

Application of Colpitts Oscillator in High Resolution Radar

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ABSTRACT

The problem of high range resolution radar imaging is around for many years. High range resolution is typically achieved by transmitting wide bandwidth waveforms. The most common type of waveform that has a wide bandwidth is bursts of short pulses. Considering power consumptions, realization of transmitter that emits short pulses is not easy. Consequently, radar system utilizes frequency (FM) or phase modulation (PM) techniques to improve the transmitted waveform bandwidth. In addition to the bandwidth, transmitted waveforms should be noise-like such that it inherits the Low-Probability-of-Intercept (LPI) and electronic-counter-counter-measure (ECCM) capabilities.

Recent study shows that noise like waveforms such as chaos has the desirable features mentioned above compared to the traditional linear FM waveforms. On that end, this project is focused on testing the wideband characteristics of FM waveforms generated using Colpitts chaotic oscillator. It discusses a method of implementing the chaotic bistatic radar using commercial of the shelf (COTS) components. Using the constructed radar we compared and tested the advantages of chaotic FM radar against the benchmark monotone FM waveform. It is found that the spectrum of the chaotic FM waveform is wide and has uniform shape compared to that of a benchmark waveform. We also tested the imaging capabilities of the constructed bistatic radar considering targets that are cylindrical and flat shapes. In particular, generation of chaotic FM waveform is quite simple compared to its counterparts such as linear FM waveforms or barker codes.

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INTRODUCTION

This project presents an effective way of implementing chaotic bistatic radar using commercial of the shelf (COTS) components. The modern radar system needs to transmit a high bandwidth waveform for detecting and classifying the targets such as airplanes, ships etc. The *problem* with current radar systems is that to obtain high bandwidth signals, the modulation techniques requires several additional devices [1]. There has been some discussion of using high power high frequency analog circuits for radar, so analog circuits are relevant [2]. The thought was that if you could generate a broad band radar signal at high power, you could avoid a lot of intermediate steps in the signal chain, making the entire system more efficient. The idea hasn't caught on because digital is so easy- but less efficient.

The *research question* is how to improve the efficiency by removing the intermediate steps of modulating and transmitting. The system we *propose* will take advantage of fast chaotic oscillator that generate a waveform at high power and high frequency and will avoid the intermediate steps. The system used will have four main components: a chaotic oscillator that generates the chaotic waveform, the transmitter antenna to generate a direct chaotic FM signal, the receiver used to receive the transmitted signal, and spectrum analyzer to determine the spectrum of received waveform.

A reference waveform can always be digitally generated with a digital waveform generator. However, it is very expensive to use [3]. In its absence, it may be necessary to generate the analog version of the reference waveform. To the best of our knowledge, it is the first time implementing a chaotic Colpitts Oscillator into a broadband radar system. In addition it is easy to implement and is inexpensive [3]. If it is shown that fast chaotic oscillators can be used as an alternative method to generate high bandwidth signals, then these advantages can be exploited in the applications of high resolution radar imaging.

Typically chaotic oscillators are broadband in nature. Bipolar RF oscillators exhibit a multi-oscillation phenomenon in which parasitic or unwanted oscillations simultaneously exist together with the main oscillation in the steady state [5]. If it is proven that the multi-oscillation phenomenon is chaotic in nature, then it can be exploited for generating broadband high power signals. Thus, there is no need for extra components that could potentially decrease the efficiency of the system by adding noise.

BACKGROUND ON CHAOS

In classical treaties, chaos is considered as disorder. With the advent of computers, it was discovered that chaos can be used for wide range of applications such as secret communications, radar imaging etc [6]. Chaos can be electronically generated using simple components such as resistors, capacitors, operational amplifiers (op-amps) and analog multipliers [7]. The voltage obtained from one of the op-amps leads to chaotic waveform. A chaotic waveform has Chaos is nonlinear and unpredictable behavior. In addition these waveforms are aperiodic, bounded, noise like yet deterministic. The most notable feature of chaos is its dependence of initial condition. A small change in initial condition can form an output that is completely different from its original.

A chaotic attractor is a function or set of values that a system tends towards, even if the initial conditions vary. Once the system approaches the expected value of the function, even if the initial conditions are change or there is a disturbance in the system, the attractor values will not be greatly affected.

COLPITTS CHAOTIC OSCILLATOR

In a paper published in 1994, Michael Peter Kennedy proved that the Colpitts oscillator exhibits chaos [5]. The chaos generated was not a parasitic effect but due to presence of a nonlinear element. The Colpitts oscillator shown in Fig 1 consists of a single bipolar junction transmitter (BJT), biased in the active region, a feedback network of an inductor in series with a resistor, a capacitive divider over the BJT, and a V_{EE} and V_{CC} of $\pm 5V$ [4]. Kennedy modeled the Colpitts oscillator using a set of nonlinear differential equations, by assuming that the BJT within the oscillator acts purely as a resistive element. Based on this assumption, Kennedy was able to describe the circuit using the three autonomous nonlinear differential equations as shown in (1).

$$\begin{aligned}
 C_1 \frac{V_{CE}}{dt} &= I_L - I_C \\
 C_2 \frac{V_{BE}}{dt} &= -\frac{V_{EE} + V_{BE}}{R_{EE}} - I_L - I_B \\
 L \frac{I_L}{dt} &= V_{CC} - V_{CE} + V_{BE} - I_L R_L
 \end{aligned} \tag{1}$$

From experimental observations, Kennedy was able to model the transistors behavior in to two operated region using a two-segment piecewise-linear voltage-controlled resistor N_R and a linear current controlled current source. They are forward active and cutoff as given in (2),

$$I_B = \begin{cases} 0, & \text{if } V_{BE} \leq V_{TH} \\ \frac{V_{BE} - V_{TH}}{R_{ON}}, & \text{if } V_{BE} > V_{TH} \end{cases}$$

$$I_C = \beta_f I_B \quad (2)$$

where R_{ON} is the small signal ON-resistance of the BJT, and β_f is the forward current gain of the device.

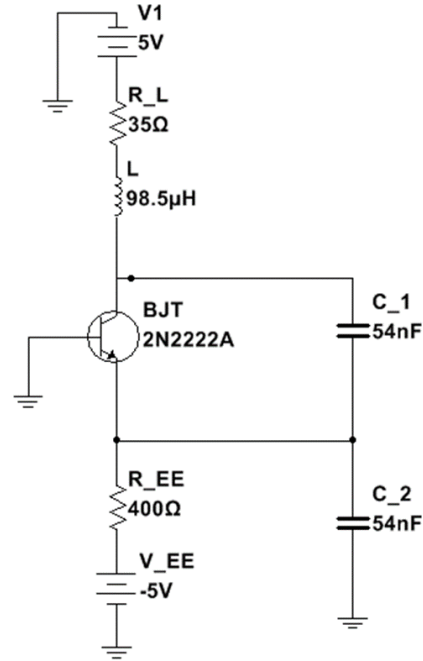


Figure 1. Circuit diagram of the Colpitts Oscillator

Using the above model, we simulated chaotic oscillator on Matlab[®] 2017. The outputs V_{CE} and V_{BE} are shown in Fig 2a. The red color plot indicates the waveform with one initial condition and the black color waveform with a different initial condition that was changed infinitesimally small. Even with change in the initial conditions, as shown in Fig 2b, the shape of the attractor plotted using V_{CE} and V_{BE} did not change. As mentioned earlier, a chaotic attractor is

a function of values that a system tends to fall in an orbit. Consequently, we can argue that the implemented circuit exhibits chaotic behavior.

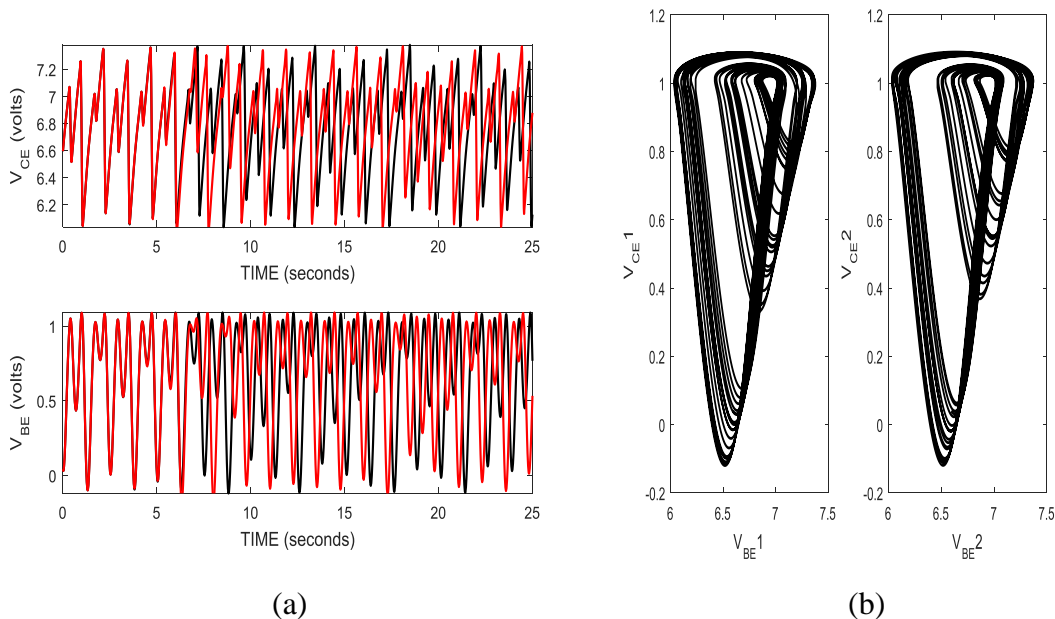


Figure 2. (a) The plot of the V_{CE} vs Time and V_{BE} vs Time of two different initial conditions (red is initial condition 1, black is initial condition 2) in a system using a chaotic oscillator. (b) The plot of V_{BE} vs V_{CE} for each of the initial conditions, with the left graph corresponding to initial condition 1, and the right graph corresponding to initial condition 2.

