OTTER RFID ANTENNA SYSTEM

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Abstract

This report details the motivation, design, and verification process for an RFID antenna system intended to track river otter movement near specific bodies of water. This document details the results of the work done in developing this system, including successfully verified requirements as well as failed verifications. The report also includes the future work to be done to develop a fully functional field-deployable unit.

Contents

1. Introduction

1.1 Purpose

The population of river otters in Illinois has recently been discovered to exceed approximately 15,000 statewide, and researchers from the Illinois Prairie Research Institute are in need of an RFID antenna system in order to track their movement into and out of a pond [1]. Commercial fish hatchery owners have observed otter latrine sites near their ponds and are concerned that the otters may be eating significant numbers of fish from their ponds. The purpose of this project is to provide the researchers a relatively inexpensive system (compared to commercially available units) to track the movement of otters into and out of specific bodies of water. The data collected by the system will help researchers determine whether or not the river otters pose a significant threat to the fish hatcheries.

1.2 Functions

The overall system block diagram of the project is shown in figure 1.1. The passive infrared motion sensors must be able to detect otter movement at a minimum distance of 3 m. When the motion sensors detect otter movement, they will signal the microcontroller to turn on the RFID receiver power supply.

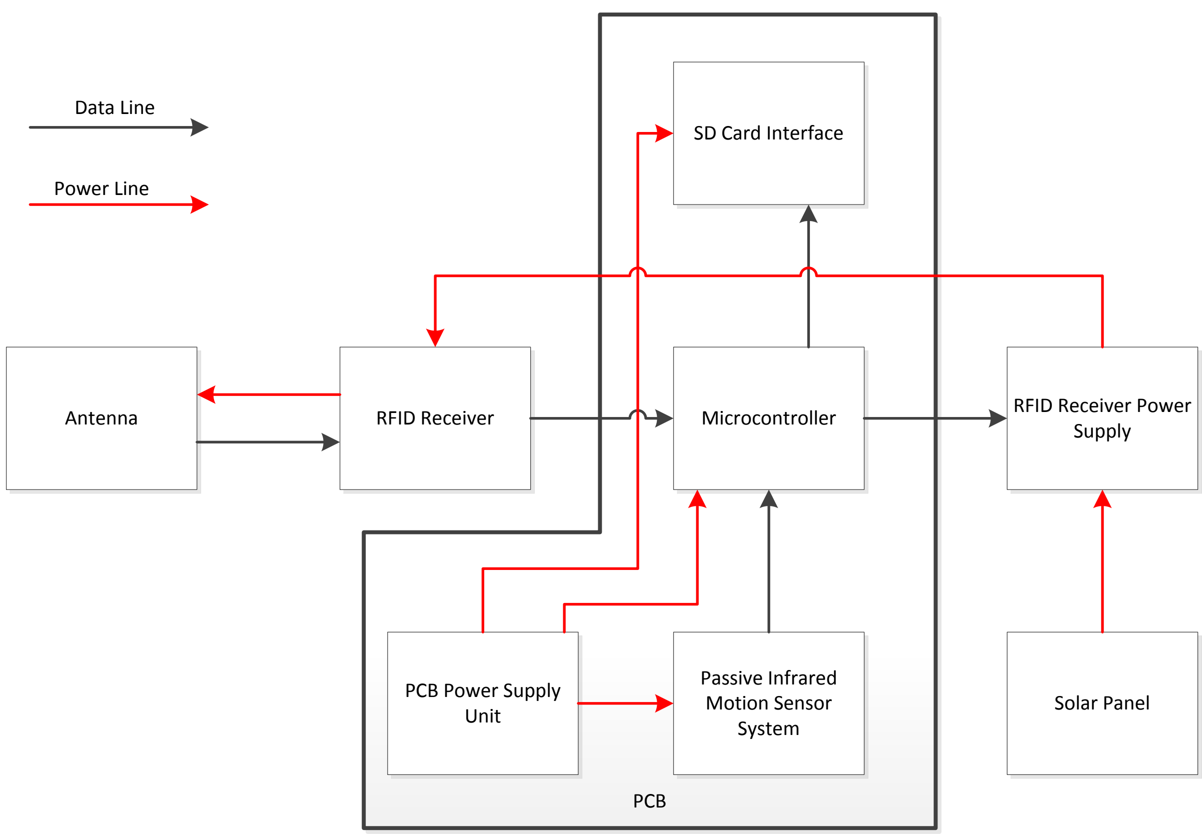

Figure 1.1. The complete system block diagram.

Once the RFID receiver unit is powered on, it will provide power to the antenna, and the antenna will broadcast a signal to read the passive integrated transponder (PIT) tags shown in figure 1.2, which are implanted underneath the skin on the bellies of the otters. The antenna provides power for the passive tags, and the PIT tags will send their unique ID numbers back to the antenna. Because the otters will be walking over the plane of the antenna, the antenna must be able to read the tags from a distance of at least 6 in. After the antenna reads in the unique ID from the PIT tag, the RFID receiver unit demodulates the signal and sends it to the microcontroller for storage.

Figure 1.2. PIT tags (bottom) used to track otters.

Depending on which of the two motion sensors are first activated, the sensor will provide information on the direction of movement. One sensor is directed towards the land, and the other is directed towards the pond. The microcontroller will write this direction of movement along with the PIT tag ID and the timestamp onto the SD card.

The PCB power supply unit provides and regulates the various voltage levels required by the different components on the board from two 9 V batteries. The solar panel recharges the 12 V car battery in the RFID receiver power supply and also prevents the battery from discharging when not in use. Both the PCB power supply and RFID receiver power supply units must be able to supply enough power for at least a week, which is the time between the researchers' visits to the site where the system will be deployed.

1.3 Block Level Changes

In the initial design, the SD card interface block shown in figure 1.1 was originally designed as a USB interface. However after further research, we determined that writing data to an SD card via a SPI interface was more feasible than implementing the USB interface and host functionality on the microcontroller. Instead of storing the data on the microcontroller and then downloading the information to a flash drive, the information is written directly to the SD card. The change in the design altered the program flow for the microcontroller. The final program flow is shown in figure 2.5, and the original program flow is shown in figure B.1.

2. Design

2.1 Antenna

The antenna, shown in figure 2.1, is a commercially available rectangular loop antenna which operates at 134.2 kHz. The antenna is the same component a previous team used in their attempts to develop an otter tracking RFID system. The decision to reuse the antenna was made due to the limited budget and the need to minimize the cost for the system as a whole; the antenna is one of the most expensive components used in this project, as detailed in table 4.1. Furthermore, the antenna is compatible with reading the PIT tags the researchers are intending to use on the otters. The antenna's inductance must match the inductance requirement of 27 µH, which is required by the radio frequency module (RFM) in the RFID receiver to ensure they are in resonance [2].

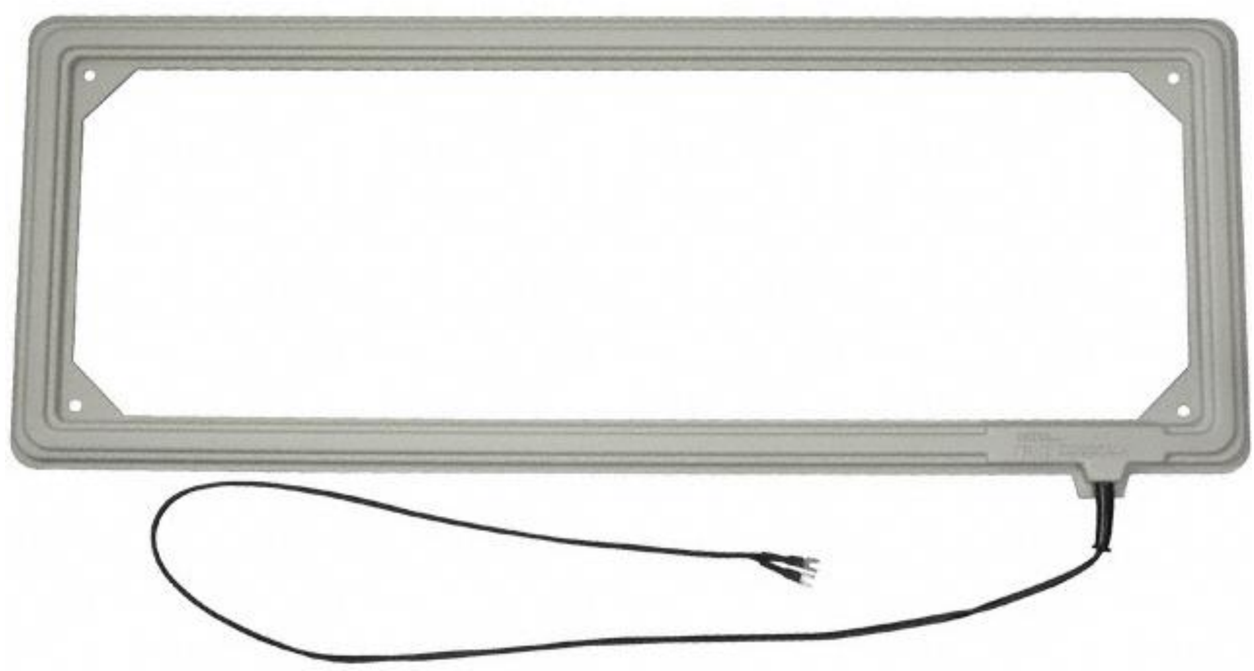

Figure 2.1. The RI-ANT-G01E loop antenna.

2.2 RFID Receiver

The RFID receiver used in the design consists of two commercially available units: the radio frequency module (RFM) and the control (CTL) module, shown in figure 2.2 and figure 2.3, respectively. These components are also the same components used by the previous team. Again, the decision to reuse these components was motivated by cost; buying an alternative RFID receiver unit would have incurred additional cost.

