REMOTE SOLAR-POWERED WATER PUMP CONTROLLER

A Design Project Report

Presented to the School of Electrical and Computer Engineering of Cornell University in Partial Fulfillment of the Requirements for the Degree of Master of Engineering, Electrical and Computer Engineering

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ABSTRACT

Master of Engineering Program

School of Electrical and Computer Engineering

Cornell University

Design Project Report

Project Title: Remote Solar-Powered Water Pump Controller

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Abstract:

Our goal is to design a remote solar-powered water pump controller. The system consists of two parts: transmitter and receiver/pump end. The transmitter end consists of a microcontroller, a float sensor, a 1.5W solar panel and an RF transmitter. The receiver/pump end consists of a microcontroller, a water pump, hose, two 40 W solar panels and an RF receiver. A steel frame is built to hold the solar panels, and a power supply circuit is built to power the microcontrollers. In software development, the microcontrollers will be programmed to enable communication over a 433 MHz channel. The pump will draw water from the pump end to the transmitter end when there is enough sunlight and the storage container is not full. The transmitter will communicate the state of the container wirelessly to the receiver.

Executive Summary

The primary aim of the project is to design and deploy a remote, solar-powered water pump controller to detect the level of water in a tank and pump in water from a remote source like a pond as and when required. The water tank and the pond are separated by about 100 meters and communicate wirelessly.

The project consists of a transmitter unit and a receiver unit. The transmitter unit is located near the water tank and receiver unit is located near the pond. The transmitter and receiver units are controlled by Atmel Atmega32 microcontroller units (MCUs).

The transmitter unit consists of a microcontroller board for control, a float switch for checking the level of water in the tank and a 433 MHz transmitter module for the wireless transmission of data. The entire module is powered by a 1.5W solar panel which gives a maximum output voltage of about 20V to power the microcontroller board and transmitter.

The receiver unit consists of a microcontroller board, a Shurflo diaphragm pump for pumping water, a 433MHz receiver module for wireless reception of data and a power transistor circuit for controlling the motor. The entire setup and the motor is powered by 2 large solar panels which are setup on a steel mount for rigidity. Furthermore, the circuitry is enclosed in a steel case to protect it from adverse weather conditions.

During operation, the microcontroller at the transmitter end senses the level of water in the tank via the float switch. If the water level is low, the microcontroller transmits a ‘pump on’ signal to the receiver through the RF transmitter using the 433 MHz wireless link. The MCU at the receiver end upon reception of this signal, sends a logic high signal to the gate of a power transistor. This turns on the power transistor and causes the motor to pump in water from the pond to the water tank.

Upon design and testing, we got the transmitter and receiver subsystems to be working separately and communicating wirelessly. We were able to achieve a good range of around 80 metres with the RF wireless medium.

The major challenges we faced were the accurate transmission of data and limited range of the wireless link. We approached these issues by increasing the baud rate from 400 to 4000 bps, and increasing the input voltage to the transmitter to about 12 V.

Individual Contribution

Roland Krieger completed the following parts of the design project

- Transmitter MCU Board development and soldering.
- RF transmitter board development and soldering.
- Software section for the transmitter.
- Building receiver steel mount.
- Introduction, Software, Results section and general formatting of the design report.
- Wireless link range tests
- Pump rate tests

Saisrinivasan Mohankumar completed the following parts of the design project.

- Receiver MCU Board development and soldering.
- RF Receiver board development and soldering.
- Software section for the Receiver.
- Building receiver steel mount.
- Abstract, Executive Summary, Design and Hardware section of the design report.
- Wireless link range tests
- Pump rate tests

Table of Contents

1		Introduction………………………………………………………………..	6
2		Requirements……………………………………………………………..	8
	2.1	System Level Requirements……………………………………………	8
	2.2	Transmitter Unit Requirements………………………………………...	8
	2.3	Receiver Unit Requirements……………………………………………	8
	2.4	Communication Protocol Requirements………………………………..	8
	2.5	Issues to be addressed…………………………………………………	8
3		Design……………………………………………………………………	10
	3.1	Approach………………………………………………………………...	10
	3.2	Concept Diagram………………………………………………………	11
4		Hardware………………………………………………………………...	12
	4.1	Custom Prototype Board………………………………………………..	12
	4.2	Regulator Circuit……………………………………………………….	13
	4.3	Transmitter Unit…………………………………………………………...	14
	4.4	Receiver Unit……………………………………………………………	15
	4.5	Motor Control Unit……………………………………………………..	15
5		Software…………………………………………………………………	17
	5.1	Transmitter Unit…………………………………………………………...	17
	5.2	Receiver Unit……………………………………………………………	18
6		Results…………………………………………………………………...	20
7		References………………………………………………………………	23
8		Appendix………………………………………………………………...	24

1. Introduction

For small-scale farm owners living near water sources, it is useful to have an affordable mechanism to obtain water from natural sources such as lakes and ponds to be used on the farm. The aim of this project is to design such a mechanism for obtaining water from natural sources automatically with limited human monitoring. We designed and built an automated remote solar-powered water pump. This system should be able to draw water from a pond or other natural source and transport it over a distance of about 100m to a water-storage container. The system consists of two parts linked in two ways. The first link is the rubber hose which carries water from the source to the destination. The second link is the radio link for communication between the two ends. We refer to the subsystem with the water tank as the ‘transmitter end’, since it signals the other end when to pump water. It will consist of: a microcontroller, a float sensor and a 433MHz transceiver. The other subsystem will be called the receiver end. It will receive signals detailing the state of the water tank at the transmitter. The receiver end will consist of: two solar panels, a perforated steel frame, a microcontroller, a 433MHz receiver and a water pump.

The rest of the documentation is organized as follows:

- Section 2: lists the requirements of the system and key issues to be addressed.
- Section 3: describes the design considerations of the system.
- Section 4: describes the hardware details and circuits of the project.
- Section 5: describes the software components involved in the project.
- Section 6: provides the results and conclusions drawn from the project.
- Section 7: lists the various sources of reference we used for the completion of the project.

- Section 8: contains the various appendices like code availability.

2. Requirements

This section details the requirements to be met by the Remote Solar-Powered Water Pump.

2.1 System Level Requirements

SYS 1. The maximum cost of the system shall be less than $500
SYS 2. The system shall run on solar energy
SYS 3. The system shall withstand rain/snow
SYS 4. The system shall be reliable and safe
SYS 5. The system shall measure the water level in tank
SYS 6. The system shall communicate from transmitter to receiver
SYS 7. The system shall be eco- friendly
SYS 8. The system parts can be easily changed

2.2 Transmitter Unit Requirements

TX 1. The transmitter unit shall measure the level of water in the tank.
TX 2. The transmitter unit shall be powered by solar energy.
TX 3. The transmitter unit shall consume limited power.
TX 4. The transmitter unit shall be easily replaceable.
TX 5. The transmitter unit shall send pump on/off signals to the receiver.

