UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

On Site Hotbox Calibration System

ECE445 - Project Proposal

Pourya Assem – Paul Lupas

TA: Rajarshi Roy

9/19/2012

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Introduction

Title

The project was selected because of a high demand and immediate need for railroad companies to be more efficient and accurate in calibrating IR heat sensors, a critical task for inspecting the train wheels and bearings, enforced by Federal Laws. We are excited to make a significant improvement in the calibration procedure. We are convinced that this product will be very marketable because it is a necessary piece of equipment, which has not been implemented before for railroad companies. Furthermore, the railroad company that we are in contact with has showed a high interest to buy this device upon completion with rated specifications.

Objectives

Goals

- Shift the railroad industry from all mechanical to all electrical sensor calibration devices.
- Guide servicemen through the calibration process by visualizing the heat signatures.
- Faster and more accurate calibration process compared to the current mechanical techniques.
- Create a universal standard for integrating the calibration process.

Functions

- Acquire data from gate opening and closing transducers.
- Acquire data from the IR heat sensors.
- Ensure proper timing synchronization between transducers and IR heat sensors.
- Ensure proper signal level of transducers and IR heat sensors.
- Ensure proper wave form read by the IR heat sensors.

Benefits

- Service time efficiency due to on-site data analysis and fast feedback.
- Service cost efficiency due to time efficient method and higher calibration quality.
- Less data traffic on servers, because servicemen do not need to collect data from the servers.
- Relatively cheap device ~$50, compared to mechanical calibration tool kit.

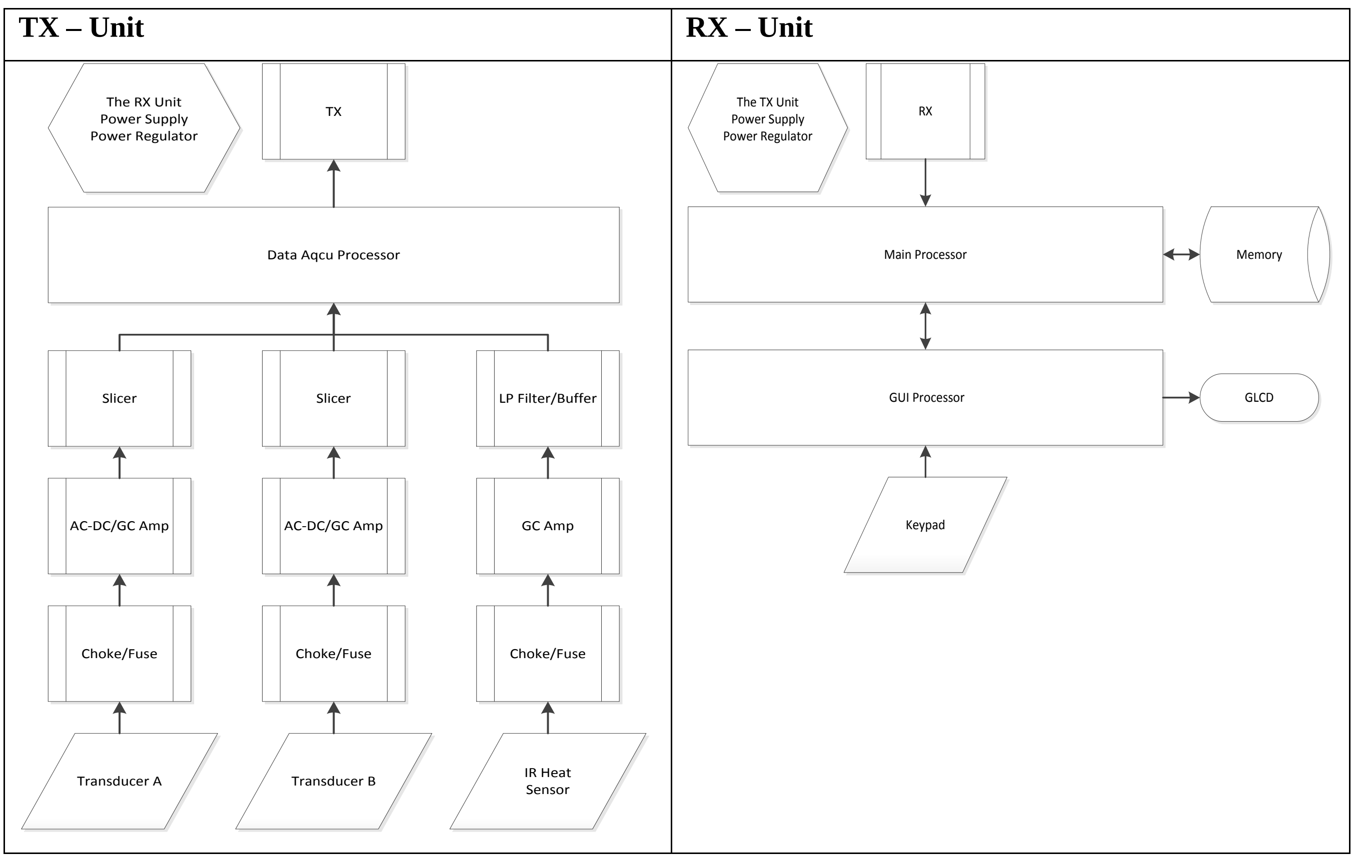
- Wireless data transmission allows service man to keep a safe distance from traveling train.
- Wireless data transmission allows the service man to collect data in critical weather conditions and unreachable bungalow locations.

