VEHICLE DETECTOR FOR CYCLISTS

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Abstract

The device described within this paper is a vehicle detector for cyclists. Consisting of a combined high frequency radar unit and a display unit, the device will promote greater safety for the cyclist. This is achieved in two ways: by providing a mirrored, rear view display from the back of the bicycle onto a handlebar mounted LCD and by alerting the user of a vehicle's presence if it is within 30m of the bicycle.

Much was learned in regards to high frequency manipulation, general radar concepts and builds, and microprocessors and Linux architecture. Though the majority of our project was successfully completed, due to reflection from mismatched impedances and limitation of processing signals with the microprocessor, there was a single disconnection between the two main components which kept the final product from working as a whole.

Contents

1. Introduction

1.1 Purpose

After researching products that aid deaf and hearing-impaired people, we found an absence of products for cyclists in this demographic. As it turns out, there is building frustration regarding this topic. Two pieces of advice were offered for cyclists that are unable to use their sense of hearing (including cyclists who ride with headphones): (1) plan your ride ahead of time to avoid traffic-ridden areas, and (2) attach rear-view mirrors either on your helmet or handlebars. Even with these tips, deaf cyclists are limited to certain areas if they want to enjoy a safe ride. For those who ride for sport (such as the U.S. Deaf Cycling Association), it is quite difficult to find streets with minimal vehicle traffic, and not much of a rear-view peripheral is provided by tiny, side mirrors.

Because of this, we decided to build a rear-view vehicle detector for cyclists. This device consists of a 3.5” LCD mounted on the handlebars that will display a rearview, mounted camera’s sight. The display will also include an overlay image in the top-left corner that appears, to alert the cyclist of a vehicle’s presence. The alert system is implemented with radar and is limited to 30m of detection. With this two-part sensing system, a user can glance down at the LCD at any time to view vehicles beyond the 30m range, and if the rider has not been paying any attention to the display, the LCD alert will flash, catching the rider’s attention, providing the rider with an early warning to avoid any potential danger. The alert allows the user to pay the majority of their attention to the road in front of them, indicating when they should check the display (as extended attention to the LCD could provide just as much, if not more, danger than if the device was never installed to begin with).

1.2 Project Divisions

The following is our block diagram of the entire system:

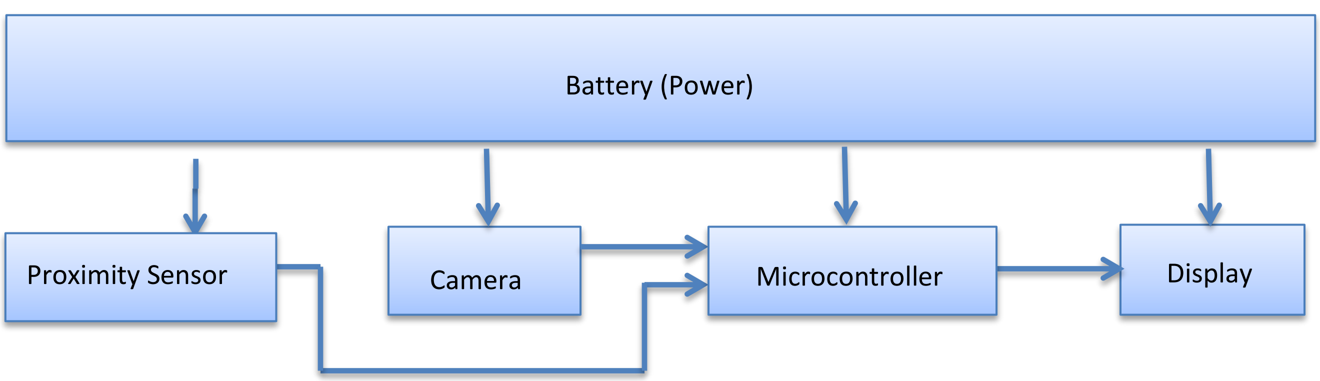

Figure 1.1 Block diagram of simplified system

We were able to simplify this into three subsystems: the sensor, the microcontroller and programming, and the power.

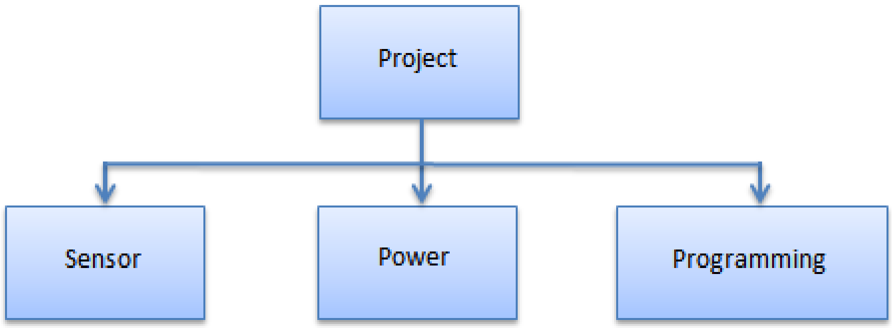

Figure 1.2 Subsystems

The sensor combines the radar and the LCD display unit. The power is the battery that single-handedly provides power to all components through the power regulator circuit. The programming is defined by the microprocessor that manipulates the inputs to the LCD screen.

2 Design

2.1 Radar Theory

2.1.1 Frequency-Modulated Continuous-Wave Radar

Before finding out about FMCW Radar, we designed a continuous-wave radar system, implementing the use of the Doppler Effect. By continuously transmitting a high frequency signal, a moving car will provide a difference in the returned frequency. Detecting this difference in frequency would only allow the system to detect the presence of a *moving* car though. This proved a serious problem, as the system was incapable of measuring distance. We needed to find a radar system that could detect the presence of a vehicle regardless of its speed relative to the bicycle's reference frame.

Given this problem, Professor Franke advised us to use FMCW radar.

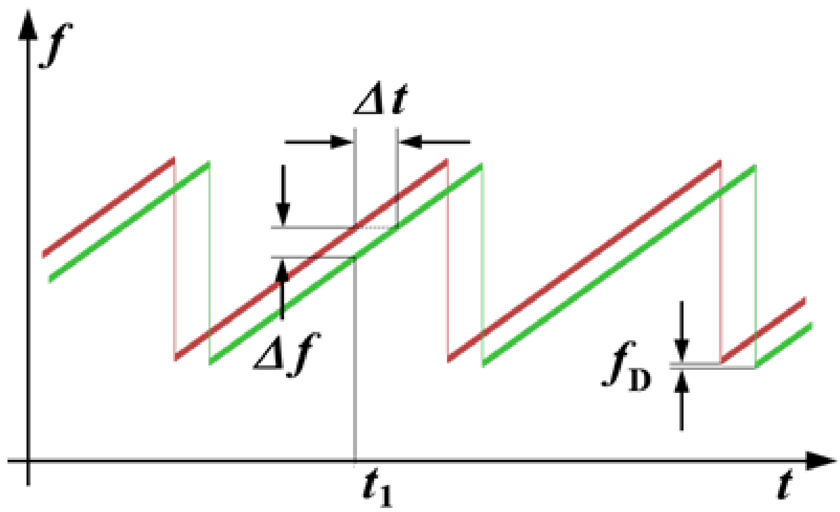

Figure 2.1 FMCW visual, time vs. frequency [2]

This system takes advantage of a continuously, linearly changing frequency around a fixed reference to detect stationary objects. The transmitted signal would then be a periodic signal of modulated frequency in the form of a sawtooth wave (see Figure 2.1). The delayed, received signal would have a difference in frequency compared to the original transmitted signal. Given this difference in frequency, distance can be calculated:

$$R = \frac{c_o\,(\Delta t)}{2} = \frac{c_o\,(\Delta f)}{2\left(\frac{df}{dt}\right)} \quad (1)$$

A timer is then no longer required to calculate the difference in time between the trasmitted and received signal. Instead, by calculating Δf and knowing the slope of the sawtooth wave, we can determine exactly what maximum Δf correlates to detecting a vehicle at our maximum distance of 30m.

2.1.2 Basic Radar Theory

Using our understanding of FMCW, the next step was to understand the basics of radar theory.

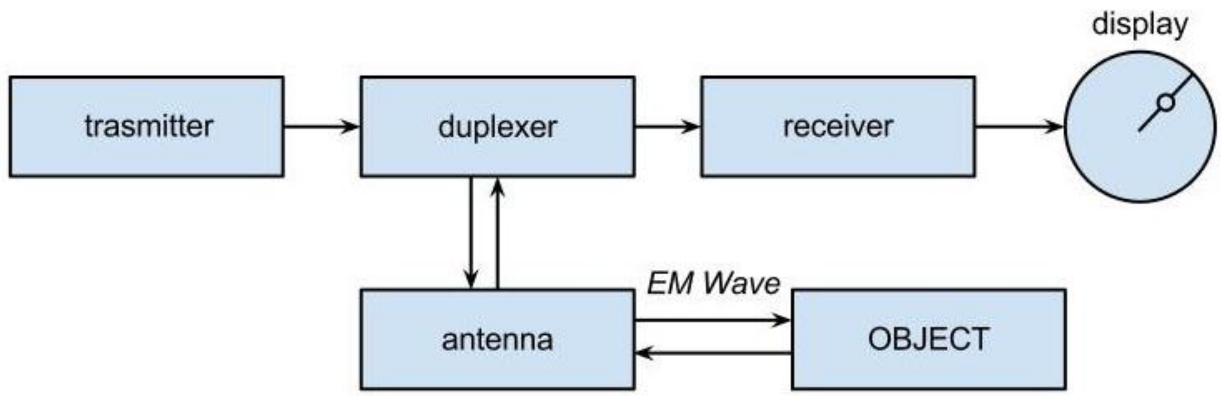

Figure 2.2 Basic Radar Diagram

A transmitter is necessary to output the desired signal. Because we only needed to direct a signal in a single, non-varying direction, only a single antenna was necessary. We decided to use a horn antenna due to its directivity and availability in our chosen bandwidth. To use a single antenna though, requires a duplexer, an electronic switch that must be used to allow an antenna to both simultaneously transmit and receive a signal. The simplest and most common duplexer is a circulator which has three ports, directing the signal from port one to port two and the signal from port two to port three. The final output of the duplexer is then analyzed as needed by the receiver.

2.1.3 Signal Power Transfer

The final consideration that needed to be made when finalizing our design was the signal power transfer of our basic radar system. From the transmitter to the receiver, a large amount of signal attenuation occurs. A signal with too small a returned power is rendered useless, as the receiver will be incapable of analyzing the signal. An ideal understanding of this power loss is calculated through use of the monostatic radar equation

$$P_r = P_t + 10\log\left(\frac{G^2\lambda^2\sigma}{(4\pi)^3 R^4}\right) \quad (2)$$

where P_r is the power received, P_t is the power transmitted, G is the gain of the antenna, λ is the wavelength of the signal, σ is the reflective cross-section, and R is the one-way distance to the object [6]. The gain is calculated using the horn antenna gain equation

$$G = .51\,\frac{4\pi}{\lambda^2}\,ab \quad (3)$$

where *a* and *b* are the dimensions of the horn antenna [4].

