Acoustic Spoke Tensiometer for Bicycle Wheels

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Final Report for ECE 445, Senior Design, Spring 2012

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May 2, 2012

Project No. 14

Abstract

This report summarizes the design process of an acoustic tensiometer that measures the tension in a bicycle spoke based on the resonant frequencies when the spokes are struck. Analyses were done on each sub component of the system to ensure their proper functionality and an overall performance test was also carried out to determine the accuracy of the tension measurements.

The results of the tests confirm that the idea for an acoustic spoke tensiometer is viable and that the measurements taken are consistent with the mechanical meter with an average error of approximately 5%. This percentage error may be due to the effects of variances in the calibration of the mechanical meter used as the control reference. Furthermore, the effects of different lacing patterns of bicycle wheels on the accuracy of the measurements have yet to be examined. This may prove to be an obstacle in future design updates.

Contents

1. Introduction

1.1 Purpose

This project aims to design a tensiometer for bicycle wheels based on the audible frequencies emitted by the spokes when they are being struck. Currently available techniques require clamping of the spokes individually in order to determine the tension based on the physical deflection of the spokes. This method is time consuming and highly dependent on the proper calibration of the meters. This project was created to measure each bicycle spoke quickly without making individual measurements to each spoke.

The goal of this project is to calculate an optimal tension for each bicycle spoke based on the audible frequencies and user inputs like length and butted/non-butted spokes. The device will pluck each spoke consistently so that the resonating frequency can be accurately measured and used to determine the tension in the spoke. This device would be ideal for individuals that want to make adjustments to their bicycles and bicycle repair shops that need to make measurements quickly and accurately for a multitude of customers.

1.2 Functions

The functions of this project can be broken down to the benefits it provides over a standard bike tensiometer as well as special features it provides the user.

Benefits:

- Consistent and accurate measurements
- Calculates optimal tension of the spokes for the user
- Does not require frequent recalibration
- Quickly measures the tension for each spoke in a wheel

Features:

- Convenient measurement of spoke length
- Built in “plucker” to ensure clean striking of the spokes
- Wireless transmission of data from sensor to receiver
- Real-time intuitive visual display for readings
- Stores readings for an entire wheel in memory

2. Design

2.1 General Design Principle

The project relies upon the fundamentals of tension in a string which is derived from basic physical laws.

$$T = m(2FL)^2$$

where F is the frequency of the resonating wire, L is the length of the wire, and m is the mass per unit length of the wire. With regards to bicycle spokes, the mass per unit length can be treated as a constant meaning that tension depends primarily on the length of the bicycle spoke. The frequency of the resonating spoke that the microphone will pick up combined with the inputted length of the spoke will give the tension of each bicycle spoke.

2.2 Detailed Block Description

Block Diagram:

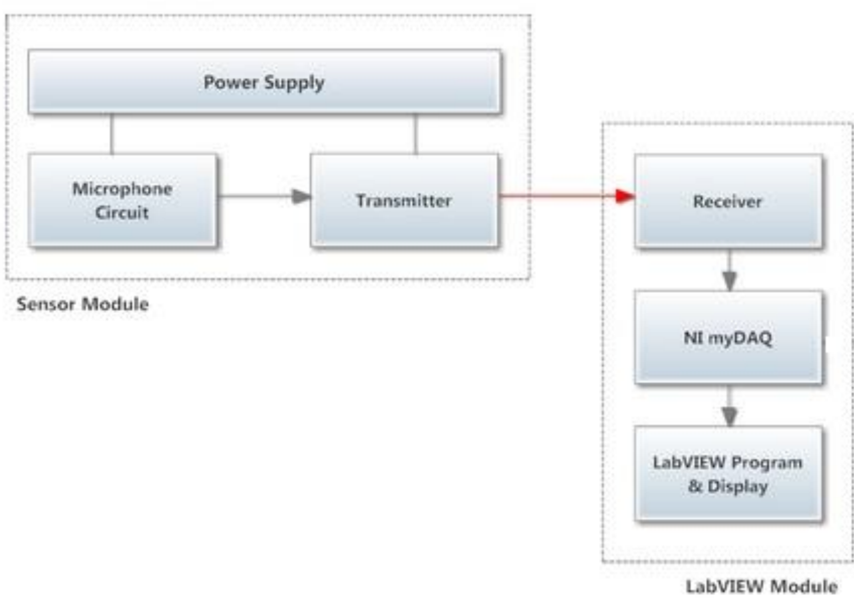


Figure 1: Modular Block Diagram

Figure 1 shows the block diagram for the project divided up into a sensor module and a LabVIEW module. The Sensor module can be broken into subsystems consisting of a power supply consisting of a 9V battery and a rectifier circuit, a Microphone Circuit made up of a microphone connected through an Op-Amp based amplifier, and a wireless transmitter chip. The LabView module is made up of three subsystems including the receiver circuit which is outputs to the myDAQ unit where the captured signal is processed through LabView.

Power Supply: This power supply will be a 5V independent source powering the Sensor Module since it will be a standalone unit separate from the LabVIEW module.

Microphone Circuit: The sensor module will be a unidirectional microphone that takes in the frequency emitted by the resonating bicycle spokes. This signal will be boosted by an amplifier which will then be relayed to the transmitter.

Amplifier: An amplifier will be used to increase the voltage signal from the microphone's output before sending it through the transmitter to the receiver. This will limit the effective error in the calculated tension that would result from noise during wireless transmission.

Transmitter: The transmitter will take the amplified signal from the microphone and transmit it wirelessly to a receiver. This is done to create a portable device for our sensor module to measure the tension of the bicycle spoke without being tied down by a computer.

Receiver: The receiver will gather the signal relayed via the transmitter and input it into the NI myDAQ board's audio in port via a 3.5mm audio jack.

NI myDAQ: The NI myDAQ board will acquire both the analog input from the microphone circuit via the transceiver and then send the signals to LabVIEW for processing.

