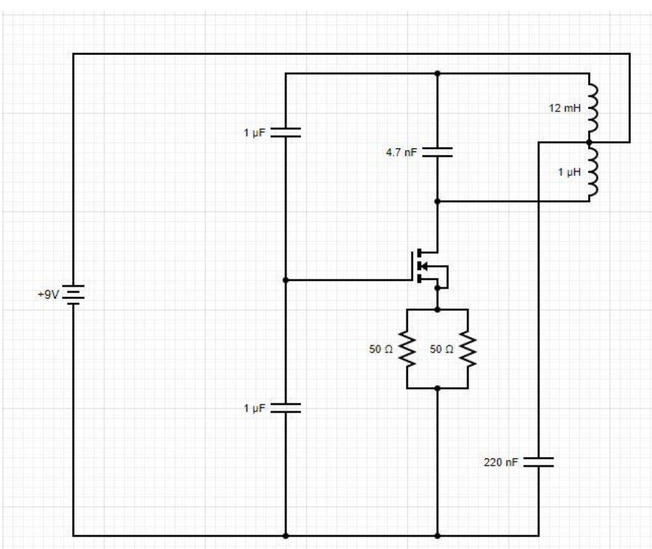

Figure 1.2 is an LC oscillator circuit that inverts the current in the 12 mH induction coil

This circuit is designed to induce an emf in a sister circuit which means a secondary circuit with another induction coil needs to be designed. This is shown in Figure 1.3 where the 12 mH induction coil in Figure 1.3 will be aligned with the same 12 millihenries (mH) induction coil in Figure 1.2. This alignment allows the changing magnetic field in the LC oscillator circuit to induce an emf in the receiver circuit. Since the magnetic field is changing, the induced emf in the receiver circuit is also oscillating. The 4 diodes turn that ac current into a dc current as an input to the voltage regulator which outputs a steady 5 V output at the point labeled Vout. This 5 V output is where the functional components of the product are connected.

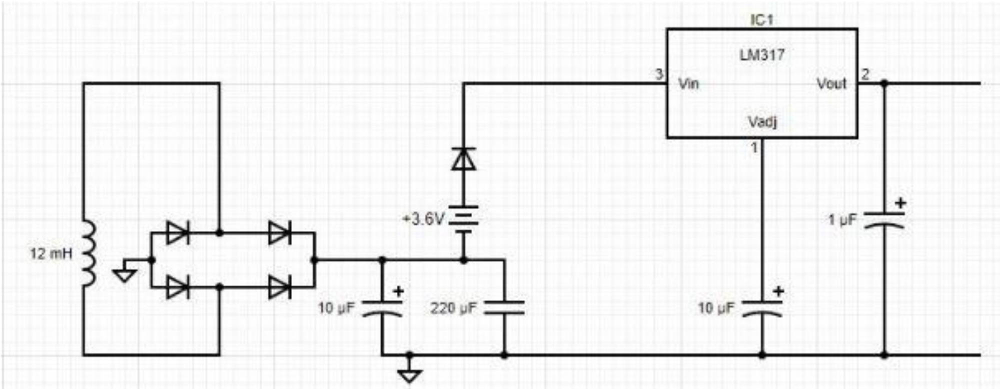

Figure 1.3 is the power receiver circuit that pairs with the LC oscillator circuit

The equation that describes the emf also known as the energy transfer from one coil to another is given below in Equation 1.1.

$\mathcal{E} = -N * (\Delta\phi \,/\, \Delta t)$ **Equation 1.3**

Where N is the number of turns in the receiver coil $\Delta\phi$ is the change in magnetic flux and Δt is the change in time. This equation says the emf depends on the number of coils and the change in flux over time. Equation 1.2 breaks down the change in flux into the B-field or external magnetic field and the area of the coil.

$\Delta\phi = B * A * cos(\theta)$ **Equation 1.4**

Where $\Delta\phi$ is the change in magnetic flux, B is the magnetic field in which the receiver coil is in, A is the area of the coil, and $cos(\theta)$ is the angle of the coil in respect to the direction of the external magnetic field lines. Again, this can be broken down by the magnetic field strength as shown below in Equation 1.3.

$$B = \mu * (N/l) * I$$ **Equation 1.5**

Where μ or mu naught is the permeability of free space, N is the number of turns in the power source coil, l is the inductance of the power source induction coil, and I is the current through that induction coil.

Receiving power from the power subsystem is the subsystem operating the door. The circuitry for this subsystem is comparatively simple as most of the complexity lies in the software. It consists of three major components. First, the servo motor is used to turn the deadbolt. The motor is controlled through standard Pulse Width Modulation, hereby PWM. Controlling the motor is a STM32F401RET6 microcontroller, chosen for a combination of plentiful RAM and flash memory, affordability, and strong vendor support. The microcontroller controls the motor by sending PWM waves through one of its General-Purpose Input-Output or GPIO pins. The last component of this subsystem is an ST25R95-VM5DT NFC reader chip which receives and decodes the signal sent by an NFC card. The chip communicates with the microcontroller over the Serial Peripheral Interface or SPI. Other NFC readers were considered such as the Melexis MLX90109, however, the ST chip stood out for its ability to communicate with both the SPI and Inter-Integrated Circuit (I2C) protocols which added flexibility to the design.

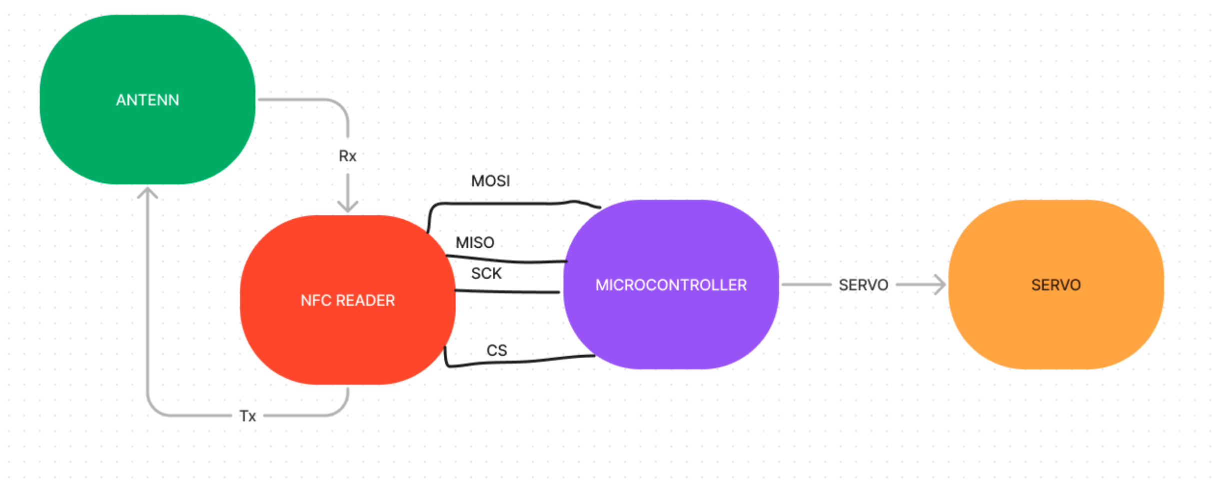

Figure 1.4 is a simplified schematic of the door management subsystem.