Given the calculated P_r we would be able to determine the received power and determine how much amplification would be necessary. Because we wanted to have a final amplified P_r of around -50dBm (limit of analyzable signal power), we had to limit P_r to -90dBm at the least. A returned power of -90 dBm would require 60dB of amplification. Since amplification introduces a large amount of noise, we were hoping to receive as large a returned power as possible.

2.2 Radar

2.2.1 Radar Design

We settled on a frequency range of 4.1 to 4.3 GHz for our FMCW design. A frequency at this magnitude was necessary to have a reasonably sized antenna (as the size of the antenna is inversely proportional to the frequency), highly reflective signal (higher frequencies are less likely to be absorbed by materials), and smaller integration time (due to the smaller wavelength).

While our radar changed quite a bit in the first few weeks with our growing knowledge of radar, our final design is as follows:

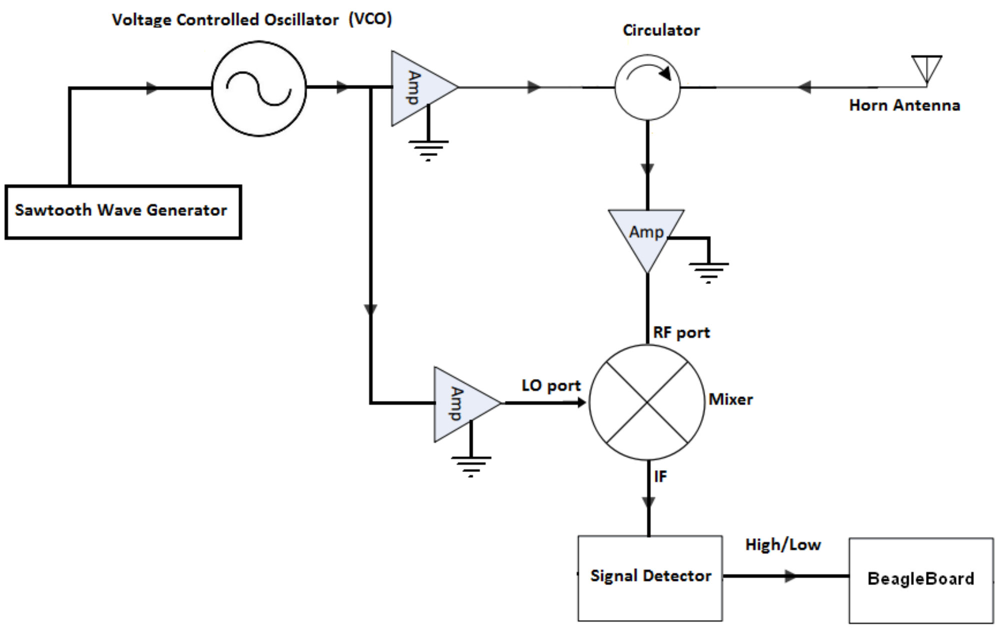

Figure 2.3 Final Radar Design

The modulated frequency is attained through the use of the Voltage Controlled Oscillator. By feeding a sawtooth wave with properly tuned voltage, the transmitted signal was controlled to a center frequency of 4.2GHz with a bandwidth of 200MHz. Also, by setting the frequency of the sawtooth wave to around 200Hz, we guaranteed a frequent update on any vehicle's position (every 5ms). This signal would both pass from port one to port two of the circulator to be transmitted by the horn antenna and be sent to the LO port of the mixer. The reflected signal would return through the same antenna and pass from port two to port three of the circulator, entering the RF port of the mixer. A difference frequency would output from the mixer to be analyzed by the signal detector. Due to the signal detector's composition of passive components, any high frequency components (leakage at ~4.2 GHz and the additive signal from the mixer at ~8.4GHz) would be naturally filtered out. The signal detector would finally output a high or low signal to the BeagleBoard microprocessor to determine whether or not to display the alert.

2.2.2 Sawtooth Wave Generator

Because the BeagleBoard could not create a sawtooth wave, we had to build our own sawtooth wave generator out of analog components [3]. We looked up a simple design and made alterations to adjust the frequency, peak to peak voltage, and the minimum and maximum voltage.

The following figure shows our final output:

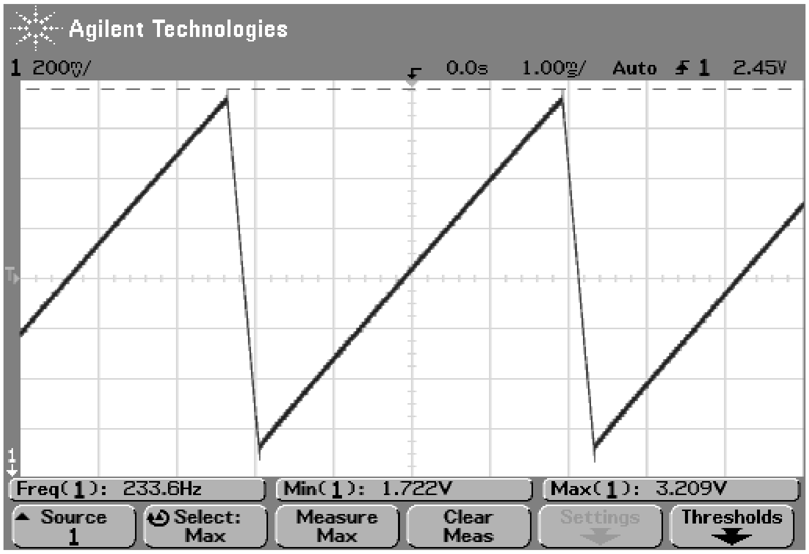

Figure 2.4 Output of sawtooth wave generator

The minimum voltage is ~1.7V corresponding to 4.11GHz on the VCO, and the maximum voltage is ~3.2V corresponding to 4.29GHz. These values put the VCO's output almost exactly to the intended range.

2.2.3 Voltage Controlled Oscillator

We ordered the VCO from DigiKey. It required a PCB which we needed to design and fabricate. The PCB which we had access to in the parts shop was an FR-4 substrate, which is lossy compared to the materials which are normally used in high frequency designs. Another problem is that the thickness of the PCB is 60 mils. This is considered thick for the frequency we are working at (average of 4.2 GHz). The thickness will give extra unwanted inductance for via holes that connect the ground plane and the microstrips on the top plane. However, since this was our only choice, we had to go with this PCB and test the performance.

Designing the PCB is important since impedance matching is a big deal at such high frequencies. Mismatched impedances can easily end in a low signal transfer ratio and reduce the signal power. Other than impedance matching, we also needed to construct a power divider for the VCO. This is because the VCO output needs to not only provide the transmitted signal, but it also must provide the LO input to the mixer. Without the power divider, the impedance will be mismatched since the output of the VCO would see two terminating impedances in parallel, reducing the impedance by half. For this, we chose to implement the Wilkinson power divider.

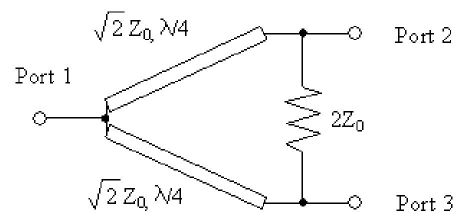

Figure 2.5 Wilkinson Power Divider [16]

The Wilkinson Power Divider splits the single input into two outputs, with each output having half the power of the input. By using the power divider, the input impedance seen from the VCO will still be 50Ω which is the same as the VCO's output impedance.

The characteristic impedance, Z_0 , is 50Ω for the VCO and the amplifiers. Plugging in the numbers we get:

$$\sqrt{2}Z_0 \cong 70.7\Omega$$

$$\frac{\lambda}{4} \cong 1.79cm$$

We will use these numbers to layout the PCB. However, the microstrip width must be calculated before this can be done.

In order to match the 50Ω terminations, the microstrip width needs to have characteristic impedance of 50Ω as well. It will act like a transmission line. Equations are used to derive the width:

$$\varepsilon_e = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\frac{1}{\sqrt{1+\frac{12d}{W}}} \tag{4}$$

$$Z_0 = \frac{60}{\sqrt{\varepsilon_e}}\ln(\frac{8d}{W} + \frac{W}{4d}) \tag{5}$$

$$\frac{W}{d} = \frac{8e^A}{e^{2A}-2} \tag{6}$$

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}(0.23 + \frac{0.11}{\varepsilon_r}) \tag{7}$$

where ε_r = 4.5 is the permittivity of the FR-4 substrate, ε_e as the effective permittivity, W is the width of the microstrip (which we solve for), and d = 60 mils is the thickness of the PCB substrate [1]. By plugging in the numbers we can solve for W.

For Z_0 = 50Ω:

$$W \cong 113\ mils$$

For Z_0 = 70.7Ω:

$$W \cong 45\ mils$$

These calculated numbers finalize the design for the PCB. The PCB layout is done in EAGLE.

The power divider proved to work after measurements were made of the final, fabricated circuit. Rather than the regular 2dBm output of the VCO, each divided output outputs a signal power of ~-2dBm, which is as expected.

2.2.4 Horn Antenna

The horn antenna we used was borrowed. Its dimensions were 18cm by 13.5cm, and more importantly, its bandwidth was defined within our frequency range.

We determined the gain of the horn antenna using the horn antenna gain equation (3):

$$G = .51 \frac{4\pi}{(.07143m)^2}(.18m)(.135m) = 30.55$$

And given this gain we were able to complete the monostatic radar equation (2):

$$P_r = -2dBm + 10\log\left(\frac{(30.55)^2(.07143m)^2(1m^2)}{(4\pi)^3(30m)^4}\right) \approx -87dBm$$

So to achieve a P_r of ~-50dBm, we require ~33dB amplification.

2.2.5 High Frequency Amplifiers

The amplifier circuit requires microstrip design as well. 50Ω impedance lines are created to connect the input and output.

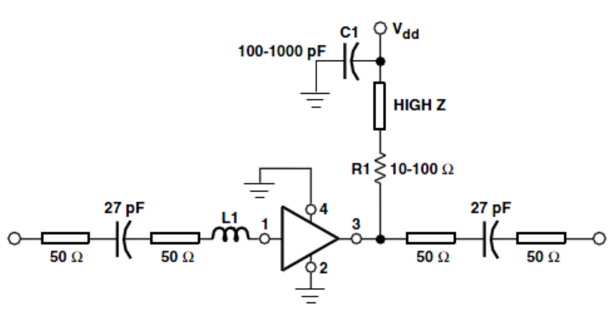

Figure 2.6 Datasheet schematic for amplifiers [9]

The above plot is the schematic derived from the datasheet. We transferred this design to EAGLE as well

The fabricated amplifier has a gain of 17dB at 4.2GHz after testing. It was said to have around a gain of 19 dB in the data sheet, but we will have loss due to the lossy and thick PCB.

