UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

On Site Hotbox Calibration System
Project #2

ECE445 - Design Review

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10/5/2012

Contents

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.

Problem Statement

To the right is a picture of the system to be calibrated using the device we proposed. The system consists of two gating transducers which alarm the system when a wheel is present in the sight of IR heat sensors. The sensors are designated to read the heat signature of the wheels and bearing perimeters as they pass over the site.

Fig. 1 Hotbox unit on track

The picture on the right shows a standard heat signature of a normal wheel. The picture on the left shows a standard heat signature of a normal bearing.

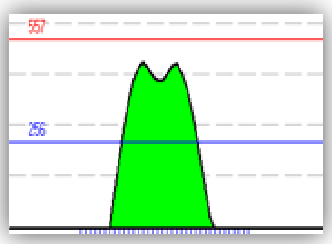


Fig.2 Standard Wheel Signature

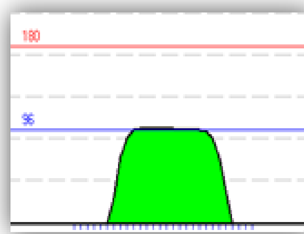
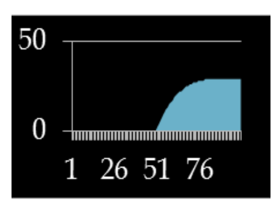


Fig.3 Standard Bearing Signature

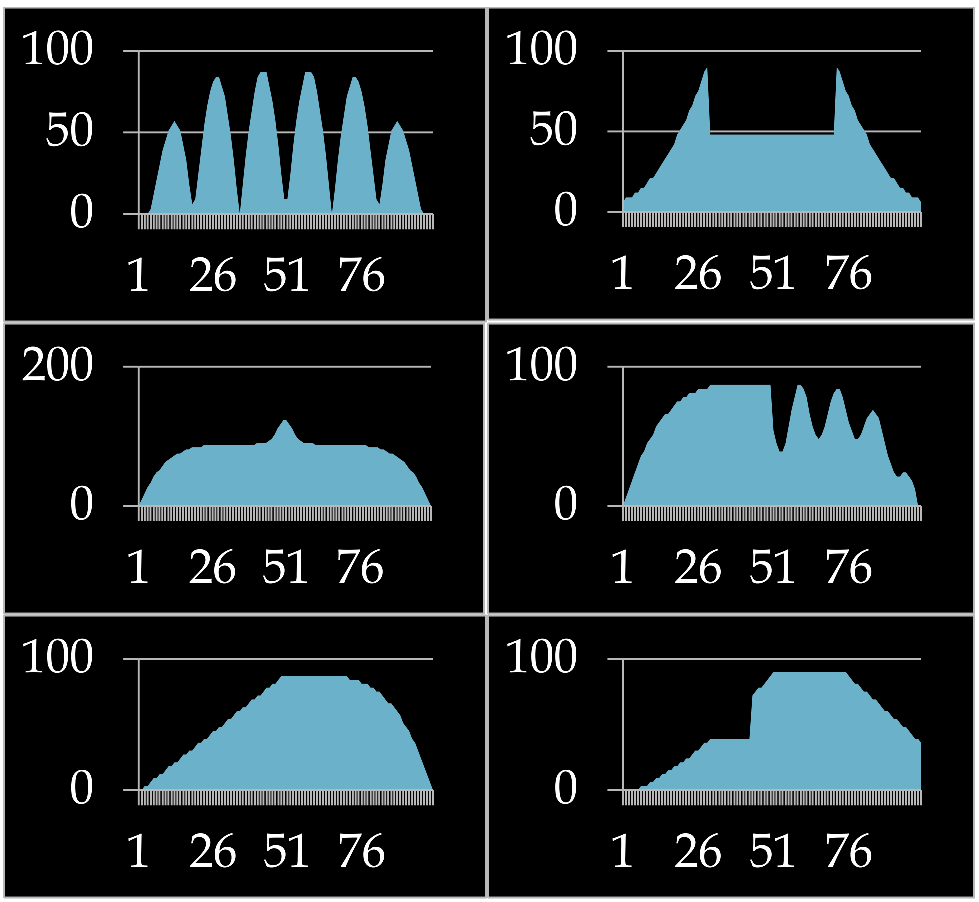
The system goes out of calibration very often because the sensors and transducers get hammered and displaced from their designated position as the passing by train exerts shocks to the tracks. A very common issue is when the displaced gating transducers awake early or late enough so a hefty portion of



heat signature is not recorded by the heat sensors. An example of such behavior is shown above for late gating. There are other common calibration issues which are not detectable without observing the heat signatures. A number of such issues are addressed below:

- The heat sensors have internal faults
- The housing connections are loose which cause abruptions in the transmission of heat signatures
- The heat sensors are shifted and looking at the wrong sight
- The sensors are looking into sun

These issues are shown below



The current technology used in the field does not have the ability to fetch and generate such plots which could allow the service man to detect the issues mentioned above.

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 methods
- 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

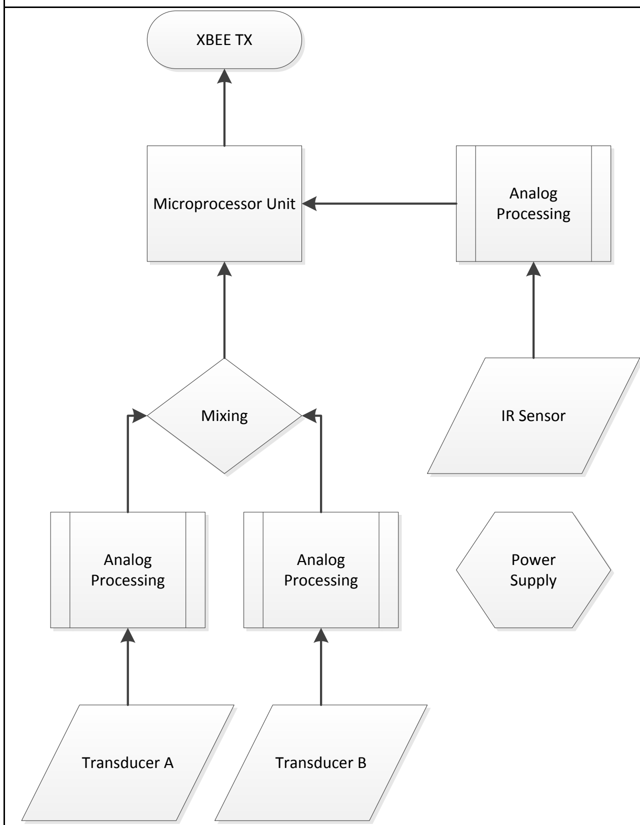
Features

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

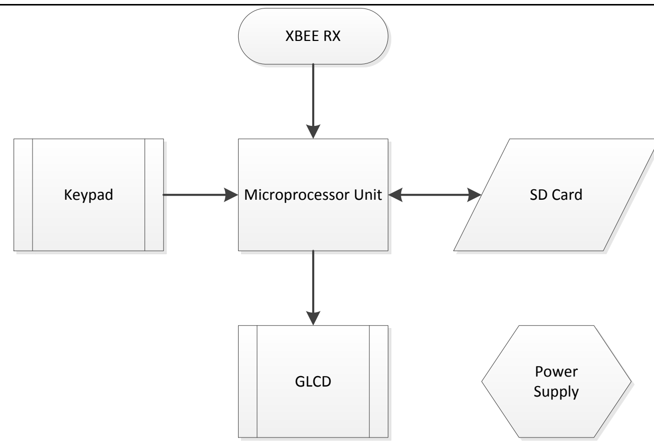
Design

Block Diagram

TX – Unit



RX – Unit



The power supply on the TX side is connected to the power pins of the analog processing chips, microprocessor, and XBEE.

