Final Report

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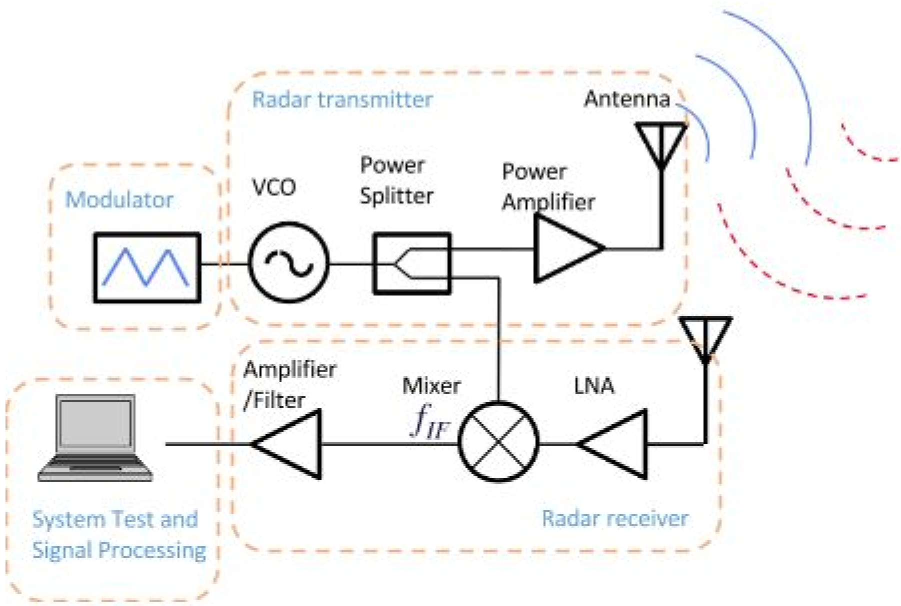
Abstract

EEC 134 is a two quarter senior design project that focuses on Radio Frequency (RF) and microwave system engineering. The system is a Frequency Modulated Continuous Wave (FMCW) radar system that can determine range and Doppler measurements. Doppler measurements send out a signal at a known frequency and then compares that with the signal reflected from the object to obtain the frequency of the oscillation. Range measurements determine the distance an object is from the radar system. The project encompasses system design, analog circuit design, and digital signal processing.

Introduction

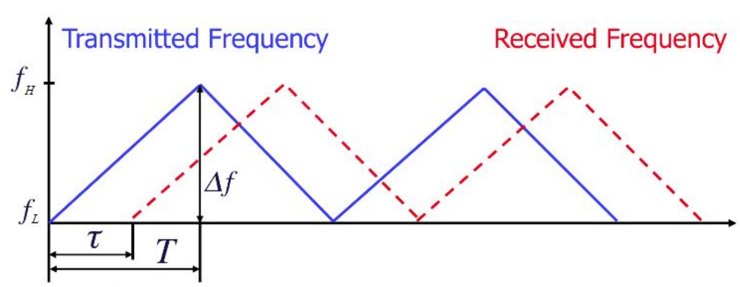
The FMCW radar system is similar to the continuous wave (CW) radar. The CW radar measures the instantaneous rate of change in the target's range by using the measurement of the Doppler shift from the returned signal. The difference between CW radar and the FMCW radar is the change in its operating frequency during the measurement process. The FMCW radar uses much smaller instantaneous transmit powers and physical size by continuously emitting periodic pulses where the frequency varies with time.

The FMCW radar system shown below transmits a radio frequency wave where the frequency is changing continuously. The voltage controlled oscillator (VCO) below produces the RF signal and the modulation voltage creates the frequency change. The power amplifier boosts the RF signal from the antenna.



When the signal makes contact with the target, a reflected signal is generated, which is received and analyzed together with the transmitted signal to deduce the range and velocity of the target. This is done by using triangle wave modulation. The transmitted signal is increased from low frequency to high frequency in the first half of the period (T) and is then decreased back to at the end of the period. Once the signal leaves the antenna, the frequency stops change and the new signal (reflected) becomes a delayed version of the transmitted signal. The difference of the two signals is related to the distance between the radar and the object.