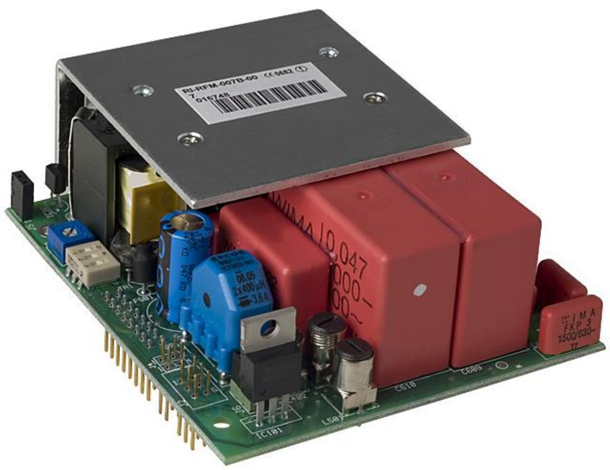

Figure 2.2. The RFM module.

Figure 2.3. The CTL module.

The RFM module receives the 22 ASCII character ID from the PIT tag and demodulates the signal [3]. The signal is amplified and sent to the CTL module for further processing. The CTL module then decodes the tag ID and outputs it in the RS-232 standard. Because the microcontroller operates at TTL voltage levels, the output from the CTL module needs to be converted from the RS-232 format to TTL. The MAX232N chip shown in figure 2.4 performs this conversion. The complete schematic for the antenna and receiver unit is shown in figure B.2.

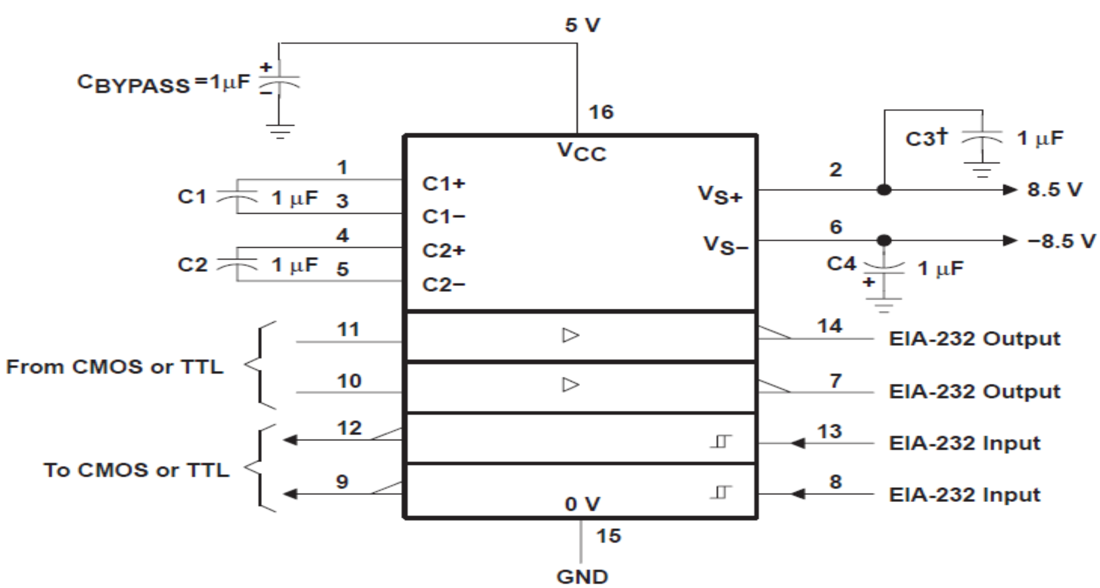

Figure 2.4. MAX232N chip connections [4].

2.3 PCB

To achieve a field-deployable and robust design, the bulk of the circuitry needs to be integrated on a printed circuit board (PCB). The width of the wire traces on the circuit board is the most important consideration. It must be able to handle the current demands of the components that are placed on the board. The microcontroller has the highest demand for current consumption, at a maximum of 500 mA

[5]. Thus, the wire trace width was chosen to have a thickness of 32 mils, which has a current handling capacity of 2.5 A at 20 °C [6]. The PCB schematic capture and layout were done in Eagle, and the circuit schematic and board layout are shown in figures B.3 and B.4, respectively.

2.3.1 Microcontroller

The microcontroller unit is responsible for power management and data storage to the SD card, with the complete details of its program flow shown in figure 2.5. In the initial design, a USB interface was considered, so the microcontroller chosen (PIC24FJ32GB002) had USB host capabilities. However, with the change in design to use the SD card, an alternative PIC that supports the SPI bus interface can be used; having USB host is no longer a requirement. While it may have potentially been cheaper to switch to a microcontroller without USB host capabilities, when we made the decision to switch to using an SD card, the PIC24 had already been ordered and coding already begun. Thus, we continued our programming using the same microcontroller.

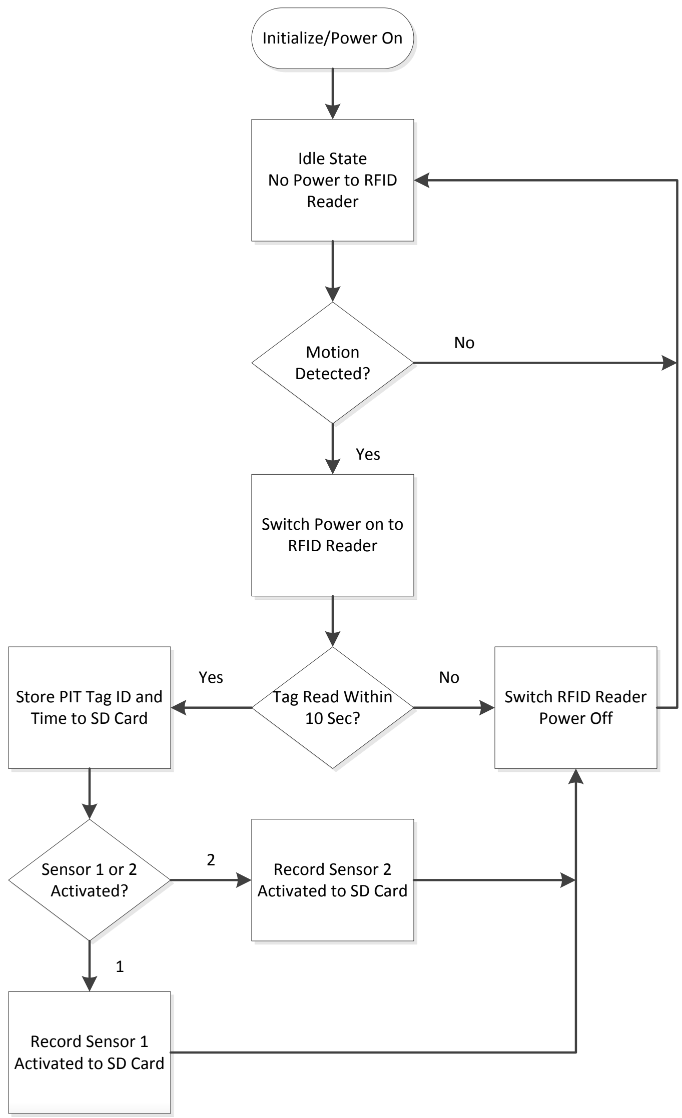

Figure 2.5. The microcontroller program flow diagram.

The system is designed to store the PIT tag identification information, the time, and the movement direction into the SD card. The direction of movement will be recorded as one of the following ASCII strings: "pond to land" or "land to pond". The direction of movement requires 80 bits to store. The 22 ASCII characters from the PIT tag ID uses 176 bits, and the number of bits required for the time stamp is 40 [2]. Therefore, each time an otter movement is detected, 37 bytes will be required to store all of the data, and the total number of bytes required to store the information collected in a week is

$$B = 37d \tag{2.1}$$

where *B* is the number bytes stored per week and *d* is the number of detections per week. Using Equation (2.1) and the estimate that there will be 10 otter movements per week, only 370 bytes are needed to store the data [1]. Any modern SD card used should have adequate space to store the data collected in a week since SD cards with capacities smaller than 1 GB are now uncommon. The movement direction will be determined by which motion sensor is activated, and the time will be recorded from the microcontroller's built-in real time clock.

The real time clock and calendar module in the microcontroller requires an external crystal to ensure accurate operation. The external crystal operates at a frequency of 32.768 kHz, and the crystal circuit is shown in figure 2.6. The circuit was designed in accordance to the microcontroller's data sheet. A 0 Ω jumper is used for R4 to allow flexibility in the design. If a non-zero resistance is needed, R4 can easily be changed with a resistor of another value. The value of R4 would only need to be adjusted if the startup time for the oscillator needed to be adjusted [6]. For the purposes of this project, the 0 Ω jumper sufficed.

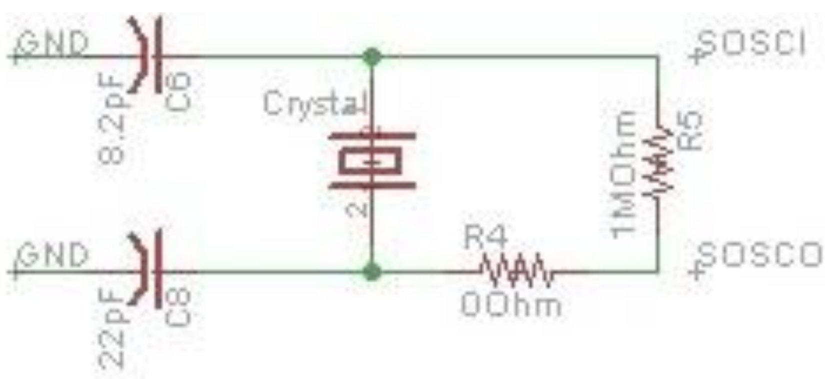

Figure 2.6. Real time clock crystal circuit.

2.3.2 Passive Infrared Motion Sensor

Passive infrared (PIR) motion sensors were included in the design since the sensors use very little power when inactive. Energy efficiency is crucial to our design since the system will be running on battery power out in the field. The motion sensors allow the system to keep the RFID receiver and antenna systems powered off until motion has been detected.

Originally the motion sensors were powered by a 5 V source. However, as shown in the measurements in table 3.1 and table 3.2, the 3.3 V source uses far less power when the sensor is active. Because power consumption is a critical design parameter, the circuit for the second revision of the PCB was redesigned to have the motion sensors run on 3.3 V instead of 5 V.

