Group 2A: Speed Gun

Members:
Roy Baker
Asaph Matheus Barbosa
Andrew Slater
Tyler Weppler

Advisor:
Dr. James West

OSU ECEN 4024
Capstone Design

Spring 2017

Abstract - Tyler Weppler

This document describes the research, design, and testing of the speed gun designed by Group 2A for the ECEN 4024 Capstone Design class of spring 2017. The project was assigned at the beginning of the semester to be turned in after demonstrating its functionality at the end of the semester. The purpose of this project was to demonstrate the skills obtained through the ECEN curriculum in one project covering many areas of electrical and computer engineering. The specifications are set by the group, and the end design must match these specifications. In this report, the responsibility breakdown, budget and schedule, background information and research, methodology, detailed design, and end results are all described.

The group was allotted $250 by the ECEN department to design and build a functional project. Group 2A broke apart the workload based on skills and comfortability working with certain areas of the overall system. These sections included RF circuitry for Roy, electronics circuitry for Tyler, software development for Matheus, and packaging design for Andrew. Each member performed their share of the work as well as contributed to the other sections as needed. After researching the respective sections, the group came together to design an overall system to perform at the specified goals. After many challenges, hard work, and collaboration, the group was able to complete the project ahead of schedule and reach some of the stretch goals for the project including a PCB design, BLE implementation, and multimode operation. The device met the specifications, successfully measuring the speed of a baseball. In normal operation, the speed gun does not exceed a total current draw of 120mA, consuming 600mW. The group stayed well under budget coming in at a grand total of $162.64.

Table of Contents

Introduction

Purpose - Tyler Weppler

Group 2A was assigned the project of building a radar speed gun. The speed gun is to measure the speed of objects such as baseballs using microwave radiation. The project is to be handheld, have low power consumption, and have a well designed casing. This project would cover many aspects of electrical and computer engineering and would be designed and built in one semester. Specifications were set by the group and were used to assess the final project demonstration.

Overview - Tyler Weppler and Roy Baker

For this design, the group proposed the project as a Solo Pitch Practice Recorder. The premise would be that a baseball pitcher could practice and record baseball pitch speeds with or without a coach to hold the radar gun. The pitcher could set up the radar gun on a tripod mount, pitch the ball, and receive the pitch speed over Bluetooth LE (Bluetooth 4.0) to view at the mound on a smartphone instead of walking to the radar gun. On the other hand, if the pitcher did have a coach, the coach could hold the gun, use a triggered transmit, and see the last throw speed and average speed on the LCD screen.

The complete system consists of four subsystems: the RF circuit, responsible for producing a signal containing information about the speed of the object; the electronics subsystem, including the microprocessor, power circuitry, LCD screen, and BLE transmitter; the software, consisting of the code necessary to extract speed information from the signal and format information to be displayed on the LCD and sent over BLE; and the packaging, housing the components, protecting the device from the environment, and providing a means for the user to interact with the device. The full design of each of these subsystems is detailed later in the document.

The basic operation is as follows. The radar transceiver emits a microwave signal, which is reflected from a moving object in the beam. The reflected signal is shifted in frequency from the transmitted frequency by the Doppler effect in proportion to the object's speed relative to the transceiver. This frequency-shifted signal is received at the transmitter and passes through the transceiver's mixer, where the difference between the transmitted signal and the reflected signal is taken, resulting in the output of a signal that is at the frequency of the difference: the Doppler shift. This signal is then bandpass filtered and amplified to the level needed by the analog-to-digital converter (ADC) of the microprocessor. Once digitally quantized, this signal is processed by means of the Fast Fourier Transform (FFT) software algorithm, resulting in a quantification of the strength of individual frequency components of the signal. The frequency component with the greatest amplitude is taken to be the frequency of the Doppler shift. Using the Doppler equation, this frequency measurement is converted into a speed. This speed is then displayed to the LCD screen and sent over the Bluetooth connection to any listening devices.

Design Parameters

Specifications - Tyler Weppler

The following list is the agreed upon specifications to be met by the final design. These were set to be obtainable within the semester but were intended to be rigorous enough to still produce a quality project comparable to similar off the shelf products. The frequency and accuracy were chosen to match those of an off the shelf product. The range was chosen to be longer than the distance between the pitcher's mound and the home plate. In professional baseball, this distance is 60.5 feet. The pitch speed was chosen to measure young pitchers all the way up to professional pitchers. The low speed threshold would ignore unwanted signals such as from people walking, and the high speed was chosen high enough to include the fastest pitches, the record pitch speed being 105mph. The battery life is set based on the length of a baseball game. Lastly, the budget is based on the allotted amount by the course.

- Frequency: 24.125 GHz
- Range: 65 feet for baseballs
- Pitch Speeds: 15-110 mph
- Accuracy: +/-1 mph
- Battery: Rechargeable LiPo
- Battery Life: 4 hours
- Cost: $250 budget
- Size: Handheld/Tripod Mountable

Responsibilities - Tyler Weppler

Responsibilities were broken up by subsections of the design and by the strengths and skills of each team member. Roy has a strong background and interest in radar, so he was the most qualified to handle the RF circuitry which includes transmitting, receiving, filtering, and amplifying the signal. Matheus has a strong software background, so he was put in charge of the coding for handling the FFT of the incoming signal. Tyler has background in embedded systems and PCB design skills, so he handled the processor circuit and electronics for I/O and made the PCB layout. Andrew had skills using SolidWorks and liked hands on work, so he was in charge of the packaging of the radar gun. On top of the project responsibilities, each member functioned in a job for the team. Tyler was designated as Team Leader to delegate work, keep the team managed, and schedule meetings and work times. Roy was the Team Scribe, responsible for keeping notes at advisor and group meetings. Andrew was made the team Parts Manager and was responsible for purchasing parts. Matheus took the job of Advisor Liaison, corresponding with the group advisor, Dr. West, to set up meeting times and relay information.

Budget - Tyler Weppler

For this project, the ECEN department allowed each group $250 to spend on the project and discouraged student purchases. The group came up with an initial design that totaled well over $300 and quickly realized a new design was needed with cheaper parts. The budget was broken into four parts: RF circuitry, electronics, packaging, and emergency funds. The RF circuitry was allotted half the budget, $125, given that it was the major portion of the design. Components for the electronics subsystem would be cheaper and easier to find, but were allotted $50 just in case. Packaging was given $40 in case the group needed to purchase their own spools of filament for 3D printing; fortunately, Oklahoma State University provided free spools for student use in labs. This left $35 as a reserve in case parts broke and to purchase PCBs if time permitted.

Schedule - Tyler Weppler

The group based the schedule of the project on deadlines for the course. These included research, design, presentations and demonstrations, course documents, and other deadlines that arose. The following Gantt chart in Figure 1 shows the schedule followed by the group through the Spring 2017 semester.

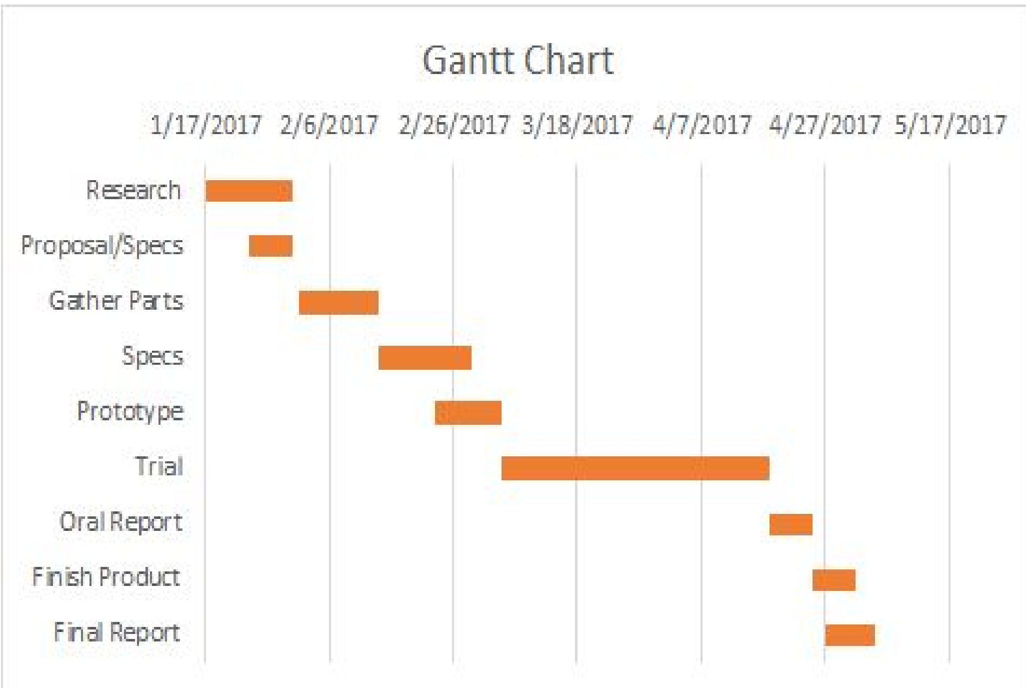

FIGURE 1: Gantt Chart

Background - Roy Baker

The primary physical phenomena utilized for this project is the Doppler effect. The Doppler effect is the apparent shift in frequency that occurs when a source of oscillating radiation (physical or electromagnetic) has motion relative to an observer or when an observer has motion relative to a source of oscillating radiation. In this application, a stationary radar transmitter emits a continuous wave of radiation that travels to a target and then travels back. If the target were stationary, reflections of the incoming wave would occur at whole wavelengths of the transmitted wave. If, for instance, the target were moving towards the transceiver, the target would intercept wavefronts before the wave moves through a whole wavelength. The reflections would then return to the transceiver with an apparent shorter wavelength and therefore a higher frequency. The effect can also be described mathematically as follows, assuming that the target velocity is very small compared to the wave velocity. The wave velocity in this application is the speed of light, so this assumption holds.

The total wavelengths contained in a transit from transceiver to target and back is $2R/\lambda$, where R is the distance to the target and λ is the wavelength of the transmitted wave. Since the wave covers 2π radians in each wavelength, the total angular displacement to the target and back is $4\pi R/\lambda$ radians [1]. Since the target is moving, this angular displacement ψ changes with the changing R. The time derivative of angular displacement is a frequency, in this case the Doppler shift. The Doppler shift frequency ω_d, in radians, is given by [2]

$$\omega_d = 2\pi f_d = \frac{d\psi}{dt} = \frac{4\pi}{\lambda}\frac{dR}{dt} = \frac{4\pi v_r}{\lambda}$$

where f_d is the Doppler shift frequency in Hertz and v_r is the speed of the target relative to the transceiver. The Doppler frequency in Hertz is then

$$f_d = \frac{2v_r}{\lambda} = \frac{2v_r f_0}{c}$$

where f_0 is the frequency of the transmitted signal and c is the speed of light.