Features

- Wireless data transmission.
- SD card data storage.
- Graphical interface.
- Battery powered.
- Small handheld unit.

Design

Block Diagram

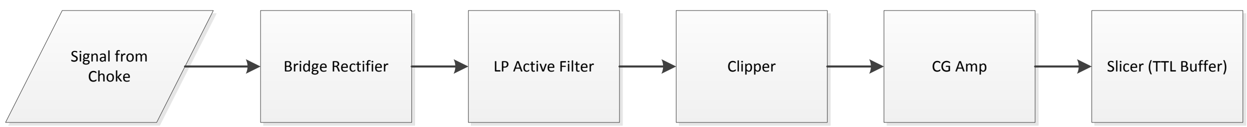


Block Description (More Details Provided in Requirements' Section)

The system consists of two main units: the TX Unit and RX Unit. They communicate wirelessly through the Zigbee protocol (2.4GHz). This protocol provides fast data transfer, reliability, and data security. All the other blocks within the TX Unit and RX Unit are interconnected using wired connections.

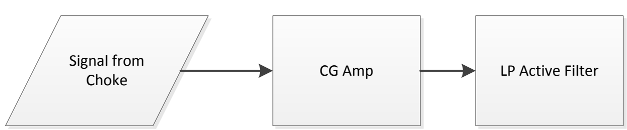
TX – Unit

Transducer A and B



These two blocks are identical. They are not part of our system. However, our system will connect to them through the chokes to read the signal. The transducer blocks are responsible for generating a signal which indicates the presence of the train wheel on top of the IR heat sensors. The transducer sends a short analog pulse (one sine period) when a wheel passes over them. In addition, these pulses activate a shutter covering the IR sensors windows. The block diagram above shows the electronics to fetch and convert the transducers' signal to a readable level for microprocessors.

IR Heat Sensor



This block sends an analog signal, which shows the heat signature of the train wheel/bearing that is detected by the transducers A and B. The signal will be further analyzed to graphically present the heat signature pattern. As in the case of the transducer blocks, this block is not part of our system. The block diagram above shows the electronics to fetch and convert the IR heat sensors' signal to a readable level for microprocessors.

Choke/Fuse

The function of the choke is to provide total electrical isolation between our system and the transducers and IR heat sensors. The manufacturer prohibits direct contact to the sensors and processors. The choke is a 1:1 transformer for low frequency signals (10 to 500 Hz) implemented using a toroid. The input ground of the choke will be connected to the ground pin of the sensors and the output ground will be connected to the ground pin of our system. This ensures there is no effect on the operation of the DUT. The fuse will protect against unexpected high voltage spikes that might be generated by lightning or other sources that might damage the system.