2.3 Receiver Unit Requirements

RX 1. The receiver unit shall pump in water to the tank.
RX 2. The receiver unit shall be powered by solar energy.
RX 3. The receiver unit shall be easily replaceable.
RX 4. The receiver unit shall be able to withstand rain/snow.

2.4 Communication Protocol Requirements

COM 1. The protocol shall be reliable.
COM 2. The protocol shall have required medium range of about 100m.
COM 3. The protocol should be able to withstand interference.

2.5 Issues To Be Addressed: The issues are enumerated below and explained in detail:

1. <u>Resistance to Harsh Weather</u>

The primary issue is to build a steady steel mount to hold the solar panels and protect the control circuitry from adverse weather conditions like snow and rain. The steel frame is high enough and the circuitry will be enclosed in a steel case so when it rains or snows, the electronics don’t get affected.

2. <u>Reliable Communication between two ends</u>

A suitable wireless mode for communication between the two parts should be selected as the two ends may be separated by forested region so the signals should not be lost.

3. Life-span of the system

The receiver end should be able to last for several years. The solar panels will be able to operate for over 10 years. The water pump is estimated to last at least 3 years. This means for 3 years, the owner should ideally not have to do any work at the receiver end.

3 Design

3.1 Approach

3.1.1. Cost

The cost factor of the project was confined to most of the hardware. The major cost of the project were the two big solar panels and the water pump. The 40W solar panels were roughly $100 each and the diaphragm pump was around $75. The custom microcontroller board was built using an Atmega32 microcontroller which was not very expensive and also the transmitter and receiver circuitry were soldered using readily available parts in the lab.

3.1.2. Robustness

The primary need of the system was to be able to withstand varying weather conditions including rain, wind and snow. To take care of this need, we decided to build a very stable and strong steel mount for holding the solar panels firmly over the ground. The elevated frame also helps in ensuring that the solar panels have more access to sunlight than at the ground level. The elevation also helps to protect the microcontroller receiver circuitry which is placed under the solar panels from rain as well as snow accumulation on the ground during winter.

3.1.3 Range

Another important consideration to be made before designing the project was to make sure that considerable range of operation would be possible using the wireless transmission. As the distance of separation of the pond and water tank in our case was roughly 80 to 100m, we decided to use the RCR and RCT 433 MHz transceiver modules because they operate on low power and also give the required range of a maximum 100 metres. Also, since the device would be deployed in a rural farm area, it is not expected that there would be many interference sources. However, the use of synchronization and start characters, as well as the repeated transmission of packets should enable the system function reasonably well under moderate interference.

3.1.4. Reliability

Reliability of the system to automate the pumping process is very essential to this project. It was one of the primary motives because the entire process has to be reliable and automated. The system works reliably without any special intervention of the user and the entire pumping procedure works automatically. As a safety precaution, in case the transmitter somehow fails to transmit after the tank has been full, the receiver is programmed to turn off the pump 3 minutes after the last ‘pump on’ signal is received. This avoids overflow of the tank when the receiver does not get a ‘pump off’ signal at all.

3.2 Concept Diagram

The concept diagram of the hardware system is shown below.

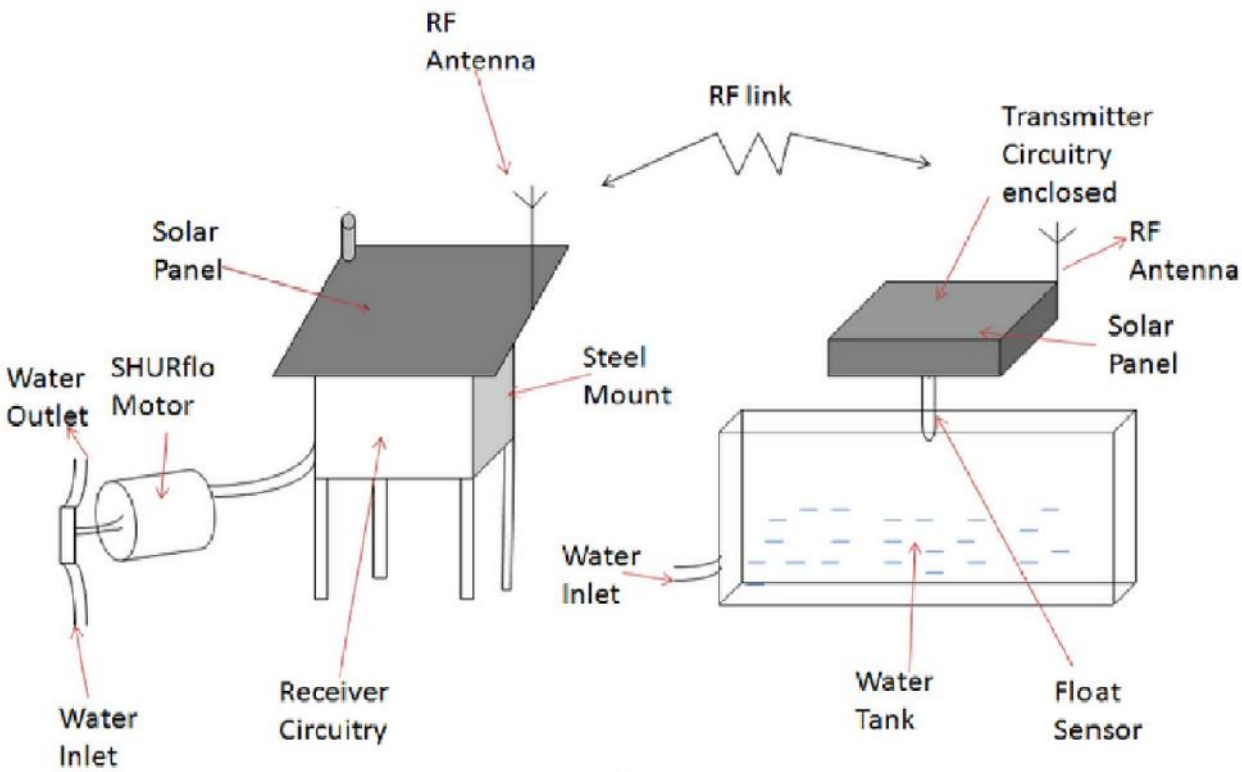


Fig.1: Function Sketch of the system

4 Hardware

4.1 Custom Microcontroller Board

We used a custom microcontroller board used in the ECE 4760 course for our project. We soldered and designed our own board according to the specifications on the course webpage. We left out certain components like serial communication module as we did not require them.