Assuming the signal containing the Doppler frequency can be quantized, extraction of the Doppler frequency is straightforward with the use of the Fast Fourier Transform (FFT) algorithm. The FFT algorithm, known historically to mathematicians such as Gauss, was independently discovered by Cooley and Tukey in 1965 [3]. The FFT allows for the efficient digital computation of the discrete Fourier transform (DFT) on a microprocessor. The DFT is a transform that operates on a waveform that is discrete in time, of finite duration, and is periodic or aperiodic and yields the discrete frequency spectrum of the signal, quantifying the strength of individual frequency components of the signal. Utilizing the FFT, the Doppler shift can be calculated for the received signal.

Methodology - Tyler Weppler and Roy Baker

The first step to designing the radar gun was to research radar theory to get an idea of where to begin. The group had a basic idea of how radar worked, but needed some further explanation on types of components that would be needed to build the circuitry. Roy discovered a design from MIT that used all discrete components to build the radar circuit itself, but these components alone came up to well over $300. Ruling out a more complicated radar system such as one that uses a frequency-modulated continuous-wave (FMCW) transmitter to get speed and ranging, the group decided to focus on cheaper continuous-wave Doppler transceivers. Luckily, Bushnell makes an off the shelf sports radar gun that has an all in one transceiver that is easily removed for only $90, which was a much better fit for the budget. The transceiver included a Gunn diode oscillator and a mixer, taking a DC input voltage and producing a sine wave at the Doppler shift of the target. To avoid any doubts about the group's design efforts, the only parts taken from the Bushnell radar gun were the transceiver and horn antenna, components that could have been purchased separately from electronic vendors, albeit at a higher cost. This set the starting design basics for the group to work around.

To ease integration and speed up the design process, the project was broken up into four subsystems, thus giving each member their specialized one while allowing all members to contribute to the others as needed. These subsystems would be the RF circuitry, electronics, FFT software, and packaging.

With the core components selected, the next decision was how to process the signal. For microcontrollers, the group debated between the Raspberry Pi and Arduino, as these were already familiar to the group and had extensive support available. The Raspberry Pi was more expensive but had more processing power, while the Arduino could be shrimped, reducing the physical size of the microprocessing circuit and lowering the cost. After deciding on the Arduino, various I/O interfaces were considered such as motion detection, microSD card data logging, an LCD display, and Bluetooth Low Energy connectivity. These components were added to the design as extra features to make it more marketable. After considering difficulties presented by a motion detection implementation, this extra feature was removed. Later in the development, the capability to log data to a microSD card was removed due to the size of the necessary software exceeding the memory of the microprocessor.

Tyler had been working on a previous project where he had designed and built a working processor circuit complete with I/O interfaces, so he immediately began breadboarding this circuit and programmed the functions needed to interact with the processor. This system was tested with sample data and was deemed worthy of use.

Andrew took apart the Bushnell radar gun, and as a group effort, the PCBs were desoldered from the transceiver. Roy began testing and designing a filter and amplifier circuit while Matheus tested various FFT algorithms on an Arduino Uno which has the same processor used by the group.

After getting each electrical subsystem ready to go, the group was ready to begin combining them together. The starting point for integration was connecting the RF circuitry to the Arduino Uno's FFT test code. This section was tested thoroughly with many different strategies to determine that it was working as anticipated. Achieving acceptable results, it was decided to connect to the electronics subsystem directly. The FFT code was added to the processor, where it was soon discovered that the global memory was fully used, meaning something had to be removed. The decision was made to remove the microSD card logging feature, freeing up enough space in the memory to store the FFT code. After this, there were no problems with the integration.

With the correct sizing, finalized circuit and components, and satisfying test results, it was time to package the design. Andrew had been sketching up some designs in Solidworks to be 3D printed. Meanwhile, Tyler used Kicad to design a PCB to be printed using through-hole components so that the circuit components could be removed from the breadboard and assembled directly on the PCB. After the PCBs arrived and a final 3D printed case was made, the group worked together to assemble the final design, where it was tested again and completed.

Detailed Design

System Design - Tyler Weppler and Roy Baker

The overall system is based on the following block diagram in Figure 2, where the block color is based on the person responsible for that particular block.

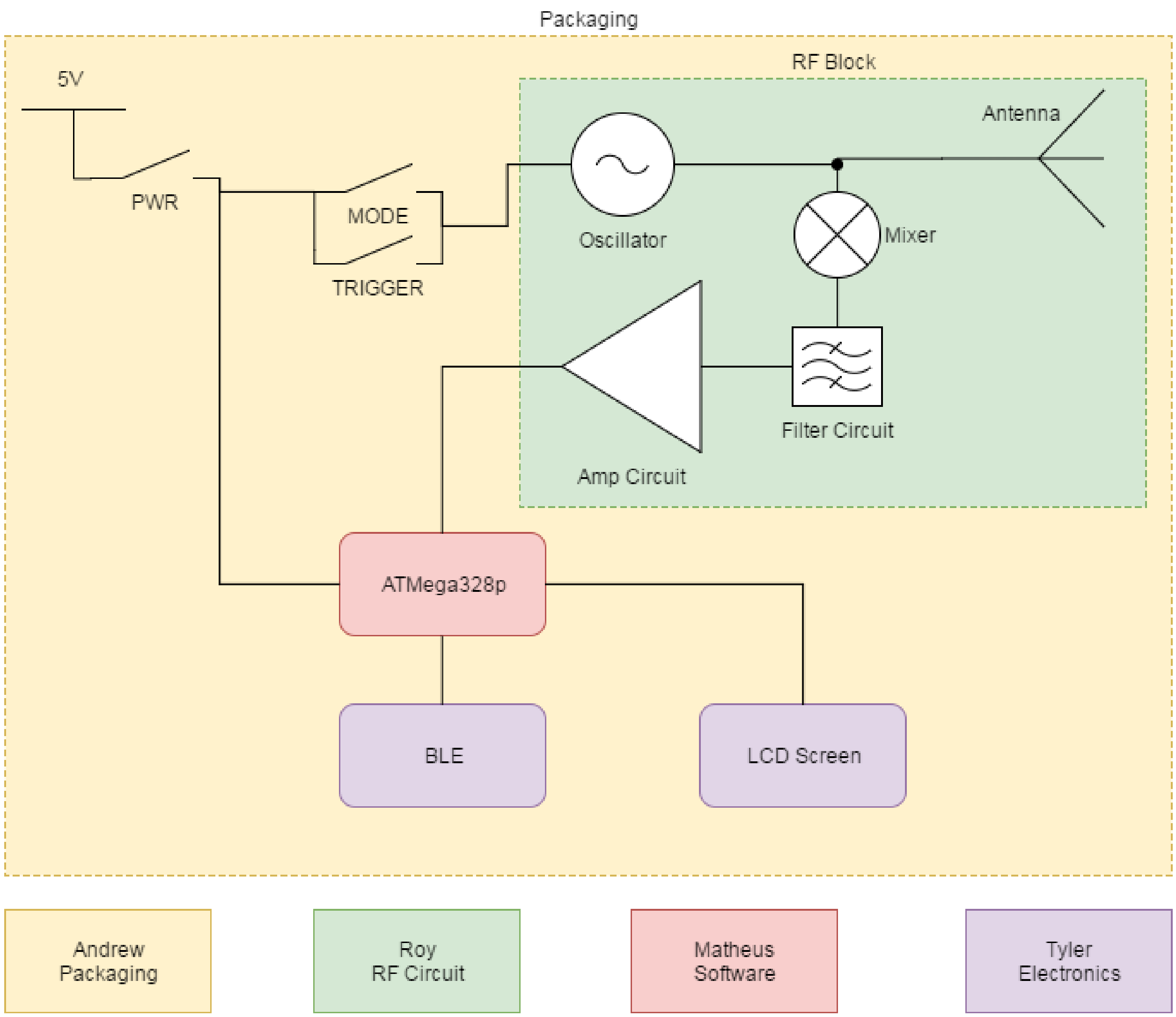

FIGURE 2: Block Diagram

The entire system is powered by one single 5V power source. This is followed by a triggering circuit which allows for an automatic solo pitching mode if the switch is on, or a coaching mode if the switch is off where the trigger is used to control the activation of the transceiver. When powered in one of these modes, the transceiver will send out a 24.125GHz sine wave that is output on the antenna. After reflecting from an object, the signal contains a Doppler shift. The reflected signal returns to the transceiver via the same antenna and is fed to the mixer, which produces an intermediate frequency in the audio range. To reduce noise and unwanted signal readings, this intermittent frequency signal is put through a bandpass filter and then amplified through various gain stages. The processor, an ATMega328p, will receive this signal on one of the analog pins. The signal is given a 2.5V DC bias before reaching the processor in order to be centered in the middle of the 0-5V range of the analog-to-digital converter (ADC). After the signal is quantized, the FFT algorithm is used to determine the frequency of the signal. This frequency is then substituted into the Doppler equation to determine the speed represented by the Doppler shift. The speed is printed on an LCD screen to be read by an observer and is also transmitted over Bluetooth Low Energy to be read on a connected smartphone. All of these components are neatly packaged in a 3D printed case that is handheld and lightweight.

RF Circuit - Roy Baker

The RF circuit contains the components for transmitting and receiving the microwave signal, extracting the Doppler shift intermediate frequency signal, and filtering and amplifying this signal. The circuit is named as it is only for simplicity; all of the circuitry except for the transceiver operates below 10kHz. This circuit has two main subcircuits: the transceiver itself, and the filter and amplifier circuit. Figure 3 shows the block diagram of this subsection.

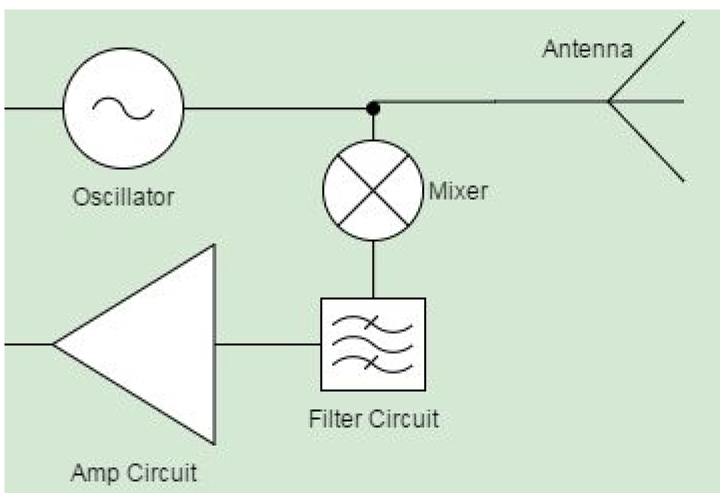

FIGURE 3: RF Circuit

The radar transceiver is the heart of this subsystem and of the entire speed gun. Figure 4 shows the external appearance of the transceiver, and Figure 5 shows the schematic [4].