2.2 Design Details

Central in the circuit diagram of Figure 1.2 is an N-type MOSFET which acts as a switch. The top of the MOSFET is the drain, the bottom is the source, and the left side is the gate as depicted below in Figure 1.5. When the voltage difference between the gate and the source is large enough, the gate will act as a short between the drain and the source which allows current to flow through the MOSFET. An LC oscillator circuit utilizes this feature to direct the current to flow in one direction through the induction coil when the MOSFET is off and once the voltage between the gate and source is large enough the MOSFET turns on and redirects the current in the opposite direction through the coil. Depending on the values of the induction coil and capacitor used in conjunction with it, this creates a fast-oscillating current in the induction coil in the given power source circuit above the current is switched every ~50 nanoseconds.

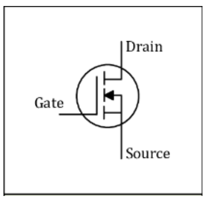

Figure 1.5 is a diagram of an N-type MOSFET similar to the MOSFET shown in Figure 1.2

The power transmitter circuit was designed to be small enough for a user to carry the product around as their “key” for the door unit, so the focus was on using only the necessary components for power on this component.

Adding in the two 50 ohms (Ω) resistors between the MOSFET source and the circuit ground allowed for a larger voltage to be built up across the parallel induction coil and 220 nanofarads (nF) capacitor. A higher voltage across the capacitor means more charge is stored in the capacitor and when that charge drains across the induction coils it does so at a higher rate which means more current is flowing through the induction coils which according to Equation 1.3 means a stronger magnetic field is created by this induction coil. One drawback to this is the fact that a higher current usually means increased heat which can quickly burn through components if they are not rated for that high of a current. This caused issues for the MOSFET and resistors since they were not rated for the current flowing through the induction coil. This burnt through some MOSFETs and resistors and created a physical limitation since resistors with higher power ratings are usually harder to find, larger, and more expensive. This ended up being a limiting factor for the power supply circuit.

The capacitors in the power receiver circuit also play a large role in the circuit's operation. They provide both negative and positive impacts. The first negative impact is that they need to be charged to achieve a voltage difference across the capacitor. The output of the full bridge rectifier would be a sinusoidal waveform reflective of the induced emf similar to the one shown in Figure 1.6 below and then rectified into the waveform shown in Figure 1.7 below. Figure 1.7 shows an |Sin(x)| wave but this wave still drops to 0 as it fluctuates. The two capacitors in parallel act like filtering systems where they will charge to the voltage peaks of each sin wave and when the voltage begins to drop, those capacitors will begin to discharge turning that |Sin(x)| wave into the one shown in Figure 1.8 which negates the voltage dropping down to 0.

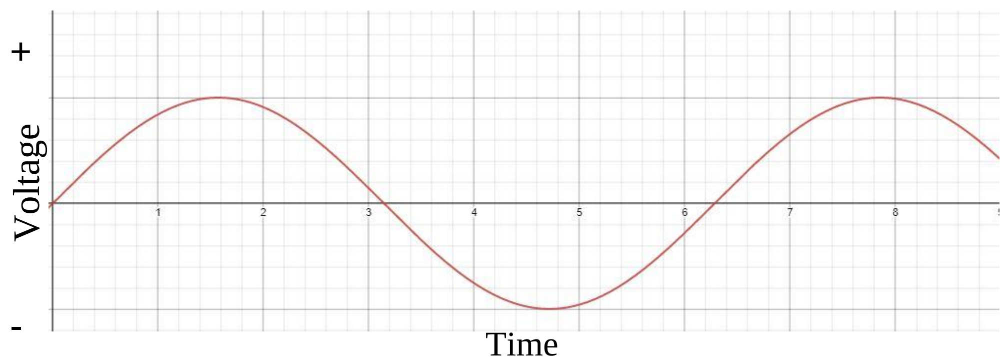

Figure 1.6 Is the AC emf in the induction coil induced by the power supply circuit

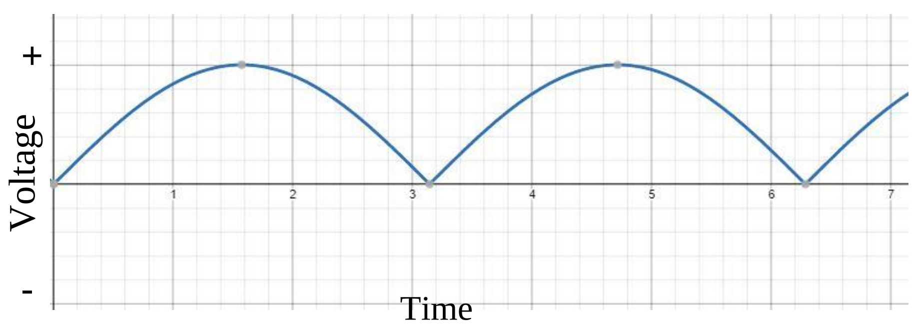

Figure 1.7 Is the rectified emf or voltage output of the full bridge rectifier

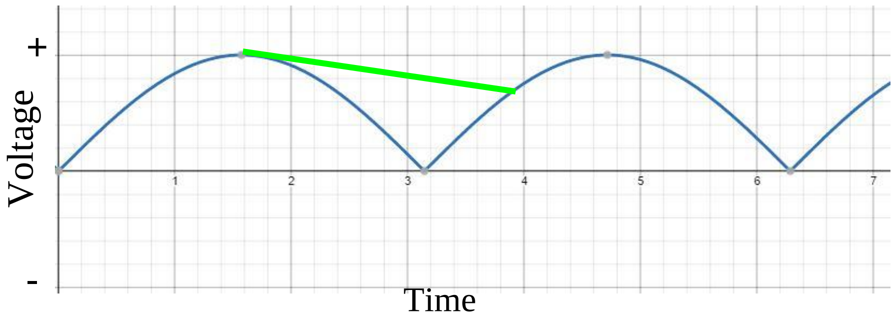

Figure 1.8 Shows P3 voltage with capacitor filtering implemented

3 Verification

3.1 Power System Verification

High-level requirements for this project included two based on the power supply and consumption for the circuit since induction power was a central aspect. These high-level requirements are reflected in the requirements and verification table found in Appendix A of this report.

The first test run on this circuit was to see how long it would take for the voltage regulator to output at 5 V to verify R&V number one. Since the power transfer is not instantaneous and there are capacitors implemented within the power receiver circuit there would be some delay as those capacitors charged up, the 1.7 V difference from the full bridge rectifier was reached and the regulator could output a solid 5 V. The testing procedure for this was as follows. With both the power source and power sink circuits set up as shown in Figures 1.2 and 1.3 a multimeter voltage probe was placed at the output of the voltage regulator in Figure 1.3 with a reference to ground. Since this circuit contains capacitors and capacitors have a discharge time, make sure the circuit is starting from an off state (capacitors are not charged at all) so shorting the positive end of a capacitor to ground for each capacitor allowed for them to discharge. The power source circuit was supplied by a 9 V battery supplying 0.132 A. The source is mentioned because increasing this voltage and current would get you different results due to the magnetic field being reliant on the current through the induction coil. However, the increased current would burn through parts of the circuit if not properly rated for that high of a current. Next, the switch on the battery casing would be turned on and a timer would be started simultaneously. Once the output of the voltage regulator showed 5 V on the multimeter, the timer was stopped. The results for the time taken to hit 5 V are shown in Table 1.1 in Appendix C.

Table 1.1 shows how long it took for the voltage regulator to output 5 V. The initial 2 trials are around 30 seconds which is relatively high for a person waiting to unlock their door. It would take 30 seconds for them to hold the power supply to the door, and then wait a few more seconds for the functional components of the circuit to register the RFID lock and then rotate the motor. Double checking the setup, the induction coils were not properly aligned which limits the power transfer. After realigning the circuit and resetting the test by discharging the capacitors the time trials continued and the resulting times took around 3.75 seconds to 7.5 seconds which is more user-friendly. However, 3.75 seconds is not instantaneous which puts this product at a disadvantage compared to other options on the market in terms of speed.

