Key Master

By

Amanda Beck

Petar Barac

Leslie Cheng

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TA: Jacob Bryan

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Abstract

The Key Master is as a key identification system ideal for users with too many keys on their key ring. Utilizing radio frequency identification (RFID), the system uses tags placed near a lock and the Key Master will read the tag. Each tag would be matched to a key on the key ring and light the LED of the corresponding key. The system also has the ability to write to RFID tags to add new keys to the system. The prototype device additional provided easy charging of internal battery to allow for everyday use.

Contents

1 Introduction

1.1 Objective

There are many doors that need to be opened, but trying to match keys to the correct doors and locks can be difficult. For the everyday use, an individual will learn which key is for what purpose through a combination of repetition and memorization, but there is still a limit to how many key/lock combinations one person can commit to memory. For individuals that carry a dozen plus keys, the task of finding the right key can be frustrating and time consuming. Professions that tend to carry key rings include landlords, maintenance workers, and groundskeepers, which may work on a number of properties that do not have upgraded features like electronic locks or even the ability to create master keys to serve many purposes. Individuals in this situation could benefit from a cost effective and time-saving product that identifies the correct key for them.

The Key Master will eliminate the need for guessing by identifying the corresponding key for a door. Instead of upgrading door locks, this system will work with any basic key and lock combination. RFID tags, each with distinct frequencies, can be discretely added near a lock, and each will match with one of the key holders on a key ring. The Key Master key ring will the let the user know the correct key by illuminating an embedded LED on the key holder.

1.2 Background

With large numbers of keys, efficiently identifying which key belongs to a lock can be difficult and defaults to trial and error. The more keys involved, the longer this process will take especially if multiple locks need to be accessed in short succession. Another problem that could delay entry is if the area has little lighting. Tags or markings matching doors with keys or the keys themselves might not be fully visible, so some error is possible in identifying the correct key by distinct features. Another option is replacing all the locks with matching ones that could use a master key to open. This involves a lot of additional cost that may not be feasible, as that upgrade will cost at least $15 per door and can add up for larger buildings.

Electronic locks is another option for making access easier because one keycard can be programmed to open all the locks, but this again would incur upgrade costs. Additionally, older buildings with physical locks would require additional installations to provide power for the new locks, not to mention the expense of electronic locks (over $1000 per lock for those in the ECEB[5]). These locks are most useful for high traffic locations with multiple restricted areas because key cards with individual access to areas is logistically simpler and safer than having keys given to and retrieved from many individuals.

1.3 High-level requirements list

- Reliably identifies the correct key for its corresponding RFID tag.
- Battery life lasts for up to 8 hours with at least 100 reads per day.
- New keys can be added to the system as needed.

2 Design

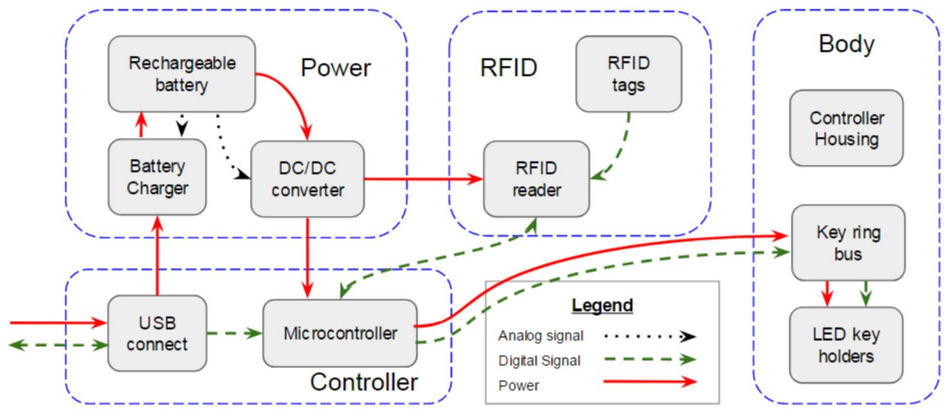

Figure 1: Block diagram of Key Master components

The Key Master consists of four main modules that will allow for proper operation: Controller, RFID, Power, and Body. The most important module is the RFID: by reading the RFID tags near the locks, a pulse will be transmitted to the keys given the correct frequency. The controller module stores the frequency information about a key/lock pair and relays the information to the other modules. The power module will provide consistent low power to all the modules but be able to handle the short bursts of power needs when the transmitter and receiver. Finally, the body module encompasses the design which connects the keys to the controls via a key ring bus.

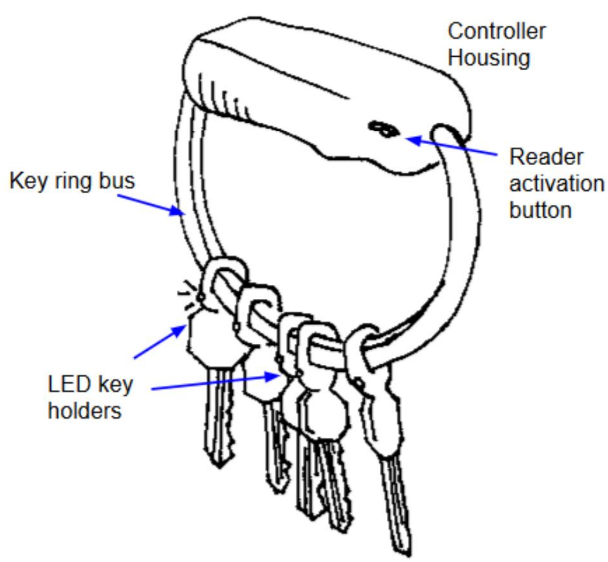

Figure 2: Sketch of the intended physical design of the system

Fig. 2 illustrates the design of the Key Master. At the top is the controller housing, which will actually hold the power, controller, and RFID and doubles as a hand grip. A button for activating the RFID reader will help allow the unit to last all day but meet the immediate demands of the user. The key ring will be attached to and loop around that housing. Ideally, the key ring will have an easy disconnect so keys can easily be added and removed if needed. Key holders fit snuggly on the key ring bus, and the bus will be protected by an outer insulated layer to protect the user. Each key holders will fit around the head of a key and house an LED for signaling the user. The look for the final product is found in Appendix A.5.

2.1 Controller

2.1.1 Microcontroller

An ATMega328P-PU was utilized as the microcontroller (MCU) due to available instructions and files to bootload it as a standalone component [2]. The bootloaded MCU is then compatible with Arduino code, making Arduino code for the RFID reader and 1-Wire ICs available as a resource. Compatibility with the RFID reader and controllers using other coding languages was not guaranteed because limited examples of code were available from the manufacturer, so the bootloaded ATmega328P-PU was chosen. A USB connection through a Sparkfun AVR Pocket Programmer was chosen as the interface to access the MCU if needed to alter the programming. The MCU interfaces with the RFID reader and 1-Wire ICs into the Key Master system and utilizes them as part of a state machine integrated into the MCU. No inputs are needed from the user other than enabling and disabling the system, and each state utilizes either the RFID reader or the 1-Wire ICs. Barring the power source, the MCU allows the Key Master system to operate with its intended function.

The bootloaded ATmega328P-PU for Arduino has 15 available digital I/O pins without the need for external components to operate besides a voltage source and ground. Two pins were needed for RFID reader, and the read and write functions were utilized from an example given by the manufacturer (Parallax, Inc.) [4].

The 1-Wire ICs can connect to a bus attached to one pin, so two pins were used: one for the key ring and one for a new key. Each bus was also connected to a 5V source with a pull-up resistor for reliability. The library needed to use the 1-Wire chip was located online [14].