We also borrowed an amplifier from the Communication lab to amplify the signal from the VCO to the LO input of the mixer. The amplifier gives a gain of 10 dB (measured). This amplifies the signal from the VCO to around 7 dBm (the output of the VCO is around -2 dBm), after considering the loss in the transmission line cables. This amplifier is supplied with 12V.

2.2.6 Circulator

The circulator was borrowed from the antenna lab. The isolation is specified to be 18.5dB although tested to be 15dB. This leakage caused the received signal to be mixed with the signal generated from the VCO. However, we can expect this leakage to be filtered out using a blocking capacitor after the mixer since it will only generate a DC component (DC is generated when two of the same signals enter the mixer, the difference term is 0Hz).

2.2.7 Mixer

The mixer was borrowed from the Communication lab. It works in the range of 2GHz to 4.2GHz. After some testing, we found out it works up to 4.3GHz as well. The conversion loss is measured to be around 6dB. The LO port power needs to be 7dBm. The output of the mixer gives a multiplication in time domain, and a sum and difference of the frequencies in frequency domain.

2.2.8 Signal Detector

A signal detector was made to detect and recognize received signals from the antenna by assessing the returned power. It will signal the Beagleboard if the return signal is within the desired range, indicating a vehicle is in the 30m range. The signal detector rejects noise from the antenna by setting a threshold to the input. Only inputs that are above a certain level can be recognized as a proper received signal. The threshold is set by a tunable resistor.

2.3 Display and Microcontroller

The Display, Microcontroller, and the Webcam are important components of this design because without them receiving a signal from the sensor would be rendered useless to the rider.

2.3.1 Microcontroller: BeagleBoard-xM

For our project we decided to use a BeagleBoard Xm. The reason why we went with a Beagleboard was because we needed a microcontroller that can obtain an image from a webcam and display it onto the board. Essentially we needed to find a board with enough RAM to process an image and have enough memory to store the image for a brief second. At the same time, we need a board that has the capability to take in an input signal and have it interlace with the code that drives the images from the webcam to the display.

The BeagleBoard has the following essential features that make it useful to this project: Its ARM® Cortex -A8 1 GHz processor, 512 MB of low-power DDR RAM, S-Video(TV out), 10/100 Ethernet Port, USB Hosts, RS-232 Serial, Micro-SD Slot, and an Expansion Port [15].

The BeagleBoard's S-Video port is used to connect to the display and the webcam is connected via USB host. For setup and debugging purposes, we can connect the board to a computer via RS232-to-USB and connect a mouse and a keyboard via USB.

Because this is an OMAP (Open Multimedia Applications Platform) device with TI's (Texas Instruments) ARM architecture, it can handle any Linux-based OS. For this project we decided to go with Arch Linux operating system because of its lightweight image [10]. Also for obtaining the image from the webcam, we used OpenCV software which is a Computer Vision software for Linux and the program was written in C language [14].

2.3.2 Display Unit

Essentially what would be ideal for a commercial product for this design would be having a small LCD panel that would mount between the handle bars of a bicycle. Keeping that in mind, we found a 3.5" LCD module with a female yellow component cable and a power port. This way we can attach an S-Video to component cable to the display and the BeagleBoard to provide an excellent monitor for this device. This way, the rider can easily ride their bike without any difficultly while still taking advantage of the safety precaution this device enables the rider to take.

2.3.3 GPIO(General Purpose Input Output)

On the BeagleBoard, there is an expansion port to attach various devices, mostly I^2C circuitry. The expansion port also has GPIO (General Purpose Input Output) capability which will allow us to read in a digital input from the signal. We can use this by taking in an input from the signal coming from the sensor and then alerting the rider on the screen of an approaching.

The way that Arch Linux's image was compiled, we had access to only a limited number of GPIO pins out of the 28 pins. Also each GPIO was default "HIGH" or 1.8V such that the only way it would toggle is if that pin was given a "LOW" or 0V. Nonetheless, GPIO capability was there and played a major role in our project.

The table B.2 shows how the MUX values are set for the Expansion port and how the GPIO signals correspond to them [11].

2.3.4 Difficulties and Solutions

We ran into several issues with the BeagleBoard that hindered our progress on the microcontroller, display, and camera unit.

1) Had trouble with installing a proper Linux image.
   a) We first tried to install Angstrom Demo image but we could not get proper boot files. This is why we could not boot into the file system like we would want to.
   b) We then tried to install Ubuntu Oneiric image. When we tried to install this image we would get stuck at "Uncompressing Linux...Done."
   c) The Angstrom Demo that came with the BeagleBoard was in grayscale and did not have a package managing capability which we needed to install proper program and libraries.
2) We also had issues with getting S-video working for the desktop GUI
   a) The GUI's we worked with worked perfectly through the BeagleBoard's HDMI output but

when we switch the default display to S-Video, the screen would immediately turn off when the GUI was activated.

b) After doing some research we narrowed down the problem to two possibilities:
   i) BeagleBoard's u-boot image needs to be modified and reconfigured to enable many attributes of an analog display unit.
   ii) Xorg.conf files need to be modified to provide a driver to the s-video port

To fix these two problems I did several things:

1) Installed Arch Linux
   - After being recommended to by a friend, we installed Arch Linux and it booted up successfully. I was able to see a terminal with my s-video connection.
2) Found a working xorg.conf file for an S-video monitor
   - Using the demo image that came with the BeagleBoard, I extracted the xorg.conf file and then placed it into the Arch Linux xorg.conf.d directory as monitor.conf file. After doing so, we rebooted the system and we were successfully able to display the GUI through our S-video connection.

2.4 Power

The power is an essential part for the final product. We used the battery as the power component to power our system. Different voltages are provided to power up different parts of the system since different circuits require different voltages.

2.4.1 Original Power Idea

Our initial idea was to have a power system that would also be powered by green energy. We proposed to use a dynamo to convert mechanical power (the rotation of the back bicycle wheel) to electrical power. To do so, we would need two batteries and a charger. (See circuit diagram in Appendix A.2)

However, due to the complexity of the Radar part of the project, we decided to drop this hybrid power system and instead go with a single battery power system.

2.4.2 Final Power Circuit

In order to power our circuit with the battery as the power source, we would need voltage regulators to regulate the voltage. There are a few different voltages that are needed to supply different parts of the system. The voltages provided are 12V, 5V, -5V, 6V, and 1.8V

Multiple Decoupling capacitors are used for the stability of the Power Supply circuit. The resistor values are chosen as according to each data sheet. The battery is proven to stably provide power to our system via the power circuit.

3. Design Verification

All requirements are listed in the appendix.

3.1 Radar

3.1.1 Noise Rejection

The threshold of the signal detector is set to 60mV and no noises are measure higher than this threshold by reading the outputs from the antenna onto the signal analyzer.

3.1.2 Return Power Limit

Using the monostatic radar equation (2), we were able to determine the estimated returned power at 30m:

$$P_r = -2\text{dBm} + 10\log\left(\frac{(30.55)^2(.07143m)^2(1m^2)}{(4\pi)^3(30m)^4}\right) = \sim\text{-}87\text{dBm}$$

To reach our requirement of -50dBm, we are required to have 37dB of amplification. Because our high frequency amplifiers have a gain of 17dB the final output is

$$-87\text{dBm} + (2)17\text{dB} = -53\text{dBm}$$

This is very close to the -50dBm requirement already. Had we been able to find the difference frequency, we would have added low-frequency, op-amp amplifiers to increase the signal further. Given this, we would have been able to add, at least, an additional 20dB gain with minimal noise figure.

3.1.3 Signal Delay

We connected output of the mixer to the signal detector. When using a metal surface to reflect the transmitted signal at different distances from the antenna, a change in the returned signal could be seen immediately (within about 0.1 seconds). This was much better than the required half second. The system was very responsive.

3.1.4 Range Detection

There were two problems that limited our ability to test the range detection: (1)reflection due to mismatched impedances between the VCO & the circulator and at the port of the antenna, and (2) resonant, harmonic frequencies from the sawtooth wave generator.

We knew their was a problem with mismatched impedances because the reflection signals dominated the received signal. This made it impossible to differentiate between the reflection and the received signal. When mixed, this caused a spectrum of difference frequencies, rather than a single, detectable peak of the actual difference frequency.

Because a sawtooth wave is made of many sine waves, we are able to see resonant frequencies in the leaked and returned signal. The sawtooth wave was at ~230Hz. When viewing the signal on the analyzer the greatest peaks are at 230Hz and multiples of 230Hz. This is how we were able to determine that this problem existed. These peaks are much larger than the expected difference frequency peak and essentially cause distortion.

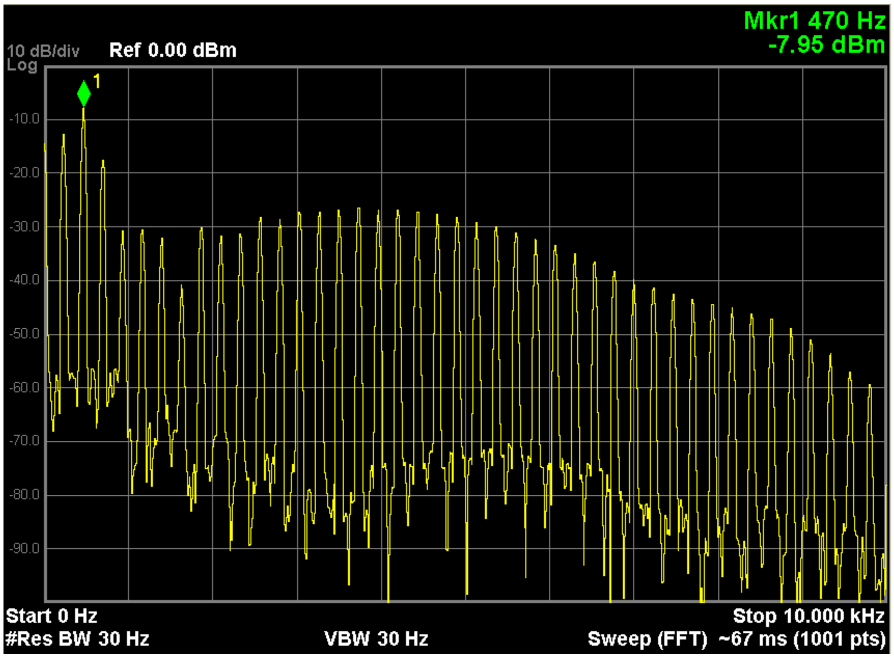

Figure 3.1 Post-mixer signal output with no reflective surface in front of the antenna