The prototype board is a custom board for Atmega644 or Atmega32 PDIP. It has an on-board 5V voltage regulator for the MCU operation and also an external crystal oscillator. The microcontroller is programmed using an AVRISPmkII by flash memory programming. The microcontroller has 32 pins which are connected through a SIP header plug to other units.

The following is the schematic of the custom board which is copyrighted by Professor Bruce Land.

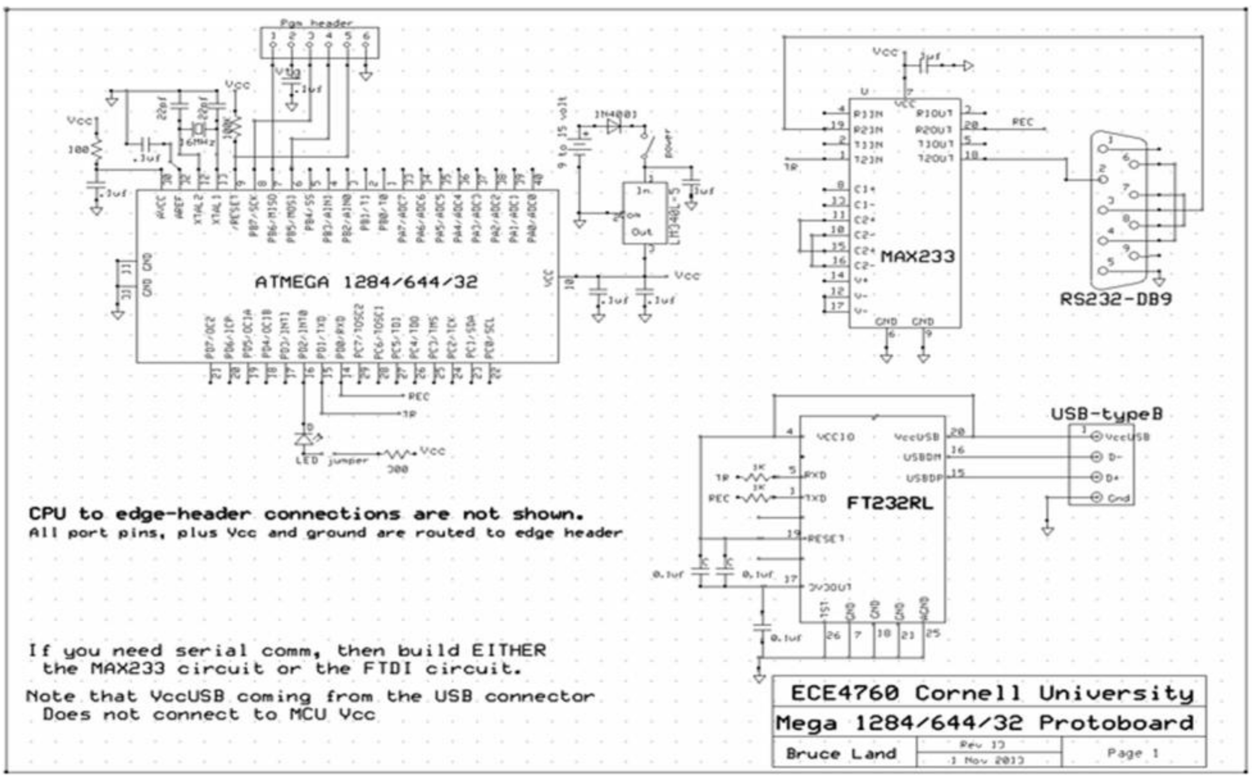


Fig. 2: Schematic of MCU board

The connection for the USB serial port was not required for our system so we left that out.

The board has a header for UART transmitter and receiver which can be used for our transmitter and receiver operation. There are also some safety capacitors and LED's for debugging purposes. The voltage regulator which is used for the microcontroller is a LM7805 linear voltage regulator which maintains a steady 5V supply for the operation of the microcontroller. The following is the default board before the components are soldered.

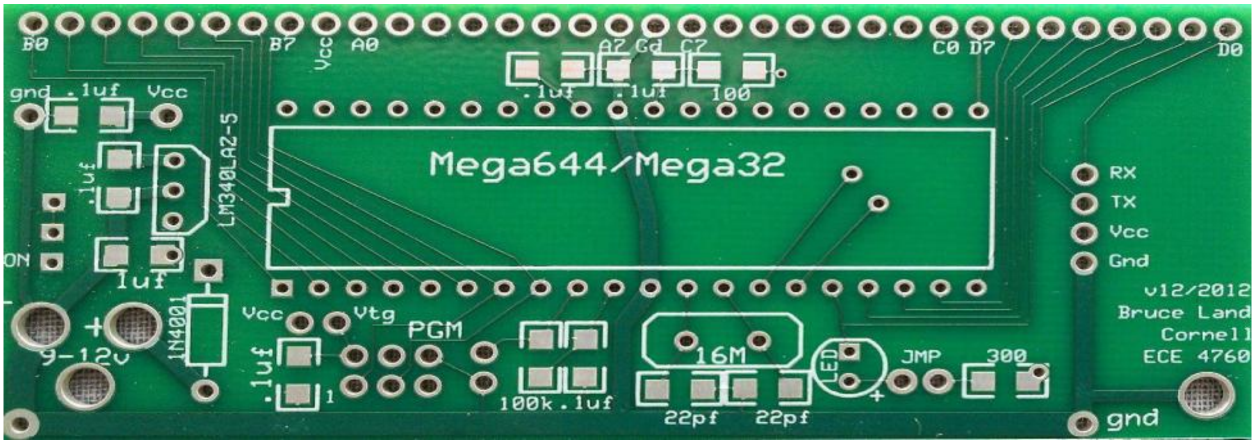


Fig.3:Picture of plain MCU board

The following is the custom built board after all the components are soldered and ready to use.