Figure A.1 in the Appendix shows the state diagram for the Key Master system. User input is needed to either start or turn off the system after reaching an end state where LED(s) are enabled or possibly enabled in the case of a key searched for on the ring. Not shown for simplicity is a button press in any state outside of idle returns the system to idle.

When the system is powered on, the MCU attempts to identify if a key is present in the new key slot. If a key is present, the unique address of the 1-Wire IC in the key is written to an RFID tag within range. If no key is present, the MCU searches for an RFID tag within range. The address in the tag will be read and matched to the keys present on the ring, and the corresponding key will light. Failure LEDs will light if either no tags are detected during the process or key is not found on the ring. Appendix section A.2 shows the pseudocode of the system.

2.1.2 USB Interface

The USB interface is the main way of accessing the controller as well as charging the system. This allows a universal charging solution in line with most phone chargers or through a computer. The intended low power consumption of the system means the USB interface is adequate for our purposes since a standard USB port outputs up to 0.5 A at 5 V for USB 2.0[6].

2.2 Radio Frequency Identification

2.2.1 RFID Tags

The RFID tags are external to the system and are expected to function once the RFID reader is within range. The tags transmit at 125 kHz, and can contain up to 33 32-bit values. Each value is located at a certain index, each index can be rewritten multiple times, and specific indices can be chosen to be read or written to. Only two indices were utilized for the Key Master system because the unique 64-bit value from the 1-Wire IC was split to be written to the tag.

2.2.2 RFID Reader

The RFID Read/Write reader is used as the interface to access the RFID tags. It was manufactured by Parallax, Inc., and it was readily available as part of the course along with 125 kHz RFID tags. Because it has both read and write capabilities, it allows the system to be modular. It is compatible with Arduino code among others, and it has four pins: power, ground, input, and output. The manufacturer has provided example code in Arduino that contains read and write functions for usage with the reader [4].

2.3 Power

2.3.1 Rechargeable Battery

The source of the Key Master's power needed to allow the device to be portable, and therefore small. For most handheld devices, batteries from AAA to 9 V could fit the initial requirements, so some calculations were in order. Consumption was based on 100 reads over the course of an eight hour work day, given 30 seconds to complete each read. The two main elements that needed power were the RFID reader and MCU, each at approximately 5 V input and requiring 200 mA and 3.6 mA, respectively, when active[11][17]. Based on the active current needs, mAh could be estimated. For a more accurate idea of the power requirements, the active and down time for the unit must be calculated:
Active

$$100reads * 30\frac{sec}{read} * (200 + 3.6)mA * \frac{hour}{3600} = 169.7mAh \tag{1}$$

Idle:

$$(8 - \frac{5}{6})hrs * (20 + 1)mA = 150.5mAh \tag{2}$$

Our total estimate for the eight hour day with 100 reads gives a total of 320.2mA. Keeping this in mind, the considerations of size meant looking at AAA or 9 V batteries. With AAA, the voltage of each cell is 1.2 V, so multiple batteries would be needed to meet the voltage requirements[18]. The benefit of these cells is that they allow for upwards of 1000 mAh, which would easily cover the requirements. Physical sizing is a primary concern, so potential for numerous cells ultimately meant other options were pursued.

The other option, a 9 V cell, cleared the voltage requirement but had a variability of mAh limits depending on battery chemistry. The chemically more safe composition, NiMH (Nickle Metal Hydride) batteries were capable of producing up to 200 mAh. Given the needs of the reader and MCU, that would be cutting it close. Through testing, it was found that 30 seconds for each read was a high estimate, at least six times greater than experimentally time to complete a read. With this knowledge, it is possible that NiMH would have worked. Using a lithium ion battery chemistry has more safety concerns, but it provides more capacity at the same cell size, giving up to 600 mAh. The dimensions of one 9 V had a smaller volume than even two AAA, a 9 V lithium ion polymer battery was chosen.

One final note is that the battery needed to be rechargeable. The expectation is that the product will be used everyday and changing batteries is a hassle for the user. By using a rechargeable battery that can last for up to a year would make the Key Master more functional for the user. This ultimately influence the battery chemistry choice as well.

2.3.2 DC/DC Converter

The power requirement for each module determined the capacity of the battery but the correct voltage needed to be met for each module. Both the controller and RFID reader required 5 V, so the 9 V needed to be attached to a step down converter. A basic buck converter would be most efficient, but it was also important that the converter handled the batterys voltage range from full charged to near empty while maintaining the 5 V automatically[13]. Additionally, as a safety precaution, undervoltage protection was necessary so that the battery would not be drained below its minimum of 5.5 V[21]. Given a standard buck converter, the duty cycle at mid range charge is calculated by [13]

$$D = \frac{V_o}{V_i} = \frac{5}{8} = 0.625 \tag{3}$$

The main issue is ensuring minimum size of the circuit elements. Inductors are necessary for converter design but they tend to be the largest part of the circuit. To minimize the size, faster switching speeds are needed to shrink the inductor. Given a switching frequency of 32 kHz that can be taken from the MCU and that the continuous conduction mode needs to operate such that

$$I_o = \frac{V_i D(1-D)}{2Lf} \leq 300mA \tag{4}$$

Knowing that the current draw would be around 200 mA with a maximum of 300 mA, the inductor size would end up being around 1.16 mH, which has a physical size of about 0.5" x 0.5" x 1"[12]. Knowing this, an integrated circuit, or IC, solution made more sense in order to size down the components required for the converter. Additionally, there needed to be undervoltage protection to ensure that the circuit would cease drawing current when the battery dipped too low. Lithium ion batteries operate within a very specific voltage range and going outside of the range risks damage to the battery that can potentially cause it to explode[21]. To meet all these specification, the MAX738 5 V step down converter was selected. It has a much faster clock, upwards of 159 kHz to minimize the inductor size and undervoltage lockout built in. This meant the inductor was almost 30 times smaller than would have been built using the MCU clock. It also handles the amount of current needed during active times with a limit of 750 mA and stops operations when the input drops before 6 V.

2.3.3 USB Battery Charger

This part of the circuit has been the most involved only because the greatest care needed to be taken with protecting the battery. The incoming source is a USB connection, which has a 5 V output and a 500 mA max current[19]. The USB connection is part of the AVR programmer, which originally was to be used for passing code to the controller. The design no longer utilized the programmer for feeding code to the controller, but using the incoming power gives it a new primary use. To charge the 9 V, the incoming voltage needed to be stepped up. For this a boost converter was needed and lead to similar concerns as the step down converter in regards to the size of an inductor unless a faster clock was used. Furthermore, IC solutions provided built-in monitoring of voltage and current going into the battery. Overvoltage and overcurrent protection are crucial to make sure the battery does not go beyond its output limits. A suggested solution was the LM317HV, which is a regulator with overload protection[21]. Because the IC is based on a differential of the input and output, a step up voltage was required to be at least 3 V above the final output for the best results. Combining this with an IC boost converter to shrink the inductor size down to a minimum made the entire charging circuit fairly compact. Part of the benefit of the linear regulator was that it could be set up as a charger for any voltage based on a voltage divider between the output and the adjustment pin. The general equation for this was

$$V_{out} = 1.25(1 + \frac{240}{R}) + I_{adj}R \quad (5)$$

The adjustment current was around 50 μA and the resistance R was found to be 1.38 kΩ to get an output of 8.5 V[15]. This voltage represented the top side of the battery's voltage value. This was found more so via trial and error after a diode with low forward voltage was placed in series with the battery as a current direction control measure. To fully utilize the protections that the linear regulator offered, a differential between the input and output needed to be at least 3 V for consistent results. To meet this differential, a step up converter IC was set to output 12 V. The converters stepping up of the 5 V to 12 V also meant that a smaller current would be passed on from the USB connection, from 500 mA to about 120 mA. This is well below the maximum charging current for the battery of 550 mA, so concerns of overcurrent were eliminated. The total set up to connect both the converter and the charger to the battery required some additional diodes to help control the flow of power depending on what system was in use. Because the charger works with a USB input, it was assumed the Key Master would not be running or reading during charging, but it was also important to make sure the flow of current would not cause issues between the systems. The setup for the power module is shown in Fig. 8 of the Appendix.