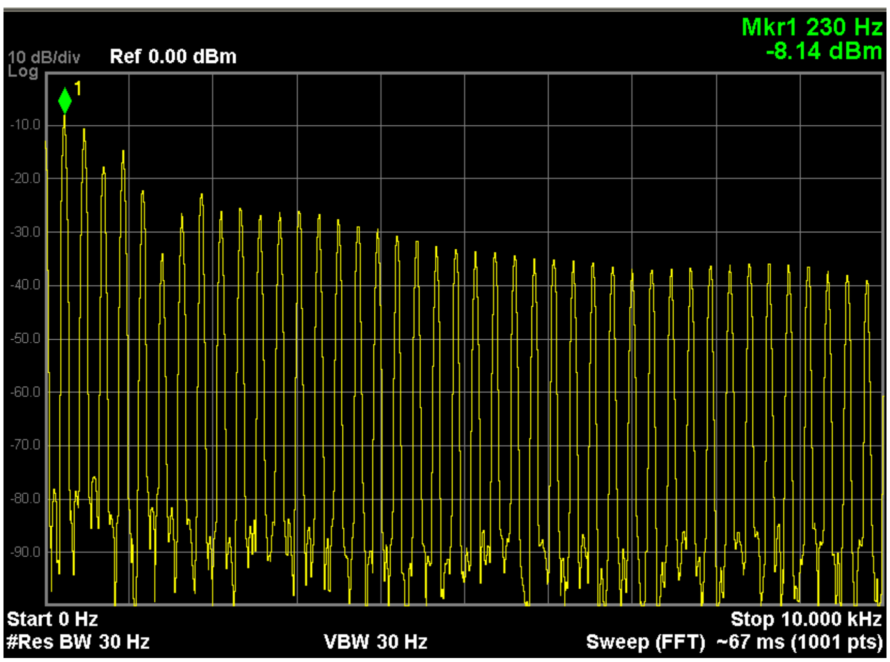

Figure 3.2 Post-mixer signal output with reflective surface at ~1m from antenna

Based on Figures 3.1 and 3.2, we can see that the difference in the signal is occurring when the reflective surface is moved towards the antenna. The same findings were seen when displaying the post-mixer output signal onto the oscilloscope where real time changes were clearly visible with movement of the reflective surface. So we tried one last attempt to attain the difference frequency by taking figures 3.1 and 3.2 and taking their difference in MATLAB. This also proved fruitless however, as the resonant frequencies and reflections still overshadowed the difference frequency.

3.3 Power

3.3.1 Power Consumption and Battery Run Time

We wanted our battery to have the capacity to power our system for at least 3 hours. We bought a 5000mAh Lithium chargeable battery to do the task. In order to make sure the battery would sustain for at least 3 hours with the system we have, we needed to calculate the power that is drawn from our system. The way to calculate the power being drawn is to convert the current that is drawn from each component at the voltage level of the battery.

$$I_{Beagleboard} = 1000mA \ @ \ 5V \cong 340mA \ @14.8V$$

$$I_{Circuitry} = 115mA \ @14.8V$$

$$I_{LCD} = 120mA \ @ \ 12V \cong 100mA \ @14.8V$$

$$I_{total} = 340 + 115 + 100 = 555mA$$

I_{total} is the total current drawn from the system is 555mA, now to convert that into power consumption over time:

$$Q = I \times t = 5000mAh \tag{8}$$

$$t = \frac{Q}{I} = \frac{5000}{555} \cong 9 \ hours \tag{9}$$

So it turns out with a 5000mAh battery, the system would be able to run for around 9 hours with the specified power consumption from the system.

3.3.2 Battery Level Detection and Battery Characterization

We want to display the status of the battery to the user. To do so, we can use the characteristic in which the voltage drops as charge is being drawn from the battery. By understanding the relation between the voltage of the battery and the charge left in the battery, we are able to make a Battery level Detection circuit by checking the voltage [5].

The first step would be to characterize the battery and get a relation between the voltage of the battery and the charge remaining. After some testing, the result is shown:

Table 3.1 Battery State of Charge vs. Voltage

Estimated state of charge (%)	open circuit voltage (V)
100 ~ 95	15.4
90 ~ 85	15.05
80 ~ 75	14.9
70 ~ 65	14.84
60~55	14.8
50 ~ 45	14.76
40 ~ 35	14.63
30 ~25	14.5
20 ~ 15	14.18
10 ~ 5	13.96
0	13.8

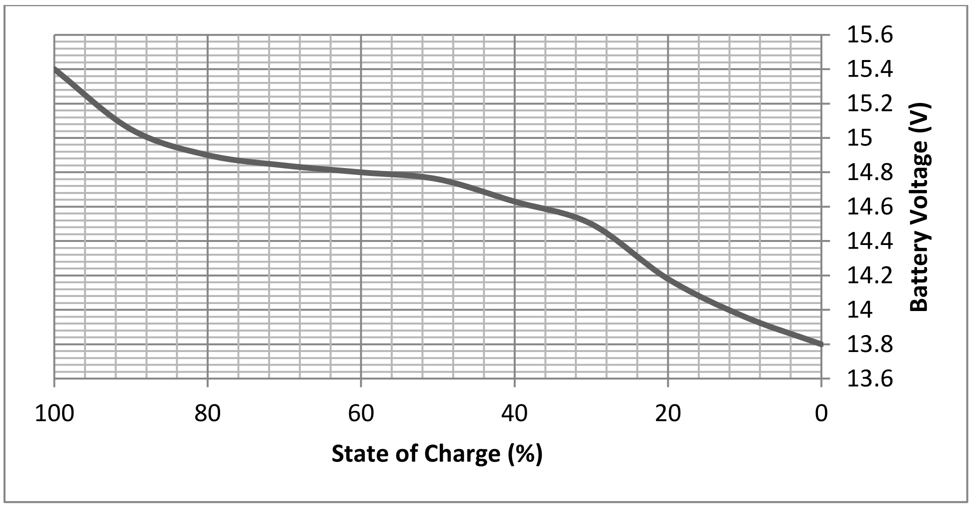

Figure 3.3 Battery State of Charge vs. Voltage

The highlighted columns indicate the voltage levels the users will be notified of when the battery voltage drops below that point. We decided since the battery run time is rather long, we will only need two levels of notification, one when the battery drops below 50%, and one when it drops below 10% of charge.

We implemented the Battery Level Detection circuit by using comparators and setting threshold voltages to the voltage of indication (14.76V and 13.96V).

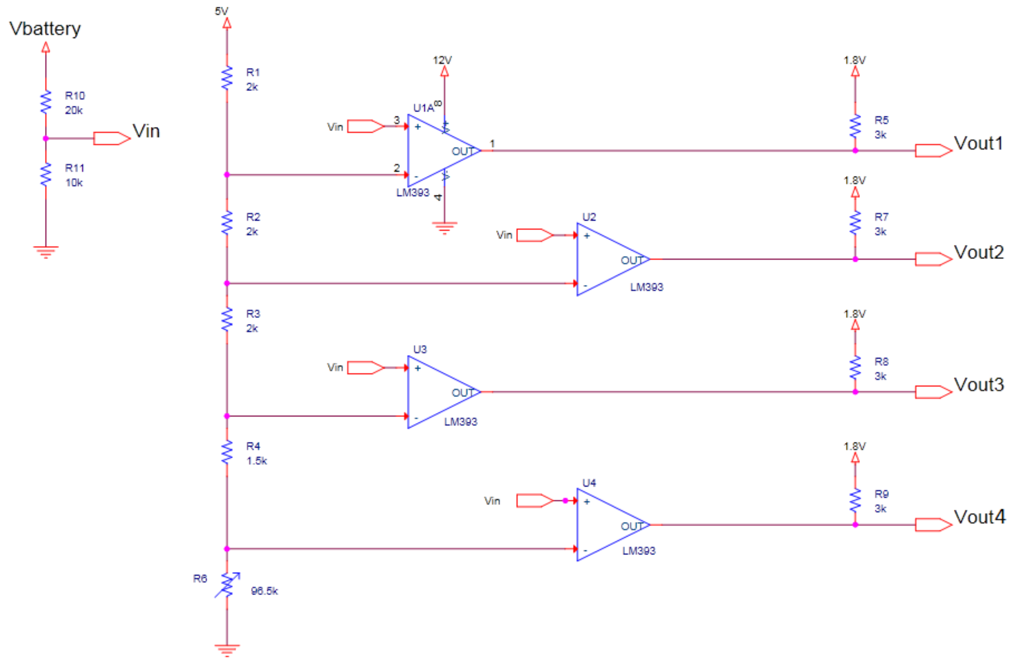

Figure 3.4 Battery Level Detecting Circuit

The Voltage of the battery is divided by three through a voltage divider to get a voltage level that is in the range of 5V which is labeled as Vin in the diagram. By doing so we can use the comparators, since they need a supply of at least 1.5V above the threshold voltages. A 12V supply was given to ensure sensitivity at voltage comparing around 5V.

Note that although all four comparators in the LM393 are showed, only two are used. The threshold voltages are generated by a voltage divider. Each threshold corresponds to a level of the battery

Table 3.2 Threshold Voltage vs. Battery Voltage

Threshold (V)	Corresponding Battery level(V)
4.92	**14.96**
4.81	14.43
4.7	14.1
4.65	**13.95**

In the end, only Vout1 and Vout4 are used since they indicate the 50% and 10% battery level. The output of the circuit connects directly to the GPIO ports of the Beagleboard.

4. Costs

4.1 Parts

Part	Part Number	Manufacturer	Quantity	Actual Cost
Beagleboard XM	rev C1	beagleboard	1	149.00
3.5" LCD Video Monitor	ALCD35LV	AEI Components	1	85.00
Turnigy 5000mAh 4S 20C	T5000.4S.20	Turnigy	1	28.60
Webcam		Hewlett-Packard	1	59.99
Circulator	e-meca cs 6.000	e-meca	1	200.00
Mixer	ZFM-4212	Mini-circuits	1	54.95
Amplifier	ZJL-3G	Mini-circuits	1	114.95
Horn Antenna			1	200.00
VCO	CVCO55B-4100-4300	Crystek Corporation	1	26.24
Amplifier	MGA-86576	Avago Technologies	2	16.10
1.2V-3.7V Regulator	LM317T	Texas Instruments	2	1.00
12V Regulator	MC7812	Texas Instruments	1	0.50
6V Regulator	LM7806	Texas Instruments	1	0.50
-5V Regulator	LT1054	Texas Instruments	1	0.50
Comparator	LM339	Texas Instruments	1	0.50
Comparator	LM393	Texas Instruments	1	0.50
Op Amp	TL082	Texas Instruments	2	1.00
Diode	1N4001		3	1.50
Capacitors			19	1.90
Resistors			40	4.00
Total				946.73

4.2 Labor

3 (partners) x $35/hour x 2.5 x 20 hours/week x 10 weeks = $52,500

5. Conclusion

5.1 Accomplishments

In the end, we were able to construct the FMCW radar and the display unit. Although we encountered some problems, we were able to verify that the FMCW radar does indeed work. The sawtooth wave generator (providing the right control voltages), VCO (outputting the right modulating frequencies), and amplifiers (producing a reasonable amount of gain) worked perfectly. They also integrated well with the borrowed components, since we were able to detect a different incoming signal based on different distances of the reflective material from the antenna.