The power supply on the RX side is connected to the power pins of the XBEE, microprocessor, GLCD and SD Card.

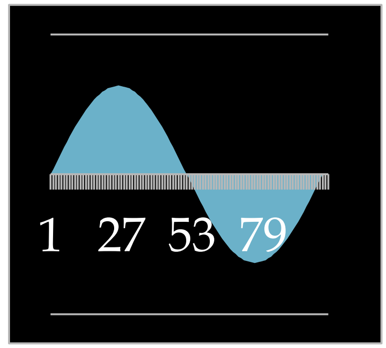
Block Description (More Details Provided in Requirements' Section)

The system consists of two main modules: the TX and RX Module. 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 Module and RX Module are interconnected using wired connections.

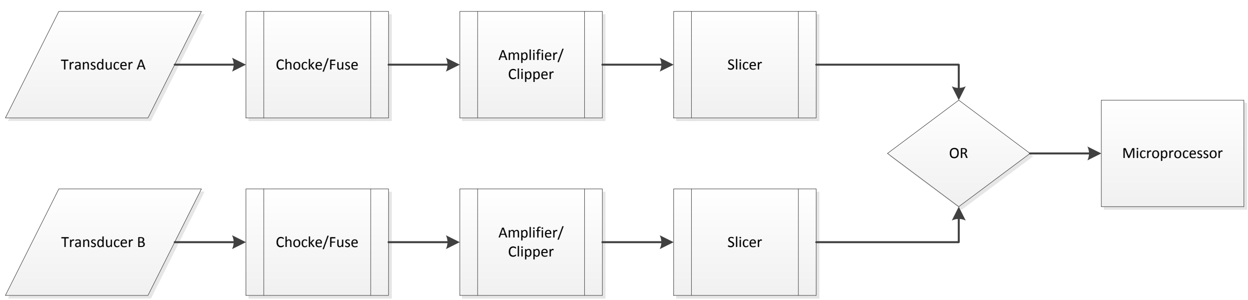
TX – Unit

Transducer A and B

These two blocks are identical and are not part of the system being deigned. However, our system will connect to them through the chokes to read the signal. These 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. Above is an example of how a transducer signal looks like as the wheel passes by.



Transducers Analog Signal Processing



The purpose of this block is to convert the transducer signals into an acceptable waveform as seen by the microprocessor. The transducer signals will be passed through a 1:1 twisted wire toroidal transformer to meet the specification set by the factory which is perfect electrical isolation by the third party user. Then the signal is passed through an amplifier which has a dual function of both amplifying the signal and also clipping the unwanted part of the signal. The next stage consists of a slicer which converts the clipped signal into an ideal digital logic signal. Both branches of transducers are finally joined together using an OR gate in order to send a single signal to the processor which indicates a change of state in either transducers.

Choke/Fuse

The choke is made on an iron powder core which has a significant response over the operating frequencies which is calculated in the following section. Materials needed to build the choke:

- White iron powder core of radius 1 cm
- Two 1 meter long pieces of AWG 20 transformer wires, twisted on each other

  This will make approximately 50 turns. The input and output inductance of the transformer can be calculated as follows:

$$L = \frac{0.2uN^2A \times 10^{-2}}{r}$$

Plugging in the values, leads to an input and output inductance of approximately 643uH.

Toroid radius to the center line	1 cm
Coil radius	1 cm
Cross sectional area	3.14 cm^2
Wire gauge	AWG 20 = 0.518mm
Number of turns	50
Permeability of the core at 20Hz	Approx. 41000

The toroid was made and tested in the lab. The inductance obtained was 670uH, as measured by a multimeter. The coupling factor was nearly 1 as tested by connecting the input of choke to a function generator at 20Hz and 1Vpp and matching the output signal. The choke behaves as a band-pass filter with center at 790Hz and 3dB cutoffs at 270Hz and 1.3 KHz. The function generator is modeled as an ideal voltage source with a 50Ω output resistance. Connecting the transformer to the function generator will make a voltage divider which approximately is modeled by the following equation at 20Hz:

$$V_{transformer-in} = \frac{V_{generator} \times 670uH \ \times 2\pi \times 20Hz}{670uH \ \times 2\pi \times 20Hz + 50} = 0.00168 \times V_{generator}$$

Note: The choice of 20Hz is explained in the next section.

This result is tightly close to what we have measured when a 1Vpp signal was fed into the transformer which generated a 1.53mVpp signal on the output of transformer.

$$Error = 9\%$$

The transformer is also modeled using Multisim and fed with a simulation signal.

It is a very common practice to use a low power fuse when sensitive electronic device is connected to equipment with direct contact to the tracks, because:

- Danger of lightning
- Electrical charge produced by the passing trains
- High voltage signals sent through the tracks accidentally by the crewman

Our system is highly sensitive to high voltage spikes due to usage of integrated circuits in the main body of the system. Therefore, we inserted a 0.5A fuse interconnecting the choke stage to the amplifier/clipper block.

Amplifier/Clipper

The voltage directed to this block is a purely AC signal. However, this block operates on a DC level signal, because the amplifier is biased to process the signals ranging from 0 to 5V. By this mean, the negative going of the transducer signal (half sine wave) will be clipped and the positive going portion of the signal will be amplified near saturation regime (for some signal levels clipped on top) to reshape the positive going (half sine wave) of the transducer pulse into a nearly square shape signal. The amplifier is implemented using LM324 Quad Op-Amp chip in the non-inverting configuration with gain approximately 401. The circuit was simulated in Multisim and tested for quality and proper signal level.

Slicer

The slicer is employed to convert the humpy shape of the amplifier output into a TTL logic level. A 74LS00 Quad NAND gate is used to create such a signal.

Note: Both branches of transducer A and B signal processing are identical.

OR Gate

The microprocessor should be informed when either transducer A or transducer B is triggered, because it is not required by the algorithm to know which transducer is trigger first. Therefore, the signals generated by the transducer signal processing branches are OR-ed together to implement such function. A NAND is borrowed from the slicer block to implement this logic.