AC-DC/Clipper/GC Amp

This block is responsible for amplifying the transducer signals, fed directly from the choke/fuse block connected to the transducer blocks. The AD-DC conversion is implemented by a bridge rectifier circuit followed by a low pass filter (RC network). The DC signal will be clipped to get rid of the bumpy top part of the signal. In the next stage, the signal is amplified using a gain controlled amplifier, which is used to scale the signal to the appropriate voltage level. To obtain a perfect square wave, the signal will be passed through a TTL buffer. The digital signal will be fed into the digital port of the processor. The Amplifier will be implemented using a non-inverting op-amp configuration. The clipper block is a simple diode biased by a resistor.

GC Amp

The gain controlled amplifier will be set to amplify the IR heat signal coming from the choke/fuse stage. This block utilizes a non-inverting op-amp configuration.

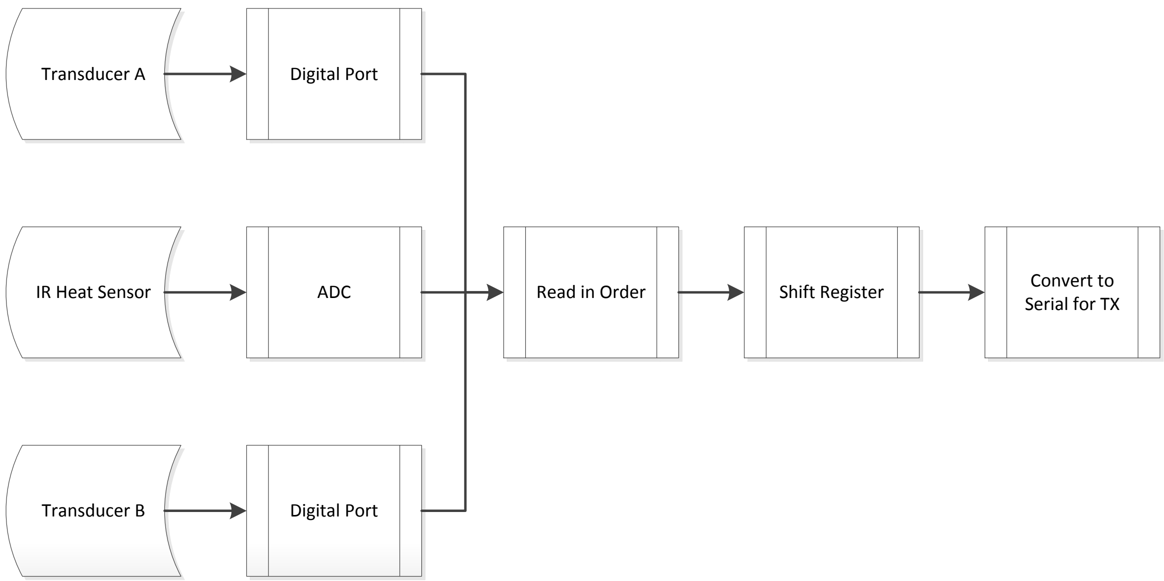
Active LP Filter

This block is responsible for filtering out all the unwanted frequency signals (mostly high frequency, noise) of the amplified IR heat signal. It will have the 3dB cutoff frequency at 200Hz and 20dB at 1KHz. The signal passes through a buffer and then goes through the ADC of the processor.

Slicer

It consists of a two serially connected TTL inverters borrowed from a hex inverter chip.

Data Acquisition Processor



This is the decision making block of the system for the TX Unit. The ATMEL328 chip is programmed to implement all the functions of this block. The chip has an 8bit ADC which will take as input the amplified IR heat sensor signal. The processor reads a digital signal from transducer A and B and the IR sensor. It will combine these three signals into a single array to have the following sequence: transducer A signal, heat signal, transducer B signal. This sequence includes the data for one wheel. This sequence will be passed through 1 bit shift register. The serial output of the processor will send this data array to the RX block. This block is also responsible for down sampling the incoming signal.