One of the high-level requirements was that the circuit would not require battery replacements since the power would be supplied via induction power when the power source is placed on the power receiver. This requirement was not achieved since the power receiver circuit only had an output of 1.7 V before a battery was added to boost the voltage and provide additional current since the transmission current was only about 0.1 A of the operational 0.4 A when everything else such as the RFID scanner, microprocessor, LEDs, and motor were on. To determine how many uses this battery would last in the circuit before needing to be replaced the average time to output 5 V as shown in the previous test is around 5 seconds. A user may hold the power source there for an additional 10 seconds while the circuit computes and operates. Drawing 0.3745 A for 15 seconds from this battery would give it a lifetime of 1,500 uses before needing to be replaced by the user which is not optimal but solves the problem in the current iteration of the design.

Solutions to remove this battery and cut down on charging time means inducing a higher emf. This means transferring more energy at the same or at a faster rate. From Equation 1.1 that means either a higher N or an increase in the rate of change of magnetic flux. Increasing N is the easiest way to increase the emf since that just means sourcing a coil with 4 or more times the turns of the current coil if all other aspects remain the same. Another option to increase the emf is the rate of change of the magnetic flux, which from Equation 1.2 can be done by increasing the area of the receiver coil or increasing the strength of the magnetic field it is in or even changing the angle. Changing the angle of the receiver coil with respect to the magnetic field is not a viable solution to explore since that would introduce rotational aspects here that would not fit with the design. Increasing the area would be possible and increase the emf at a rate that is the same as the ratio of the new area divided by the previous area. Finally, increasing the magnetic field strength is another option that relies on the current through the power source induction coil, the number of turns in that coil, and the inductance value of that coil as shown by Equation 1.5. Increasing the number of turns is an easy solution and again would need to be done by a factor of 4 or more. Increasing the number of turns is possible and a viable solution but a higher current rated MOSFET and resistors would be needed before exploring this idea to avoid burning out the components.

Next, tests to see how long the circuit would remain in an operational condition after the power source was removed were tested for R&V number two. Capacitors in the power receiver circuit have the negative aspect of needing to be charged so the voltage regulator takes more time to hit its operational voltage but has the positive aspect of storing that charge and discharging it as a current and keeping the circuit operational even after the power source is removed. This test setup is similar to the previous where the capacitors need to be discharged and then induction coils aligned. Connecting a digital multimeter voltage probe to the output of the voltage regulator and negative to ground allows measurement of the voltage output of the regulator. Since the functional components of the circuit need a power supply at 5 V from the output of the voltage regulator, testing how long the regulator outputs 5 V after the power supply is removed tells how long the circuit can function after the supply is removed. Assuming a user holds the power supply to the power receiver for 10 seconds after the voltage regulator outputs 5 V (operating voltage) this test is run as follows. Once the voltage probe reads 5 V at the output of the regulator, start a timer for 10 seconds. Once the 10 seconds is up, the power source is removed and a new timer measures how long it takes for the output voltage to drop below 5 V. Those times are shown in Table 1.2 in Appendix D.

The dropout voltage times rely mainly on the discharging times of the capacitors. Increasing the charge on the capacitors would increase how much time they have before fully discharging and then allow the regulator output to drop below 5 V.

3.2 RFID Verification

The core requirement for the RFID system was that it would be able to receive the NFC card's data, transmit it to the microcontroller, verify its presence in the microcontroller's flash memory, and unlock the door all within thirty seconds. This system was tested on development boards provided by the chip manufacturer but proved successful when wired on a breadboard. The system was able to receive, decode, transmit, lock, and unlock the door all within 20 seconds which was even faster than the expected minimum of only unlocking the door. This measured time also factors in software delays implemented to make sure the user had time to open and close the door before it locked itself again. Several trials were run each coming to the same result. The biggest slowdown for the entire system came as a result of the evaluation board for the NFC reader. The evaluation board contained a PCB etched antenna which at times failed to pick up the NFC card presented to it for up to 5 seconds. Tests were run with cards of several NFC sub-protocols, out of 100 attempts, roughly 10 attempts experienced delay creating a 90% success rate. Since the tests were done on the evaluation board and not the real system it is difficult to determine if similar results would be seen on an external design which is what the system is designed to use in the end. Usage of the vendor-provided Radio Frequency Abstraction Layer (RFAL) enabled consistent reading of the NFC card's data meaning at no point was there incorrect information being received by the microcontroller from the microcontroller. An issue that did present itself was a memory-indexing issue when adding, removing, or verifying a key in the flash memory. As cards were added to the flash memory over the testing period, memory started to display undefined behavior. For example, cards that had been added would not be found and the program would crash, or cards that had not yet been added would register as present and the door would unlock even though it should have remained locked. The issue compounded as testing progressed. It initially did not show up at all, and then ended up occurring roughly 60% of the time. To avoid this, several design changes could be made. Foremost, would be moving off of flash memory entirely and storing all keys in RAM as only 140 bytes of memory is required to store the maximum amount of ten keys with a length of 14 characters each when using the NFC ISODEP protocol.

$$KeyMemory = NumKeys * KeyLength * sizeof(char) \qquad \textbf{Equation 1.6}$$

However, to do this would require some sort of power to be consistently delivered to the microcontroller to ensure that ram is not deleted. Another potential solution would be to move off of using the onboard flash memory as that is harder to index given that certain regions must be reserved for program space and other microcontroller essentials. In any case, all of this would require further exploration, which is not the point of this report.

4 Costs

4.1 Labor

The overall cost for this project takes into account student labor, machine shop labor, and the cost of materials used. The estimated average salary for computer engineers after graduating from the University of Illinois is $105,352[1], in the hourly wage for a 40-hour work week comes to $50.65 per hour. Each member contributed about 8 hours a week, including TA meetings, group meetings, circuit design, integration, debugging, and documentation which totals approximately 80 hours of work for the production of this 10-week-long project. Eighty hours a student per $50.65 per hour turns into $12,156 total in wages per student. For all three students, this comes out to $36,468 in student labor for the project.

For the machine shop, they installed a motor around a deadbolt onto a miniature door large enough for demonstration purposes. The miniature door was already available at the machine shop but the cost to make it from scratch would take about 6 total hours, estimating a cost of $35 an hour for labor, making it out to be a total of $210 from the machine shop.
The daily work schedule is found in Table 1.4 in Appendix G.
The final parts list is shown in Table 1.3 in Appendix E and the total of the parts comes out to $55.85.

Total Cost = Machine Shop Labor + Parts + Student Labor **Equation 1.7**

$36,678 = 210 + $55.85 + (3students) ($12,156)

4.2 Parts and Commercial Viability

All of the parts in table 1.3 made it into our circuit excluding the ST25R3916-AQWT which was swapped for the VMD5T chip and the Crystal which was delayed in delivery. Prices for Integrated Circuits (ICs) on Mouser are nearly half when buying in quantities over 100. This means that if this product were to make it in large-scale production, chip costs would be half of the calculated price for all parts as shown in Appendix E. Logically following, to produce 1000 units per month would cost roughly ten thousand dollars (a rough estimate has been taken to account for the fact that large scale sales through distributors like Mouser are often eligible for discounts that are hidden to small scale buyers such as student projects).