2.3.3 SD Card Interface

As mentioned in the introduction, the SD card interface was originally a USB interface. While the USB interface is a viable alternative, the SD card interface was ultimately chosen because it was more feasible to implement. Also the SD card interface operates at a voltage level of 3.3 V, which is the same voltage at which the PIC microcontroller operates. Thus, the signaling from the microcontroller is compatible with the SD card and no additional hardware is necessary to properly interface the two components.

Initially, the project was designed to store the data collected onto the microcontroller's internal SRAM, but the SD card has the advantage since its memory is nonvolatile, while SRAM is volatile. Thus, if the system does lose complete power, the data stored will not be lost.

2.3.4 PCB Power Supply Unit

This unit powers the microcontroller, the PIR motion sensors, and the SD card interface. The power supply must be able to power the system for at least a week, and the bulk of the power consumption occurs when the sensors detect movement, which is estimated to be about 30 times per day. The microcontroller is designed to be active for 10 seconds per activation, which is an adequate amount of time for the tag to be read from the otter and the data stored. The microcontroller runs at 14.86 µW in idle mode and 1.65 W when active [2]. The motion sensors run at 429 µW when idle and 0.076 W when active [5].

$$\text{9 V Battery Rating (Idle)} = \frac{(14.86 + 429)\ \mu\text{W} \times (168 - 0.58)\ \text{h}}{9\ \text{V}} \approx 0.008\ \text{Ah} \tag{2.2}$$

$$\text{9 V Battery Rating (Active)} = \frac{(1.65 + 0.076)\ \text{W} \times 0.58\ \text{h}}{9\ \text{V}} \approx 0.11\ \text{Ah} \tag{2.3}$$

Adding together the results from Equations (2.2) and (2.3), the weekly battery usage is 0.118 Ah. Two 9 V batteries are used because they are easy to transport and replace. Furthermore, each 9 V battery has a rating of 0.5 Ah, so the batteries will last for at least a week based on the weekly power consumption calculated [7].

The 9 V batteries cannot directly power the components on the PCB; the microcontroller unit operates at 3.3 V and 2.5 V, and the SD card interface also requires 3.3 V for proper operation. The 9 V provided by the batteries are regulated to 3.3 V and 2.5 V by the two low-dropout voltage regulators shown in figure 2.7.

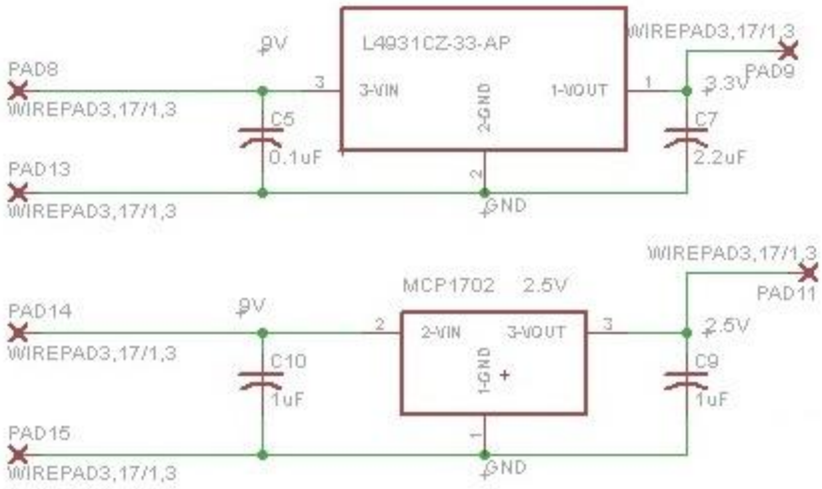

Figure 2.7. PCB Voltage Regulators

2.6 RFID Receiver Power Supply Unit

This unit is the main power source for the antenna and RFID receiver, and the power is supplied by a 12V car battery. To extend the battery life, a solar panel is connected to the unit to recharge the battery and protect it from being discharged at night. A MOSFET was chosen to act as the switch to turn the RFM/CTL module on and off when motion is detected.

In the initial design, the switching circuitry was designed with the 3.3 V signal from the PCB directly connected to the gate of the MOSFET. However, the 3.3 V signal was too low to switch the MOSFET properly. So an op-amp and two resistors were added to the circuit increase the voltage of the signal up to 4.8 V. Figure 2.8 shows the circuit connection of the resistors with the op-amp.

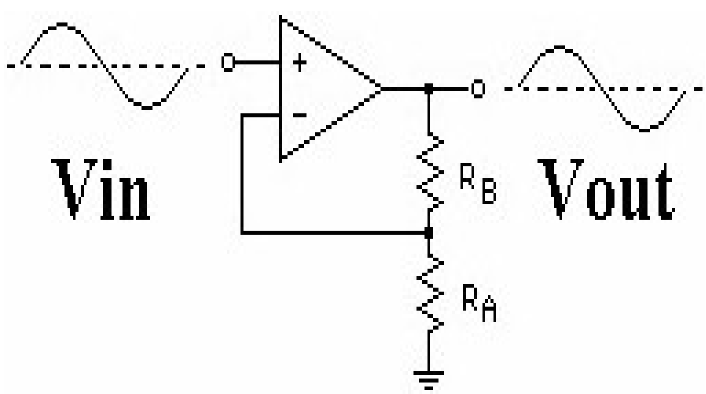

Figure 2.8.The op-amp and two resistors for voltage amplification [8].

The following equation was used to determine proper resistor values to obtain the output voltage that we desired.

$$\frac{V_{out} - V_{in}}{V_{in}} = \frac{R_b}{R_a} = \frac{15k}{33k} = \frac{V_{out} - 3.3}{3.3} \tag{2.4}$$

Based on the calculations made in Equation (2.4), 15 kΩ and 33 kΩ resistors were used to obtain an output voltage of 4.8 V. When the MOSFET receives a high signal, it activates the 12 V voltage regulator, shown in figure 2.9, which provides power to the RFM/CTL module and a 5 V voltage regulator, shown in figure 2.10, which provides power for the MAX232N chip.

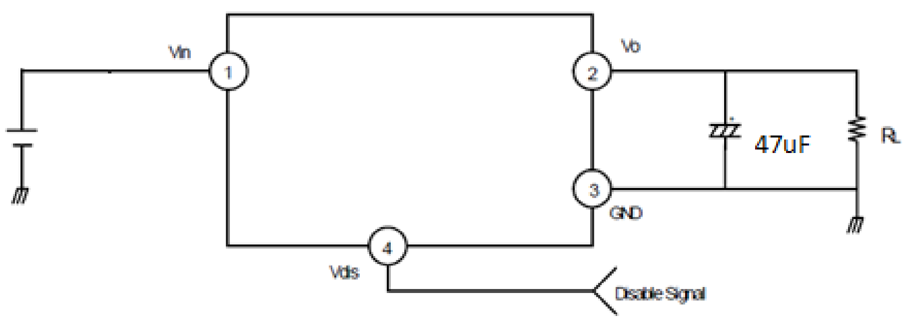

Figure 2.9. The 12 V low-dropout regulator [9].

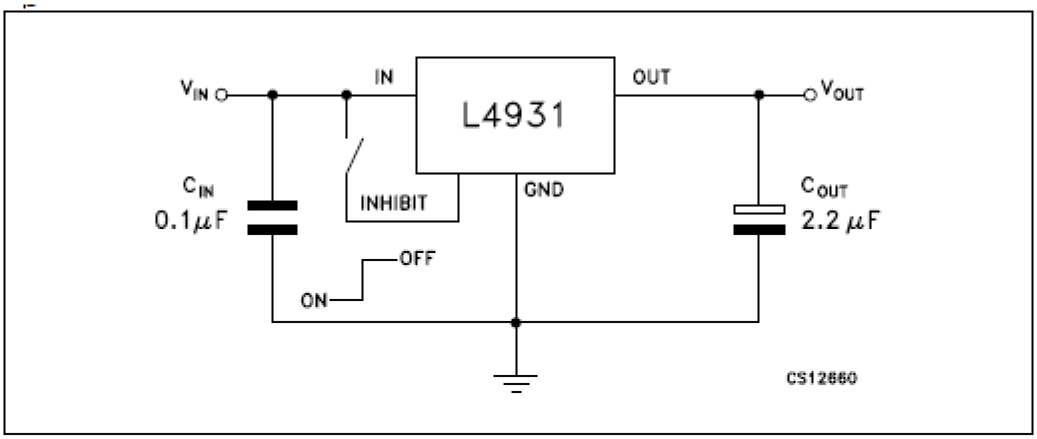

Figure 2.10. The 5 V low-dropout regulator [10].

Calculating the power usage for the RFID receiver unit will determine the battery rating required for the design. According to the prairie researchers' estimates, we can expect to have ten otter movement detections per week [1]. However, there will be movements from other animals which will also activate the motion sensors, so the number of detections per day is estimated to be as high as 30. For each detection, the system will draw power for 10 seconds, so the system could be operating for as long as 0.58 hours every week. The max current draw for the RFM/CTL unit is 300 mA, and the max current draw for the MAX232N chip is 10 mA; the total current draw is 310 mA [2], [11], [12]. The RFID receiver unit's charge consumption is

$$Q = it \tag{2.5}$$

where *Q* is the charge consumption in ampere-hours, *i* is the max current draw in amperes, and *t* is the time in hours. Using Equation (2.5), the charge is 310 mA x 0.58 hours = 0.18 Ah. Since the unit only consumes 0.18 Ah per week, the 12 V battery which has a 75 Ah rating is capable of providing enough power for more than a week; researchers will not need to increase the frequency of their visits to the site to replace the battery.

2.7 Solar Panel

The solar panel is a commercially bought unit that is connected to the 12 V car battery to charge and extend the battery life. It is connected to the 12 V car battery via battery clamps as shown in figure 2.11, which provides an easy way to disconnect and reconnect when replacing the battery. The solar charger has an integrated battery overcharge protection system, and it also has a blocking diode circuit that protects the battery from being discharged through the panel's circuitry when there is no sunlight.

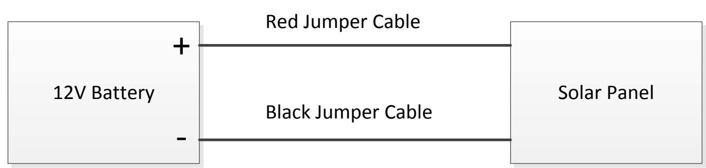

Figure 2.11. Battery-solar panel connection.