FIGURE 4: Transceiver

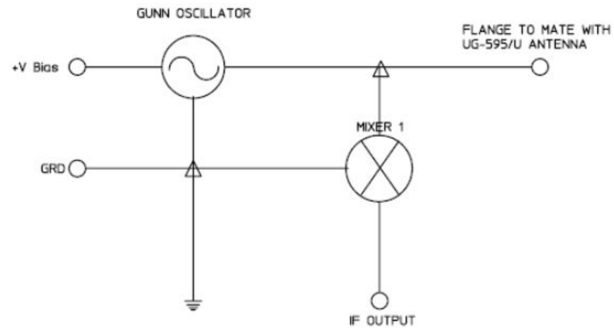

FIGURE 5: Transceiver schematic

The transceiver is manufactured by Macom, and was extracted along with the horn antenna from the Bushnell speed gun. The oscillator is a Gunn diode that is powered at 5V DC. The diode, contained within a resonant cavity, produces a 24.125GHz EM wave (K-band microwave). This wave is conducted via a waveguide to the horn antenna which establishes the radiation pattern. A dielectric lens, also from the Bushnell gun, is placed at the end of the horn to collimate the pattern. The reflected signal is received with the same antenna and is fed to the internal mixer. The mixer takes the original transmitted signal and the reflected signal and produces the intermediate frequency (IF), which is the difference between the two. The IF is at the frequency of the Doppler shift.

The Macom transceiver was chosen due to the economy of acquiring it along with a horn antenna for less than $100. Other transceiver and antenna combinations were considered but were ruled out on the basis of complexity or cost.

After emanating from the transceiver, the IF signal is then routed to the filter circuit. The filter and amplifier circuits are based on the MAX414CPD amplifier chip [5]. This chip was chosen for its quad amplifier circuits, low cost, high bandwidth (28MHz), and low noise. The filter employed is an active bandpass filter. The schematic of the filter is shown in Figure 6. Not shown in the figure is the 2.5V DC applied to the non-inverting terminal of the operational amplifier. This is shown in Figure 8.

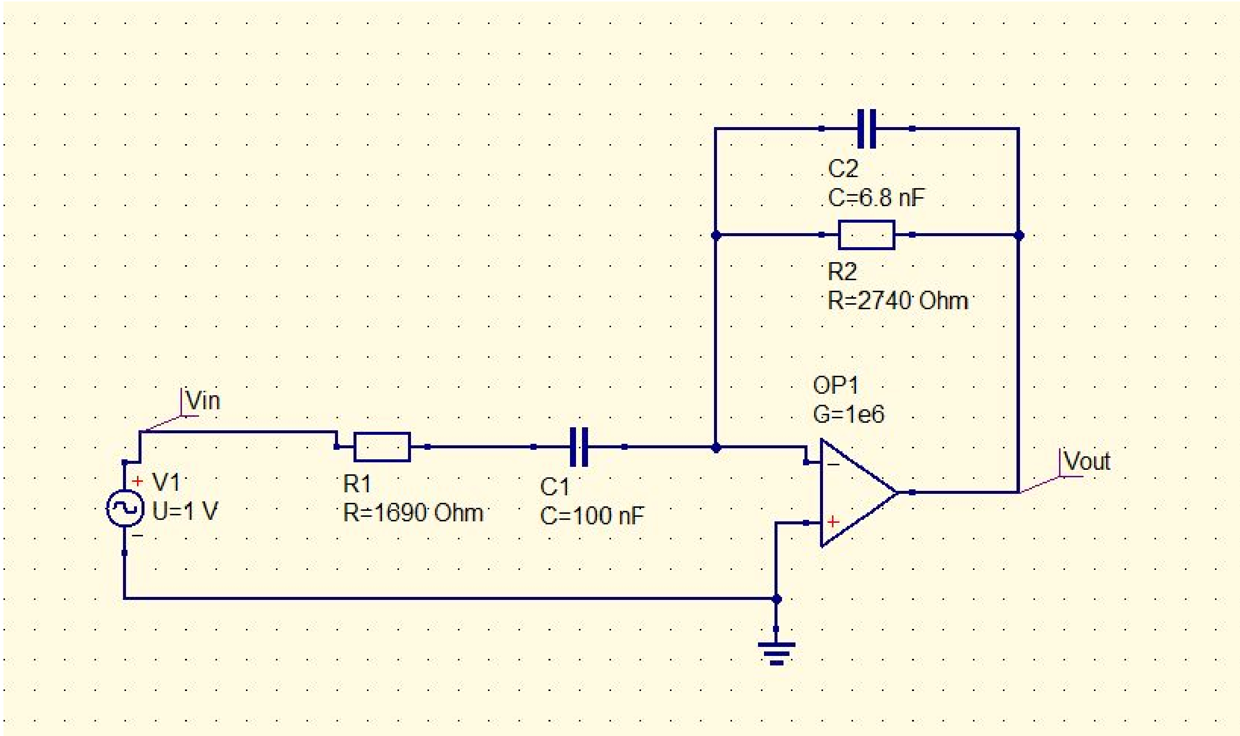

FIGURE 6: Filter schematic

The filter cascades two first order sections, the first providing a highpass response and the second providing a lowpass response. The overall transfer function of this filter is second order, but the rolloff is that of a first order filter. The passband gain at the center frequency is given by Rf/Ri = 1.62x. The cutoffs are found by 1/(2*pi*R*C) for each section: 941Hz for the highpass section and 8542.02Hz for the lowpass section. The lower and upper speeds given in the specifications of 15mph and 110mph correspond to Doppler frequencies of 1078Hz and 7909Hz respectively. The cutoff frequencies of the filter are therefore situated just outside of this desired passband. Figure 7 shows the simulated frequency response of the filter from DC to 20kHz.

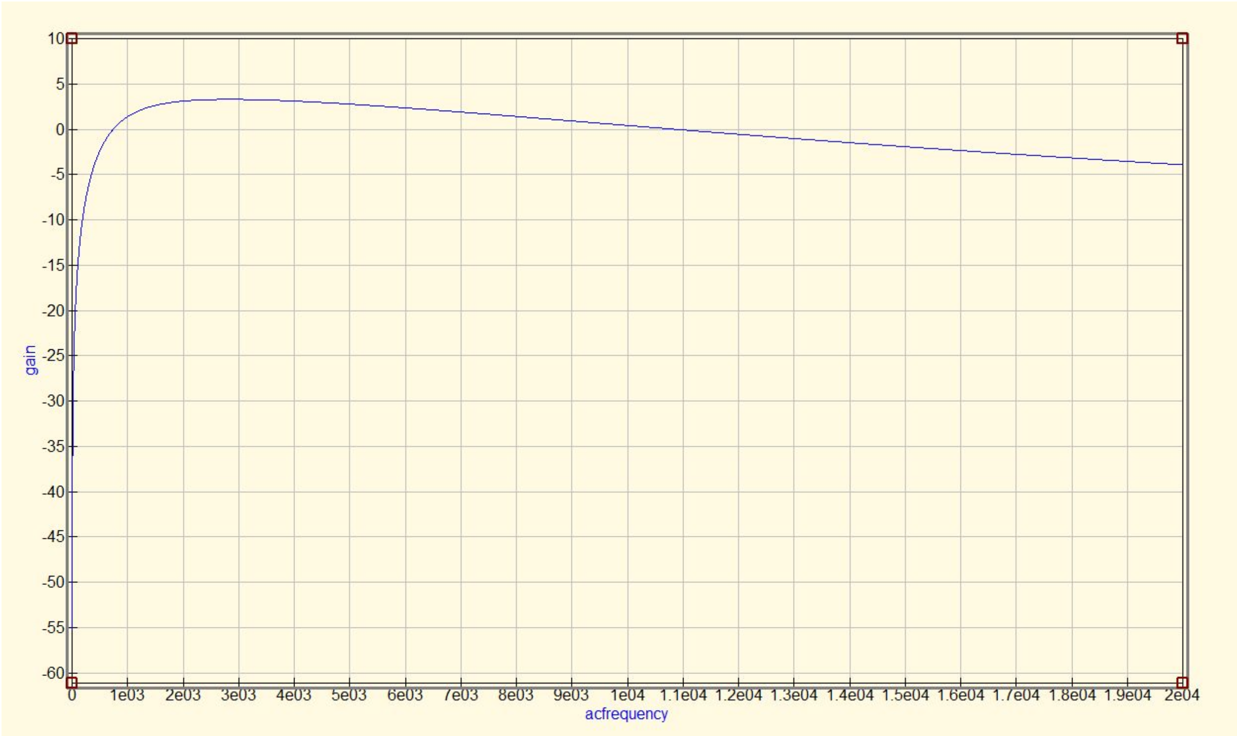

FIGURE 7: Simulated filter response

Table 1 gives data from a test of the constructed filter using a function generator as input and measuring the output with an oscilloscope. As seen from the table, the realized cutoff frequencies, shown in bold type, were further outside the passband than designed. The cutoffs were determined by finding the frequency of the highest response and then finding the frequencies to either side where the response was lowered by 3dB. The gain at the center of the passband at 3Hz was found to be 2.78x instead of the theoretical 1.62x. This was accounted for by modifying the gain of the later gain stages. The rolloff for both the highpass and lowpass sections was found to be less than 20dB/decade. This is a rather poor response but was found to be adequate during testing of the complete system.

Frequency (Hz)	**Vin (Vpp)**	**Vout (Vpp)**	**Gain (dB)**
100	1.00	0.240	-12.40
500	1.00	1.480	3.41
760	**1.00**	**1.970**	**5.89**
1000	1.00	2.25	7.04
3000	1.00	2.780	8.88
8000	1.00	2.280	7.16
10500	**1.00**	**1.980**	**5.93**
12000	1.00	1.830	5.25
100000	1.00	0.340	-9.37

TABLE 1: Filter data

Initially, it was decided to build a filter using 3rd order RC lowpass and highpass filters. However, the effect of component tolerances was only considered for a single stage and not for all three. This led to the cutoff frequencies for the filter being much further into the desired passband, putting the 15mph and 110mph frequencies outside of the passband. This was not acceptable, so the design was shelved. Instead, the active bandpass filter described was built using the components already acquired.