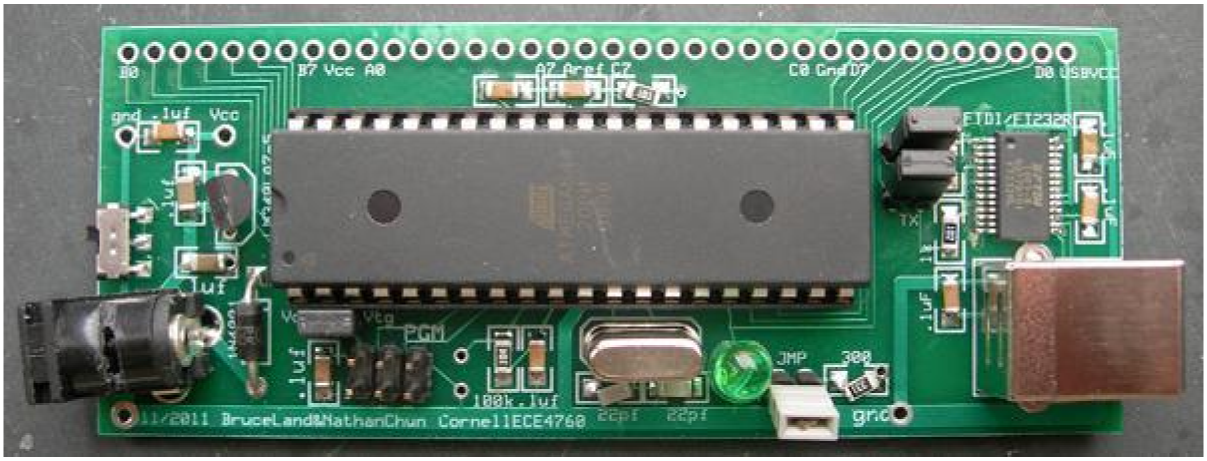


Fig.4:Picture of populated MCU board

4.2 Voltage Regulator Circuit

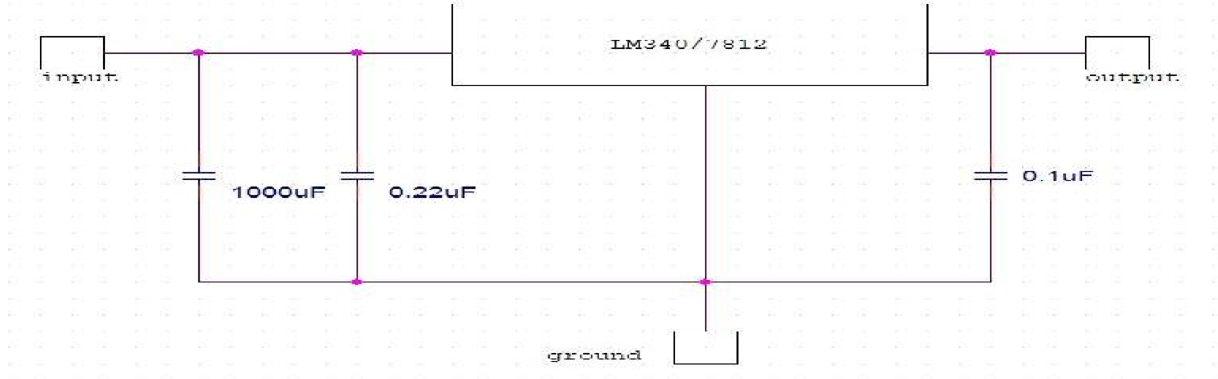


Fig.5: Schematic of Voltage regulator circuit

The above figure is the schematic of the voltage regulator circuit required at the transmitter end. The output from the solar panels in unregulated and may vary but the transmitter module requires constant 12V for its operation at a higher range. To achieve this voltage, a linear voltage regulator LM340 is used. It converts the unregulated voltage from the solar panels to a constant 12V DC supply.

4.3 Transmitter Circuit

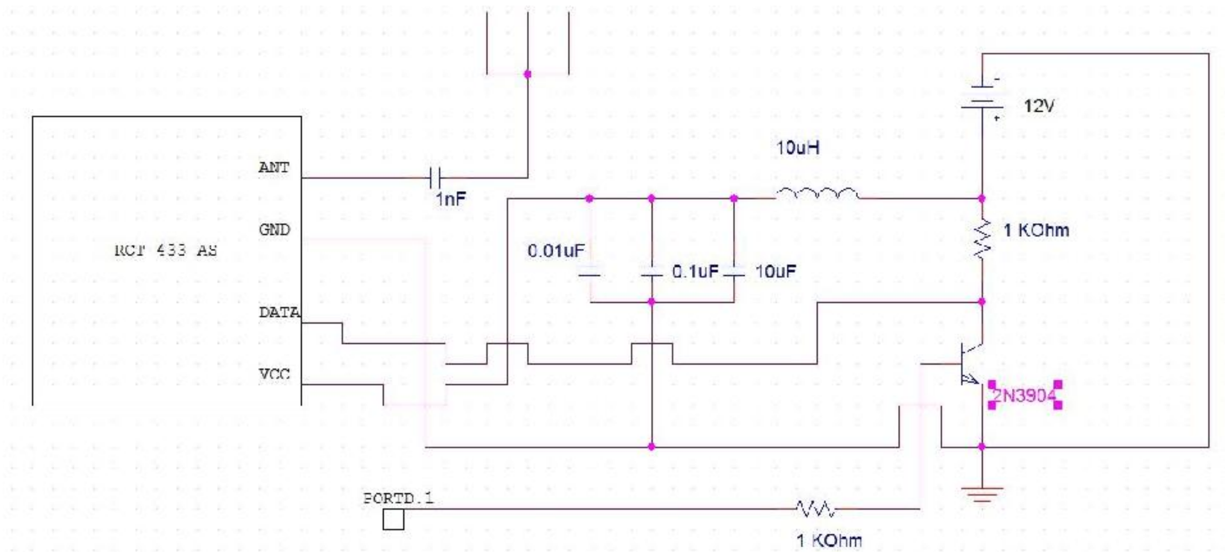


Fig.6:Schematic of RCT-433 AS Transmitter Board

From the figure above, RCT-433AS is the wireless transmitter module. The input to the transmitter block is from the PORTD.1 pin of the microcontroller. This pin is the UART transmitter pin of the microcontroller. When the MCU senses the level of the float switch, it writes a message to the USART buffer, which in turn sends bits out of the USART TX pin at a baud rate of 4000 bps. The communication protocol used is called On-Off Keying (OOK). By On-Off Keying, a bit 1 is equivalent to a transmission at the carrier frequency and a bit 0 is equivalent to no transmission. In order to save power at the transmitter, a pnp transistor inverts the output for transmission so that the transmitter is idle most of the time. In order to take into account this inversion, we need a similar inverter on the receiver and decode this inverted transmission. The signal from D1 is connected to the base of the NPN transistor.