, where c is the speed of light.



The low noise amplifier (LNA) is used to strengthen the received radar signal. Both transmitted and received signals are passed through a power splitter and into a mixer to generate the sum and difference frequency. The low pass filter is used to amplify the difference frequency. A computer is used to digitize and perform Fourier Transform signal processing on the difference frequency.

After obtaining the difference frequency and the delay , we can determine the distance by

.

Description

In our project, we designed an FMCW radar that needed to have the capability of accurately detecting the distance of an object up to fifty meters and testing the sensitivity of our system. After measuring the distance of one object or the frequency of a moving object, we then uploaded the data as a sound file into MATLAB for analysis to obtain the distance or frequency of the object. Overall, the system is the same as the initial design from Fall quarter mounted on a printed circuit board which greatly helped reduce the weight of the entire system. The system is reliant on a regulated power supply and a computer equipped with a few required pieces of software.

Design Details

The RF/Analog portion of the system is based on the prototype system from quarter one. The prototype operates at a center frequency of 2.4GHz. It uses an Arduino Uno to perform the analog to digital conversion (A/D) and generate a triangle wave at around 40Hz. To upload the recorded data, a computer sound card is used to sample the intermediate frequency (IF) signal, which is processed by the computer using MATLAB.

The improved system has an operating frequency at 2.4 GHz as well and still maintains the Arduino Uno for A/D conversion, but was installed with an XR-2206 Monolithic function generator that transmitted a triangle at around 1kHz. We retained the 2.4 GHz operating frequency because it is one of the most common frequencies used, so there will be an abundance of components at reasonable prices. Also, the atmospheric attenuation of the RF signal is one of the least at 2.4 GHz.

The A/D has 8-bit resolution. Even though the resolution is not as high as a 16-bit A/D, it will suffice for this particular application. The Fast Fourier Transform (FFT) is done by the computer through MATLAB. Computing power is responsible for sampling, transmitting the signal, performing the FFT, and finally, to display the data acquired. MATLAB will output a range versus time graph for the range test and a velocity versus time graph for the Doppler test.

<u>IC Components:</u>

Power Amplifier: **MGA-83563**: This amplifier was used to boost the signal before the antenna transmits it. The signal was amplified about 20 dB before reaching the transmission antenna. The operating voltage is 3V.

Low-Noise Amplifier: **ADL5523**: The low-noise amplifier provided about 13 dB of gain and was used in two places. The first one was used before the mixer on the transmission side of the system. The other one was used after the antenna on the receive side to amplify the signal before it reaches the mixer.

Power Splitter: **SBA-2-22**: The power splitter used was a passive, 2-way power splitter which operated at around 2000 to 2600 MHz.

Mixer: **ADE-R3GLH**: The mixer we used was a passive, 10 dB local oscillator (LO) power mixer which means that the signal had to be at least 10 dB before reaching the mixer, so a low noise amplifier was used to amplify the signal before reaching the mixer. It had a conversion loss of about 5.2 dB and an isolation of 25 dB.