DESIGN REQUIREMENTS

The purpose of the project is to use to generate a broadband chaotic signal, transmit the broadband chaotic signal, receive the signal, and analyze the characteristics of received FM waveform. The system described is depicted in Fig 3. There are already systems that perform the similar functions but they are very expensive. The system proposed must use commercial off the shelf components to be cost effective and easy to implement. The Colpitts oscillator is able to generate a chaotic signal using resistors, a BJT transistor, capacitors, and an inductor. These components are easily accessible and are affordable. The desired cost of the new system is less than \$30.

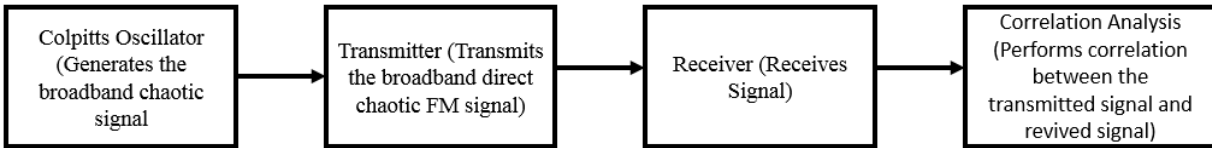


Figure 3. Block diagram of the proposed system

The current radar systems also use additional components such as function generators, amplifiers and modulators there by taking additional space and adding noise to overall system. The reduction in the number of components needed in the system decreases the overall space that the system takes up, reduces the cost of the system, and reduces the amount of noise within the system.

On other hand, the Colpitts oscillator is able to generate waveforms greater than 4 MHz bandwidth. The transmitter and receiver must be able to handle such high frequencies. The desired overall noise factor between the transmitter and receiver should be less than 12Db to avoid false alarms. The transmitter and receiver must also be able to communicate, prior to the testing. While we want to observe the capacity of the system in radar applications, we must also remain within the legal range of frequencies. We cannot engage in tests that use frequencies that could potentially interfere with the government, local authority, or air traffic because of the potential danger.

DESIGN ALTERNATIVES

As far as we know, implementing a Colpitts oscillator into a system to generate high power high frequency signals has not been attempted before. To ensure the validity of our findings, we will use the same component values that were used in Kennedy's research. This will allow us to compare our results of the actual implementation to the expected results generated through simulations.

PRELIMINARY PROPOSED DESIGN

The proposed design of the system consists of a Colpitts oscillator that generates a high power high frequency signal, a 10 GHz transmitter that transmits the chaotic signal, a 10 GHz receiver that receives the signal, and spectrum analyzer to observe the spectrum of received waveform.

The Colpitts oscillator utilized the low cost and easy access to commercial of the shelf components. The overall system costs less than \$15 to make, as seen in table 1, and it is well beneath the desired budget of \$30.

Component	Quantity	Cost (per piece)
$C_1 = 56.3\text{nF}$	2	\$0.59
$R_{EE} = 390\Omega$	1	\$0.02
$R_L = 36\Omega$	1	\$0.01
$L = 90\mu\text{H}$	1	\$9.92
BJT 2N2222	1	\$3.00

Total Cost	\$14.13
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Table 1. The price breakdown of the components

The Colpitts oscillator was a clear choice for the transmitter because it satisfies all the requirements. However, it was not certain if the Colpitts was a viable option for the transmitter because all the work we had seen thus far was theoretical. To test the practicality of using the Colpitts oscillator we constructed (as shown in Fig. 1) and observe it to determine if it actually demonstrated the chaotic behaviors that we suspected.

The values of the components mentioned in M. P. Kennedy's paper were values that we did not have on hand. We chose to prototype the Colpitts oscillator using the closest components we could find to the given values. The original circuit described in Kennedy's paper called for $C_1 = C_2 = 54\text{nF}$, $R_L = 35\Omega$, $R_{EE} = 400\Omega$, $L = 98.5\mu\text{H}$, a $V_{CC} = +5\text{V}$, a $V_{EE} = -5\text{V}$, and a BJT type 2N2222 [4]. The actual component values tested were $C_1 = C_2 = 56\text{nF}$, $R_L = 36\Omega$, $R_{EE} = 490\Omega$, $L = 98.5\mu\text{H}$, a $V_{CC} = +5\text{V}$, a $V_{EE} = -5\text{V}$, and a BJT type 2N2222. Once constructed, we observed the base emitter voltage and collector emitter voltage using an oscilloscope. The captured waveforms of V_{BE} and V_{CE} of the prototype, illustrated in Fig. 4 were closer to the theoretical results. To determine if the Colpitts oscillator was an attractor V_{BE} vs V_{CE} was plotted as shown in Fig. 5. The resulting plot confirmed the intuition of Kennedy. During the steady state, the plot of V_{BE} vs V_{CE} tends toward a function. This validates and permits the use of a Colpitts oscillator as a transmitter for our system.

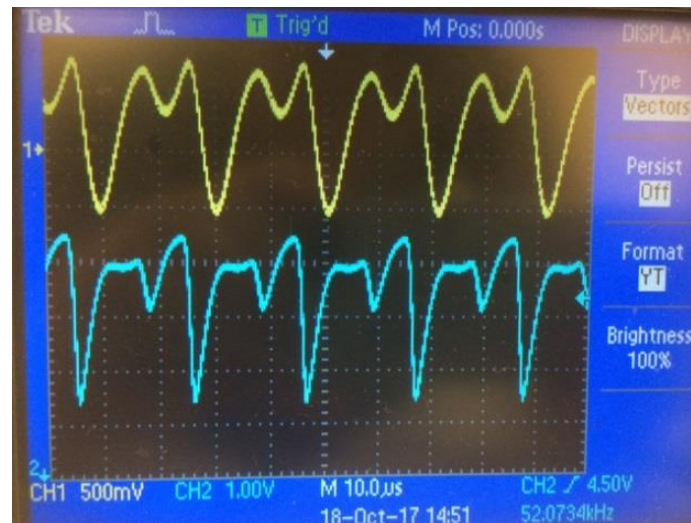


Figure 4. V_{BE} vs Time (Yellow) and V_{CE} vs Time (Blue)

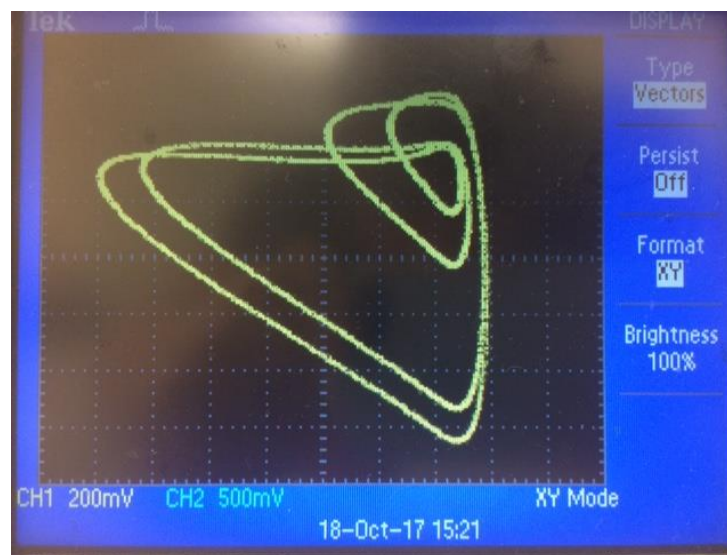


Figure 5. V_{BE} vs V_{BE} for the Colpitts oscillator prototype

The transmitter and receiver need to handle the high power high frequency signals generated by the Colpitts oscillator. The selection of a 10 GHz transmitter and receiver will be more than capable of handling the generated waveforms with 4 MHz bandwidth. The transmitter and receiver are ideally the same piece of equipment. The transmitter converts electrical signals to radio waves and the receiver converts radio waves into electrical signals.

The 10 GHz transmitter and receiver use a Gunnplexer diode to eliminate the necessity of microwave construction techniques or an extensive test equipment setup [8]. The Gunnplexer is a

complete transceiver consisting of a Gunn source, a circulator, and a Schottky mixer diode. The antenna and Gunnplexer are usually physically independent of the operating panel, so an intermediate frequency amplifier, enhances the constant frequency of a modulated signal, is attached to the Schottky diode to get a desirable overall noise factor, less than 12 dB [8].

In the next stage of this paper, we will construct the complete system with the exact components values specified in the simulations.

FINAL DESIGN AND IMPLEMENTATION

System Overview:

To confirm that the constructed bistatic radar works, we considered a monotone FM signal that acts a benchmark waveform. It consisted of a function generator, a biasing op-amp, a transmitter, a receiver, a spectrum analyzer, and a 52 MHz FM receiver. The setup was arranged as shown in Fig. 6. The purpose of this system was to verify if the transmitter and receiver were communicating properly by observing if the demodulated received signal was the same as the original transmitted signal. A block diagram of the benchmark system can be seen below.

