To: Dr. Winfree

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Subject: Design Review 4 Documentation

Date: Apr 12, 2019

Design Review 4

1 Introduction

For this project, our team known as Team Wave Riders, includes Mike Eck, Mohammad Hussein, and Ricardo Toledo. The project that our team is currently working on is a tabletop doppler radar sponsored by our clients: Dr. Willie and Dr. Chrysler. Our clients requested a radar that uses the doppler effect for detecting object locations and eventually would like to determine velocity. The doppler radar must also be small enough to fit on a tabletop so that transportation can be easy enough for just one person. The doppler radar must work in the S-Band frequency range of 2-4 GHz and should be able to detect objects within 100 meters. The clients also requested that the radar is capable of transmitting a continuous wave with the antenna rotating 360 degrees around its axis. The purpose of this project is to eventually make it easier for students to understand electromagnetic wave propagation and the doppler effect. This report will be discussing our current progress in the project, detailing any risks or challenges our team encountered, as well as our work breakdown structure of the entire project and what will be completed for our project to succeed.

2 Client Problem

Our clients requested a Doppler radar that operated in the x-band 35Ghz. The restrictions on the radar were a budget of $800,have a range of 1 kilometer, have a lightweight, and small design. To qualify lightweight they stated that it would need to be easily moved by one person. To further qualify the size it needs to fit on a table top. The hope for this design was for a mobile weather station. Due to constraints of budget we had to review our objectives.

Our clients then requested a Doppler radar that uses the doppler effect for detecting object locations and eventually would like to determine velocity. The Doppler radar must also be small enough to fit on a tabletop and lightweight so that transportation can be easy enough for just one person. The radar must work in the S-Band frequency range of 2-4 GHz and should be able to detect objects within 100 meters. The clients also requested that the radar is capable of transmitting a continuous wave with the antenna rotating 360 degrees around its axis. The purpose of the new project is to create a resource that students can use to assist with understanding electromagnetic wave propagation and the Doppler effect.

3 Design Process

When beginning our design process, one of our beginning steps was to think of how this project will be created and assembled together. Our team devised multiple subsystems early on that would define the different parts of the project. For our project, we came up with three different subsystems that we felt would split up the system with ease. The subsystems that were picked include: Transmit, Receive, and Antenna. These three subsystems were picked because each system plays a vital role for the entire project. The transmit subsystem was picked because in a radar system, there must be a signal that can be sent through the transmission line to the antenna and then must be transmitted by the antenna. This subsystem must also transmit a continuous RF wave or a sinusoidal RF wave that has a constant frequency. Unlike normal radar systems that either use a klystron or magentron to generate and transmit RF waves, our system will use a software defined radio to generate and transmit a continuous RF wave. The RF signal will be generated with MATLAB to define what we are sending out and for how long while the software defined radio will physically transmit the RF wave through the transmission line. The radar system must transmit a continuous RF wave because the system relies on sending out RF waves to hit other objects such as people, cars, or even rain drops. Part of this subsystem includes being able to amplify the generated signal so that it is able to reach farther distances. The receive subsystem was picked because in a radar system, once the RF wave was sent out to hit an object, an echo will be sent back to the antenna and then travel through the circulator and the transmission line to the software defined radio to be processed for distance and velocity. The receive subsystem will utilize the software defined radio to not only receive the echo but to also perform signal processing with the help of MATLAB. Once the echo is received by the radar system, there will be I-Q values generated into a CSV file. These values are quadrature signal values that can go through a different filtering techniques to separate the signal from the noise floor so that it can be usable for displaying. Once the signal is discernible, it will then be displayed in a radar GUI. The GUI will have broken up sections to define the radar resolution. Each section will represent a general idea of what is happening such as distance from the radar system as well as directional velocity. The third subsystem picked was the antenna subsystem because in a radar system, there must be an antenna to transmit and receive a signal and each system is dependent on orientation such as its angle in regards to direction. Included in this subsystem was the capability of the antenna rotating 360 degrees clockwise and a rotary joint to minimize cable tangling. The radar antenna must rotate 360 degrees clockwise so that it can constantly transmit and receive to map out objects surrounding it and can determine their velocity and distance in regards to the radar. However, the radar must first transmit and receive in one single position to guarantee initial success. The antenna subsystem will also keep track of the angle of the antenna to use for calculations and orientation. In order to realize some of these concepts for our three subsystems, prototypes were required. For our original prototypes, our team still tested transmit, receive, and antenna. The transmit prototype utilized a HackRF software defined radio in order to show a simple test of transmitting a continuous wave but with the use of an isotropic antenna instead of a parabolic antenna. Our team used a software called GNU Radio to transmit a continuous RF wave at multiple frequencies to showcase the versatility of using a software defined radio. The outputted RF wave was displayed on a waterfall GUI sink on GNU Radio to show its power output along with the noise generated. This experiment was meant to showcase that a SDR can generate and transmit a continuous RF wave and to showcase one of the most important steps of a radar system. This signal was not directed at any object as that was not its purpose for this experiment. The receive prototype also utilized the HackRF SDR in order to show a simple test of receiving a continuous wave with an isotropic antenna as well. This experiment used GNU Radio to be able to receive a signal generated from the local radio station and listen to its broadcast clearly. The purpose of this test was to showcase a SDR receiving a signal while using filtering techniques to make the received signal overcome the noise floor to make it discernible. The success of these prototypes meant for our team that a SDR can transmit a signal and can also receive a signal. However, since that SDR was only a half duplex system, it was not capable of receiving and transmitting simultaneously. The antenna prototype was to show the use of a rotary joint, a motor, and a mount for the motor and antenna altogether and see how it should look like in the final product. We learned from our prototypes that a SDR needed to be full duplex so we can transmit and receive simultaneously just like a normal radar system can do. This can be achieved through the use of a circulator which will separate the transmit port from the receive port but connect the antenna port with the transmit port. These tests also proved to us that GNU Radio had a steep learning curve and was limited to only transmitting and receiving one at a time as well so we pursued a software for a future SDR that can do both transmit and receive at the same time.

