Small Rotor-Craft Imaging Avoidance Radar

EE/CprE 492 - Final Report

SDMAY21-07

Dr. Mohammed Tayeb Al Qaseer

Felipe Varela Carvalho – Signal Processing

Matthew Bahr – Antenna Design

Matthew McDermott – Circuit Design/Logistics

Leonardo Bertoncello Machado – Circuit Design

Michael Ostrow – Microcontroller Programming

Joshua Welton – Circuit Design

sdmay21-07@iastate.edu

Contents

List of Figures

Acknowledgements

The completion of this project would not have been possible without the assistance of many people. Specifically, the group would like to thank the following:

The Electrical and Computer Engineering Department, the Electronics and Technology Group, and Iowa State University, thank you for the invaluable help and learning opportunities you have presented each member of this group with throughout each member's college career. Thank you for providing materials towards the completion of the project and for giving the team a space in which to collaborate on the project.

To Dr. Mohammad Tayeb Al Qaseer whose knowledge and expertise has provided the group with countless learning opportunities and experience. To Leland Harker who aided with both manufacturing and ordering of parts.

Thank you again to all those who have aided the group throughout this project.

Introduction

Problem and Project Statement

When flying any type of vehicle, it is imperative to avoid any collisions with other objects. One of the most dangerous objects that a flying vehicle could hit are overhead power lines and guywires. These wires are capable of not only damaging the craft but also causing large amounts of damage through fires. Since these wires are difficult to see in low-visibility conditions they are especially dangerous.

To avoid potential collisions, a proof-of-concept system will be developed that utilizes antennas to detect and visualize wires and their orientations relative to the vehicle. This radar system will be comprised of a combination of circuitry and programming that will allow an antenna to find and visually recreate a wire's location and orientation for an operator. At the end of this project, we will have a proof-of-concept prototype system that can successfully locate a wire and visually recreate it at a computer that is connected to our radar system. This visual recreation should contain enough information so that an operator would know how to avoid the wire with their vehicle.

Operational Environment

Since this product will be used to locate wires that are normally difficult to see, this product will be required to operate at most outdoor conditions. Specifically, the finished product will be able to operate in both dusty and foggy conditions and must also be able to operate at any time of the day. This solution assumes that an operator will not operate under extreme weather conditions.

Intended Users and Uses

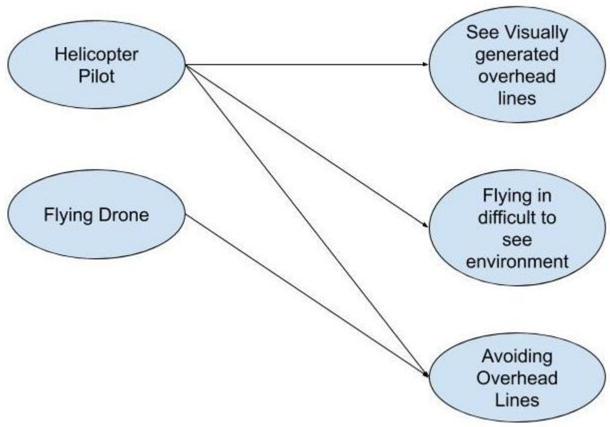


Figure 1: User-Use case diagram

The radar system is intended to be used by any company or individual that would like increased security or situational awareness while flying a vehicle or craft. The use of this project would be for a remote-controlled aircraft to be able to detect small wires and other objects that are either too small to detect by camera or if there are visibility reducing weather conditions.

Project Design

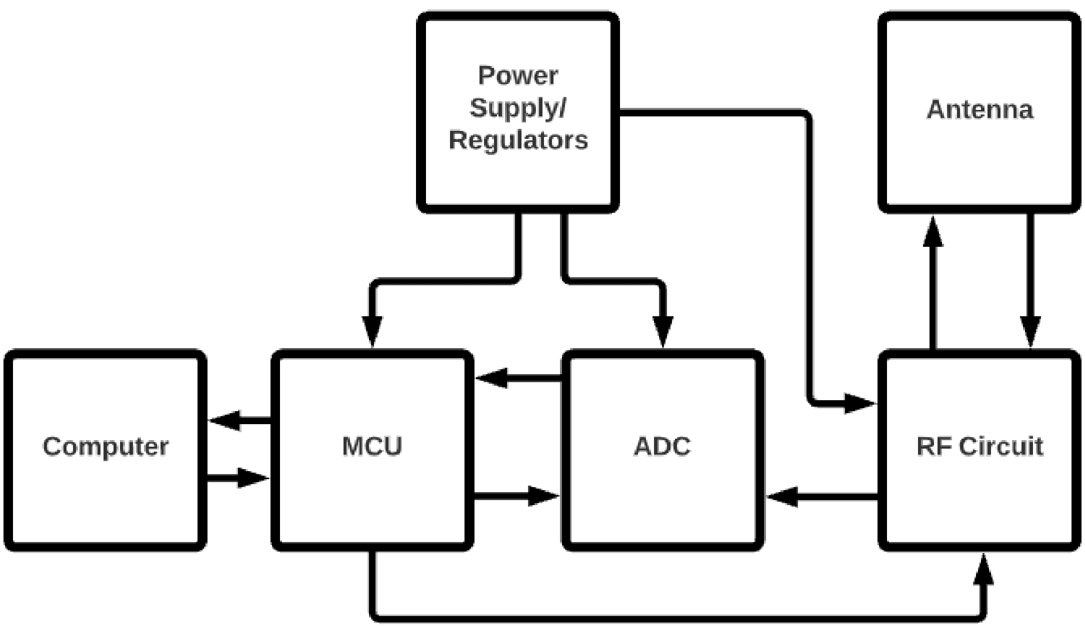


Figure 2: Block Diagram

Our design is an integrated circuit that utilizes a set of 5 antennas (1 transmitter and 4 receivers). The functionality of this device is to collect the reflected signal off of an object in front of the antenna array, these signals will them be outputted as differential signals which are then fed into the ADCs. The ADCs will convert these differential signals into 16-bit numbers with a sampling frequency of 100 kHz. This digital data will then be sent to a microcontroller, which will process the data and send it to the PC to be used. The PC will then either avoid the obstacles itself or notify the machine operator.

Antenna

The original antenna design was an antenna that was split into two portions, a top part and a bottom part. This original antenna was modified last semester to be a horn antenna to better suit the project's needs due the required distance and accuracy. An independent waveguide was also designed to act as the bridge between the coaxial cable connector and the antenna. This waveguide was to be screwed on to the antenna on the sides of the bottom portion of the antenna.

The new antenna design integrates the coaxial cable connector directly into the bottom portion of the antenna instead of an external connector that must be screwed into the bottom portion of the antenna. With this change, the coaxial cable will be fed directly into the waveguides from the sides of the antenna. This change in design was done to facilitate an easier CNC creation process.