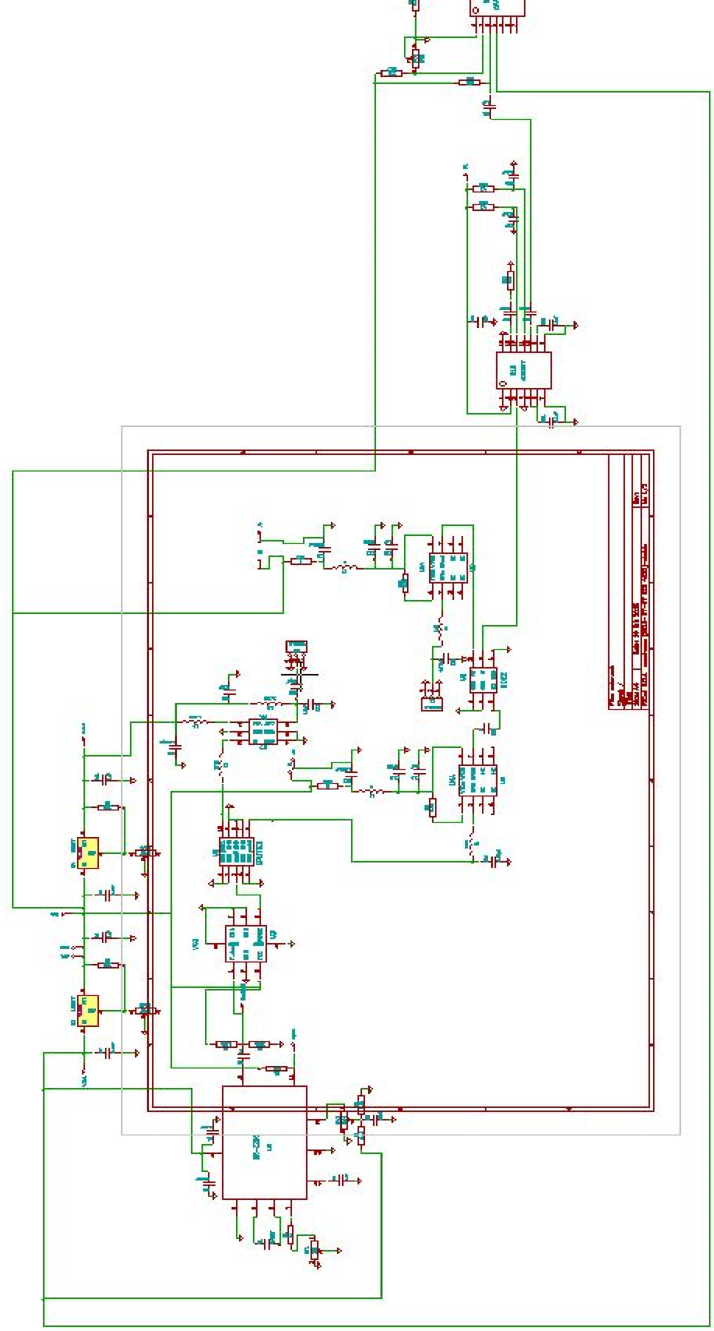
Monolithic Function Generator: **XR-2206**: The function generator provides 1 kHz for us as the modulator of the system.

AGC Power Amplifier: **AD8367**: The automatic gain control (AGC) operates at a frequency of 30 kHz to 500 MHz. It provided about 40 dB of gain however, was primarily used for forcing the voltage to 1V so that the digital to analog converter could detect the signal after modulation.

Operational Amplifier: **OPA4228**: The operational amplifier used 5V and was implemented to construct a 2 stage intermediate frequency filter.