5 Conclusion

5.1 Accomplishments

The power supply circuit itself was a large source of issues throughout the development of this project. Since the voltage between the gate and source of the MOSFET needs to be high enough to drain this means an increased current through the circuit in order to get this voltage at a high enough value to turn on the MOSFET at a quick enough speed without also burning out other components. Finding the sweet spot in terms of high enough current-rated resistors, the source circuits voltage, current, and testing different capacitance values here required a lot of testing since components had to be swapped out 1 by 1 and tested to see if it affected the switching speed, current draw, or if the MOSFET even turned on. In the end, this circuit was in working condition and acted as a proper LC oscillator circuit which was used to transmit power via induced emf to the power receiver circuit.

Outside of the power circuit, the rest of the system hinged on the functionality of the NFC reader. NFC proved to be a much more complicated protocol than anticipated. When first researching NFC components it was thought all that would be necessary was the transceiver and the proper wiring. It was through further research that there were no NFC readers that contained an integrated antenna so an external antenna along with a tuning circuit would need to be provided.[2] Outside of that, it was also determined that reading NFC data was not as simple as communicating over SPI. Through additional research, it was found that ST had developed abstraction layers [3] for the NFC reader which were then used to successfully read data from the NFC cards.

5.2 Uncertainty

The biggest uncertainty for the project was the PCBs. During breadboard testing of the power transmitter circuit, it was found that the wattage for most of the resistor components at ⅛ watts was not high enough for the circuit components' needs and would lead to burn out. When ordering parts, we realized that the higher the wattage rating for the components, the higher the price. In the future design for these circuits, there will need to be more research in designing a circuit that balances trade-offs between cost and power to prevent future burnouts while keeping costs low.

5.3 Ethical Considerations

The IEEE Code of Ethics states that the security and well-being of the user must be the foremost priority [4]. This project centers on home safety so it's important that the project only unlocks those who carry the appropriate RFID tag. Additionally, the mechanical aspect of this project centers around the motor. For safety, the motor needs to move at a pace where the user won't accidentally harm their person while using the product. Another concern is that the electrical components can be an electrical hazard to the user, however, to prevent this, the motor and wires connected to the motor will be reinforced with a rubber encasing to help increase protection for the user.

Another important element of the IEEE Code of Ethics that pertains to the project is to be truthful in the results based on technical data [4]. Recording all data points as accurately as possible has been key throughout the project to make accurate claims.

Lastly, the IEEE Code of Ethics emphasizes the need to treat others with respect with no room for discrimination of any kind [4]. During the entire process of the project, each team member made sure to communicate and engage with each other in healthy and productive ways, show professionalism towards each other, and respected each other's opinions and ideas.

5.4 Future work

For the power subsystem, as previously mentioned the end goal was to have a circuit powered without using any batteries, which was not achieved. Future work here would include inducing a higher emf in the receiver coil in order to get rid of this battery. This could be done in a few ways that were enumerated earlier as increasing coil turn counts for either or both coils, increasing the current flowing through the source coil, or increasing the area of both coils. Each of these has its own advantages and disadvantages that were discussed in 3.1 Power Systems Verification.

For the presentation of the product itself, it still needs to be encased in a rent-friendly casing that can be easily mounted to a door deadbolt. The version provided by the machine shop had almost completely replaced the inside portion of the deadbolt and made it unusable without an RFID key and also had screws to mount it into the door, which is something this product set out to avoid. This is a mechanical design aspect and was not the main focus of the electrical and computer engineers working on the circuit but is a consideration when making this product feasible for production and a viable market competitor.

Appendix A Requirement and Verification Table

R&V Table

Requirement	Verification
As shown in previous power requirement calculations, a power of .4745 W will be drawn by the system.	Figure 1.3 shows a full bridge rectifier, measuring voltage from the output diode to ground and current out of those diodes, the power supplied by the power transmitter across induction coils can be measured, and using equation P=IV the overall power delivered can be measured.
The output in Figure 1.3 labeled Vout is where the load (microcontroller, motor, LEDs…) will go. This must maintain a steady 5 V when powered on.	Placing voltage probes here across the 5 V output will allow verification of a steady or as close as possible to steady DC 5 V. Any steady voltage above 5V is also acceptable and can be dropped over a resistor to get the load to 5 V.
The motor has to be able to turn the deadbolt lock and overcome stall when starting from the stop or peak resistance of the deadbolt.	Verification of peak current and power delivery should satisfy the motor getting enough power. However, to be certain the motor should be hooked up in parallel with the rest of the system load such as the microcontroller and RFID tag scanner and be able to rotate the deadbolt lock when all other components are turned on.
The motor needs to turn at a safe slow speed in order to better protect human operators from any pinching that may occur during its operation.	Operating speed needs to be tested both when other components are turned on and turned off. They may not always be turned on when the motor is operating so verification of safe speeds needs to be confirmed in both scenarios. This should be done by controlling the motor using the motor's encoder which is then hooked up to a microcontroller.

Appendix B: PCB Diagrams

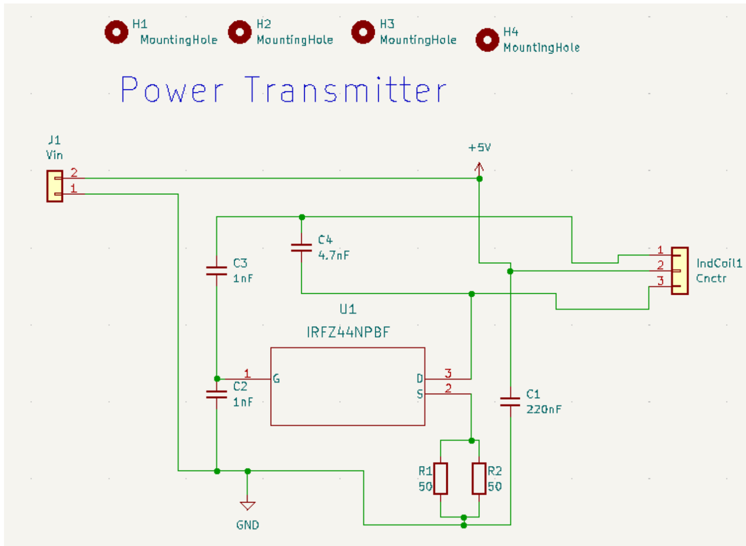

Figure 1.9 is a diagram of the final PCB schematic for the power transmitter circuit.