In central Illinois, the average hours of sunlight per day are 4.2 hours [13]. The design uses a 5 W solar panel which charges at a current of 0.3 A [14]. Again using Equation (2.5), the solar panel charges the battery 8.82 Ah per week. The RFID receiver unit's battery usage is only 0.18 Ah per week. Under ideal conditions, the battery will not require replacement unless the battery health deteriorates from age, and it no longer holds its charge properly.

For field deployment, the solar panel is mounted on top of the enclosure for the system and faces south for maximum sunlight exposure. The panel has a fixed mounting, and the angle at which the panel is mounted is 40° from the horizontal to achieve optimum sunlight exposure. The angle determined is based on the latitude of the Champaign area from the equator [15].

3. Design Verification

The complete list of design requirements and verifications are detailed in table A.1 in Appendix A.

3.1 Antenna

The first requirement detailed is that the antenna should have an inductance of 26 to 27.9 µH at a frequency of 134.2 kHz. Using an LRC meter, the requirement was verified, and the inductance of the antenna was measured to be 27 µH.

The requirement that the antenna read the PIT tag at a minimum distance of 6 in was verified by connecting the antenna to the RFM/CTL module. The RFM/CTL module was connected to the computer via a USB interface, where the data read by the module was viewed through the terminal opened in PuTTY. The PIT tag was placed over the antenna at a measured 6 in distance, and the corresponding PIT tag ID was observed in the terminal, verifying the antenna's 6 in minimum read range.

3.2 RFID Receiver

To verify that the RFID receiver unit is operating correctly, pin 4 on the CTL module was probed with an oscilloscope. The RFM/CTL unit was set to operate in line mode, in which the RFM/CTL module continuously outputs the ASCII character 'L'. Figure 3.1 shows the measurement of the output taken by the oscilloscope. Reading the data from right to left, the ASCII code for the character 'L' is confirmed from the scope measurement.

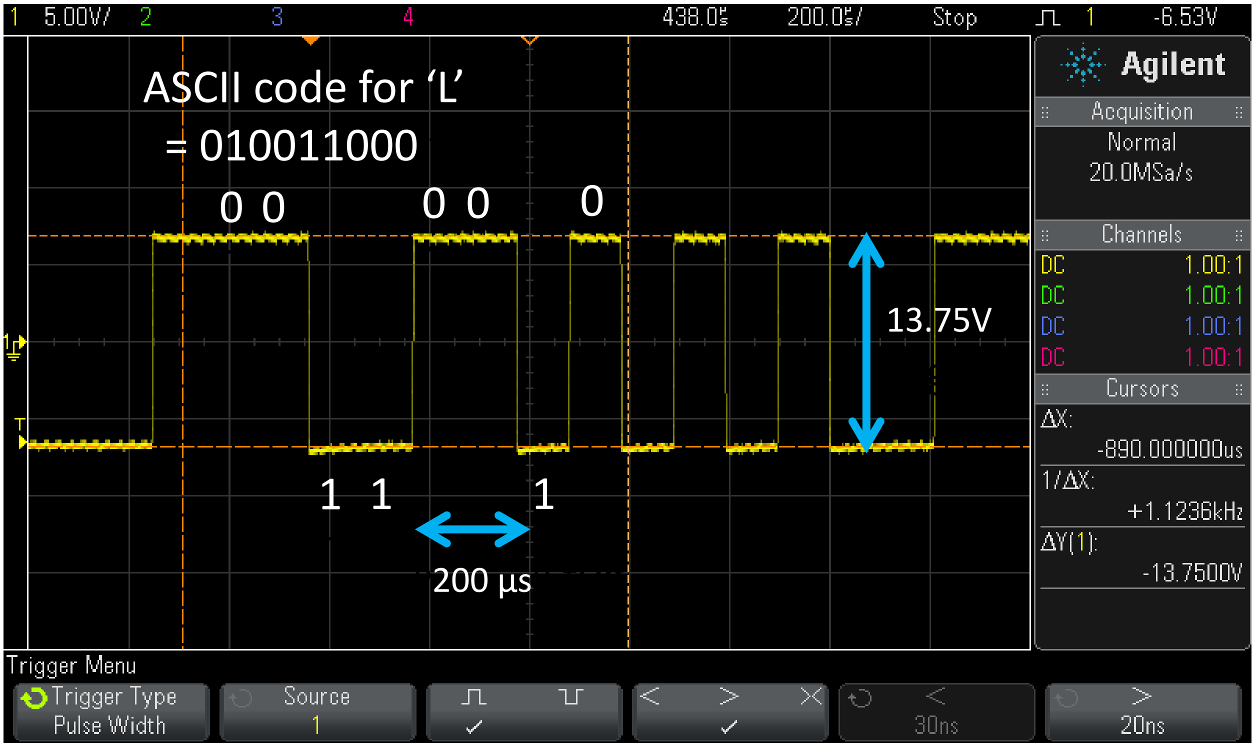

Figure 3.1. Oscilloscope output from pin 4 on CTL unit in RS-232 format.

As shown in figure 3.1, the data outputted from the CTL module is in the RS-232 format with a voltage range of 13.75 V; a logical '0' is represented as a high voltage, and a logical '1' is represented as a low voltage. The MAX232 chip converts the RS-232 logic to TTL logic, and the voltage levels from pin 12 on the chip were probed with an oscilloscope. Figure 3.2 shows the output of the MAX232 chip on the oscilloscope with the appropriate TTL voltage levels, making the signal compatible with the microcontroller.

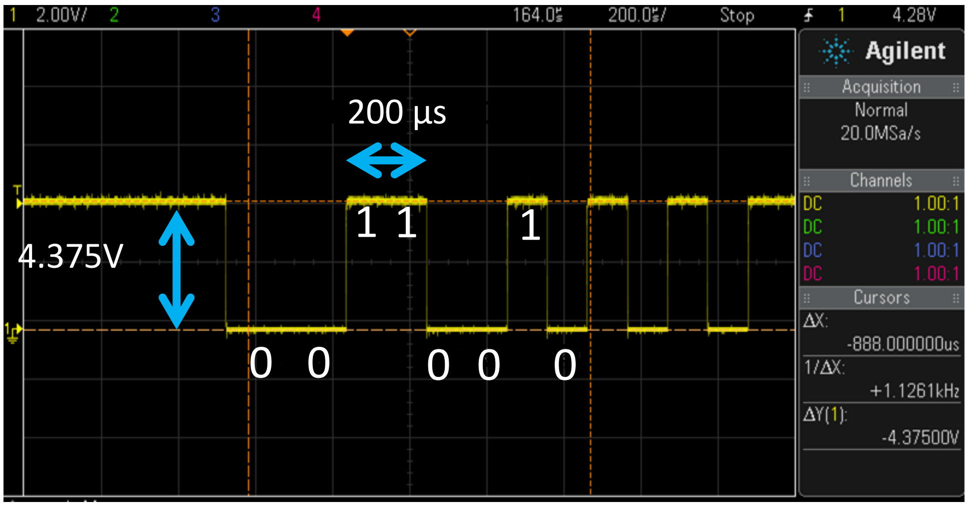

Figure 3.23. Scope reading of the output from the MAX232N chip at TTL logic levels.

3.3 Microcontroller

The clock speed needed to be verified on the PIC since there is a timing requirement for the RFID receiver's power switching. The program code sets the internal oscillator (f_{osc}) to 8 MHz, as shown in Appendix C. The waveform shown in figure 3.3 is a measurement of the PIC's oscillator output on pin 10. The pin outputs the clock speed at which the program code is executed, which is $f_{osc}/2$ [5]. Therefore, the waveform verifies that the internal oscillator is programmed correctly, since the clock speed measured is 4 MHz.

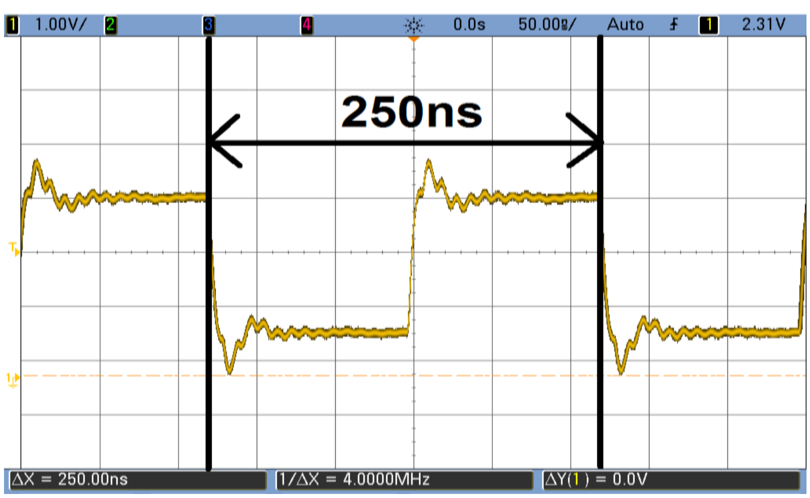

Figure 3.3. The PIC microcontroller's program execution frequency.

The requirement that the RFID receiver unit is powered on for 10 seconds when movement is detected was also verified. The test was completed by activating a sensor and observing the LEDs on the RFM/CTL module. As soon as the motion sensor was activated, the LEDs blinked for approximately 10 seconds and then turned off.

The critical requirement that the PIT tags are properly processed by the microcontroller is verified by programming the microcontroller with the code shown in Appendix C. Figure 3.4 shows the different PIT tags read and outputted by the microcontroller in the PuTTY terminal.

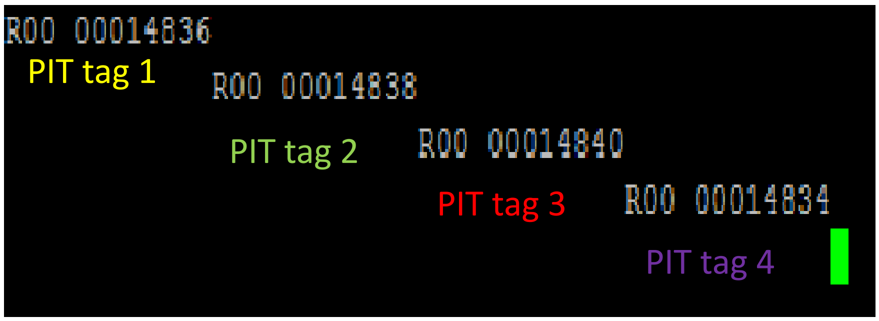

Figure 3.4. PIT tag IDs sent to the microcontroller.