New simulations were conducted in our computer aided design (CAD) software CST Studio with the updated antenna model. These simulations measured various parameters of our antenna like S-Parameters, axial ratio, and directivity. As the antenna model was changed, simulations were conducted to ensure that all properties of the antenna met the specification of our system. This can be seen in the following figures:

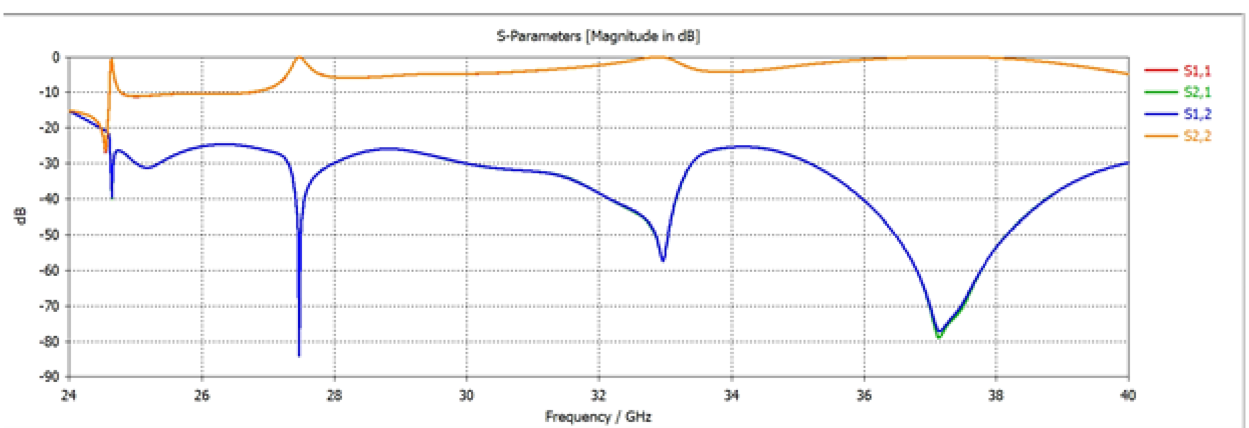


Figure 3: S-Parameters from Antenna Model

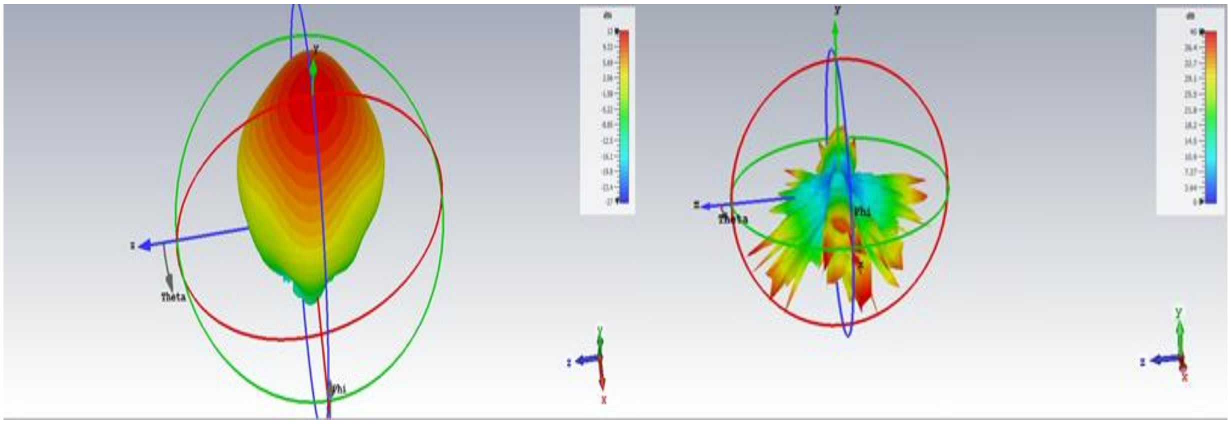


Figure 4: ABS Measurement of the Horn & Axial Ratio

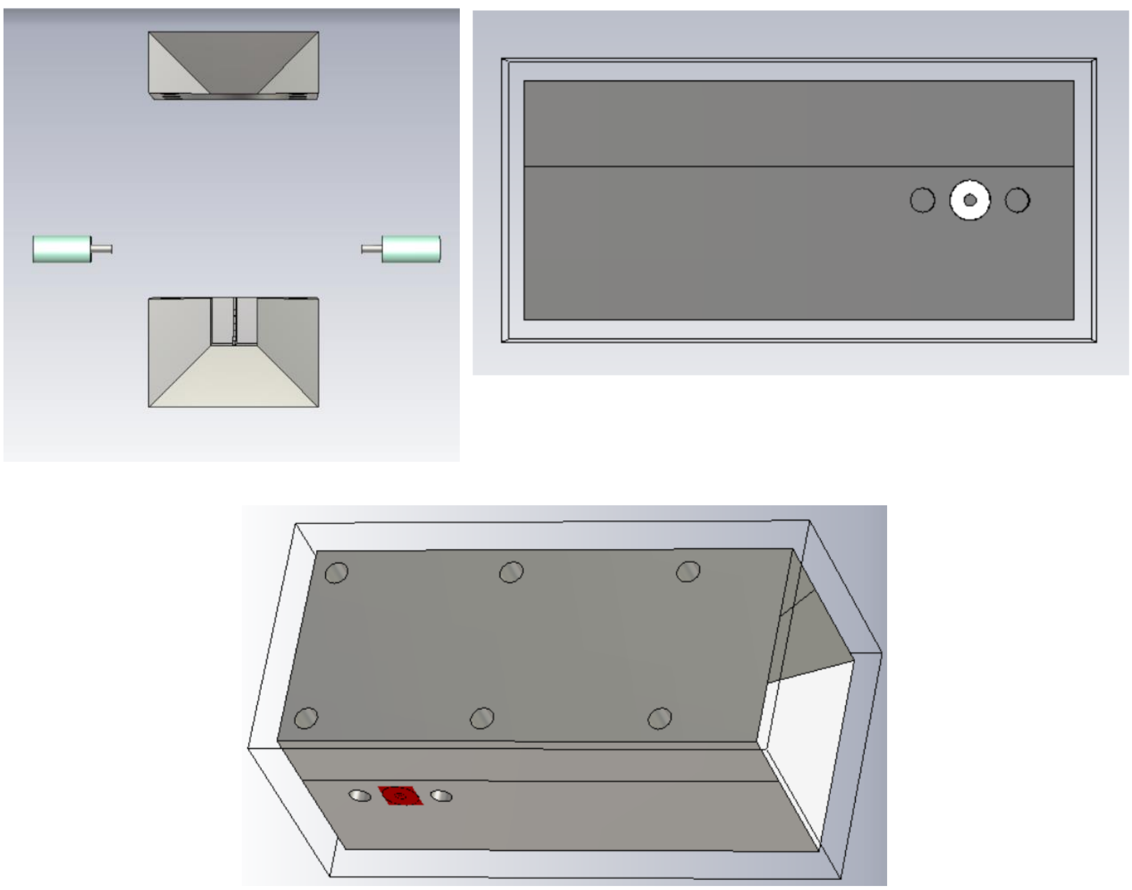


Figure 5: Antenna CST Model

PCB (RF – PLL – Power Supply)

The printed circuit board (PCB) containing all of the integrated circuits (ICs) will allow for streamline testing of appropriate power delivery and output signals from all components. However, since we are having to split a high frequency line between two receivers, this does open up the possibility of power loss if poorly designed. The trade-off in having to carefully designing a power divider for convenient and compact testing is worth it. Designing the RF PCB also required the correct width for high-frequency lines to match impedance. Furthermore, designing the power divider through the PCB editor required a different set of design rules to ensure correct operation/splitting of high frequency lines.