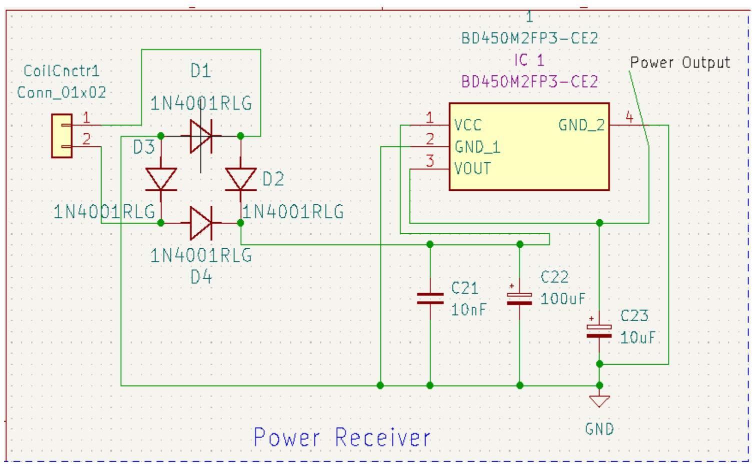

Figure 1.10 is the schematic for the power receiver circuit

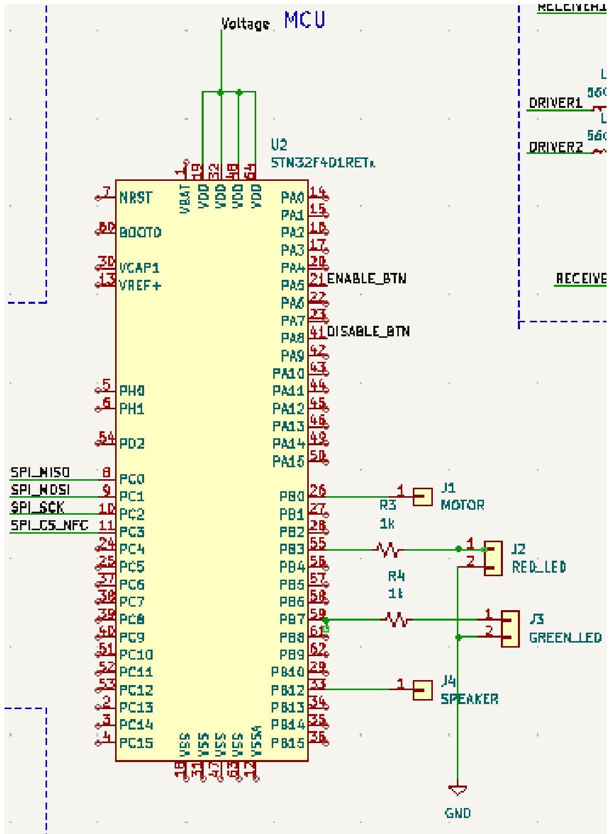

Figure 1.11 is the schematic where the pins used on the microcontroller are shown. The microcontroller used the RFID reader to process the signal and turn the motor when the RFID tag was identified.

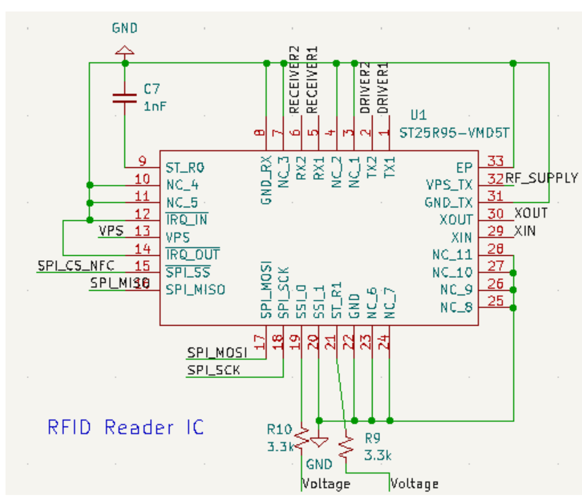

Figure 1.12 is the RFID Reader IC in the schematic

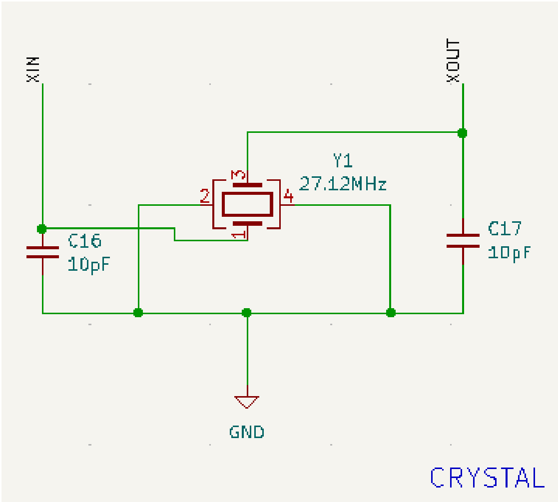

Figure 1.13 is the schematic for the crystal at 27.12Mhz for the RFID Reader IC

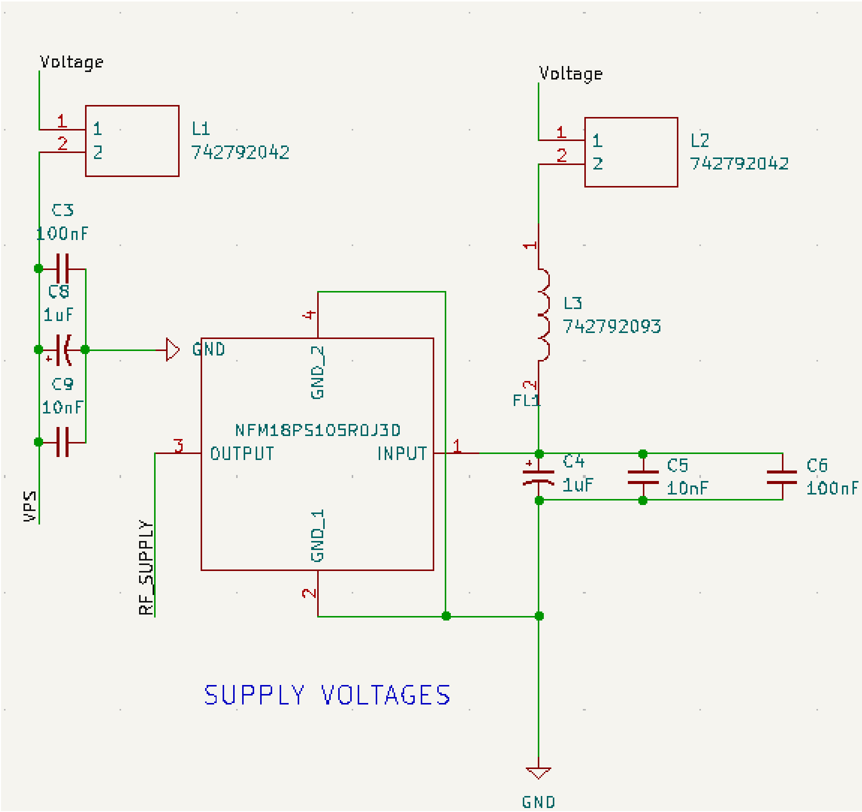

Figure 1.14 is the schematic for the supply voltages for the RFID Reader IC

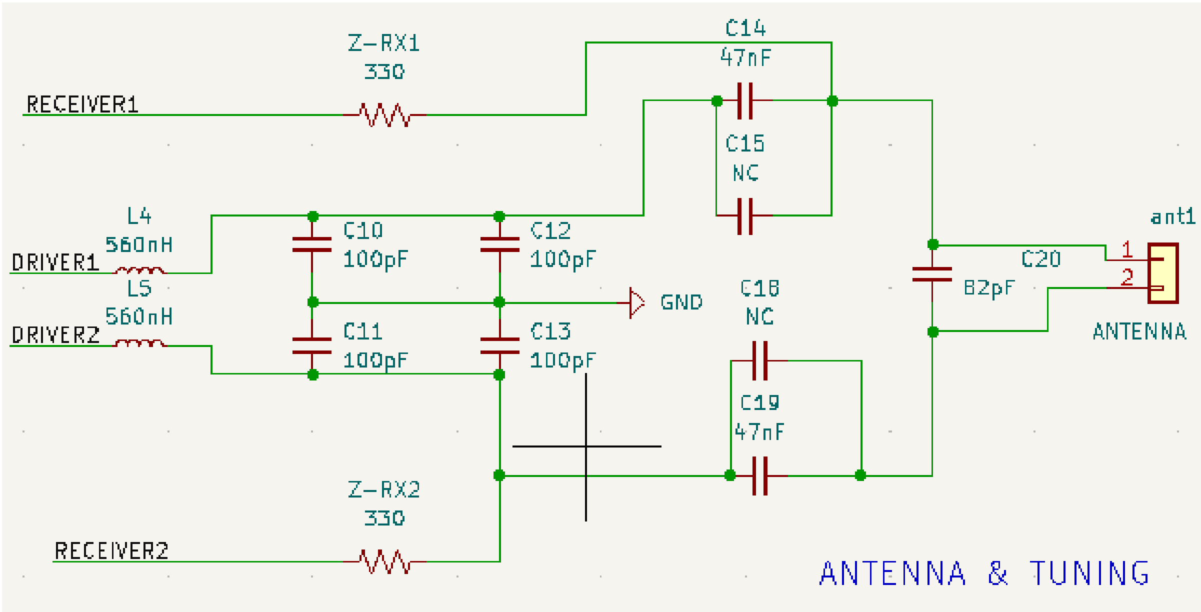

Figure 1.15 is the schematic for the Antenna and Tunning that the RFID Reader IC took signal readings.