4.4 Receiver Circuit

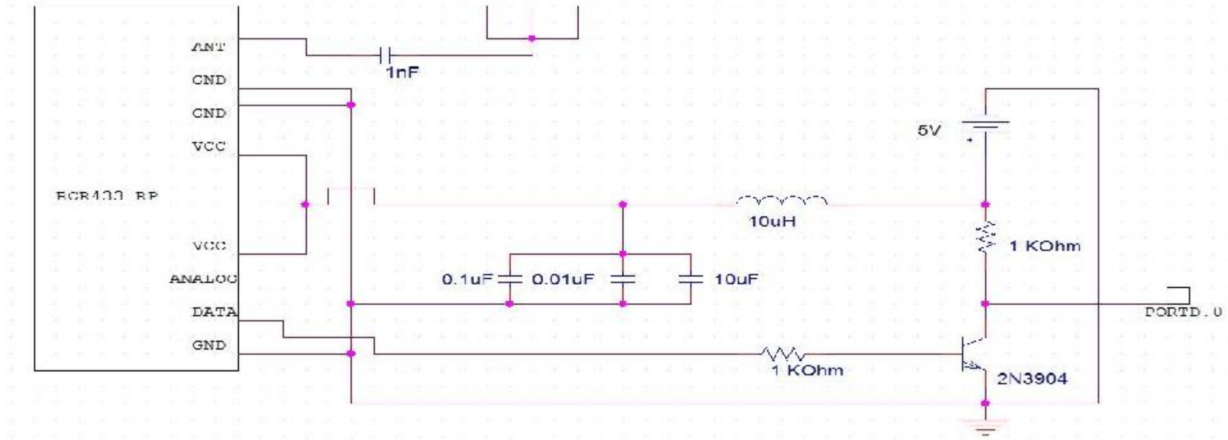


Fig.7: Schematic of RCR-433 RP Receiver Board

The above figure shows the schematic of receiver module: the RCR-433RP. The output of the receiver block is connected to the pin D.0 of the microcontroller. The pin is the UART receive pin of the microcontroller. When the receiver receives a ‘pump on’ signal, the microcontroller turns on another port pin B.0 high to operate the motor. The signal from pin B.0 is connected to the gate of a power transistor (BUZ71 below).

4.5 Motor Control Circuit

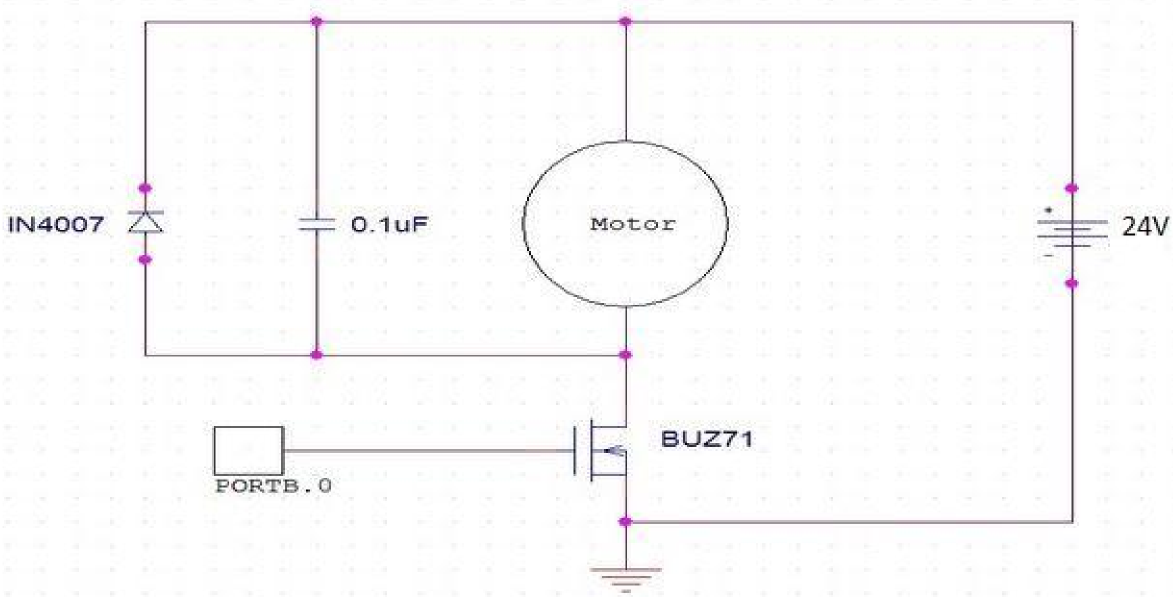


Fig.8: Schematic of Motor Control Circuit

The above circuit is used to control the motor on the receiver side. The output port pin B.0 of the microcontroller is connected as the gate of a power transistor BUZ71. When the pin is turned high, the transistor turns ON and the motor turns on which pumps the water from the pond to the water tank. The capacitor and reverse-biased diode are connected in parallel with the motor to avoid inductive spikes which might damage the MCU.

5. SOFTWARE:

The software programs for the microcontrollers were written in C in the AVR studio development environment. The transmitter and receiver end microcontrollers share a base code for initializing registers for the communication protocol (txrx.c). The transmitter end program is described below.

5.1 Transmitter End:

As stated earlier, the requirements of the transmitter unit include the ability to detect the input voltage from a float switch, and to control a 433-MHz transmitter. The USART module on Atmega32 is used to control the data transfer from the MCU to the transmitter. At initialization, timer 0 is set up to give a 1ms time scale which can then be used to time tasks. Then interrupts are enabled. The two interrupts that are unmasked are the timer 0 compare match and the USART_UDRE_vect (triggered by empty transmit buffer). The baud rate of the serial module is set to 4000 bps. The MCU is programmed to send one packet of information every 200 ms. At the end of every 200 ms period, the program checks the state of the float switch (connected to port A0). If the switch is on, the character ‘symbol_On’ is transmitted whereas ‘symbol_Off’ is transmitted when the switch is off.

<u>Data Transmission:</u> The packet structure used is a modified version of that available from Desai et. al. It consists of 3 synchronization bytes, a start character, a single data byte and an end character. According to the protocol, each byte that is transmitted consists of an equal number of 0s and 1s (DC balancing) to ensure that calibration at the receiver is not lost during transmission[1]. The packet structure is shown in the table below:

Transmit Order	Byte type	Binary Value	Decimal Value
0	synch_char	0b10101010	170
1	synch_char	0b10101010	170
2	synch_char	0b10101010	170
3	start_char	0b11001010	202
4	data char	symbol_Transmitted	149/180
5	end_char	0b11010100	212

Table 1: Transmitter Packet structure

The data symbol that is transmitted is symbol_Off (149) and symbol_On (180). One character is loaded into the transmit buffer at a time when the empty transmit buffer interrupt occurs (USART_UDRE_vect). The USART module then outputs the bits out of PIN D.1 which is the transmit pin. This pin is connected to the base of an npn transistor to turn on or off the transmitter. The benefit of the symbols used above is that the minimum Hamming distance between any two symbols is 2, which means that at least two bit flips are required before one symbol is wrongfully decoded as another[1].