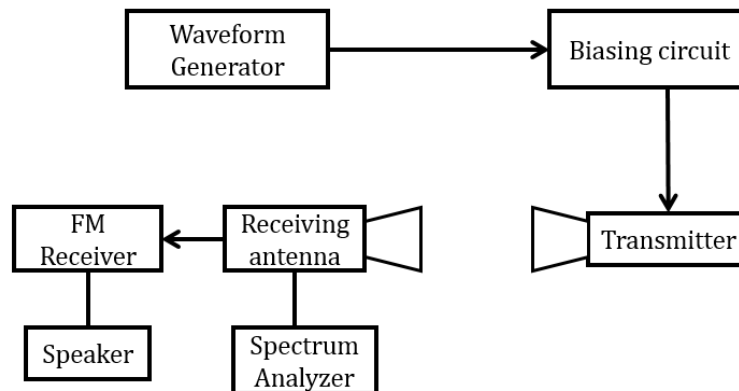


Figure 6. Block diagram of benchmark system

Waveform Generator:

For the benchmark system, we generated a sinusoidal waveform using a function generator with a frequency of 100 KHz and various amplitudes ranging from 100 mV_{pp} to 1 V_{pp} . This waveform is used as input to the varactor diode. However, the varactor diode accepts input voltage that is in the range of 1V to 20V. This demands to implement a new biased circuit that changes the mean voltage of input signal such that the minimum voltage is above 1 V and maximum is below 20 V.

Biased Op-Amp Circuit:

The 10 GHz transceivers that were used in both the benchmark and final systems controls the modulated waveform frequency via a varactor diode. By changing the voltage input to the varactor diode, it is possible to tune the FM of the inputted signal. If the input voltage is not in the limits as mentioned above, there is a risk of damage to the transceiver. Thus a biasing op-amp circuit was created to protect the varactor diode by ensuring that the input waveforms voltage stays within the range of 1V to 20V [9]. The schematic of the biased op-amp system can be seen below in Fig 7.

The resistor values were determined using the characteristics of ideal op-amps. We found the equation that modeled the output of the biasing circuit to be

$$V_{out} = (V_{in2}R_5 - V_{in1}R_6)(R_2 + R_1)/(R_2R_5 - R_2R_6) \quad (3)$$

where V_{in1} is the output voltage of the voltage divider and V_{in2} is the input waveform.

An LM358 op-amp was used to reduce the number of elements needed in the entire system. The LM358 can be powered by the same 9V supply and ground used to power the transceivers. In addition, a voltage divider was used at the positive input pin to eliminate the need for an additional power supply of 5V.

The biasing circuit also utilized a potentiometer to allow quick tuning of the system. As the amplitude of the input waveforms to the varactor diode increase the biasing voltage must also be increased. This is required to increase the robustness of the system because the single circuit can be used for waveforms with various amplitudes. The input voltage to the varactor controls the modulating frequency, so the biasing voltage is used to adjust the frequency of the transmitter. The difference in modulating frequency between the transmitter and receiver is the frequency at which the FM receiver needs to be tuned to in order to demodulate the received signal. Thus the biasing circuit can be used to tune the frequency of the transmitter that yields a frequency difference within the operating range of the FM receiver. The final soldered version of the biasing circuit can be seen in Fig 8.

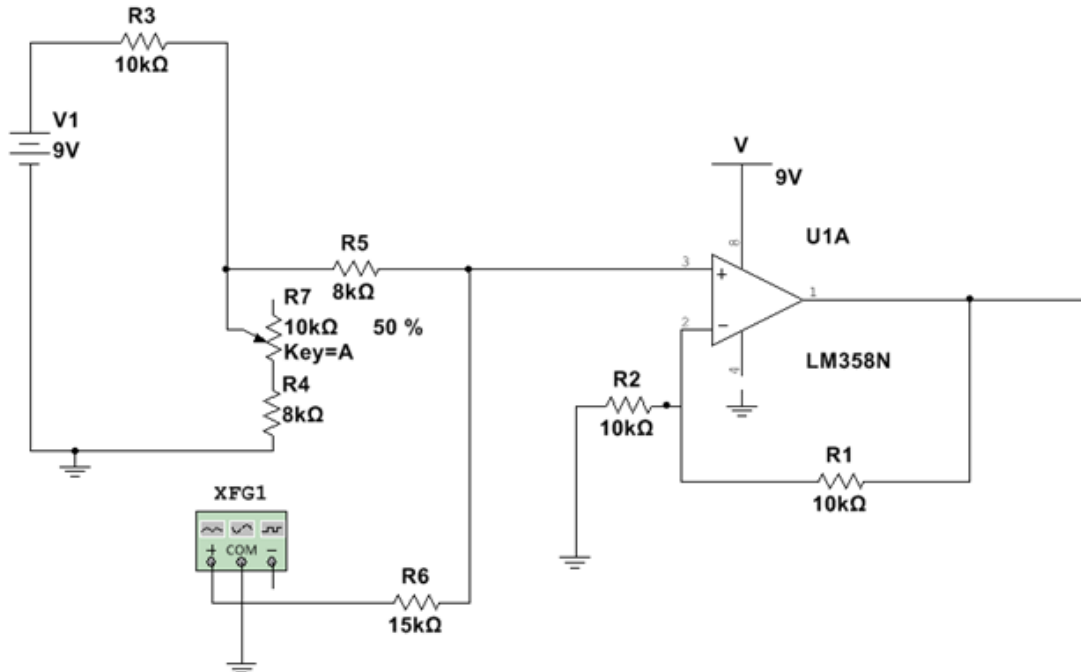


Figure 7. Schematic of adjustable biasing circuit using a 10k potentiometer

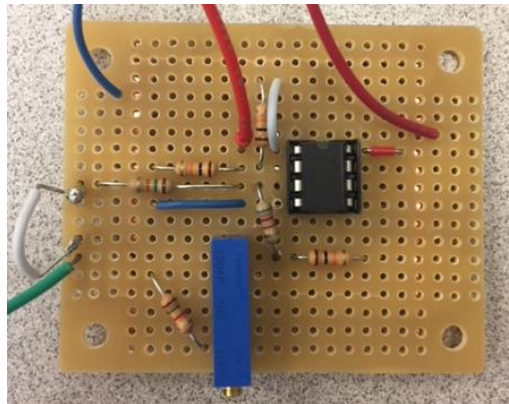


Figure 8. Final soldered version of adjustable biasing op-amp circuit

The output of the biasing circuit now acts as the input to the transmitter. The transmitted waveform bandwidth now varies as function of the input voltage amplitude. The spectrum of the receiver output is observed on the spectrum analyzer. Figs. 9 to 11 illustrate the spectral behavior of the monotone FM transmitted/received waveforms. From Fig. 9, for the input voltage of 100 mV_{pp} the spectrum bandwidth is around 0.5 MHz. Similarly, from Fig. 10 for the input voltage of 500 mV_{pp} the spectrum bandwidth is around 2 MHz. Lastly, from Fig. 11 for the input voltage of 2 V_{pp} the spectrum bandwidth is around 7 MHz.

In all the cases, it can be observed that an increase in amplitude of the inputs results in an increase of the bandwidth of the frequency spectrum. Signals transmitted with larger bandwidths have higher resolution. However, as the amplitude of the input sinusoid increases, the amplitude distortions in the spectrum also increase. These distortions can create unwanted spikes when correlation is performed. These spikes can create ambiguities while obtaining target imagery, making it difficult to correctly determine the location of a target.

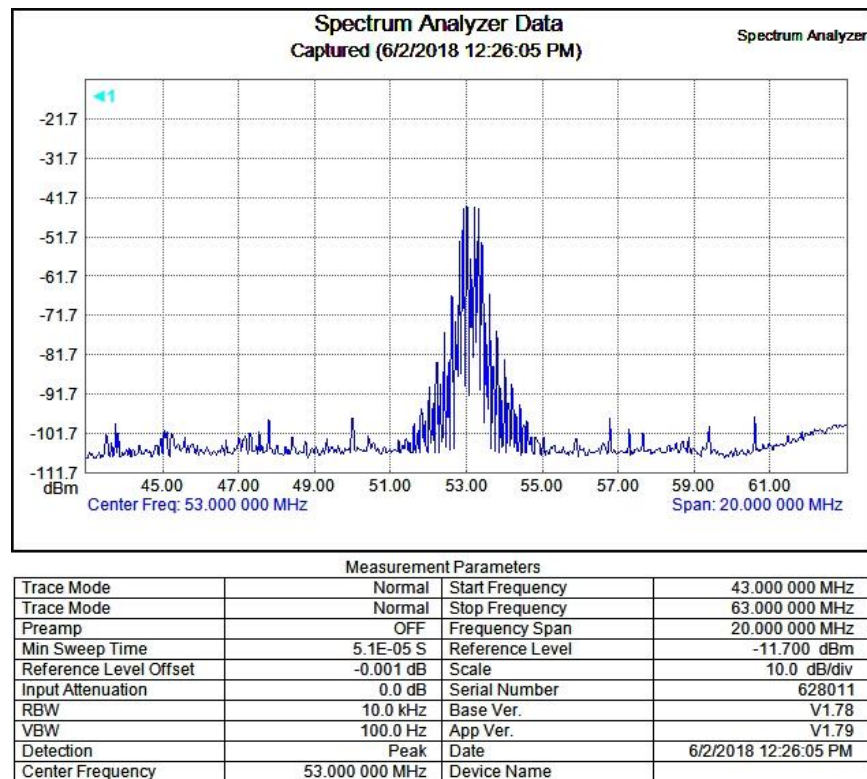


Figure 9. Spectrum of FM with modulating signal of 100mV_{pp} sine wave and bandwidth of approximately .5 MHz