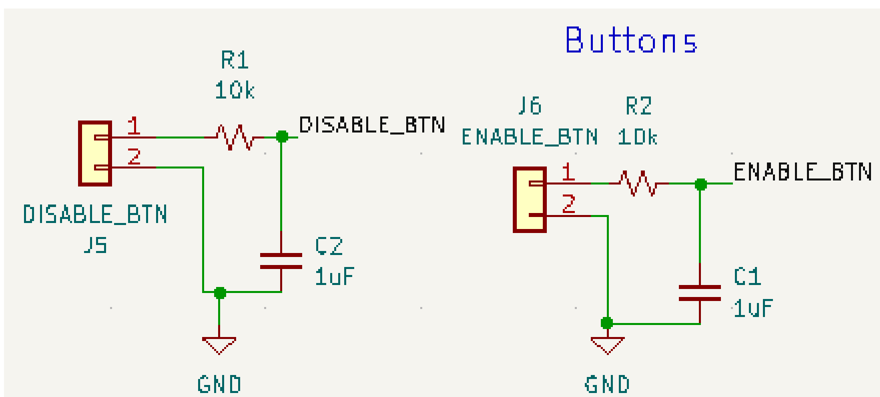

Figure 1.16 illustrates two buttons connected to the microcontroller that allow enabling and disabling of the device.

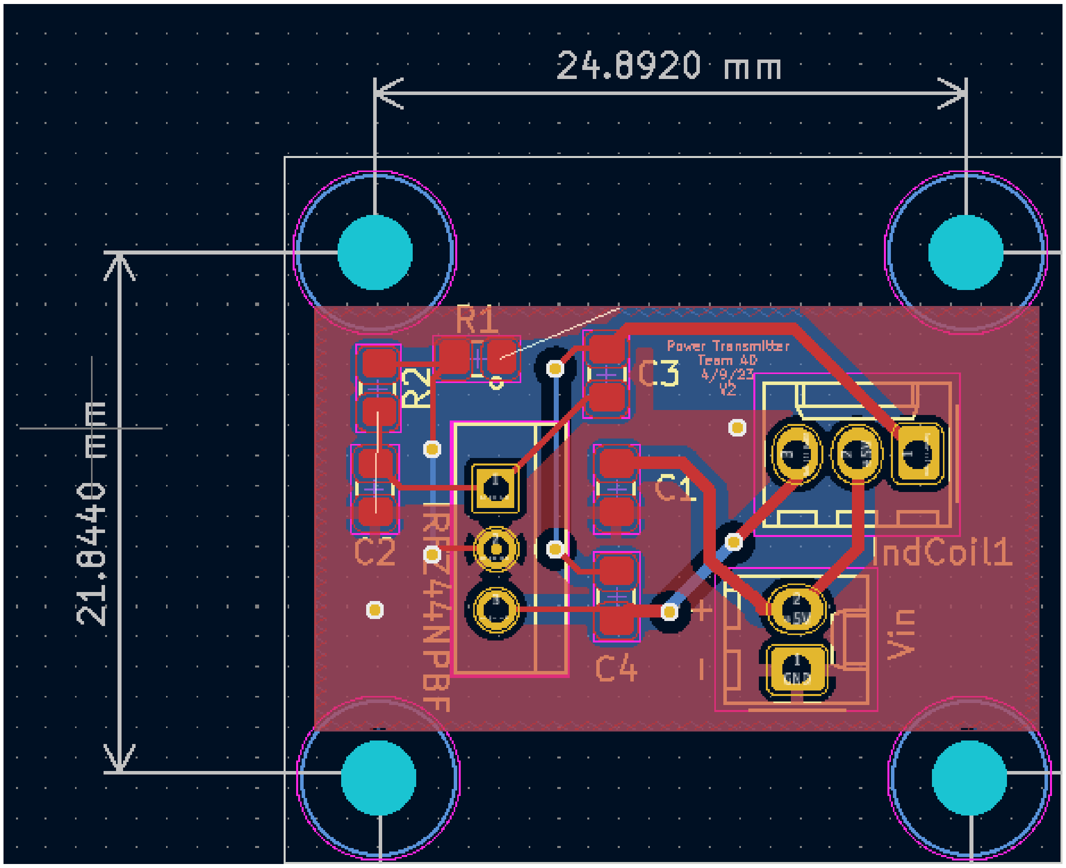

Figure 1.17 is the Kicad PCB design for the power transmitter circuit that the user would carry to unlock their doors.