Analog-to-Digital Converter (ADC)

This circuit will present to the microcontroller the RF analog data output in a readable manner. By doing this, however, we lose accuracy in rounding the analog values to the nearest binary value. To minimize this issue, we used a 16-bit ADC. Another aspect of the ADC is to choose a sampling rate high enough to alleviate issues from aliasing. To do so, we have chosen a ADC with a sampling rate of 100 kHz.

Raspberry Pi

This component functions as the microcontroller for processing the incoming and outgoing data and to control the RF and ADC circuit. This microcontroller is going to control the operation of the device, from the initializations of the circuit to the data control, and finally the communication between the circuits and the PC.

MATLAB Programming

Originally there were two sections of software required for this project. The first relates to the communications between PCB and PC. The original plan was to use a Raspberry Pi to set SPI communication protocols and send data for the PC to process. However, as the project progressed, we had to shift the software focus to a simulation-based approach. We also had to put our efforts into processing data that was acquired from the testing with the Vector Network Analyzer.

MATLAB is a powerful language to do data processing with RF data. Its libraries provide strong and accessible tools for such tasks. One of the downfalls of MATLAB is that the language can be slow and heavy and requires a somewhat resourceful machine with good computational power. MATLAB is used to process data coming from the microcontrollers and output the distance and orientation of a detected wire object.

Functional & Non-Functional Requirements

For this project, the functional requirements are:

- The solution must detect distant objects and that object's distance, size, and orientation
- The antennas can detect objects in the range of 10 – 100 meters away
- A visual overlay of any objects or items seen by the antenna must be created for a user to view and interpret
- Operating frequency range must be within ISM band. Due to this, the antenna will be operated at 24 GHz

Similarly, the non-functional requirements are:

- The antennas must be able to interface with the RF PCB through surface mount connections
- This RF PCB will have specific circuits for the transmitter antenna and a different circuitry for the receiver antenna
- The PCBs must be integrated with computer software for data transmission and interpretation
- Multiple antennas will be used to triangulate the obstacles

Standards

The following standards are de facto for our proof-of-concept project:

The first standard that was used for this project is IEEE 145. This standard outlines definitions for antennas and for systems that include antennas as a portion of the overall system. This standard was used in this project to outline basic definitions for our overall system and the antennas that are being designed in this project.

The second standard used for this project is IEEE 370. It also describes practices on how to obtain high quality measured data for any high-frequency electrical interconnects. This standard applies to any high-frequency components up to a frequency of 50 GHz. This standard was used to establish a baseline for any methods and processes the group used for testing of the PCBs. Specifically, this standard was used as a reference for what to compare the measured S-Parameters of the PCBs and their interconnections to the antennas.

Constraints

The constraints for this project include the fabrication layout limitations for both the PCB and antenna manufacturing. For the PCB manufacturing, this is due to the requirements that our supplier JLCPCB has for creating boards. These requirements must be met for manufacturing to begin on the boards, regardless of the function of any board. Another constraint regards soldering both of the boards. Since both of these boards have mostly surface mount components, it was difficult to ensure proper solder joints for the components. A major point of difficulty came from reflow oven soldering for the components unable to be hand soldered. For the antenna manufacturing, the constraints are due to the ability of the group's chosen CNC machine to manufacture a proper antenna that will still meet all functional requirements.

Other major constraints of the project have to do with electrical properties and characteristics of the SMA connectors that are being utilized to connect the antenna to the RF PCB. These connectors behave ideally at 22 GHz – 26 GHz, which matches with the antenna's operation frequency of 24 GHz. However, any imperfections or errors in the antenna or SMA connectors could limit the overall performance of the system. This range of frequencies was chosen due to it being part of the industrial, scientific, and medical (ISM) radio-frequency band, which does not require an operating license.

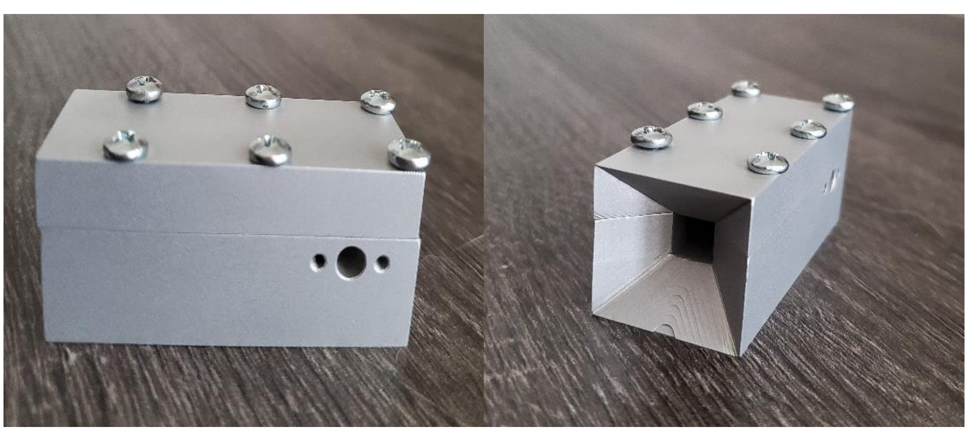
Security Concerns

Due to this project being mostly hardware with only some software integration, the security concerns for this project are minimal. The only potential security concerns facing this project would be related to the physical security of the system. The integrity of the hardware and the connections between the different components of our system may be susceptible to tampering in the future, which could lead to a system failure. A system failure could result in a user not seeing an oncoming obstacle, due to their reliance on the software, and cause an accident. To reduce the effect of this type of hardware issue, it should be considered to add a manual included with the device will advise a quick test of the software to ensure functionality before the pilot takes flight.

Implementation

Antenna

For machining purposes, aluminum was chosen as the material to build the antenna out of instead of brass. This material was chosen to ensure high electrical properties while still being an easy metal to cut. Due to the change in material, #6-32 screw holes were added into the antenna at the top to fasten the two portions of the antenna together. #2-56 screw holes were also added into the side wall to fasten the coaxial cable connector to the bottom portion of antenna for a stable connection. The antenna can be seen below:



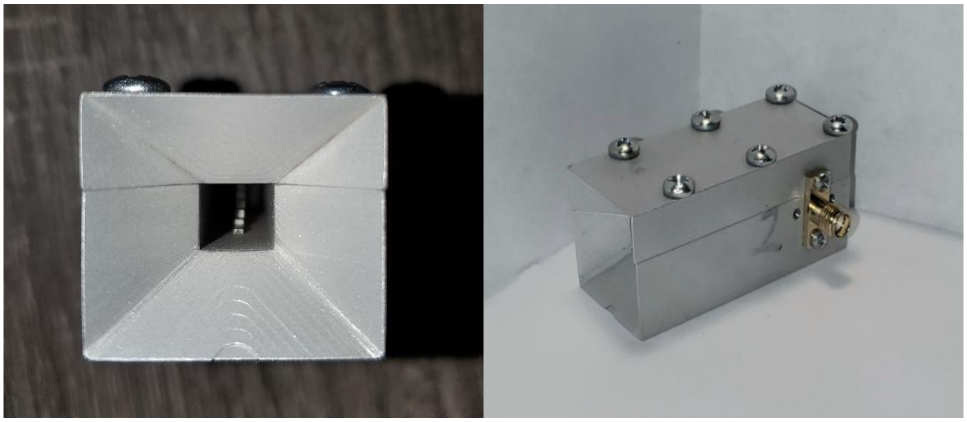


Figure 6: Machined Antenna

Printed Circuit Boards

After preliminary design work made during EE/CprE 491 and the subsequent winter break, we discussed the design and decided to move in a different direction. Originally, we were to have all modules pertaining to circuitry on a singular board. We found that this design would make it harder to diagnose and remedy potential mistakes in our designs, and we decided to separate the analog to digital converter module and the radio frequency module into two separate printed circuit boards.