The other major requirement that needed to be verified was the real time clock, since a timestamp is required each time a PIT tag is read. Figure 3.5 depicts the real time clock operating correctly and providing a timestamp each time a PIT tag is read.

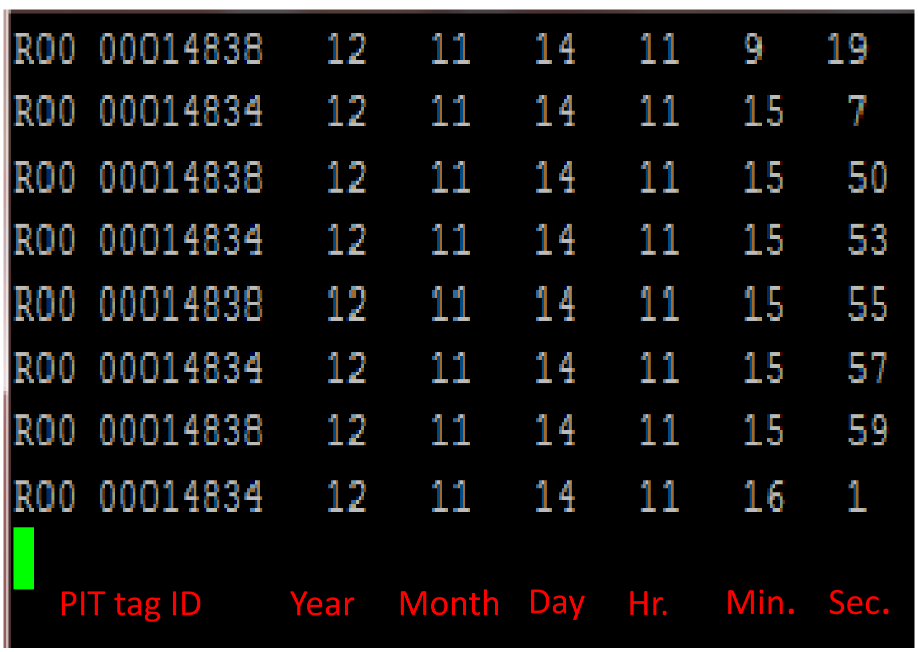

Figure 3.5. PIT tag IDs and timestamp.

The final requirement is that the microcontroller must save the collected data onto an SD card. We were unable to successfully implement this function. The first sub-requirement tested was whether the SPI interface was properly implemented by reading and writing data directly to the raw memory of the SD card. The PuTTY terminal shown in figure 3.6 displays the results of the test. It can be seen that the value stored at the memory location 1234 is 'B0'. Then, the new value 'AB' was written to this same memory location. When this memory location is read again, it has the new value, 'AB'. The process was repeated but the value 'CD' was stored in memory location 1234, to confirm that the SD card read and write was not confined to only a specific address and value.

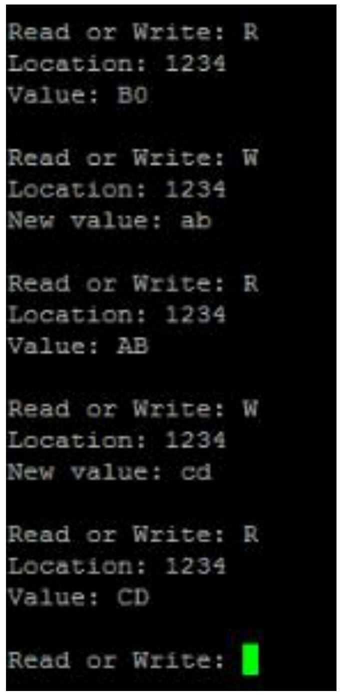

Figure 3.6. Data read and written on raw memory of SD card.

While data could be written directly via the terminal, the requirement that the microcontroller store that information was not verified. The code to implement that function was unsuccessful in writing the data to the SD card. When the SD card was connected to the PC to check if the PIT tag IDs, timestamp, and direction had been stored, the SD card was empty.

3.4 Passive Infrared Motion Sensor

The power consumption of the PIR sensors was an important factor to consider since power efficiency is critical to the battery longevity. The measurements shown in table 3.1 and table 3.2 verify that the sensors draw less than 130 μA when idle. The active power consumption for the sensors connected to 3.3 V was significantly smaller than the consumption for a 5 V source. Thus, the 3.3 V source was used to power the sensor to improve energy efficiency.

Table 3.1 Sensor power consumption on 3.3 V source

Sensor State	Current (mA)	Power (mW)
Inactive	0.119	0.3927
Active	2.563	8.4579

Table 3.2 Sensor power consumption on 5 V source

Sensor State	Current (mA)	Power (mW)
Inactive	0.120	0.6
Active	19.680	98.4

3.5 SD Card Interface

The SD card interface power pin requirements were verified by measurement. Furthermore, the ability to read and write to the raw memory of the SD card also confirms that the interface works properly.

3.6 RFID Receiver Power Supply Unit

The major requirement of the RFID receiver power supply unit is that it only powers the receiver unit when the sensors detect motion. By using a MOSFET and an op-amp to work as a switch, we confirmed that the RFM/CTL module only gets power when the sensor is activated. Also, we checked and verified that the module turns off after 10 seconds.

By measuring the voltage of 12 V and 5 V voltage regulators, we confirmed that the power supply unit provides the appropriate voltages to the RFM/CTL module and MAX232N chip. Furthermore, the successful reading of the PIT tags and voltage levels of the signal verifies that the RFM/CTL module and MAX232N are operating correctly.

3.7 Solar Panel

The main purpose and requirement of the solar panel is that it should charge the 12 V car battery while there is sunlight. To verify that the solar charger charges the battery properly, we measured voltage of the battery every hour while the charger was connected. The procedure for testing was to charge the battery for 8 hours and then to check the voltage 2 hours after disconnecting the charger. The measurements shown in figure 3.7 were taken on November 28, 2012, under the following conditions: weather condition: clear 47 °F/21 °F; sunrise: 6:53 AM; sunset: 4:29 PM.

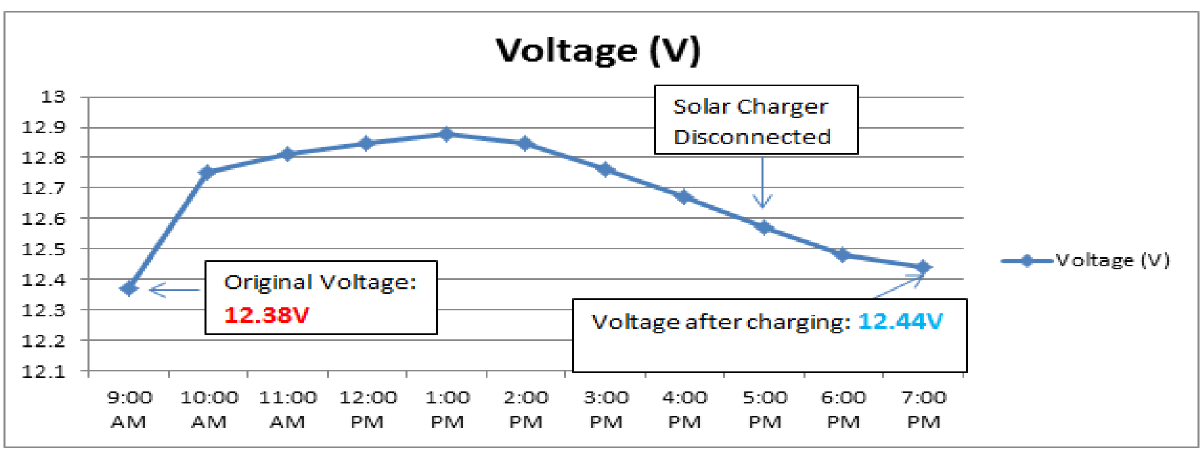

Figure 3.7. Solar panel charging voltage measurements.

Figure 3.7 shows the original voltage of the battery to be at 12.38 V. The voltage of the battery after charging was 12.44 V. Knowing the voltage level of the battery provides the necessary information to determine the state of the battery's charge [16]. According to table 3.3, the battery was initially more than 70% charged. After eight hours of charging, the battery was charged to 80% capacity, confirming that the solar charger properly recharges the battery.

Table 3.3. Battery voltage and its state of charge

State of Charge (%)	12 V Battery Output Voltage (V)
100	12.70
90	12.50
80	12.42
70	12.32

3.8 PCB Power Supply Unit

PCB power supply unit provides power from two 9 V batteries. The requirements dictate that the supply unit must provide 3.3 V and 2.5 V to the microcontroller, and 3.3 V to the motion sensors. Using the multimeter, we measured and verified that the outputs of the voltage regulators provide the 3.3 V and 2.5 V required by the design.