The signal detector was able to properly threshold different powers of incoming signals and provides the proper high and low signals to the GPIO of the BeagleBoard. The BeagleBoard was then able to analyze these signals and enable the alert overlay image in the top-left corner of the LCD. Meanwhile, the LCD simultaneously displayed a mirrored image of the rearview camera. By lowering the resolution rate, the refresh frame rate was enough for the user to comfortably detect vehicles beyond the 30m distance.

As for the power, the circuit completely powered our entire circuit (no outer power was necessary) through appropriate voltage regulation. An additional circuit was also able to correctly detect charge of the battery and output this to the BeagleBoard through GPIO inputs.

5.2 Uncertainties

The problem we ran into that caused problems and inconsistencies were the reflection in combination with leakage through components. The impedance mismatching between at the circulator and antenna caused reflections that overshadowed our received signal in terms of power. In combination with leakage, there were just too many separate frequencies entering the mixer. Because of this it was very difficult to differentiate between these signals and the difference frequency.

Had we had a better (more expensive) high frequency components (i.e. circulator and antenna adapter), we would have had no trouble differentiating these signals, as reflection would be diminished and higher isolation would reduce the amount of leakage. Since the difference frequency would be easier to differentiate from other noise, the problem with the sawtooth resonant frequencies could have also been ignored. However, this would require almost a separate $1000 budget just for these high frequency components (not taking into account all of the other parts).

5.3 Ethical considerations

Any guarantees made regarding the safety the product provides would have to be extremely well tested before made commercially available. We would also need to make sure that once safety testing was completed that clear directions regarding the proper use of the device were thoroughly provided. If used incorrectly, the device could cause more danger than if it were not installed in the first place.

Another consideration is FCC (Federal Communications Commission) regulations on frequency. According to the FCC rule 97.313(e), no station may transmit with a transmitter power exceeding 5 W PEP on the UHF band [7]. We followed this rule, as our transmitted power is around 20dBm (100mW).

Because the product we have worked on relates greatly to the safety of the user, it is important to take in ethical considerations as listed out in the IEEE code of ethics. The following portions we find to be especially important [8].

"To accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;"

The purpose of the device is to provide extra safety to the user. Since it is natural for the user to rely on the product while using it, we should take into all different kinds of considerations and situations which might lead to a failure in the detection or stability issues. By ensuring that no problems occur, safety can be guaranteed.

"To seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others; "

If any errors should pop up, we should work on it immediately to solve them. We should also give credit to all the people that have helped us through the project.

"To avoid injuring others, their property, reputation, or employment by false or malicious action;"

We should ensure the stability of the product so that injuries can be avoided. We should also include clear instructions for the use of the project and should not falsify any information.

5.4 Future work

The first thing that we would want to improve for the system is to fix the problem for the mismatched impedance. This task can be hard since we want to match the impedance over a large frequency range (200MHz), and working at such high frequencies. One way to match the impedance would be using RF (radio frequency) stubs. We might be able to achieve a matching network by applying the stub in between the circulator and the antenna. Another option would be to get another antenna that has a lower reflection coefficient and is designed to perform in the region we want it to (4.1~4.3GHz). This might be a more feasible idea since matching impedance over a range of 200MHz can be a hard task. Finally if both of the mentioned options are not possible, another way would be to use a DSP to do signal processing. We were able to retrieve a recognizable signal in frequency domain by subtracting the incoming signal from the antenna with the reflecting signal coming from the mismatched impedance. After doing FFT (fast Fourier Transform), we are able to observe a signal with a strong peak near DC. The peak is close to the calculated Δf, and is what we were originally hoping to see. The only downside of using the DSP is it might introduce a slight amount of delay (which we believe we can control it to be under 0.5 seconds still).

If time allowed, we would have added the hybrid power system to our project and provide an eco-friendly product. Our design for the hybrid power system has already been laid out and would not take much more budget and time to make.

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Appendix A Requirement and Verification Table

Table A.1

Requirements	**Verifications**
Power 1.) The battery should last for at least three hours with the sensor, microcontroller, and LCD load. 2.) Must detect battery level and alert BeagleBoard when battery is low. 3.) Need to be able to model the relationship between voltage and the power stored.	1.) Simulate the system with a load that simulate the power consumption of the entire system (calculate estimated power consumption) and run until battery depletes. 2.) Use a comparator and modify the threshold voltages to output low voltage when battery power is low. 3.) When running the simulation to determine battery duration, we will also record the voltage drop and the power remaining over time. We will then model these two onto a graph to determine comparator threshold voltages.
Sensor 1.) The system should not recognize noise from the antenna as an incoming signal. 2.) The final power output should be not be worse than -50dB. 3.) Limit the total delay time to be a half second (from VCO output to BeagleBoard input). 4.) Limit power consumption to 2W. 5.) System should be able to detect vehicles within a 30m range.	1.) Will measure noise with a signal analyzer, and according to the measurements, will adjust the comparator threshold. 2.) Read measurements from incoming signal with signal analyzer without amplification. Based on the allowed power-input for the circulator, add an appropriately valued amplifier between the VCO and the circulator. Do the same for the signal processing components and measure the final output just before the comparator. 3.) Send FMCW pulse and use Δf to determine Δt. Using the BeagleBoard, we will write a program to send and receive a pulse through the signal processing components. This program will count the time it takes for this pulse to travel through all components, from port 3 on the circulator to the output of the comparator. 4.) Use an amp meter to read the total current used in the circuit. With given output voltages, use this current to calculate the total power consumed, and adjust amplifier usage accordingly. 5.) Determine the most efficient frequency sweep rate for the FMCW (and from this designation design the BPF and LPF to handle unwanted frequencies) by speeding up the sweep rate until the system cannot properly do calculations, while also still keeping noise to a minimum.

Microcontroller, Programming 1.) Needs to output various sawtooth waveform voltages for the sensor. 2.) Needs to take in signal from the sensor. 3.) Needs to display a flipped image from the webcam display. 4.) Needs a signal in the upper left-hand corner from the sensor when a vehicle is within 30m and also the battery level in the lower left-hand corner of the screen.	1.) We will attach a voltmeter to the output of the board and measure the appropriate voltages that come from the board. We know that the board gives a maximum of 5V, but the voltmeter will read the fractions of the 5V maximum voltage output. 2.) We can test this by setting a switch and making sure the board can read in the signal using a simple LED. 3.) To test this, we will input images and then simply flip the image and print it to the LCD screen showing that the image has been flipped. 4.) We will test this by simply displaying a dummy graphic on the screen in response to a button that sends a signal to the board.

Appendix B Diagrams, Miscellaneous Circuits & Tables, EAGLE PCB's

B.1 Hybrid Power System

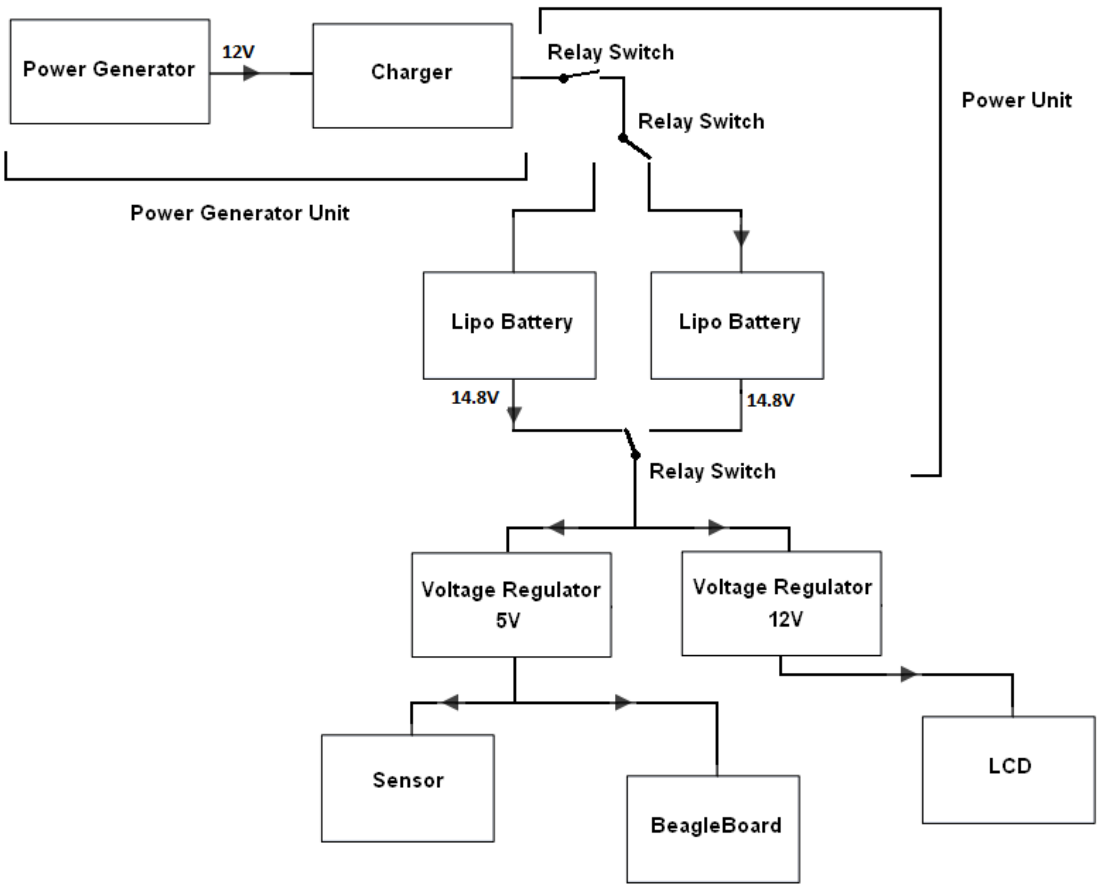


Figure B.1 Discarded hybrid power system (could be used in future additions)

Table B.2 Expansion Connector Signals [ ]