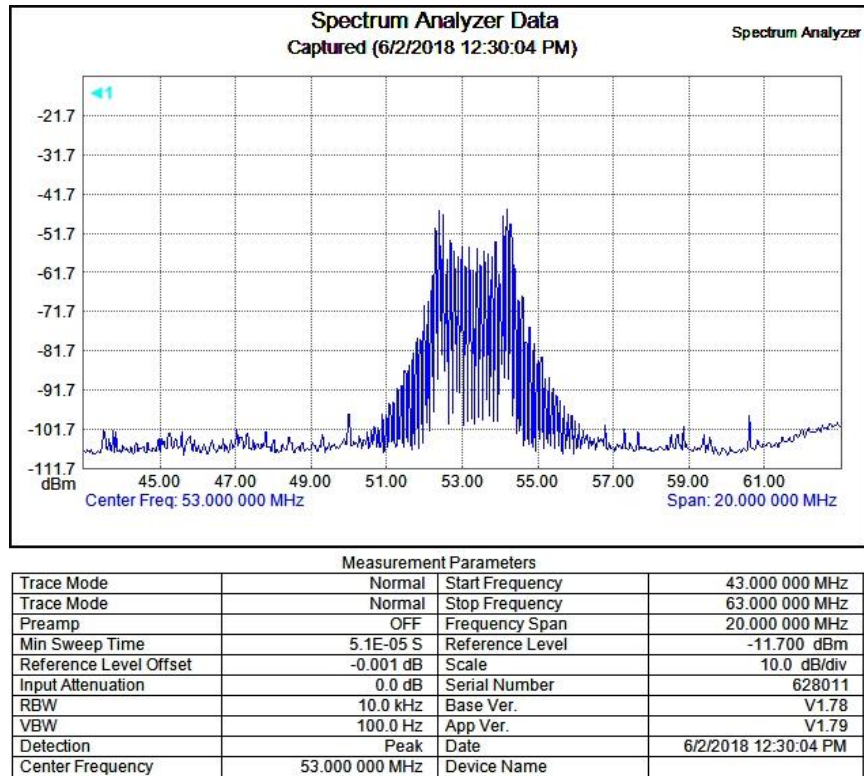


Figure 10. Spectrum of FM with modulating signal of 500mV_{pp} sine wave and bandwidth of approximately 2 MHz

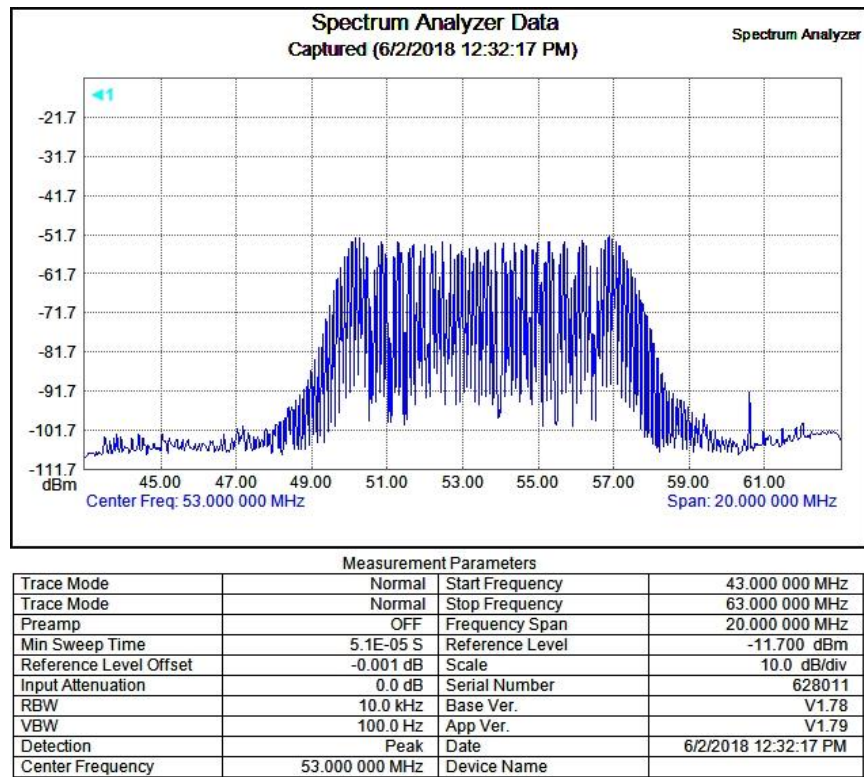


Figure 11. Spectrum of FM with modulating signal of 2V_{pp} sine wave and bandwidth of approximately 7 MHz



Figure 12. 52 kHz FM Receiver.

Using a coaxial cable, it was possible to connect the received FM modulated waveform at the receiver to the FM receiver. By tuning the frequency difference between the transmitter and receiver to about 52 kHz the FM receiver depicted in Fig. 12 was used to demodulate the signal received by the transmitter.

By connecting the oscilloscope probe to the audio port of the FM receiver and ground, it was possible to observe the demodulated signal. Shown in Fig 13, the demodulated waveform of the received signal (blue waveform) is a sinusoid with slightly reduced amplitude, added noise, and a phase shift. The noise and reduced amplitude are most likely due to the biasing circuits and the FM receiver. The phase shift is expected because it takes time for the waveform to travel through the air from the transmitter to the receiver.

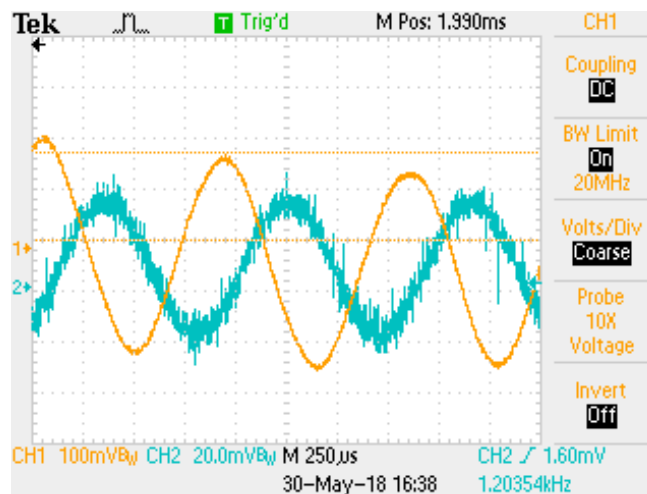


Fig 13. Input $1V_{pp}$ sinewave using function generator (orange waveform) vs demodulated waveform of received signal (blue waveform).

Chaotic Oscillator:

The chaotic oscillator used to generate the chaotic waveform to be transmitted follows the same design as shown in Fig 2. The chaotic waveform generated by the Colpitts oscillator, V_{CE} , has an amplitude of around $2V_{pp}$. The final soldered circuit of the Colpitts oscillator can be seen in Fig. 14.

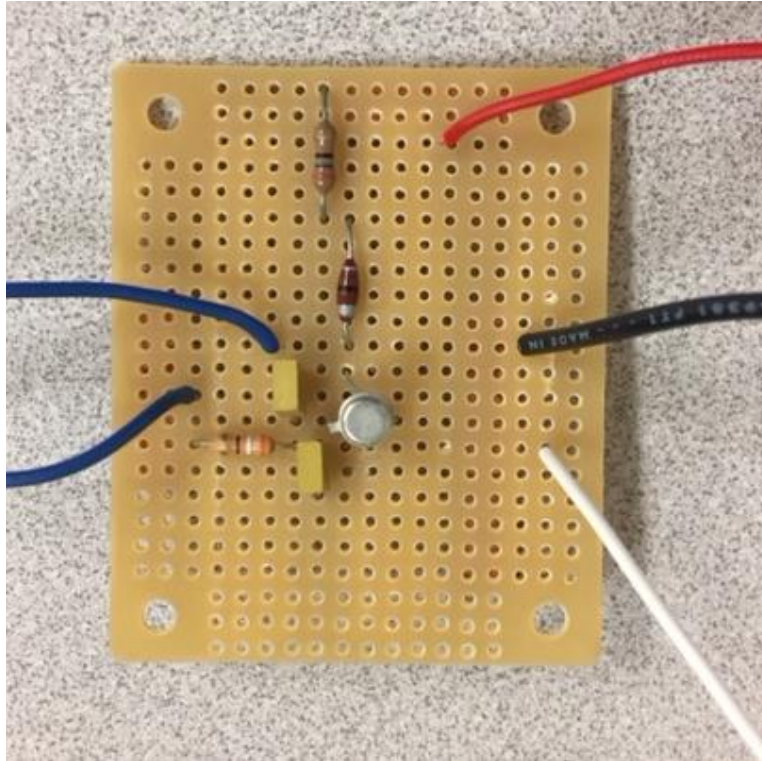


Figure 14. Soldered version of Colpitts Oscillator

High range resolution, the ability to resolve two closely placed targets in range, is achieved by transmitting wide bandwidth waveforms. The relationship between range resolution and bandwidth is given as $\Delta R = \frac{c}{2B}$, where $c = 3 \times 10^8$ m/s, the speed of light, and B = bandwidth of the transmitted waveform measured in Hertz. Thus by increasing the bandwidth of a signal it is possible to decrease ΔR , thus increasing the resolution of the system. One way bandwidth can be increased is by increasing the amplitude of the message signal.