4. Costs

4.1 Parts

Table 4.1 Parts costs

Part	Manufacturer	Retail Cost ($)	Quantity	Bulk Purchase Cost ($)	Actual Cost ($)
PIC Microcontroller (PIC24FJ32GB002)	Microchip	4.14	1	(10) 3.26	4.14
PIR Motion Detector (555-28027)	Parallax	10.99	2	(5) 10.44	21.98
3.3 V Voltage Regulator (L4931CZ33-AP)	STMicroelectronics	0.97	1	(10) 0.86	0.97
2.5 V Voltage Regulator (MCP1702-2502E)	Microchip	0.52	1	(10) 0.48	0.52
12 V Voltage Regulator (KA378R12CTU)	Texas Instruments	1.33	1	(10) 1.18	1.33
5V Voltage Regulator (L4931CZ50-AP)	STMicroelectronics	0.73	1	(10) 0.61	0.73
8.2 pF Capacitor (1206 SMD)		0.10	1	(10) 0.02	0.00
22 pF Capacitor (1206 SMD)		0.24	1	(10) 0.16	0.00
0.1 µF Capacitor (1206 SMD)		0.25	5	N/A	0.00
2.2 µF Capacitor (1206 SMD)		0.25	1	(10) 0.17	0.25
47 µF Capacitor		0.35		N/A	0.35
1 µF Capacitor (1206 SMD)		0.10	2	N/A	0.00
10 kΩ Resistor (1206 SMD)		0.04	5	N/A	0.00
470 Ω Resistor (1206 SMD)		0.04	2	N/A	0.00
0 Ω Jumper (1206 SMD)		0.02	1	(50) 0.01	0.02
PCB	ECE Shop Parts	30.00	1	N/A	30.00
SD Card Connector	TE Connectivity	3.33	1	“300” 2.11	3.33
Solar panel package (B0006JO0TC)	Sunforce	55.04	1	N/A	55.04
12 V Battery (24DC)	Everstart	72.96	1	N/A	0.00

Table 4.1 (continued)

Antenna (ANT-GO1E-30)	Texas Instruments	240.00	1	N/A	0.00
Transponder (TRP-RR2B-30)	Texas Instruments	5.46	4	N/A	0.00
Frequency module (RFM-007B)	Texas Instruments	350.00	1	N/A	0.00
Control Module (CTL-MB2B)	Texas Instruments	320.00	1	N/A	0.00
RS232 to TTL (MAX 232N)	Texas Instruments	0.62	1	N/A	0.62
9 V Battery	Duracell	4.00	2	N/A	8.00
Enclosure	Sterilite	20.00	1	N/A	20.00
SD Card	Pqi	6.50	1	N/A	0.00
MOSFET (IRF510)	Vishay Siliconix	0.96	1	“25” 0.74	0.96
Crystal (CFS-206)	Citizen	0.28	1	“10” 0.24	0.28
LED		0.25	1	N/A	0.00
Perfboard (276-170)	Radio Shack	2.49	1	N/A	2.49
Op-Amp (LNM324)	Texas Instruments	2.29	1	N/A	2.29
Switch (85908)	Dorman	5.49	1	N/A	5.49
15 kΩ Resistor (CF12JT15K0)	Stackpole Electronics	0.14	1	N/A	0.14
33 kΩ Resistor (CF14JT33K0)	Stackpole Electronics	0.08	1	N/A	0.08
1 µF Capacitor (EF2105-ND)	Panasonic	0.68	5	N/A	3.40
Machine shop labor cost		120.00	1	N/A	120.00

4.2 Labor

Table 4.2 Labor costs

Name	Hourly Rate ($/h)	Total Hours Worked (h)	Total = Hourly rate x 2.5 x Total Hours Worked ($)
Jinwoo Bae	35.00	200	17500.00
Charles Huang	35.00	200	17500.00
Sumsaamuddin Mohammed	35.00	200	17500.00
Total			52500.00

4.3 Total Costs

Table 4.3 Total costs

Category	Cost ($)
Parts	282.41
Labor	52500.00
Total	52782.41

5. Conclusion

5.1 Accomplishments

While the system we developed is not ready for field deployment, the modularity in our design allowed us to implement a majority of functions required by the design. We were successful in implementing the functionality of multiple blocks individually, including the power switching function that interfaced the passive infrared motion sensors with the microcontroller to switch on the power for the RFID receiver unit. Furthermore, we successfully implemented the PIT tag ID read and time stamp functions as well. We were also able to integrate the system components in a field deployable enclosure. The physical enclosure was assembled and mounted with all the components inside, with the solar panel mounted on the cover of the enclosure, and the antenna outside of the box.

5.2 Uncertainties

Although the individual modules were successfully implemented both in the physical hardware and in the microcontroller coding, we were unable to meet all the requirements. Specifically, the requirement we were unable to meet was to write the data collected onto the SD card from the microcontroller. The driver that we were using was potentially buggy and we were not able to initialize the FAT32 file system. The other problem involved integrating the individual functions (power switching, PIT tag reading, time stamping, etc.) together in the code, which also did not work properly.

5.3 Ethical Considerations

In regards to the IEEE Code of Ethics, the primary ethical consideration for the project is ensuring that the system does not harm the river otters or any other animals. The enclosure must properly isolate the electrical components from the external environment so that animals are not harmed. Furthermore, the enclosure for the system must be environmentally friendly and not introduce harmful elements to the ecosystem. With the use of batteries and especially since the unit is intended to be deployed near bodies of water, acid leakage is a major concern, so the batteries in the system must be isolated from the environment within a container. Another ethical consideration is properly crediting every source consulted as well as not falsifying the data gathered from testing.

5.4 Future Work

To bring the project to completion and provide a field deployable device, we would need to successfully integrate the individual program functions developed into one complete program. Most immediately, work on writing the microcontroller code to save the data directly to the SD card would be developed first. However, a new driver for the SD card that can enable writing the data collected in a text file and storing in the FAT32 format could also be implemented to provide researchers an easier method for retrieving the data. Once the programming is complete and the system is fully operational, field testing of the system at the pond would be the subsequent step to ensure that it works out in the field. Upon successful deployment, further work would then be done to extend to area in which the system can read PIT tags. This could possibly be achieved by connecting additional antennas to the system or considering an alternative antenna design. Regardless, further research and design will be necessary to increase the area in which the system can read PIT tags.

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Appendix A Requirement and Verification Table

Table A.1 System requirements and verifications

Requirements	Verifications	Verification Status
Antenna	**Antenna**	
1. The antenna must match its inductance to the induction requirement of the RFM module. The antenna inductance must be between 26 to 27.9 µH.	1. The antenna will be connected to the vector signal analyzer to check if its inductance is between 26 and 27.9 µH.	Y
2. The antenna must be able to read the transponder's unique ID from a distance of 6 in.	2. The PIT tag will be moved across the antenna at a distance of 6 in and the output (pin 4) of the control module will be probed by an oscilloscope to verify that the PIT tag has been read.	Y
RFID Receiver	**RFID Receiver**	
1. The control module should decode the PIT tag ID number.	1. The output (pin 4) of the control module would be analyzed using an oscilloscope to see what the ASCII code is.	Y
2. The receiver must output an ASCII 'L' and 'R' as the first and second characters from a successful read of the PIT tag.	2. The ASCII codes of 'L' and 'R' will be verified via an oscilloscope at the RS-232 output of the control module. The ASCII code for 'L' is 01001100 and the ASCII code for 'R' is 01010010.	Y
3. The output to the microcontroller must be converted to TTL voltage levels between -7 V and 7 V.	3. The output of the MAX232N chip will be probed by a multimeter to verify the voltage levels are between -7 V and 7 V.	Y
Microcontroller	**Microcontroller**	
1. The microcontroller must operate in low power idle mode when there is no motion, drawing no more than 1 mA.	1. Probe the Vdd pins on the microcontroller with an ammeter to verify current is less than 1 mA when in idle mode.	Y
2. The microcontroller must operate in normal mode when there is motion detected.	2. Probe the Vdd pins on the microcontroller with an ammeter to verify current is between 1 to 15 mA.	Y

Table A.1 (continued)

3. The microcontroller must signal the 12 V power supply to provide power to the RFID receiver when motion has been detected.	3. Probe pin 16 from the microcontroller to the MOSFET switch with the oscilloscope to verify that a high signal is sent when movement is detected.	Y
a. PIR sensor 1 must signal the microcontroller that motion has been detected.	a. Activate sensor 1 and verify the sensor output signal is high on the oscilloscope.	Y
b. PIR sensor 2 must signal the microcontroller that motion has been detected.	b. Activate sensor 2 and verify the sensor output signal is high on the oscilloscope.	Y
c. The microcontroller must send a high signal to the MOSFET once the microcontroller receives a high signal from either PIR sensor.	c. Probe pin 16 on the microcontroller with the oscilloscope to verify that a high signal has been sent.	Y
d. The output signal from the microcontroller to the MOSFET must be around 5 V.	d. An op-amp will be used to increase the voltage signal of 3.3 V from the microcontroller unit to 5 V to make the MOSFET works properly. The gate-source voltage on the MOSFET will be probed with the oscilloscope to verify the high signal is around 5 V.	Y
e. The power supply must be switched on for 5 seconds.	e. Verify that the waveform for the gate-source voltage on the MOSFET is high for 5 seconds.	Y

Table A.1 (continued)

f. The RFM/CTL unit must be powered on.	f. The LEDs on the control module will be checked to verify the RFM/CTL unit is powered on. Blinking or constantly lit up LEDs indicate the system is getting power.	Y
4. The microcontroller must be able to store information onto the SD card.	4. The SD card is connected to a computer and read to verify data is properly written.	N
a. The SPI interface must be implemented.	a. Test code will be written to read and write directly to the SD card. The SD card memory is read in the WINHEX program to verify the data is properly written on the SD card.	Y
b. The microcontroller must also detect when a SD card has been detached.	b. The program output will output an error saying it cannot initialize the SD card if there is no SD card attached.	Y
c. The microcontroller must properly process and store otter ID information and the time when the PIT tag is read onto the SD card.	c. PuTTY is used to display the ID information stored in the microcontroller.	N
Passive Infrared Motion Sensor 1. The PIR sensor must detect otter movement at a minimum range of 3 m.	**Passive Infrared Motion Sensor** 1. Probe the output of the PIR sensor with the oscilloscope to verify that a high signal is generated when there is motion at a 3 m distance from the sensor.	Y
2. The V+ pin should draw no more than 150 µA current.	2. Probe the V+ pin with a multimeter to verify that the current is less than 150 µA.	Y

Table A.1 (continued)