1

EXP	Processor	0	1	2	3	4	5	6	7
1		VIO_1V8							
2		DC_5V							
3	AE3	MMC2_DAT7	*	*	*	GPIO_139	*	*	Z
4	AB26	UART2_CTS	McBSP3_DX	GPT9_PWMEVT	X	GPIO_144	X	X	Z
5	AF3	MMC2_DAT6	*	*	*	GPIO_138	*	X	Z
6	AA25	UART2_TX	McBSP3_CLKX	GPT11_PWMEVT	X	GPIO_146	X	X	Z
7	AH3	MMC2_DAT5	*	*	*	GPIO_137	*	X	Z
8	AE5	McBSP3_FSX	UART2_RX	X	X	GPIO_143	*	X	Z
9	AE4	MMC2_DAT4	*	X	*	GPIO_136	X	X	Z
10	AB25	UART2_RTS	McBSP3_DR	GPT10_PWMEVT	X	GPIO_145	X	X	Z
11	AF4	MMC2_DAT3	McSPI3_CS0	X	X	GPIO_135	X	X	Z
12	V21	McBSP1_DX	McSPI4_SIMO	McBSP3_DX	X	GPIO_158	X	X	Z
13	AG4	MMC2_DAT2	McSPI3_CS1	X	X	GPIO_134	X	X	Z
14	W21	McBSP1_CLK X	X	McBSP3_CLKX	X	GPIO_162	X	X	Z
15	AH4	MMC2_DAT1	X	X	X	GPIO_133	X	X	Z
16	K26	McBSP1_FSX	McSPI4_CS0	McBSP3_FSX	x	GPIO_161	X	X	Z
17	AH5	MMC2_DAT0	McSPI3_SOMI	X	X	GPIO_132	X	X	Z
18	U21	McBSP1_DR	McSPI4_SOMI	McBSP3_DR	X	GPIO_159	X	X	Z
19	AG5	MMC2_CMD	McSPI3_SIMO	X	X	GPIO_131	X	X	Z
20	Y21	McBSP1_CLK R	McSPI4_CLK	X	X	GPIO_156	X	X	Z
21	AE2	MMC2_CLKO	McSPI3_CLK	X	X	GPIO_130	X	X	Z
22	AA21	McBSP1_FSR	X	*	Z	GPIO_157	X	X	Z
23	AE15	I2C2_SDA	X	X	X	GPIO_183	X	X	Z
24	AF15	I2C2_SCL	X	X	X	GPIO_168	X	X	Z
25	25	REGEN							
26	26	Nreset							
27	27	GND							
28	28	GND							