2.4 Body

2.4.1 LED Key Holder

In order to associate a physical key to a RFID tag, each physical key needs to be attached to a key holder. The key holders are what allow the user to locate the right key. During the process of identifying the key, it is the key holder that actually gets searched for on the key ring bus. When the right key holder is found the LED on the holder blinks which lets the user know that key holder contains the corresponding physical key to that door. All the key holders lay on the key ring bus and new keys can be added to the bus.

Inside each key holder, there is one PCB which contains all the components. The key holders components consist of a LED, a 3V coin battery, a DS2413 chip, and a 1k Ω resistor. The DS2413 chip used is a 1-Wire addressable switch, which utilizes the 1-Wire communication protocol to switch on the LED that corresponds to the key being searched for on the key ring bus. The DS2413 chip was used in this design because of it provides many advantages and features over other methods of identifying specific keys. Each DS2413 has a globally unique 64-bit address, which means that no two chips share an address and therefore none of our key holders will be mapped to the same address. The 1-Wire protocol provides us a matching function. The matching function will take the address stored in the RFID tag that was read in by the RFID reader and search for that specific address, when that address has been found then only that specific device is told to blink.

The protocol of the 1-Wire consists of three major states for cases with multiple slaves connected to one master. In this design, the microcontroller is the master and each key holder is a slave device connected on the same data bus. The first state in the identification of the specific device is resetting all the devices, this brings all the slaves into the same state. From this state, the next state is the search state where the address of the specific device is passed down the data bus. All the slaves on the bus will receive this address but only the device that matches this specific address will be activated in the next state. The final state is where the master has isolated the specific slave device and begins issuing direct commands to the device. All other slaves on the bus are in an idle state. The isolated slave device is issued commands, in the Key Master design the device is told to switch on and off to blink the LED until the device is shut down by the user. After the command has been issued, the next state is the reset state which brings all the slaves out of idle and the one isolated device into a state where the next device is selected.

The inputs to the DS2413 chips are a data line and ground. These wires are connected by contact on the key ring bus. Initially, the LED was going to be powered parasitically through the data line but this proved to be too little to illuminate the LED in a well lit room. A 3 V coin battery was attached the the key holder PCB to provide more current and sufficiently illuminate the LED.

Another major aspect of our key holder design is the modular feature that allows for new keys to be added on the bus. Because each key holder contains a 64-bit address, whenever a new key is placed on the new key port that address is read into a RFID tag. This feature allows for many keys to be added to the key ring bus without external programming.

2.4.2 Key Ring Bus

The key ring bus is the data line and ground contacts that connect the microcontroller to the key holders. The bus was utilized for the 1-Wire protocol to send 64 bits serially at a speed of 15.4 kbps in three phases. The key ring also physically supports all the key holders and ensures contact is maintained with the key holders.

The key ring bus has two copper conductor plates that lay parallel to each other with a plastic rod separating them. One of the conductors is the data line which will contact the microcontroller to the wire lead that goes to the input of each DS2413 chip in the key holder housing. The other conductor serves a ground for the data line and the internal coin battery in the key holder. The key ring bus is able to support the weight of twenty key holders. The contact between the key ring bus and the key holder are copper brushes that are bent towards the key ring bus.

2.4.3 User Interface

The user interface consists of a switch, key holder LEDs, and three indicator LEDs: read failure, read success, and key search failure. The system is intended to run without any user input besides enabling and disabling power.

The switch on the system enables power to the system and allows the system to operate; and it also disables power once an end state, such as a failure to read, is reached. Disabling power at any time will return the system to idle, and enabling power will always start the system from the beginning.

The key holder LEDs are uniquely addressed keys due to the DS2413 ICs that will light after a successful key search cycle. Only one can be on at a time, and the one that is on will blink to indicate a found key.

The three indicator LEDs indicate the current state of the system: successful read, unsuccessful read, and key search failure. The successful read LED informs the user that the RFID tag was successfully read in the case of the search cycle, and it blinks for the new key cycle when the system has finished writing to the RFID tag. The unsuccessful read LED is enabled for either cycle if no RFID tag was successfully read. The key search failure LED indicates that the key associated with the RFID tag being read is not located on the bus.

3 Design Verification

3.1 Controller

3.1.1 Microcontroller Unit

The MCU must be able to output at least 64 bits through a single pin. This was tested using the RFID reader because each RFID tag can hold multiple lines of 32-bit values. A known 64-bit value was broken into two pieces to be written into two separate, specific lines. An RFID tag was read using an Arduino Uno prior to being written to confirm the current values using the console before testing, and then the MCU was used to write the values onto the tag. The Uno was used again to read the output and verify the values. The tags were successfully written no matter which lines or values were chosen, so this enabled the Key Master system to write the 1-Wire ICs' unique 64-bit address to the tags and read the values back.

The MCU was also required to run an entire Key Master cycle within two seconds of powering on. The key search cycles consistently ended within a quarter of a second if an RFID tag was in range, but the new key cycles were very inconsistent and unreliable because the time ranged from a few seconds to not writing at all after twenty seconds. The position and orientation, which also had to vary considerably, of the tag also determined the speed of the cycle as determined by the activity LED on the reader while writing to the tag. Although the code was functional, the reader was very unreliable for this specific task.

3.2 Radio Frequency Identification

3.2.1 RFID Tags

A lower bound for the maximum read distance was given as 3 inches for the RFID tags. This was tested by holding a tag 3 inches from the reader and verifying a read through the output in the console. Multiple tests were done, but a distance of 2 inches was determined to be more reliable and quicker to be read.

3.2.2 RFID Reader

The RFID reader used had a requirement of reading a tag within 2 seconds of powering on. An Arduino Uno had a simple read program loaded, and the output could be monitored on the computer. A tag was held next to the reader as the Arduino powered on, and the time it took for an output to be read was timed. Over multiple trials, the tags were read almost instantly with a time of less than a quarter second needed for the tag's content to be displayed.

3.3 Power

3.3.1 Rechargeable Battery

The battery has inherent characteristics like nominal voltage and amp-hours that are well understood and documented. For instance, the data sheet for the 9 V gives a range of the maximum voltage as 8.4 ± 0.3 V and minimum voltage of 5.5 V[18]. To confirm with these values will the current battery in use, tests were run to verify the output as was required for the system. For a starting point, the battery was fully charged using a separately purchased charging unit. When the unit showed the battery was full charged, the voltage was measured to be 8.39 V. This was used later for setting the top side of the charging circuit built into the Key Master. The main concern was if the battery would be able to run the 100 reads and work over an eight hour period. Starting with the fully charged battery, a series of reads was completed of no less than 100 reads over an hour time span. Prior to each sets of 10 reads, the voltage was measured to monitor the state of charge for the battery. Additionally, each set of 10 had a slightly different way in which the read was applied, either varying the tag and key holder to be identified or the position of the tag and reader. The data is shown in Table 1.