SD Card Interface 1. The SD card interface must have a voltage of 3.3 V +/- 10% on its Vdd pin.	**SD Card Interface** 1. Probe the Vdd pin with a multimeter to verify that the voltage is between 2.97 V and 3.63 V.	Y
RFID Receiver Power Supply Unit 1. The battery should not be discharged when motion has not been detected.	**RFID Receiver Power Supply Unit** 1. The RFID Receiver unit will be turned off when there are no detections. So the power will be used only when the sensors are activated.	Y
2. The RFID Receiver power supply should provide a regulated 12 V +/-5% for the RFM/CTL units.	2. Probe the output (pin 2) of the voltage regulator (KA378R12CTU) with voltmeter to verify that the voltage is between 11.4 V and 12.6 V.	Y
3. The RFID Receiver power supply should provide a regulated 5 V +/-10% to the MAX232N chip.	3. Probe the output (pin 1) of the voltage regulator (L4931CZ50-AP) with voltmeter to verify that the voltage is between 4.5 V and 5.5 V.	Y
Solar Panel 1. The solar charger must recharge the 12 V battery when sunlight is present.	**Solar Panel** 1. When sunlight is present, the voltage of the battery will be probed while solar panel is connected.	Y
PCB Power Supply Unit 1. The PCB power supply unit should supply a voltage of 3.3 V +/- 10% for the Vdd pins on the microcontroller.	**PCB Power Supply Unit** 1. Probe the output (pin 1) of the voltage regulator with an oscilloscope to verify that the voltage is between 2.97 V and 3.63 V.	Y
2. The PCB power supply unit should supply a voltage of 2.5 V +/- 10% to the Vcap/Vddcore pin on the microcontroller.	2. Probe the output of the voltage regulator with an oscilloscope to verify that the voltage is between 2.25 V and 2.75 V.	Y
3. The PCB power supply unit should supply a voltage of 3.3 V +/- 10% to the PIR motion sensors and Vdd for the SD interface.	3. Probe the output (pin 1) of the voltage regulator with an oscilloscope to verify that the voltage is between 2.97 V and 3.63 V.	Y

Appendix B Schematics and Diagrams

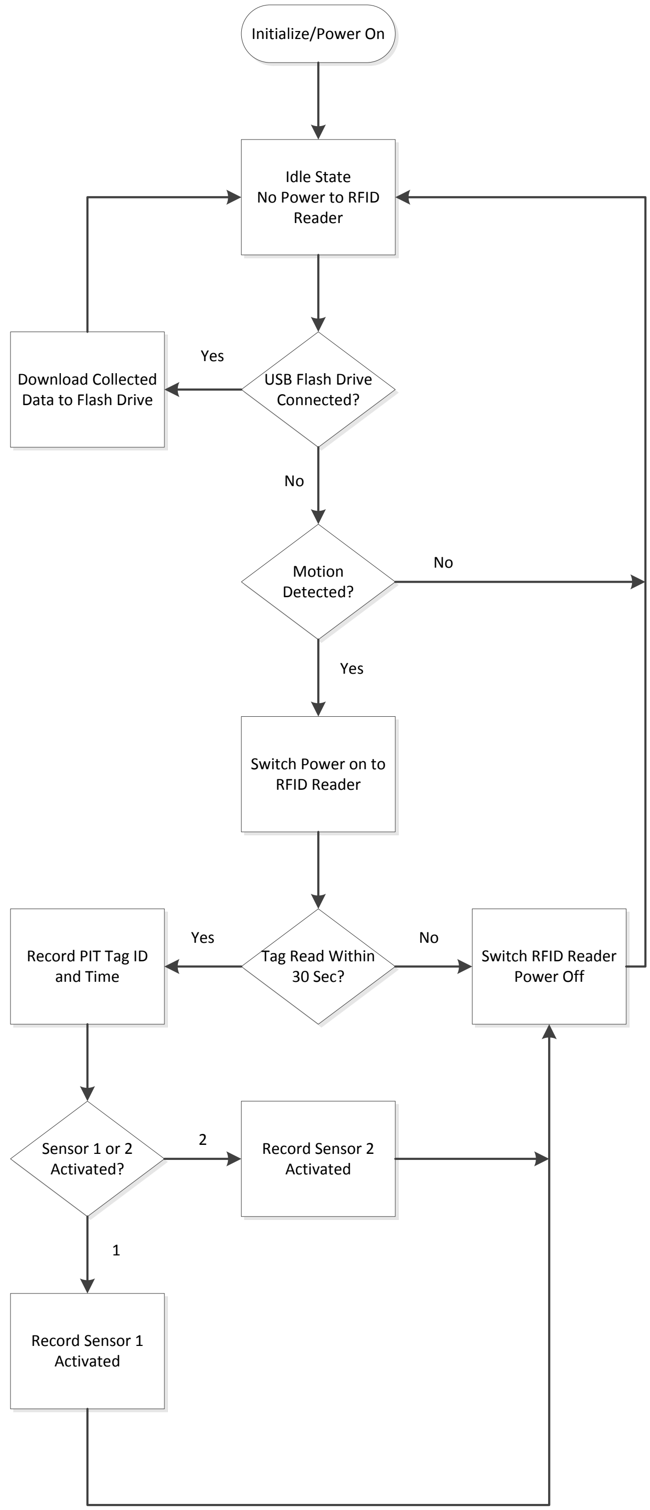

Figure B.1. The original microcontroller program flow diagram.

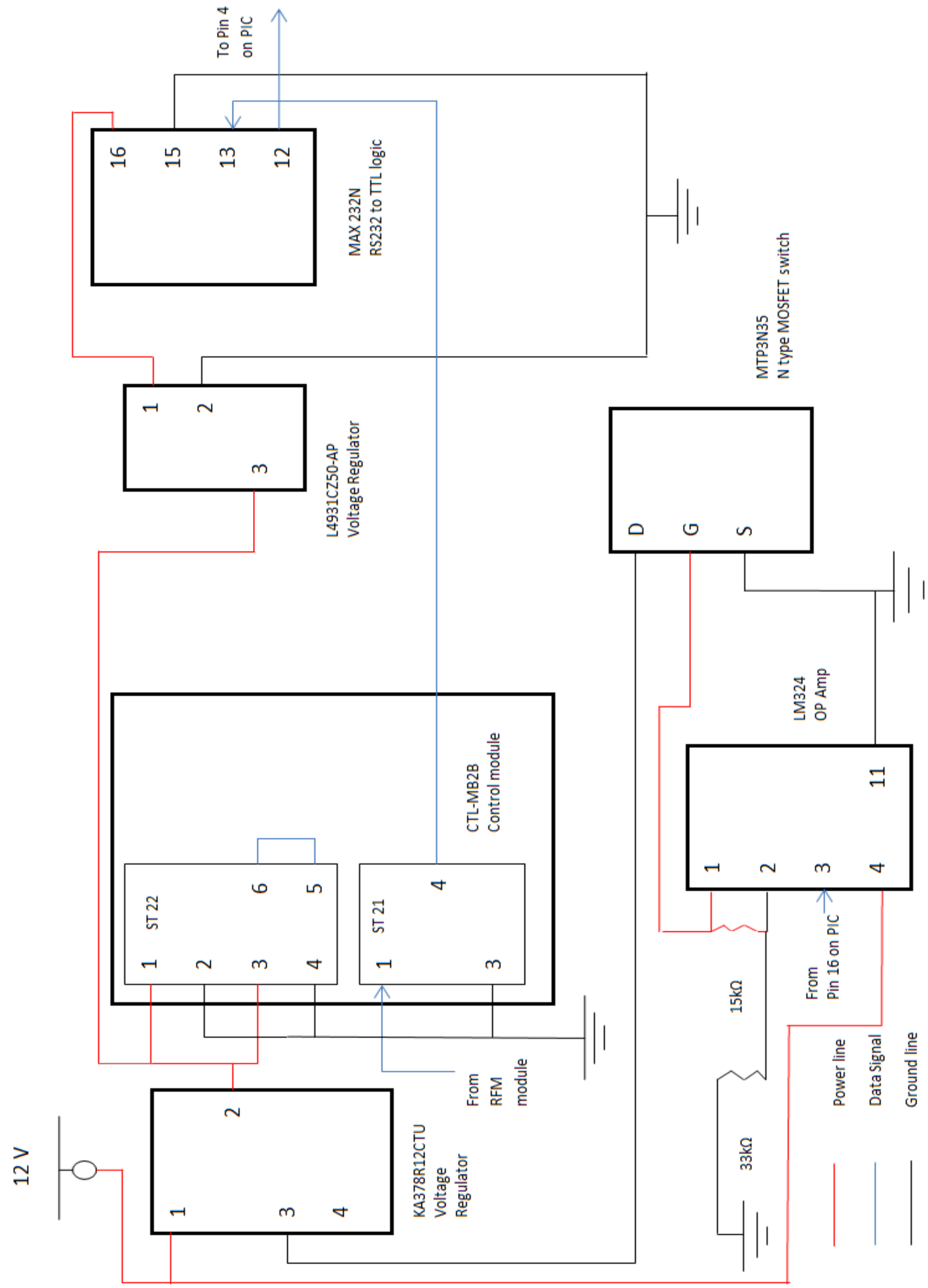

Figure B.2. The complete antenna, RFID receiver unit, and switching circuit schematic.