The output of the filter is then routed to two gain stages that boost the signal to the level needed by the ADC on the microprocessor. Figure 8 shows the overall schematic of the filter plus gain stages. Shown in the figure is the 2.5V DC bias applied to the non-inverting terminal of each op amp. As the ADC accepts a 0-5V input, it was necessary to center the signal in this range, which was accomplished by means of the 2.5V offset. This offset was produced with a simple voltage divider on the 5V power supply using two 10kΩ resistors. The amplifiers are powered at 0V and 5V, enabling the signal to match the range of the ADC.

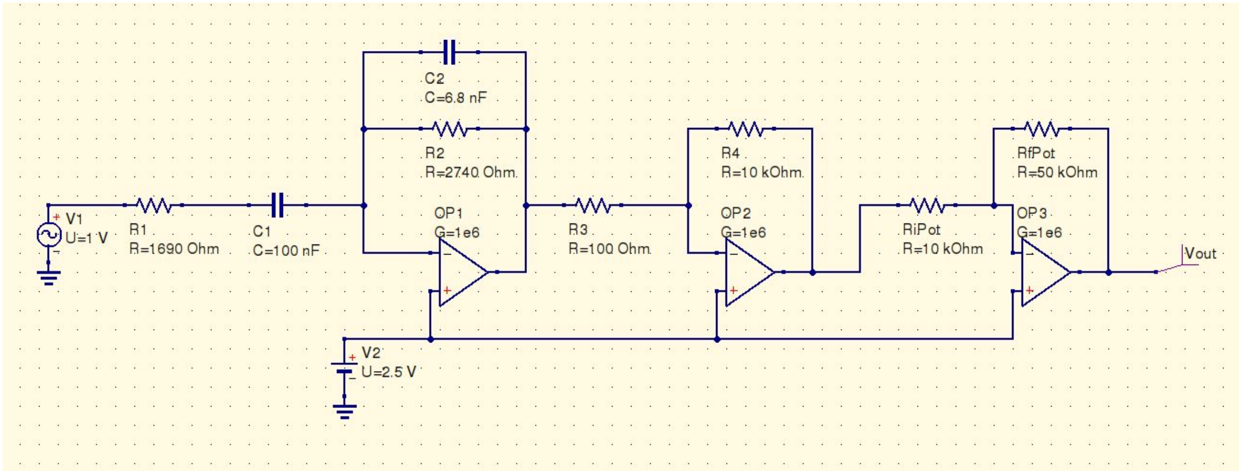

FIGURE 8: Filter and amplifier schematic

The two gain stages are configured as inverting amplifiers, with the gain of each stage found as Rf/Ri. The first stage has a fixed gain of 100x. The second stage is fully variable with potentiometers as both the the input and feedback resistors. With the input potentiometer set at 1.4kΩ, the maximum gain of the final stage is 35.71x. The overall filter and amplifier circuit therefore has a total gain of 9928.6x, approximately 80dB. Above this level, the noise floor approaches the rails of the amplifier, and the accuracy of the system falls considerably.

The signal to noise ratio (SNR) when quantizing is maximized when the input signal covers the entire range of the ADC. As the ADC operates from 0V to 5V, it was desired to ensure the signal occupied this entire range at all times. However, without using an automatic gain control chip, this is not feasible. To attempt to solve this problem, the Rf potentiometer on the final gain stage is exposed to the user, functioning as a “sensitivity” dial. Increasing the gain for lower signal levels (more distant objects, smaller radar cross sections) causes the signal to approach the limits of the ADC range. The signal can be allowed to clip at the rail voltages of the amplifier, producing a square wave. This creates significant harmonics in the signal as processed by the FFT; however, the harmonics are at low enough amplitudes that they are not mistaken for true readings. Allowing the signal to clip does lower the SNR however, as the noise floor will continue to increase with increasing gain as the signal stays at the rail voltages. With this in mind, it is desirable to increase the gain only until readings can be obtained. For higher signal levels (closer objects, larger radar cross sections), the gain can be reduced so that the signal does not clip. This is not an accurate process, so care must be taken by the user to achieve the most accurate readings. The amplifier chip used was found to not amplify all the way to the rail voltages of 0V and 5V, instead only ranging between 1V and 4V. This limited the SNR that could be realized but was found to be adequate for achieving the precision given in the specifications.

Electronics - Tyler Weppler

To process the incoming signal, calculate speed, and distribute information, a microprocessor was needed. For this design, a simple programming interface was desired, so the ATMega328p was chosen. This processor is the same as the one used in an Arduino Uno, so the Arduino bootloader could be used to program it in the Arduino IDE, which was familiar to all members of the group. The ATMega328p offers 32KB of program memory, 2KB of RAM, and 23 I/O pins [6]. The processor is seen in Figure 9 with the pinout.

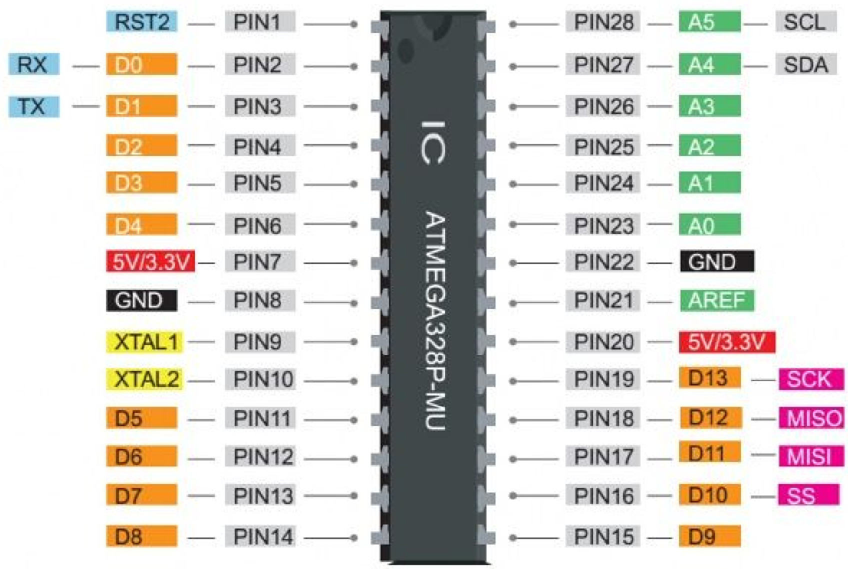

FIGURE 9: ATMega328p Pinout[6]

The processor circuit, based on an Arduino, is constructed with a 16MHz crystal oscillator, two 22uF capacitors, four 100uF capacitors, a 10uF electrolytic capacitor, a 1k ohm resistor, and a push button used to reset the processor [7]. This circuit is seen in Figure 10.

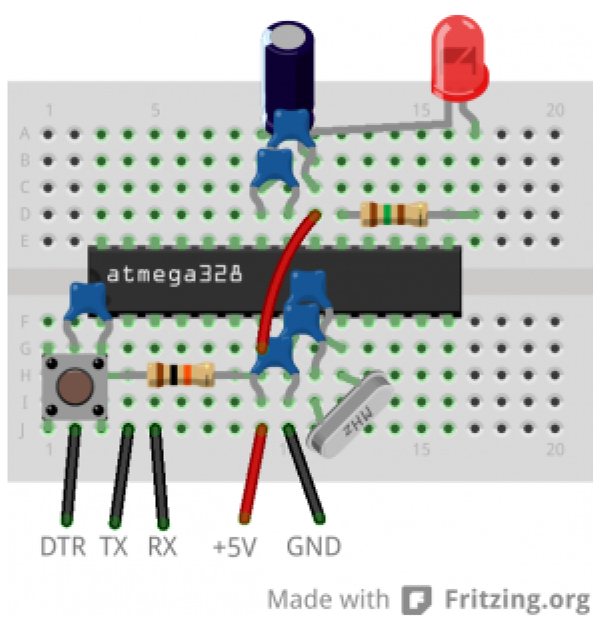

FIGURE 10: Processor Breadboard Circuit [7]

This circuit for the processor has all the same functionality as an Arduino Uno but is much cheaper, and can be implemented on a breadboard or PCB in a small form package. The signal out of the RF circuit is sent to one of the analog pins which has an internal 10 bit ADC to quantize the signal. The only other pins used were digital pins for I/O devices. These devices include a 16x2 LCD screen and an Adafruit BLE UART Friend module. The LCD screen was connected on pins D2 through D7, and the BLE module was connected on the serial communication pins D0 and D1. The LCD screen also has resistors for the LED backlight brightness and the white on blue contrast. The contrast resistor was traded for a potentiometer so that the contrast could be changed by the user.

The LCD screen chosen for this project was a simple 16x2 character screen that is designed for use with the Arduino. This screen, shown in Figure 11, was decided upon for being large enough to show two lines of text, the last pitch and the average pitch speed, while also having the internal backlight. This would make it easy to see the screen in bright outdoor conditions as well as in cloudy or dimly lit conditions.

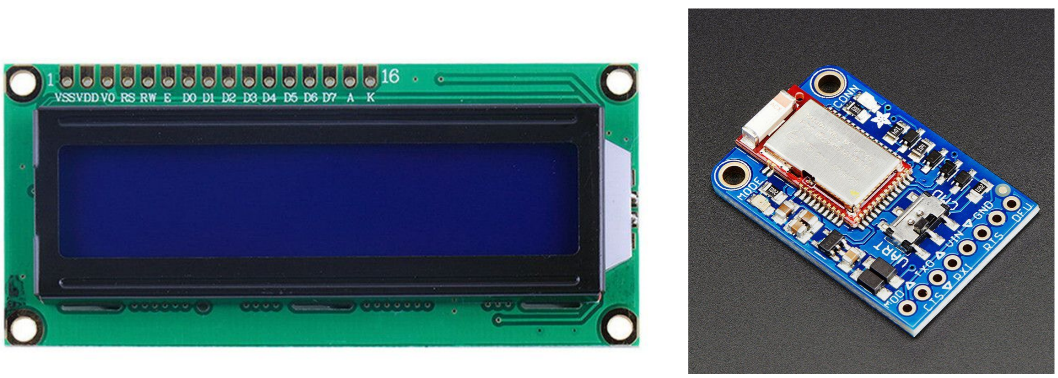

FIGURE 11: LCD Screen and BLE module [8] and [9]

The Adafruit BLE UART Friend module, shown in Figure 11, is the simplest BLE module that the group could find to use. BLE works over the 2.4GHz band on the Bluetooth 4.0 protocol. Under this protocol, a GATT service is needed with characteristics to transmit up to 20 bytes. This module uses a GATT service proprietary to Nordic that functions as if it were a Bluetooth 3.0 serial module [9]. This allowed for minimal programming and can communicate with all modern phones that are Bluetooth compatible. Any string printed on pins D0 and D1 would be output over the BLE technology. Conveniently, Adafruit also has an app called Bluefruit designed to communicate with this module in a terminal like interface. With this, a user would be able to see the pitch speed without needing to walk over to the radar gun.