Designing the separate boards was the best decision to make, as voltage inputs between components differed greatly enough to justify separating the modules.

The Main PCB, which houses the RF ICs and coaxial connectors that lead to the antenna array, has changed slightly due to the splitting of the boards. This comes in the form of connecting said boards, as we had to find a low noise solution to ensure minimal data corruption. The remedy to this was to use a 32-wire ribbon connector, with 16 wires being used for the 8 differential pairs, and 16 wires used to shield the differential pairs by connecting the ground nodes of the 2 boards. SPI connection was also redesigned to accommodate for pin allocation on this board as well, with only 1 data net is used throughout the entire board. Each programmable IC has its own program enable pin from the MCU to ensure correct programming.

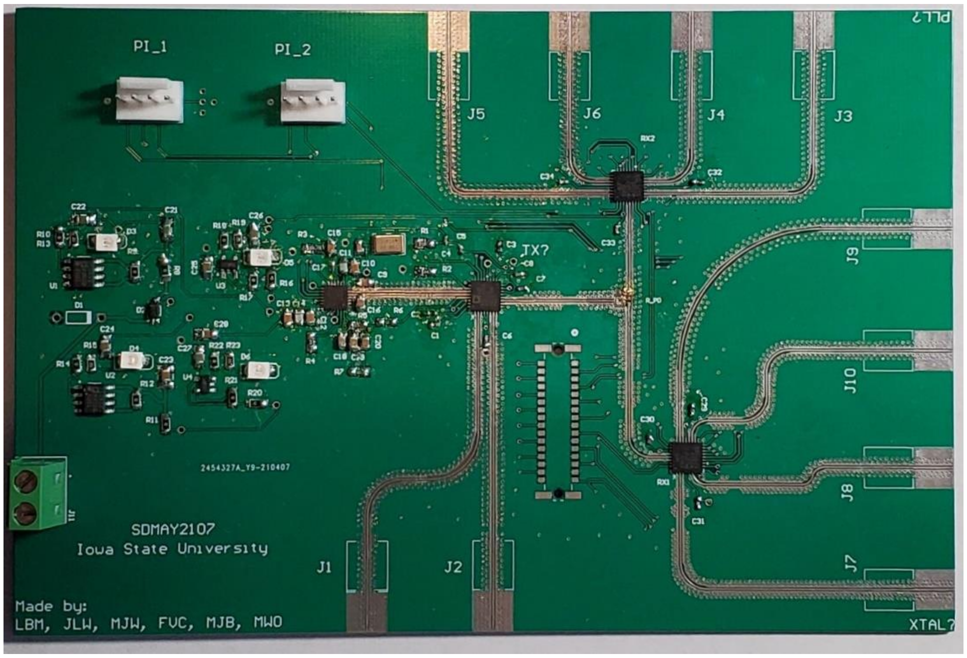


Figure 7: Radio Frequency Board

The new ADC PCB took some design for voltage regulators as the ADC components we chose have similar analog and digital input voltages when compared to the RF ICs on the Main PCB. After recycling those designs, we added novel design work for a very low noise voltage reference for the ADCs to use, since the data being handled is low voltage and noise susceptive. To combat pin allocation from the microcontroller, a Raspberry Pi, we also decided to daisy-chain our 8 ADC ICs into 4 component blocks, resulting in 2 data packets being delivered to the MCU for each sample.

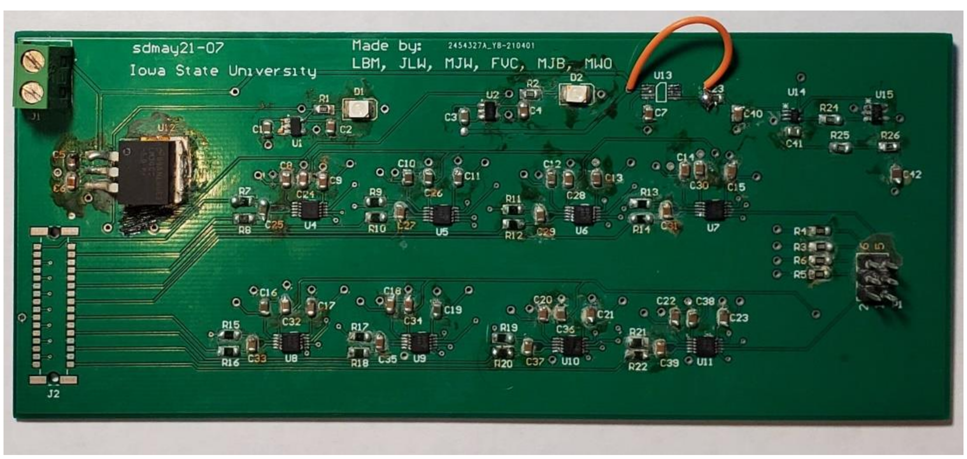


Figure 8: Analog-to-Digital Converter Board

Raspberry Pi

The pi uses the two separate SPI controllers, one to communicate with each PCB. On the initialization of the code, the pi signals to the PC it is ready to initialize and waits for a response. If the PC requests for initialization, the pi will set the register values on the radio frequency PCB based on the initialization register values found in the datasheets.

```
#Initialize PCB
spi1_0 = spidev.SpiDev(1, 0) #RF output chip
spi1_1 = spidev.SpiDev(1, 1) #RF input chip
spi1_2 = spidev.SpiDev(1, 2) #pll chip

RF_output_init = [0x02000007, 0x0000002B, 0x0000000B, 0x1D32A64A, 0x2A20B929, 0x40003E88, 0x809FE520,  0x011F4827
RF_input_init = [0x00000003, 0x00020406, 0x20001499, 0x40001499, 0x60001499, 0x80001499, 0xA0000019, 0x80007CA0]

spi_clock = 4000000 #4 MHz
```

Figure 9: Antenna Board Initialization

After the PCB has been initialized, the pi will notify the PC and wait for the second command. When the PC responds for a second time, the pi will begin looping, reading data and sending the data readings to the PC.

```
while(1):
    #Sampling
    GPIO.output(convst, GPIO.LOW)
    GPIO.output(convst, GPIO.HIGH)

    #Reading values
    val03 = spi0_0.readbytes(8)
    val48 = spi0_1.readbytes(8)

    #Sending values
    ser.write(val03)
    ser.write(val48)
```

Figure 10: Analog-to-Digital Converter Sampling Loop

Data Processing

MATLAB was used as the main tool for working with generating and processing data. Using scripts provided by the project's advisor, it was possible to generate simple antenna arrays to estimate antenna data. After testing, scripts were written in MATALB to process the acquired data. The MATLAB scripts took the S-parameters outputted by the Vector Network analyzer and plotted it as a spectrum for easy data visualization. Since our antenna had circular polarization, it was also possible to observe the phase of the signal, which was used to discover the angle of the detected wire by calculating the phase difference between a detected wire and a reference one.