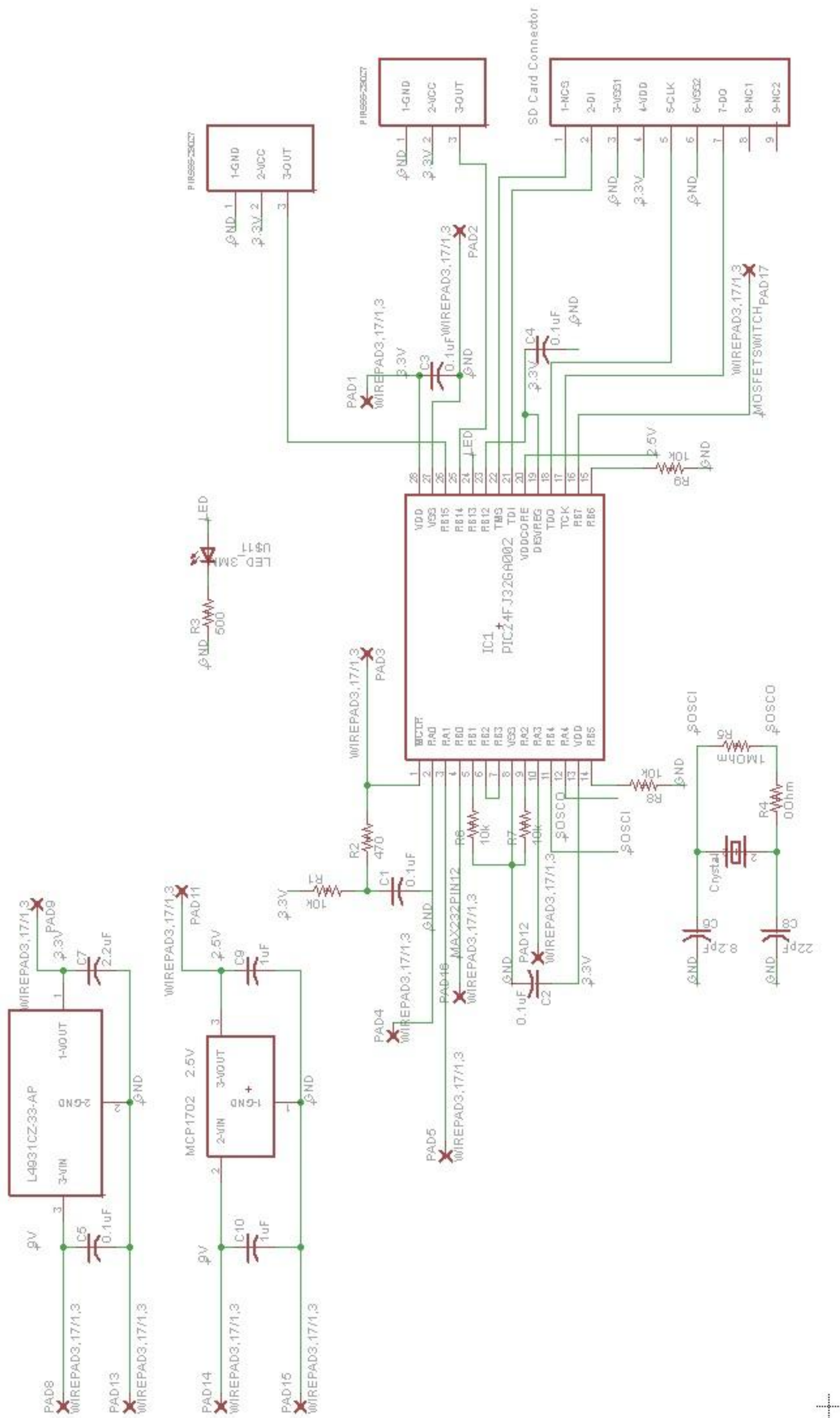

Figure B.3. The PCB circuit schematic.

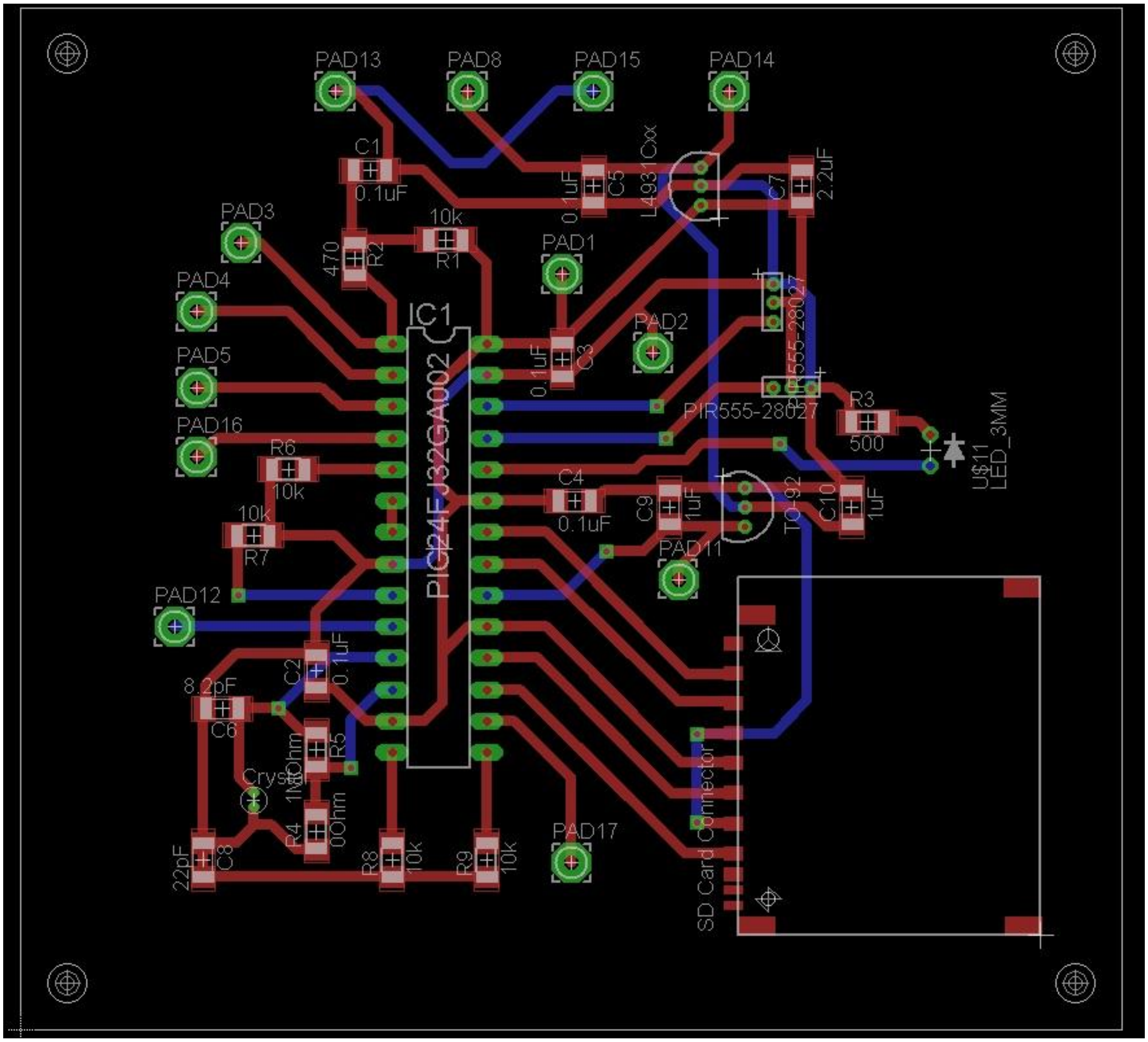

Figure B.4. The PCB physical layout.

Appendix C Microcontroller Code

RFID Receiver Power Switching

```
#include <24FJ32GB002.h>
#fuses NOWDT, NOJTAG, NODEBUG, NOPROTECT, NOWRT, NOPR, NOCKSNOFSM, NOIESO
#use delay(type=internal, clock=8MHZ)
#use RS232(baud=9600, xmit=PIN_A0)


void main(){
   int1 sensor1;
   int1 sensor2;
   set_tris_b(0xC000); //Specify B15, B14 as inputs

   while(true){

   sensor1 = input_state(PIN_B14); //Sensor pointing towards pond
   sensor2 = input_state(PIN_B15); //Sensor pointing towards land


   if(sensor1 == 1)
      printf(" pond to land");
   if(sensor2 == 1)
      printf(" land to pond");

   if(sensor1 == 1 || sensor2 ==1){
      output_high(PIN_B13);
      output_high(PIN_B7);
      delay_ms(10000);
      output_low(PIN_B13);
      output_low(PIN_B7);
   }
   }
}
```

Reading the PIT Tags

```
#include <24fj32gb002.h>
#USE DELAY(CLOCK = 4000000)
#use rs232(baud=9600, parity=N, bits=8, rcv = PIN_B0, xmit = PIN_B1, stop=1)

void main(){
       while(TRUE)
       {
              if(kbhit())
              {
                     putc(getc());
              }
       }
}
```

Reading and Writing Data to the SD Card

```
#include <24fj32gb002.h>
#fuses NOWDT, HS, NOPROTECT

#USE DELAY(CLOCK = 4000000)
#use rs232(baud=9600, parity=N, bits=8, rcv = PIN_B0, xmit = PIN_B1, stop=1)

#include <stdlib.h>

#use fast_io(B)
#define MMCSD_PIN_SCL              PIN_B9
#define MMCSD_PIN_SDI              PIN_B8
#define MMCSD_PIN_SDO              PIN_B10
#define MMCSD_PIN_SELECT           PIN_B11

#include <mmcsd.c>
#include <input.c>
#include <mmcsd.c>

void main()
{
       BYTE value, cmd;
       int32 address;

       printf("\r\n\nex_mmcsd.c\r\n\n");


        do {
               do {
                     printf("\r\nRead or Write: ");
                     cmd=getc();
                     cmd=toupper(cmd);
                     putc(cmd);
              } while ( (cmd!='R') && (cmd!='W') );

       printf("\n\rLocation: ");

       address = gethex();
       address = (address<<8)+gethex();

       if(cmd=='R')
       {
                      mmcsd_read_byte(address, &value);
                      printf("\r\nValue: %X\r\n", value);
       }

       if(cmd=='W') {
                     printf("\r\nNew value: ");
                     value = gethex();
                     printf("\n\r");
                     mmcsd_write_byte(address, value);
                     mmcsd_flush_buffer();
              }
       } while (TRUE);
}
```

Reading PIT Tags and Displaying the Timestamp

```
#include <24fj32gb002.h>
#USE DELAY(CLOCK = 4000000)
#use rs232(baud=9600, parity=N, bits=8, rcv = PIN_B0, xmit = PIN_B1, stop=1)
void main()
{
	rtc_time_t datetime = {12,0,14,11,11,0,0,15,0};
	setup_rtc(RTC_ENABLE | RTC_OUTPUT_SECONDS,0x00);
	rtc_write(&datetime);

	while(TRUE)
	{
		if(kbhit())
		{
			int i =1;
			for(i;i<13;i++)
			{
				putc(getc());
			}

			setup_timer1(T1_EXTERNAL_RTC);
			rtc_read(&datetime);
			printf("   %u",datetime.tm_year);
			printf("   %u",datetime.tm_mon);
			printf("   %u",datetime.tm_mday);
			printf("   %u",datetime.tm_hour);
			printf("   %u",datetime.tm_min);
			printf("   %u\r\n",datetime.tm_sec);
		}
	}
}
```