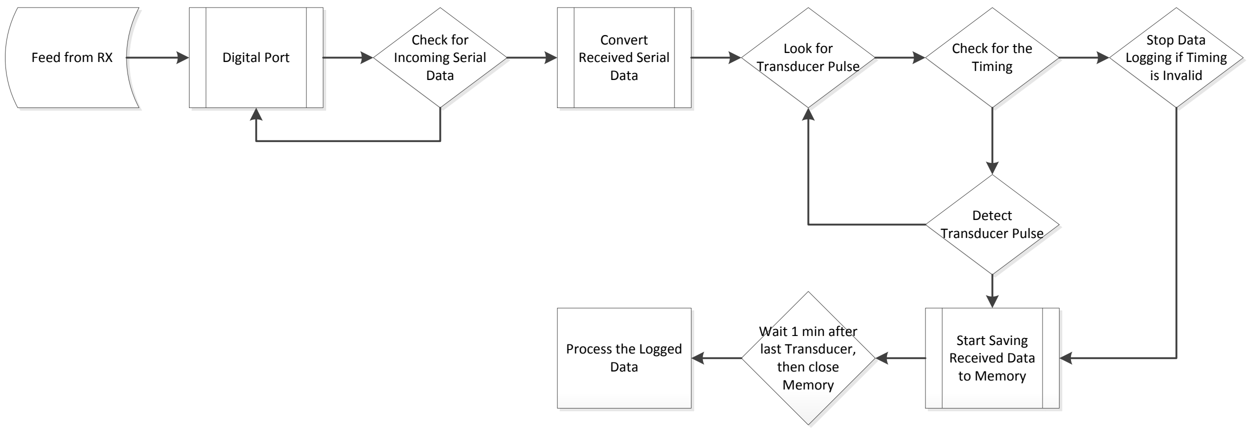
TX XBEE

This block is implemented using a XBEE wireless module. It is responsible for transmitting the serial data generated by the processor block from the TX Unit. The XBEE wireless module employs the Zigbee protocol to communicate to the receiver module.

RX – Unit

This block is implemented using XBEE wireless module. It is responsible for receiving the serial data from the TX block.

Main Processor



This block uses the ATMEL328 chip to analyze the data received by the RX block. It has an algorithm that searches for the transducer pulses. As soon as a transducer pulse is observed, a counter is triggered which interrupts data analysis if the time between transducer pulses is greater than 3 seconds. Another algorithm works in parallel to check for data between the transducer pulses and send it to the memory block. If the time between the two transducer signals is greater than 3 seconds, the user gets the permission to access the data from the SD card. The 3 second time interval is calculated for a train traveling at 20mph. So, if the time interval is greater than 3 seconds, it means that the train passed over the site and all the wheels/bearings are scanned.

Memory

This block consists of a SD card (secure digital flash memory). It is responsible for storing the data sent by the Main Processor via SPI protocol and has it accessible for further analysis and graphical display. The data will be saved in a text format.

GUI Processor and GLCD

The Graphical User Interface Processor is used for the GLCD (graphical liquid crystal display) block. The processor is the driver for the GLCD which will be used to display signal waveforms and other features of the train wheels/bearing. When the Main Processor grants permission to the user for accessing the data on the SD card, the data is passed to this block using I^2C bus through the main processor.

Keypad

This block consists of a keypad which will be used for going through the data collected for the train wheels/bearing. This is connected to the Main Processor through the GUI processor. The commands such as accessing previous or next heat signature data or calculating the train's speed for that period will be available.

Requirements and Verification

Requirements

Choke + Fuse

As the first stage of our system, which is in direct interaction with DUT, the choke has to be used at the sensors' terminals to make perfect isolation between DUT and the calibration system. This is required by the manufacturer. Chokes should not drain more than allowable current as specified by the manufacturer. The chokes have to have a flat response over frequency span of 10Hz to 500Hz with 1:1 transfer ratio, and minimum coupling loss. The chokes have to have small impedance over the operating frequency, and the fuses should be capable of handling 0.25A. Fuses are for the mere reason of preventing high voltage spikes entering the calibration system. This is a common practice in railroad equipment, because of lightings and static charge dangers.

AC-DC Converter + Amplifier + Clipper

This stage is directly fed from fuses, with minimum power consumption. Full wave bridge rectification and LP filtering is used to convert the transducer pulse (one sine period) to a raised cosine shape. The larger amplitudes improve the detection quality and system becomes more sensitive to short pulse periods (good LP filter). The expected input from transducers at the fastest rate is a one full sine wave period every 5ms, and 500ms for the slowest rate. The pulse period is positively correlated to the time span between the pulses. We expect to see a quiet time or low noise level between the pulses at the output. The clipper (clipping the raised cosine) and amplifier circuits should be tuned to provide a large enough pulse to drive the TTL buffer.