LabVIEW Program & Display: LabView will apply proper filtering techniques to exclude unwanted frequencies that the microphone is picking up. The software tool will also be able to calculate the resonating frequency that the microphone is picking up and hence, the tension of the bicycle spoke. LabView will also display a user friendly interface that indicates the tension of each bicycle spoke.

Physical Set-up: The Microphone-Amplifier Module will be attached to the truing stand via a clamp as seen in Figure 2 below. It will be outfitted with a wireless transmitter to communicate with the MyDAQ.

Figure 2: Physical Set-up

2.3 Schematics

For full system schematics: **See Appendix B**.

Microphone-Amplifier Module

1. 5V Power Supply
2. Microphone audio preamplifier
3. Transmitter circuit

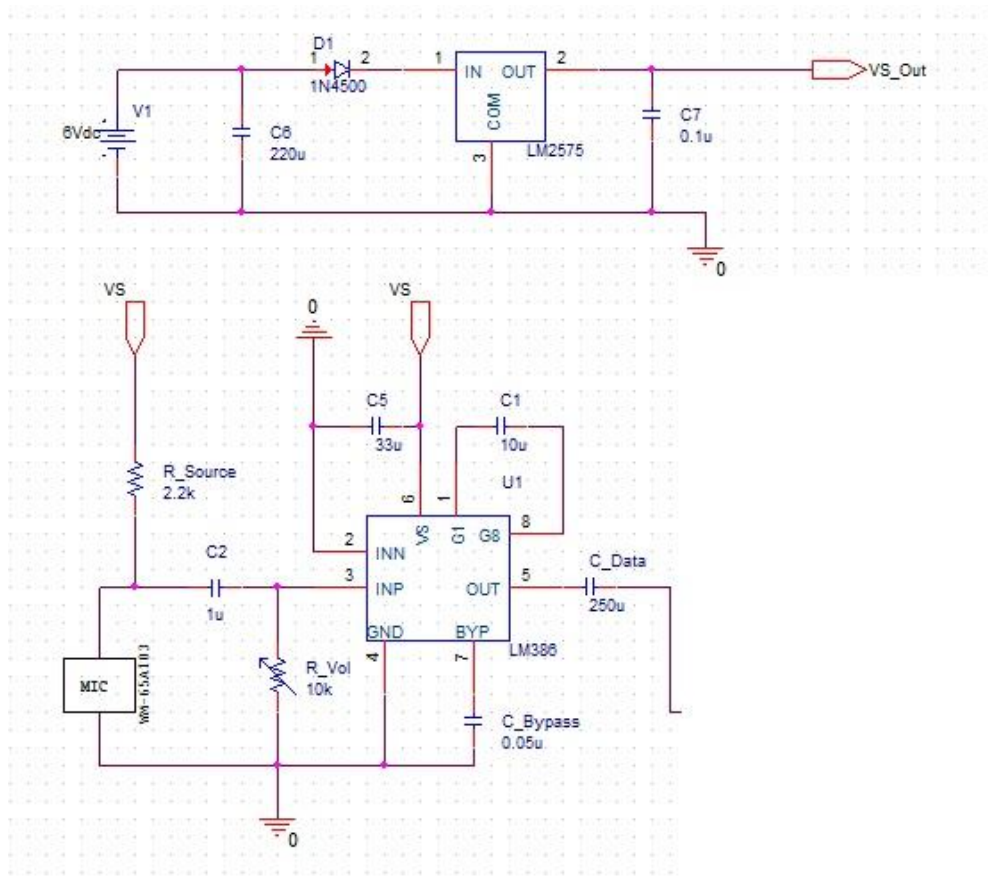


Figure 3: Microphone Amplifier Module

Labels for the Circuit Above:

- V1 = one 9v battery
- C6 = Decoupling capacitor
- D1 = Diode to prevent reverse polarity
- C7 = Decoupling capacitor
- VS_Out = Power supply output
- VS = Power input from power supply
- R_Source = Pull up resistor
- C2 = Input coupling capacitor
- R_Vol = Variable resistor to adjust output
- C5 = Decoupling capacitor
- C1 = Gain capacitor, sets gain
- C_Bypass = Bypass Capacitor, prevents gain degredation
- C_Data = Output coupling capacitor

- CS0, CS1, CS2 = Channel Select Inputs
- Antenna = 50 Ω
- LM2575 = DC Step Down Voltage Regulator
- LM386 = Instrumentation Amplifier
- TXM-900-HP3 = RF Transmitter

The sensor module is made up of 3 main components which include the power supply, the microphone preamplifier and the transmitter.

In the power supply, a 220uF capacitor is used on the input side to prevent any input voltage ripples. A 0.5V diode is placed in the signal path into the voltage regulator for reverse polarity protection. The LM2575 voltage regulator was selected because of its high quality and low noise, and it is able to maintain a constant 5V output at 1A guaranteed current, which satisfies the circuit's requirements of 5V at 20mA. A 0.1uF decoupling capacitor is placed across the output to smooth out any ripple that might occur from the voltage regulator output.

The preamplifier circuit has a 2.2kΩ pull up resistor to ensure that in case of the microphone being disconnected, the input maintains a steady voltage. A 1uF coupling capacitor is connected to the input to block out any DC current. a 10uF capacitor is place between Pin 1 and 8 of the LM386 such that they are on either side of an internal 1.35kΩ resistor. If not bypassed in some way, the chip would set the initial gain at 20. If a 10 uF capacitor is placed across these pins, it provides a low impedance path for the audio frequencies to go around the internal resistor. That effectively removes the resistor from the signal path allowing the internal 150 kΩ resistor to set the gain at 200. The value of the capacitor sets the frequencies that pass around the resistor. The smaller the value, the more low end frequencies get cut off. A 0.05uF bypass resistor is connected to Pin 7 of the LM386 to reduce noise.