Multisim Simulations

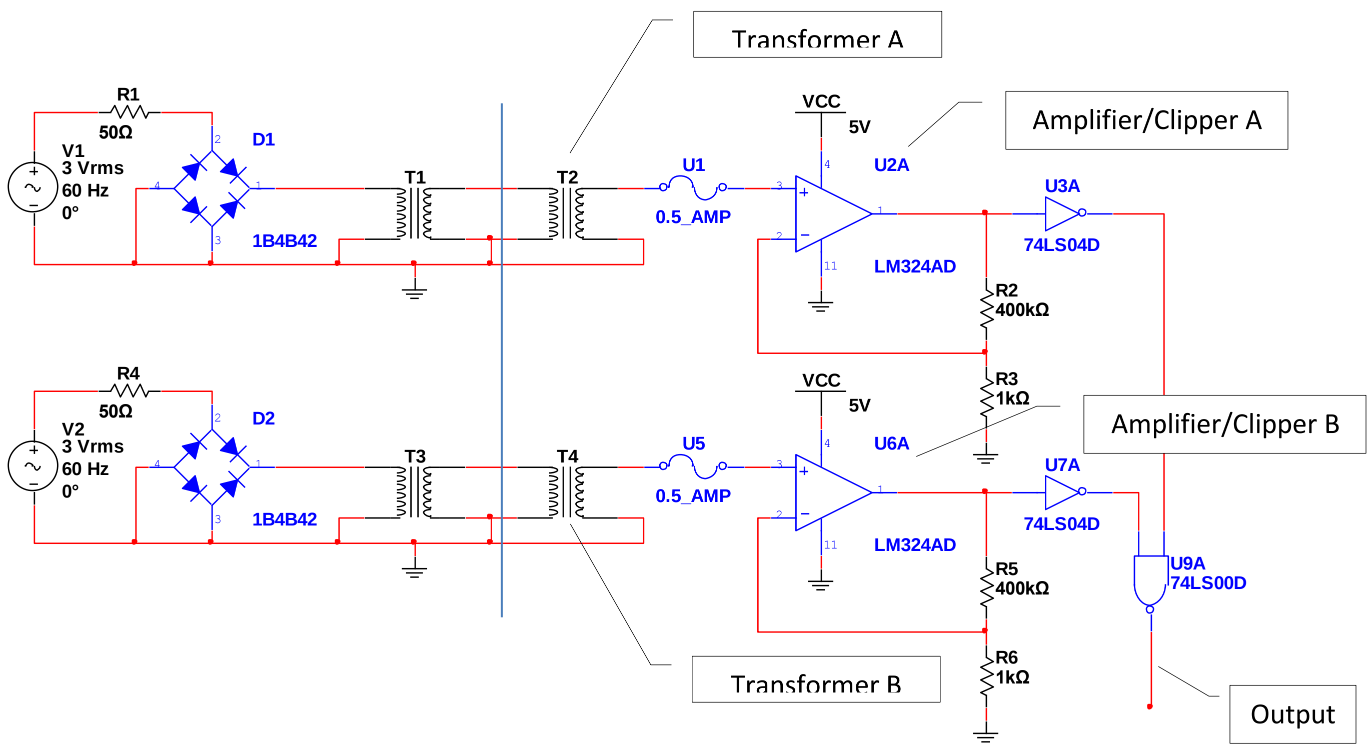


Fig. 4 The circuit described above is to the right of line drawn in the schematic above

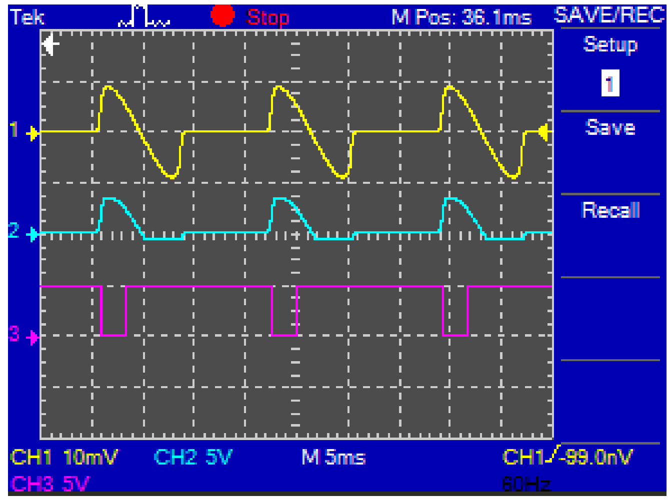
The gain for both amplifiers is set to:

$$Gain = 1 + \frac{400K\Omega}{1K\Omega} = 401$$

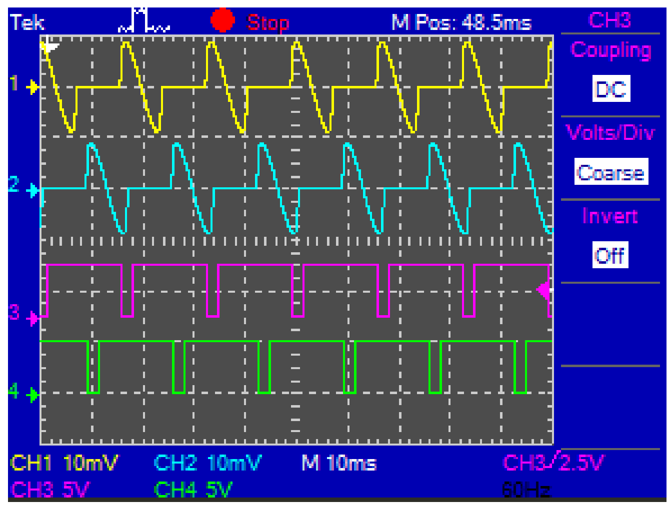
The system shown on the left side of the line is solely for the purpose of simulating transducers (one full sine wave period) signal to be used as a test vector.

Sample signal taken from simulation:

- Yellow is signal on the output of transformer A
- Cyan is the amplified and clipped signal on the output of amplifier A
- Purple is the inverted sliced version of the amplified/clipped signal



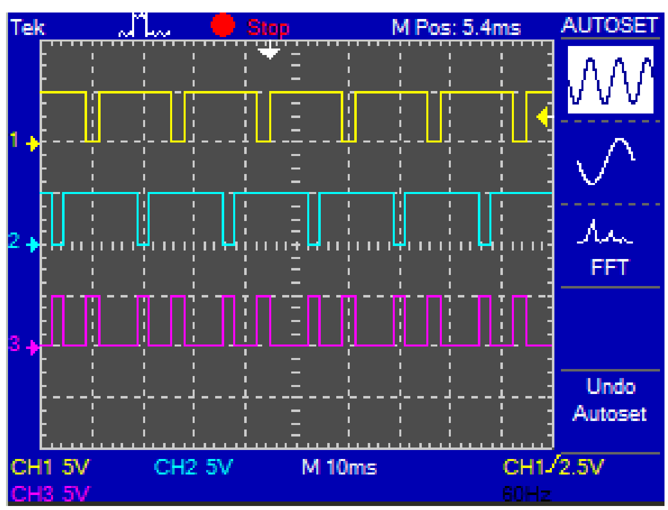
Sample signal taken from simulation (the transducer signal produced by signal simulator above are set to have 0.01 sec of delay, in order to check the behavior of each branch individually and the system as a whole after OR-ing the transducer branches):



- Yellow is transducer A
- Cyan is transducer B
- Purple is inverted sliced of A
- Green is inverted sliced of B

With the same setup as previous part:

- Yellow is inverted sliced of A
- Cyan is inverted sliced of B
- Purple is OR-ed sliced of A and B



So, the signal within the microprocessor will be recording hear signatures during the off times between the transducers.