Amplifier should have low noise and low power consumption. Amplifier gain is expected to be within a controllable range of 0.5 to 10.

TTL Buffer

This stage is fed by the amplifier stage, to convert the clipped signal to a perfectly acceptable TTL logic level by the microprocessor's digital ports, and providing wide noise margins. TTL buffers should be provided enough input power for proper operation. The input signal from the amplifier should not have a steady state in the unknown region of TTL operation. The TTL output is directly connected to the microprocessor.

Gain Controlled Amplifier + Active Filter

To scale up or down the IR sensors' signal to an acceptable level seen by the microprocessor's ADC. This range is 0 to 5VDC. The amplifier should have a low noise level, low power consumptions and controllable gain of 0.5 to 5. The LP filter should have a flat response over frequency span of 10Hz-100Hz with 3dB at 200Hz and 20dB at 1KHz. The inputs are directly connected to the choke, and the outputs are driving the microprocessor's ADC.

TX Microprocessor

Should be able to handle process and transmit the collected data into a serial connection, fast enough for a train at 100MPH. The microprocessor is clocked at 20MHz. So the calculation should be performed to take enough number of samples for a train going at minimum and maximum speed. The sampling at 8KHz should be downed sampled according to this calculations, and optimized for minimal data traffic on the serial data bus going to XBEE TX at 9600 rate.

XBEE TX Side

Make proper connection with the microprocessor through the serial channel.

XBEE RX Side

The receiver should be placed within the covering range of TX side, and make proper serial connection with the main data analyzing microprocessor.

RX Microprocessor

It should be able to handle and process data at the rate which transmitted by the TX microprocessor. Should be fast enough to analyze and deliver the data to SD card. It should have reliable counters and algorithms to properly detect transducers pulses. It should have a reliable algorithm to make a safe connection to GLCD microprocessor driver through the I2C bus. The I2C bus should be implemented with minimal line capacitance to ensure proper data transition.

SD Card

It should be compatible with the driver. No more than 8GB of data is accessible. Furthermore, it has to be formatted in FAT32 file system. The writing process should be fast enough to catch up with the incoming data rate.

GCLD Microprocessor

It has to have a proper I2C connection with the main microprocessor. It should have the serial port reserved for GCLD connection. This microprocessor does not have to have a high data rate transfer rate, since it is not a real time processor.

GCLD

The firmware should be formatted to SGC, and compatible with the driver.

Keypad

It is a small 4x4 matrix keypad, compatible with the driver.

TX Power Supply

It should provide a regulated 5VDC at minimum current drive of 100mA. This power supply is being used to drive all the blocks within the TX unit. The power supply regulator is fed from a 9V battery.

RX Power Supply

It should provide a regulated 5VDC at minimum current drive of 40mA. In addition, it should provide a regulated 3.3VDC at minimum current drive of 30mA. The 3.3VDC will be used for the GLCD microprocessor, and GLCD. The power supply regulator is fed from a 9V battery.

Verification

Choke + Fuse

The Chokes' input will be connected to a function generator sweeping from 10Hz to 500Hz and the output response will be traced analyzed on the scope. This process can be done on a network analyzer. The average input impedance will be calculated using a network analyzer. A passive network will be added to the input to scale the impedance to a proper level, so the drain current is less than 5mA. The current level can be monitored on a loaded choke with AC-DC converter using a DMM, while choke's input is fed from a function generator at specific frequencies. The coupling factor, and terminals' impedance will be calculated, so a choke model can be simulated in software. In case of transfer ratio mismatch (poor coupling), number of turns on the choke's core will be increased, until the proper transfer ratio and flat response is observed over the operating frequency.

AC-DC Converter + Amplifier + Clipper

The AC-DC converter consists of a full bridge and LP filter. The LP filter should be well tuned to handle operating frequencies to return a smooth raised cosine. LP filter will be tuned using by sweeping over desired frequency at scaling until a flat response in observed over the pass band, with sharp transition to stop band. The amplifier will be built and tested individual to check for proper gain values. The gain will be controlled using a pot. Then choke, AC-DC converter and amplifier will be chained to check for proper operation level. The clipper circuit (Loaded with TTL) will be added at the next stage to tune the amplifier for proper clipping. If the signal level from amplifier to clipper drops significantly, change the amplifier chip to a higher power version.