Receiver Module

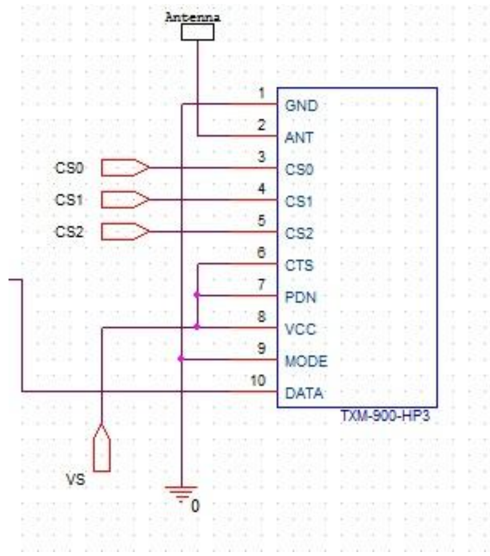


Figure 4: Receiver Module

Labels for the Circuit Above:

- Vs = +5V Supply Voltage from myDAQ
- CS0, CS1, CS2 = Channel Selection
- Antenna = 50 Ω
- 3.5mm Jack = Input into Audio LINE IN on myDAQ
- RXM-900-HP3-PPO = RF Receiver

The receiver module has an AUDIO out which will output the analog audio that was inputted into the transmitter to a 3.5mm jack. The 3.5mm jack is used for easy input into the myDAQ. Channel Select determines the band of frequency at which to receive the signal. PDN is high to signal that the circuit should be receiving a signal.

LabVIEW Module

The LabView module will take the output from the receiver and feed it into the NI MyDAQ. The MyDAQ will serve as a bridge to communicate with the LabView software which will process the data. The myDAQ board is powered from the computer via the USB cable and is able to output a 5 Volt supply which will be used to power the receiver of the circuit.

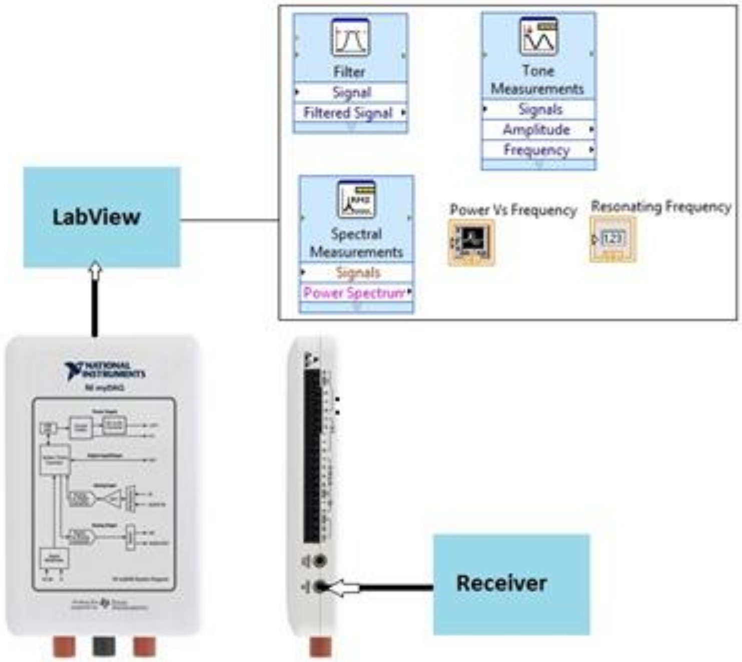


Figure 5: LabVIEW Module

3. Design Verification

3.1 Testing Procedure

Power Supply Test

A range of voltages from 5 V to 10 V was used as the source voltage of the power supply to determine the effect on the output voltage of the amplifier. The test was repeated with a diode connected because it requires a certain voltage to turn on.

Microphone Test

Five candidates for the ideal microphone have been selected based on their frequency response and output voltage levels in order to obtain the best performance. To conduct a fair and comparative test between the five microphones, a 3.5mm audio jack is soldered to each of the microphones, and then plugged directly into the Audio In port of the NI myDAQ data acquisition device. A pair of computer speakers was used as the audio source. The output of the microphone is displayed in terms of a voltages vs. frequency graph in LabView. Also a band pass filter from 200Hz -1000Hz was applied to the output of the microphone in LabView such that only the fundamental frequencies relevant of this project are detected.

The test was then carried out such that sound of 3 fixed frequencies (196Hz, 493.9Hz, 987Hz) were played normal to the plane of the microphone. This corresponds to the full range of frequencies that bicycles spokes could produce. The maximum distance L at which a stable output signal could be detected was then tabulated for all the microphones. The best candidate is then selected based on the maximum distance giving a stable output and the output voltage level.

<u>Amplifier Test</u>

The amplifier test was relatively straight forward, where a test signal at 30mV peak to peak and 500Hz from the function generator was plugged into the input of the amplifier circuit to simulate the output from the microphone, and then the output was displayed on an oscilloscope to measure the gain. The requirements for these tests are to ensure the output signal from the microphone is reproduced cleanly and that the gain factor is within 10% error range from the set gain at 100.

<u>Tranceiver Test</u>

A frequency sweep between 200-1000 Hz was inputted into the transmitter and the output was measured at the receiver to determine if the two signals were the same.

<u>LabVIEW Test</u>

A sweep of frequencies from a computer was generated and the myDAQ was directly connected to the AUDIO OUT jack of the computer. LabView was setup to determine the frequency of an inputted signal.

<u>System Functionality Test</u>

Once the enclosure was completed and all components had been fitted inside it, the unit was mounted to the truing stand and tested for accuracy. The position chosen for the plucker was near the center point of the spokes with the plucker extended just far enough to make contact with each spoke. The microphone was slid into the hole of the enclosure at about a one centimeter depth to provide some added buffering of outside noises. Measurements of the length of the spokes as well as the diameter of the spokes were taken for parameters of the analysis program as well as to make comparisons to tensions measured from a TM1 Park Tool Tensiometer.

With all parameters inputted into the program and it set to record, the wheel was rotated around its axis by hand such that there was a little over a one second delay between the plucking of each spoke. Once every spoke had been plucked the program stops recording and provides a complete record of the measured tension in each spoke as well as a comparison to the calculated perfect tension. For an accuracy calculation, the tension of each spoke was then measured with the Park Tool Tensiometer with the closest approximate value being recorded from the TM1 conversion chart.