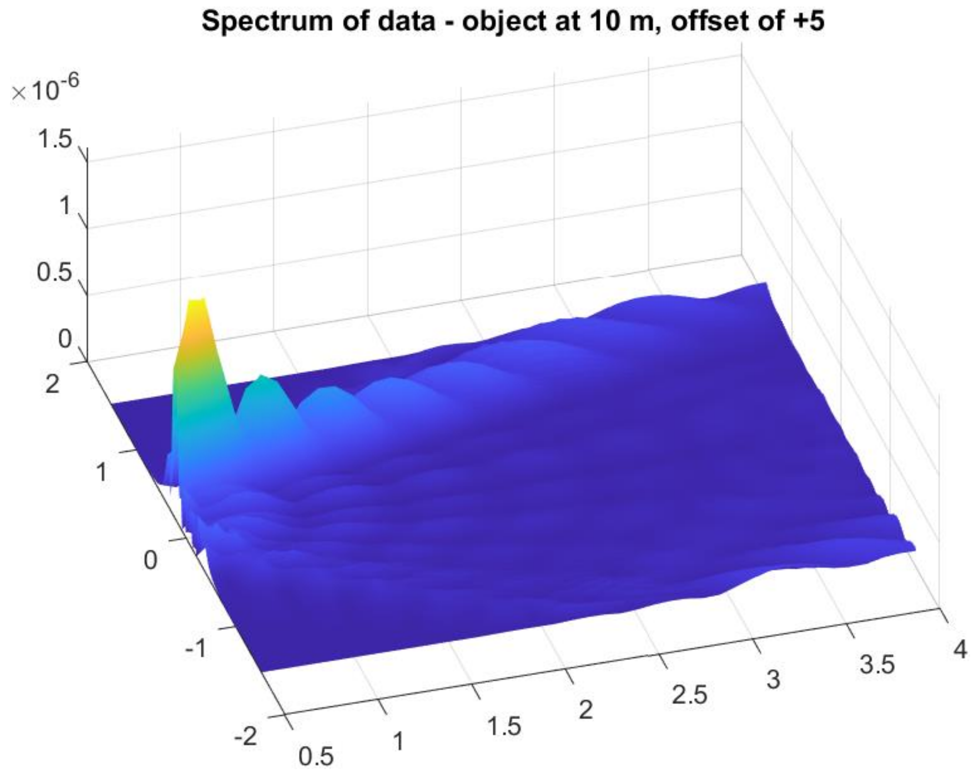


Figure 11: Spectrum of Data

Testing Process

Simulated Data Testing

Another way to test and predict our values for the antenna was to write a software that was able to simulate how our system would behave. We tested using ideal conditions. The code was mostly provided by our project advisor Dr. Al Qaseer.

The code was able to simulate an antenna array with a given number of antennas with a distance between them with a single wire centered in the middle at a certain distance with a given angle. For example, our ideal system would have 4 receiver antennas. Therefore, we can simulate four receiver antennas and one transmitter antenna. Together with that, we can simulate an object at 10 meters away at our reference angle of 90 degrees. Below are the exemplified results:

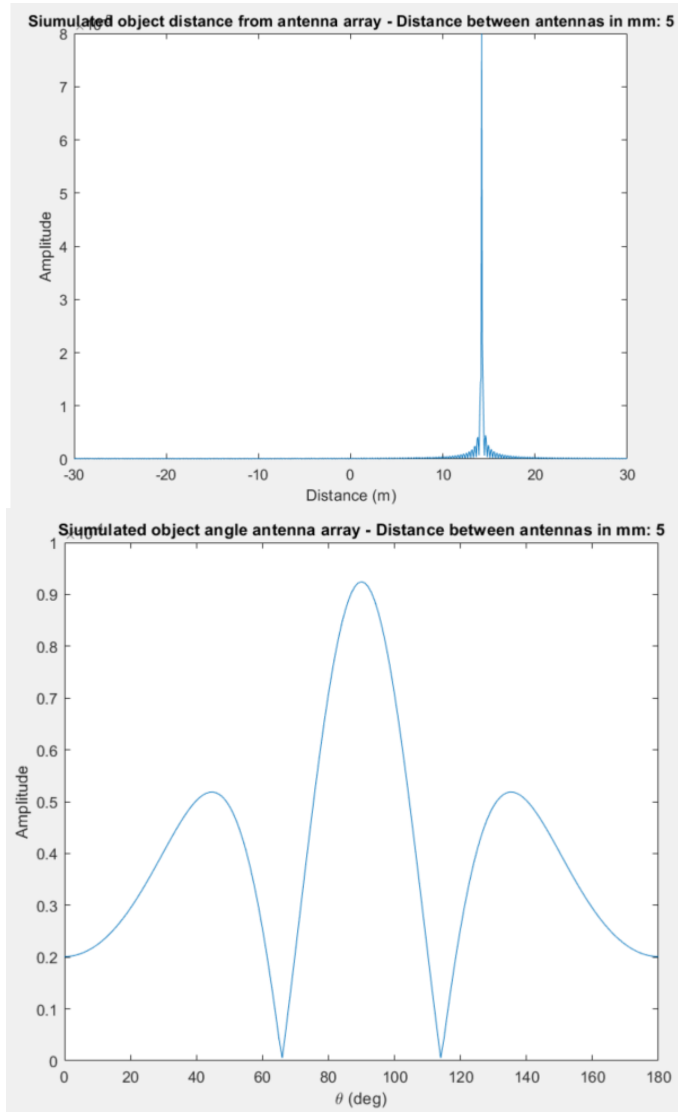


Figure 12: Simulated Antenna Results

The sidelobes on the angle result are due to aliasing with our data.

With that information we had to look at the peak of each graph and analyze the coordinates of them. With the example above, it is possible to see the phase at 90 degrees. It is also possible to see the distance from the antenna to be around 10.

Because our ideal project was supposed to detect wires from 10 to 100 meters, we set the simulations with an obstacle at 55 meters. When it comes to the distance between antennas, the best distance is about 10 millimeters from receiver to receiver, leaving a space in the middle to the transmitter antenna.

Antenna Testing

The antenna was first tested singularly. We used a Vector Network Analyzer to acquire the S-parameters of our machined antenna. We then compared the acquired S-parameters with our simulation S-parameters. Below is the acquired S-parameters of our antenna compared with the one that we acquired from CST simulation.