TTL Buffer

After adding TTL buffer to the clipper, test the circuit at different frequencies and a sweep from 10Hz to 500Hz. If the output is not following the input freq or observe steady oscillation on the output, check the input voltage level to ensure it is within the acceptable range of TTL operation.

Gain Controlled Amplifier / Active Filter

Sweep the input from 10Hz to 1KHz to ensure proper pass and stop band regions with proper attenuation at the stop band. Check the noise level. If the filter does not meet the specifications, use a higher order filter.

TX Microprocessor

Should be able to handle, process and transmit the collected data into a serial connection, fast enough for a train at 100MPH. The microprocessor is clocked at 20MHz. So the calculation should be performed to take enough number of samples for a train going at minimum and maximum speed. The sampling at 8KHz should be downed sampled according to this calculations, and optimized for minimal data traffic on the serial data bus going to XBEE TX at 9600 rate.

XBEE TX Side

In case the XBEE does not make a proper connection with the microprocessors, test the functionality of XBEEs. Connect RS232 to XBEE units on two separate computers and use terminal to send and receive data. If passed, then program the microprocessor to only transmit specific data to XBEE. Proceed to the RX XBEE, and program the microprocessor to respond to the specific transmitted data by activating a LED. Repeat this for number of specific words.

XBEE RX Side

In case the XBEE does not make a proper connection with the microprocessors, test the functionality of XBEEs. Connect RS232 to XBEE units on two separate computers and use terminal to send and receive data. Put the XBEE units next to each other to avoid and test again to ensure proper link between the units. Repeat the steps described in the previous part.

RX Microprocessor

This is the heart of our project, all the important triggering and data processing is performed within the algorithms run on this microprocessor. Triggering the algorithms is the most important block of the program written for this block. Algorithms are set of client functions called at proper time. We are not expecting any major faults for the algorithms. So the first sets of tests are to be performed on the triggering functions, calling dummy algorithms (replaced by delays that presents algorithms running time) to check proper trigger timings. The triggers are:

- Wake from standby mode trigger.
- Transducer pulse detection trigger.
- Transducer timing trigger, to measure time span between transducers pulses.
- Data ready trigger, to give the user (I2C bus) permission to access SD card.

To debug the algorithms, just debug them and drink coffee!!!

SD Card

Use a separate micro controller to read/write to the SD card, and use a timer to measure the read/write period. Check if the read data matched with the one you wrote. If the timing is severely large increase the bud rate or optimize the algorithm.

GCLD Microprocessor

Make sure I2C bus is responding to the data transmitted by the main microprocessor by use specific data, and program the GLCD microprocessor to respond to that specific transmitted data by enabling a LED. Try several specific data. If passed, try to show that data on the screen. Do not use a complex algorithm. If passed, review the program and look for bugs and interrupts.

GCLD

Use a microprocessor to run a demo program on the screen. If GCLD does not respond to the microprocessor, then use RS232 cable to reinstall the firmware (SGC not GSX).

Keypad

Use a DMM to check the connectivity of matrix, by pressing a key at the time and measuring resistance of corresponding pins.

TX Power Supply

Load both by proper resistive loads and monitor the voltage and current. Then load by the actual circuit and monitor the voltage and current. Observe the difference. In case of any reduction in voltage for the second case, change the power regulators to handle more power. If the problem yet exists, try to disconnect one block at the time to find the problem making block. Find all block with the same problem, and assign a new power regulator for those blocks. The working block will produces lots of noise on the power line, measure the noise level and use decoupling caps to attenuate the noise.

RX Power Supply

Load both 5V and 3.3V by proper resistive loads and monitor the voltage and current. Then load both 5V and 3.3 V by the actual circuit and monitor the voltage and current. Then follow the steps from the previous part. If any, it is most likely that the 3.3V regulator will behave non-idealistically. Change the chip to handle more power.

Tolerance Analysis

Choke

This is the component that most affects the performance of the project. It is implemented using a toroid to provide electrical isolation. Signal variations are present because the frequency response is not perfectly flat at low frequencies. These signal variations will translate to the amplifier stage. For this reason, the maximum tolerance accepted is ±5% on a narrow band of operating frequency, to prevent partial saturation and loss of the signal.