3.2 Results & Measurements

Power Supply Test

Table 1: Power Supply Test Result

Vs (V)	Vout (V)	Vout With Diode (V)
5	3.57	2.65
6	4.46	4.11
7	4.96	4.96
8	4.96	4.96
9	4.96	4.96
10	4.97	4.97

It is evident that the regulator cannot output a steady 5 Volts if the source voltage is less than 7 Volts. It is also easy to observe that the output voltage is steady if the source voltage is above 9 volts indicating that a 9 V battery should be enough to power the circuit.

Microphone Test

Table 2: Microphone Test Result

Model Name	Directionality	Source Frequency (Hz)	Max Distance (cm)	Amplitude (uV)
WM65A	Omni	196	91.5	35
		493.8	92.8	40
		987	84	60
WM55D	Uni	196	13	50
		493.8	45.3	50
		987	73.9	48
CMI-5247	Uni	196	89.1	75
		493.8	150	105
		987	148	85
CMC-2242	Omni	196	0.1	650
		493.8	11.5	800
		987	5.4	600
54C6	Omni	196	NA	NA
		493.8	0.5	1500
		987	NA	NA

The CMI-5247 microphone was chosen because it gave a large output amplitude for the various frequencies at farther distances compared to any of the other microphones.

Amplifier Test

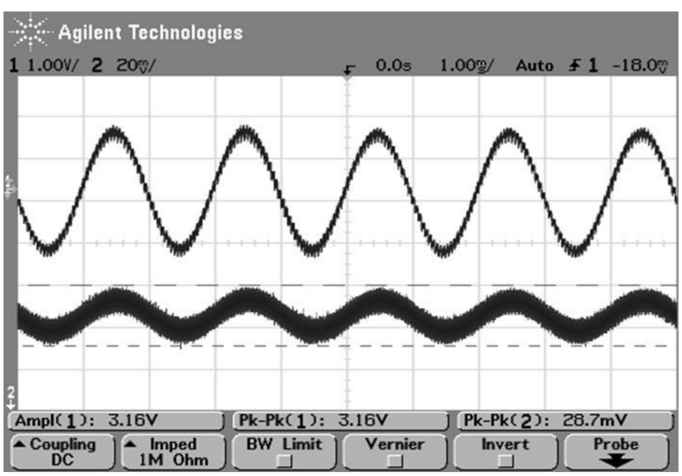


Figure 6: Amplifier Test

The 30 mV input signal was amplified to 3.16 V which is amplification by a factor of more than 200.

<u>Tranceiver Test</u>

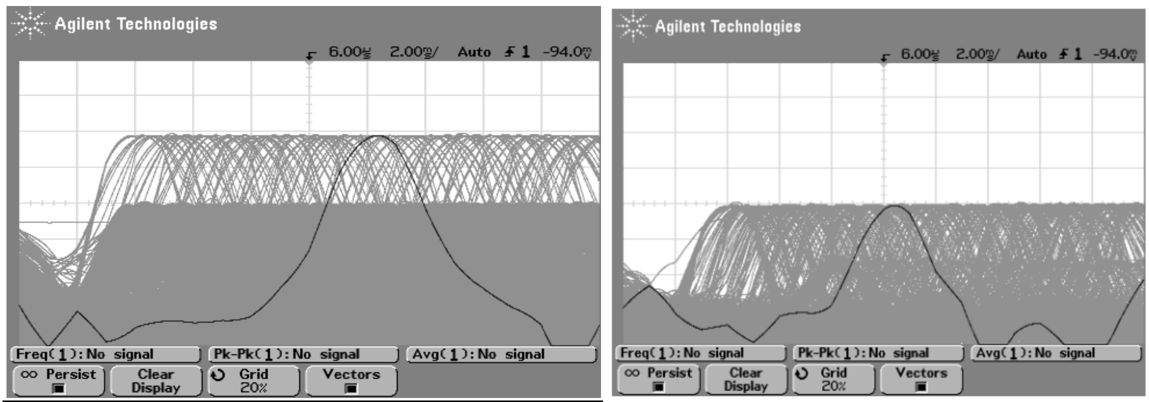


Figure 7: Tranceiver Input/Output Plots

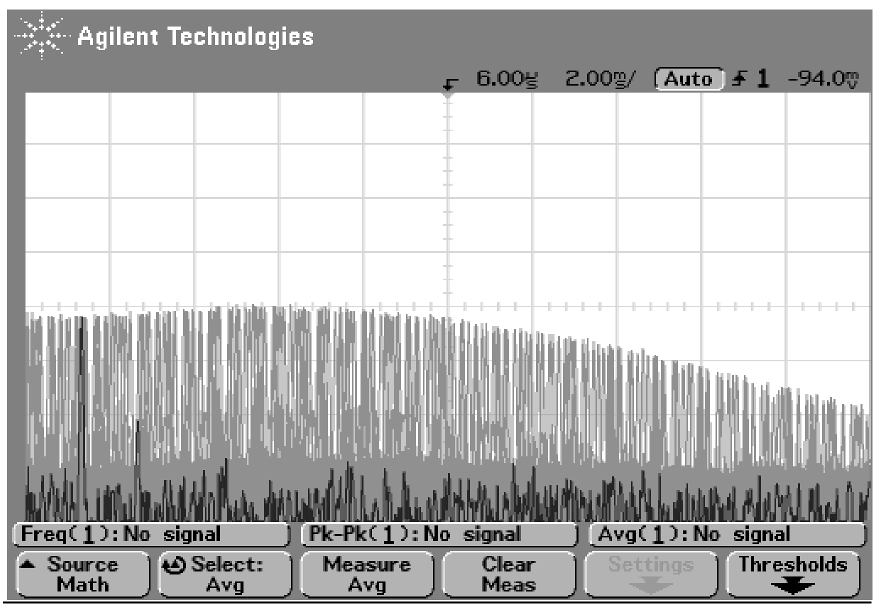
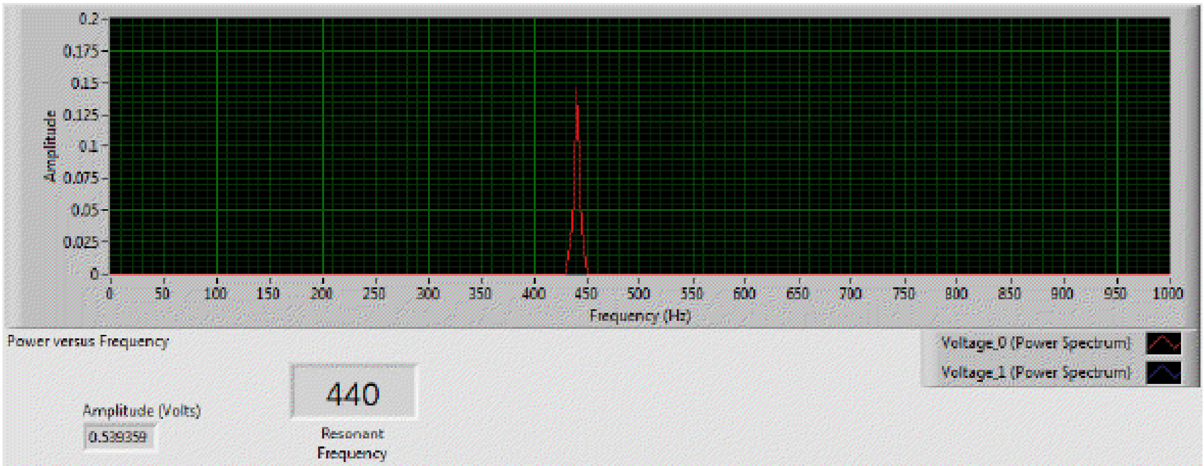