Table 1: Read Cycle Tests

Read Set	Failures	Voltage [V]	Tag	Tag position
0	0	8.3	1	Next to reader
10	0	8.298	2	Next to reader
20	0	8.2847	3	Next to reader
30	1	8.288	3	Inch away from reader, in one spot
40	2	8.28	2	Inch away from reader, in one spot
50	3	8.2567	1	Inch away from reader, in one spot
60	0	8.2625	1	At least 2 inches away, hovering
70	0	8.259	3	At least 2 inches away, hovering
80	1	8.2456	2	At least 2 inches away, hovering
90	0	8.2507	1	At least two inches below, through plate, hovering
100	1	8.2485	3	At least two inches below, through plate, hovering

At bare minimum, this shows the battery can easily handle standard read times. On average, the system was turned on for 5 seconds rather than the 30 assumed. This is partially because the key holder circuits were no longer pulling power from the lithium battery but instead were powered by coin batteries in each key holder. Given that the blinking LED would have drawn about as much power as the other units in standby mode, the affects of waiting longer were negligible. It was also found that the draw currents were less than the original assumptions. By monitoring the current draw over a number of read cycles, the average maximum and minimum voltages are recorded in Table 2.

Table 2: Average Current Draw

I_{Max} [mA]	I_{Min} [mA]
128.4	18.39

The Key Master was never fully discharged or run for a full eight hours. Instead, the data informs the total power consumption to help in estimate the eight hour usage. These current values, representing active mode for the maximum current and standby mode for the minimum current, are less than the estimations from equations 1 and 2. This means that, even with the original approximation, the battery has double the required capacity and the lower current draw would mean even less capacity is needed for a full day.

Since the Key Master did not require the entire battery capacity, the battery was never full discharged in our system. To determine the lower voltage threshold, a simple resistive circuit was run overnight, only to find that the battery stopped working at a point and had no appreciable voltage across its terminals after that. Putting it on the charge, it would quickly show voltage again across the terminals, but because it had to be placed on the terminals to read the values meant minimum voltage was never verified as 5.5 V. The minimum voltage observed over the testing time was above 7 V, well above the value listed on the data sheet.

The final verification was that the battery never go above 35°C. Over all testing periods, a simple touch test was utilized to check if the battery every heated up beyond room temperature of approximately 23°. That was never the case, so further verification was not needed.

3.3.2 DC/DC Converter

The selection of an IC solution for both handling the undervoltage protection and to act as an efficient converter meant that, in theory, all the specs should have been met. Informal tests were run for the MAX738 when it was first attached to the board to verify that 5 V output was give over a range of input voltages, as well as shut off when voltage was less than 5.5 V. The plan had been to test the full functionality when the entire circuit was hooked up so the current draw of the RFID reader and MCU could be monitored at the same time. Unfortunately, a reversal of the battery polarity on a test run hook up to the PCB seemed to have damaged the MAX738. After the erroneous connection the converter was still capability of producing 5 V over the same range of voltage, between 9 and 6 V, but could no longer provide the max current promised. Instead, the maximum draw when it was hooked up with the RFID reader was 40 mA, far too low to actually run a read cycle.

Due to this issue, a stand-in converter was constructed to meet the minimum requirements of the verifications. This consisted of two linear regulators in parallel, the LM78L05, to drop the voltage to 5 V while also providing enough current to meet the maximum values. Since each regulator had a nominal current of 70 mA allotted in the 5 V ± 5%, it could host a peak current of 140 mA[23]. With the two in parallel, this would meet the current requirements and did. It was tested for 200 mA and is currently used in the final product, only requiring two capacitors each to complete the converter circuit. The schematic for a single linear regulator is shown in Fig. 3.

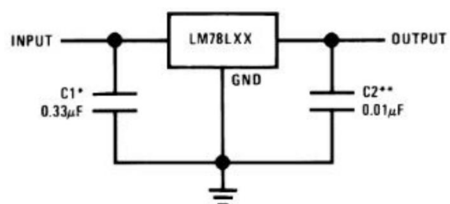

Figure 3: Fixed Output Linear Regulator LM78L05

3.3.3 USB Battery Charger

This circuit put together two IC components that had built in current and voltage monitoring systems, as well as thermal shutoffs. This simplified the verification as the components just needed to run to their individual specifications. The first verification was that the current limit not go above the battery's charging capacity of 550 mA. This was satisfied by the simple fact that the USB connection provided only 500 mA of current.

The second requirement was that the voltage never go above 8.5 V and only begin recharging again if a 5% drop in voltage occurred due to self-discharging of the battery. To determine the behavior when the battery was near its full charge, a battery was placed in the charger starting at about 7.5 V. It was then observed over five hours, as is seen in Fig. 4.

As can be seen in the plot, the voltage levels off significantly when it reaches approximately 8.3 V. This means that the current is tapering off as well, although the current was never measured directly to compare. It can be estimated that the voltage would continue to rise slowly for several more hours before it hits the maximum of 8.5. Considering that the time scale of the plot is over a 5 hour period, this suggests that, given a partially discharged starting battery, it would easily charge overnight in a 12 hour period. It also suggests that most of the time would be spent in the slow charging period. This would seem to verify that, at minimum, the maximum voltage would not be easily reached. Additionally, the design of the linear regulator

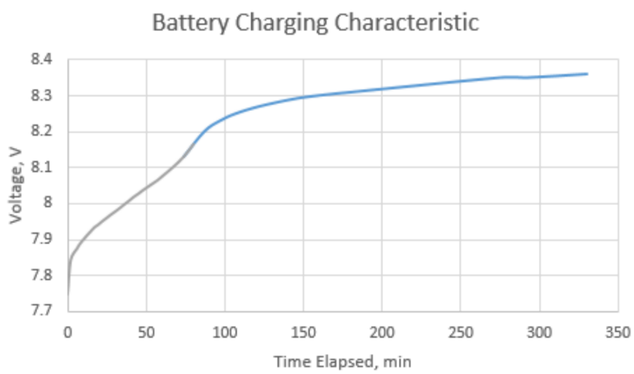

Figure 4: Charge Characteristics

allowed for setting the top end of the voltage output that would go to the battery. Since it was set to 8.51 V with a diode that has low turn on voltage, almost the entire voltage would be applied to battery but puts it right at the maximum before the regulator would shut off. So, although this wasn't tested in full by waiting eight or more hours for a full charge cycle, the specifications and set up the regulator should accommodate the requirement.

3.4 Body

3.4.1 Key Holder

The contact between the key holder and key ring bus was unable to maintain itself without assistance. The leads of the key holder needed to be manually pressed onto the key ring bus to transmit the data to the key holder.

All three key holder circuits worked on the bus. The address of a key holder was able to be read into a tag than then be identified by the very same tag. Multiple key holders were placed on the bus and all of them were able to be identified by the corresponding tag every time the contacts were secured to the key ring bus.

3.4.2 User Interface

All indicator LEDs operated successfully under controlled conditions, such as no tags within several feet of the system to force a read failure. The timed read failure was also timed to be close to ten seconds.

The new key slot functioned as intended when a key was inserted. The key was recognized through a pin separate from the bus, and the system reliably read the key's unique address.