In order to adjust the amplitude of the chaotic waveform, a simple inverting op-amp circuit was used. The schematic of the circuit can be seen below in Fig 15. The op-amp chosen was a LM7410, powered by $\pm 5V$, with a gain of $\frac{R_2}{R_1}$, where $R_2=100\Omega$ and $R_1= 1k\Omega$ potentiometer.

Since we wanted to test the system with message signals of various amplitudes, it was advantageous to use a potentiometer as a variable resistor to adjust the amplitude of the message signal quickly, instead of constantly changing resistors. Using the $1\text{k}\Omega$ potentiometer allowed us to get a wide range of gains starting at $\frac{1}{10}$.

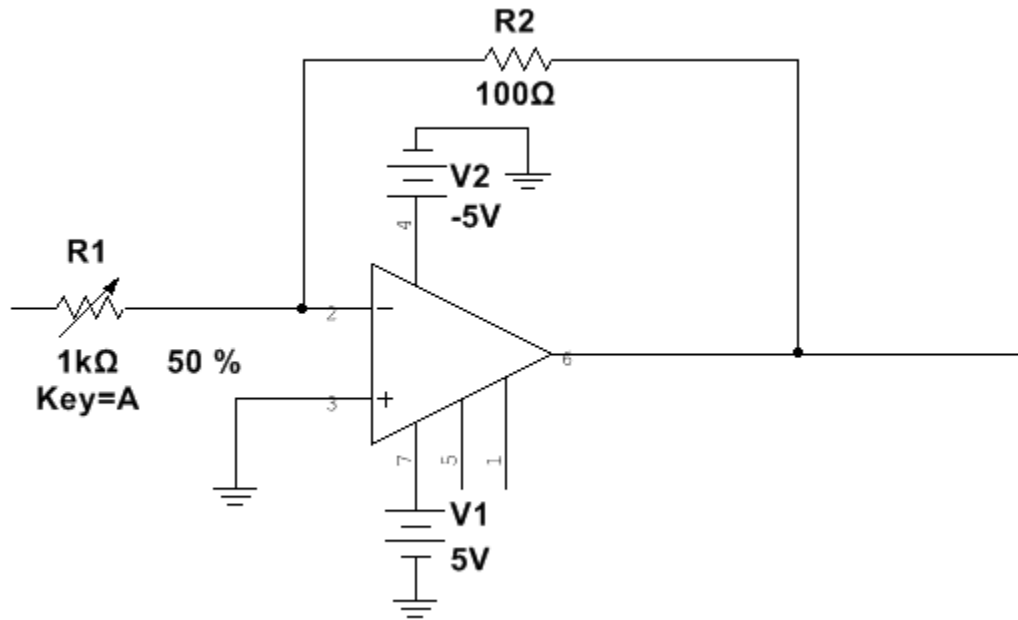


Figure 15. Schematic of Inverting Op-Amp circuit with potentiometer used as variable resistor to adjust gain of circuit.

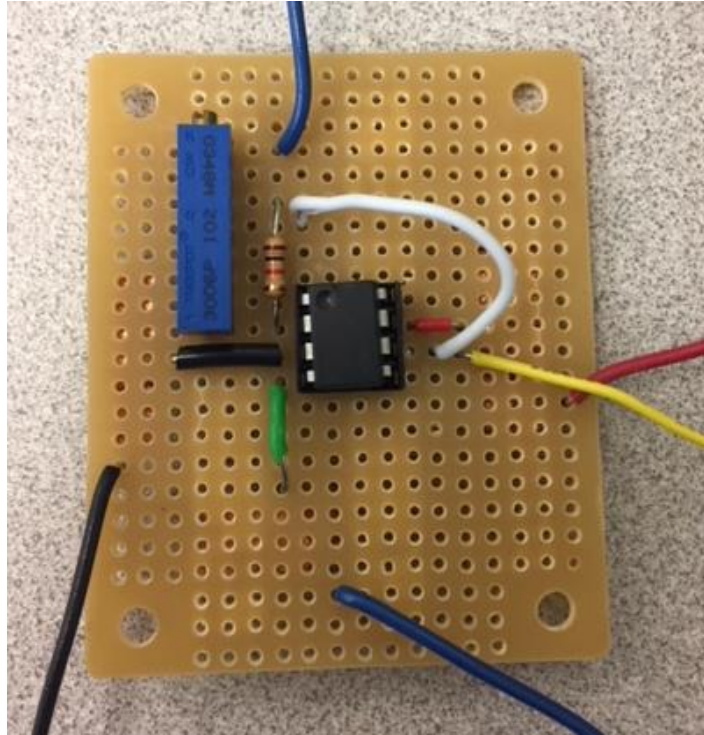


Figure 16. Final soldered version of Inverting Op-Amp circuit with adjustable gain

Transceivers:

The transmitter and receiver implemented into the system were both 10 GHz transceivers, powered by 9V. As previously mentioned, the transceivers utilize a varactor diode to adjust the modulating frequency. The frequency of the transmitter is adjusted using the biasing op-amp circuit, while the receiver frequency is adjusted using an external DC power supply. The external power supply allowed us to vary the voltage input to the varactor diode from 1V to 20V. The biasing circuit maximum voltage was limited by the LM358 op-amp because the op-amp could only output voltages up to its power supply of 9V. Therefore, the frequency range of the receiver was much larger than the frequency range of the transmitter and could be adjusted easier.

In order to stabilize and secure the transmitter and receiver two identical stands were built. Each stand was built using a two 2in. by 4in. pieces of wood. The length of the base was the 12in. and the length of the arm was 16in. The arm was placed directly on top of the base at a 90° angle and screwed into place. At $\frac{1}{2}$ in. from the top of the arm, a 1.5in by 1.75in rectangle was carved out, so that the rectangular shape of the transceivers could slide snugly into place. An

$\frac{1}{4}$ in. wide slit was made from the top of the arm to the center of the rectangular cut out to create an opening that allowed wires to pass through the opening. The completed stand with the transceiver in place can be seen in Fig 18.

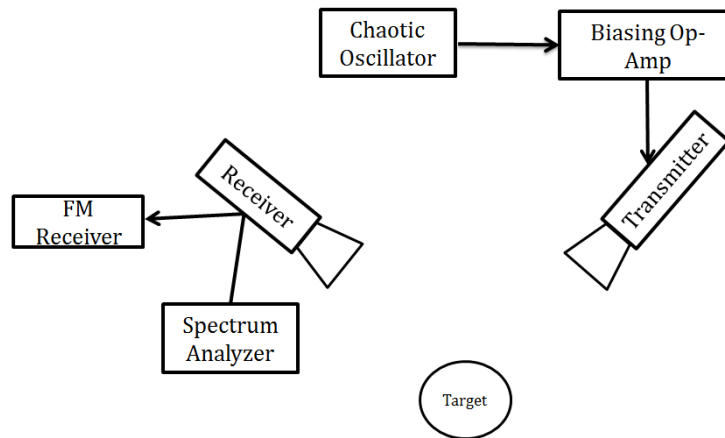


Figure 17. Block diagram of final system using a chaotic oscillator to generate message signal



Figure 18. Image of functional radar final system and test setup

PERFORMANCE ESTIMATES AND RESULTS

The chaotic radar system was functional, but it was extremely sensitive. Ideally, the biasing op-amp should have been able to output voltages from 0V to 9V without any clipping. However, during our testing we observed that clipping was occurring at around 7.81V. This clipping was due to the LM-358N op-amp single 9V power supply properties. This lowered the frequency range of the transmitter because it reduced the range of voltages that could be input to the varactor diode. In addition, the maximum amplitude of input signals to the varactor was lowered.

Originally, we expected the frequency difference between the transmitter and receiver to be in the range of 52 MHz, based on the testing of the bench mark system. After testing, we observed that the maximum frequency difference we could obtain for the chaotic radar system was around 32 MHz. In order to successfully demodulate the received signal we needed a frequency difference of around 52 MHz. By redesigning the biasing op-amp circuit to output a larger range of voltages, it would be possible to increase the frequency difference to 52 MHz.

Using the same placement of transmitter and receiver as the benchmark system, shown in Fig. 6, we captured frequency spectrum of the receiver output of the chaotic radar system, as shown in Figs. 19 to 21. In contrast to the frequency spectrum of the benchmark system, the spectrum is relatively flat. This feature is useful because, like noise, the signal has energy content at every frequency. To outsiders our transmitted signal looks similar to noise.

From Fig. 19, for the input voltage of 360 mV_{pp} the spectrum bandwidth is around 2 MHz. From Fig. 20 for the input voltage of 620 mV_{pp} the spectrum bandwidth is around 3 MHz. Finally, from Fig. 11 for the input voltage of 1 V_{pp} the spectrum bandwidth is around 5 MHz. Similarly to the benchmark system, an increase in amplitude of the input voltage results in an increase in the bandwidth of the spectrum. The difference here is that the increase in input voltage did not result in severe amplitude distortion. However, when comparing the chaotic waveform spectrum to the sine wave spectrum, it can be seen that the bandwidth of the chaotic waveform is larger for any given amplitude.