Figure 8: Tranceiver Saturation Frequency

The output signal gave the same flat band response as the input signal, but with an attenuated amplitude. The transceiver units flat band response starts to diminish at around 25 KHz.

LabVIEW Test



LabView was successfully able to read the 440 Hz signal coming from the computer.

System Functionality Test

In general, the test provided good results with each spoke yielding a calculated tension. The comparison to the Park Tool measurements are provided in the table below where the Control Tension refers to the tensions read from the TM1 conversion chart.

Table 3: Tension Measurements

Measured Tension (kgf)	Control Tension (kgf)	Percent Difference (%)
91.2	94	3.023758099
97.22	105	7.69459005
69.99	77	9.538063814
78.2	94	18.35075494
89.67	94	4.71497795
72.71	77	5.731080088
109.63	105	4.314401528
63.82	70	9.23628755
96.99	94	3.131053982
67.67	70	3.384905934

90.85	94	3.408168786
65.27	70	6.993420566
107.54	105	2.390138327
94.25	94	0.26560425
54.91	64	15.28887394
91.65	94	2.53164557

The average of the percent difference values is about 6.2%. Looking at the table there are two clear outliers well above the percent error of the other spokes, so ignoring those two values and recalculating the percent difference yields an average error of 4.8%.

3.3 Discussion of Results and Verifications

Results from the final test were overall very good. Every component functioned and there were no issues with the circuits built. On that end, all subsystem verifications were met. The only discrepancy with the verifications is the condition that the design *calculates the tension within 5% of the reference value when supplied a frequency at the input of the myDAQ*. The average percent difference that was observed was slightly over that 5% target at 6.2%. However, this result could be the effect of several different influences. A generalized value was used for the mass per unit length of the spoke as it was difficult to obtain the exact value for each kind of spoke so the tensions calculated are not exactly specific to the tested spokes. Also the Park Tool Tensiometer used was borrowed and the history of its use including how well it was calibrated is also unknown.

Furthermore, looking at Table #3, the measured tension values are consistently less than the control tension values. To account for this, a new average percent difference can be calculated by using measured tension values increased by 4.8% (the average without outliers). Doing so yields a new average (including the outliers) of 4.7% with a much more even distribution of tension values above and below those of the control tensions. In the end, the 5% benchmark can reasonably be considered achieved.

Detailed Testing and Verifications Table: See **Appendix A**.

4. Cost and Analysis

4.1 Bill of Materials

Table 4: Parts List

Part	Quantity	Provider	Cost
MyDAQ w/Labview	1	National Instruments	$199.00 (Student)
Receiver *(RXM-900-HP3-PPO-ND)*	1	Digikey	$43.40
Transmitter *(TXM-900-HP3-PPO-ND)*	1	Digikey	$23.60
3.5mm Jack	1	Monoprice	$.65
Op-Amp *(LM386N)*	1	Digikey	$0.93
Microphone *(P9964-ND)*	1	Digikey	$2.18
Battery - 9V Standard *(P647-ND)*	1	Digikey	$1.98
Regulator *(LM2575)*	1	Digikey	$3.13
Capacitors	7	ECE Parts Shop	$1.40
Resistors	2	ECE Parts Shop	$.20
Truing Stand	1	Amazon	$61.49
ON/OFF Switch	1	ECE Parts Shop	$2
Park Tool Tension Meter	1	Amazon	$52.84

4.2 Labor

Table 5: Labor/Cost

Employee	Labor
Xi Li	12 hrs/week x 2.5 x 12 weeks x $30/hr ($60k Salary) = $10,800
Andrius Bobbit	12 hrs/week x 2.5 x 12 weeks x $30/hr ($60k Salary) = $10,800
Sakeb Kazi	12 hrs/week x 2.5 x 12 weeks x $30/hr ($60k Salary) = $10,800
TOTAL	($10,800/person x 3 persons) = $32,400

Total Cost = $392.80 + $32,400 = $32,792.80

5. Conclusion

5.1 Accomplishments

Some of the key accomplishments of the project was at first, the amplifier's ability to amplify the microphone signal. Originally the amplitude of the signal the microphone was capturing was about .015 Volts and the amplifier was able to amplify it to 3.16 Volts, or an amplification by a factor of 210. The next successful accomplishment was having the transceiver successfully transmit and receive the microphone signal without distortion. At first, there was concern that the transceiver module would distort the frequency of the signal which is the basis of the project. Fortunately, the transceiver didn't disrupt the frequency of the signal, but rather just attenuated the amplitude of the signal which wasn't a concern because of the amplifier. Finally, LabView was successfully able to indicate the frequency of the signal inputted into the myDAQ. Once LabView could successfully process the signal into a frequency reading, the rest of the user interface could be constructed.