All of these electronics were assembled in the circuit seen on the breadboard in Figure 12.

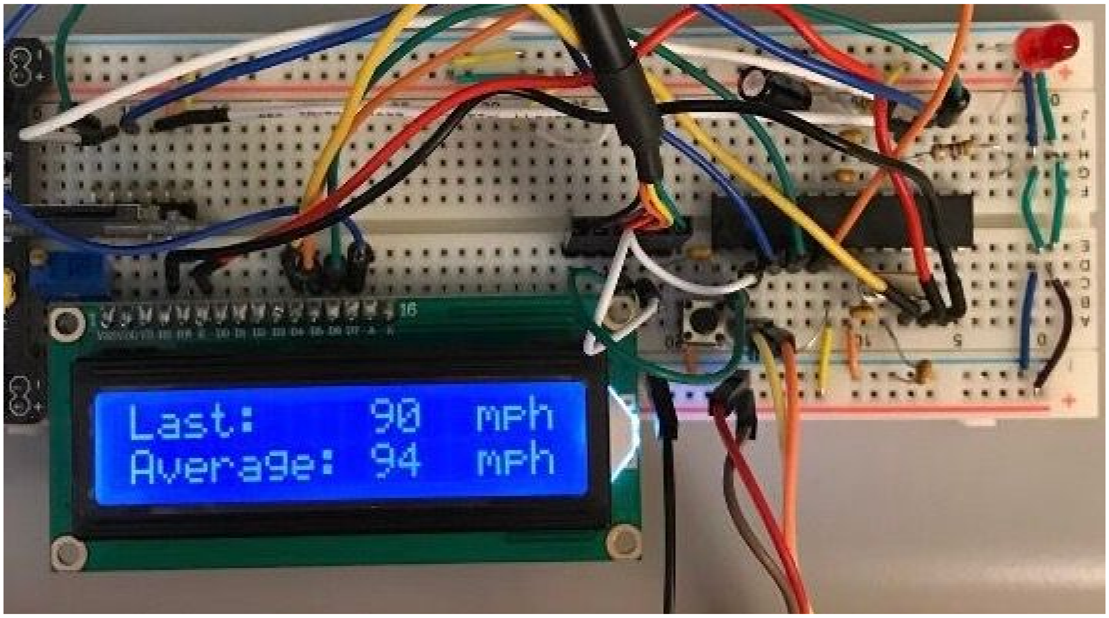

FIGURE 12: Electronics Breadboard

Power - Tyler Weppler

All components for this system operated at 5V. Since no common battery sizes at 5V are easy to find with the amount of current draw required, the team decided on using a phone power block as the power source. Internally, this block is a 3.7V lipo battery boosted up to 5V. This power source was convenient because it was compact, had ample power storage and maximum draw capabilities, low price, and was rechargeable. Instead of having the user change batteries when the radar gun died, the group wanted a rechargeable gun so that not extra batteries were needed. The specific power supply was chosen because it was only $10 on Amazon and had 3300mAh capacity with a max draw of 1000mA. The maximum current draw from all components is 120mA, so the power block would last around 27.5 hours which far exceeds the 4 hours given in the specifications. When this power supply was hooked up to the radar gun, it generated lots of noise, causing random readings on the radar. To fix this, several small bypass capacitors were added in parallel to the power supply, reducing the noise significantly enough to get accurate readings.

Software - Matheus Barbosa

Most of the software system in this project revolved around back-end code that sampled the Analog-to-Digital Converter (ADC), ran the Fast Fourier Transform (FFT) algorithm, analyzed the FFT output to extract the Doppler shift and estimated the object speed using the Doppler Equation.

A. Sampling and ADC

In order to sample the Intermediate Frequency (IF) signal, an ADC was used to take voltage measurements and save the values to an array, also known as *digitizing* the signal. The first design decision to make was whether to use the ADC built-in on the processor, or to acquire an external ADC (and if so, a library to properly interface with it) which is more dynamic and more precise. As an engineering decision, we decided to keep the cost as low as possible, which means that attempting to use the built-in ADC first was the best option. After some tests which will be described later, the built-in ADC was found to be adequate and was put into the final design. The following are the main specs for the Atmega's ADC [10]:

- 10-bit precision
- 6 sampling pins (only 1 needed for our purposes)
- 0 - 5V input range
- 0.005V (5mV) detection
- Prescaler for /2, /4, /8, /16, /32, /64 and /128 available
- 13 ADC clock cycles per sample
- Other: the FFT requires 256 samples and the main clock is 16 MHz

After choosing the ADC to use, the next step was to set-up the device in order to sample our full input frequency range without aliasing. Our specifications say that our reported value must be +/-1 mph from the true value (i.e. as reported by a commercial speed gun or speedometer). Using the Doppler equation, which is described later, we know that +/-1 mph is approximately equal to 72 Hz. This means our frequency resolution has to be approximately 70 - 150 Hz. In terms of the FFT bins, this calls for 70 - 150 Hz per bin, so for 256 bins that is 18 - 38 kHz as the sampling rate or (divided by 13) 233 - 500 kHz ADC clock. Considering the Atmega clock speed, and the prescaler options and the fact that the ADC needs 13 clock cycles per sample, we have the following sampling frequencies to choose from:

Prescaler	ADC Clock	Sampling Rate (for 13 cycles/sample)
/2	8 MHz	615 kHz
/4	4 MHz	308 kHz
/8	2 MHz	154 kHz
/16	1 MHz	769 kHz
/32	500 kHz	38 kHz
/64	250 kHz	19 kHz
/128	125 kHz	9 kHz

Table 2: Different prescaler options for the Atmega ADC, and the resulting sampling rates

From the table, one can see that either the /32 and /64 options could be used. However, the library documentation suggests that the /32 option be used for a 38 kHz sampling rate. Additionally, with our signal having a Nyquist rate of about 16 kHz, the /32 option is a safer bet to prevent aliasing.

In the code, the ADC was set up for free running mode, which means that it continuously sampled at the set sampling rate without needing to be triggered. To set up the sampling rate, the Atmega provides a register location which can be changed [6]. After each sample, the value can be retrieved from two registers, one of which holds the low byte and the other holds the two most significant bits (MSBs). Once retrieved, the value is converted to a 16 bit integer by multiplying the two MSBs by 256 and adding the low byte to the result. The value is then stored in an array to be used by the FFT algorithm.

B. FFT Algorithm

When it came to the FFT algorithm, we decided to find an open source library which had been thoroughly tested and optimized, as opposed to writing our own from the bottom up. Most of the libraries that Matheus found at first did not work for various reasons. First, the Atmega is not suited for fast floating point arithmetic and the libraries performed 16-bit floating point (FP) operations during the runtime of the program, taking up most of available RAM. Second, the size of most of the FFTs was limited to 128 bins due to how slow they ran. However, OpenMusicLabs (OML) [11] has optimized an FFT library to run on the Atmega chip quickly, performing FFTs of 256 bins.

Instead of performing FP operations during the runtime of the program, OML uses Lookup Tables (LUTs) which are filled with all the values necessary for a particular operation. This causes the RAM to be significantly freed up, while using EEPROM (program space) to compensate. Also, OML uses 8-bit math to keep the tables fairly low. While 16-bit math may be more precise, the ADC's output is only 10 bits so the highest 6 bits of a 16-bit datatype are not used. Using 8-bit arithmetic loses precision but is a good compromise between precision and speed.

In addition to the quickness of this library, it also adds accuracy to the output by using a windowing technique. OML uses a Hann window, which multiplies the signal by preset coefficients, much like a filter. As the window goes through, it provides a 16dB roll off. This effect causes noise reduction and causes the FFT response of the desired frequency to be more apparent.

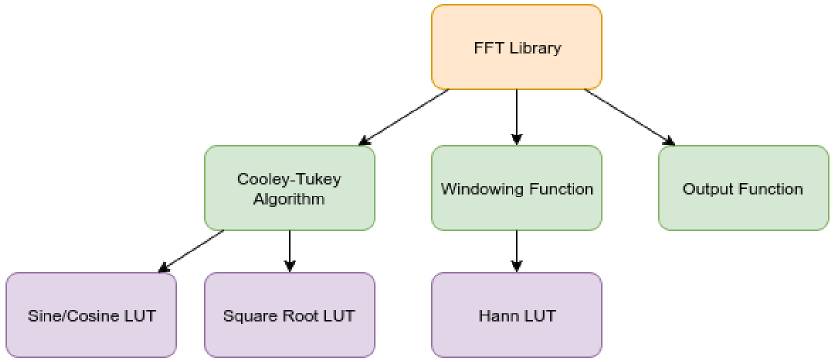

FIGURE 13: OML FFT Library Architecture

C. Doppler Shift and Doppler Equation

Once the FFT finishes, the bin output is logged to an array which can be globally accessed. This array needs to be analyzed in order to determine which one of the frequency components of the signal is the Doppler shift. The logic used to find the Doppler shift was very simple: the code simply looks for the FFT bin with the largest frequency response, and takes that frequency as the Doppler shift.

Packaging - Tyler Weppler and Andrew Slater

Packaging contains two areas. Firstly the 3D printed packaging necessary to contain all the components, and secondly the PCB printed to hold all electronic components.

The first area of the packaging was the main gun casing for all the components of the project. The design was split into two halves so it would be easier to print and allow easy access to the inside for securing the components. Solidworks was used to draw the case, and Craftware was used to slice the design layer by layer for printing. PLA was chosen for the print material for its ease of use and durability. Once the initial design was printed, the case was tested for ergonomics. It was soon apparent that the handle was not comfortable for a user, so changes had to be made. After several iterations of handle adjustments, the design was finalized. The mating halves were designed to snap together tightly, requiring no other bonding elements. Nestled within the bottom of the handle are two indentations that are used to hold the battery pack and the charging cable to prevent them from rattling in the case. Another important feature for the casing was a small screw hole so that the gun could be mounted onto a tripod. After many tests and trials, the gun casing now fits comfortably in human hands and is able to fit all of the internal components.