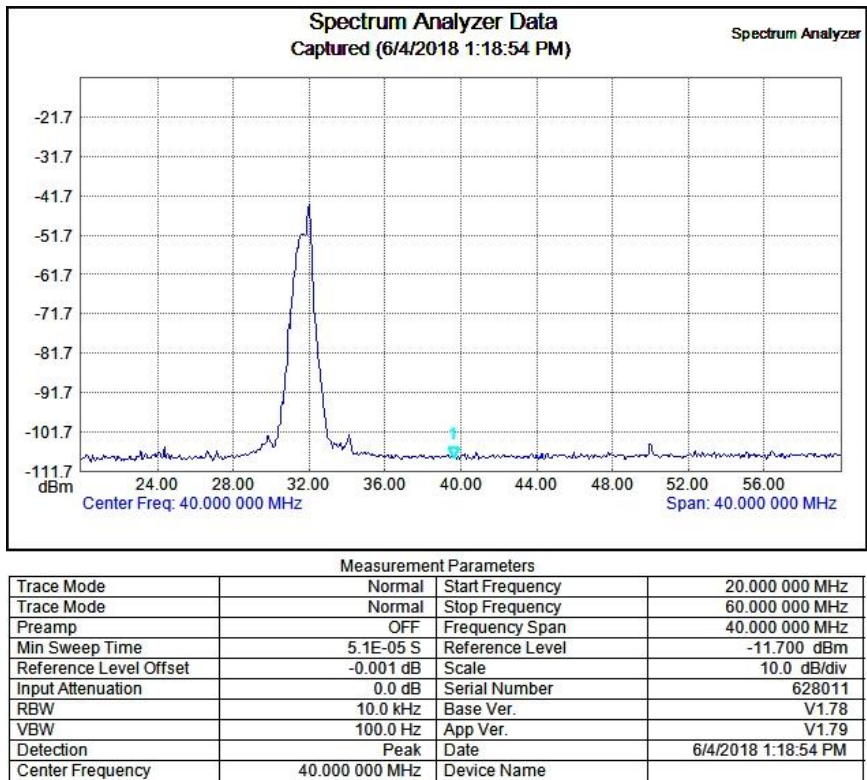


Figure 19. Spectrum of FM with modulating signal of 360mV_{pp} chaotic waveform (V_{CE})

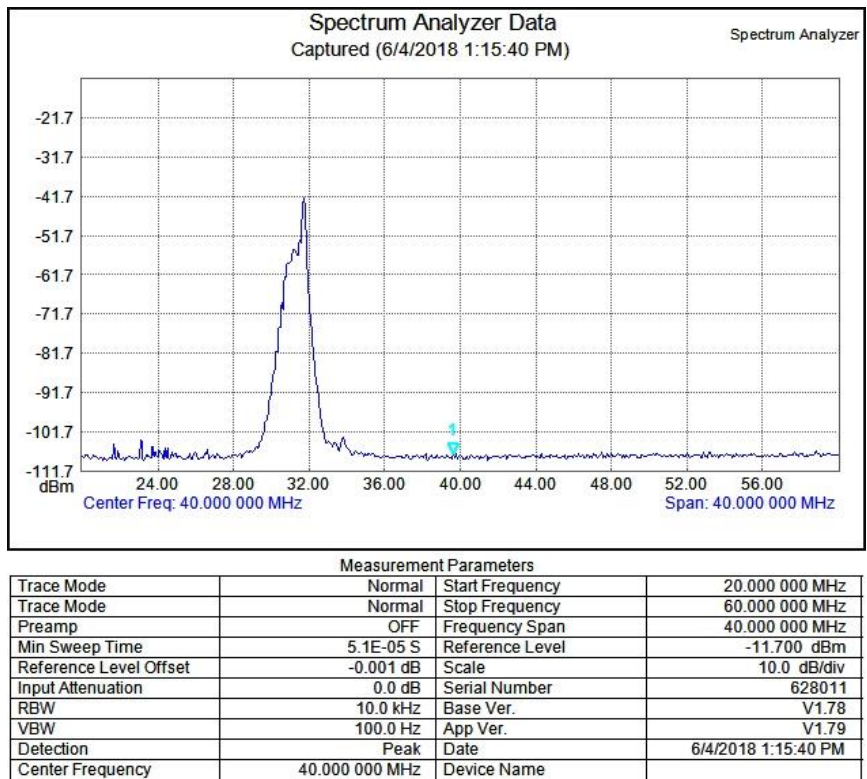


Figure 20. Spectrum of FM with modulating signal of 620mV_{pp} chaotic waveform (V_{CE})

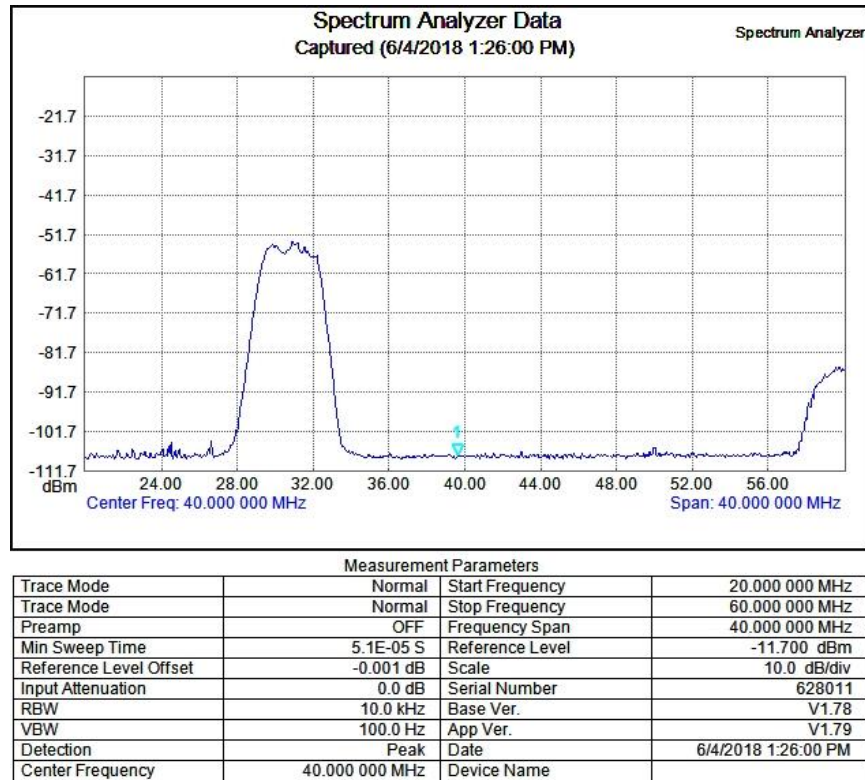


Figure 21. Spectrum of FM with modulating signal of $1V_{pp}$ chaotic waveform (V_{CE})

The system used to test the imaging capabilities of the chaotic radar system can be seen in Fig 17. The transmitter and receiver were both rotated -45° and a target was placed at the bisection. The imaging capabilities of the system were tested using two targets with different geometry and observing the spectrum at the output of the receiver.

Shown in Fig. 22 is the captured spectrum of the system in the absence of a target. The small peak with a bandwidth of 1 MHz centered at 30 MHz indicates that the transmitter and receiver are communicating. Fig 23. shows the frequency spectrum when a cylindrical target is placed at the bisection of the transmitter and receiver. The bandwidth of the received signal increases to 4 MHz, indicating that a target has been detected. The increase in bandwidth is a result of the increased number of reflections received at the receiver. Fig. 24 depicts the spectrum when a flat target is present. Similarly, the bandwidth of the spectrum increased to just over 4 MHz, and there was also an increase in amplitude of the spectrum, indicating that a target detected.