5.2 Challenges

Coding in LabView had to be the most difficult aspect of the project. Prior to this project, there was little experience and familiarity with LabView. LabView uses drag and drop graphical coding which is much different than the C programming taught in the ECE curriculum. Implementing a multiplication or an if statement in C is much simpler than dragging out each

component needed for LabView coding. Also, the graphical coding causes the entire code to look messier with wires going everywhere and it is difficult to debug if any problems arise.
The sturdiness of the plucker would also diminish over time as continuous testing was conducted. This would require constant adjustments of the plucker ensuring it would not damage the spoke and produce a loud enough signal for the microphone to pick up.

5.3 Ethical Considerations

This project adheres to the IEEE Code of Conduct and Ethical Guidelines provided. The device produced in this project will not harm others in any way or form. This project shall not disclose of any personal information for unauthorized use and will ensure the safe storage of such information.

5.4 Future Work & Alternatives

In order to streamline the process of measuring the tension in each spoke of the bicycle wheel even further, an additional plucker and microphone could be mounted to the other side of the wheel. With one spin of the wheel the tensions for each spoke on the entire wheel would be recorded instead of having to flip the wheel around. The microphones would be placed on opposite ends of the wheel so that the resonating frequency of the two spokes wouldn’t interfere with each other. This would require additional transmitters, receivers, and microphones increasing the cost of the project. Also, the plucker material and placement might want to be redesigned to ensure long term use of the plucker without the sturdiness being compromised.

References

Components

- Receiver: http://search.digikey.com/us/en/products/RXM-900-HP3-PPO_/RXM-900-HP3-PPO-ND/1917077
- Transmitter: http://search.digikey.com/us/en/products/TXM-900-HP3-PPO/TXM-900-HP3-PPO-ND/444157
- Microphone: http://search.digikey.com/scripts/DkSearch/dksus.dll?vendor=0&keywords=wm%2065a103
- PreAmp: http://media.digikey.com/pdf/Catalog%20Drawings/Audio/MicCartridgeCircuit.jpg
- Keypad: http://search.digikey.com/us/en/products/96AB2-102-R/GH5002-ND/180930
- Batteries: http://search.digikey.com/us/en/products/A76VZ/N402-ND/704827
  Regulator: http://www.ti.com/lit/ds/symlink/lm2575-n.pdf

Research

- Wheel Tension Measuring: http://www.parktool.com/blog/repair-help/wheel-tension-measurement
- Spoke Pitch: http://www.bikexprt.com/bicycle/pitcheqn.htm

Appendix A: Requirements & Verifications

Component	Verification	Successful
1.0 Sensor Module: Able to capture a frequency within the range of a plucked spoke and accurately (within 5% of the initial frequency) transmit that signal to the receiver unit connected to the my-DAQ.	Test: A 500 Hz signal is generated through the function generator and output through a speaker. The output of the receiver will be connected to an oscilloscope. If working properly, the displayed waveform should have a 500 Hz(+/-5%) frequency. A non-related signal means part of the module is not operating correctly.	Yes
1.1 Power Supply: For all components of the sensor module to operate correctly it will supply a continuous voltage of 5V.	Test: Power supply will be connected to a 1.5 kΩ resistor and with the voltage across it probed on a multimeter. 5V being detected across the resistor signify a working power supply.	Yes
1.2 Microphone: Continuously captures and transmits frequencies from 200-1000 Hz.	Test: A varying signal from 200 to 1000 Hz will be outputted onto a speaker using a function generator. The output of the microphone will be probed and displayed on an oscilloscope. If the microphone works, a graph of voltage values corresponding to the range of frequencies will be displayed.	Yes
1.3 Amplifier: Amplifies the signal from the microphone by a factor of 150(5%) and maintains the frequency within 5% of the input.	Test: A waveform from a function generator with a 1mV amplitude at a frequency of 500 Hz will be supplied to the input of the amplifier. The output will be displayed on an oscilloscope where the resulting amplitude and frequency will be measured. An operating amplifier will have an amplitude of 150 mV (5 7.5mv) with a frequency of 475-525 Hz.	Yes
1.4 Transmitter/Receiver: Continuously transmits a wireless signal that maintains a frequency and amplitude within 5% of the original value	Test: Waveforms from a function generator with a 100mV amplitude at a frequencies of 200 and 1000 Hz will be supplied to the input of the transmitter. The output of the receiver will be displayed on an oscilloscope where the amplitude will be checked to be within the range of 95-105mV and the frequencies should be between 190-210 Hz and 950-1050 Hz.	Yes
2.0 LabVIEW Module: Takes in data from receiver and keypad matrix and calculates the correct frequency along with the corresponding	Test: A waveform will be supplied to the input of the transmitter with a frequency of 440 Hz and amplitude of 150 mV. User input for a non-butted	Yes

tension within 5% of a tension calculated by a manual tensiometer. Information will be displayed with an easy to read module through LabVIEW	330 mm spoke will be input. The LabView module should calculate a tension within 5% of the perfect tension. No tension calculation or a tension outside of that range means the module is not working as a whole.	
2.1 myDAQ : Provides quick and up-dated information from the input signals as well as a power supply for the LabVIEW Module	Test: The LabVIEW measurement and automation explorer will be setup and a 100 mV amplitude sine wave with a frequency of 500 Hz from a function generator will be connected to the input of the myDAQ. The module in LabVIEW should instantly output a waveform corresponding to a 500 Hz, 200 mV peak to peak signal. This can also be used to verify that the myDAQ is supplying 5V from its supply terminals.	Yes
2.2 LabView : Quickly filters the signal supplied to the myDAQ and calculates the responding tension as well as provide all the data in an easy to read module. Requirement 1: Filters out the frequencies in the input signal outside the range of 200 to 1000 Hz. Requirement 2: Calculates the tension within 5% of the reference value when supplied a frequency at the input of the myDAQ.	Test 1: Supply a range of frequencies from 0 to 1500 Hz to the input of the myDAQ. A frequency vs time graph will be implemented through LabVIEW and connected to the output of the low-pass filter. A working filter will only show frequencies between 200 to 1000 Hz. Test 2: Supply a waveform to the input of the myDAQ with a frequency of 440 Hz and amplitude of 150 mV. User input for a non-butted 330 mm spoke will be input. The LabVIEW module should calculate a tension within 5% of 138Kgf (the perfect tension).	Yes