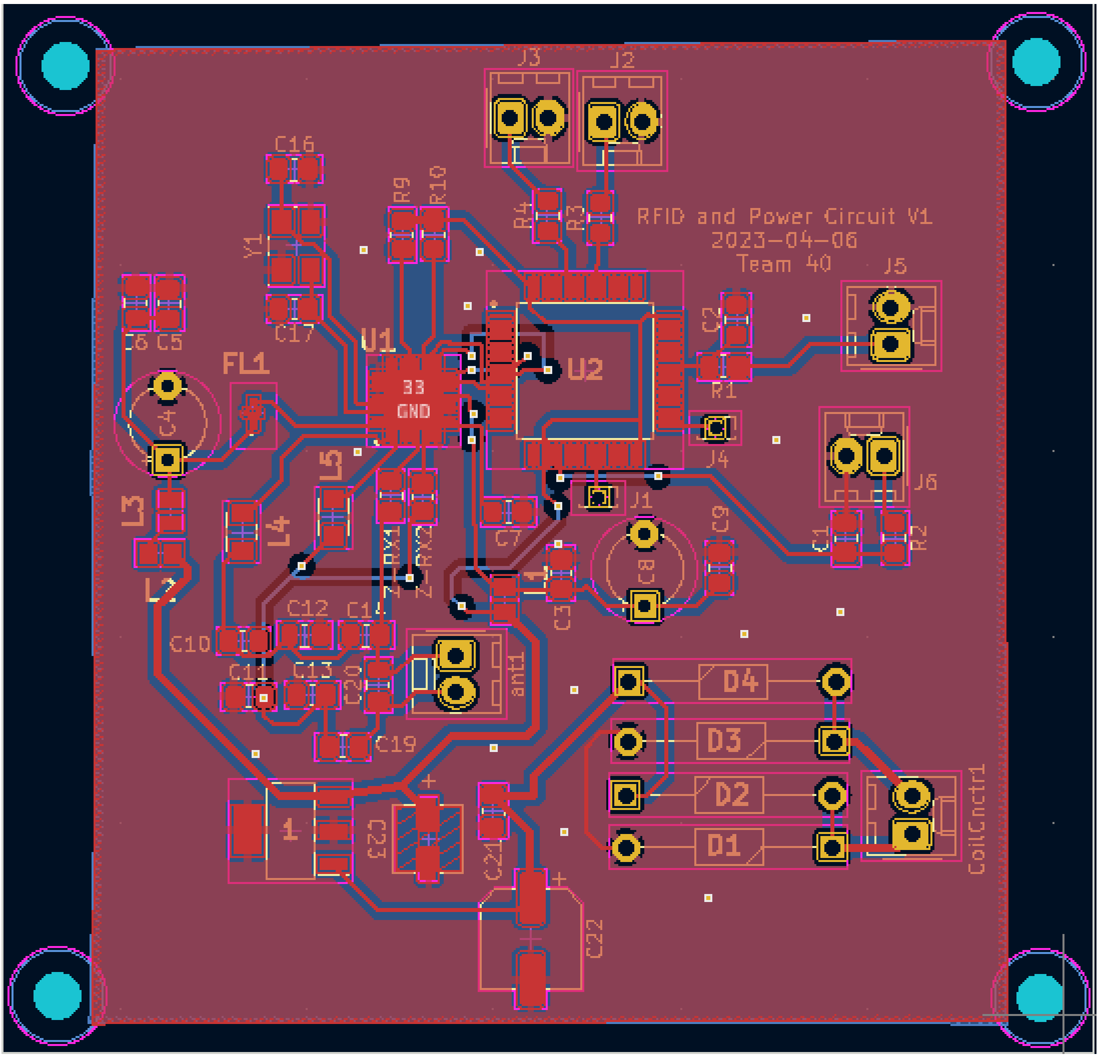

Figure 1.18 is the Kicad Design for the PCB with the power transmitter, microcontroller, and RFID reader that would be on the door unit.

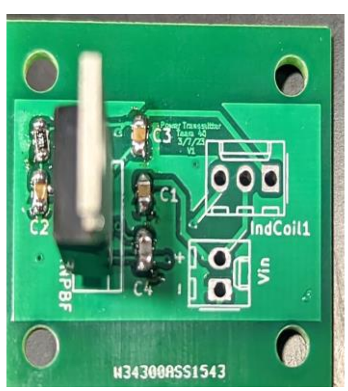

Figure 1.19 is the User PCB with the power transmitter circuit

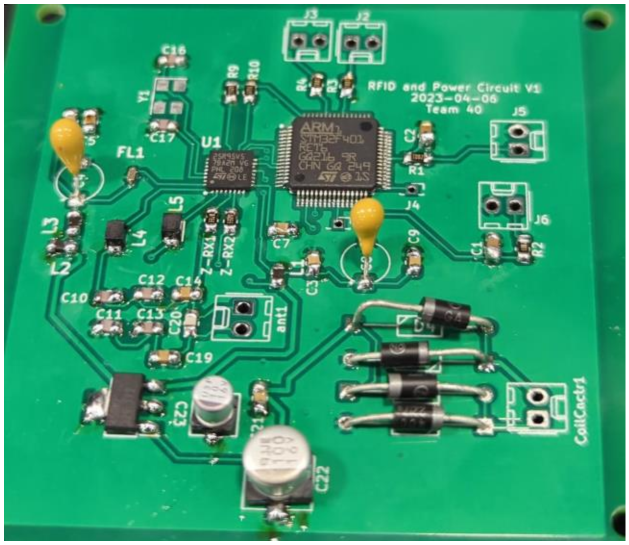

Figure 1.20 is the door unit PCB with the power receiver circuit as well as the microcontroller, RFID Reader IC, and other components.

Appendix C: Charging Data Table

Trial	Time to output 5 V (seconds)
1	29.75
2	31.68
3	7.55
4	4.17
5	6.86
6	4.9
7	5.83
8	4.36
9	3.96
10	3.75

Table 1.1 shows how long it took for the output of the voltage regulator to reach 5 V

Appendix D: Discharging Data Table

Trial	Time to dropout voltage (seconds)
1	32.6
2	33.21
3	34.23
4	34.31
5	34.49
6	34.29
7	34.49
8	35.22
9	34.63
10	34.87

Table 1.2 shows how long it took for the output of the voltage regulator to drop below 5 V

Appendix E: Parts Cost Table

Reading the following table as follows. The manufacturer part name is under the part column with a different part in each row. Under price, you can find the cost of one item of that part, the number of times that part is used in the circuit in parentheses, and then finally the total cost for purchasing single or multiple parts.

Part	**Price**
STM32F401RET6	$9.13 (2) (mouser) = $18.26
ST25R95-VMD5T	$4.07 (1) (mouser)
Molex 146236-0131	$4.60 (1) (mouser)
ST25R3916-AQWT	$7.64 (1) (mouser)
Lantronix 60050 (RFID tags)	$2.93 (3) (mouser) = $ 8.79
0.22 uF Capacitor (1276-1093-1-ND)	$0.10 (2) (digikey) =$0.20
1000pF Capacitor (478-1371-1-ND)	$0.10 (2) (digikey) =$0.20
1 uF Capacitor (1276-1066-1-ND)	$0.10 (3) (digikey) =$0.30
0.1uF Feed Through Capacitor (1276-1003-1-ND)	$0.10 (1) (digikey)
10000pF Capacitor (1276-1015-1-ND)	$0.10 (1) (digikey)
100pF Capacitor (1276-1261-1-ND)	$0.10(4) (digikey)=$0.40
0.047uF Capacitor (1276-1250-1-ND)	$0.10(2) (digikey)= $0.20
10pF Capacitor (1276-2561-1-ND)	$0.10(1) (digikey)
82pF Capacitor (478-1315-1-ND)	$0.13(1) (digikey)
Diodes (1N4001RLGOSCT-ND)	$0.30(4) (digikey)=$1.20
100uF Capacitor (P5182-ND)	$0.47(1) (digikey)
1uF Capacitor(478-1836-ND)	$0.82(1) (digikey)
1uF Capacitor (490-6974-1-ND)	$0.14(1) (digikey)
4700pF Capacitor (478-1332-1-ND)	$0.88(1) (digikey)

Ferrite Bead 600 Ohm (732-4642-1-ND)	$0.21(1) (digikey)
Ferrite Bead 2.2k Ohm(732-1609-1-ND)	$0.21(1) (digikey)
Inductor 560NH (445-16518-1-ND)	$0.24(2) (digikey)=$0.48
IC Linear Reg 5V (BD450M2FP3-CE2CT-ND)	$2.00(1) (digikey)
10k Resistor (1712-RA73F2A10KBTDCT-ND)	$1.46(2) (digikey)=$2.92
1k Resistor (1712-RA73F2A1K0BTDCT-ND)	$1.46(1) (digikey)
3.32k Resistor (1712-RA73F2A3K32BTDCT-ND)	$1.39(2) (digikey)=$2.78
332 Resistor (1712-RA73F2A332RBTDCT-ND)	$1.39(2) (digikey)=$2.78
5.11K Resistor (1712-RA73F2A5K11BTDCT-ND)	$1.39(1) (digikey)
27.12MHz Crystal (ECS-271.2-10-30B-CKM-TR)	$0.66(1) (digikey)
Total Parts Cost:	$55.85

Table 1.3 is the total parts list used in the PCB final design iteration

Appendix F: Abbreviations

Unit or Term	Symbol or Abbreviation
alternating current	ac
American wire gauge	AWG
ampere	A
ampere-hour	Ah
amplitude modulation	AM
angstrom	Å
antilogarithm	antilog
atomic mass unit (unified)	u
audio frequency	AF
automatic frequency control	AFC
automatic gain control	AGC
automatic volume control	AVC
average	avg
backward-wave oscillator	BWO
bar	bar
barn	b
beat-frequency oscillator	BFO
bel	B
billion electronvolts*	BeV
binary coded decimal	BCD
bit	b
British thermal unit	Btu
byte	B
calorie	cal
candela	cd
candela per square foot	cd/ft^2
candela per square meter	cd/m^2
cathode-ray oscilloscope	CRO
cathode-ray tube	CRT
centimeter	cm
centimeter-gram-second	CGS
circular mil	cmil
continuous wave	CW
coulomb	C
cubic centimeter	cm^3
cubic foot per minute	ft^3/min
cubic meter	m^3
cubic meter per second	m^3/s
curie	Ci
cycle per second	Hz
decibel	dB
decibel referred to one milliwatt	dBm
degree Celsius	°C
degree Fahrenheit	°F
degree Kelvin**	K
degree (plane angle)	...°
degree Rankine	°R
degree (temperature interval or difference)	deg
diameter	diam
direct current	dc
double sideband	DSB
dyne	dyn
electrocardiograph	EKG
electroencephalograph	EEG
electromagnetic compatibility	EMC
electromagnetic unit	EMU

*Deprecated: use gigaelectronvolt (GeV).
**Preferably called simply *kelvin*.