IR Sensors Analog Signal Processing

An active filter was used to filter and amplify the signal coming from the IR heat sensors. The gain of amplifier should be adjustable in order to provide an appropriate range to the ADC of the microprocessor which ranges from 0 to 5V. The filter is a 2nd type low pass configuration with cutoff frequency at 1 KHz, providing 40dB of attenuation. The active part was implemented utilizing a non-inverting Op-Amp borrowed from the LM324 (used in the transducers branch). The cutoff frequency and gain can be calculated as follows:

$$f_{cut-off} = \frac{1}{2\pi\sqrt{\frac{1}{R8 \times R9 \times C1 \times C2}}} = 1\ KHz$$

$$Gain = 1 + \frac{R_{10}}{R_{11}} = 1$$

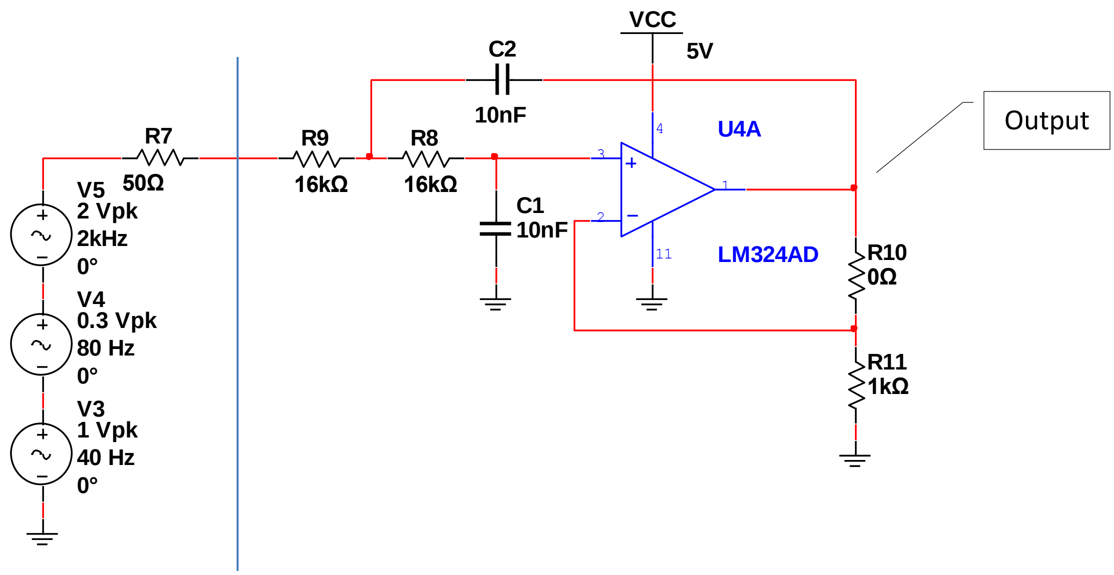


Fig. 5 The circuit to the right of the line drawn above is the active filter

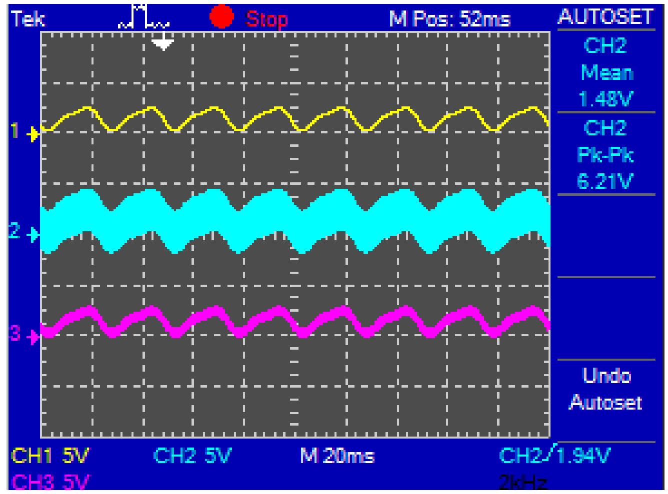
The series of AC source signals to the left of the line drawn above was implemented to approximately simulate the bearing heat signature read by the IR sensors, plus a 2 KHz sinusoidal signal to test the filter.

Note: The heat signature circuit does not include a choke and fuse, because it is implemented within the breakout circuit inside the heat scanners. In addition, R_{10} and R_{11} can be replaced by a pot to adjust the gain.

Simulations

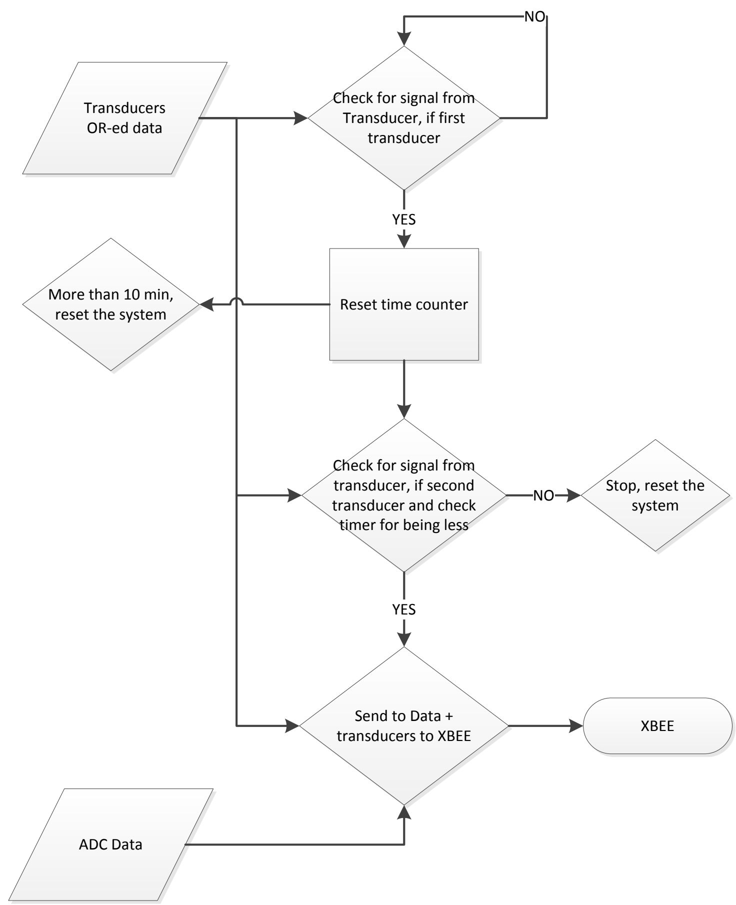
The sample signal taken from active filter simulation:

- Yellow is the approximated bearing signature for 8 axles back to back (no inter-trucks)
- Cyan is yellow plus 2 KHz sinusoidal injected into the amplifier
- Purple is the filtered output



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 a 10bit ADC which will take as input the amplified IR heat sensor signal. The processor reads a digital signal from OR-ed transducer signal and the IR sensor. It will combine these signals into a single array to have the following sequence: transducer signal, heat signal, transducer signal. This sequence includes the data for one wheel. The serial output of the processor will send this data array to the TX Xbee block.



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.