Appendix B: Circuit Schematics

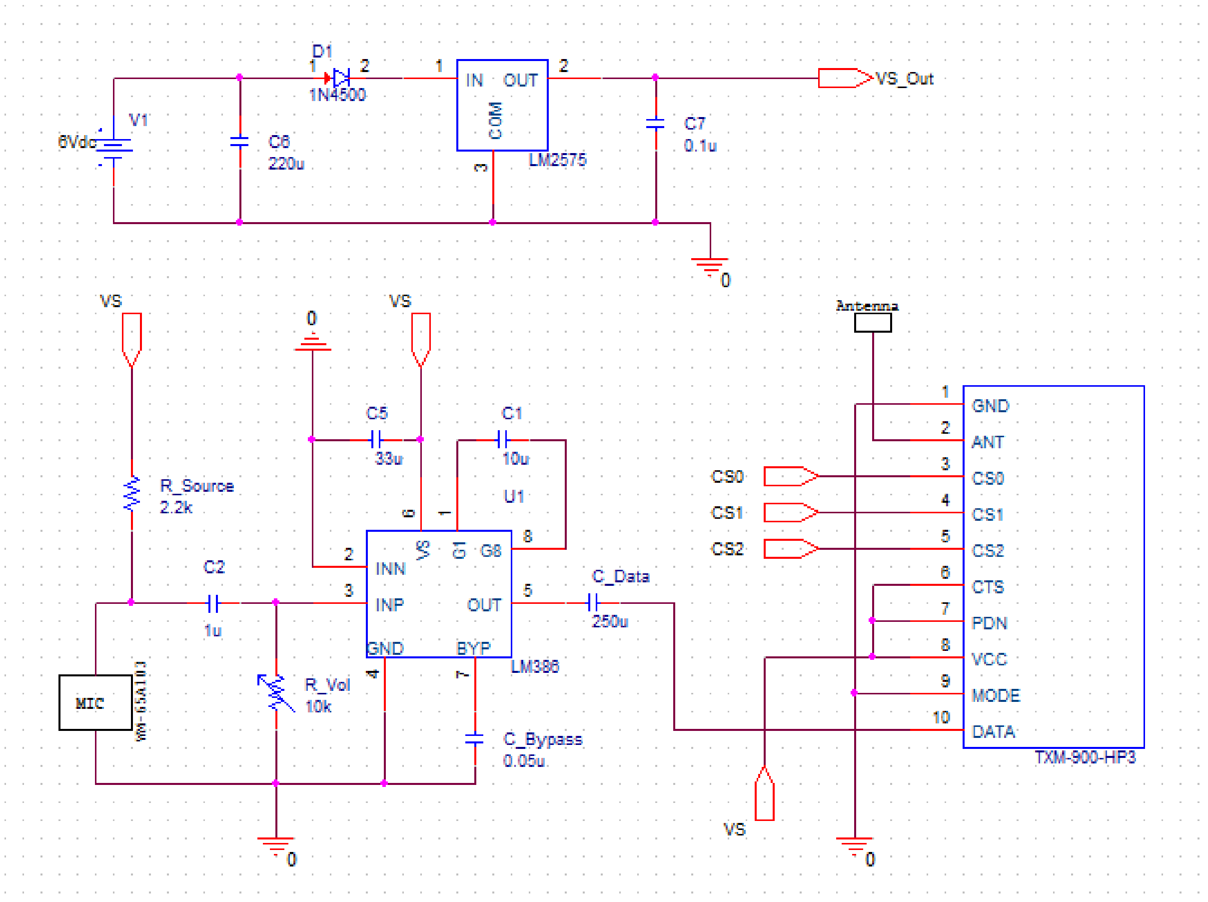


Figure 9: Full System Schematic