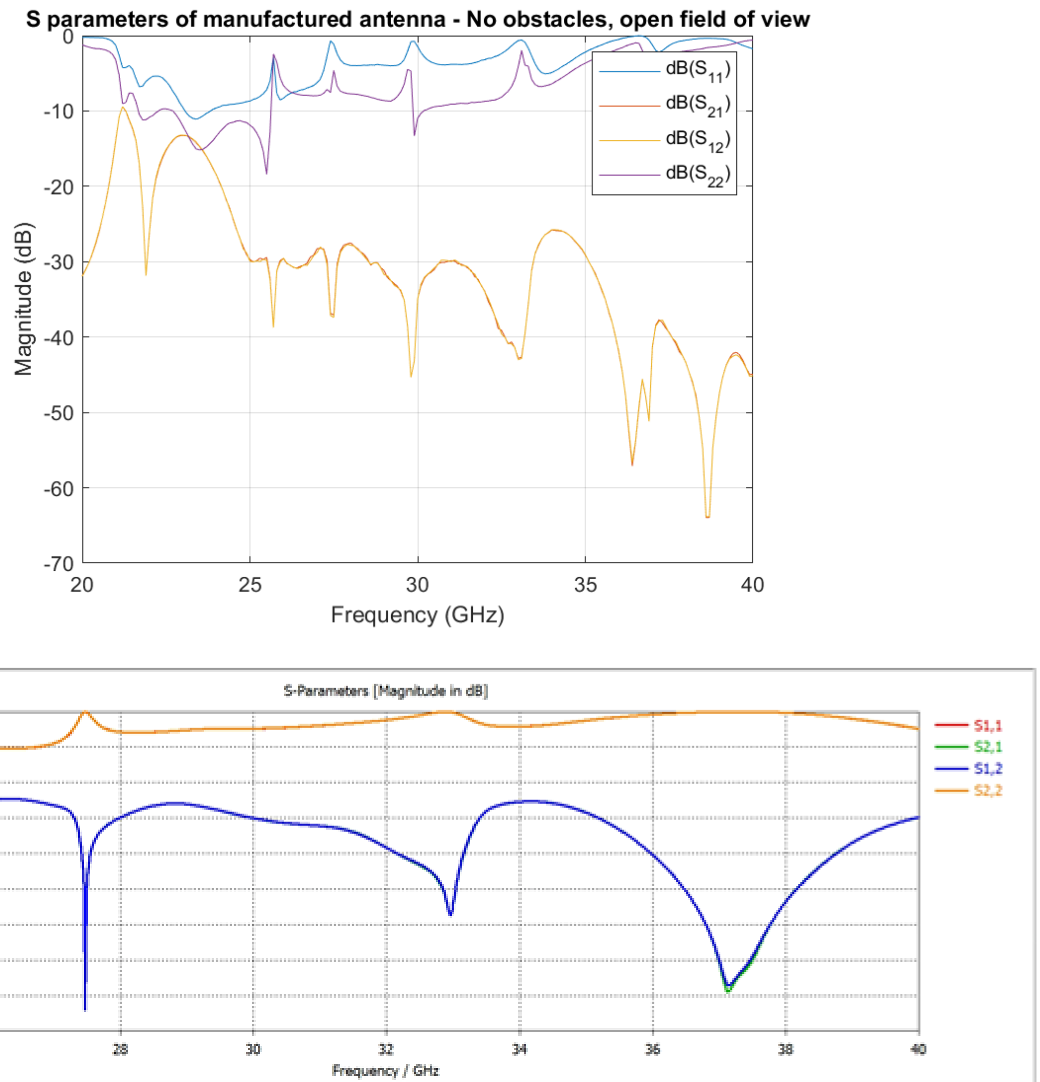


Figure 13: S-Parameters from Machined Antenna

With these results, it is possible to see that our manufactured antenna has similar parameters when compared to the one that we simulated. There is leakage and imperfections with our manufactured antenna as expected. The manufactured antenna had an imperfection at the edge of the horn together with leakage coming from the two parts being screwed together.

Using the Vector Network Analyzer again, but with a different configuration, an array of antennas can be simulated using only two antennas. Once this machine simulated an antenna array, various wires we placed one meter in front of the antennas at various orientations for the array to detect. The detection data was then complied in the machine and then exported for data analysis.

Below is our controlled testing environment with an example of what the antenna was observing. Due to the assembly complexity, it was not possible to take a picture of the antenna perspective without the coaxial cable. It is important to note that the coaxial cable was not, at any point, in front of our antenna.

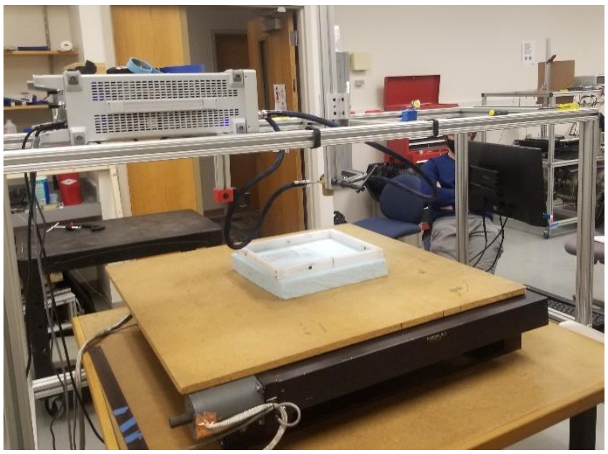
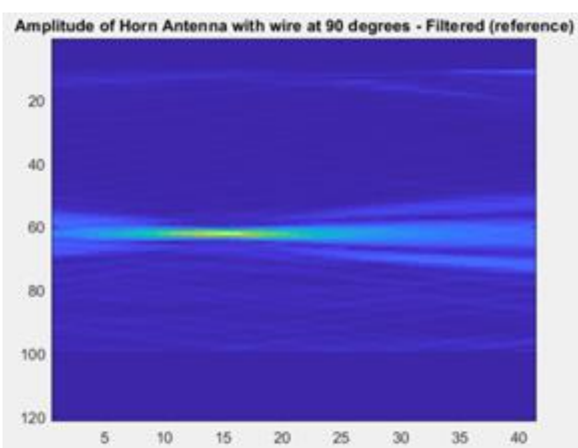
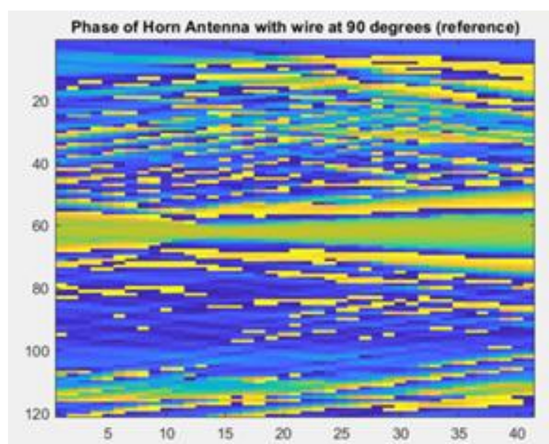


Figure 14: Testing Environment

Figure 15: Antenna Perspective

Below is our testing results data with processing for better spectrum visualization and noise reduction for a wire at 90 degrees. This was used as reference for the test that we ran with the wire at 45 degrees.