B.3 Image Overly Algorithm

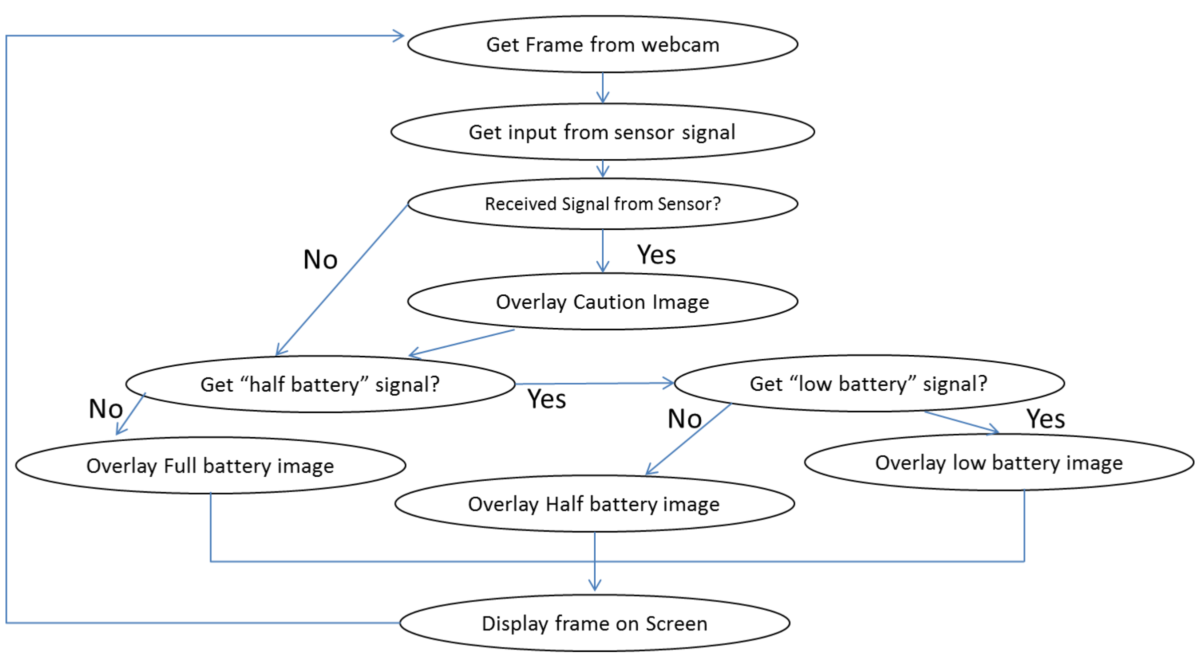


Figure B.3 Flowchart of image overlay algorithm

B.4 Diagram showing component connections to BeagleBoard

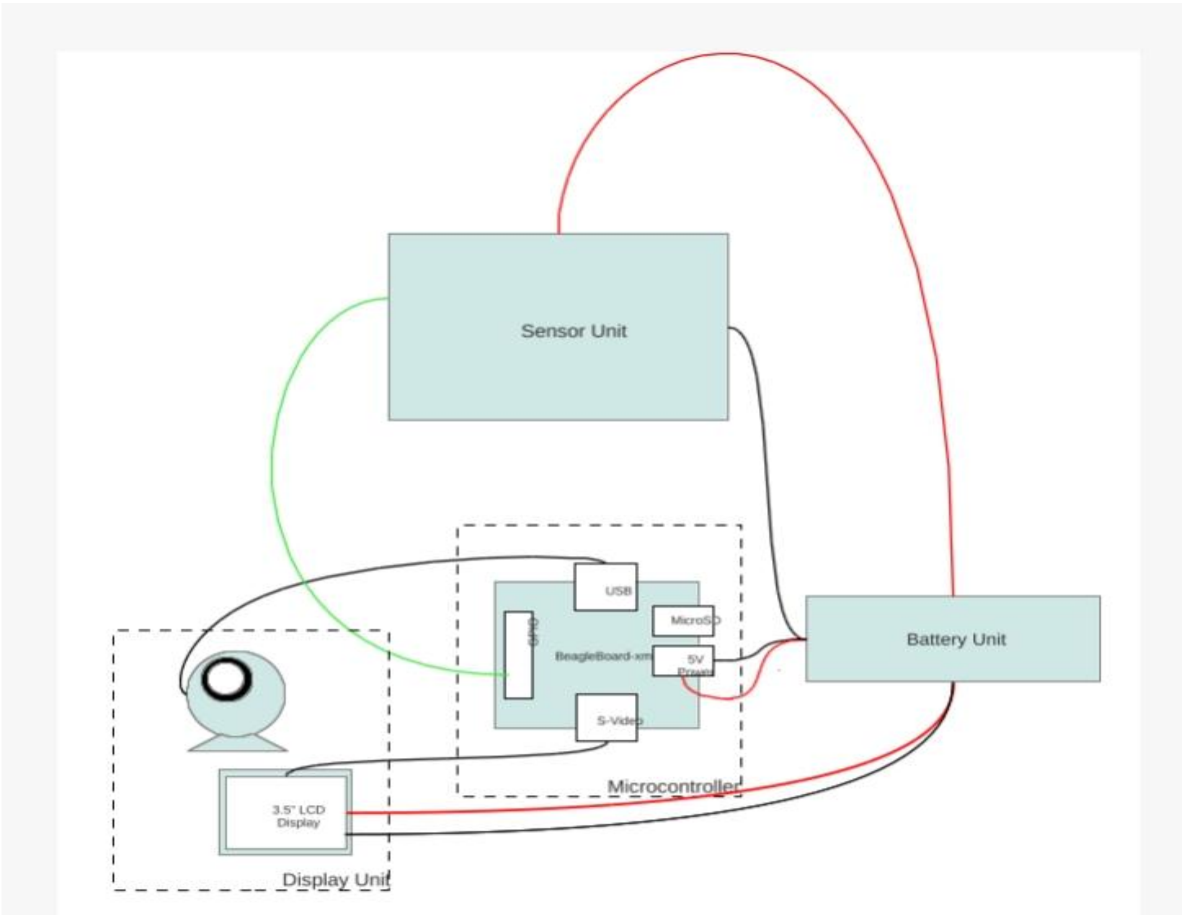


Figure B.4 Diagram showing component connections to microprocessor

B.5 Final Power Circuit

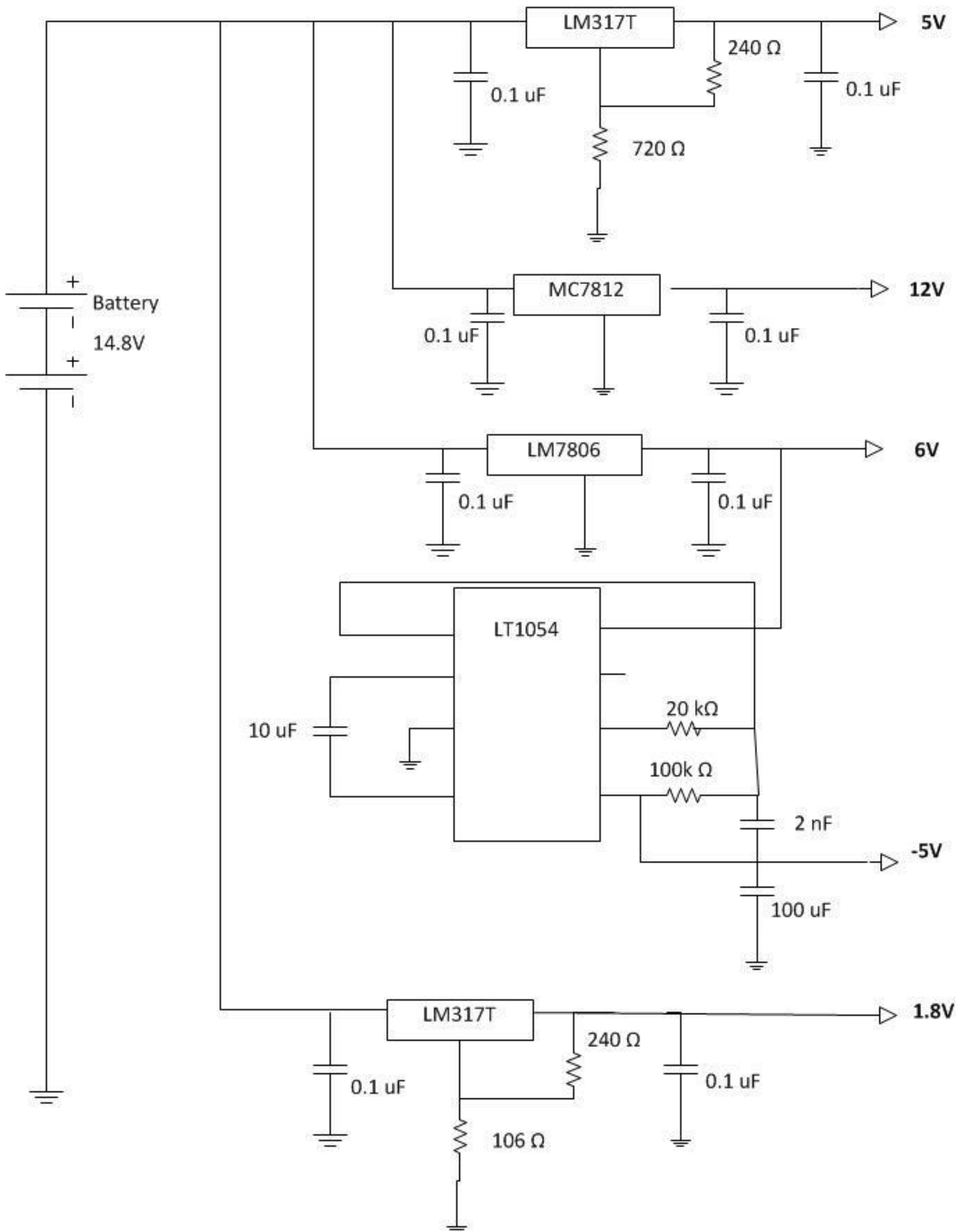


Figure B.5 Final Power Circuit, providing regulated voltages

B.6 EAGLE PCB for VCO

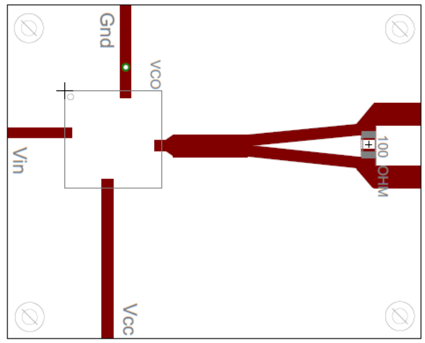


Figure B.6 Finalized PCB layout for VCO

B.7 Eagle PCB for Amplifiers

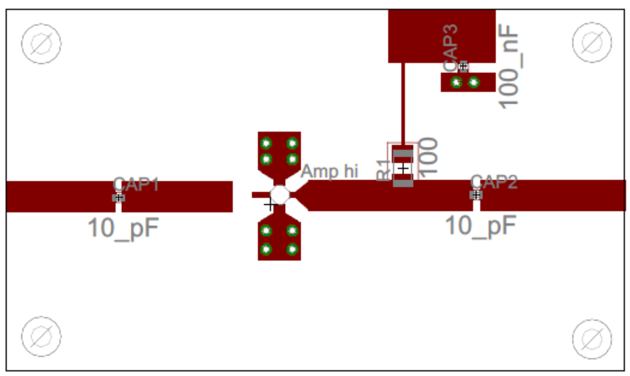


Figure B.7 EAGLE design for amplifiers

B.8 Circuit for Signal Detector

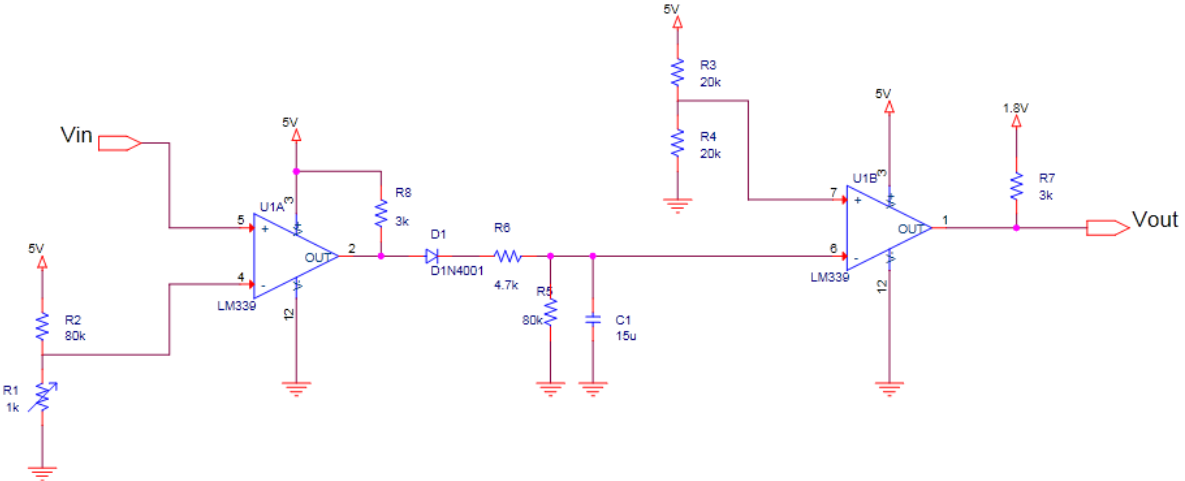
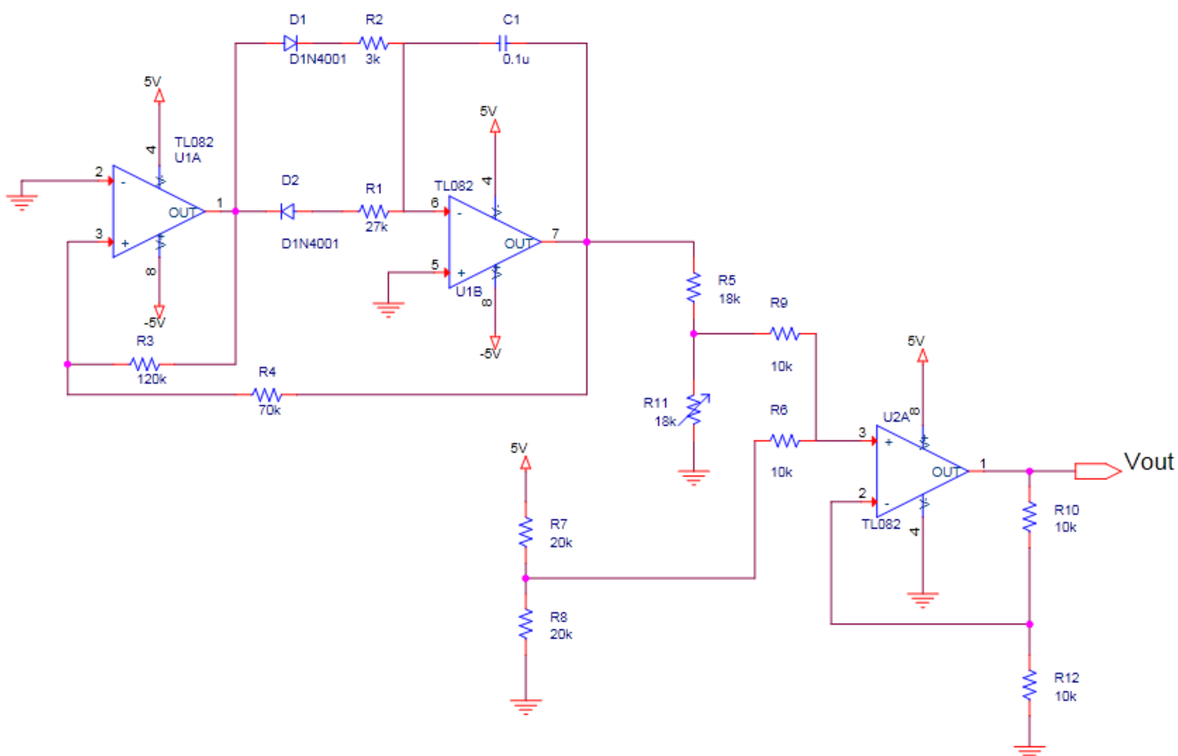


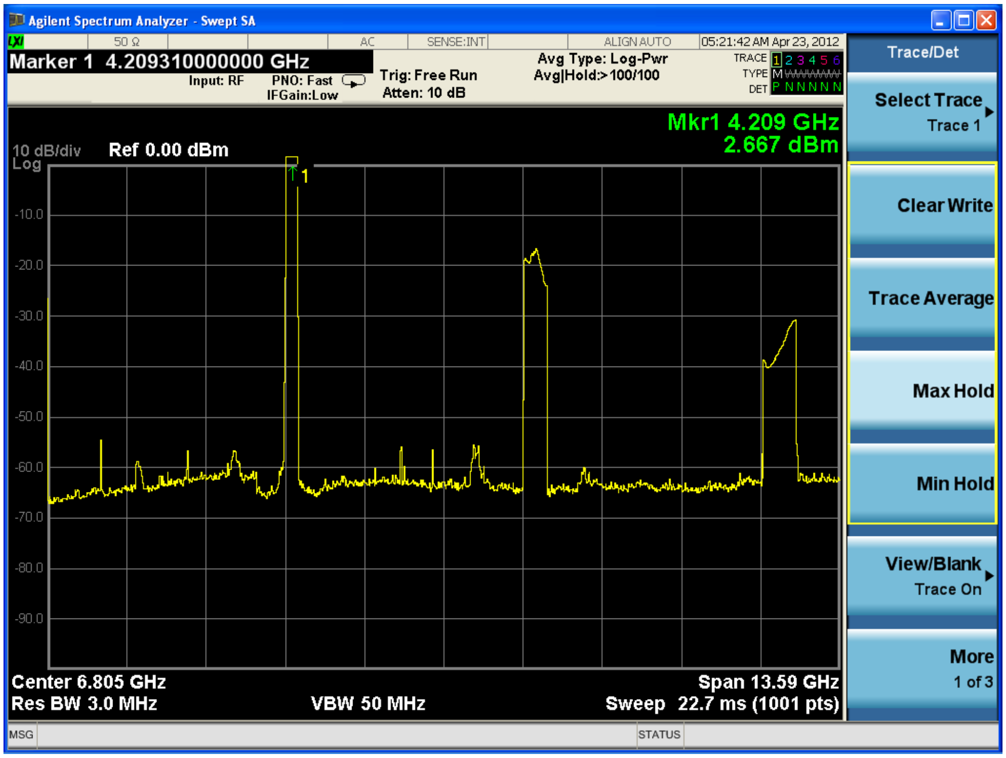
Figure B.8 Circuit design for signal detector