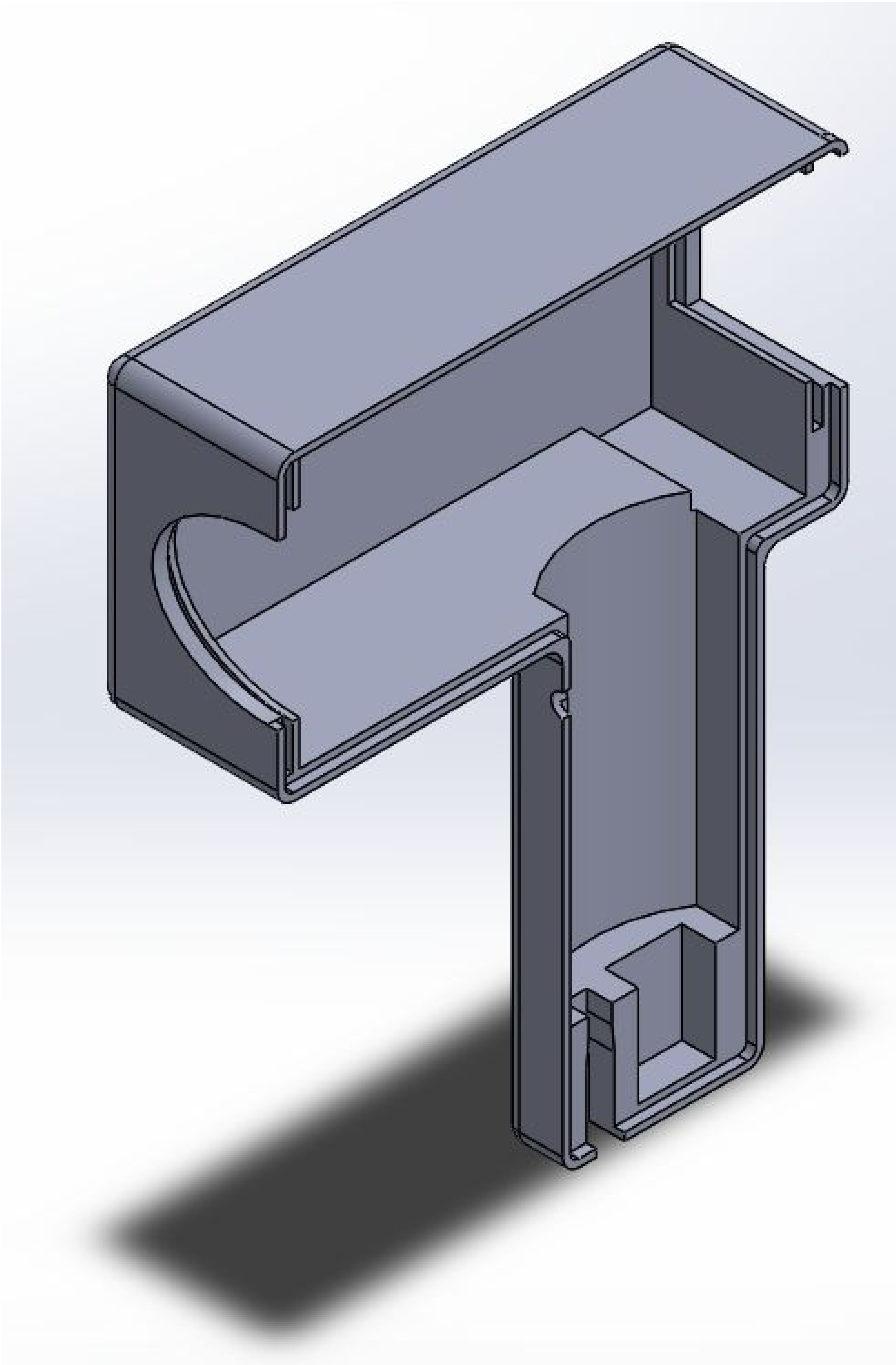

FIGURE 14: Gun casing final design rendering

The PCB was designed using the Kicad open source design software that Tyler was already familiar with. Instead of using surface mount components and thus a smaller board, through-hole components were used so that the components could be pulled directly from the working breadboard prototype and placed into the PCB. This resulted in a board that was still relatively small at 50x100mm^2 surface area. All components were placed on one side allowing a flat surface on the bottom to be mounted in the 3D printed casing. Screw holes were cut allowing screws to mount the board firmly. Components that needed placement in another area in the packaging such as the LCD screen, transceiver, BLE, and switches were allowed empty header pin spots to solder wires. The final PCB block diagram design is seen in the appendix, and a 3D rendering of the PCB is seen in Figure 15. As labeled, the processor circuit is seen in red, the RF circuit in turquoise, and the power circuit in blue. The components were placed as close to the other subcircuit components as possible to reduce trace length.

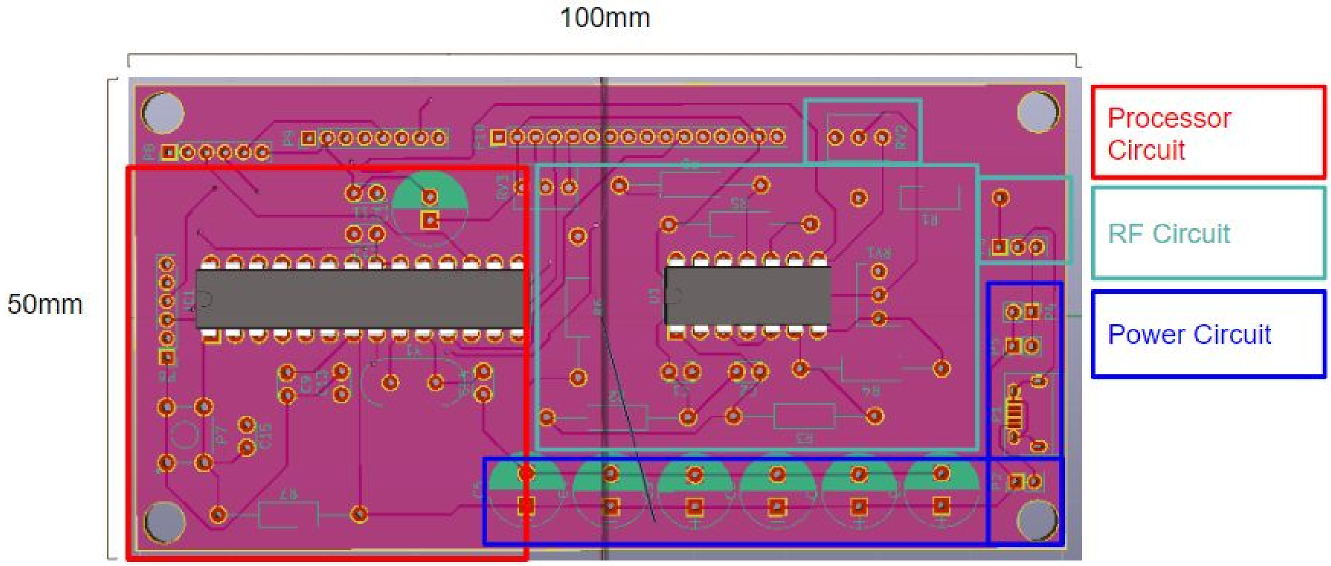

FIGURE 15: PCB

Bill of Materials - Tyler Weppler

As mentioned previously, the budget was broken up into four sections: RF circuitry ($125), electronics ($50), packaging ($40), and emergency funds ($35). All sections were below the budgeted values keeping the project low cost. The RF circuitry totaled $120.34, electronics totaled $42.30, packaging $0, and $0 for emergency funds. Packaging ended up not needing any money as the University provided PLA filament for free in the Design Commons, and the faculty member in charge of purchasing for the Senior Design teams forgot to place the group's order of a tripod, so one was borrowed for free. Table 3 displays the parts ordered and the total cost of the project.

Part Name	Vendor Part No.	Mfr. Part No.	Quantity	Price	Shipping	Total
Radar Circuit						
Bushnell Radar Gun			1	$89.24	$0.00	$89.24
Quad amp chip	700-MAX414CPD	MAX414CPD+	2	$6.36	$5.00	$17.72
1.69k resistor 0.1%	71-RN55C1691B	RN55C1691BB14	6	$0.63	$0.00	$3.78
100nF capacitor 10%	80-C320C104K5R	C320C104K5R5TA	6	$0.15	$0.00	$0.90
2.74k resistor 0.1%	71-CMF552K7400BER6	CMF552K7400BER6	6	$0.59	$0.00	$3.54
6800pF capacitor 5%	80-C430C682J5G	C430C682J5G5TA	6	$0.86	$0.00	$5.16
					Total	**$120.34**
					Budget	$125.00
Electronics						
LCD			1	$1.79	$1.99	$3.78
MicroSD Module			1	$1.79	$0.00	$1.79
MicroSD/Adapter			1	$6.85	$0.00	$6.85
Rechargable Power Pack			1	$9.99	$0.00	$9.99
BLE			1	$19.89	$0.00	$19.89
ATMega328p-pu			2	$2.14	$0.00	$4.28
16MHz crystal oscillator			2	$0.33	$0.00	$0.66
22pF ceramic cap			4	$0.13	$0.00	$0.52
100nF ceramic cap			8	$0.26	$0.00	$2.08
10uF electro cap			2	$0.62	$0.00	$1.24
28 pin DIP Socket			2	$0.95	$0.00	$1.90
14 pin DIP Socket			2	$0.50	$0.00	$1.00
Shipping			1	$0.00	$4.99	$4.99
					Total	**$42.30**
					Budget	$50.00

TABLE 3: Bill of Materials

Results

Testing - Tyler Weppler and Matheus Barbosa

The first element to be tested was the BLE module for distance. The module was not rated to go a full 65 feet, so in order to determine if it was useable or not, data was sent from various distances. Every foot, a string was sent over BLE to determine if connection was still there and if data could be transmitted at that distance. At 75 feet, the BLE lost connection to the phone, but exceeded the required distance by 10 feet.

Next, the processor circuit with all the I/O was tested with a sample program. This sample program ran through a series of hard coded velocities that were passed into the functions to gather the running average, print to the LCD screen, report over BLE, and save to the SD card (later removed). All of these functions were implemented properly.

Simultaneously, the FFT software was also being tested. First, the library provides some example code which allows the user to test the FFT on a hard coded sine wave. The first software test was simply to run the example code, which worked. This proved that the library can work on an ideal sine wave sampled at the perfect timing (i.e. complete cycles). We wanted to make sure that the FFT would also work on signal which may not be sampled at perfect cycles. In order to achieve this, the next tests were done on a signal sampled from a function generator. The function generator was configured to produce a continuous sine wave of variable frequencies from 1 to 8 kHz, which was then sampled by the Atmega ADC on an Arduino board. Code was implemented to then run the FFT library, as well as analysis to determine the doppler shift from the output. Various frequencies were tested, making sure that the frequency value output by the code was at least within +/- 75Hz of the true frequency.