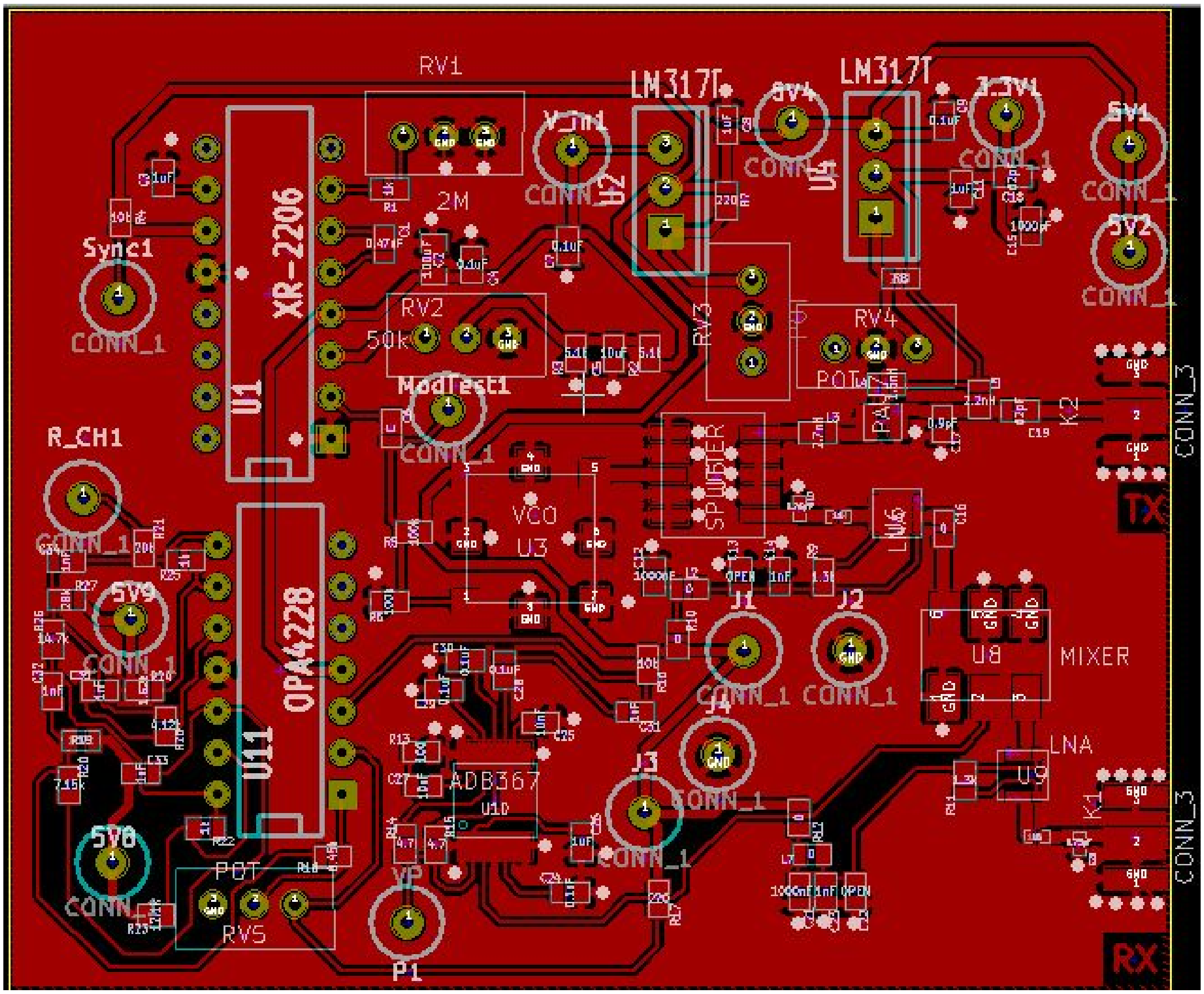
Schematic

Using the Electronic Design Automation (EDA) tool, KiCad, the schematic for the system was drawn out and is shown below.



Printed Circuit Board (PCB) Footprint

Again, using KiCad, the footprint was designed and is shown below.



Bill of Materials

Value	Size	# Needed	# Bought	Price
0.47 uF	SM0603	1	50	2.88
100uF	SM0805	1	10	10.42
1uF	SM0603	5	50	1.44
0.1uF	SM0603	7	50	0.51
10uF	SM0603	2	50	3.88
0.75pF	SM0402	2	50	3. 94
1nF (1000 pF)	SM0603	8	50	0.54
0 ohms	SM0603	5	50	0.63

0.9pF	SM0603	1	25	3.6
62pF	SM0603	2	50	1.43
10nF (0.01uF/10,000pF)	SM0603	2	50	0.51
	SMA Connector	2		
1nH	SM0402	2	5	0
2.7nH	SM0603	1	50	3.08
1.5nH	SM0603	1	50	2.32
2.2nH	SM0603	1	50	2.32
1k	SM0603	3	50	0.63
5.1k	SM0603	2	50	0.46
10k	SM0603	2	50	0.63
100k	SM0603	2	50	0.63
220 ohms	SM0603	3	50	0.42
1.3k	SM0603	2	50	0.63
100 ohms	SM0603	1	50	0.63
4.7 ohms	SM0603	2	50	0.63
8.45k	SM0603	1	50	0.75
102k	SM0603	1	50	0.42
7.15k	SM0603	1	50	0.75
20k	SM0603	1	50	0.75
12.1k	SM0603	1	50	0.42
1.62k	SM0603	1	50	0.75
14.7k	SM0603	1	50	0.75
28k	SM0603	1	50	0.75
4.12k	SM0603	1	50	0.42
2M	PV36	1	5	6.67
50k	PV36	1	5	6.67
Power Splitter	SBA-2-22	1	1	0
IC RF AMP	MGA-83563	1	1	0
LNA	ADL5523	2	2	0
Mixer	ADE-R3GLH+	1	1	0
VCO	MOS-2545-119+	1	1	0
AGC	AD8367ARUZ	1	1	0
			Total Cost*	**61.26**