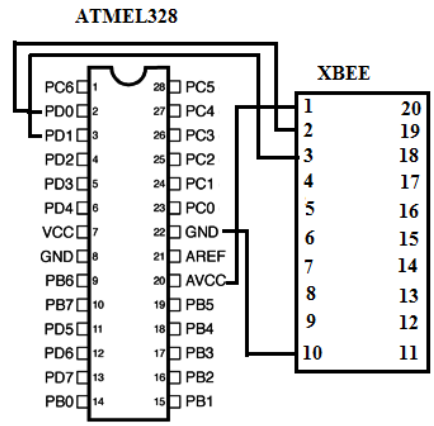


Fig. 6 XBEE connection

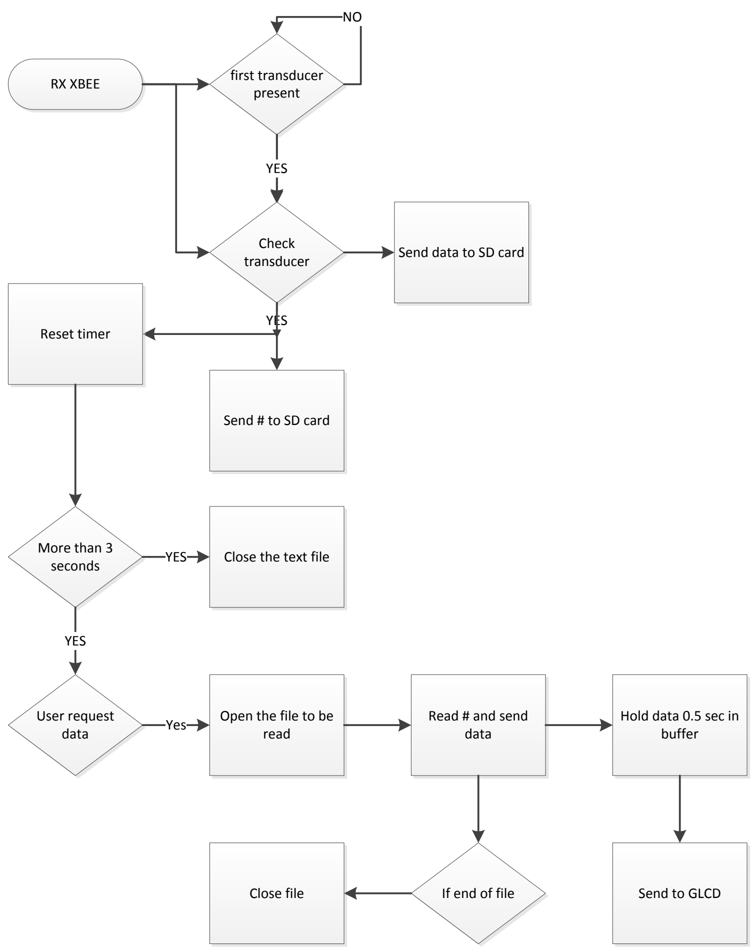
RX – Unit

RX XBEE

This block is implemented using XBEE wireless module. It is responsible for receiving the serial data from the TX Xbee. The connections will be similar to what was described in the TX Xbee.

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 powered from a 5V supply. The SD card is responsible for storing the data sent by the Main Processor via SPI protocol. The data will be stored in a text file. Each sample from the wheel signature will be separated by a comma and the data between every wheel will be delimited by the # character. This format makes it easier for the algorithm to read the data for every wheel and display it on the GLCD.

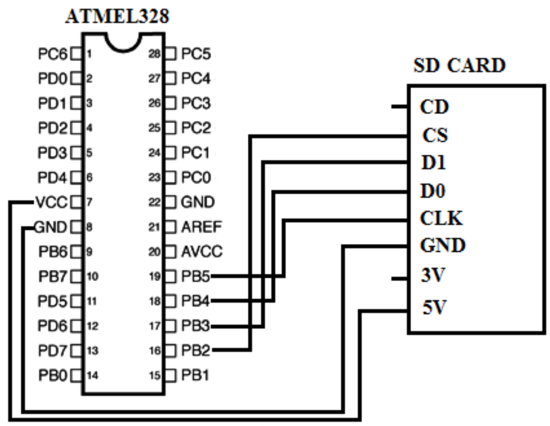


Fig. 7 SD Card connection

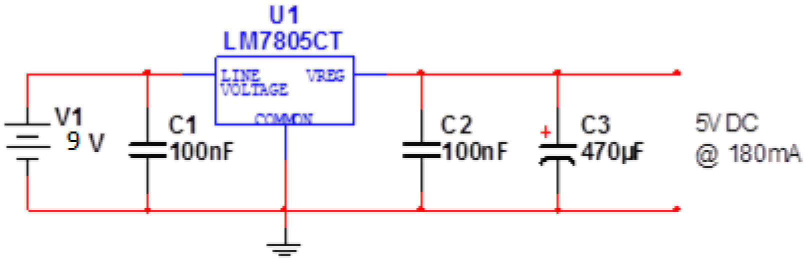
GUI Processor and GLCD

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 serial 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.

Power Supply

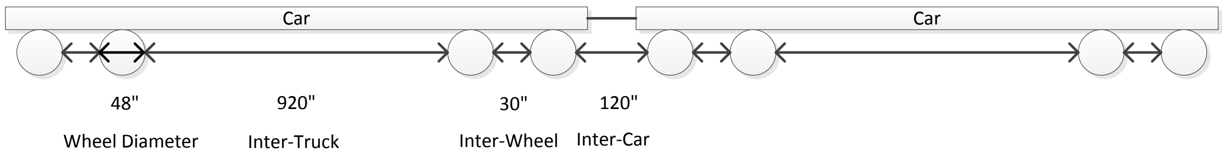


Both TX and RX units are powered by a 5V supply. This voltage is regulated by the circuit shown above. This circuit is capable of delivering 5VDC @ maximum drive current of 1Amp. The input voltage can be chosen from a range of 7V to 32V, which is suitable for running the system by a 9V battery. The power consumed by the TX and RX units is calculated below:

- TX unit at sleep mode→5mA (Xbee) + 5mA(processor) + 10mA(all three amplifiers) + 2mA(TTL chip) = 22mA @ 5VDC = 110mW
- TX unit at active mode→35mA(Xbee) + 10mA(processor) + 30mA(all three amplifier) + 2mA(TTL chip) = 77mA @ 5VDC = 385mW
- RX unit at active mode→35mA(Xbee) + 10mA(processor) + 2mA(SD card) + 15mA(GLCD) = 62mA @ 5VDC = 310mW

According to the above specifications, the voltage regulator is capable of handling such power requirements. The TX unit running on a standard 1000mAh battery will last for less than 8 hours (in sleep mode) and 3 hours in active mode. The RX unit can be operated on the battery for less than 3 hours. The alternative option for providing TX unit with the rated power is a solar panel.

Wheel Calculations



The picture above shows the extreme dimensions of a standard train car operated in Northern America. There are five major sizes that characterize the metrics used in designing the system.

- Inter-Truck Distance →920 inches
- Inter-Car Distance → 120 inches
- Inter-Wheel Distance →30 inches
- Wheel Diameter →48 inches
- Closing-Opening Transducer Spacing→ 50 inches

The transducers will trigger when the center of the wheel is aligned with the center of transducers. The calculations below are carried out to find the shortest timespan between the triggering pulses coming from the transducers. The timespan is a function of the train' speed and the spacing addressed above. The two speed extremes are 20 mph for the lower and 60 mph for the upper bound.

The shortest time is calculated for the train going at the fastest speed, when a wheel passes a closing transducer and the next wheel passes the opening transducer. This distance is the axle to axle spacing of the two closest wheels minus the transducers spacing, which is 24+30+24-50 = 28 inches. The top speed is 60mph = 1056 in/sec, which means the minimum transducer timing is 26.5ms.

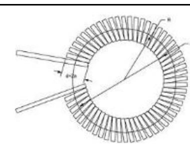
The longest time is calculated for the train going at the slowest speed, when the two furthest (truck to truck) wheel pass over the transducers. The longest distance is 24+ 920+24 = 968 inches. The train's slowest speed at 20mph = 352 in/sec. This results in 2.8sec.

As calculated, the minimum time was 26.5ms. The algorithm developed in the TX Unit should be fast enough to distinguish transducer pulses 26.5ms apart from each other. The microprocessor used in the TX Unit is capable of processing or reading digital pulses as short as a tenth of a millisecond.

The transducer spacing is set to 50 inches, which results in wheel scan time of 47ms for the train going at 60 mph. A minimum number of 12 samples are needed for each wheel scan, which requires minimum read time of 4ms for each sample. The ADC should be fast enough to handle such conversion rate. The microprocessor ADC has conversion rate of 10 kilo samples per second which satisfies the requirement.