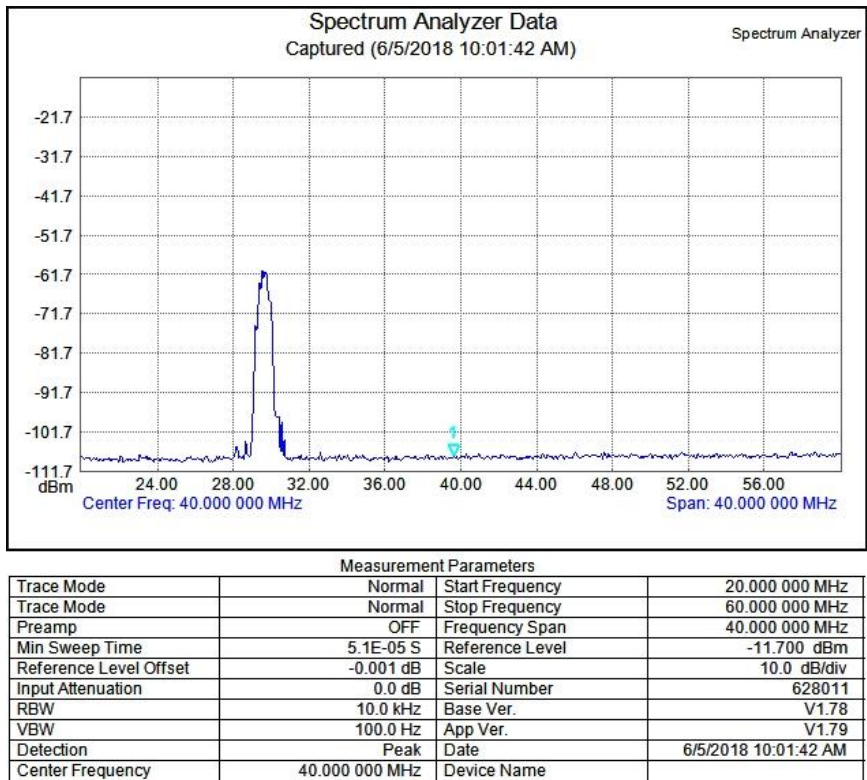


Figure 22. Radar imaging in absence of target

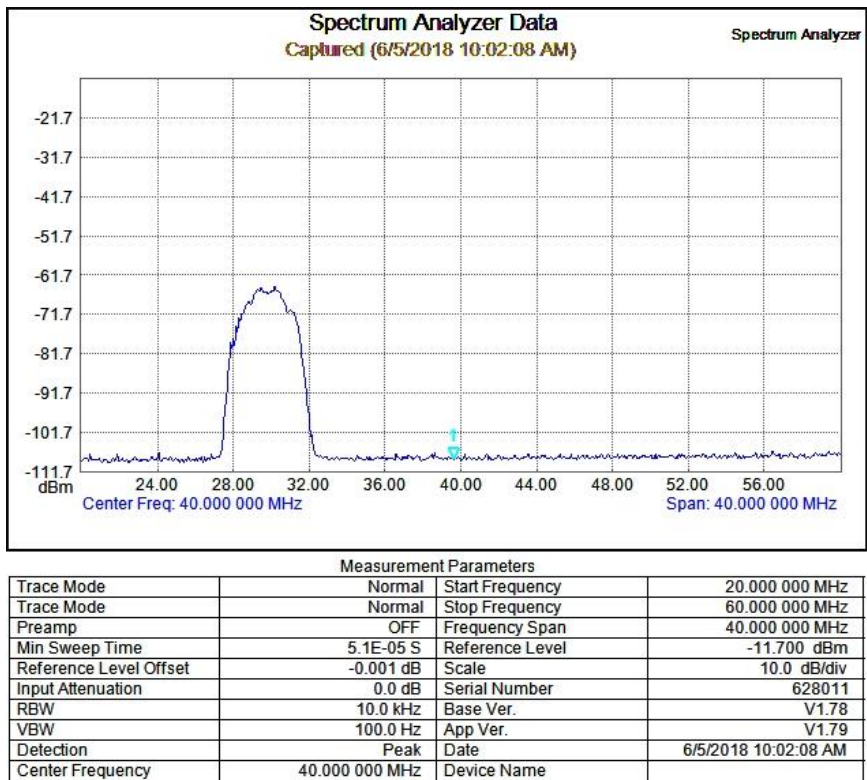


Figure 23. Radar imaging in presence of cylindrical target

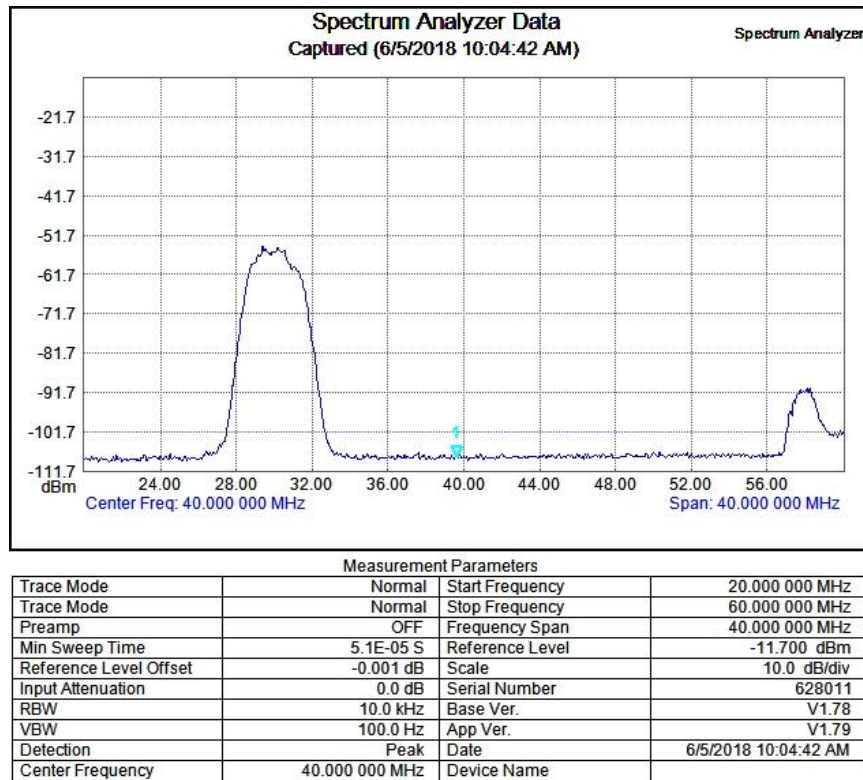


Figure 24. Radar imaging in presence of flat target

PRODUCTION SCHEDULE

The schedule set out for the term was spread out and realistic. The main goal of the project for the first 5 weeks was to construct and test a radar system using a Hewlet Packard 33120A function generator to generate a waveform to be frequency modulated, transmitted, received, and demodulated. Once this was achieved, we then tried implementing a chaotic radar system by replacing the function generator with the chaotic Colpitts oscillator. A timeline of the tasks and week they were completed can be seen below in Table 2.

Spring 2018	Task
Week 1	-Build voltage regulators as power sources transceivers
Week 2	-Verify that the transmitter and receiver are communicating
Week 3	-Design biasing op-amp circuit
Week 4	-Simulate and prototype biasing op-amp circuit
Week 5	-Construct benchmark system

Week 6	-Test benchmark system and observe its frequency spectrum
Week 7	-Demodulate received signal using 52 MHz FM receiver
Week 8	-Complete soldered version of Colpitts oscillator -Design and build soldered version of inverting op-amp
Week 9	-Construct and test chaotic radar system -Construct stands to hold transceivers
Week 10	-Continue testing chaotic radar system and capture frequency spectrum images for no target, cylindrical target, and flat target. -Create presentation and poster
Finals Week	-Finish ECE-499 design report

Table 2. Project timeline for Spring 2018

Many of the tasks that required testing were difficult to complete on time because the amount of time needed to achieve the desired result was unpredictable. Some tests took several minutes to complete, and others took several hours because we were unable to determine the source of the problem.

Overall, the schedule for the design, simulation, and construction of the benchmark and final system was extremely efficient and organized. The sections of the schedule that could have been improved were the creation of the presentation and poster, and the writing of the final design report. Putting these tasks off to the end of the term proved to be extremely stressful because of the responsibilities of other final papers and exams.

COST ANALYSIS

The need for a biasing circuit and an inverting op-amp circuit slightly increased the price of the overall system. A breakdown of the cost of the additional components needed is shown below in Table 3.

Component	Quantity	Cost
100Ω Resistor	1	\$0.01

8k Ω Resistor	2	\$0.32
10k Ω Resistor	4	\$0.64
15k Ω Resistor	1	\$0.17
1k Ω Potentiometer	1	\$2.75
10k Ω Potentiometer	1	\$2.90
LM358N	1	\$0.57
Total Cost		\$7.63

Table 3. The price breakdown of the additional components needed to create the biasing op-amp circuit and inverting op-amp circuit.

The additional cost of \$7.63 added to the original cost of the Colpitts oscillator, \$14.13, yields a total cost of \$21.79. The design requirements specified that the cost of the entire system should be less than \$30, and even with the cost of the additional components, this design specification is still met. The cost of both transceivers is approximately \$300, and the cost of the materials to build the transceiver stands was \$32.28. However, these costs are not factored into the total cost of the system because the transceivers and stands are necessary for any high resolution radar system. We are only interested in the cost of the circuits and devices needed to generate the wide bandwidth waveform that will be transmitted.

USER'S MANUAL

It is assumed that the user has a basic knowledge of circuitry, as well as minor experience with oscilloscopes, spectrum analyzers and DC voltage supplies. This section provides instruction on how to properly operate and maintain the chaotic radar system in the steps that follow.

Setup:

- 1) Start by checking to make sure that all of the circuits are not hooked up to each other yet.
- 2) Begin by hooking the red, blue and black wires of the chaotic Colpitts Oscillator and inverting op-amp to +5V, -5V, and ground respectively.
- 3) The power and ground wires for both the transceivers and the biasing op-amp circuit should be soldered to the 9V voltage regulator power source.

- 4) The transmitter and receiver should be several feet apart and facing each other. Rotate both the transmitter and receiver -45° from each other, as shown in Fig. 17.
- 5) Using an external power supply attach the red alligator clip to the varactor diode of the receiver, and attach the black alligator clip to ground. Remember not to turn on any of the power supplies yet.

Operation:

- 1) First, turn on the power supply that is connected to the inverting op-amp and Colpitts oscillator. Using an oscilloscope probe, measure V_{CE} by connecting the probe to positive lead of C_1 and connecting the black alligator clip to ground. The resulting waveform should be similar to the orange waveform depicted in Fig. 25. Do not remove the probe.