*Total cost only encompasses the components, does not include the ordering of the PCB

Test & Measurement Results

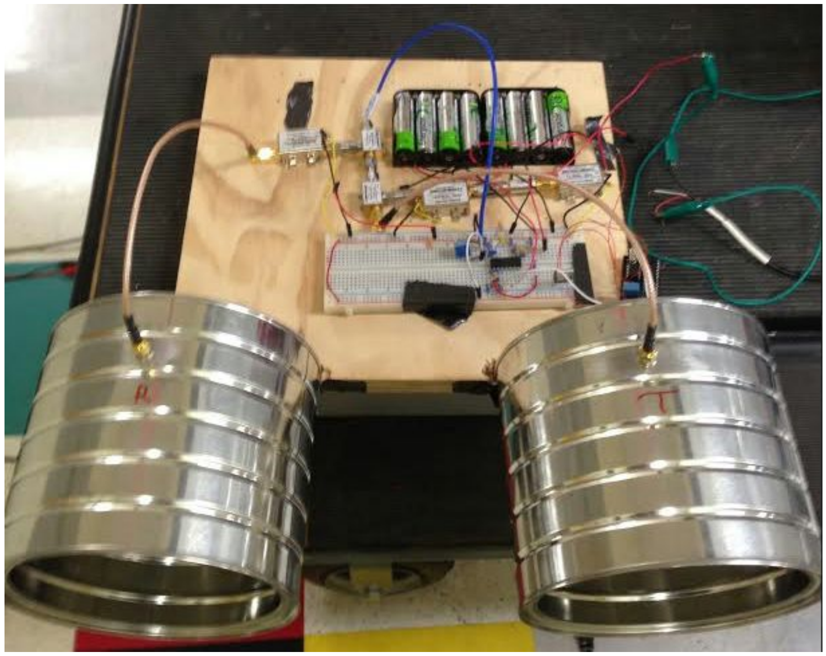


Figure 0: First quarter radar system

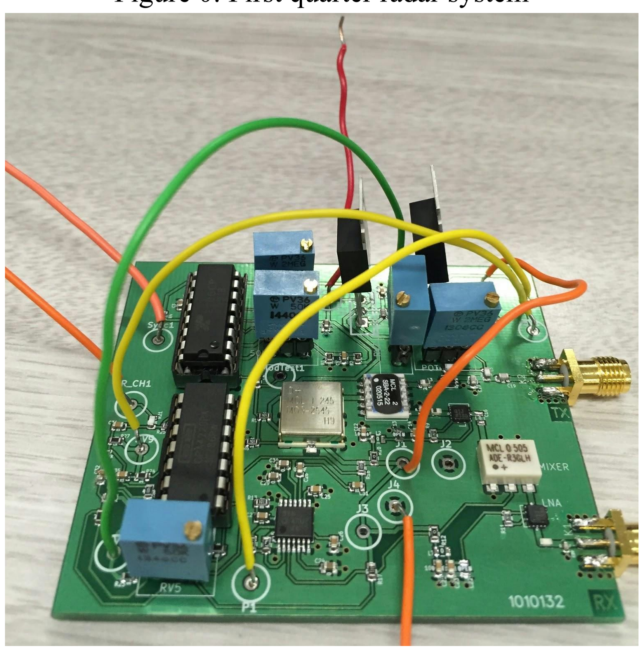


Figure 1: PCB with wires connecting the power lines

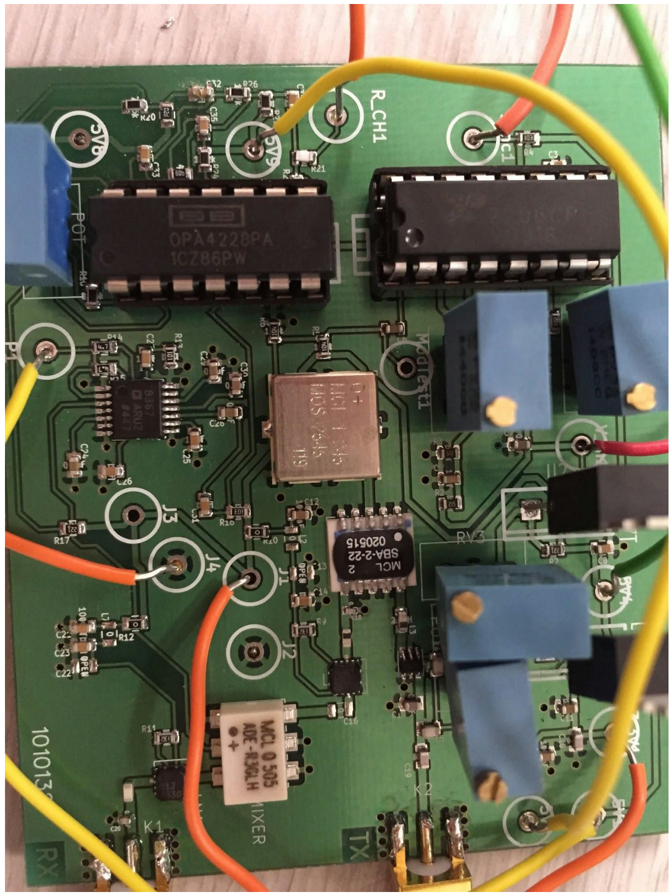


Figure 2: Close-up on PCB

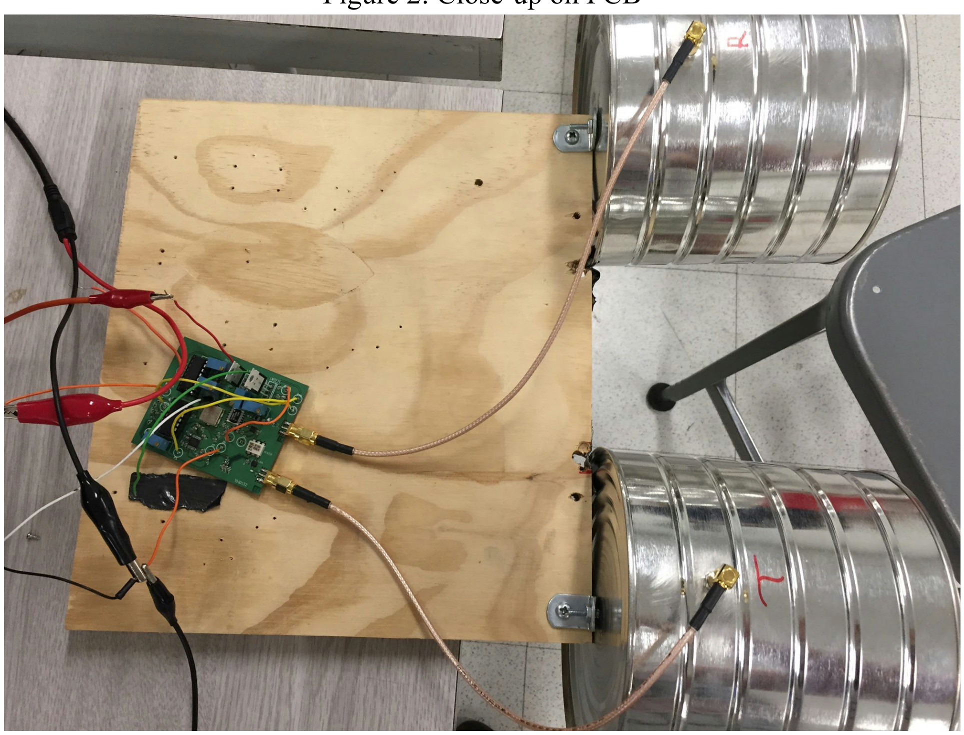


Figure 3: Completed radar system

From the first quarter radar system to the current radar system, the improvements lie mostly in the transition from breadboard to PCB. Figure 0 is shown for comparison with Figure 3. In the first system, the modulator outputting the triangle wave was on a separate PCB, located on the right side of Figure 0. As an improvement, we have incorporated the modulator with the A/D converter, the RF path and components, and the low pass filter onto one PCB. The coffee can antennas have been kept on the wooden board for stability.