Now, to test the RF circuitry, a speaker was set up in front of the antenna with various signals being passed into the speaker. With the Bushnell radar gun, the velocity of the oscillating speaker diaphragm was measured to determine which frequency mapped to a speed. Then, that setup was used with the high and low frequencies that corresponded to the highest and lowest speeds the team's radar gun was set to meet. This was shown to professors, which spurred a lot of discussion on whether this was an accurate test or not. The premise of this test was to show the gun could meet specifications of 110 mph without needing to be able to throw a ball that fast. The professors however, said that this test was not an accurate way to measure the speed of the speaker diaphragm. Instead, the group used a hand wave in front of the antenna to measure the speed of a hand. This produced accurate readings that were measured and displayed on the oscilloscope with an FFT function running.

As the project progressed, it became important to cut off speeds less than 15 mph, making it difficult to test with hand waving. A bed sheet was hung from a rack with the radar gun set behind the sheet. A tennis ball was thrown at the sheet to record the speed. The issue with this test was that a tennis ball was not as reflective for the Doppler shift as a baseball, so the tennis balls were wrapped in aluminum foil to artificially increase the radar cross section. This test, when thrown on target, was very accurate. The thrown balls were measured behind the sheet, to the left side of the sheet at an angle to the ball throw, and with the ball thrown from above the radar gun. The best results came from above the radar gun as it was targeted perfectly each throw. The ball was thrown and recorded next to the Bushnell radar gun and results were always +/- 1mph of the Bushnell reading. After this test, it was determined that the group radar gun was meeting the accuracy specifications.

The last test performed was similar to the tennis ball tests, but with a guided ball. Zip-n-hit is a ziplined baseball that can be used to practice batting, or in this case, measuring baseball speeds. One end is tied to a pole, and the other end has two handles to sling the ball when pulled apart. At the pole end, the zipline was tied around the radar gun to get a straight ahead reading which came across very accurately. This test would be repeated for the final demonstration as it was safer and easier to aim the radar gun.

Demonstration - Tyler Weppler

On the ECEN Design Day, the radar gun was demonstrated using the Zip-n-hit baseball trainer. This product allows a guided ball to be thrown at the radar gun without risking hitting someone with a baseball. It was also convenient to assist the group in aiming the radar gun appropriately at the ball to ensure a reading every time the baseball was thrown. This setup also encouraged participation by those interested in the design because they got to throw the ball themselves, and made other people try to throw the ball faster. With the demonstration, it was possible to show faculty members that the radar gun exceeded the specifications set by the group. Figure 16 shows the final production model.

FIGURE 16: Final Product

Team Analysis - Tyler Weppler

After the end result of the semester, the team has taken time to look back at how it performed as a group. Ultimately, the main goal of the project was complete by designing and building a final product meeting specifications. The group went above and beyond by pulling many hours in the lab and collaborating together. Each member performed to the best of their abilities and always put extra effort into the project. The team worked very efficiently and managed to not only spend much less money than expected, but also were ahead of schedule each step of the way. This allowed the group to relieve the stresses of the Capstone Design course. All members take pride in not only their work, but the work by other members in the group.

Acknowledgements - Tyler Weppler

Team 2A would like to thank the ECEN department for allowing the use of funds to purchase parts for the radar gun and use of lab equipment. We would like to particularly thank the group advisor Dr. West who assisted us by giving advice and expertise in radar theory and keeping the group on track. Another particular thank you to Dr. Piao and Dr. Ekneligoda for their time in evaluating the group throughout the semester, and another thank you to Dr. Piao for his ideas on demonstration setup.

Conclusion - Matheus Barbosa

This project tested our group in the many areas of Electrical Engineering: power electronics, electromagnetic theory, amplification and filtering, signal processing, software/hardware interfacing and software development. The team faced some challenges, but was able to work out problems through engineering solutions. Although some members had to learn new techniques and concepts, or work outside of their areas, the team was able to pull through in the end to complete the project on time. Many of the skills and experiences acquired during this course will carry over into students' careers as engineers, so we can build on knowledge base and contribute to the electrical and computer engineering field. Ultimately, a successful design was produced that met and even exceeded the specifications laid out at the beginning of the course.

References

[1] M. I. Skolnik, “CW and Frequency-Modulated Radar,” in *Introduction to Radar Systems*, 2nd ed. Singapore: McGraw Hill, 1980, ch. 3, sec. 1, pp. 68

[2] Ibid., pp. 69

[3] A. V. Oppenheim, A. S. Willsky, S. H. Nawab, “Fourier Series Representations of Periodic Signals,” in *Signals and Systems*, 2nd ed. Upper Saddle River: Prentice-Hall, 1997, ch. 3, sec. 1, pp. 182

[4] Macom, “Mono Doppler Transceiver,” MACS-007801-0M1RM0 datasheet, rev. V4.

[5] Maxim Integrated, “Single/Dual/Quad, 28MHz, Low-Noise, Low-Voltage, Precision Op Amps,” MAX414CPD datasheet, September 2009, rev 6.

[6] "ATmega328P - Microcontrollers and Processors", Microchip.com, 2017. [Online]. Available: http://www.microchip.com/wwwproducts/en/ATmega328P.

[7] "Shrimping it", Disconnected.systems, 2017. [Online]. Available: http://disconnected.systems/blog/shrimping-it/.

[8] L. Arduino, "Aliexpress.com : Buy LCD Display For Raspberry PI LCD 1602 Display LCD1602 HD44780 LCD Module 16x2 DIY KIT 5V Blue Screen And White Code For Arduino from Reliable display phone suppliers on E-visiontek Store", aliexpress.com, 2017. [Online]. Available: https://www.aliexpress.com/store/product/LCD-Display-For-Raspberry-PI-LCD-1602-Display-LCD1602-HD44780-LCD-Module-16x2-DIY-KIT-5V/1543304_32473651550.html.

[9] "UART Service | Introducing the Adafruit Bluefruit LE UART Friend | Adafruit Learning System", Learn.adafruit.com, 2017. [Online]. Available: https://learn.adafruit.com/introducing-the-adafruit-bluefruit-le-uart-friend/uart-service.

[10] G. Berg, “Advanced Arduino ADC – Faster analogRead(),” Microsmart.co.za, 2017. [Online]. Available: http://www.microsmart.co.za/technical/2014/03/01/advanced-arduino-adc/.

[11] "Open Music Labs", Openmusiclabs.com, 2017. [Online]. Available: http://www.openmusiclabs.com/.

Appendix A - User Manual

Overview: This appendix provides information for the user on how to operate the radar gun device. On the back of the radar gun (side opposite to the horn) there are two switches, one labelled ON/OFF and the other labelled COACH/SOLO as well as an LCD screen. These switches will be referred to as SW1 (ON/OFF) and SW2 (COACH/SOLO) while the LCD screen will be referred to as “the display”. There is an push-button on the front side of the gun handle, which will be referred to as “the trigger”. Also, there is a microUSB female port and a screw attachment at the bottom of the handle which will be referred to as “the charging port” and “the screw mount” respectively. Lastly, there is dial on the side of the gun (left side if horn facing away from holder) which will be referred to as “the sensitivity dial”.

Grip/Aim: Due to the device containing a lens on its horn, the detection width (antenna beam width) is very narrow. As a result, the grip and aim of the device are very important for operation. The device should only be held by the handle, with the horn facing away from the user such that SW1/2 and the display face toward the user. Depending on the operating mode, the handle should be held with an index finger on the trigger or with all fingers below the trigger. When aiming, the user should make sure that the longest side length of the barrel (where the horn is housed) is as parallel as possible to the object trajectory which they wish to measure. For example, if using the device to measure the speed of a baseball pitch, a good setup would be to stand next to home plate (or the catcher, or anywhere along the eventual trajectory of the pitch) and aim at the pitcher at about chest height.

NOTE: *if the device is aimed perpendicular to the object trajectory, nothing will be detected. Accuracy will increase as the aim gets closer to being parallel to the object trajectory.*

Modes: In order to make the user experience better, the device provides two modes of operation: coaching mode and solo mode. Either mode can be used at any time, but they provide different features which may be more or less useful depending on the situation. To use any mode, SW1 must be flipped to the ON position, and SW2 will toggle the mode between solo and coaching.

Solo Mode
- Always reading and reporting (if appropriate)
- Trigger is inactive
- Bluetooth transmits
- No need for an operator

Coaching Mode
- Does not automatically read nor report (only when trigger is pressed)
- Trigger is always active
- Bluetooth transmits
- Needs an operator

Sensitivity: The device can be used to detect speeds from objects that may be up to 65ft away. However, some configuration may be required. The sensitivity dial will tune how sensitive the detection is, or in other words, how far the object is from the device. Turning the dial clockwise increases the sensitivity, allowing for further detection. Turning the dial counterclockwise decreases the sensitivity, shortening the detection range.

NOTE: *for best results in any setup, always use the lowest sensitivity level which works for that setup. Increasing the sensitivity level above what is needed may introduce false readings.*

Charging: As an added feature, the device runs off of rechargeable batteries. Although the battery can run the device in solo mode for over 20 hours, charging may be eventually required. To charge the device, simply plug a microUSB cable's male connection into the charging port. Charging time will depend on the output of the power source.