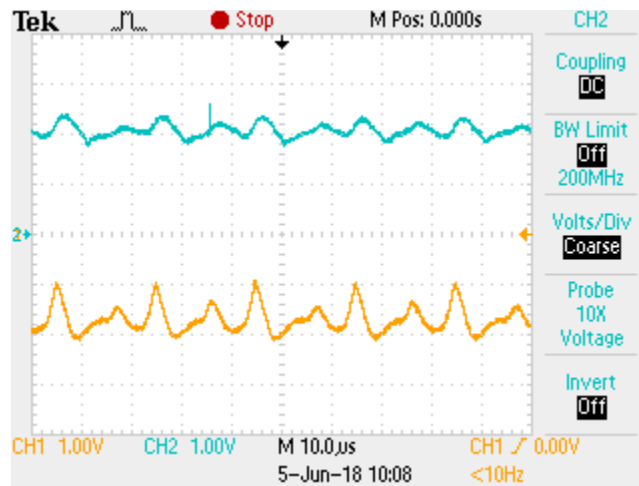


Figure 25. Oscilloscope screenshot of V_{CE} (orange waveform) vs 2V Biased V_{CE} (blue waveform)

- 2) Turn off the power supply and solder a wire from V_{CE} to the $1k\Omega$ potentiometer of the inverting op-amp circuit, which is shown as R_1 in Fig. 15. Turn on the power supply. Using a second probe, measure the output of the inverting op-amp by connecting the probe to pin 6 of the op-amp, the yellow wire seen in Fig. 16. The resulting waveform should look similar in shape to the blue waveform depicted in Fig. 25. Do not remove probe.
- 3) Measure the amplitude of the output of the inverting op-amp using the cursors button on the oscilloscope. You can adjust the gain of the op-amp, and thus the amplitude of V_{CE} , by using a flathead screwdriver and rotating the knob of the potentiometer counterclockwise to increase the amplitude, and clockwise to reduce the amplitude.

- 4) Turn off the power supply and solder the yellow wire, the output of the inverting op-amp, to input of the biasing op-amp circuit, pin 3, the green wire shown in Fig. 8.
- 5) Turn on all the power supplies and measure the output of the output of the biasing op-amp circuit, pin 1, using the first probe that was originally attached to V_{CE} .
- 6) Again using a flathead screwdriver, by turning the knob of the $10k\Omega$ potentiometer clockwise, you can increase the resistance of the potentiometer, which increases the biasing voltage. Similarly, rotating the knob counter-clockwise has the opposite effect.
- 7) Observe the output of the biasing op-amp to ensure that the minimum voltage of the V_{CE} is above $1V$. Avoid having the maximum voltage of V_{CE} be above $7.81V$ to avoid clipping.
- 8) Turn of all power supplies and solder the output of the biasing op-amp to the varactor diode of the transmitter. Turn on the power supplies. Using the EIP Model 458 Microwave frequency counter measure the frequency of the FM signal by placing the antenna in front of the horn of the transmitter. When the green light next to the word gate turns on, the frequency counter will display the frequency of the transmitted signal.
- 9) Turn on the $9V$ power source that powers the receiver. Turn on the external power source that is attached to the varactor diode of the receiver. Make sure that the voltage input to the varactor stays within the range of $1V$ to $20V$. Increasing the voltage across the varactor will decrease the frequency of the receiver, while decreasing the voltage increases the frequency.
- 10) Measure the frequency of the receiver using the same process mentioned in step 8. Calculate the difference in frequency between the transmitter and receiver. Try and obtain the largest frequency difference possible by adjusting the voltage input to the varactor diode of the receiver.
- 11) Turn on the spectrum analyzer and set the center frequency of the spectrum to the frequency difference. For a frequency difference of 30 MHz set the minimum frequency of the spectrum to 20 MHz and the maximum frequency to 40 MHz .
- 12) There should be a peak around the center frequency, when no object is present. This peak indicates that the transmitter and receiver are communicating.
- 13) Place the stationary target at the bisection of the transmitter and receiver as shown in Fig. 17. When a target is detected, the bandwidth and the amplitude of the spectrum shown on

the spectrum analyzer will increase. The number of reflections received by the receiver should change based on the geometry of the target.

Troubleshooting

- 1) Due to the nature of the setup and operation of the system, if there is a problem with the circuitry it will be easily identified because of the checkpoints done at each step.
- 2) Once a problem is identified, check for loose or broken wires in the subsystem that the problem occurred in.
- 3) Double check each subsystem to ensure that they are connected to the correct power supplies.
- 4) Make sure that the ground and power busses of the circuit are not in contact with any metallic surface because this could unintentionally ground the circuit.

Maintenance

- 1) After operating the system, ensure that all of the power supplies and devices are turned off.
- 2) In addition, disconnect the output of the biased op-amp from the varactor diode of the transmitter to ensure that the biased op-amp is only connected when its output is known to be between 1V and 20V.

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Discussion:

The goal of this project was the hardware implementation of a fast chaotic oscillator into a high resolution radar system. Over the course of two terms, many meetings, and many hours of testing, a final system was realized that was able to detect the presence of a target by transmitting a chaotic waveform. The system was made cost effective by the use of commercial off the shelf components.

High range resolution is typically achieved by transmitting wide bandwidth waveforms. Current radar systems use modulation techniques and other devices such as amplifiers to obtain these signals. The need of additional components in a system increases the cost of the system, takes up physical space, and adds noise that decreases the overall efficiency of the system.

Using a chaotic oscillator it is possible to generate a high power high frequency modulating waveform the intermediate steps and devices needed to generate high bandwidth signals can be avoided. The chaotic oscillator implemented for this project, the Colpitts oscillator, was comprised entirely of commercial off the shelf components. The benchmark system generated sinusoidal waveforms, and transmitted and received the modulated signal to verify that the designed radar system was functional. For the final system, the function generator was replaced by the chaotic oscillator, both the transmitter and receiver were rotated -45° and a target was placed at their bisection.

The final system was successful at detecting the presence of a static target. When no target was present, the spectrum of the receiver showed a small peak with a small bandwidth at around 30 MHz. When a cylindrical target was placed at the bisection, the number of reflections received by the receiver increased, resulting in an increase in bandwidth of the frequency spectrum. Furthermore, when a flat target was present the receiver picked up even more reflections, resulting in an even larger increase in bandwidth of the frequency spectrum. However, due to time restrictions, we were unable to demodulate the received signal to compare to original signal generated by the chaotic oscillator.

Recommendations:

While this system was successful in detecting the presence of a static target, there are still adjustments to system that could improve its performance and robustness. The LM358N op-amp used in the biasing circuit had a limited output range from 0V to 7.81V, as a result of only having a single 9V supply. The desire to limit the number elements in the system, limited the range of input voltages to the varactor diode of the transmitter. In order to demodulate the received signal, the frequency difference between the transmitter and receiver needs to be approximately 52 MHz. The maximum frequency difference we could obtain during the testing of the chaotic radar system was 30 MHz.

In future work, designing a new biasing op-amp circuit with an output voltage range of 0V to 20V would increase the range of transmitter modulating frequencies, increasing the maximum frequency difference between transmitter and receiver, and experimentation with chaotic waveforms of larger amplitudes would be possible. Increasing the amplitude of the

modulating waveforms is desirable because it will yield a broader frequency spectrum, increasing the resolution of the system.

In addition, demodulation could be achieved, if the maximum frequency difference becomes larger than 52 MHz, using the FM receiver by tuning the frequency difference between the transmitter and receiver to 52 MHz. If demodulation is achieved, the location of the target can be determined using correlation analysis between the transmitted and received signals. Correlation would result in a peak at a given time delay, τ , and the range in meters of the target from the receiver could be calculated using the formula $range = \frac{c\tau}{2}$, where c is the speed of light, 3×10^8 m/s, and τ is the time delay.

Conclusions:

This project required a great deal of dedication, learning, and effort to complete. I learned several key lessons throughout the process of designing, prototyping and testing the system. First, during the design process it is important to understand how implementation of a subsystem will impact the other subsystems. It is important to calculate the impedance of each subsystem to avoid the potential loading effects. The second lesson emphasized was the value of simulation before prototyping. Circuits that appear to be designed appropriately can contain subtle miscalculations that greatly impact its functionality. For example, the LM358N op-amp expected voltage output range was 0V to 9V, but since it was powered by a single supply, it experienced clipping at 7.81V.

Since this project involved regular testing, a majority of the learning that took place was during the experiments. During these test, the system often behaved unexpectedly, so a large portion of time was devoted to troubleshooting. This was done by comparing measured values obtained using an oscilloscope probe and a voltage meter, with expected values to determine the source of the problem.

The most important lesson learned from the project was the importance of teamwork. The design, construction, and testing of the chaotic radar system would've been an extremely difficult task for one person, but by combining our knowledge, abilities, and skills it was made possible.

In conclusion, the implementation of a high resolution radar system using chaos was successful. The chaotic radar system was able to detect two different types of stationary targets.

The preliminary design proved to be insufficient, and additional subsystems such as the biasing op-amp circuit were implemented into the final design. Due to time restrictions, the demodulation of the received signal was not feasible. The system was able to meet all of the design requirements that we set. Despite the functionality of the system, there are still many ways in which its performance can be enhanced. The experience and knowledge I acquired as a result of this project are extremely practical, valuable, and made the whole processes worthwhile.

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