The current system is very finicky. After a couple test runs, the system ceased to operate correctly. Luckily, we were able to gather a set of data for the range test before that happened.

The radar system was able to reach a maximum range of about 15 meters. Once again, the system was tested in the hall of Kemper Hall, which resulted in many background reflections from past transmissions.

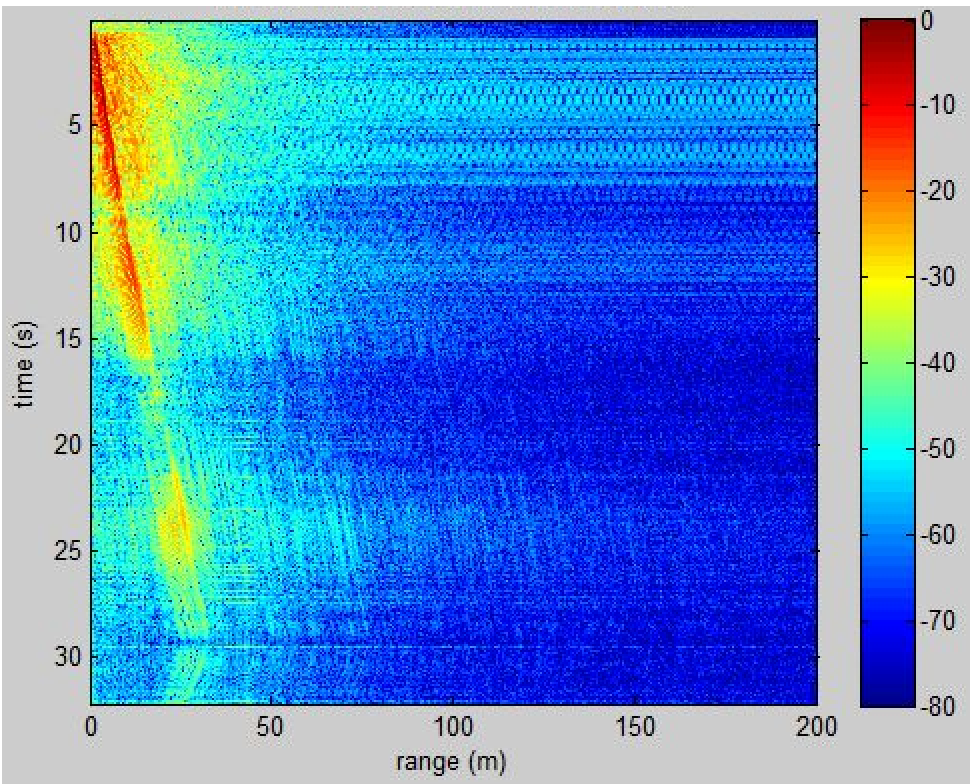


Figure 4: Results of range test

Unfortunately, the system did not function correctly for the Doppler test, so we do not have any data for that.

Discussion

Overall, we had trouble getting our radar to work. At some point, we were able to measure a range of 15 meters; however, the radar system stopped functioning. One possibility for this may be because the transmitted power from the system is too low, thus limiting the range. Our current design has one amplifier in the transmitting stage that draws a lot of power. We had to find a balance between power consumption and a decent amount of power transmitted.

There were many background reflections due to the testing environment. Therefore, another factor may be noise. As the target moves away from the radar system, there is further attenuation of an already weak transmitting signal. Since the signal to noise ratio (SNR) is already low for the transmitting signal, the SNR will be close to zero for the received signal.