GC Amplifier for the Heat Sensor

The gain should be optimized such that the amplified signal does not reach the saturation limit of the amplifier. It is required to keep the amplified signal below the saturation region in order to identify different heat signatures. Different bungalow locations might generate different voltage levels for the IR heat sensors. As a result we have to take into account all these variations and set the gain to an appropriate global value, between 0.5 and 5, to ensure the amplified signal is not too high (saturation limit) or too low (not detectable).

Cost and Schedule

Cost Analysis

Labor

Member	$/hour	# of weeks	hours/week	Total of hours	Subtotal	Multiplier (x2.5)
Pourya Assem	40	13	14	182	$7280	$18200
Paul Lupas	35	13	14	182	$6370	$15925
Grand Total						$34125

Parts

Parts	Quantity	Cost/unit	Total
Atmel-Atmega328 Microprocessor	4	$6.00	$24.00
Digi-XBEE 1mW with Chip Antenna Transceiver	2	$24	$48.00
SD Card Slot	1	$18.70	$18.70
SD Card 2GB	1	$8.00	$8.00
GLCD	1	$29.00	$29.00
Low Freq Choke	3	$4.00	$12.00
0.25A Fuse + Holder	3	$2.00	$6.00
Diode Bridge	2	$2.00	$4.00
LM741	4	$1.00	$4.00
TTL Hex Inverter	1	$1.00	$1.00
Resistors	28	$0.10	$2.80
Capacitors	17	$0.15	$2.55
20MHZ XTAL + Isolator	4	$1.50	$6.00
LM7805	2	$2.00	$4.00
LM317	1	$2.00	$2.00
Push buttons	5	$0.50	$2.50
Switches	2	$0.50	$1.00
PCB	2	$15.00	$30.00
Grand Total			$205.55

Grand Total

Labor	Parts	Grand Total
$34125	$205.55	$34330.55

Schedule

Week	Task	Member Assigned
9/2	Work on RFA	Paul & Pourya
9/9	Work on Proposal Research XBEE Transceiver Research GCLD/Choke/ Fuse Update Project Page	Paul & Pourya Paul Pourya Pourya
9/16	Order GLCD and XBEE Order SD Card Slot Verify Proposal & Submission Chokes: Assemble and Test	Pourya Paul Paul & Pourya Pourya
9/23	Transmit and Receive data via XBEE Test SD Card Boot-Load Atmel-Atmega328 MP Research Amplifiers Amplifier: Design, Assemble and Test	Paul Paul Pourya Paul Pourya
9/30	AC/DC Converters: Design, Assemble and Test Slicers & Buffer: Assemble Test Design Sign-up LP Filter: Assemble and Test Put it together	Pourya Pourya Paul & Pourya Paul Paul & Pourya
10/7	Start Designing PCB Research Power Supply Power Supply: Design, Assemble and Test	Paul & Pourya Pourya Paul & Pourya
10/14	Finish PCB Design Start Programming the TX MP Test TX MP, Coupled with XBEE Start Programming the RX MP	Paul & Pourya Pourya Paul & Pourya Paul & Pourya
10/21	Individual Progress Report Test Wireless Link and Verify MP Functionality	Paul & Pourya Paul & Pourya

	Start Programming SD Card for MP Interference Start Programming GLCD for MP Interference	Paul Pourya
10/28	Put the MP together and Test for Functionality More Testing	Paul & Pourya Paul & Pourya
11/4	Mock-up Demo Mock Presentation Sign-up More Testing & Troubleshooting	Paul & Pourya Paul & Pourya Paul & Pourya
11/11	Mock-up Presentation Last day to request First revision PCB More Testing & Troubleshooting	Paul & Pourya Paul & Pourya
11/18	Thanksgiving Last day to request Final revision PCB More Testing & Troubleshooting	 Paul & Pourya
11/25	Demo and Presentation Sign-up More Testing & Troubleshooting	Paul & Pourya Paul & Pourya
12/2	Demo and Presentation	Paul & Pourya
12/9	Presentation/ Final Paper	Paul & Pourya