5.2 Receiver End:

The program running on the microcontroller at the receiver should be able to detect the data that is received, and to turn on or off the voltage at a port pin to control the pump. As in the transmitter program, timer 0 is once again used to generate a 1 ms timer using compare match interrupts. The baud rate is also set to 4000 bps since both transmitter and receiver have to operate at the same baud rate. Reception of bytes occurs via the USART_RXC_vect ISR which gets triggered when the USART buffer (UDR) receives one byte of data. At this point, the program checks for the synchronization character. If the synchronization character is absent, the program ignores the received byte. However, if the synchronization character is received, the program then searches the next 3 bytes for the start character. The program would then receive the data byte if the start character is found or if it isn’t found after 3 attempts to find the start character. Finally, bytes are received until the stop character is found, or the maximum number of receivable bytes (32 bytes) is reached. When the whole data array is received, the program then checks if the data is valid (if the 2nd element of the message array is the start character). If the data is valid, the program then checks if the 3rd element of the message array(my_rx_data) is symbol_On. If that is the case, pin B.0 is written a logic high to turn on the pump. Otherwise, it is written a logic low to turn off the pump. We programmed some redundancy into controlling the pump switch. A timer is started every time a symbol_On is received. If after 3 minutes no other symbol_On is received, the pump is turned off. This is to account for the possibility that, if there is a problem at the transmitter and it last transmitted a symbol_On, the pump should not be perpetually on provided the MCU is powered.

The state machine for receiving a message is shown below:

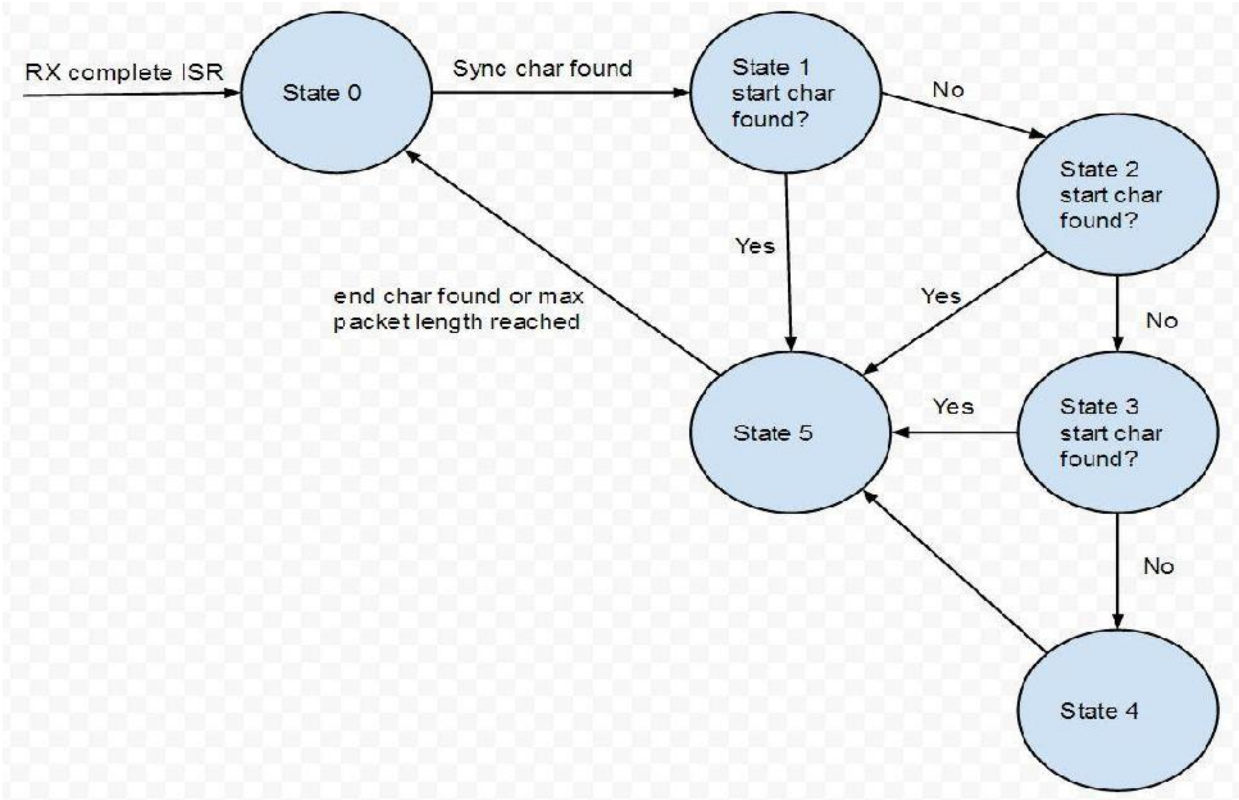


Fig.9: State diagram of receiver

6. RESULTS

6.1 Accuracy and reliability

The subsystems of this project have been independently tested and are working. The first major test is the range test of the 433 MHz wireless link. Indoor and outdoor testing produced a range of about 80 meters. The indoor test was performed at opposite ends of Duffield Atrium, which is quite spacious but still has some reflecting surfaces like walls and tables. The outdoor test was performed across the engineering quad, with the transmitter at the top of the staircase leading to Duffield Hall and the receiver at the entrance to the engineering library. It was mostly open space, with only a few trees in the vicinity of the transmitter and receiver. This range has been achieved without sophisticated antenna design (impedance matching and different antenna topologies). We used a quarter wavelength wire (17 cm) at the transmitter. At the receiver end, we first used a 17-cm wire as an antenna, and then a 17-cm tape measure. We found that, even though both cases gave the same range, a receiver antenna made out of tape measure received signals more often than one made out of wire. The downside of using tape measure as an antenna is that it is too heavy and needs a rigid base which is present at the receiver because of the steel case enclosing the receiver circuitry. With better antenna design, it is possible to increase the range above 80 meters.

The pump at the receiver will pump at varying speeds from 24V to about 3.5V. Thus, when it becomes reasonably cloudy, the pump is still expected to work albeit at slower speeds.