4 Cost

4.1 Parts

Table 3: Parts and Costs

Part	Manufacturer	Vendor	Quantity	Cost (per unit)	Cost (bulk)	Cost (total)
Pocket AVR Programmer	Sparkfun	Sparkfun	1	$14.95	$14.95	$14.95
9V Rechargeable Li-Ion Battery R-LI9600	Batterymart	Battery-mart	1	$11.95	$10.95	$11.95
ATMEGA328P-PU Microcontroller	Microchip Technology	Mouser	1	$2.14	$1.71	$2.14
RFID Read/Write Module	Parallax, Inc.	Parallax, Inc.	1	$49.95	$49.95	$49.95
Yellow LED 1000mcd	Kingbright	Digi-Key	10	$0.546	$0.21	$5.46
MAX738ACWE+-ND DC/DC Converter	Maxim Integrated	Digi-Key	1	$4.32	$3.70	$4.32
LM317HVH/NOPB Battery Charger IC	Texas Instruments	Digi-Key	1	$13.26	$8.39	$8.39
125 kHz RFID Tag	Parallax, Inc.	Mouser	10	$2.80	$2.80	$28.00
Toggle Switch	Carling Technologies	Digi-Key	1	$4.79	$3.021	$4.79
9V Battery Holder	Keystone Electronics	Mouser	1	$1.94	$1.15	$1.94
9V Lead Connector	Memory Protection Devices	Digi-Key	1	$0.66	$0.3774	$0.66
DS2413P+ 1-Wire Dual Channel Addressable Switch	Maxim Integrated	Digi-Key	10	$2.38	$1.25	$23.80
1 μF Tantalum Capacitor	KEMET	Digi-Key	1	$0.26	$0.06339	$0.26
22 μF Tantalum Capacitor	AVX Corporation	Digi-Key	1	$0.36	$0.0957	$0.36
47 μF Tantalum Capacitor	AVX Corporation	Digi-Key	1	$1.61	$0.8448	$1.61
68 μF Tantalum Capacitor	Vishay Sprague	Digi-Key	1	$0.85	$0.41828	$0.85
100 μF Tantalum Capacitor	Vishay Sprague	Digi-Key	1	$0.69	$0.3208	$0.69

Continued on next page

Table 3 – continued from previous page

Part	**Manufacturer**	**Vendor**	**Quantity**	**Cost (per unit)**	**Cost (bulk)**	**Cost (total)**
33 μH Inductor	Sumida America Components Inc.	Digi-Key	1	\$0.98	\$0.588	\$0.98
100 μH Inductor	Sumida	Mouser	1	\$0.67	\$0.234	\$0.67
MBRS130T3G Schottky Diode	ON Semiconductor	Digi-Key	1	\$0.46	\$0.11473	\$0.46
N5817-T Schottky Diode	Diodes Incorporated	Digi-Key	1	\$0.41	\$0.10197	\$0.41
2N4403TF PNP Transistor	Fairchiold/ON Semiconductor	Digi-Key	1	\$0.21	\$0.04137	\$0.21
2N2222A NPN Transistor	Central Semiconductor Corp	Digi-Key	1	\$2.23	\$0.9828	\$ 2.23
Total						\$165.08

4.2 Labor

Labor will account for the largest chunk of expenses in completing this project. Given an above average salary for UIUC graduates of approximately \$72,000 plus benefits of \$6,000, we can estimate an hourly rate of

$$\frac{78{,}000}{40 \text{ hours per week}} \times \text{ 52 weeks} \quad = \$37.50$$

Work on this project is expected to be about 10 hours a week per person for 16 weeks to complete the prototype with additional expenses for equipment and workspace cost at 2.5 of the total.

$$3 \times \$\ 37.50 \times 10\frac{\text{hr}}{week} \times 16\text{weeks} \times 2.5 \quad = \$45{,}000$$

Additional costs for housing is estimated at \$50 with machining labor of 20 hours of labor at \$25/hour and 5 hours of machining at \$50/hour. Machine shop costs total at \$800. Including all parts, labor, and etc. costs is a grand total of \$45,953.94.

5 Conclusion

5.1 Accomplishments

The Key Master system fulfills its functional requirements of being a modular system that can add and identify keys via RFID. The final product can be seen in the Appendix, with Fig. 11 showing the final casing, Fig. 12 and 13 showing the main components as original intended, and Fig. 14 showing the in and out of the key holders. Despite the usage of bulky parts and hand assembly, the device was semi-portable and could be carried using one hand. The system was also very reliable in identifying keys from a given tag assuming good contact with the bus, and the system functions well with multiple keys on the bus. Battery life was more than adequate because the system used less current than anticipated, identifies a key within two seconds, and a battery was not able to be drained during constant testing over the course of days. Recharging over USB also functioned well, and it recharged fast enough that leaving it overnight would fully charge the system.

5.2 Uncertainties

The modularity of the system is functional, but the RFID reader has issues reliably writing to an RFID tag. There have been many occasions during testing where a tag could not be written to very quickly or at all unless it was oriented in various positions. The size of the RFID reader is also an issue because it set a hard lower bound of the size of system, so a more compact reader would be needed for future work. The ability to either find a better replacement or build one requires more research than was originally part of the design process.

5.3 Ethical considerations

Due to the usage of code written by others, they will be properly credited as providing the functions used in the system according to the ACM code of ethics [1]. The RFID module read/write functions were retrieved from the manufacturer's website [4]. The 1-Wire functions were from a modified library provided online at PJRC [14].

The system's physical bus should also be redesigned to minimize the chance of harm for the user and others because of the exposed contacts. Although no accidents have occurred when both contacts were held while the system was active, it still remains an issue.

5.4 Future work

There are many ways in which this project still needs to improve to be a viable product. To increase the system's writing reliability, a new RFID reader likely is necessary. A RFID reader was a contributing factor on the size of the system as we were using provided parts on loan from the Senior Design lab. By researching into custom building an RFID reader/writer could be optimized to better fit into a new design. The main PCB, containing the power converters and microcontroller, can also be optimized for a smaller footprint in the future. Moving the components of the recharging circuit out of the housing and instead into a plug and cord combination is another option for shrinking size. The key holder PCBs also present an opportunity for downsizing. Replacing the individual batteries in each key holder used to power the LEDs would also save on space.

The main housing needs optimization to minimize the dimensions so it would ideally fit within the palm of someone's hand or as small as possible once the components have been redesigned. The connection between the bus and key holders also need to be redesigned because the current design provides unreliable contact.

A revision involving increased pressure, such as a spring clip, could possibly make reliable contact. This revision would also need to have a third contact on the bus for a 5V power source to power the LEDs in the key holders, and the contacts should be hidden to minimize the chance of a short circuit between the 5V and ground contacts.

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Appendix A Requirement and Verification Table

Table 4: System Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
Microcontroller: 1. Be able to receive and output at least 64 bits through one pin. 2. Must be able to run entire Key Master Cycle in less than two seconds.	Microcontroller: 1. Perform consecutive writes of known values to an RFID tag using the reader (reader has one input pin). Confirm the written values are as expected. 2. Power on the Key Master system while timing at the same time. Stop timing once a cycle has been completed.	1. Y 2. Y
RFID Tags: 1. Tags must be able to be read when the reader tag is placed directly above it and at most be able to read the tag from 3 inches away.	1. Read and write a value to a certain index in a tag after clearing it. Enable a write and read to the index while holding the tag 3 inches away from the reader and confirm write to the tag in the console output.	1. Y
RFID Reader: 1. The reader must be able to read data from a tag within 2 seconds of being turned on.	1. Have an Arduino perform a read of a tag and output the contents to the console while recording the time between powering on and the first output.	1. Y
Rechargeable Battery: 1. Must provide a minimum of 300mAh over an eight hour period with a minimum of 5.5 V as final discharge voltage and no more than 300mA drawn during the operations. 2. Must stay below 35°.	1. Measure starting voltage of charged battery. Run 100 read operations, monitoring voltage and max/min current during each cycle and determine entire time duration. Extrapolate for 8 hours of operation. 2. During each run above, also record the peak temperature over the hour.	1. Y 2. Y
		Continued on next page