4 Constraints

Since we started our project we have been through a lot of challenges. We have a lot of constraints that make our process go slower than expected. First, both of our clients were not here when we started our project which made it slightly difficult to contact them. We had set up online meetings with them and we contacted them by sending emails, but it was not as in touch due to late responses or being given reading material that we needed to try and fully comprehend. Second, our project budget was not enough to receive all the parts that were necessary for this project. Our budget put us in a very serious situation and which led us to try and find an alternative to the original plan set up for us with 90% of the budget being applied to afford the SDR. In order to save money for our budget, we had to make some calls to the manufacturer in an attempt to give us a discount which was successful and included high power amplifiers and low noise amplifiers making it possible to achieve our range requirements. All our constraints heavily influenced the pace of how fast we could work. Also, it affects our subsystems. When we got our BladeRF SDR we face a lot of constraints, since it kind of new SDR and there was not enough source material to go through in order to fully understand it. Upon asking our clients about SDRs, it seems they are not familiar with it which made our transmit/receive signal go somewhat slow with a lot of constraints. Also, we were not sure if a circulator was necessary and after asking our client about it, they said we might not have to use a circulator and that we would be fine with a splitter between the transmit and receive port with the antenna. After testing and calculations with timing delays, we discovered that it was not feasible to use a splitter as the transmitter could not switch off fast enough so it was necessary to purchase a circulator. Our second plan was to purchase more antennas so that we could transmit and receive without turning the transmitter on and off but those parts were completely out of our budget. Upon request, we got support from Dr.Winfree and we were able to get the funds needed to purchase that equipment. The biggest problem we have now is time. We need to get the parts in as soon as possible and make sure that everything is set up properly and try to get our receive signal and process the signal in order to display it.