Requirements/Verification

Choke + Fuse

Requirement	Verification
a). Chokes should not drain more than allowable current as specified by the manufacturer (GE). The maximum rated drain power is 400mW. b). The chokes have to have a linearly increasing response over frequency span of 10Hz to 500Hz with 1:1 transfer ratio, and minimum coupling loss. c). The chokes have to have small impedance over the operating frequency range of 10Hz to 500Hz. d). The fuse should be capable of handling 0.5A. 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.	1. Wrap the twisted wire transformer (choke) as specified by the calculations. Make sure each leg of the twisted pair is of the same size, 1 meter. There should be exactly 50 turns on each transformer and make sure the wires are tightly wrapped on the core with a minimum of 30 degrees spacing between the terminals.  2. Connect the input of the transformer to a function generator @ 5Vpp - 10Hz sinusoid and trace the output with the resolution set on averaging. This signal should be @ 3.83mVpp – 10Hz sinusoid with maximum phase shift of 6 degrees w.r.t function generator. 3. Set the 2nd channel of the oscilloscope to trace the input signal of the transformer. This signal should be @ 3.83mVpp – 10Hz sinusoid. Use the Math function to subtract the input and output signals to ensure a perfect match. This indicates a high coupling factor. 4. Increase the function generator frequency to 20Hz and repeat step 3 (this time @ 7.65mVpp) to check for

	coupling factor. 5. Repeat step 3 for frequencies up to 500Hz. 6. If the coupling factor differs or decays over the frequency span, repeat step 1 with a core (better low frequency handling characteristics) and ensure the twisted wires are tightly wrapped. 7. Use two DMMs to monitor the current and voltage on the input of transformer and find their product to ensure the drain power is below 400mW. 8. If the specs on step 7 are not met, increase the number of turns and repeat steps 1-7 (iteratively and calculate new voltage values on the output using the equations provided). 9. If the above steps are satisfied, make a second transformer. 10. For more accurate measurements, use a Network Analyzer to check for all the specs. 11. Connect the fuse to the output of the transformer and trace the output @ 10Hz and 20Hz to ensure the values match with the voltages provided in steps 3 and 4. If not, change the fuse and repeat step 11.

Amplifier + Clipper

Requirement	Verification
a). This stage is directly fed from fuses, with minimum power consumption. b). The expected input from transducers at the fastest rate is a one full sine wave period every 26.5ms and 3s for the slowest rate. c). 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. d). The amplifier circuits should be tuned to provide a large enough pulse to drive the TTL buffer. e). Amplifier gain is expected to be within a controllable range of 200 to 401.	1. Construct the amplifier as shown in Fig.4 and use a DMM to monitor the current being drained by the Quad Amplifier Chip (LM324). 2. Set the potentiometer to obtain a gain of 200 and check the input/output response as described in the next step. 3. Set the function generator @ 20mVpp - 10Hz sinusoid. Amplify the signal using the amplifier built and tuned in step 1-2 and trace the output on the oscilloscope to have the right frequency and non-inverted amplitude of 2Vpp - clipped with maximum phase shift of 6

	degrees. 4. Repeat step 3 with 20Hz (amplifier output @ 4Vpp - clipped). 5. Change the gain to 401 and repeat steps 3 and 4, and check for output voltages of 4.01Vpp and approximately 4.70Vpp correspondingly. 6. Note: The amplifier power rails are biased from 0 to 5VDC, and signal coming from generator is purely AC. So the signal will be clipped (rectified) in steps 4 and 5. 7. If the voltage levels are not within the mentioned values in step 5, increase the gain above 401. 8. Consistently, during all these steps, check for the current drained by the amplifier to ensure it does not exceed 30mA. 9. Build the second branch of amplifier for the second choke and repeat steps 1-8. 10. In steps 1-9, the amplifier is driving a 1KΩ resistor (simulating a TTL Buffer). 11. In steps 1-9, check the output signal of the amplifiers when no input signal is injected to the input terminals (tied to ground). The output signal should have a minimum noise level. Preferably for TTL logic safety, the noise level should be less than 0.3V. 12. If any of the specs are not met, change the Amplifier Chip is a lower power noise version. Additionally if the gain values can be redefined to meet the specifications.

TTL Buffer

Requirement	Verification
a). This stage is fed by the amplifier stage, to convert the clipped signal to an acceptable TTL logic level by the microprocessor's digital ports. Meanwhile, it provides a wide noise margin. b). TTL buffers should be provided	1. Use the Quad NAND gate chip (74LS00) to implement the combinational logic as shown in Fig. 4. 2. Use a 1MΩ resistor on the output of the combinational logic to simulate the microprocessor digital port impedance.

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 providing a full TTL logic swing.	3. Use a DMM on the power line connecting to the chip to monitor the drain current. It should not be more than 2mA. If it is not the case, replace the TTL chip with a lower power version. 4. Connect one of the inputs of the combinational logic (OR) to a function generator set at 10Hz square wave (0-5V swing) and the other input to ground. Trace the output signal to ensure full swing and the pulse shape (perfect square wave) matches the input. 5. Repeat step 4, this time with 10Hz square wave at a lower swing (0-4V). This test should be performed because the signals coming from the amplifier stage were calculated to have similar values for the rated frequency. 6. If step 5 is not passed then reconfigure the amplifier gain (to a higher value), so the amplifier output swing is within the acceptable TTL range. 7. Increase the frequency to 20Hz and repeat steps 4-6. 8. In all steps, trace the noise level (tolerance) of the input signal and ensure it is not more than 0.3Vpp

Gain Controlled Amplifier + Active Filter

Requirement	Verification
a). Scale up or down the IR sensors' signal to an acceptable level seen by the microprocessor's ADC. The ADC range is 0 to 5VDC with 10 bit resolution. b). The amplifier should have a low noise level, low power consumption and controllable gain of 0.5 to 5. c). The LP filter should have a 2nd order implementation with cutoff at 1KHz. The response should be as flat as possible over frequency span of 10Hz-500Hz.	1. Build the active filter as shown in Fig.5. Connect a 1MΩ resistor as the load to simulate the microprocessor ADC. 2. Use a DMM to monitor the current drain by the amplifier chip. It should be less than 30mA, while all three (two from transducers + active filter amplifier) are loaded and running. 3. Use the function generator to generate a 50Hz sinusoid with 1Vpp and 0.5VDC bias to simulate the heat signature signal as read by IR sensor. Make sure

	the function generator is set to 50Ω mode to simulate the IR sensor terminal impedance. Set the amplifier gain to 1 by choosing the feedback resistance to be 0Ω. This resistance (consequently the gain) is controlled by a potentiometer (log tape 0-500KΩ). 4. Read the signal level on the input of active filter. This signal should not be less than less than 0.9V. Otherwise, the feedback loop or the filter's resistive network has a bad connection. Double checks the active filter to ensure the right components are used. 5. If step 4 is passed, use the function generator's sweep mode to sweep the signal injected into the active filter from 10Hz to 2KHz. Trace the output using an oscilloscope to ensure flat response over the critical region 10Hz to 500Hz and 80dB attenuation over 1KHz cutoff point. If the signal is not attenuated by the rated value at 1.2KHz then shift the cutoff point toward a lower frequency (not lower than 800Hz). The 800Hz was chosen to satisfy the bandwidth of heat-signature signal. 6. Adjust the function generator to generate a 50Hz sinusoid of 3Vpp (a common heat-signature peak value) with 1.5VDC bias. Change the gain (increase) using the potentiometer and trace the output signal of the active filter to bring up the peak voltage level value to approximately 4.5V. The 5V ADC limit is not used to provide headroom for the heat-signature to prevent clipping in case the input signal exceeds 3Vpp limit. 7. Inject the signal described in step 6 + a square wave with fundamental frequency at 1.5 KHz, and trace the output signal to ensure the additive noise (in this case square wave) is well attenuated.