A plot of pump rate at selected input voltages according to our observation is shown below:

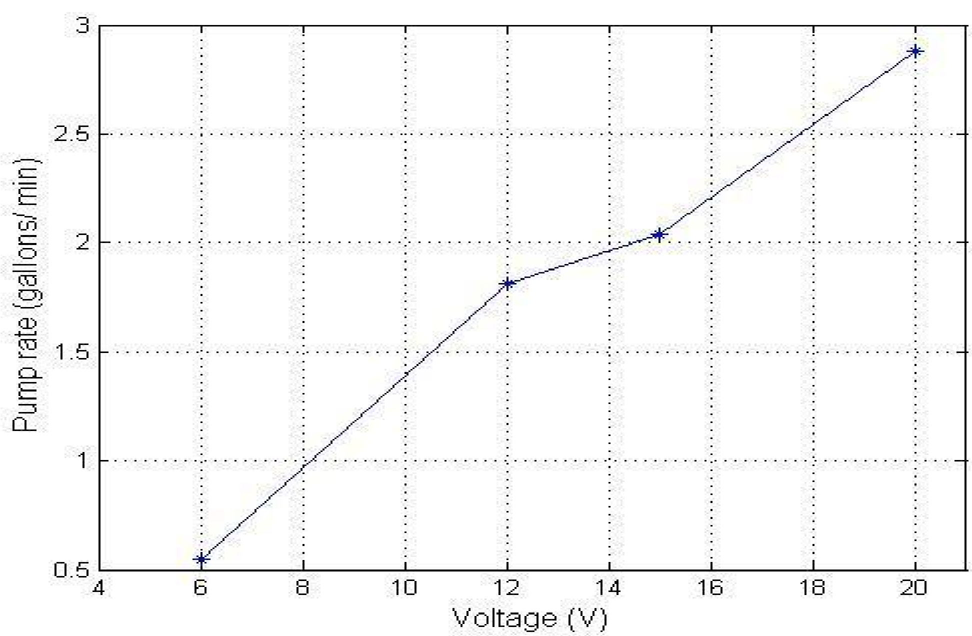


Fig 10. Pump rate versus input voltage

6.2 Requirements Match

Requirement ID	Requirement	Status
SYS 1	The maximum cost of the system shall be less than $500	Met
SYS 2	The system shall run on solar energy	Met
SYS 3	The system shall withstand rain/snow	Partially Met
SYS 4	The system shall be reliable and safe	Met
SYS 5	The system shall measure the water level in tank	Met
SYS 6	The system shall communicate from transmitter to receiver	Met
SYS 7	The system shall be eco- friendly	Met
SYS 8	The system parts can be easily changed	Met
TX 1	The transmitter unit shall measure the level of water in the tank	Met
TX 2	The transmitter unit shall be powered by solar energy	Met
TX 3	The transmitter unit shall consume limited power	Met
TX 4	The transmitter unit shall be easily replaceable	Met
TX 5	The transmitter unit shall send pump on/off signals to the receiver	Met
RX 1	The receiver unit shall pump in water to the tank	Met
RX 2	The receiver unit shall be powered by solar energy	Met
RX 3	The receiver unit shall be easily replaceable	Met
RX 4	The receiver unit shall be able to withstand rain/snow	Met
COM 1	The protocol shall be reliable	Met
COM 2	The protocol shall have required medium range of about 100m	Partially Met
COM 3	The protocol should be able to withstand interference	Partially Met

6.3 Conclusions

The entire receiver steel mount has been built. The individual components in the receiver and transmitter end have been built and soldered using non-conducting dotted boards. The system has is working well in the required range of about 100 metres. The prototype water pump controller is ready for deployment in the field. The map of the targeted area of deployment is shown in the picture below.

Fig. 11: Map of area of deployment

The receiver and transmitter circuits have to be placed in their respective storage boxes before they are deployed in the field. The storage box made of steel is shown below.

Fig. 12: Storage box for the receiver

7. REFERENCES:

1. Desai, M.Wireless Transmit and Receive Project
http://people.ece.cornell.edu/land/courses/eceprojectsland/STUDENTPROJ/2005to2006/mpd25/report.html

2. Mega 644 Prototype board
http://people.ece.cornell.edu/land/PROJECTS/ProtoBoard476/

3. Report Guideline
http://people.ece.cornell.edu/land/courses/eceprojectsland/STUDENTPROJ/2010to2011/arv44_zx52/arv44_report_201105200944.pdf

8. APPENDIX

8.1 Code

Code available upon request from the authors.

8.2 Pictures

Fig. 13: Receive side solar panels and pump

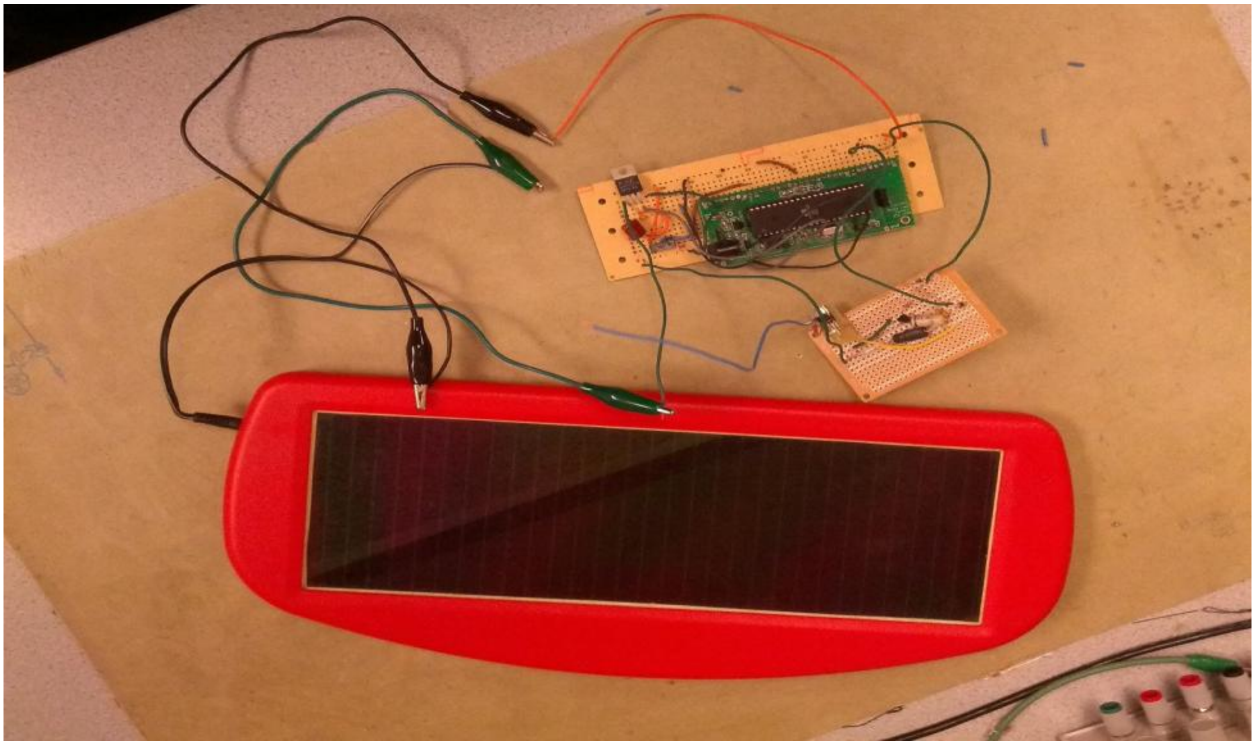


Fig. 14: Transmitter Unit (without float switch)