Table 4 – continued from previous page

Requirement	Verification	Verification status (Y or N)
DC/DC Converter: 1. Must maintain 5 V +/- 5% over a current draw range of 0 mA to 200 mA for each output. 2. Must shut off when supply voltage drops to 5.5 V.	1. Test output at different battery starting voltages (i.e., 20%, 50%, 90% charge). Monitor output current and voltage over 100 read cycles. 2. Given battery at 10% or less charge, run read cycles until battery hits lowest voltage. Verify battery voltage and confirm converter output at zero for voltage less than 5.5 V.	1. Y 2. Y
USB Battery Charger: 1. Must pull no more than 1C charging current, or 500 mA, into the battery. 2. Must cut off current when battery reaches maximum charge voltage of 8.5 V and start feeding current after a 5% drop in voltage.	1. Discharge the battery to below 8 V and measure starting voltage. Hook up to charger and monitor voltage and current over the charging cycle, keeping track of time elapsed with each reading. 2. Continue from above, continue charging until max voltage of 8.39 V for battery is met. Leave on charger and monitor current and voltage to verify shutoff of current at or before 8.5 V.	1. Y 2. Y
Key Ring Bus: 1. Must maintain its shape with the weight of 10 keys and holders during normal usage. 2. Bus contact points must maintain a minimum of 95% voltage from input to the bus to key holder	1. Carry the Key Master around for a day. Visually inspect for shape deformation. 2. Measure voltage at starting point and at contacts of key holders along bus. Compare and vary distance of key holders before remeasuring for voltage variance.	1. Y 2. Y

Continued on next page

Table 4 – continued from previous page

Requirement	Verification	Verification status (Y or N)
LED Key Holder: 1. Commands can be issued from key ring bus to the key holders. 2. LED must be visible in well lit room from a meter away.	1. Connect the data and ground leads to the key ring bus. First only connect one device and run the read program on the Arduino. The address of the device should be displayed on the Arduino console, if not then check and fix connection issues until the device is displayed on the bus. Adding another key and observe an added address. Continue adding keys and make note of all the address that are read into the console. The number of addresses should equal the number of keys on the bus. 2. Run the blinking code on the key holder, if the LED is visibly blinking from a meter away then verified. If the LED is not bright enough, use another LED or add a battery.	1. Y 2. Y
User Interface: 1. LED 2 turns on for a successful read. 2. LED 1 turns on for a failure to read. 3. LED 3 turns on for a failure to search. 4. Be able to detect if a new key is inserted.	1. Upload simple Arduino code that performs a RFID read function while transitioning to a failure state after 10 seconds. Run this code and attempt to read an RFID tag. 2. Same as above but waiting 10 seconds without an RFID tag. 3. Attempt to find a key on the bus using a tag not associated with those keys. 4. Attempt to access a key holder through the new key slot while monitoring the output through an Arduino.	1. Y 2. Y 3. Y 4. Y

A.1 State Diagram

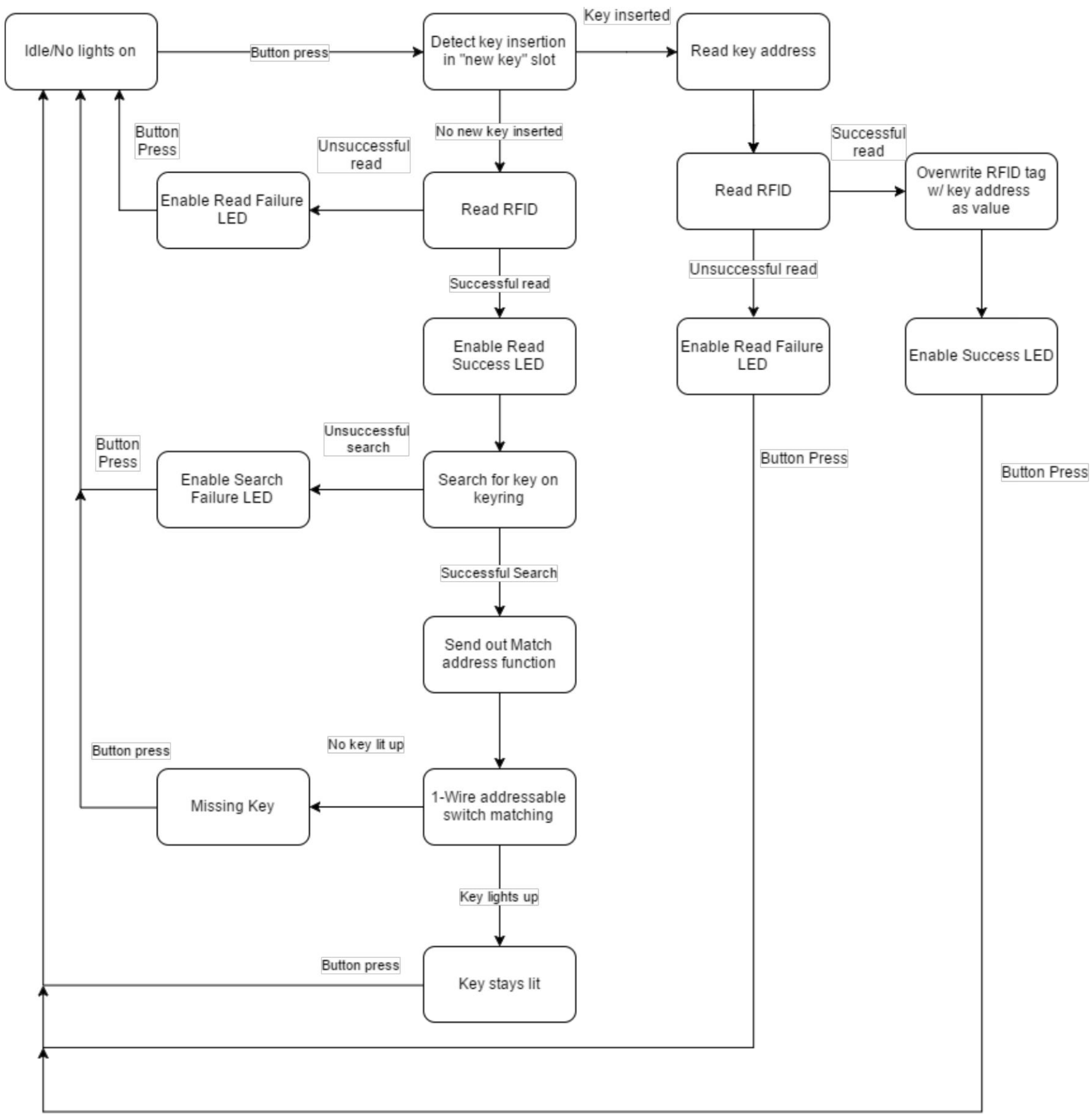

Figure 5: State diagram for Key Master System. Not shown is that a button press from any state that is not idle will return the machine to its idle state.