	8. If step 7 is not passed, repeat steps 3-7 to adjust the gain and cutoff frequency to a reasonable value so that the output signal has a proper signal level (not higher than 4.5V) and noise level. 9. Note: For reconfiguring the cutoff frequency it is easier to change the active filter resistors' values (utilizing a pot eases the tuning process).

TX Microprocessor

Requirement	**Verification**
a). Should be able to handle process and transmit the collected data into a serial connection, fast enough for a train at 60MPH. b). 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. c). The sampling at 8KHz should be downed sampled according to these calculations, and optimized for minimal data traffic on the serial data bus going to XBEE TX at 9600 baud rate.	1. Ensure the connections from TX microprocessor to TX XBEE are correct. TX of the microprocessor goes to the RX of the XBEE and the RX of the microprocessor goes to the TX of XBEE. 2. There are several triggering algorithms running in parallel which are controlled by a watchdog timer. The watchdog timer should be reset at the beginning of each iteration. Failing to do so, will prevent the algorithm from being reset. 3. The main functioning trigger is the transducer detection algorithm. If in case of any malfunction, this algorithm should be tested individually (in the first step of troubleshooting procedure) to evaluate its proper timing and correlation to incoming transducer signals. The most important body of this algorithm is the most frontal stage responsible to detect the first transducer followed by the second transducer within a predefined period (as defined in the flowchart and calculations). This stage tells the TX processor to wake up and start fetching next incoming transducer pulses along with the heat-signature. Use a function generator to feed the transducer's digital port reserved on the TX microcontroller. Change the duty cycle until the low

	time of the square wave is less than the specified time span mentioned in the calculations and use the serial terminal to send checkpoints if the algorithm detected and triggers the wake-up signal. Decreases the duty cycle until the low time is larger than the time span specified in the calculations. Use checkpoints to be sent to serial terminal to ensure the algorithm does not trigger the wake-up signal. 4. The next layer of troubleshooting the TX microprocessor is to feed the data acquisition's trigger manually to ensure the transducers and sampled heat-signatures are mixed and saved to an array properly. Feed the newly created array (transducers + heat-signatures) into the serial terminal (to a computer) and verify if the signals going into the microprocessor match with data obtained on the serial terminal. 5. Ensure the serial transmission rate is fast enough so the data traffic will not prevent data samples to get lost or delayed. This can be done by setting the serial baud rate to values higher than 9600. 6. If steps 1-5 are passed, connect XBEE to the TX processor and connect RX XBEE to the computer. Feed the TX chip with simulated signals and read the data transmitted to the computer.

XBEE TX/RX Side

Requirement	**Verification**
a). Make proper connection with the microprocessor through the serial protocol. b). The maximum distance between the TX and RX is 30 meters. c). The TX and RX should communicate with each other and the microprocessors at baud rate of 9600.	1. Connect RS232 serial cable to XBEE units on two separate computers and use the terminal port to send and receive specific test vectors. 2. If the transmitted data matches the received data, then program two microcontrollers to send and receive a known test vector of ASCII characters

	over a wired channel. Check for accuracy of received data (with 0 bit error rate). 3. Connect the XBEE units to the programed microcontroller from step 2 and check for accuracy of data received (ideally 0 bit error rate).

RX Microprocessor

Requirement	Verification
a). The XBEE transceiver on the RX Unit and RX microprocessor communicate with each other through serial protocol at a baud rate of 9600. b). The algorithm has to detect transducers pulses so that the samples of the heat-signature is logged on the SD card. c). The multiplexer is used to switch between XBEE to the GLCD at proper timing.	1. Ensure the connections from RX XBEE to the RX microprocessor are correct. TX of the XBEE goes to the RX of the microprocessor and the RX of the XBEE goes to the TX of microprocessor. Ensure the data transmission baud rate is set to values higher than 9600 (to prevent data traffic, loss of data samples). 2. There are several triggering algorithms running in parallel which are controlled by a watchdog timer. The watchdog timer should be reset at the beginning of each iteration. Failing to do so, will prevent the algorithm from being reset. 3. The main functioning trigger is the transducer detection algorithm. If in case of any malfunction, this algorithm should be tested individually (in the first step of troubleshooting procedure) to evaluate its proper timing and correlation to incoming transducer signals. This algorithm looks for transducer signals by checking the max (1023) value from the incoming array of data (1023 is only reserved for transducers and heat-signature cannot have such a high value). 4. The most important body of transducer detection algorithm is the watchdog timer that activates the SD Card interference algorithm. As calculated, this watchdog timer should cut off the data link going to the SD Card, if no transducer is detected within 10 min

	period. Test this functionality by manually feeding signals using the serial port to the microprocessor and use checkpoints to evaluate proper functioning of this watchdog timer. 5. If step 4 is passed, test the algorithm that isolates the transducer signals from the array of incoming data and provides the heat-signature in array form to be saved individually on the SD card. Test this algorithm by manually sending a mix of transducer signals and heat-signature array through the serial port from computer to the processor. Use a checkpoint to verify proper isolation heat-signature data from the transducer signal on the serial port connect to the computer. 6. If step 5 is passed, test the SD card following the SD card verification procedure. 7. Ensure the algorithm that cuts off the data logger algorithm to the SD card and provides the link for the user to access the SD card data also triggers the multiplexer used to switch the serial port from XBEE interference to the GLCD at the same time along with sending reset signal to the GLCD to refresh its memory, otherwise the GLCD will not function properly.

SD Card

Requirement	**Verification**
a). It should be compatible with the driver, either FAT16 or FAT32 file format. b). The memory size should not exceed 8GB. c.) Writing to a text file on the SD card should take 2ms at 9600 baud rate. d) The data read from text file should be identical to the data present in the text file.	1. Connect the SD card to an Arduino microcontroller as shown in Fig. 7. Upload the 'card info' code and ensure the SD card is in the FAT16 or FAT32 file format. Also ensure that the SD card does not exceed 8GB. 2. Using the same configuration, upload the 'write to file' code and check that it takes 2ms at 9600 baud rate using the serial monitor. Repeat this process 6 times to ensure full functionality.

	3. Using the same code as in step 2, write a predefined array of 20 digits to an empty text file. Power off the microcontroller. Take the SD card out and check with a card reader that the 20 elements of the array were written only once. Repeat this step 6 times to ensure full functionality. 4. To check the reading functionality, upload the 'read from file' code and use the serial monitor to read serially all the data on the file. Repeat this process 6 times to ensure full functionality.