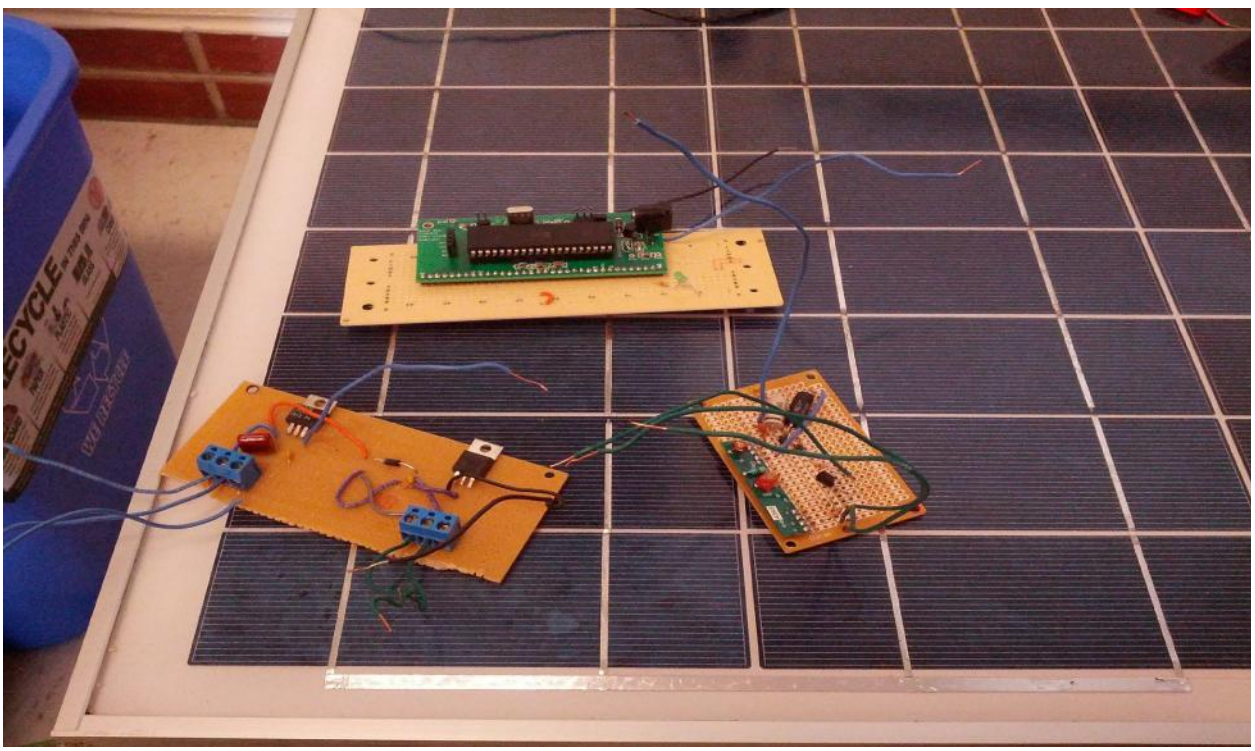
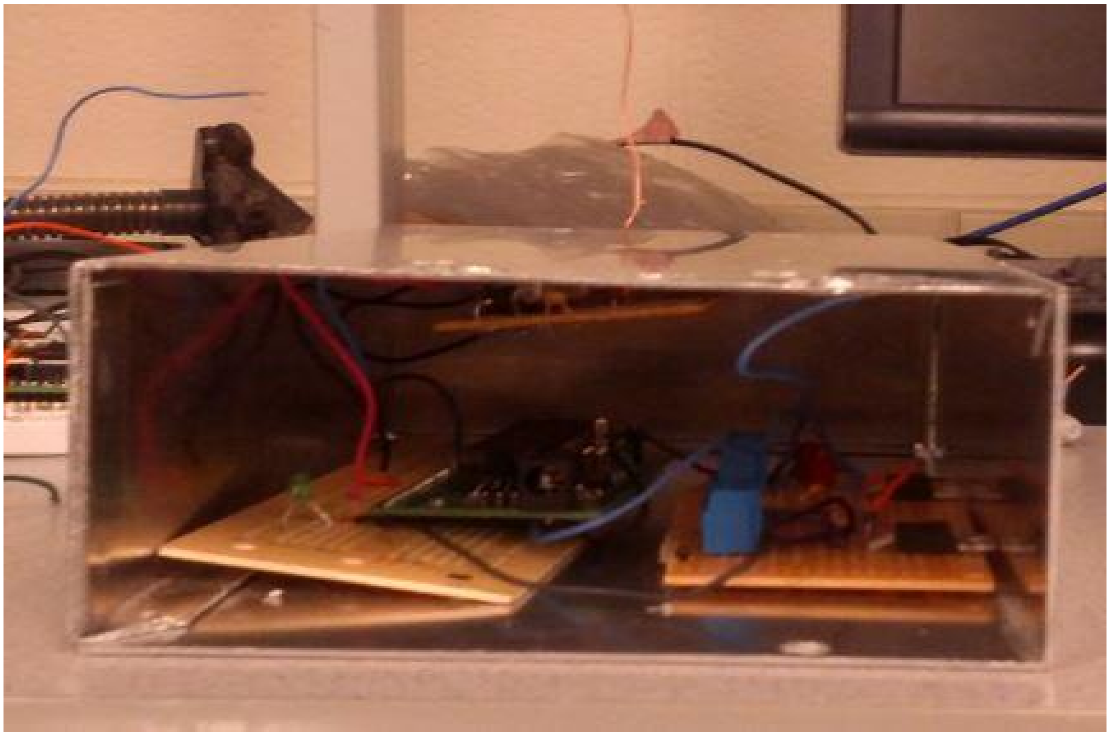


Fig.15: Receiver Circuitry



Receiver Circuitry embedded in steel case