A.2 Pseudocode

Algorithm 1 State Diagram Pseudocode

```
procedure State Machine
idle loop:
    if button press then
        goto key check
key check:
    if new key inserted then
        goto new key cycle
    else
        goto key find cycle
new key cycle:
    Read key address using 1-Wire protocol
    Attempt to access RFID tag
    if unsuccessful read then
        Enable Read Failure LED
    else
        Overwrite RFID tag with address values
        Enable Success LED
    goto hold
key find cycle:
    Read RFID tag and store address value from tag
    if unsuccessful read then
        Enable Read Failure LED
        goto hold
    Enable Read Success LED
    Use 1-Wire search protocol using address value retrieved from tag
    if unsuccessful search then
        Enable Search Failure LED
        goto hold
    Attempt to match retrieved address with key address using 1-Wire protocol
    Light LED of specific key (may not light if key is missing or made poor contact)
    goto hold
hold:
    while no button press do
        Nothing
    goto idle loop
```

A.3 Schematics

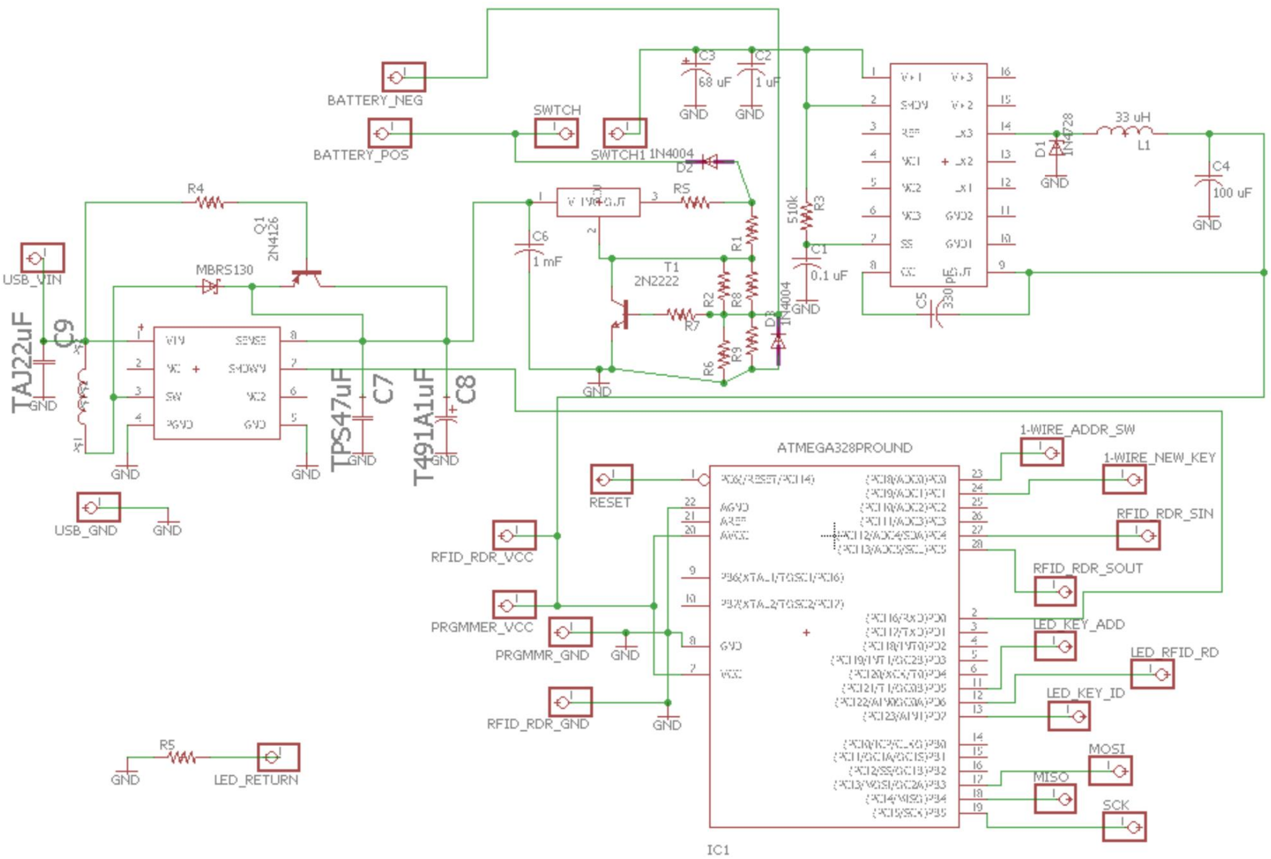

Figure 6: Circuit schematic for the PCB acting as the main hub for parts to connect to.