Unit or Term	Symbol or Abbreviation
electromotive force	EMF
electronvolt	eV
electrostatic unit	ESU
erg	erg
extra-high voltage	EHV
extremely high frequency	EHF
extremely low frequency	ELF
farad	F
field-effect transistor	FET
foot	ft
footlambert	FL
foot per minute	ft/min
foot per second	ft/s
foot-poundal	ft-pdl
foot pound-force	ft•lbf
frequency modulation	FM
frequency-shift keying	FSK
gallon	gal
gallon per minute	gal/min
gauss	G
gigacycle per second	Gc/s
gigaelectronvolt	GeV
gigahertz	GHz
gilbert	Gb
gram	g
henry	H
hertz	Hz
high frequency	HF
high voltage	HV
horsepower	hp
hour	h
inch	in
inch per second	in/s
inductance-capacitance	LC
infrared	IR
inside diameter	ID
intermediate frequency	IF
joule	J
joule per degree	J/deg
joule per kelvin	J/K
kilobit per second	kb/s
kilobyte	kB
kilocycle per second	kHz/s
kiloelectronvolt	keV
kilogauss	kG
kilogram	kg
kilogram-force	kgf
kilohertz	kHz
kilohm	kΩ
kilojoule	kJ
kilometer	km
kilometer per hour	km/h
kilovar	kvar
kilovolt	kV
kilovoltampere	kVA
kilowatt	kW

Unit or Term	Symbol or Abbreviation
kilowatthour	kWh
lambert	L
liter	l
liter per second	l/s
logarithm	log
logarithm, natural	ln
low frequency	LF
lumen	lm
lumen per square foot	lm/ft^2
lumen per square meter	lm/m^2
lumen per watt	lm/W
lumen-second	lm•s
lux	lx
magnetohydrodynamics	MHD
magnetomotive force	MMF
maxwell	Mx
medium frequency	MF
megacycle per second	MHz/s
megaelectronvolt	MeV
megahertz	MHz
megavolt	MV
megohm	MΩ
metal-oxide semiconductor	MOS
meter	m
microampere	μA
microfarad	μF
microgram	μg
microhenry	μH
micrometer	μm
micron†	μ
microsecond	μs
microsiemens	μS
microwatt	μW
mil	mil
mile per hour	mi/h
mile (statute)	mi
milliampere	mA
milligram	mg
millihenry	mH
milliliter	ml
millimeter	mm
millimeter of mercury, conventional	mmHg
millimicron‡	nm
millisecond	ms
millisiemens	mS
millivolt	mV
milliwatt	mW
minute (plane angle)	...'
minute (time)	min
nanoampere	nA
nanofarad	nF
nanometer	nm
nanosecond	ns
nanowatt	nW
nautical mile	nmi

†The name *micrometer* (μm) is preferred.
‡The name *nanometer* is preferred.

Unit or Term	Symbol or Abbreviation
neper	Np
newton	N
newton meter	N•m
newton per square meter	N/m^2
oersted	Oe
ohm	Ω
ounce (avoirdupois)	oz
outside diameter	OD
phase modulation	PM
picoampere	pA
picofarad	pF
picosecond	ps
picowatt	pW
pound	lb
poundal	pdl
pound-force	lbf
pound-force foot	lbf-ft
pound-force per square inch	lbf/in^2
pound per square inch§	psi
power factor	PF
private branch exchange	PBX
pulse-amplitude modulation	PAM
pulse code modulation	PCM
pulse count modulation	PCM
pulse duration modulation	PDM
pulse position modulation	PPM
pulse repetition frequency	PRF
pulse-repetition rate	PRR
pulse-time modulation	PTM
pulse-width modulation	PWM
radian	rad
radio frequency	RF
radio-frequency interference	RFI
resistance-capacitance	RC
resistance-inductance-capacitance	RLC
revolution per minute	r/min
revolution per second	r/s
roentgen	R
root-mean-square	rms
second (plane angle)	..."
second (time)	s
short wave	SW
siemens	S
signal-to-noise ratio	SNR
silicon controlled rectifier	SCR
single sideband	SSB
square foot	ft^2
square inch	in^2
square meter	m^2
square yard	yd^2
standing-wave ratio	SWR
steradian	sr
superhigh frequency	SHF
television	TV
television interference	TVI

§Although the use of the abbreviation psi is common, it is not recommended. See pound-force per square inch.

Unit or Term	Symbol or Abbreviation
tesla	T
thin-film transistor	TFT
transverse electric	TE
transverse electromagnetic	TEM
transverse magnetic	TM
traveling-wave tube	TWT
ultrahigh frequency	UHF
ultraviolet	UV
vacuum-tube voltmeter	VTVM
var	var
variable-frequency oscillator	VFO
very-high frequency	VHF
very-low frequency	VLF

Unit or Term	Symbol or Abbreviation
vestigial sideband	VSB
volt	V
voltage controlled oscillator	VCO
voltage standing-wave ratio	VSWR
voltampere	VA
volume unit	vu
watt	W
watthour	Wh
watt per steradian	W/sr
watt per steradian square meter	$W/(sr \bullet m^2)$
weber	Wb
yard	yd

Appendix G: Schedule

Week	Task	Person
1/30	Project Approval	Everyone
2/6	Proposal	Everyone
	Soldering	Individual-Everyone
2/20	Design Document	Everyone
	Team Contract	
2/27	Design Review	Everyone
3/6	First round of PCB Orders due (Tuesday)	Everyone
	Team Evaluation (Wednesday)	
	Last day for revisions to machine shop (Friday)	
	Build and troubleshoot power transmitter and receiver circuit	Everyone-Individual
3/13	Work on design of RFID, microcontroller and servo motor connections	Everyone
	Work microcontroller coding for controlling RFID and motor connections	
3/20	Assembly of components without PCB	Everyone
	Work on motor and microcontroller	
	Finalize design of circuit	Everyone

3/27	Second Round of PCBway Orders (Tuesday)	Everyone
	Individual Progress Reports (Wednesday)	Everyone-Individual
4/3	Soldering PCB components	Everyone
	Component and RFID Testing	Everyone
4/10	Team Contract Fulfillment (Friday)	Everyone-Individual
4/17	Mock Demo	Everyone
4/24	Final Demo	Everyone
5/1	Final Presentation	Everyone

Table 1.4 Shows the work schedule for the group when working on the project

References

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[3] *STM32duino ST25R95*, web page. Available at:
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[4] *IEEE*, IEEE Code of Ethics, Online. Available at:
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