5 Metrics of Success (WBS)

ID	Activity / Task	Description	Deliverables	Other people
1	Impedance matching for transmission	Complete calculations for minimal reflection on the transmission	Correct cable impedance	
1.1	Purchase transmission line		-Identify parts -Place order -Receive parts	
1.2	Construct and Test	Assemble all the parts together and prepare for testing	-Assembled	
1.3	Transmit continuous wave	Transmit a continues wave using SDR and MATLAB	-Output signal result -Transmit program	
1.4	Receive continuous wave	Receive a generated continuous wave through MATLAB	-Frequency response -Noise floor -Receive program	
1.5	Transmit and receive continuous wave	Simultaneously transmit and receive a continuous wave with the same SDR	-Full duplex system -proper noise floor -Output power considerations	
1.6	Signal process CSV format	The SDR will store all receive value in a csv file	Separate receive file to individual pulses	

1.7	Signal process Organize	Take the individual pulses and separate them by data timestamp and amplitude	Separate each measurement and plot to see receive data	
1.8	Stationary Tx/Rx Filter	Subtracting several signals from each other will give remained of all shifting object	Number of samples per pulse to determine clarity of radar	
1.9	Cross sections	Get a baseline for sizes to amplitude based off distance	Look up table that relates distance to cross section	
2	Rotary Tx/Rx	Using beam width and rotation speed we will be able to determine which section a moving object	Return azimuth deg from north	
2.1	Output Parameters	We need to take all Rx data and display it	-Velocity -Cross section Azimuth	
2.2	Antenna.	Searching for antenna that would work well for our project.	Specifications of antenna. -Order part	
2.3	Adapter.	Looking for adapter to connect the antenna with rotary joint.	-Specification of adapter. -Order part	

2.4	Connect antenna with rotary joint.	Test the adapter to make sure It work well.	-Connect and test.	
2.5	Rotator	Rotate antenna 360 degrees	- Specifications. -Order part.	
2.6	Display.	Getting through MATLAB and display process	-Design flowchart to display data.	
2.7	Display.	Coding radar display	-Velocity. -Azimuth. -Range	
2.8	Display receive data.	The display must be able to receive our data	-Receive signal. -Signal process	

The work breakdown structure our team devised from the beginning is still being upheld as of now. While our team is currently trying to follow every step of the way to fulfill the requirements of our WBS, not every step has been achieved yet. When creating our metrics of success for this project, we each pieced out and devised an activity that needed to be completed in order to move onto the next step. So we developed requirements step by step based around our three subsystems:transmit, receive, and antenna. The first activity that was required was based around the concept of impedance matching for our transmission line and load so that our reflections across the line would be minimal. If these reflections were not minimal, then our final output would be affected and not be as detectable through signal processing. That was successfully achieved by purchasing a coaxial cable with an impedance of 50 ohms along with SMA connectors on it. The impedance of our transmission line and load all need to be 50 ohms to match our 50 ohm antenna. The coaxial cable was purchased once the parts were identified and so after receiving the cable, our next task was to construct and test the SDR with the antenna and transmission line. The construction included connecting the SDR with the coaxial cable to the rotary joint which then connected to our antenna. The next task was to transmit a continuous wave using our SDR and MATLAB. This task was first going to be achieved with the use of Simulink but our team discovered that the SDR can be controlled by using MATLAB code as well as an executable command prompt for our specific SDR. Our team found code examples that utilized libraries created to work with the SDR and MATLAB. Our team was able to get the SDR to transmit a continuous wave using the executable command prompt which allowed us to set up parameters such as tx/rx frequencies, bandwidth, sample rate, and even gain. Once those were set up then a file in MATLAB that generates the sinusoidal signal to be transmitted is loaded in and then the command prompt will then begin the transmission of the tone. MATLAB code can perform the same function right now as it just calls functions from the executable and programs with certain timings and delays can be utilized with the transmission of the signal. The next task to be completed was receiving a continuous wave with our SDR and MATLAB code. Our team was able to receive just noise right now as we were testing the capabilities of receiving some sort of signal. It was achieved through the use of MATLAB code that can set up specific parameters required and then calls functions from the executable command prompt to tell the SDR to receive and for a certain time frame and then takes the I-Q sample data and places them into arrays in a CSV file. This can also be achieved with the executable command prompt as well but it sacrifices the capability of automating the receive process especially with necessary timing. Transmitting and receiving at the same time was the next task and is possible with the use of MATLAB code and the executable command prompt for the SDR in theory. It was observed that it would be much easier for our team to write MATLAB code that can set up parameters and then automate our transmit and receiving timing to fulfill our ”pulse then listen” setup. The MATLAB code would begin transmission for a certain time period then stop and wait a time period until the next transmission all simultaneously without having to actively type in commands. However this has not be successfully tested yet as a circulator was needed in order to correctly achieve this with a mono-static radar system or a radar system with one antenna to transmit and receive. Once we achieve this task, we will have a full duplex system and can test our noise floor as well as create tests to check for proper output power.