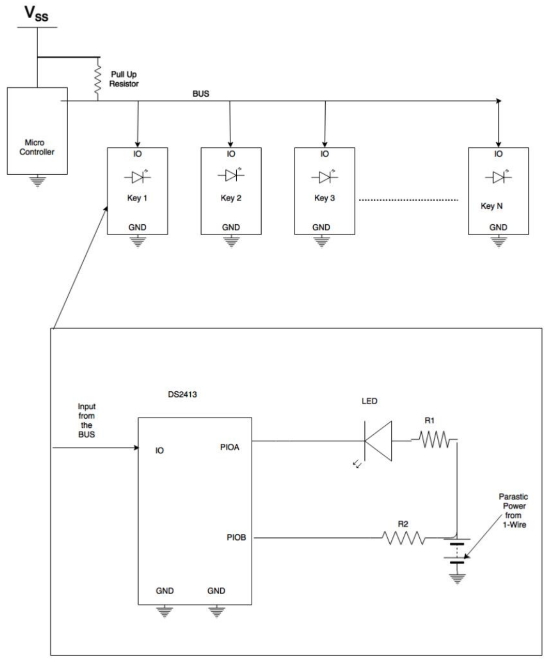

Figure 7: Schematic of the key holder system and for individual keys

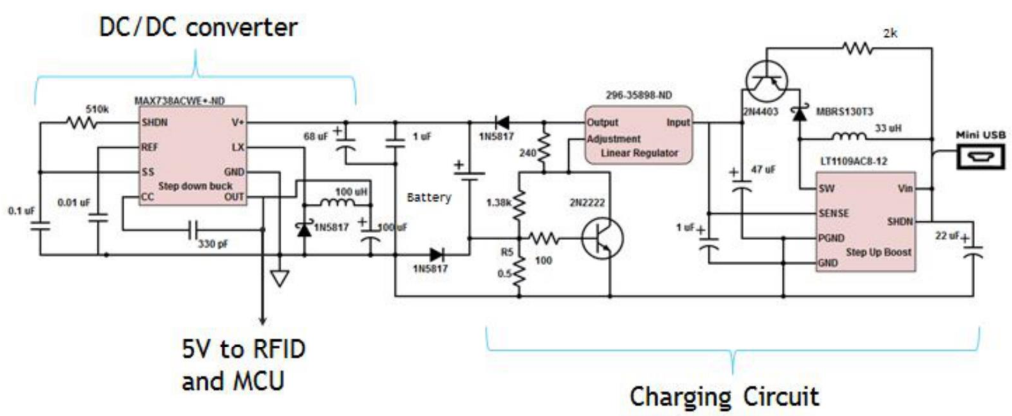

Figure 8: Circuit schematic for the power module

A.4 PCB Design

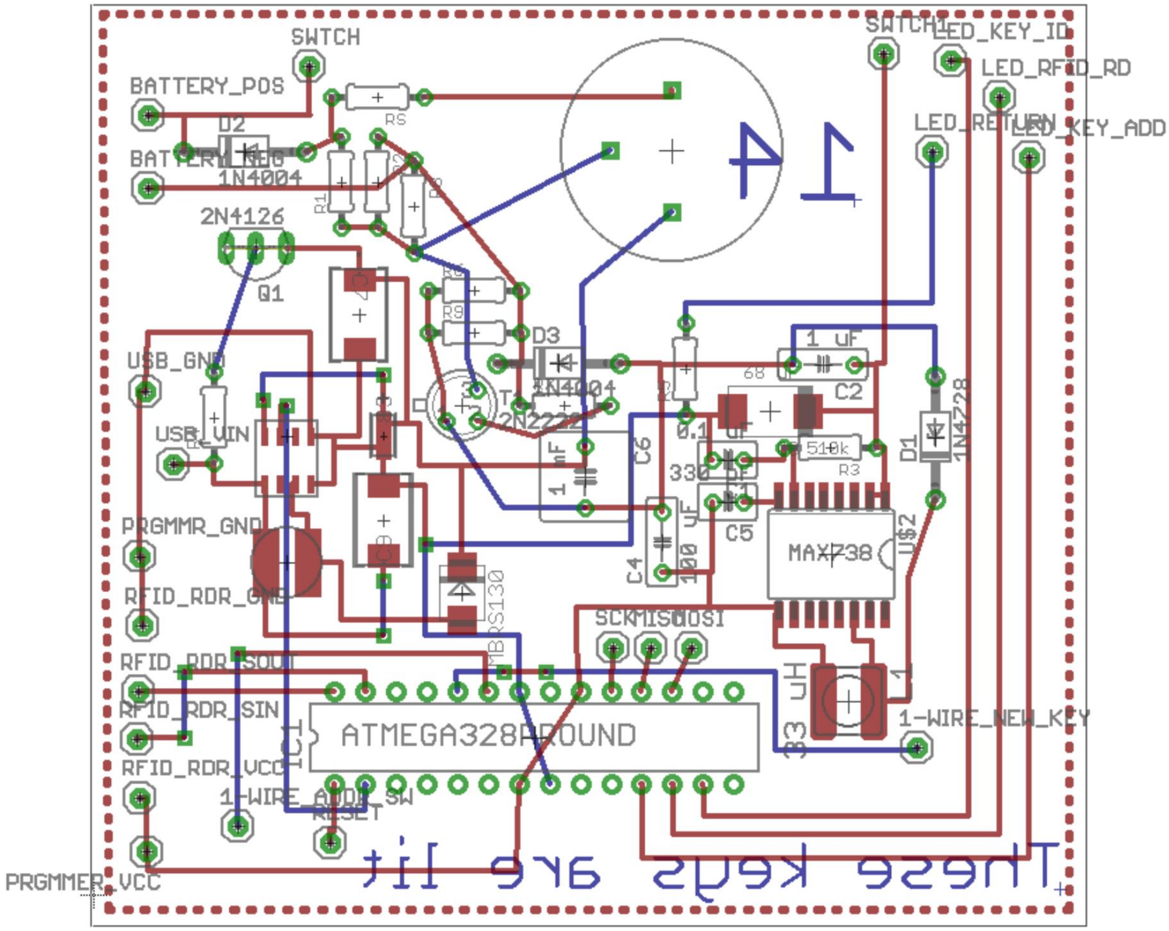

Figure 9: Circuit PCB layout acting as the main hub for component interface

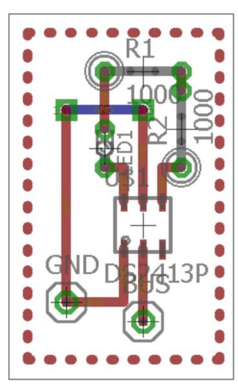

Figure 10: Circuit PCB layout for the key heads

A.5 Physical Prototype

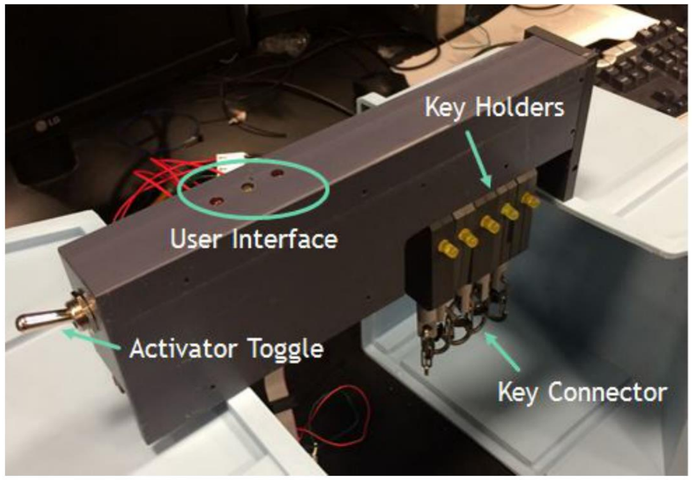

Figure 11: Prototype Housing

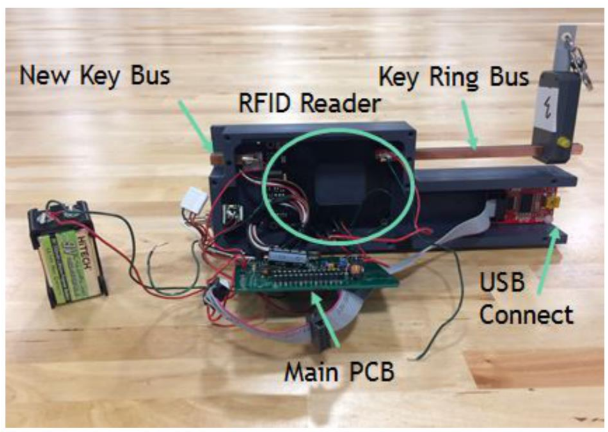

Figure 12: Inner Components

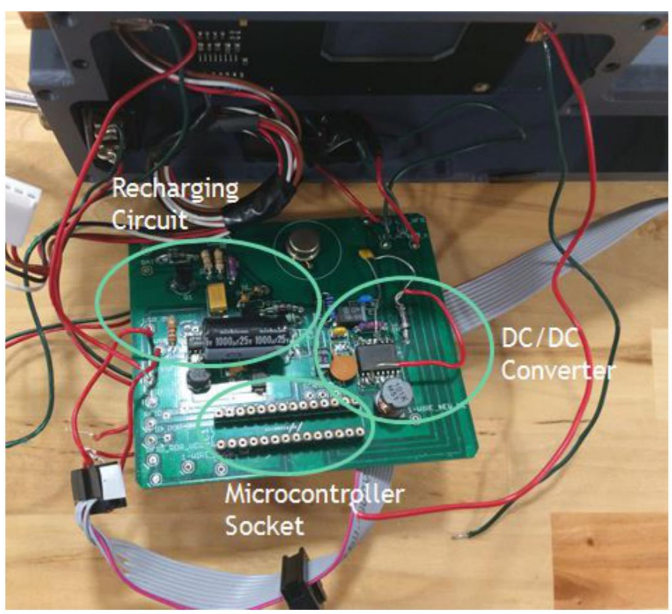

Figure 13: Physical PCB layout

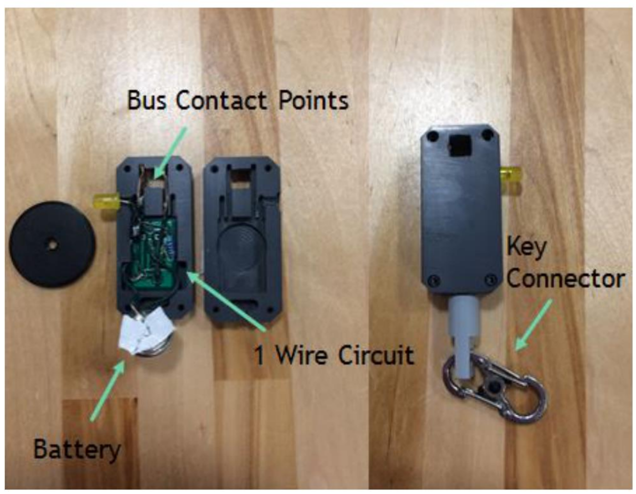

Figure 14: Physical Key Holder