For the Doppler test, sensitivity of the system was an important factor. One reason it may not have functioned properly may be because the A/D converter was not sensitive enough. We continued to use the A/D converter from quarter one, which had only 8 bits. Perhaps if we upgraded to one with 16 bits, the sensitivity of the radar system would have been improved enough to pick up the fast oscillations of the moving object in this test.

Possibility of Future Expansion

Future work could include antenna design and fabrication. The team looked into commercially available patch antennas and horn antennas that operate at 2.4 GHz, however, one was never found to fit the requirements that we specified. We wanted an active antenna with a 5% fractional bandwidth (FBW) and a gain of at least 8 dB. Since we were unable to find one with those specifications, we decided to use the same antennas that we used in quarter one. In quarter one, we made antennas from empty coffee cans and tested the insertion loss using the S21 parameter. The insertion loss requirement for the can antennas were to be as close to -10 dB as possible. No changes were made to the antennas in quarter two. If time allowed, we would have liked to design and fabricate a patch antenna array for both transmitting and receiving ends in order to improve radar performance.

Our design was optimized for power outputted in order to maximize the detection range of the radar system for the range test. Two low noise amplifiers (LNA) and one power amplifier were used to boost the output signal on the transmitting end as well as boost the incoming signal on the receiving end. Because of this, the power consumption was not minimized. If we were to redesign our system and PCB, we would try to design to reduce power consumption across the whole system.

Currently, the system utilizes the computer running MATLAB to sample and process the incoming data. For a more compact and standalone system, the Tiva C microprocessor would be ideal in performing the digital signal processing in place of the computer. The Tiva was chosen in light of other microprocessors available (Arduino, Beaglebone, Raspberry Pi, etc.) because of its superior processing power to the Arduino and the Raspberry Pi. In comparison to the Beaglebone, the Tiva is more widely used and has more accessories that can be shared across other platforms. Since the Tiva will be a standalone processor for the radar system, a touchscreen display will also be incorporated to select the test to be performed and to display the final results.

The advantage of using the Tiva would shine here. The screen that we would be using has been used for a similar project using the TI Stellaris. Thus, the transition from the Stellaris will allow the team to concentrate on innovation and optimization within the system design.

Suggestions for Future Classes

- Expand the scope of the class to encourage students emphasizing in digital, analog, and communications to join the senior design, in addition to RF students. This allows for a more diversified team with different specialties to divide the work and learn from one another.
- Have stricter time restraints in order to complete the project within the two quarter timeframe. Have the teams create and update a Gantt chart at the weekly meetings.

Conclusion

The entire EEC134 series aided in our understanding of RF and Microwaves. When our group first started in the Fall, we were introduced to the various instrumentation of spectrum and network analyzers to measure certain parameters of our RF components. By utilizing these measuring devices, we obtained hands-on experience with measuring data for voltage controlled oscillators (VCO), mixers, low noise amplifiers (LNA), and various other RF components. The design implementation of the first quarter forced us to use many applications of electrical engineering: PCB designs were implemented for the modulator and RF amplifier, breadboard wiring was utilized to construct the active low pass filter, data collection was done with MATLAB for range and doppler testing. Our team was able to show our versatility in order to complete all of these tasks. After the completion of a working radar at the end of the first quarter, we were then asked to innovate and improve upon our existing system for the second quarter of senior design.

We brainstormed several ideas for our new radar design by working off of what we learned in the first quarter. We first wanted to maximize portability by eliminating all of the bulk RF components and transitioning them to ICs. In addition, the breadboard circuitry will be miniaturized onto a PCB. Instead of constructing new antennas, we used the same coffee can antennas as last quarter because they were already functional. Although our new radar system did not work as well as our first quarter design, we were able to get some data for range testing.

Overall, our team felt that the second quarter process for senior design was a lot more difficult because the design implementation was more open-ended in terms of creating our own radar. Even though we had more room to explore ways to design a radar system, we were challenged because we did not have a clear-cut guidelines for building an efficient radar other than the first quarter design.

In conclusion, our team found the 134 series to be intellectually stimulating and challenging. We were able to utilize everything we have learned from the electrical engineering department. This senior design gave us a first hand experience of what it would be like to work in a team on an industry level type project.

Acknowledgements

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