B.9 Circuit for Sawtooth Generator

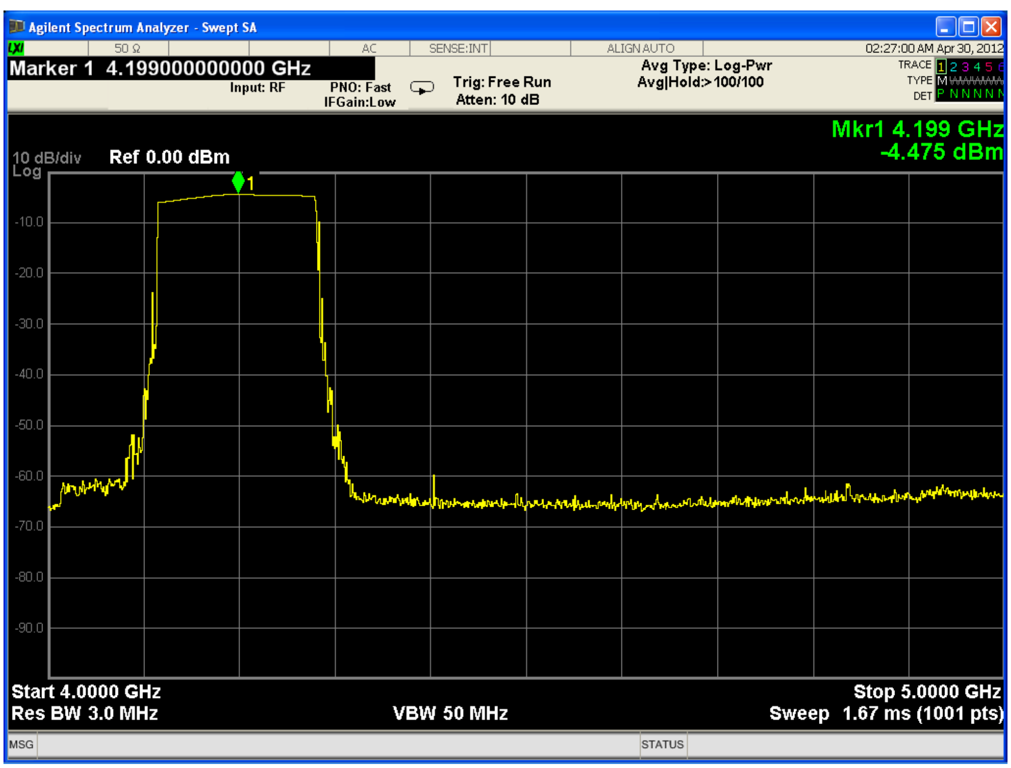


Appendix C: Miscellaneous Data Graphs

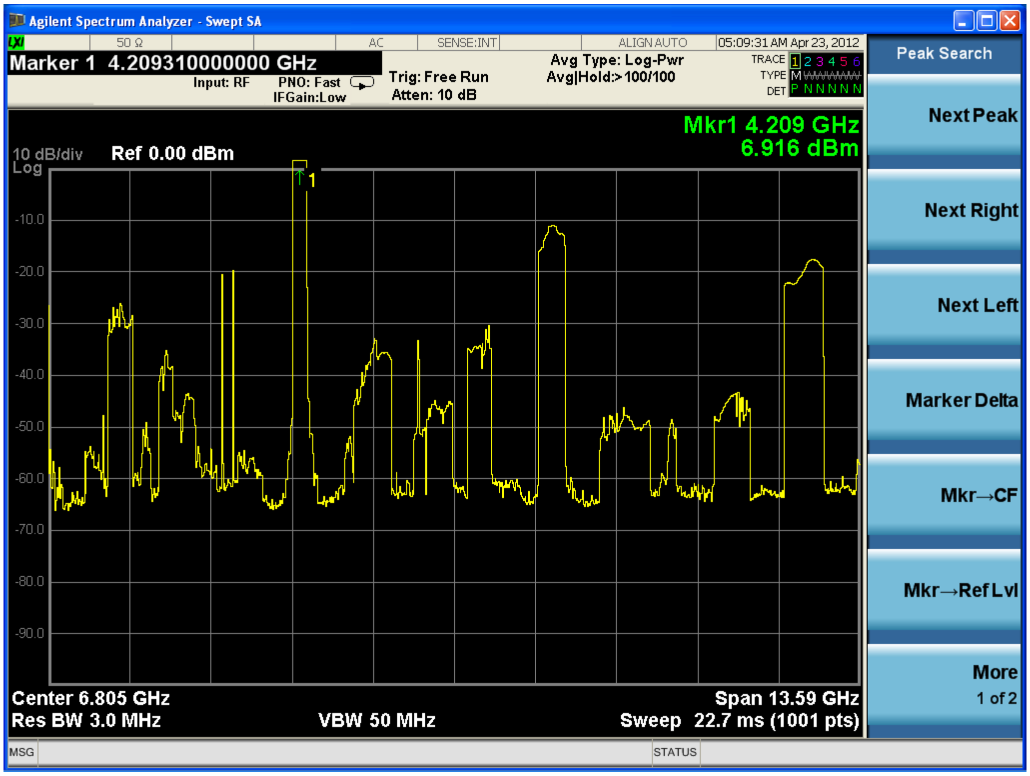
C.1 Pre-circulator (Port 1) Amplification - MaxHold



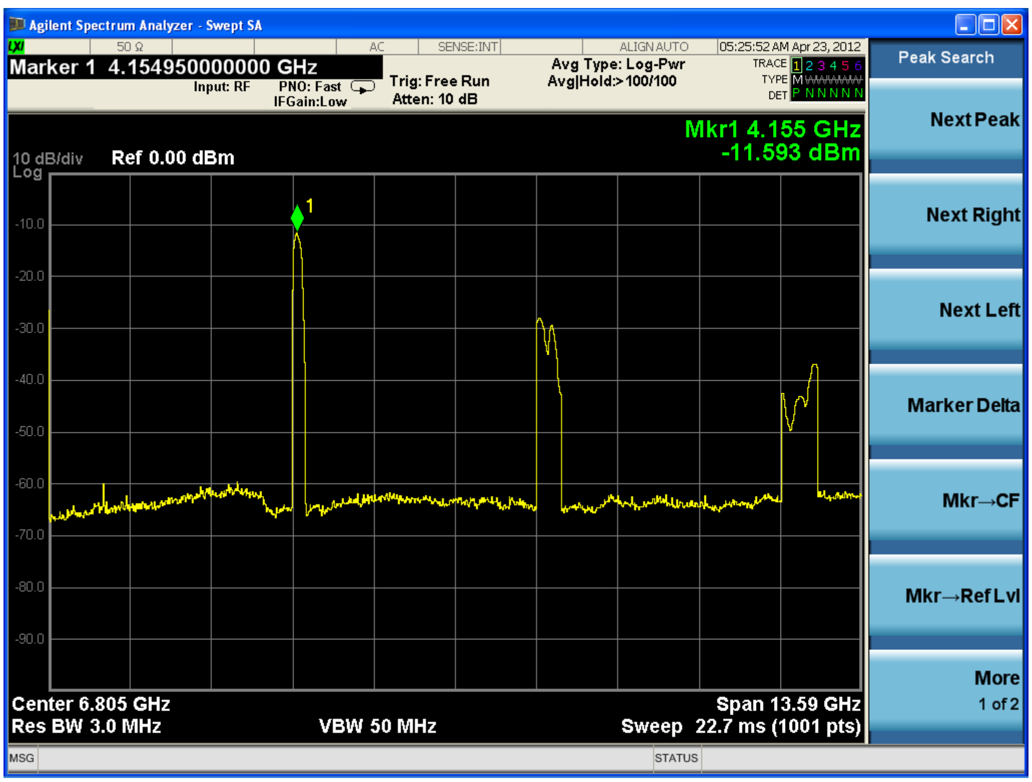
C.2 VCO Output – MaxHold



C.3 Mixer Lo Input – Post Amplification

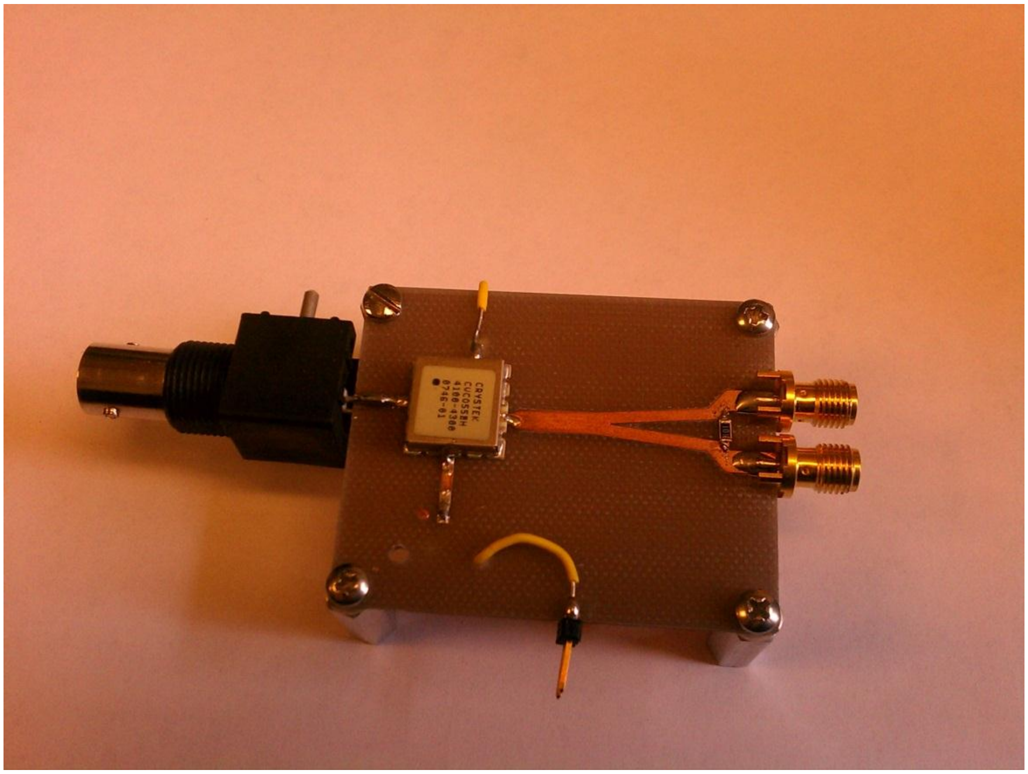


C.4 Circulator Leakage – Port 1 to Port 3 with Antenna Attached to Port 2



Appendix D: Pictures of Built PCB’s

D.1 Fabricated and soldered VCO



D.2 Fabricated and soldered High frequency Amplifier