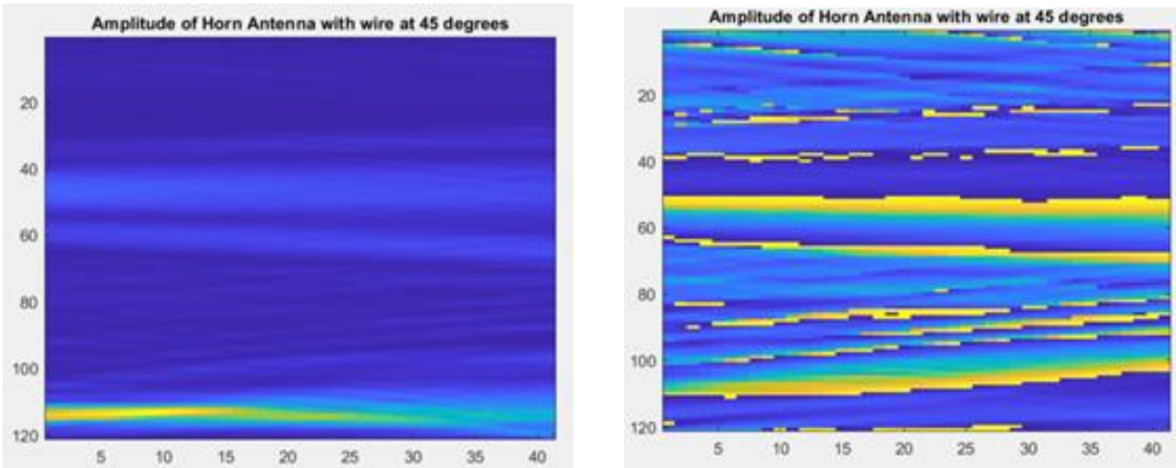


Figure 16: Spectrum of Analyzed Data from Vector Network Analyzer

As it is possible to see, the peaks in intensity in the spectrum shows where our antenna identify the wire object in front of it. If we save the x and y location of the peak value in our spectrum and translate it to the phase spectrum plot, we will get the angle of our wire. We did this process with a wire at a 90-degree angle and used it as reference. We then tested a wire at 45-degrees and repeated the process. At the end, we subtracted the phase of the 45-degree angle wire and the reference 90-degree one. In the case above, we got an angle of 35.65-degrees.

Our antenna was made out of two parts, the top and the bottom part were machined separately and then screwed together. Because of this, there was leakage in our antenna due to machining imperfections generating the error that was exemplified above. Another source of error was the coaxial connectors, which had to be manually trimmed. Thus, generating imperfections.

PCB Testing

For the ADC PCB, testing involves use of a function generator, as that will best mimic the output of the receiver ICs on the Main PCB. The function generator will output 2 differential pair outputs, and this output will be connected to the input of 1 daisy-chain of ADCs. The output of the ADC is then fed to either an oscilloscope or an MCU through a serial pin. We then confirm the differential input through use of these external objects. The results of the test are below:

This testing resulted in max values for all ADCs in the daisy chain regardless of the input value. This leads us to believe the ADC PCB contained a short somewhere between the reference voltage line and the input/output voltage line. This is the most likely the cause as the data packets received are always high, and the short produces a voltage above the binary threshold of the Raspberry Pi. We are pretty sure the issue is not software, because when the reference voltage is 0, the output is instead a line of 0s.

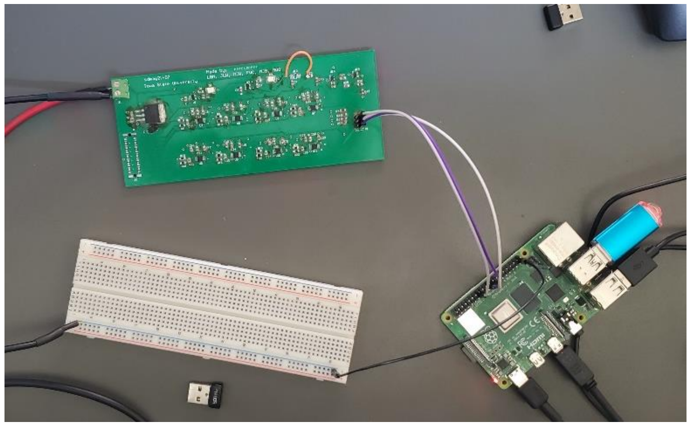


Figure 17: Setup of Raspberry Pi Connected to ADC Converter Board

The Main PCB would be tested by connecting to the MCU and ADC PCB. The antenna array must also be a connected to the Main PCB. The MCU will initialize the RF ICs to properly function, and the receiver ICs will output to the ADC PCB through the shared ribbon connector. Lastly these results are to be packaged by the MCU and sent to a computer running the script needed to process the data. Beforehand, testing the components individually, similarly to the ADC,

Placing Products in the Context of Related Products & Related Literature

For many components of our project, there are existing products and literature associated with them. For the antenna, an original design was supplied to the team from the project advisor that needed to be modified to accomplish the goals of this project. The coaxial cable connectors used to integrate the RF PCB and the antenna is the Adam Tech RF2-156-T-00-50-G.

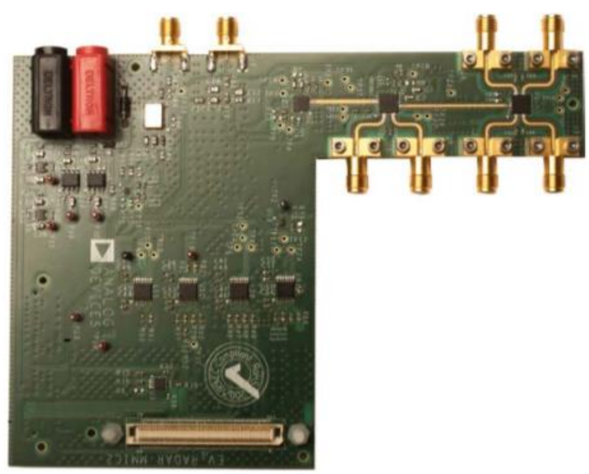


Figure 18: EV-RADAR-MMIC2 Radio Frequency Chip

The PCB is based on is Analog Devices' EV-RADAR-MMIC2 board. Our system utilizes the same RF components and also utilizes a phase-locked loop same as our design. This board also works in the Industrial, Scientifical, and Medical (ISM) frequency band, therefore not requiring any licenses to operate. However, our board uses two receiver chips instead of one, since orientation is a requirement. Therefore, the need for a power divider (Wilkinson Power Divider) is one of the many changes that our design includes. Our board processes the incoming signals through a series of ADCs while the EV-RADAR board implements FPGAs. Lastly, due to potential modularity in testing phase, we split the single board design into two smaller ones.

Conclusion

The work done by the group for this semester consists of finalizing all hardware designs for the antenna and PCBs and manufacturing the hardware for use in the radar system. With the manufactured hardware testing was done to determine the performance of each piece of hardware. For the antenna, this testing allowed the data processing portion of the project to begin working on visual recreation. For the PCBs, the microcontroller implementation could begin in for interfacing with the ADC PCB.

Many skills were used, and many more were learned over the course of this project. This project helped us all with lifelong learning skills in general, as not one of us knew everything we worked on at the start of this project. This project helped all of us become more prepared for the future careers ahead of us.

The original application for our project was to provide a proof-of-concept system to provide additional perception to one's surroundings whether they are an unmanned or manned aircraft. Our implementation of this concept would increase the overall awareness of one's environment with an emphasis on these hazardous obstructions. We managed to fully flesh the design, and spot the issues with our implementation. Our largest limitation was our lack of access to professional tools. If this project were to be picked up by a team in the future, they would need to focus on these 3 things:

- Re-evaluate the PCBs with the new testing knowledge we now have access to. Due to the short in the ADC board, we would advise to have the whole process (design, construction, and assembly) done professionally.
- Test the antenna with functional equipment to ensure the functionality and then have a new prototype built with higher grade materials, and higher-grade milling.
- Build a full-fleshed application so a user can download the software and have it ready to work at the push of a button. Potentially, using a more modular and lighter language, such as Python or C++, would facilitate system integration. Since these languages could run in the same microcontroller.