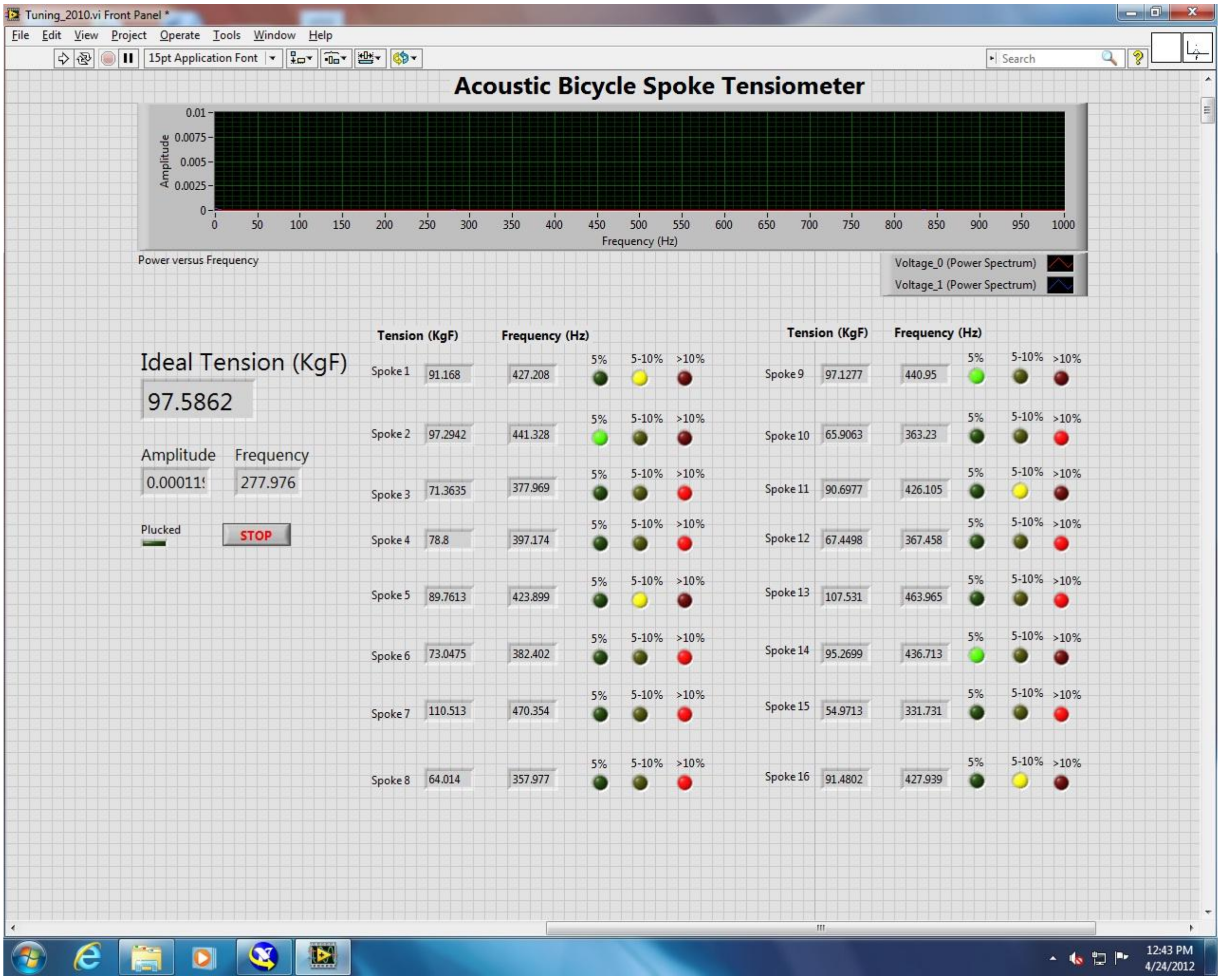


Figure 10: LabVIEW Interface

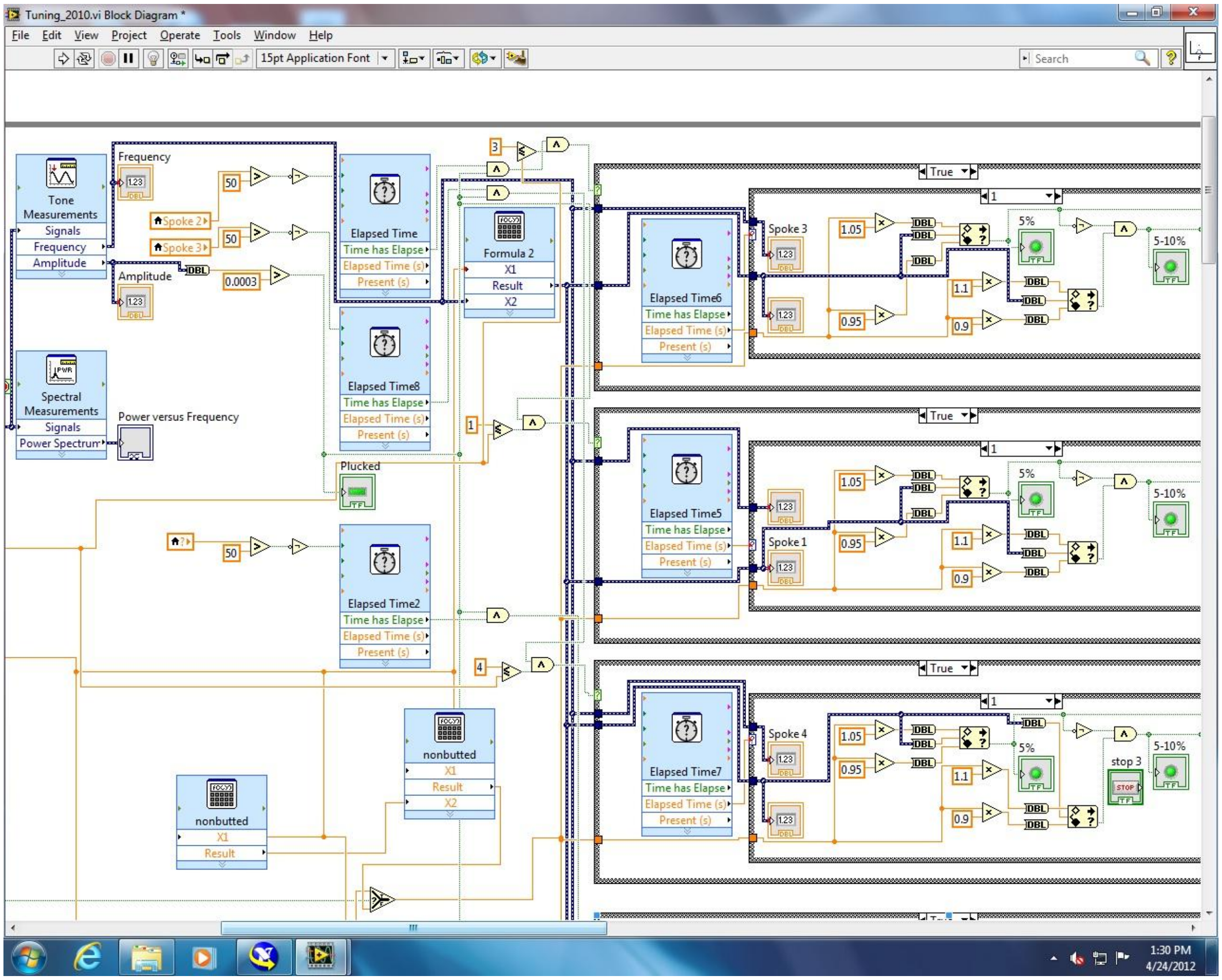


Figure 11: LabVIEW Program