The original signal processing expected from the clients was to be identify the direction are speed of weather as a final goal and measure person sized objects velocity to begin with. However due to constraints on the budget we had to reduce this goal to be able to measure the velocity and distance of person sized objects as well as output these measurements onto a display. Researching further into the requirements to make this happen we identified that the equipment we were able to afford was not sufficient in producing this. After further discussion with our client we would be able to simply identify if an object was moving toward or away from our antenna. Since our range was set to be 100m identifying objects inside this range would require less than 1 micro second pulse. The range resolution equation is R = Ct/2. Where C is the speed of light, R is range in which we would be able to see different object, t is the pulse width of the transmit. With the original outputs of the parameters being velocity, cross section, and azimuth; we would now only be able to tell direction of the object and azimuth. This is primarily due to cross section being related to the amplitude of the signal and distance from the antenna. With a greater budget we would be able to include a circulator that would be capable of reducing our transmit pulse and quickly following it up with the receiver our range resolution would be improved, possibly giving us the ability to include the cross section and the velocity.

We are using MATLAB to display. Our project subsystems process is very related to each others. We should be able to transmit and receive signal in good shape and we process the signal process to have a clear signal data so we can display it. We would be able to display the velocity of an object and show that in canvas and recognize if the velocity of an object moves toward/away from the radar. Also, we would get the azimuth angle and the range. The display canvas would show the object velocity if it move toward or away of radar but we would not be able to get the position or exact location. With the current system that we were trying to implement we do not have the ability to measure velocity or distance. This required me to change the design of the radar display to include sections matching the size of our range resolution to include only direction of travel and azimuth.

6 WBS Status Update

Since we were able to get funding for a circulator and a separate antenna we will now be capable of sending and receiving signals. For the circulator we will need to know the rate in which the switch between transmit and receive occurs in order to solve an equation for range resolution. if we are unable to use the circulator we will need to implement a software application that switches between the four channels we have available on our SDR. The limitation on this is the speed at which the transmitter is able to switch on and off. Using MATLAB timing functions we have determined that we are able to turn on and off in half of a second allowing us to set up the device to alternate between transmit 1 (T1) receive 1 (R1) and transmit 2 (T2) receive 2 (R2). This gives us an operation that would look something like start T1 for 1 micro second end T1 then start R1 for .24 seconds end R1 and start T2 for 1 micro second end T2 and start R2. This would give us a cycle that where we are transmitting every quarter of a second. With the faster transition time we would have greater resolution for velocity. However the range resolution depends entirely on the transmit pulse duration. So if we are not able to control the SDR with the software at less than 1 micro second than we would have to rely on the circulator to reduce the transmit pulse duration. With low familiarity on the SDR we were unaware that we would need more than one antenna or a circulator despite our best attempts to stay in our budget. Theoretically it should be possible to only use one antenna and alternate between transmit and receive, however the speed in which the SDR can alternate is not fast enough to support one antenna. With the implementation of new components we should be able to to have improved range resolution. This would cause us to need to update the sizes of the boxes we are displaying. If we are able to get the range resolution down to 2-3m we should be able to re-introduce the velocity and distance variables we had originally hoped for.

7 Conclusion

While our client's expectations have drastically changed from the beginning of the assignment, we have been able to create achievable deliverables. We were able to stick with creating a Doppler radar which will measure direction of travel and azimuth. With unforeseen setbacks, our team now is waiting to get the parts that we ordered to continue the project process to be able to have our major part, transmit/receive signal, to be tested. Then, we would be able to do the signal processing to have the data that we are going to display. Hopefully we get the parts as soon as possible so we can be on track. Also, our team are working really hard and try to do our best to have the project at least work and get a sample of detecting an object such as a person.