References

Evaluation Board

[1] A. D. Inc., “EV-RADAR-MMIC2 Analog Devices Inc.: RF/IF and RFID,” Digi Key, 2017. [Online]. Available: https://www.digikey.com/en/products/detail/analog-devices-inc/EV-RADAR-MMIC2/6072228?utm_adgroup=xGeneral. [Accessed: 15-Nov-2020].

Academic Work

[2] M. Dvorsky, M. T. A. Qaseer and R. Zoughi, "Detection and Orientation Estimation of Short Cracks Using Circularly Polarized Microwave SAR Imaging," in *IEEE Transactions on Instrumentation and Measurement*, vol. 69, no. 9, pp. 7252-7263, Sept. 2020, doi: 10.1109/TIM.2020.2978317. [Accessed: 25 – April – 2021]

Appendix 1 - Operation Manual

1. Setting up the components

Assembly of the individual components is required from the user as this project does not come packaged as a single unit. Future iterations that go beyond proof-of-concept may see changes to this step of the Operation Manual.

1.1 Setting up the Antenna

The antennas, if not connected to the RF PCB, should be attached through the connectors found on the board. Using a coaxial cable with matched impedance (50 ohms) is necessary in order to obtain clean signals. Each antenna has two connections which are due to the utilization of circular polarity, ensuring that the SMA connector is tight on both ends will help limit power loss and noise. It should be noted that the receiver antennas need to be at 10mm away from each other with space for the transmitter antenna in the middle of the receiver array to ensure optimal functionality and minimal coupling between antennas.

1.2 Setting up the RF and ADC boards

After the antennas are successfully attached, the RF board and the ADC board share a number of pins and signal outputs that must be connected through the ribbon connector included. The main point of concern is ensuring that the ribbon connector is properly orientated, though that should not prove challenging since the point of contact is keyed. The RF and ADC boards also communicate directly to the Microcontroller (MCU) and have designated pins for each IC and output signal the MCU may utilize. The ADC’s designated point of contact is found to the right of the board (P1) while the RF board has PI_1 and PI_2.

1.3 Setting up the MCU
Since one of the pins within the RF board already grounds the MCU to a common ground with both boards, the next step is to connect the MCU to a PC running the provided MATLAB/Python scripts. The computer operator would then proceed to initialize the MCU's functionalities through a serial terminal of their choice (such as PuTTy) once the entire system is properly powered.

1.4 Powering up the system
Connecting each of the aforementioned parts to their appropriate power supplies should be the last step as is good practice for such sensitive equipment. Ensuring that the respective voltages are provided through the on-board connections labelled J1 (ADC board) and J11 (RF board).

2. Setting up a testing environment
2.1 Setting up a testing target
The target can be anything that will physically approach the appearance of a power line. Ideally testing should be done with different angles and orientations of the target, one way of achieving this is by creating a frame that holds the target in numerous orientations. See the below figure for an example.

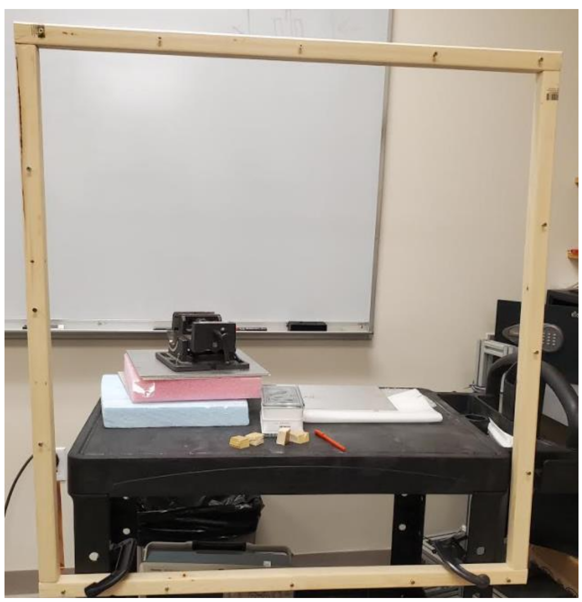


Figure 19: Wooden Frame for Testing Purposes

2.2 Controlled testing
Given the nature of this project, a controlled testing environment is idea to ensure the system is working as intended. The target range is 10-100 meters; however, it is advised that first tests be performed at a closer range to ensure the data observed is consistent with the expected outcome. Adjusting the range of the target and slowly approaching the desired range allows for controlled changes.

3. Run initialization/Things to watch out for
As previously mentioned, both boards and the antennas will not function without proper initialization from the MCU. Booting the serial terminal and initializing the board will be met with clear outputs being received on the monitor.

3.1 Common errors
Ensuring the antennas are well built is crucial to the entire system implementation. Ideally these are to be fused or as closely enclosed as possible. This is to avoid any signal leakage and power loss before the signal has a chance to leave the transmitter antennas, and avoid noise corruption once the receivers are engaged. If a Vector Network Analyzer is being used, or any other means of simulating signals, make sure the components are properly calibrated and orientation is taken into consideration, since otherwise the results will appear incorrect.

4. Process data/Things to expect
The PC receives the data read by the system as a set of numbers fed through the serial connection between the MCU and the PC. Make sure you have the corresponding software up to view the processed data

4.1 Expected results
The data should show as a graphed line. This line graph will give data on distance of the obstacle as well as the orientation the obstacle is facing in units of degrees. Depending if you have a live feed of the obstacles as well, you may also see a drawing of the obstacle overlayed onto the video feed.

Appendix 2 – Alternate or Initial Versions of the Design

The original design for our system included different versions of the antenna and PCB. These initial designs were changed once more knowledge was acquired. Once more was known about the system, the designs were able to be changed.

The main difference between the final version of the antenna and the initial version is the form of the coaxial cable waveguide and the material of the antenna. The coaxial connector waveguide was originally a separate part that was to be screwed onto the antenna body. This waveguide was modeled in CST and simulations were run to analyze different parameters of the waveguide. Finally, the material of the antenna changed from brass to aluminum. This was to simplify the CNC process and to ensure that the antenna could be created as quickly as possible.

Originally, the schematic for the circuits designed was all encompassing in that it included both RF circuitry and analog-to-digital circuitry. This proved difficult to layout in printed circuit board

CAD software, as there are many high frequency lines that require very low noise from other voltage nets on the board. To supplement these lines, the team decided it would be beneficial to split the two main circuits on the PCB into 2 separate boards, the RF and ADC PCBs. This also proved helpful in increasing modularity in our system, making it easier to identify and diagnose issues in designs.

Appendix 3 – Other Considerations

Testing of the antenna was done using the group advisor’s Vector Network Analyzer. This machine allowed the group to simulate antenna arrays and gather data from many measurements during a short time. Due to the complexity of this machine, portions of the data we received contained unexpected variables that had to be accounted for in the group’s data readings.

The group soldered all components for both the ADC and the RF PCBs by hand. Several group members learned how to solder during this portion of the project. Due to the sizing of some of the parts, soldering became difficult to do accurately.

Appendix 4 – Code

Please visit the project repository through Iowa State for the code used:
https://git.ece.iastate.edu/sd/sdmay21-07