GLCD

Requirement	Verification
a). The GLCD should be capable of handling baud rate up to 115200 using serial protocol. b). Both TX and RX serial terminals are used to establish a connection between GLCD and the RX microprocessor. So, the microprocessor RX and TX terminals are reserved for GLCD. c). The firmware installed on GLCD should support and feature SGC serial protocol, because the driver has been written for this protocol (do not use GSX).	1. The GLCD driver is only compatible with Arduino Compiler 002X. 2. Make sure the TX of the microprocessor is connected to RX of GLCD, and the RX of microprocessor is connected to the TX of GLCD. 3. The datasheet and GLCD drivers can be downloaded from the manufacturer website (included in the references section). 4. Make sure when the initialization process is done in the microprocessor the baud rate is set to 115200. 5. Make sure the transparent mode is activated during initialization otherwise the GLCD will remain black all the time. 6. Make sure the RESET of GLCD is connected only to the RESET of microprocessor and there are no other external analogs interfering with the RESET pin. 7. The alphabetical print command is passed by reference type and passing strings by value will not display anything on the screen. 8. The algorithm that fetches the data from SD card and responsible for ASCII to integer conversion is

	embedded within the GLCD algorithm. Any type of conversion (down sampling) should be performed with respect to GLCD screen size with minimum loss of data. 9. The most number of pixels shown on the horizontal scale is 128 so the data points for each heat-signature which is usually in the range of roughly 300-500 should be down sampled by a factor of 2 to 4. The algorithm should calculate the exact down conversion rate (for example 2.34 for the case of 300) so the down sampling conversion is optimized for minimum data loss. 10. After all the train wheels are scanned (detected by the microprocessor when a delay of 3s is seen between the transducer pulses), the user gets access to read the SD card and activate the GLCD algorithm. If GLCD and interference keys are not locked during that time, the writing process gets interrupted and data samples will be lost. Therefore, check proper triggering of GLCD algorithm controlled by the main running algorithm on RX microprocessor. 11. If the data on the screen has missing components that could be caused by static arrays which should be avoided and instead utilize heap memory. 12. The algorithm structure should allow a minimum of 5ms for each write instruction as well as clear and refreshing signals. So displaying a full heat signature can take up to 0.6 seconds. 13. Reset the GLCD and microprocessor if they do not hand shake and random pixels are displayed on the screen.

Keypad

Requirement	Verification
a). The keypad should be a 4x4 matrix (8 pins for vertical-horizontal scan) type. b). The keypad should be a resistive type network, because the library written for this type of keypads (as opposed to capacitive network keypads).	1. Set the DMM to continuity mode. Connect the DMM to all possible combinations of rows and columns. Check all the keys for each combination, and ensure that only the corresponding key of that row and column makes a closed circuit. 2. Connect rows and columns of the keypad to the microprocessor and upload the test program. Press all the keys and check the right key is detected on the serial terminal.

TX/RX Power Supply

Requirement	Verification
a). It should provide a regulated 5VDC at minimum drive current of 400mA. b). This power supply is being used to drive all the blocks within the TX and RX units. c). The voltage regulators are fed by a 9VDC-32VDC supply capable of handling a minimum of 410mA (the extra 10mA is saved for the voltage regulator internal circuitry).	1. Load both voltage regulators by a proper resistive load (10-12Ω) to ensure drive current of 400mA. 2. Use the function generator to couple the input power supply of the voltage regulators with the 60Hz sinusoid 0.5Vpp. Monitor the regulated signal on the output. If the voltage variation on the output of voltage regulator is more than 0.005Vpp, then change the bypass capacitors so that the voltage variation on the output is less than 0.005Vpp. This procedure is critical because the variation on the power supply will modulate the amplifier stage output signal. 3. If step 2 is passed then load the voltage regulators by the actual circuit. Again, monitor the voltage variations on the regulator's output and the drained current to ensure the rates specs are met. 4. If the power supply tolerance is not met, change the bypass capacitors. If the drain current is not within the specs, change the voltage regulator to a higher power version. 5. If the current drain problem is not

	resolved, connect each stage of the circuit individually to the voltage regulator in order to find which stage is causing the problem (draining more than what is supposed to) to troubleshoot.

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. These signal variations will translate to the amplifier stage. For this reason, the maximum tolerance accepted is ±5%.

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 value, between 0.5 and 5, to ensure the amplified signal is not too high (saturation limit) or too low (not detectable).

Data Acquisition Processor

It is very critical that the sensor data is put together to form a serial array. For this reason, corner cases of different data patterns will be simulated to ensure no glitches occur and the expected data sequence is present.

GLCD

It is very critical that the data acquired will be displayed correctly to the user. All possible heat signatures will be tested on the GLCD to ensure proper waveform is present.

NOTE: All the system components will be integrated on two separate PCBs. The system will consist of two motherboards, each with smaller daughter boards as required by the number of chips that go on each subsystem (TX unit and RX unit). The design technique of dedicating a separate slot for each chip will make the design more robust because this

allows further updates to the system without altering the entire PCB design. The chips (ATMEL328) will be boot loaded individually and programmed using the Arduino compiler. Arduino boards will be used only for testing and debugging. The final design will NOT include Arduino boards.

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 8GB	1	$8.00	$8.00
GLCD	1	$29.00	$29.00
Low Freq Choke	3	$4.00	$12.00
0.5A Fuse + Holder	3	$2.00	$6.00
TTL Quad NAND 74LS00	1	$1.00	$1.00
Resistors	10	$0.10	$1.00
Capacitors	7	$0.10	$0.70
20MHZ XTAL + Isolator	4	$1.50	$6.00
LM7805	2	$2.00	$4.00
LM324	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			$193.90
Note: Cost of purchased items as of today			$118.00

Grand Total

Labor	Parts	Grand Total
$34125	$193.90	$34318.90

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 Paul & 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	Pourya Paul Pourya Paul Paul & Pourya
9/30	Slicers & Buffer: Assemble Test Design Sign-up LP Filter: Assemble and Test Put it together	Pourya Paul Paul & Pourya Paul & Pourya
10/7	Start Designing PCB Research Power Supply Power Supply: Design, Assemble and Test	Paul Pourya Paul & Pourya
10/14	Finish PCB Design Start Programming the TX MP Test TX MP, Coupled with XBEE	Paul & Pourya Pourya Paul

	Start Programming the RX MP	Paul & Pourya
10/21	Individual Progress Report Test Wireless Link and Verify MP Functionality Start Programming SD Card for MP Interference Start Programming GLCD for MP Interference	Paul & Pourya Paul & Pourya Paul Pourya
10/28	Put the MP together and Test for Functionality More Testing	Pourya Paul
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 Note 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

Ethical Issues

We adhere to the statements of the IEEE Code of Ethics that pertain to our project as follows:

- *"3.to be honest and realistic in stating claims or estimates based on available data"*

  We will ensure that all calculations are accurate. All the conclusions drawn from experimental procedures will be supported by data calculations and simulation graphs.

- *"6. to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;"*

  We will apply our analytical and technical skills learned thus far to the best of our abilities in creating a product that will promote railroad safety.

- *"7. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others."*

  Because this is a group project, each person will communicate his ideas on improving the design and provide feedback on the other person's work in terms of quality and things that need improvement. In addition, all information used from outside sources will be credited in the Reference Materials section.

References

"4D Systems, Research and Development." *4D Systems, Research and Development*. N.p., n.d. Web. 29 Sept. 2012. <http://www.4dsystems.com.au/>.

Boot loading procedures for the ATMEL328 microprocessor: Courtesy of CN RR, authored by Pourya Assem

Component datasheets available upon request

Faludi, Robert. *Building Wireless Sensor Networks: With ZigBee, XBee, Arduino, and Processing*. Farnham: O'Reilly, 2010. Print.

Fig.1, Fig.2 and Fig.3: Courtesy of CN RR authorized by Pourya Assem

"Micro SD Card Tutorial - Using SD Cards with an Arduino!" *Micro SD Card Tutorial - Using SD Cards with an Arduino!* N.p., n.d. Web. 29 Sept. 2012. <http://www.ladyada.net/products/microsd/>.

Sedra, Adel S., and Kenneth Carless. Smith. *Microelectronic Circuits*. 6th ed. New York: Oxford UP, 2010. Print.

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