Appendix B - Source Code

```
//ATMega use Due
#define LOG_OUT 1
#define FFT_N 256 // set to 256 point fft

#include <LiquidCrystal.h>
#include <FFT.h>  // include the FFT library

const uint8_t CHIP_SELECT = 10;

#define MIN_SPEED 5.0 //the minimum speed that we want to detect

LiquidCrystal lcd(7,6,5,4,3,2);
int pitchCount = 0;
int pitchTotal = 0;
int averageSpeed = 0;

void setup() {
  // put your setup code here, to run once:
  Serial.begin(9600);
  lcd.begin(16,2);
  ADCSRA = 0xe5; // set the adc to free running mode and 33k sampling rate
  ADMUX = 0x40; // use adc0
  DIDR0 = 0x01; // turn off the digital input for adc0
}

void loop() {
  // put your main code here, to run repeatedly:
  const int _speed = get_speed( );
  Serial.println( _speed );
  if( _speed != -1 ) calcAverage( _speed ); //-1 means a speed outside our range
}

void calcAverage(int pitch)
{
   pitchCount = pitchCount + 1;
   pitchTotal = pitchTotal + pitch;
   averageSpeed = pitchTotal / pitchCount;
```

```
  printScreen(pitch);
}

void printScreen(int pitch)
{
 lcd.clear();
 lcd.setCursor(0,0);
 lcd.print("Last:");
 lcd.setCursor(9,0);
 lcd.print(pitch);
 lcd.setCursor(13,0);
 lcd.print("mph");
 lcd.setCursor(0,1);
 lcd.print("Average:");
 lcd.setCursor(9,1);
 lcd.print(averageSpeed);
 lcd.setCursor(13,1);
 lcd.print("mph");
 Serial.print("Last Pitch: " + String(pitch) + " mph\nAverage: " +
String(averageSpeed) + " mph\n");
}

//returns -1 if the speed is outside range
int get_speed( void ) {
 for( int i = 0 ; i < 512 ; i += 2 ) { // save 256 samples
    while( !( ADCSRA & 0x10 ) ); // wait for adc to be ready
    ADCSRA = 0xf5; // restart adc
    byte m = ADCL; // fetch adc data
    byte j = ADCH;
    int k = ( j << 8 ) | m; // form into an int
    k -= 0x0200; // form into a signed int
    k <<= 6; // form into a 16b signed int
    fft_input[i] = k;   // put real data into even bins
    fft_input[i+1] = 0; // set odd bins to 0
 }

 fft_window( ); // window the data for better frequency response
 fft_reorder( ); // reorder the data before doing the fft
 fft_run( ); // process the data in the fft
```

```
  fft_mag_log( ); // take the output of the fft
  int largest_index = 0;
  int largest = 0;
  for( byte i = 2; i < 52; i++ ) {
      if( fft_log_out[i] > largest ) {
        largest_index = i;
        largest = fft_log_out[i];
      }
  }
  int freq = 0;
  if( largest_index == 7 ) freq = 1100;  //this is our slowest speed hardcoded
  else freq = largest_index * 150;       //frequency resolution is ~150Hz so we
multiply the bin index by it
  double obj_speed = 2.23694*( double )( freq )*300000000.0/48250000000.0;
//Doppler equation step
  if( largest > 150 && obj_speed > MIN_SPEED && obj_speed < 110.0 ) {
    return ( int )( obj_speed );
  }
  else return -1;
}
```

Appendix C - CD Contents

The CD with this report contains all of the material associated with the project. This includes the PCB design files, researched information, meeting minutes from advisor and group meetings, all reports and presentations, the source code and libraries, block diagrams, and various spreadsheets used for budgeting and other purposes.

Appendix D - Meeting Minutes

Meeting Minutes

20 January 2017

Attendees

Dr. James West (Advisor), Roy Baker, Matheus Barbosa, Andrew Slater, Tyler Weppler

Scribe

Roy Baker

Commencement

Meeting was commenced at 4:15 PM

Notes

- Explanation of FMCW - how to ramp signal, how to extract range from data
    - FMCW - Frequency modulated continuous wave
- Explanation of CW Doppler Radar
    - Oscillator connected to circulator (single antenna design)
    - Directional coupler - splits signal from oscillator between mixer (for reference) and TX antenna
    - Carrier frequency f_0
    - Received signal frequency is $f_0 + f_d$ where f_d is Doppler shift
    - $f_i = (f_0 + f_d) - f_0 = f_d$ returned from mixer
    - LNA - low noise amplifier
- Dr. West might be able to furnish report from previous senior design project with radar from 10 years ago
- Output of mixer is called video
- SMA connectors
- Use Mini-Circuits (supplier) for parts

- Sign determination requires heterodyne or INQ (In-phase quadrature)
- Books - Introduction to Radar Systems (2e) by Skolnik
- Look into using USB sound card to to A/D processing
- Next steps - determine meeting times, lots of research

Next Meeting

To be determined

Adjournment

Meeting was adjourned at 4:45 PM

Meeting Minutes

26 January 2017

Attendees

Dr. James West (Advisor), Roy Baker, Matheus Barbosa, Andrew Slater, Tyler Weppler

Scribe

Roy Baker

Commencement

Meeting was commenced at 3:30 PM

Notes

- Transceiver data sheet was shown to Dr. West who confirmed it looked viable
- Indicated Dr. Krasinski may not be happy with need; need back-up design
- Determined that it would be useful to indicate during the presentation that a more complex design was considered before being ruled out due to cost
- To Do:
    - Calculate Doppler shift from 24GHz transceiver
    - Contact manufacturer and confirm specs of transceiver
    - Use radar equation to determine needed gain
    - Look into dynamic gain adjustment and dynamic range of ADC
    - Compare radar cross section of baseball, softball
    - Check legal restrictions re power of transceiver
- Determined that patch antenna at 24GHz will not be suitable -- too finicky
- Can use FFT for multiple object tracking
- Clarified difference between resolution and accuracy of the FFT

Next Meeting

Friday, February 3

Adjournment

Meeting was adjourned at 4:30 PM

Meeting Minutes

3 February 2017

Attendees

Dr. James West (Advisor), Roy Baker, Andrew Slater, Tyler Weppler

Scribe

Roy Baker

Commencement

Meeting was commenced at 12:30 PM

Notes

- Need to reconsider using passive IR sensor
- Need to consider response time of storage when lots of entries are stored
- Reading the doppler shift of an object travelling perpendicularly is possible but requires object to be at the farfield continuous beam pattern distance -- don't worry about this
- Addressed concerns about transceiver variance -- 100MHz bandwidth would mean 0.42% shift in transmit frequency
- Considered radar cross section -- perfectly conducting baseball would have cross section in optical region
- Can calibrate gun against vehicle -- use speedometer to get true reading
- Address considerations of getting data from ADC to CPU, whether buffering would be necessary or not
- Need to consider stabilizing time of components e.g. gunn diode
- For ESD protection wear grounding straps; components should be safe once packaged

Next Meeting

9 February 3:30 PM

Adjournment

Meeting was adjourned at 1:15 PM

Meeting Minutes

9 February 2017

Attendees

Dr. James West (Advisor), Roy Baker, Matheus Barbosa, Andrew Slater, Tyler Weppler

Scribe

Roy Baker

Commencement

Meeting was commenced at 4:38 PM

Notes

- Status update -- some parts ordered, radar gun should arrive on Friday 02/10
- Presentation feedback -- good grades but no feedback
- Don't worry about getting doppler on perpendicular with freq bandwidth shift
- Attempt to reverse engineer radar gun -- determine level of amplification
- Gave initial filter idea -- active low pass followed with active high pass -- Dr. West indicated that would work at least initially
- Use signal to turn on data logging
- Look into logarithmic amplifier

Next Meeting

17 Feb 2:00 PM

Adjournment

Meeting was adjourned at 5:00 PM

Meeting Minutes

17 February 2017

Attendees

Dr. James West (Advisor), Roy Baker, Matheus Barbosa, Andrew Slater, Tyler Weppler

Scribe

Roy Baker

Commencement

Meeting was commenced at 2:00 PM

Notes

- Tyler demonstrated electronics setup
- Dr. West reviewed radar gun setup
- Dr. West recommended determining output impedance of transceiver
- Matheus discussed FFT code
- Dr. West cautioned against assuming DSP would be easy and recommended working intensely now
- Worst case scenario for FFT: starting on the up-part of sinusoid and the down-part of ending sinusoid, not truncated neatly at an integer multiple of wavelength
- Looking for worst slope discontinuities and/or worst amplitude discontinuities

Next Meeting

24 February 3:30 PM

Adjournment

Meeting was adjourned at 2:30 PM

Meeting Minutes

24 February 2017

Attendees

Dr. James West (Advisor), Roy Baker, Matheus Barbosa, Andrew Slater, Tyler Weppler

Scribe

Roy Baker

Commencement

Meeting was commenced at 3:30 PM

Notes

- Tyler described electronics breadboarding
- Explained speaker testing idea
- Matheus showed FFT progress, Dr. West recommended doing plot
- Dr. West advised using different FFT library
- Matheus demonstrated preliminary FFT test results, Dr. West indicated that results were not adequate
- Dr. West indicated that a longer sampling time -- more cycles of the waveform -- yields higher SNR
- Andrew discussed progress on packaging
- Dr. West advised looking into current and overcurrent requirements of transceiver to determine what, if any regulation is needed in excess of USB pack regulation
- Dr. West strongly advised ensuring all power connections are connectorized

Next Meeting

2 March 3:30 PM

Adjournment

Meeting was adjourned at 4:05 PM

Meeting Minutes

2 March 2017

Attendees

Dr. James West (Advisor), Roy Baker, Matheus Barbosa, Andrew Slater, Tyler Weppler

Scribe

Roy Baker

Commencement

Meeting was commenced at 3:30 PM

Notes

- Discussed progress on prototyping
- Covered FFt results, frequency counter
- Dr. West recommended reverse engineering
- Discussed failure of radar proto and possible solutions
- Confirmed proto demo times

Next Meeting

9 March 3:30 PM

Adjournment

Meeting was adjourned at 3:55 PM

Meeting Minutes

9 March 2017

Attendees

Dr. James West (Advisor), Roy Baker, Matheus Barbosa, Andrew Slater, Tyler Weppler

Scribe

Roy Baker

Commencement

Meeting was commenced at 3:30 PM

Notes

- Dr. West showed FFT example
- Washington University St. Louis FFt code looks useful
- Speaker setup should not work -- must be inductively coupling
- Can test with car/bike

Next Meeting

TBD

Adjournment

Meeting was adjourned at 4:05 PM

Meeting Minutes

23 March 2017

Attendees

Dr. James West (Advisor), Roy Baker, Matheus Barbosa, Andrew Slater, Tyler Weppler

Scribe

Roy Baker

Commencement

Meeting was commenced at 3:30 PM

Notes

- Discussed progress on artes; close to being ready to integrate
- Forgot about automatic triggering circuit; assigned to Andrew
- Discussed radar lensing

Next Meeting

TBD

Adjournment

Meeting was adjourned at 3:47 PM

Meeting Minutes

13 April 2017

Attendees

Dr. James West (Advisor), Roy Baker, Matheus Barbosa, Andrew Slater, Tyler Weppler

Scribe

Roy Baker

Commencement

Meeting was commenced at 3:30 PM

Notes

- Project mostly done -- packaging remains
- PCB is ordered; have boards for hand soldering as a backup
- SD card was scrapped because it was too large in the program memory
- Poster, power point, and final paper remain
- Report needs coherent structure -- needs outline - into needs to say how the project works -- signal source, doppler shift, how each part works together. Later subsections go into detail.

Next Meeting

TBD

Adjournment

Meeting was adjourned at 3:40 PM

Meeting Minutes

20 April 2017

Attendees

Dr. James West (Advisor), Roy Baker, Matheus Barbosa, Andrew Slater, Tyler Weppler

Scribe

Roy Baker

Commencement

Meeting was commenced at 3:30 PM

Notes

- Need to get case printed now
- Use a Wikipedia article's introduction as an example of a coherent intro
- Will be putting parts onto the PCB soon, Tyler will be doing the soldering
- Can move parts from the breadboard one at a time and replace on the breadboard so that the breadboard circuit still works

Next Meeting

TBD

Adjournment

Meeting was adjourned at 3:45 PM